AN EXPERIMENTAL AND THEORETICAL INVESTIGATION OF MULTICOMPONENT POOL BOILING ON SMOOTH AND FINNED SURFACES

Volume I

By

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ABSTRACT

AN EXPERIMENTAL AND THEORETICAL INVESTIGATION OF MULTICOMPONENT POOL BOILING ON SMOOTH AND FINNED SURFACES

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A comprehensive experimental and theoretical study of the effect of mixture composition on nucleate pool boiling heat transfer coefficients in multicomponent mixtures has been performed. Measurements of saturated and subcooled pool boiling heat transfer coefficients were made in mixtures with up to four components on conventional smooth and finned tubes.

The effect of a component on the degradation in multicomponent pool boiling heat transfer coefficients due to the mass transfer process was found to depend on the difference between the vapor and liquid equilibrium compositions for that component. In general for a multicomponent mixture, the degradation in heat transfer coefficients increase with the sum of the differences between the vapor and liquid equilibrium compositions for the light components in the mixture.

The multicomponent mixture boiling correlations of Palen and Small, Stephan and Preusser, Schlunder, and Thome and Shakir were evaluated by comparing their predictions of pool boiling heat transfer coefficients to the experimental values. Predictions of multicomponent pool boiling heat transfer coefficients for these correlations were significantly improved by using the Stephan- Abdelsalam correlation for pure hydrocarbons with mixture properties rather than the linear mixing law to calculate the ideal heat transfer coefficient. The Schlunder and Thome-Shakir correlations were found to estimate the experimental nucleate pool boiling heat transfer coefficients with average errors no greater than 30% for each mixture system.

A new correlation for boiling in multicomponent mixtures that includes cross-term diffusion coefficients was derived based on the film theory. A new expression relating the heat and mass transfer at a bubble interface was also derived and is used as part of the new correlation. The new correlation is general and does not require any empirical constants. The new correlation was found to predict the experimental boiling heat transfer coefficients in dilute aqueous ternary mixtures with an average error of less than 12% for those mixtures tested.

The new correlation was also used to determine that the effect of cross-term diffusion coefficients is to decrease multicomponent pool boiling heat transfer coefficients. The effect of the cross-term diffusion coefficients was not found to be significant.

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NOMENCLATURE

A_o	empirical constant in Eq. 2-30
b	bubble height, m
B_0	scaling parameter in Eq. 2-39
c	liquid concentration, moles/m^3
c_p	liquid specific heat, kJ/kg-K
d	bubble departure diameter, m
$\mathcal{D}_{AB}$	binary mass diffusion coefficient, m^2/s
D_{ij}	multicomponent mass diffusion coefficient, m^2/s
g	gravitational acceleration, m/s^2
f	bubble departure frequency, s^{-1}
G	Gibbs free energy, J
H	enthalpy, kJ/kg
Δh_v	differential latent heat, kJ/kg
I	current, amps
J	molar flux, moles/m^2-s
K	vapor-liquid equilibrium constant
K_{in}	experimental parameter in Eq. 2-32
k	liquid thermal conductivity, W/m-K
Le	Lewis number
M	molecular weight, kg/kg-mol
$\mathcal{N}$	boiling site density, m^{-2}
N	molar flux, moles/m^2-s
P	pressure, N/m^2
$\mathcal{P}$	non-specific physical property
q	heat transfer rate, W
q''	heat flux, W/m^2
Q	individual bubble heat transfer rate, W
R	cavity site radius, m
R	gas constant
r	bubble radius, m
r	relative boiling rate
$\mathfrak{R}$	universal gas constant
Sn	parameter defined by Eq. 2-15
T	temperature, °C or K
t	time, s
v	molar volume, kg/mol
V	voltage, volts
$\mathcal{V}$	volume, m^3
x	liquid mole fraction
y	vapor mole fraction
Z	compressibility
z	distance, m

Greek Symbols

α	heat transfer coefficient, W/m^2-K
β	mass transfer coefficient, m/s
λ	eigenvalue of diffusion matrix $\underline{D}$
γ	contact angle
δ	diffusion length, m
θ	cavity half-angle
κ	thermal diffusivity, m^2/s
μ	liquid viscosity, $N\text{-}s/m^2$
ρ	density, kg/m^3
σ	surface tension, N/m
υ	specific volume, m^3/kg
ω	acentric factor
$\Delta\vartheta$	wall superheat reduction, K
η	binary interaction parameter
θ	binary interaction parameter
ϕ	superficial volume fraction

Superscripts

o	spherical reference fluid
$\imath$	reference fluid
E	excess

Subscripts

az	azeotrope
b	bulk
bl	boundary layer
bp	bubble point
c	critical
D	departure function
dp	dew point
exp	experimental
g	growth period
h	homogeneous
i	interface
id	ideal
ℓ	latent heat
l	liquid
pure	pure
p	particular
R	reduced
s	saturation
s	sensible heat
TE	thermal effective
v	vapor
vp	vapor pressure
w	wall
w	waiting period
∞	plane interface

CHAPTER 1

INTRODUCTION

Boiling is a fundamental physical phenomenon that is important in a wide variety industrial processes and has been the subject of a great deal of research over the past several decades. Much of this research was performed in response to needs of the nuclear power industry in the area of light water reactor operation and safety. A need for more efficient heat exchangers generated interest in boiling and condensation of water and typical refrigerants. Boiling in binary and multicomponent mixtures is an important concern to several industries and has also been the subject of many investigations. An understanding of mixture boiling is necessary in the design of heat exchange equipment used in petrochemical processing and air separation. Mixture boiling also has applications in the liquid natural gas industry and in the pharmaceutical industry. A Kalina cycle, which replaces pure water in the Rankine cycle with an ammonia-water mixture, has been proposed as a means of substantially increasing the thermodynamic cycle efficiency.

Mixture boiling is controlled by transport phenomena that are significantly different from those that govern boiling in pure components. Thermodynamic vapor-liquid phase equilibrium dictates that the vapor composition within a bubble differs from the liquid composition in the surrounding liquid. A species gradient forms around a growing bubble, and as a result the boiling process is controlled by the mass transfer process. Since the mass diffusivity is usually much smaller than the thermal diffusivity, bubble growth in a mixture is significantly slower than in a pure fluid. The nucleate boiling heat transfer coefficient, which is dependent on how bubbles grow and depart from the heated surface, is often dramatically reduced from what would be expected from a pure component with physical properties of the mixture.

A typical pool boiling curve for a water is shown in Figure 1.1. Natural convection heat transfer is represented by the curve between points A and B. The wall superheat between points B and B' is referred to as the incipient superheat ΔT_{inc}, and represents the minimum temperature difference between the heating surface and the bulk fluid that is required to initiate boiling. Point B' is termed the Onset of Nucleate Boiling (ONB) since it is the lower bound of the nucleate boiling regime. The temperature difference between points B and B' is due to the increase in heat transfer that occurs from the agitation of departing bubbles at ONB. For a highly polished surface and a liquid that readily wets the surface, this temperature overshoot can be nearly 100 K. Typical heating surfaces show temperature overshoots of only several degrees K, or none at all. The nucleate boiling regime lies between points B' and C and is terminated at the critical heat flux (CHF), shown by point D. At the CHF, the interaction of the vapor and liquid streams prevent liquid from reaching the surface. For a heat flux controlled system, the heat transfer regime will abruptly switch from nucleate boiling to film boiling at the CHF. The surface temperature can rise several hundred degrees K from D to D', and failure of the heater is often the unfortunate result. The phenomenon places a practical limit on boiling systems, and knowledge of the point of the

CHF is an important safety concern and design constraint. Transition boiling is characterized by partial wetting of the heated surface and lies between points D and E on Figure 1.1. In transition boiling, an unstable vapor blanket covers the heating surface and vapor is intermittently released. The film boiling is represented by the curve to the right of point E, and is the regime that occurs when the heated surface is blanketed by vapor and heat is transferred to the liquid by conduction and radiation across the vapor film.

The main objectives of this investigation are to determine the effect of composition on and how to predict nucleate boiling heat transfer coefficients for binary and multicomponent mixtures. Several experimental and theoretical studies have been previously performed on this subject. However, nearly all have focused on binary mixtures. Only two non-proprietary studies have been reported for mixture systems with more than two components. Thus, a goal of this study is to extend the present understanding of mixture boiling to mixtures with more than two components and to determine the appropriate means to estimate the nucleate boiling heat transfer coefficient in an *n* component mixture.

The secondary objectives of this investigation are to consider the effects of finned surfaces and subcooling on multicomponent nucleate pool boiling heat transfer coefficients. There are no reported studies on mixture boiling from a finned surface, and only two that have considered mixture boiling with subcooling. Studies such as these would provide important information on boiling in mixtures. In subcooled boiling, the net contribution due to latent heat approaches zero as the subcooling increases, and the enhancement of the boiling heat transfer coefficient above that from convection is due to the agitation caused by the growth and collapse of bubbles at the heated surface. A finned surface is considered because it is a common means of enhancing heat transfer, but no information is available on how it affects mixture boiling.

The following chapter reviews the fundamentals and previous studies of mixture boiling. Chapter 3 describes the experimental apparatus and procedures used to develop a database for multicomponent mixtures. Chapter 4 discusses the methods used to estimate mixture physical properties. Predictions of the experimental results described in Chapter 5 are documented in Chapter 6 using the existing correlations that are applicable to multicomponent nucleate pool boiling. A new, entirely mechanistic correlation for multicomponent mixture boiling is derived and examined in Chapter 7.

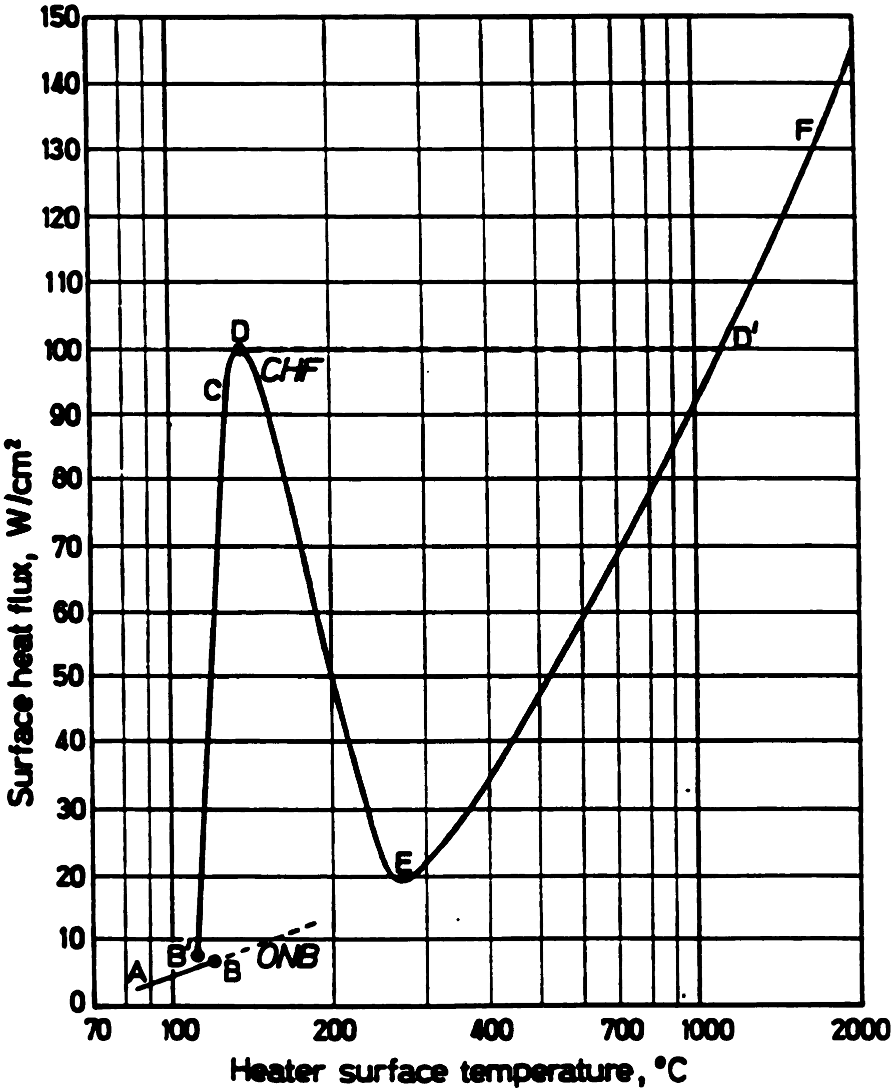

Figure 1.1 Typical pool boiling curve. From Collier (1972).

CHAPTER 2

LITERATURE SURVEY

The purpose of this section is to describe the physical processes that are important in pool boiling, and to review previous studies that are relevant to the present investigation. The emphasis in this section is on the physical mechanisms of nucleate boiling and on the predictive methods that have been proposed to estimate nucleate pool boiling heat transfer coefficients in binary and multicomponent mixtures. A complete review of boiling in pure components and mixtures, including boiling nucleation, convective boiling, and post-CHF heat transfer has been performed by Van Stralen and Cole (1978), and a comprehensive review of mixture boiling has been published by Thome and Schock (1984).

2.1 Mechanism of Bubble Growth in Pure and Multicomponent Liquids

Nucleate boiling is an efficient mode of heat transfer that is characterized by a large surface heat flux that can be maintained by a relatively small wall superheat. Because of this feature, many practical devices are designed to operate in this heat transfer regime. The augmentation in heat transfer that occurs during nucleate boiling in comparison to convection is due to the phase change process and to the hydrodynamic mixing near the wall that is induced by a growing bubble.

Consequently, a fundamental understanding of bubble growth dynamics and transport phenomena near a vapor-liquid interface is necessary to understand the nucleate boiling process.

Inception of Boiling The nucleate boiling process is initiated when bubbles begin to form on the heated surface. Numerous studies such as those by Clark et al. (1959) and Cornwell (1977) have demonstrated that nucleation occurs at microscopic imperfections that are found on an otherwise smooth surface. The cavities are on the order of .1-10 μm in diameter and act as nucleation sites for boiling due to their ability to trap vapor. As the cavity is heated, the preexisting vapor grows into a bubble and detaches. Upon bubble departure, some vapor remains trapped within the cavity and acts as an embryo for the next bubble. The criteria for vapor trapping and activation of the vapor embryo are useful to determine wall superheat needed to initiate boiling.

The expression for the equilibrium superheat between a vapor bubble and its surroundings is derived by considering a force balance on the bubble. Mechanical equilibrium requires that the pressure difference between the vapor and the liquid be balanced by the surface tension acting on the bubble perimeter:

$$(P_v - P_l)\pi r^2 = 2\pi r\sigma \tag{2-1}$$

Since the vapor pressure is greater than the pressure in the liquid at a given temperature, the liquid must be uniformly superheated in order for thermal equilibrium to exist. To determine the equilibrium superheat, the Clausius-Clapeyron equation,

$$\frac{dP}{dT_{sat}} = \frac{\Delta h_v}{T_{sat}(\upsilon_v - \upsilon_l)} \tag{2-2}$$

is integrated from (P_l, T_{sat}) and (T_l, P_∞), and the Kelvin equation,

$$P_v/P_\infty = \exp(2\sigma\upsilon_v/r\Re T_{sat}) \tag{2-3}$$

is used to relate the vapor pressure inside a curved interface to that at a planar interface. The resulting expression for equilibrium superheat is

$$\Delta T_{sat} = \frac{2\sigma}{r(dP/dT)_{sat}} \tag{2-4}$$

Bubble growth begins when the equilibrium superheat is exceeded. The equilibrium superheat for a bubble with radius of curvature r in a single component liquid is approximated by:

$$\Delta T_{sat} = \frac{2\sigma T_{sat}}{\rho_v \Delta h_v r} \tag{2-5}$$

At a heated surface, the superheat requirement depends on the effective radius of curvature of the vapor. Griffith and Wallis (1960) considered the growth of a vapor nucleus from its initial volume as it emerged from a conical cavity. They noted that as a bubble first begins to emerge from a cavity with mouth radius R, the superheat required is given by a modification of Equation 2-5:

$$\Delta T_{sat} = \frac{2\sigma T_{sat}}{\rho_v \Delta h_v R} \tag{2-6}$$

In Figure 2.1, this condition occurs when $r/R > 1$. While the vapor is still within the cavity ($r/R < 1$) the initial radius of curvature determines the equilibrium superheat requirement. This again depends on the vapor trapping mechanism.

The vapor trapping mechanism was investigated by Bankoff (1958), who considered the spread of liquid over a surface with a conical cavity with cavity half angle θ. Bankoff showed that for a liquid, with contact angle γ, an advancing liquid front will strike the opposite side of a cavity before reaching the bottom of the cavity if the contact angle is greater than 2θ. Thus, the condition for vapor trapping by an advancing liquid front is:

$$\gamma > 2\theta \qquad (2\text{-}7)$$

If $\gamma < 2\theta$, liquid completely wets the cavity and no vapor is trapped. Figure 2.2 depicts the vapor trapping process for an advancing liquid front.

Lorenz, Mikic, and Rohsenow (1974) considered vapor trapping for different geometric cavity shapes and liquid contact angles. The volume of trapped vapor forms an embryo with an effective radius of curvature, r_{eff}. The effective radius was determined to be a function of the contact angle and the included angle of the cavity mouth. The equilibrium superheat when $r < R$ is again given by a modified form of Equation 2-2:

$$\Delta T_{sat} = \frac{2\sigma T_{sat}}{\rho_v \Delta h_v R f(\gamma, 2\theta)} \qquad (2\text{-}8)$$

where $f(\gamma, 2\theta) = r/R$ and is determined from Figure 2.3.

Boiling incipience occurs if the vapor embryo, once it grows to the mouth of the cavity, continues to develop into a bubble and detaches or collapses, as in the case of subcooled boiling. It is important to note that Equation 2.2 is strictly valid only in a fluid with uniform superheat. Thus, as a bubble emerges from a cavity into a region in which there are temperature gradients, a more sophisticated model is needed to determine the minimum superheat required to sustain nucleate boiling. This was clearly shown by the experimental results of Griffith and Wallis (1960).

Hsu (1962) proposed a model for boiling incipience in a temperature gradient for pure fluids by assuming one-dimensional heat conduction into the liquid layer adjacent to a nucleation site. The nucleation model of Hsu assumes that the detachment of a bubble completely removes the wall thermal boundary layer. During the bubble waiting period, a new thermal boundary layer forms from transient

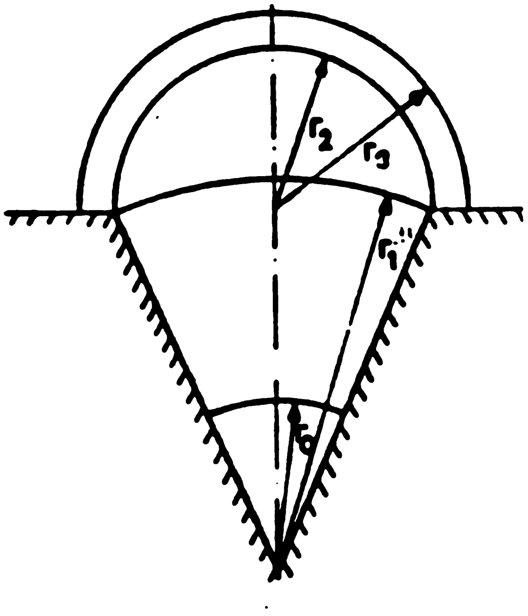

Figure 2.1 Effect of bubble radius of curvature on nucleation superheat.

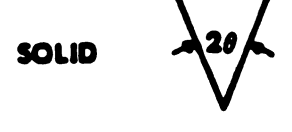

Figure 2.2 Vapor trapping mechanism for an advancing liquid front.

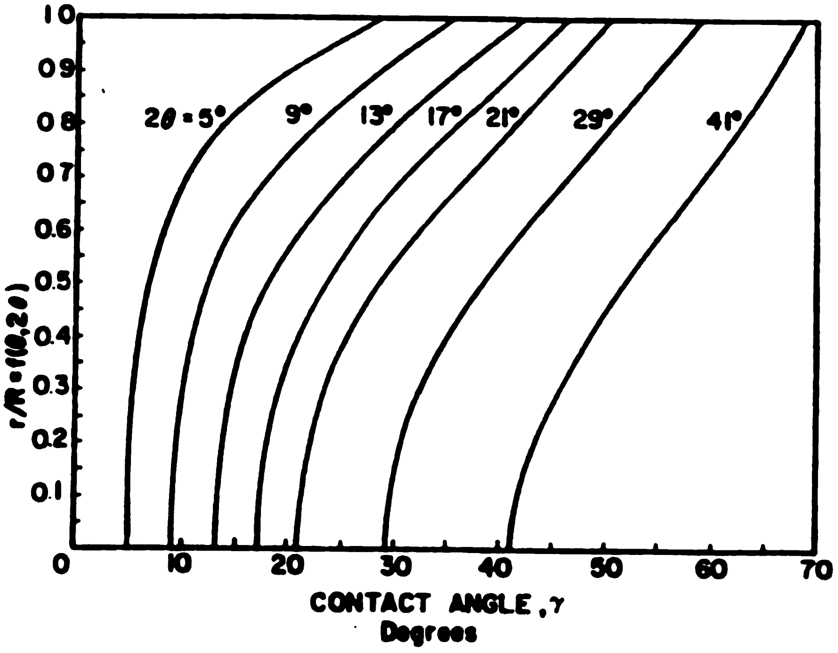

Figure 2.3 Dimensionless radius of curvature as a function of contact angle and cavity angle. From Lorentz et al. (1974).

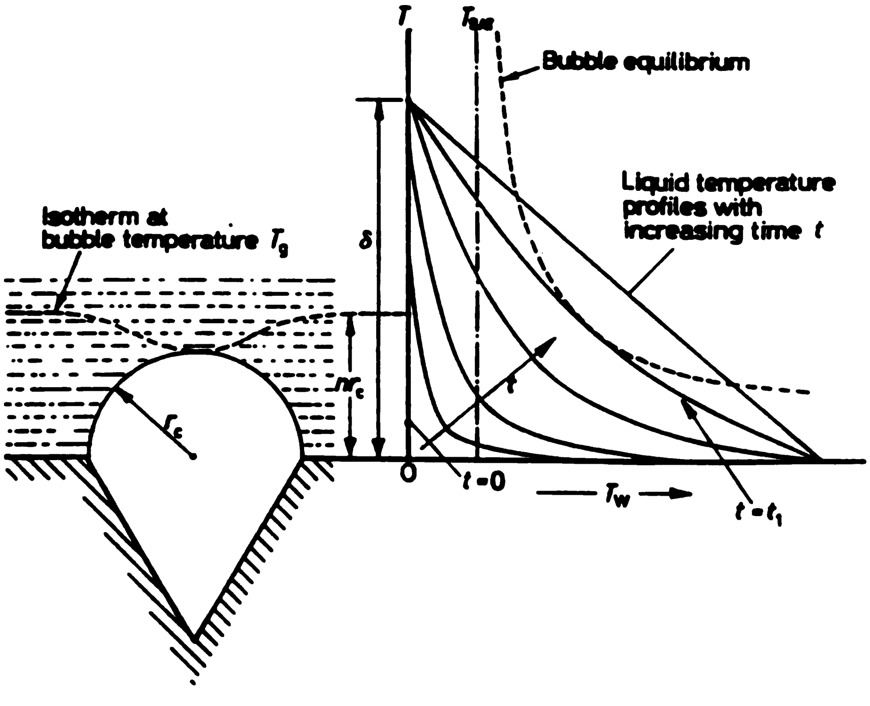

Figure 2.4 Nucleation model of Hsu (1962).

conduction until the temperature at a distance nr_c from the wall is equal to that required for bubble growth. If there is an active cavity, bubble growth will occur. Figure 2.4 diagrams Hsu's criterion for bubble growth. Hsu assumed the location of the isotherm with equilibrium superheat is at a distance $2r_c$. Howell and Siegel (1967) however, contradicted Hsu and concluded that only a favorable energy balance is required for bubble growth. They note that it is not necessary that for the thermal boundary layer surrounding the bubble to be at a higher temperature than the vapor nucleus at all distances.

Boiling incipience in binary and multicomponent mixtures has been the subject of only a few investigations. Stephan and Korner (1969) approached the problem of boiling nucleation in mixtures by considering the reversible work that is required in bubble formation. The work of formation of a vapor nucleus is given by the Gibbs potential ΔG. For a pure component, the Gibbs potential is given by:

$$\Delta G = \frac{16\pi\sigma^3 \upsilon_v{}^2}{3\Delta T^2{}_{sat}\{\Delta h_v/T_{sat}\}^2} \qquad (2\text{-}9)$$

and for a binary mixture by:

$$\Delta G = \frac{16\pi\sigma^3 \upsilon_v{}^2}{3\Delta T^2{}_{sat}\{\Delta h_v/T_{sat} + [(y-x)(\partial^2 G/\partial x^2)(\Delta x/\Delta T_{sat})]\}^2} \qquad (2\text{-}10)$$

Stephan and Preusser (1978) showed that the additional term in Equation 2-10 compared to 2-9 is always negative. Therefore, the work of bubble formation in a mixture is greater than that of a pure fluid with the same properties as the mixture.

Shock (1977) examined the effects of σ, $(dP/dT)_{sat}$, and contact angle γ on equilibrium superheats in ethanol-water and ethanol-benzene mixtures at 1.01 bar. Figure 2.5 shows the variation in surface tension and $(dP/dT)_{sat}$ with composition for ethanol-water mixtures. The trends in both σ and $(dP/dT)_{sat}$ indicate that a

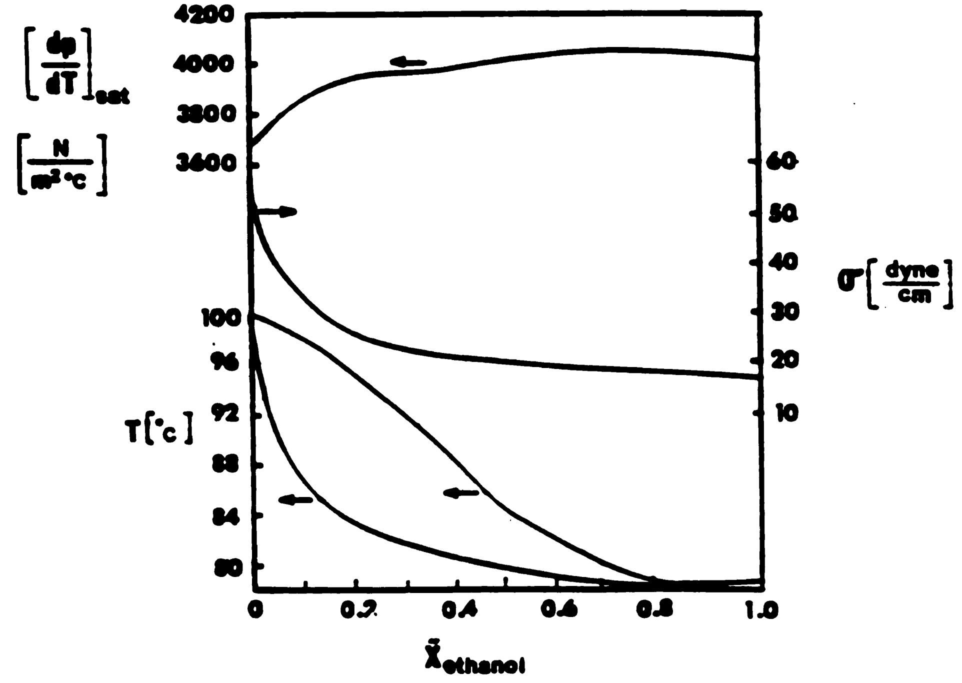

Figure 2.5 Phase equilibrium, surface tension σ, and slope of the bubble point curve $(dP/dT)_s$, for ethanol-water mixtures by Shock (1977).

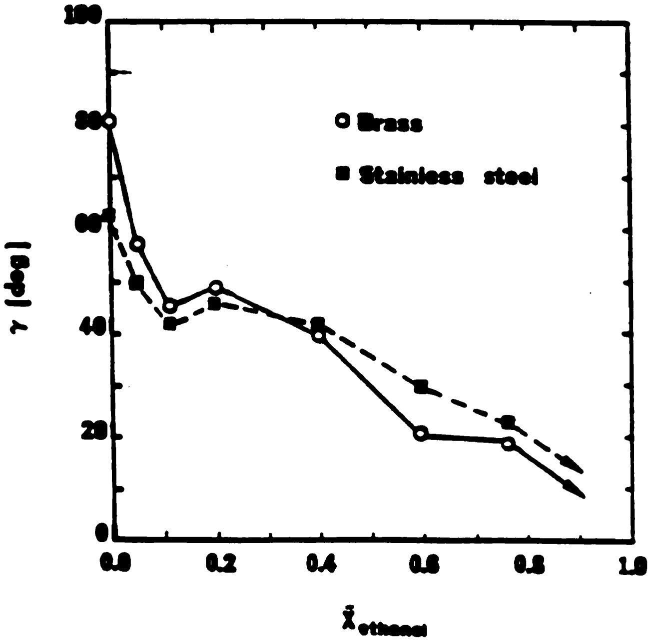

Figure 2.6 Contact angle data for ethanol-water mixtures by Eddington and Kenning (1979).

decrease in the incipient superheat should occur. The experimental measurements by Shock of the wall superheat at the onset of nucleate boiling in a vertical tube showed however, a significant increase in the incipient superheat for mixtures, which was attributed to the large decrease in contact angle that occurs. Figure 2.6 shows measurements by Eddington and Kenning (1979) of contact angles in ethanol-water mixtures. Low contact angle fluids trap less vapor in the cavities, and decrease the initial radius of curvature. Thus, the contact angle effect tends to increase the incipient superheat in mixtures in comparison to pure components.

Shakir and Thome (1986) have recently completed a study of boiling incipience in binary mixtures on both plain and enhanced surfaces. Contact angles were measured for methanol-water, ethanol-water, and 1-propanol-water binary mixtures, and were found to sharply decrease at dilute alcohol concentrations. Incipient superheats for mixtures were measured and found to be larger than the superheat that would be expected for a single component fluid with properties of the mixture. Shakir and Thome concluded that the classical nucleation criteria were inadequate to predict the incipient superheats in mixtures.

Bubble Growth in a Homogeneous Liquid Bubble growth begins when the equilibrium superheat is exceeded. For a free spherical bubble growing in a uniformly superheated liquid, three modes of bubble growth can be distinguished. The initial mode is the relatively short hydrodynamic mode, during which liquid inertia dominates and the bubble expands with a constant radial velocity. The final phase is the asymptotic mode, when bubble growth is controlled by diffusion processes and the rate of bubble growth gradually decreases. The asymptotic mode has the longest duration of the three modes, and it is during this growth phase that departure occurs. A transient mode occurs between the hydrodynamic and asymptotic modes. During the transition mode, bubble growth is governed by a combination of liquid inertia and thermal diffusion.

Asymptotic bubble growth in a pure component depends on the diffusion of heat to the bubble interface to provide the latent heat of vaporization. In a mixture, the equilibrium vapor composition differs from the liquid composition, and the bubble growth rate also depends on diffusion of the more volatile components to the bubble interface. Since liquid mass diffusivity is normally an order of magnitude lower than the liquid thermal diffusivity in mixtures, the bubble growth rate is retarded by the mass transfer process.

Van Wijk et al. (1956) were the first to explain the mass transfer process that occurs during bubble growth in a binary mixture. For the non-azeotropic mixture shown in Figure 2.7, the composition of the more volatile component in the vapor y, is greater than in the liquid, x. As the bubble grows, the liquid layer immediately adjacent to the bubble interface becomes depleted of the more volatile component, and a composition gradient is formed around the bubble. The liquid mole fraction at the interface decreases from x_b to x_i, which increases the local bubble point from $T_{sat,b}$ to $T_{sat,i}$ as shown in Figure 2.7. The rise in the local bubble point decreases the effective superheat that is available for evaporation by the amount $\Delta\vartheta = (T_{sat,b} - T_{sat,i})$. The reduction in available superheat causes a decrease in the growth rate in a mixture in comparison to a single component fluid with the same properties of the mixture.

Scriven (1959) developed an analytical model for asymptotic bubble growth in a binary mixture. Scriven considered the one-dimensional heat and mass transfer to a spherical bubble growing in an initially

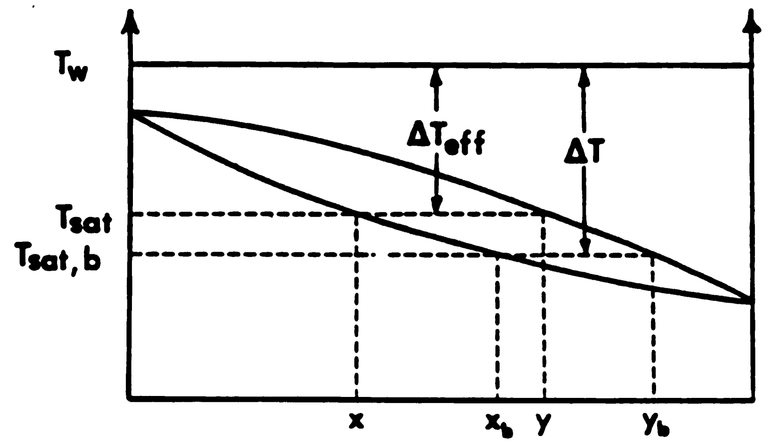

Figure 2.7 Decrease in effective wall superheat during boiling in a binary mixture.

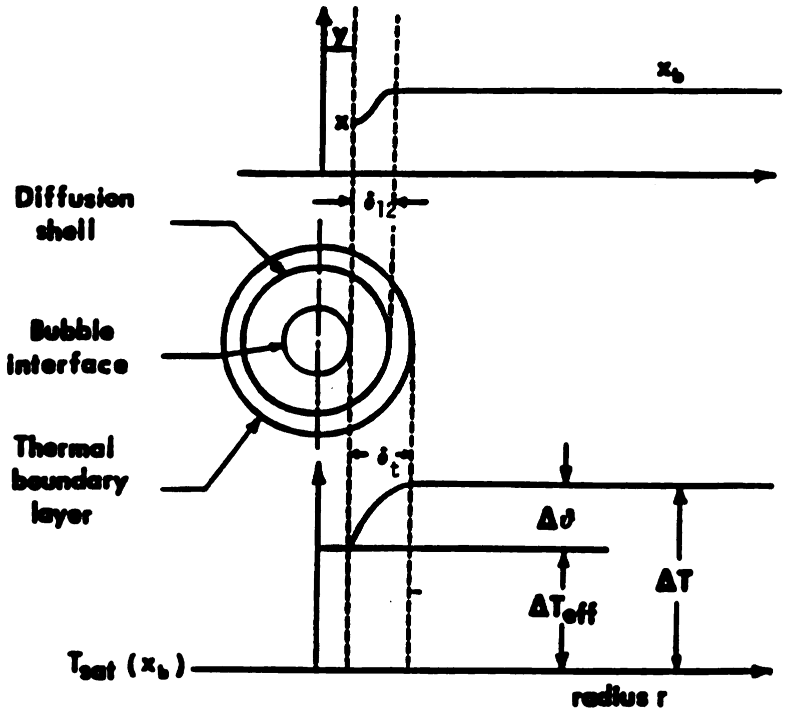

Figure 2.8 Bubble growth model in homogeneous superheated binary mixture by Van Stralen.

uniformly superheated liquid. The equations governing bubble growth were solved numerically, and a simplified expression for superheats of practical importance was determined to be:

$$r(t) = r_{pure}[1 - (y-x)(dT/dx)(\kappa/\mathcal{D})^{1/2}(c_p/\Delta h_v)]^{-1} \qquad (2\text{-}11)$$

where (dT/dx) is the slope of the bubble point curve, and r_{pure} is the Plesset and Zwick (1954) solution for bubble growth in a pure fluid:

$$r_{pure} = \frac{(12/\pi)^{1/2}\Delta T(\kappa t)^{1/2}}{(\rho_v/\rho_l)(\Delta h_v/c_p)} \qquad (2\text{-}12)$$

The terms (y-x) and (dT/dx) are always of opposite sign. Thus, the Scriven model shows that the bubble growth rate in a binary mixture is always slower than in a pure fluid with the same properties as the mixture.

Van Stralen (1966a,1966b) also derived a theoretical model for asymptotic bubble growth in a binary mixture. Van Stralen approached the problem by considering the mass balance for the most volatile component in the mixture. The hydrodynamic mode of bubble growth was ignored since it is short, and the concentration and thermal gradients were assumed to exist at the start of bubble growth. Figure 2.8 shows the diffusion shell and gradients about a spherical bubble growing in a superheated binary liquid. Van Stralen obtained an expression for bubble growth using this approach that was identical to Scriven's result, given by Equation 2-11.

<u>Bubble Growth Near a Heated Surface</u> Bubble growth from a cavity on a solid heated surface is significantly more complicated than growth in a homogeneous uniformly superheated liquid. At a heated surface a non-uniform temperature field and wall shear form two layers that have

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important effects on bubble growth; the relaxation microlayer, and the evaporation microlayer.

Unlike bubble growth in an initially isothermal liquid, a bubble growing on a heated surface enters the thermal boundary layer, in which there can be a steep temperature gradient. Depending on the size of the bubble and the thickness of the thermal boundary layer, only a portion of the interface may be in a region of the boundary layer that is superheated. Van Stralen (1970) termed this region the relaxation microlayer. Since evaporation will occur only in regions with sufficient superheat, the temperature gradient near a heated surface clearly has a strong influence on the bubble growth rate.

The evaporation microlayer refers to the very thin layer of superheated liquid that becomes trapped between the bubble and the heated surface during rapid bubble growth. A 0.5-2.0 μm film is left under a growing bubble due to the viscous stress in the liquid at the wall. The liquid in the evaporation microlayer has the highest liquid surface temperature to which the bubble is exposed, since it is immediately adjacent to the heated wall. A large percentage of the total mass evaporated into the bubble is thought to originate from this layer. Moore and Mesler (1961) were the first to deduce the existence of the evaporation microlayer from their observations of rapid temperature fluctuations in a surface on which bubbles were being generated. They explained that the temperature fluctuations were due to rapid variations in the surface heat flux due to a thin liquid film at the base of each bubble. Sharp (1964) provided the first direct evidence of the evaporation microlayer by using interferometry to visualize the formation, evaporation and dryout of a thin liquid film under a growing vapor bubble.

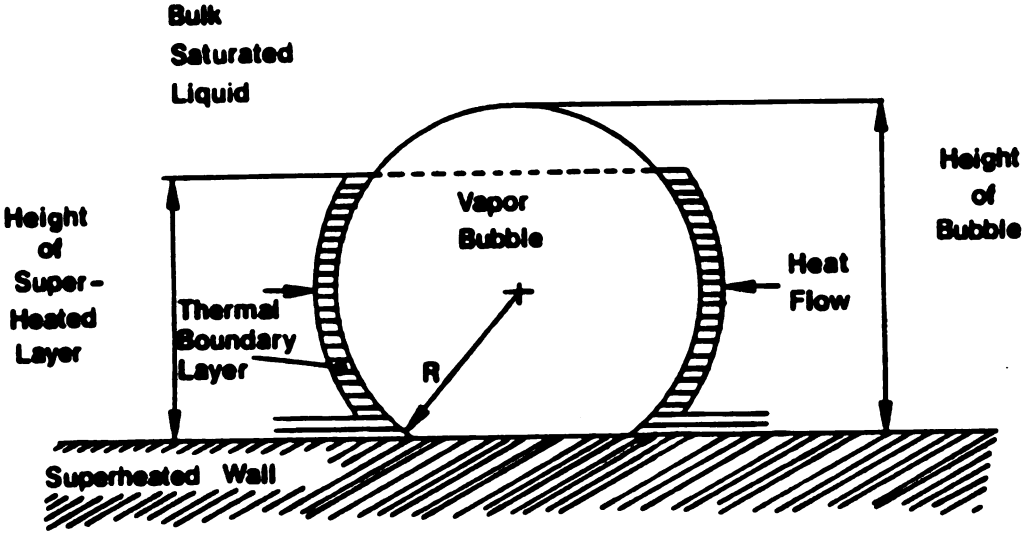


Figure 2.9 Bubble growth at a heated surface by Van Stralen.

Several models have been proposed that include the effects of the relaxation microlayer and the evaporation microlayer on bubble growth. Van Stralen (1970) extended his model for bubble growth in an initially uniformly superheated liquid to a bubble growing on a heated surface. Van Stralen assumed that all evaporation takes place at the bubble interface along the relaxation microlayer. The parameter *b* was introduced to represent the ratio of the thickness of the relaxation microlayer to the height of the bubble as shown in Figure 2.9. Van Stralen arrived at the following expression for bubble radius growing on a heated surface in a binary mixture:

$$r(t) = \left[\frac{12\kappa}{\pi}\right]^{\frac{1}{2}} b \, \frac{\rho_l c_p}{\rho_v \Delta h_v} \left\{ \frac{\Delta T \exp(t/t_g)^{\frac{1}{2}}}{1 - (y-x)(dT/dx)(\kappa/\mathcal{D})(c_p/\Delta h_v)} \right\} t^{\frac{1}{2}} \qquad (2\text{-}14)$$

Note that the parameter *b* is assumed in this model to be independent of time, which is not true. Initially, the bubble is completely covered by the relaxation layer and then begins to expand. In the Van Stralen model, the bubble height is assumed to be always larger than the relaxation layer. In addition, the parameter *b* is a function of composition and is generally not known, which makes the model difficult to apply. Van Stralen (1975) also formulated a bubble growth model for binary mixtures on a heated surface that includes the evaporation microlayer. This model also includes the parameter *b* and is difficult to use.

Van Ouwerkerk (1972) developed a theoretical model for bubble growth in a binary mixture near a heated wall. The bubble was assumed to have a hemispherical shape, with an evaporation microlayer beneath it. Evaporation was permitted over the hemispherical interface and from the microlayer. Assuming one-dimensional heat and mass transfer at all locations around the bubble, Van Ouwerkerk obtained a solution that was identical to Scriven's model, Equation 2-11, except for a constant.

All of the bubble growth models for mixtures that have been discussed in this section have been found to include the term:

$$Sn = [1 - (y-x)(dT/dx)(\kappa/\mathcal{D})^{1/2}(c_p/\Delta h_v)]^{-1} \qquad (2\text{-}15)$$

This dimensionless parameter represents the effects of heat and mass diffusion on bubble growth rate. Since (y-x) and (dT/dx) always have opposite signs, $Sn \leq 1$. Thus, the bubble growth rate in mixtures is predicted to be less than the growth rate in an equivalent pure fluid. This theoretical conclusion has been confirmed experimentally for bubble growth on heated surfaces as well as for remotely growing bubbles by Florscheutz and Khan (1970), Benjamin and Westwater (1963), and Thome and Davey (1981). Agreement with the theoretical models however, has been only qualitative. For example, Thome and Davey observed the exponent in $r = at^n$ to vary with a function of composition rather than being a fixed value of ½.

<u>Bubble Departure Diameters</u> The bubble growth period is terminated by departure of the bubble from the heated surface. The condition for departure depends on the dynamic forces that act on the bubble. At the moment of departure, buoyancy is balanced by surface tension, liquid inertia, drag and excess pressure forces. In aqueous mixtures, the surface tension sharply decreases with the addition of an organic fluid. This reduces the surface tension force which causes a bubble to adhere to the surface. The bubble growth rates in mixtures are reduced as compared to an equivalent pure fluid, and thus, the liquid inertia and drag forces which act to prevent departure are also reduced. Since there is less resistance to departure in mixtures, smaller departure diameters result. This mixture effect was first observed by Van Wijk et

al. (1956) and later confirmed in comprehensive experimental investigations by Tolubinskiy and Ostrovskiy (1966,1970). Tolubinskiy and Ostrovskiy studied ethanol-water, methanol-water, ethanol-butanol, ethanol-benzene, and water-glycerine mixtures and found that the minimum in departure diameter occurred at the maximum in |y-x|, except for the water-glycerine system. Isshiki and Nikai (1973) also measured departure diameters in ethanol-water mixtures, but found a minimum departure diameter at 0.02 mole fraction ethanol and a maximum at 0.5. Thome (1978) measured departure diameters in nitrogen- argon mixtures, as shown in Figure 2.10. The minimum in departure diameter was found to be very close to the composition at which |y-x| is maximum.

Thome and Davey (1980) considered the dynamic forces acting on a growing bubble in order to obtain a physical explanation for the minimum in departure diameter in mixtures. Slower bubble growth rates in mixtures were attributed to cause a reduction in liquid inertia and drag forces. The lower resistance to bubble departure resulted in smaller departure diameters.

Thome (1981) rederived the Keshock and Siegel (1964) bubble departure equation to include the effect of a volatile component on bubble growth. For inertia controlled growth, the expression obtained was:

$$\frac{d}{d_{id}} = Sn^{4/5} \tag{2-16}$$

Since Sn < 1 for mixtures, where Sn is defined by Eq. 2-15, Eq. 2-16 predicts a minimum in departure diameter when Sn is at a minimum, which is near the composition at which |y-x| is maximum. For surface tension controlled departure, Thome showed that:

$$\frac{d}{d_{id}} = Sn\left\{ \frac{\sigma \sin\gamma}{\sigma_{id}\sin\gamma_{id}} \right\}^2 \tag{2-17}$$

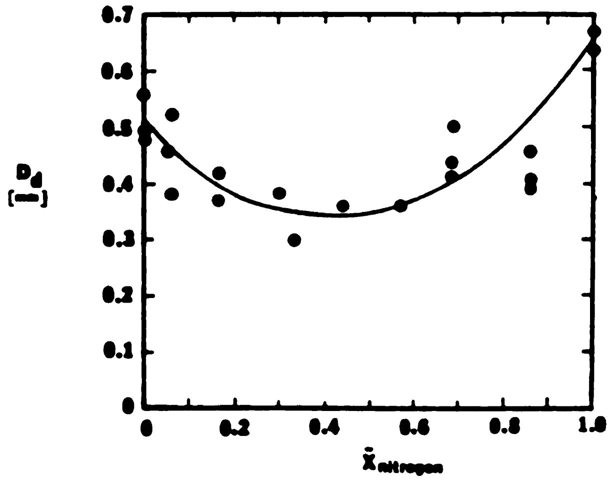


Figure 2.10 Bubble departure diameters in nitrogen-argon mixtures at 1.13 bar by Thome (1978).

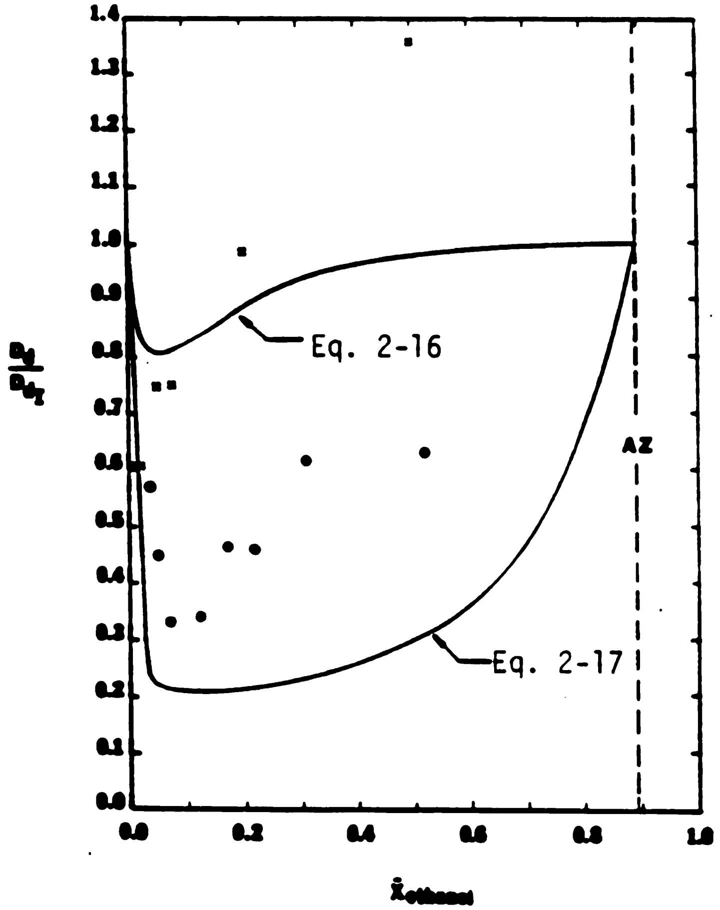


Figure 2.11 Comparison of bubble departure diameter equations 2-16 and 2-17 by Thome (1981) to experimental data of (•) Tolubinskiy and Ostrovskiy (1966,1970) and (×) Isshiki and Nikai (1973) for ethanol-water mixtures.

Figure 2.11 shows predictions of departure diameters for ethanol-water mixtures using Eqs. 2-16 and 2-17 compared to experimental data. The expressions for surface tension and inertia controlled departure bound the all of the Tolubinskiy and Ostrovskiy data, but not all of the Isshiki and Nikai data.

Bubble Departure Frequency The bubble departure frequency is defined as:

$$f = (t_g + t_w)^{-1} \tag{2-16}$$

where t_g is the bubble growth period from nucleation to departure, and t_w is the time lag that occurs between departure and when the cavity is reactivated. The bubble growth period depends on the growth rate, and the departure diameter. In mixtures, the growth rate is slower than in the pure components, but this can be compensated for by smaller departure diameters. The bubble waiting time depends on the rate at which the thermal boundary layer reestablishes itself, and to attain sufficient superheat to activate the vapor nucleus in the cavity.

Experimental investigations have shown that the departure frequency for mixtures is generally higher than for a linear combination of the pure components. In an experimental study of ethanol-water and ethanol- butanol mixtures, Tolubinskiy and Ostrovskiy (1966) measured departure frequencies and found the maximum for ethanol-water mixtures at a 0.3 mole fraction ethanol composition. Ethanol-butanol mixtures did not exhibit a maximum. Thome and Davey (1980) reported departure frequencies for nitrogen -argon mixtures and found that the departure frequencies increased for mixtures relative to the pure components. Figure 2.12 shows departure frequency data for nitrogen-argon mixtures. There is a large amount of scatter in the data, but the general trend is a maximum at an intermediate composition.

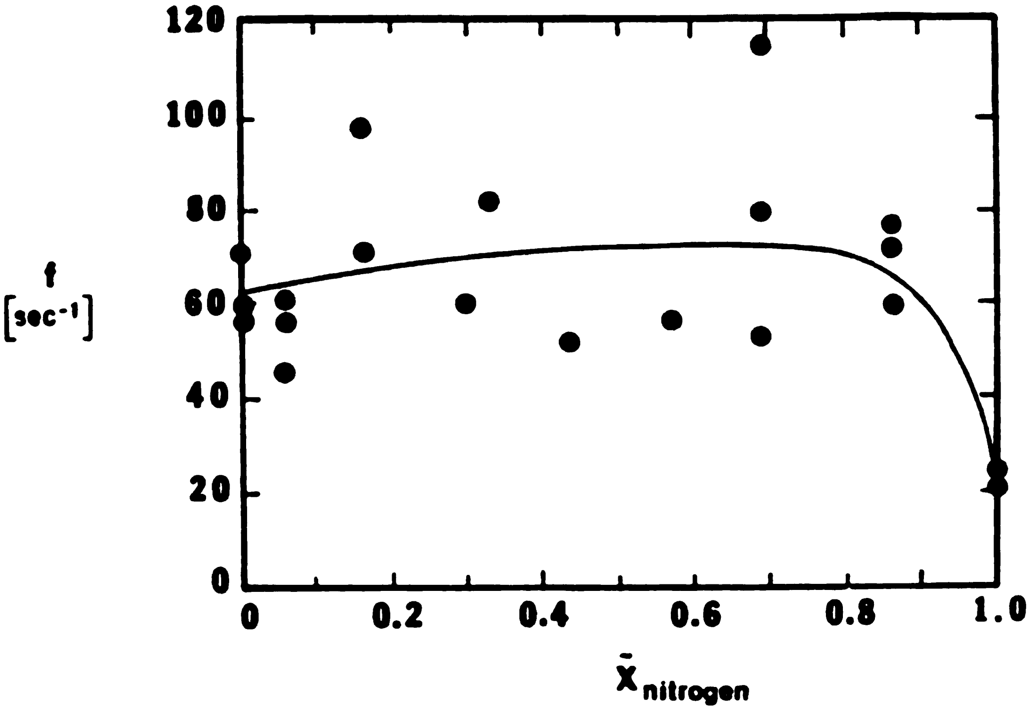


Figure 2.12 Bubble departure frequency in nitrogen-argon mixtures.

The increase in bubble departure frequencies in mixtures is the result of two effects. As discussed previously, the bubble departure diameters are smaller for mixtures, thus the bubbles do not grow as large. The bubble growth time t_g was shown by Thome (1981) for inertia controlled growth to be:

$$t_g = t_{g_{id}} Sn^{2/5} \tag{2-18}$$

Since for mixtures Sn < 1, the growth time is predicted to decrease, which increases the bubble departure frequency.

2.2 Predictive Methods for Mixture Boiling Heat Transfer Coefficients

There are several physical processes that contribute to the transport of heat from a surface during nucleate boiling. As a bubble grows, hot liquid in the thermal boundary layer is pushed into the bulk liquid and cooler liquid is drawn towards the surface. When the bubble departs, a volume of cool liquid is brought into contact with the heating surface. Forster and Grief (1959) proposed this bubble pumping mechanism to help account for the large increase in the heat transfer coefficient that occurs in nucleate boiling. Interferometric studies by Matekunas and Winter (1971) have also shown an addition vapor-liquid exchange mechanism to be the mixing of the thermal layer liquid drawn into the wake of the departing bubble. The evaporation microlayer, which was discussed earlier, has been shown by Judd and Hwang (1976) to represent a significant proportion of the total heat transfer in saturated and subcooled pool boiling. Clearly, the heat transfer that occurs during nucleate boiling is highly dependent on the criteria for bubble growth and departure.

Nucleate boiling heat transfer coefficients in mixtures are reduced in comparison to those expected in an equivalent pure fluid.

Theoretical and experimental studies have shown a reduction in bubble growth rates, departure diameters, and boiling site densities for mixtures relative to pure components. In terms of the mechanisms of heat transport in nucleate boiling, reduced bubble growth and smaller departure diameters decrease the effectiveness of the bubble pumping vapor-liquid exchange mechanisms. This results in a decrease in the nucleate boiling heat transfer coefficient in mixtures.

Decrease in the Heat Transfer Coefficient Van Wijk et al. (1956) were the first to provide a physical explanation for the reduction in mixture boiling heat transfer coefficients. The preferential evaporation of the more volatile component causes a rise in the local boiling point, and a decrease in the effective wall superheat as shown in Figure 2.7. Sterling and Tichacek (1961) claimed three reasons for the reduction in mixture boiling heat transfer coefficients: (1) mixture thermophysical properties, (2) bubble growth rates, as Van Wijk et al. explain, and (3) nucleation site deactivation. Sterling and Tichacek suggest that nucleation sites may eventually become clogged with the accumulation of the heavier component. Thome and Shock (1984) note however, that this mechanism is not likely to occur since the mass diffusion layer is very thin and is probably stripped away with the departing bubble.

Thome (1982) sought a physical explanation of the degradation in mixture boiling heat transfer coefficients by considering the mechanisms that remove energy from a heated surface. Latent heat transported from the surface by a departing bubble can be estimated by:

$$q_{\ell} = \rho_V \Delta h_V V f \tag{2-19}$$

As a bubble departs from a heated surface, part of the wall thermal boundary layer is carried away with the bubble. This removal of boundary layer fluid is often referred to as the thermal boundary layer stripping mechanism. Assuming the area of influence of a departing bubble to be twice its diameter, the heat transport due to the thermal boundary layer stripping mechanism is:

$$q_s = \tfrac{1}{2}\pi^{3/2}(\rho_1 c_p \kappa_1 f)^{\frac{1}{2}} d^2 \Delta T \tag{2-20}$$

Thome evaluated equations 2-19 and 2-20 using experimental bubble departure diameters and frequencies for nitrogen-argon mixtures. Both heat transfer mechanisms exhibited a minimum for an individual boiling site that nearly coincided with the minimum in nucleate boiling heat transfer coefficient. Figure 2.13 shows estimates of q_ℓ and q_s and heat transfer coefficients for nitrogen- argon mixtures.

The total heat transfer from a surface can be expressed as:

$$q'' = NQ \tag{2-21}$$

where Q is the rate of heat transfer at an individual boiling site, and N is the boiling site density. The boiling site density in mixtures has been the subject of only a few investigations. Boiling site density is difficult to measure, because departing bubbles tend to obscure the heated surface. Van Stralen and Cole (1978) reported boiling site densities on a thin horizontal wire for several aqueous mixture systems and found that the boiling site densities for mixtures were less than that in either of the pure components.

Thome and Shock (1984) conclude in their review of mixture boiling, that the degradation in mixture boiling heat transfer coefficient is the combined result of bubble nucleation and site density, bubble growth rate and departure, and non-linear variation of physical properties.

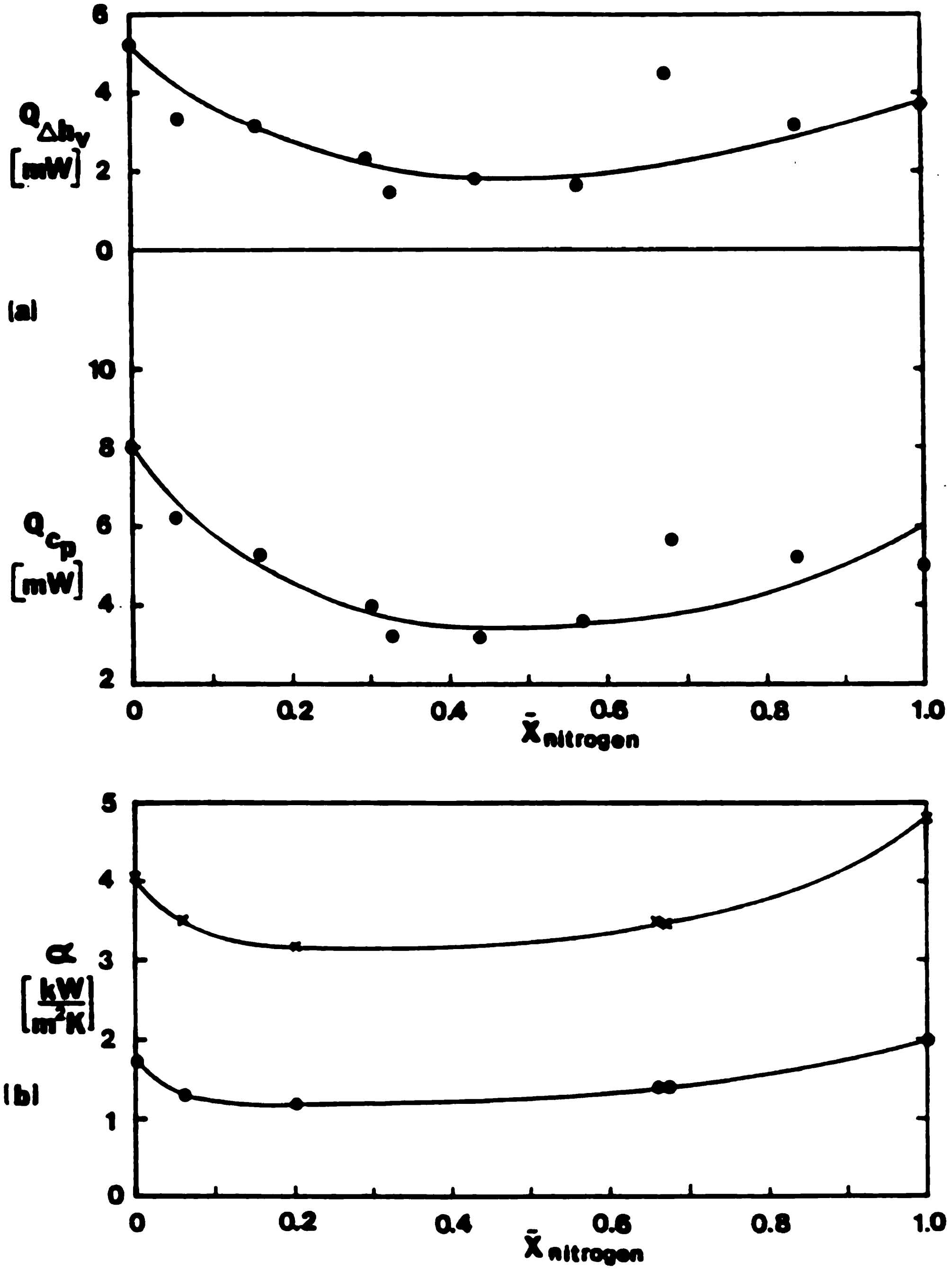


Figure 2.13 (a) Heat transfer rates for an individual bubble site in nitrogen-argon mixtures at 1.3 bar an $q''=2.1$ kW/m^2.
(b) Heat transfer coefficients in nitrogen-argon mixtures at 1.0 bar from Thome (1982).

Predictive Methods Many correlations for nucleate boiling heat transfer coefficients in mixtures have the general form:

$$\alpha = \alpha_{id}\Psi(x_i, y_i, T, P, q", \mathcal{D}, \ldots) \tag{2-22}$$

where $\Psi(x_i, y_i, T, P, q", \mathcal{D}, \ldots)$ is a function of thermodynamic variables, heat flux, physical and transport properties. It accounts for the mixture effect on the boiling heat transfer coefficient. The term α_{id} is known as the ideal heat heat transfer coefficient and represents the heat transfer coefficient for a single component fluid with the same physical physical properties as the mixture. The ideal heat transfer coefficient is defined in two ways. The most common definition assumes a linear mixing law, with α_{id} given by:

$$\frac{1}{\alpha_{id}} = \sum_{i=1}^{i=n} \frac{x_i}{\alpha_i} \tag{2-23}$$

where α_i represents the heat transfer coefficient of the pure component at the same heat flux as the mixture. An azeotrope behaves like a single component fluid. Thus, for azeotropic mixtures, Equation 2-23 should be modified as suggested by Thome and Shock (1984). To the left of the azeotrope, the wall superheat is given by:

$$\Delta T_{id} = \frac{x_1}{x_2}\Delta T_{az} + \frac{(x_{az} - x_1)}{x_{az}}\Delta T_2 \tag{2-24}$$

and to the right of the azeotrope by:

$$\Delta T_{id} = \frac{(x_1 - x_{az})}{(1 - x_{az})}\Delta T_1 + \frac{(1 - x_1)}{(1 - x_{az})}\Delta T_{az} \tag{2-25}$$

The ideal heat transfer coefficient is then determined from:

$$\alpha_{id} = \frac{q"}{\Delta T_{id}} \tag{2-26}$$

It is not always possible to apply the linear mixing law definitions of α_{id} at high heat fluxes and at very high and very low reduced pressures. The heat flux for DNB in mixtures is typically higher than that in the pure components. Thus, it may not be possible to provide a nucleate boiling heat transfer coefficient for low DNB pure components at some mixture heat fluxes. An alternative definition for α_{id} is to use a pure fluid boiling correlation with properties of the mixture. By defining α_{id} in this way, the non-linear variation of mixture properties with composition is taken into account. However, since no single component pool boiling correlation has been found to be completely adequate, this alternative definition for α_{id} increases the uncertainty in the estimation of α.

The earliest correlation for estimating nucleate boiling heat transfer coefficients in mixtures was proposed by Palen and Small (1964). For mixtures with wide boiling ranges they give the relation:

$$\alpha = \alpha_{id}\exp(-0.027\Delta T_{bp}) \qquad (2\text{-}27)$$

The boiling range $\Delta T_{bp} = T_{dp} - T_{bp}$ is the difference of the dew point and bubble point temperatures at the liquid composition. Palen and Small recommended the McNelly (1953) correlation using average properties to evaluation the ideal heat transfer coefficient.

Stephan and Korner (1969) developed a predictive method for binary mixtures using the observation that the maximum wall superheat in mixtures occurs at approximately the composition corresponding to the maximum in $|(y-x)|$. The wall superheat was expressed as:

$$\Delta T = q''/\alpha = \Delta T_{id} + \Delta T^{E} \qquad (2\text{-}28)$$

A linear mixing law was used to determine the α_{id}:

$$\Delta T_{id} = x_1\Delta T_1 + x_2\Delta T_2 \qquad (2\text{-}29)$$

The excess superheat, valid for 1-10 bar, was given by:

$$\Delta T^E = A_o(0.88 + 0.12P)|(y-x)|\Delta T_{id} \tag{2-30}$$

The empirical constant A_o depends on the pair of pure components of the mixture system. Stephan and Korner determined values of A_o for 17 binary mixture systems.

Stephan and Preusser (1979) extended the binary mixture correlation of Stephan and Korner for mixtures with *n* components. Stephan and Preusser also assumed that the wall superheat is composed of an ideal part and an excess part as given by Equation 2-28. The ideal superheat for multicomponent mixtures is given by:

$$\Delta T_{id} = \sum_{i=1}^{i=n} x_i \Delta T_i \tag{2-31}$$

where x_i is the liquid mole fraction of component *i* and ΔT_i is the temperature difference required to transmit the same heat flux q" by the pure component *i*. The excess part is,

$$\Delta T^E = \sum_{i=1}^{i=n-1} K_{in}(y_i - x_i) \tag{2-32}$$

The K_{in} are coefficients that were determined using the method of least squares using experimental data from 32 binary and 50 ternary compositions at 1.01 bar in the heat flux range 50-200 kW/m^2. The values for K_{in} were found for six binary and two ternary mixture systems are shown in Table 2-1. However, these empirical coefficients are not applicable to other mixture systems or even the same mixture system at a different pressure. Thus, this approach does not appear to be the best way to treat the problem.

Table 2-1

Coefficients Used in the Stephan-Preusser Correlation

Mixtures:	K_{in}	Binary	Ternary
Acetone(1)-Methanol(2)-Water(3)	K_{12}	1.19	--
	K_{13}	0.81	0.58
	K_{23}	0.56	0.54
Methanol(1)-Ethanol(2)-Water(3)	K_{12}	1.39	--
	K_{13}	0.56	0.31
	K_{23}	0.71	0.23

Stephan and Preusser (1979) also extended the Stephan and Abdelsalam (1980) pure component nucleate boiling correlation to multicomponent mixtures. The exponents of the Stephan and Abdelsalam correlation were fitted to the heat transfer coefficients of pure substances and an additional term was added to account for the effect of mass transfer:

$$\begin{aligned} Nu = (\alpha d/k_l) = \; & C\,(q''d/k_l T_s)^{0.674}(\rho_v/\rho_l)^{0.156}(\Delta h_v d^2/\kappa^2)^{0.371} \\ & (\kappa^2/\sigma d)^{0.350}(\mu c_p/k_l)^{-0.162} \\ & \left(1 + \sum (y_i - x_i)(\partial y_i/\partial x_i)_{x_j,p}\right)^{-0.0733} \end{aligned} \tag{2-33}$$

where the bubble departure diameter $d = 0.0146\gamma[2\sigma/g(\rho_l-\rho_v)]^{1/2}$ and $C=0.100$. The contact angle γ was assumed to be 45° for water and 35° for all organic compounds and mixtures. This correlation was reported to predict experimental results to within ±15% for 92% of the data. However, the maximum decrease in α/α_{id} in their data was only 10%. Thus, this correlation has been found to overestimate the experimental results of other investigators.

A completely analytical expression for the wall superheat in binary mixtures was derived by Calus and Leonidoplous (1974) based on the Scriven and Van Stralen bubble growth models. The expression they derived is:

$$\alpha = \alpha_{id}[1 - (y-x)(dT/dx)(\kappa/\mathcal{D})^{1/2}(c_p/\Delta h_v)]^{-1} \qquad (2\text{-}34)$$

or,

$$\alpha = \alpha_{id}Sn \qquad (2\text{-}35)$$

where Sn is defined by Eq. 2-15, and ΔT_{id} is given by Eq. 2-18. This model however, was not based on an energy balance nor a mass balance and hence lacks a physical basis.

Thome (1981) developed an analytical expression for nucleate pool boiling heat transfer coefficients in binary mixtures from a heated surface. Thome accounted for the effects of mass diffusion, growth rate and departure frequency and arrived at two different expressions for the heat transfer coefficients. For inertia controlled bubble departure the expression is:

$$\alpha = \alpha_{id}Sn^{7/5} \qquad (2\text{-}36)$$

and for surface tension controlled departure:

$$\alpha = \alpha_{id}Sn^{3/2}\left(\frac{\sigma \sin\gamma}{\sigma_{id}\sin\gamma_{id}}\right) \qquad (2\text{-}37)$$

Linear mixing laws are used to determine σ_{id} and γ_{id}.

Thome (1983) also derived an expression for nucleate boiling heat transfer coefficients based on the local rise in saturation temperature due to the preferential evaporation of the more volatile component. Thome showed that the decrease in wall superheat due to the mass transfer process is bounded by the boiling range ΔT_{bp}. Figure 2.14 shows the boiling range for a binary mixture. This correlation requires only information from a phase equilibrium diagram and can be used for multicomponent mixtures:

$$\frac{\alpha}{\alpha_{id}} = \frac{\Delta T_{id}}{\Delta T_{id} + \Delta T_{bp}} \qquad (2\text{-}38)$$

This model however, does not predict a variation of α with heat flux as has been found to occur in experimental data.

Schlünder (1982) derived a semi-empirical equation for nucleate boiling heat transfer coefficients in binary mixtures based on the film theory of mass transfer. For binary non-azeotropic mixtures, this equation is:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''}\left[(T_{s2}-T_{s1})(y-x)\left[1-\exp\left(\frac{-B_0 q''}{\rho \Delta h_v \beta_1}\right)\right]\right]\right\}^{-1} \qquad (2\text{-}39)$$

In this expression, B_0 is a scaling factor which relates the fraction of the total heat transfer that is latent heat. Schlünder assumed $B_0=1.0$ and set the liquid mass transfer coefficient β_1 equal to a fixed value of 0.0002 m/s. An important assumption used in the derivation of the Schlünder equation is that the slope of the bubble point curve can be approximated by $(dT/dx) = (T_{s2}-T_{s1})/(1.0-0.0) = (T_{s2}-T_{s1})$. The ideal heat transfer coefficient is obtained using the linear mixing law, Equation 2-23. The Schlunder correlation has been tested by Uhlig and Thome (1985) and Shakir et al. (1986) for aqueous mixtures, and by Bier et al. (1982) for mixtures of SF_6 and refrigerants. Good agreement was found in general, but at high and low compositions of the lighter component the correlation was not satisfactory.

Schlunder (1986) also extended Equation 2-39 to account for multicomponent mixtures. For a multicomponent mixture of *n* components, this equation has the form:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''}\left[\sum_{i=1}^{i=n-1} (T_{sn}-T_{si})(y_i-x_i)\left[1 - \exp(-B_0 q''/\rho \Delta h_v \beta_{1,im})\right] \right]\right\}^{-1}$$

(2-40)

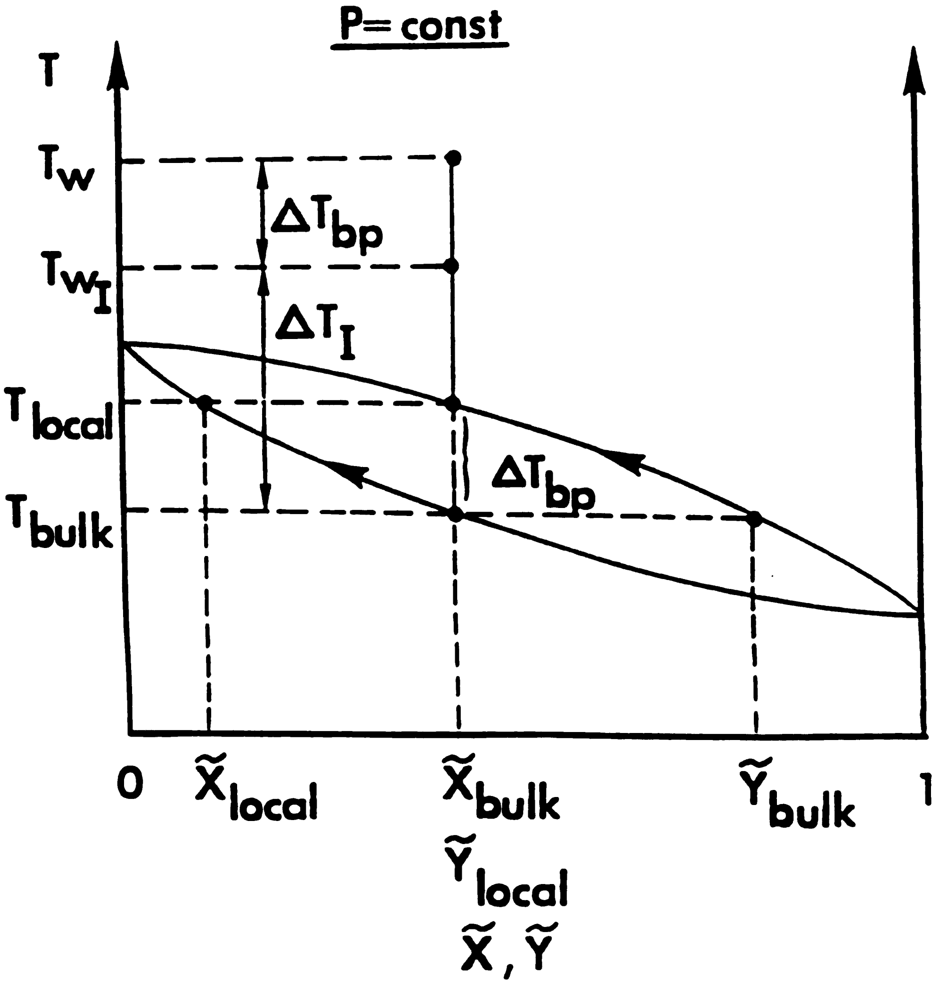


Figure 2.14 Boiling range in a binary mixture.

A linear mixing law is again used to determine the ideal heat transfer coefficient and β_1 is assigned a constant value of 0.0002 m/s.

Thome and Shakir (1987) have recently modified the Schlünder correlation by using the boiling range to provide a better approximation of the slope of the bubble point curve. The boiling range ΔT_{bp}, as shown in Figure 2.14, is the difference between the dew point and bubble point temperatures at constant mole fraction. The slope of the bubble point curve was approximated as $(dT/dx) = \Delta T_{bp}/(x_i - y_i)$, where $(x_i - y_i)$ is the difference between the vapor/liquid equilibrium compositions at the bubble interface. Thome and Shakir used this approximation to arrive at the expression:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''} \Delta T_{bp} \left[1 - \exp\left(\frac{-B_0 q''}{\rho \Delta h_v \beta_1}\right)\right] \right\}^{-1} \qquad (2\text{-}41)$$

The Stephan- Abdelsalam correlation was used to calculate the ideal heat transfer coefficient. Thome and Shakir reported good agreement between their correlation and experimental data from four binary aqueous mixture systems assuming $B_0 = 1.0$, and $\beta = 0.0003$ m/s. Since the boiling range is defined in the same manner for multicomponent mixtures, the Thome-Shakir correlation applies to both binary and multicomponent systems.

Sardesai, Palen and Thome (1986) have modified the Schlunder equation for binary mixtures, Equation 2-40, to correlate multicomponent hydrocarbon mixtures. They proposed the expression:

$$\alpha/\alpha_{id} = [1 + (\alpha_{id}/q'')\Theta_n \Theta_m]^{-1} \qquad (2\text{-}42)$$

where

$$\Theta_n = \sum_{i=1}^{i=n-1} [(T_{sn} - T_{si}) x_i (K_i - 1)]^{mc} \qquad (2\text{-}43)$$

and

$$\Theta_m = 1 - \exp(-B_y (B_0 q''/\rho_1 \Delta h_v \beta_1)^{B_z}) \qquad (2\text{-}44)$$

The values of mc, B_y and B_z must be determined empirically. Sardesai et al. reported good agreement between Eq. 2-42 and their experimental data for hydrocarbon mixtures with up to five components. The values of mc, B_y and B_z however, were not reported.

2.3 Parametric Effects on Nucleate Boiling in Mixtures

Effect of Pressure   The nucleate boiling heat transfer coefficients in both pure components and mixtures increase as the pressure increases. The increase in heat transfer coefficient is due to an increase in the boiling site density, which results from a decrease in the wall superheat required for activation with increasing pressure. The degradation in α however, becomes more pronounced at higher pressure. This has been shown experimentally by several investigators, including Tolubinskiy et al. (1973) in ethanol-water mixtures, Jungnickel et al. (1980) in refrigerant mixtures, and by Bier et al. (1982) in SF_6-CF_3Br mixtures near the critical point.

As pressure increases, the local rise in the boiling point due to the mass transfer process and non-linear property variation remains nearly constant. The wall superheat for the mixture, and for each of the pure components decrease with increasing pressure. The degradation in the mixture boiling heat transfer coefficient becomes more profound since as the pressure increases, the rise in local boiling point becomes a larger proportion of the total wall superheat decreasing the effective superheat available for bubble growth.

Effect of Subcooling There have been only two reported investigations on the effect of subcooling on nucleate boiling heat transfer coefficients in mixtures. Sterman et al. (1966) investigated benzene-diphenyl mixtures at 3.5 and 8.0 bar with subcoolings up to 80°C. Similar to the effect of subcooling on boiling in pure components, the heat transfer coefficient in mixtures based on (T_w-T_b) decreased as the subcooling increased. The degradation in heat transfer coefficient due to mixture effects were found to be less with subcooling than at saturation conditions. Hui and Thome (1985) found similar reduction in heat transfer coefficients in pure mixtures and pure components in their recent investigation of ethanol- water and ethanol-benzene systems.

Effect of Surface Structure Characterization of the heating surface is of vital importance in the determination of boiling heat transfer coefficients. Because of the significant effect that the surface has on thermal performance, many techniques for enhancing the heat transfer involve modification of the surface structure. In general, a surface can be classified as plain, structured, or porous. A plain surface is one that has not been artificially roughened or specially modified. Structured surfaces are those which employ a regular, patterned surface such as finned or grooved surfaces. A porous surface is one in which there are a large number of reentrant grooves. Reentrant grooves can be formed by coating a surface with a porous material or using deeply knurled fins. Webb (1981) has published a detailed review of enhanced surface geometries for nucleate boiling.

Several investigations have considered the boiling of mixtures on porous surfaces. Czikk et al.(1981), Ali and Thome (1984), Uhlig and Thome (1985) and Shakir et al. (1986) presented results on boiling binary mixtures on a porous Union Carbide High Flux surface. The nucleate boiling heat transfer coefficients in mixtures were found to be significantly larger on the enhanced surface than for the same composition on a conventional plain surface. Thome (1987) explains that liquid phase convection within the porous matrix is the dominant enhancement mechanism. The mixture effect is thus smaller for a porous surface than for a plain surface with the same other conditions.

As discussed by Westwater (1973), finned surfaces are often employed to augment heat transfer. Some low-fin tubes have been used in reboilers. While there has been a great deal of research into single component nucleate boiling on extended surfaces, there have not been any reported studies of mixture boiling on finned surfaces.

Multicomponent Mixtures Many industrial processes involve the boiling of several components. Multicomponent mixtures, defined as mixtures with more than two components, tend to be encountered more frequently than binary mixtures in practice. Despite this fact, nearly all studies of mixture boiling have been performed with binary mixtures. Only three studies have reported data for mixture systems involving three or more components. Grigor'ev et al. (1968) performed an experimental investigation using a 7.72 mm diameter stainless steel tube for acetone-methanol-water and acetone-ethanol-water at 1.0 bar. Their results indicated a minimum heat transfer coefficient for a ternary composition, and three binary minima. The minimum for the ternary composition was less than any of the three binary minima.

Stephan and Preusser (1979) measured the nucleate pool boiling heat transfer coefficients in acetone-methanol-water and methanol-ethanol-water mixtures. Their data did not indicate the presence of a ternary minimum heat transfer coefficient as the Grigor'ev data had shown. The data by Stephan and Preusser suggests that the ternary mixture experiences less degradation than the corresponding binary mixtures due to a flattening of the bubble point curve upon the addition of a third component. Stephan and Preusser also presented a predictive method for multicomponent nucleate boiling heat transfer coefficients using experimental measurements for binary mixtures.

Recently, Sardesai, Palen and Thome (1986) reported a study in which they compared the Schlünder correlation to nucleate pool boiling data of 18 hydrocarbon multicomponent mixtures. Mixture data included 2,3,4 and 5 component mixtures of n-pentane, n-heptane, p-xylene, 1-decene, and 1-tetradecene. Their modified Schlünder correlation was found to correlate the majority of the data to within ±30%. An empirical adjustment to the Schlünder equation was suggested to improve the agreement between the correlation and the data. The data and the empirical constants used in the study however, were not reported.

2.4 Summary of the Literature Survey

Several correlations for nucleate boiling heat transfer coefficients in mixtures have been proposed and verified using binary mixture data. In most cases, the correlations are general and theoretically extendable to multicomponent mixtures. Yet, due to the lack of an experimental database, it has not been possible to assess the accuracy of these proposed correlations for multicomponent mixtures. Therefore, there is vital need for experimental data for boiling in mixtures with three or more components. Currently, there is limited data for only two ternary mixture systems at 1.01 bar. Experimental data is needed for several new multicomponent systems in order to make a more comprehensive evaluation of existing multicomponent mixture boiling correlations.

The review of literature also shows that there are no published data for mixture boiling on a finned tube. Since finned tubes are commonly used to enhance the heat transfer in many multicomponent processes, measurements of pool boiling heat transfer coefficients for mixtures on a finned tube would be an important contribution to the present body of knowledge.

CHAPTER 3

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The pool boiling facility in the Multiphase Heat Transfer Laboratory at Michigan State University was used to obtain the measurements reported in this study. The facility has been used to obtain nucleate boiling incipient superheats and nucleate boiling pool boiling heat transfer coefficients in several previous investigations including those by Shakir (1987) and Hui (1983). This section describes the pool boiling facility and peripheral equipment, and the procedures followed in obtaining the experimental values of nucleate boiling heat transfer coefficients.

3.1 POOL BOILING FACILITY

The pool boiling facility consists of a pressure vessel and its supporting structure, the peripheral equipment and the measuring instruments. The pressure vessel, shown in Figure 3.1, is a stainless steel cross with four 101.6 mm ID flanged openings. A recessed Teflon O-ring in each flange sealed the openings between the pressure vessel and each of the four stainless steel cover plates. Openings through the cover plates provided entry into the pressure vessel for the test section, condenser, thermocouples, electrical connections, and fluid inlet and outlet lines. Attachments to the pressure vessel were made through and sealed by stainless steel Swagelok fittings. One of the cover plates was designed so that a window could be mounted and used to observe the boiling process. The pressure vessel was supported by a structure fabricated from 50 mm pipe.

The vessel was filled with liquid through an inlet line in the bottom plate. Approximately 4.2 ℓ were required to fill the vessel to a level at least 80 mm above the top of the test section. A coiled 1350 W Chromalox immersion heater was used to heat the bulk liquid up to test conditions. The bulk liquid temperature was measured by two 30-gage copper-constantan thermocouples. Each thermocouple had a stainless steel sheath, and entered the pressure vessel through the bottom plate. A water cooled condenser, made from several coils of 6.35 mm OD stainless steel tubing was mounted inside the top cover plate. Tap water was used as coolant and could be chilled by routing it through an ice bath before entering the condenser. The flow rate through the condenser was controlled manually. Vapor leaving the vessel through the degassing line in the top plate was condensed by passing it through copper tubing submerged in a tank of room temperature water. A pressure relief valve was mounted to the top plate in order to prevent accidental over pressurization of the vessel above its maximum rating of 150 psig.

3.2 EQUIPMENT AND INSTRUMENTATION

Power to the test section was supplied by a Variac variable AC power supply. The power delivered to the test section was determined by measuring the current in the electrical circuit and the voltage drop across the heating element in the test section. The current was

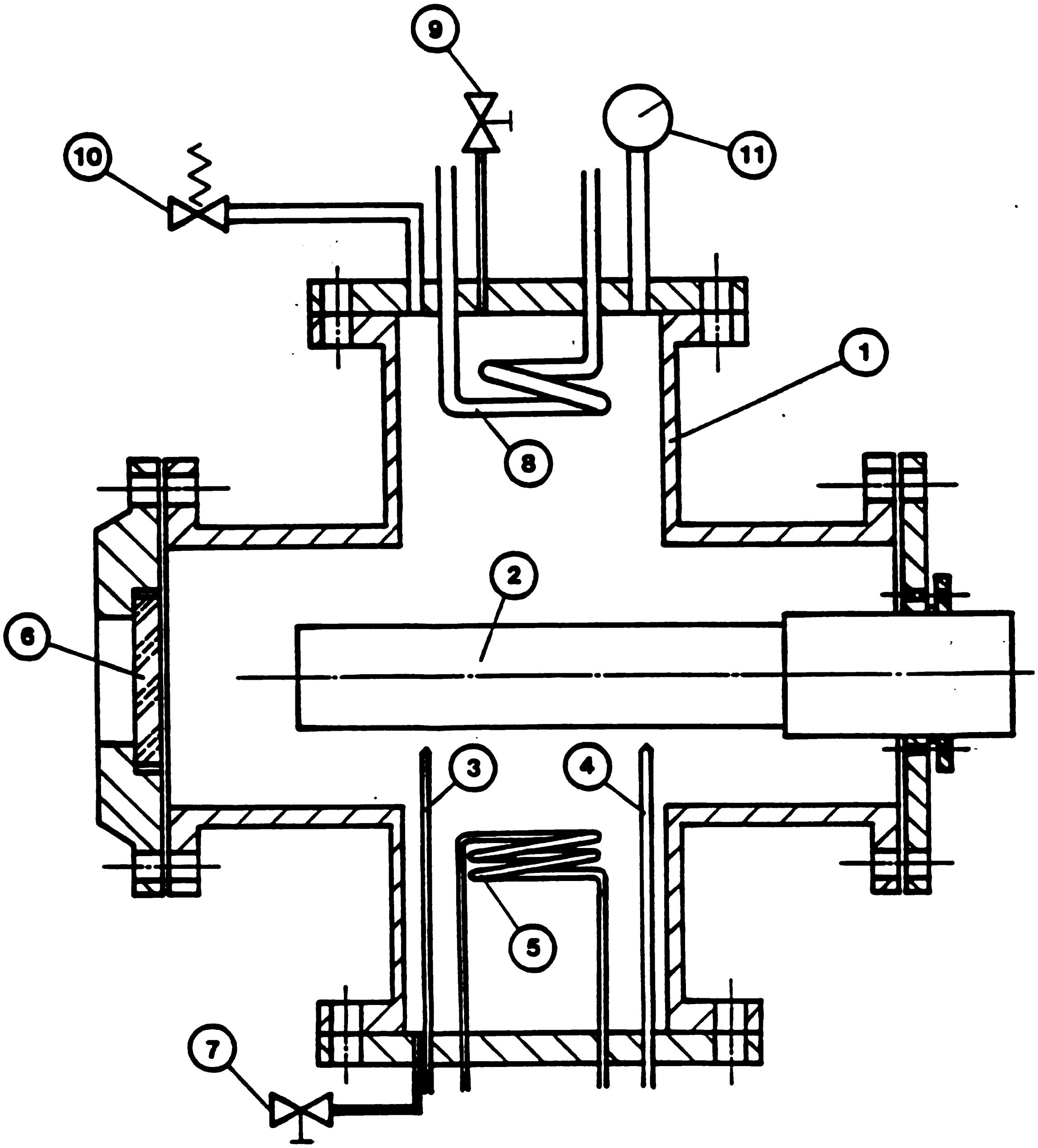


Figure 3.1 Pool boiling facility pressure vessel. Legend: 1-boiling vessel, 2-test section, 3,4-bulk liquid thermocouples, 5-immersion heater, 6-glass window, 7-liquid feed line, 8-water cooled condenser, 9-degassing vent, 10-pressure relief valve, 11-pressure gage.

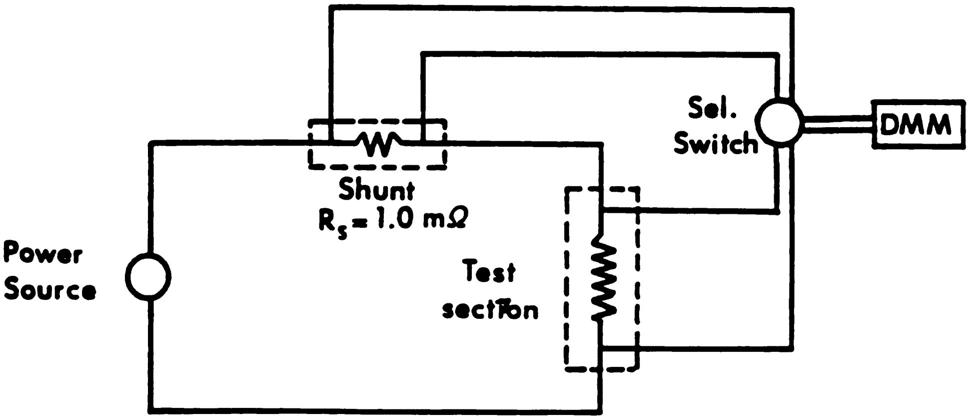


Figure 3.2 Electrical circuit to supply power to test section.

determined by measuring the voltage drop across a 1.0±1.0% mΩ, resistance element placed in the circuit. A Keithley 177 Microvolt digital multimeter accurate to 1% of full scale was used to measure the voltages. Figure 3.2 shows the electrical circuit used to supply and measure power to the test sections.

The temperatures were measured with three Omega Trendicator model 400A digital indicators, accurate to within ±0.1 K. The Omega Trendicators were calibrated using a Northrup potentiometer as a known voltage source. A convenient check of the calibration was to observe the measured temperatures of a fluid at saturation in the vessel and compare those measurements to the known saturation temperature.

Pressure was measured using a Heise digital pressure gage accurate to within ±0.1 psi (0.00689 bar). The digital pressure gage was calibrated against the atmospheric pressure obtained from a mercury barometer corrected for local conditions.

3.3 TEST SECTIONS

The experimental measurements reported in this study were obtained using three different test sections. Two of the test sections were plain tubes and the third was a finned tube. All experimental tests were performed with the tubes supported horizontally inside the pressure vessel.

Figures 3.3 and 3.4 present cross sectional diagrams of the two plain tube test sections. The first test section, shown in Figure 3.3 was originally constructed and used in the investigation by Shakir (1987). This tube had a diameter of 22.2 mm and had a heated length of 76.2 mm. The heating element was a Chromalox CIR 3030 electrical resistance heater. Copper-constantan thermocouples were inserted axially in the wall of the copper tube. Four thermocouples were located at the center of the heated length, and two additional thermocouples were positioned at the edge of the heater closest to the stainless steel support holder. The surface of the tube was prepared by rubbing it with 400 grade emery paper.

The second plain tube test section, shown in Figure 3.4, was constructed and used in this investigation only. This tube had a diameter of 19.05 mm and had a heated length of 50.8 mm. A RAMA 500 W resistance heater was used for the heating element. Four copper-constantan thermocouples were located at the center of the heated length. Two other thermocouples were located at the end of the heated length, and two additional thermocouples were placed 6.35 mm outside the heated length. The tube surface was also finished using 400 grade emery paper. Only 4 tests were performed with this tube due to a premature failure of the heating element.

The third test section used in this study was a finned tube, shown in Figure 3.5, with 19 fins/in (750 fins/m). The root diameter of this tube was 16 mm and the outer diameter including the fins was 19.07 mm. The heating element was a RAMA 500 W resistance heater. Three copper-constantan thermocouples were located in the tube wall at the center of the heated length, and an additional thermocouple was placed near the edge of the heated length. The base surface and the fins were finished using 400 grade emery paper to try to match the appearance of the plain tubes as close as possible.

The test sections were cleansed before use by thoroughly rinsing the surfaces with acetone. After the surfaces had been prepared, care was taken to insure that the surfaces were not marred or scratched for the duration of the investigation.

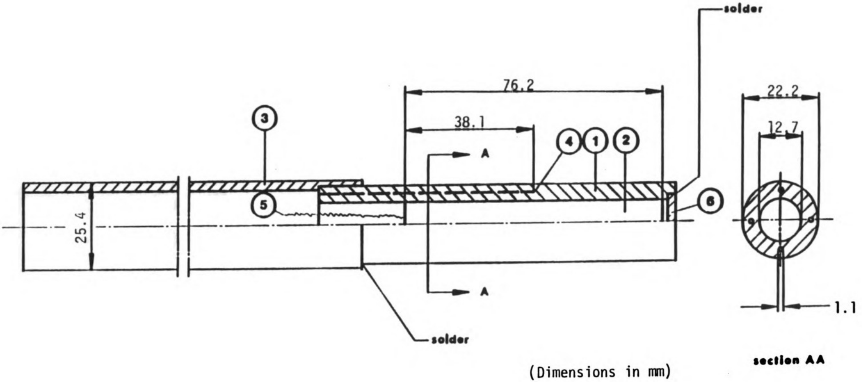
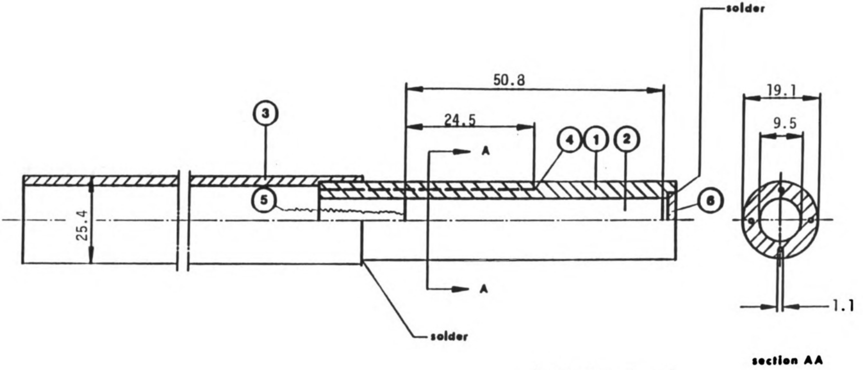


Figure 3.3 Plain copper tube test section #1. Legend: 1-Boiling Surface, 2-Cartridge Heater, 3-Stainless Steel Support Sleeve, 4-Thermocouple Well, 5-Electrical Leads, 6-End Plug.



(Dimensions in mm)

Figure 3.4 Plain copper tube test section #2. Legend: 1-Boiling Surface, 2-Cartridge Heater, 3-Stainless Steel Support Sleeve, 4-Thermocouple Well, 5-Electrical Leads, 6-End Plug.

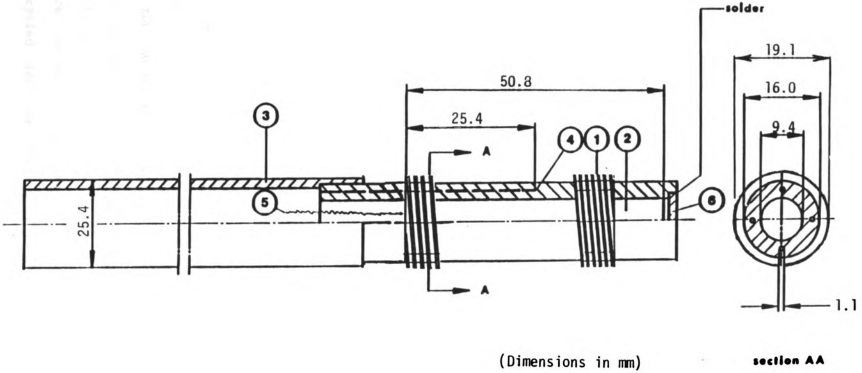


Figure 3.5 Finned tube test section. Legend: 1-Fins, 2-Cartridge Heater, 3-Brass Holder, 4-Thermocouple Well, 5-Electrical Leads, 6-End Plug.

3.4 EXPERIMENTAL PROCEDURE

Before recording measurements from a test section, the surface of each tube was aged by boiling each tube at a high heat flux (175 kW/m^2) several hours per day for at least five consecutive days. This was done in order to completely prepare the surface.

Reagent grade liquids and double distilled water were used in the preparation of all mixtures. The mixture compositions were prepared using a balance accurate to ±1.0 gm.

The pressure vessel was filled to a level at least 10 cm above the top of the test section. An Edwards vacuum pump was used to initially evacuate the vessel before filling it with a mixture. During the time in which the vessel was being filled, water was circulated through the condenser in order to condense vapor that might evaporate and to speed the filling process. After reaching the desired fill level, the immersion heater was turned on and both the liquid inlet line and the degassing vent were closed. When the pressure in the vessel exceeded 1.01 bar, the degassing vent was momentarily opened in order to degas the system. This was continued until saturation conditions for that fluid were attained. Degassing was performed over a period of approximately 1.5 hours. Once the system was at saturation, power was applied to the test section, and increased until the heat flux was at least 175 kW/m^2. This heat flux was maintained, and the surface was permitted to boil for a minimum of 45 minutes to remove trapped gases from the nucleation sites. The power to the test section was then slowly decreased to zero so that the surface deactivated and came to equilibrium with the bulk liquid. Power was then re-applied and the surface cycled through the boiling curve once again. The test section was cycled and the temperatures of the test section and bulk fluid monitored until the same boiling curve was being repeated. During the cycling of the test section, the vessel was carefully maintained at constant pressure to avoid the effects pre- pressurization on boiling site activation.

After the pre-test cycling was complete, the surface heat flux was increased in small increments starting from zero, and the temperatures of the thermocouples in the test section and of the bulk liquid were recorded. The voltage and current to the test section heater were recorded at each heat flux level in order to determine the applied power. The heat flux was increased to the maximum level that could be attained while maintaining the vessel at the test pressure.

The recorded measurements were then used to estimate the wall surface temperature and superheat, the surface heat flux and the heat transfer coefficient. Conductive losses through the holder were accounted for in these estimations. Details of these calculations and the computer program to perform them are found in Appendix A.

3.5 EXPERIMENTAL ERROR AND UNCERTAINTY

The measurement error associated with the wall superheat at low heat flux (≤ 50 kW/m^2) was estimated to be ±0.2 K. This value assumes that each of two Omega Trendicators were in error by ±0.1 K. The combined error in heat flux due to uncertainty in the electrical current and voltage measurements is estimated to be ±2%. The error in the heat transfer coefficient due to these errors is ±4%.

At high heat flux (≥ 150 kW/m^2) for several mixtures, the temperature measurements sometimes fluctuated ±0.5 K about a mean value. These fluctuations were probably due to condensation and reflux in the line leading to the pressure gage. At high heat flux, the wall superheat exceeded 20 K. Therefore, even if the temperature measurement errors resulted in a 1.0 K superheat error, the error in the heat transfer coefficient would still be no larger than ±5%. Assuming the error in heat flux measurements remained ±2%, the maximum error in heat transfer coefficient at high heat flux was estimated to be ±7.5%.

Reproducibility of experimental results is always an important concern in boiling. To demonstrate reproducibility of the experimental data, several tests for pure components and mixtures were repeated. Figure 3.6 shows six boiling curves for pure water at 1.01 bar all obtained on the same plain surface. At $q"=50$ kW^2 the heat transfer coefficients varied from 5.15 to 5.81 kW/m^2 about an average value of 5.43 kW/m^2. That is, all heat transfer coefficients at this heat flux in water on a plain surface were repeatable to within 6.9% of the average value. At $q"=200$ kW/m^2, the variation in heat transfer coefficients was from 11.68 to 13.82 kW/m^2. The average value of α_{exp} at $q"=200$ kW/m^2 was 12.51 kW/m^2-K. These values ranged from 10.5% above to 6.6% below the average heat transfer coefficient at this heat flux.

Figure 3.7 shows four boiling curves for pure acetone at 1.01 bar all from the same plain surface. For these tests, the experimental data ranged from 13.8% above to 9.8% below the average heat transfer coefficient at $q"=50$ kW/m^2 and from 15.3% above to 7.4% below the average value at $q"=150$ kW/m^2.

Repeatability of the tests for mixtures on a plain surface is shown in Figure 3.8. Two boiling curves for 0.05 mole fraction acetone and 0.95 mole fraction water mixtures are shown to differ by 15.7% at q"=50 kW/m^2, and then converge to become negligibly different at higher heat flux.

Several boiling curves for pure ethanol on the finned tube at 1.01 bar are shown in Figure 3.9. At q"=100 kW/m^2, the of the heat transfer coefficients varied from 7.28 to 8.10 kW/m^2-K. These values range from 3.8% above to 6.6% below the average experimental value of 7.80 kW/m$_2$. At q"=300 kW/m^2 the experimental heat transfer coefficients are within ±2.7 K of the average value.

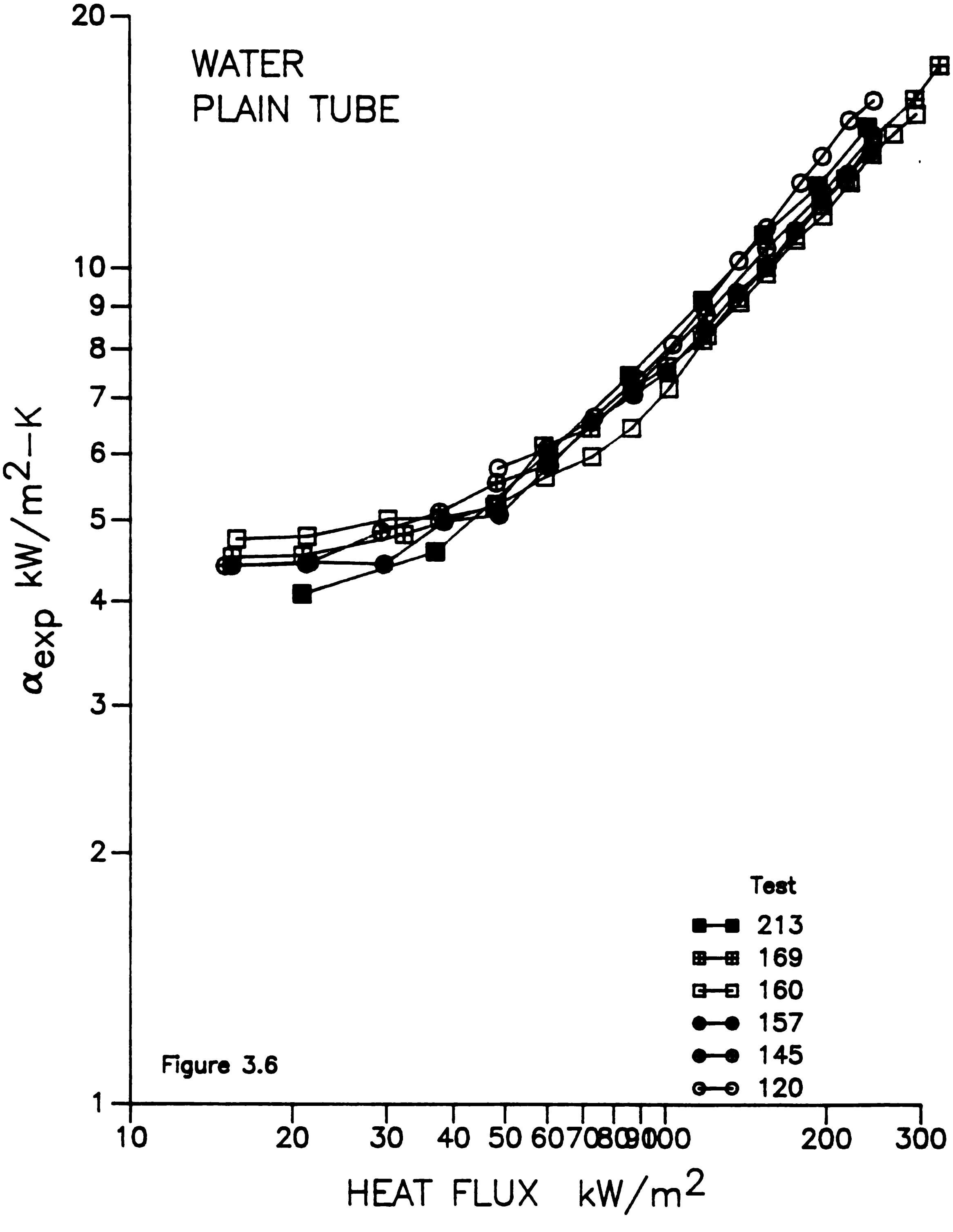


Figure 3.6 Boiling curves for water on a plain surface at 1.01 bar.

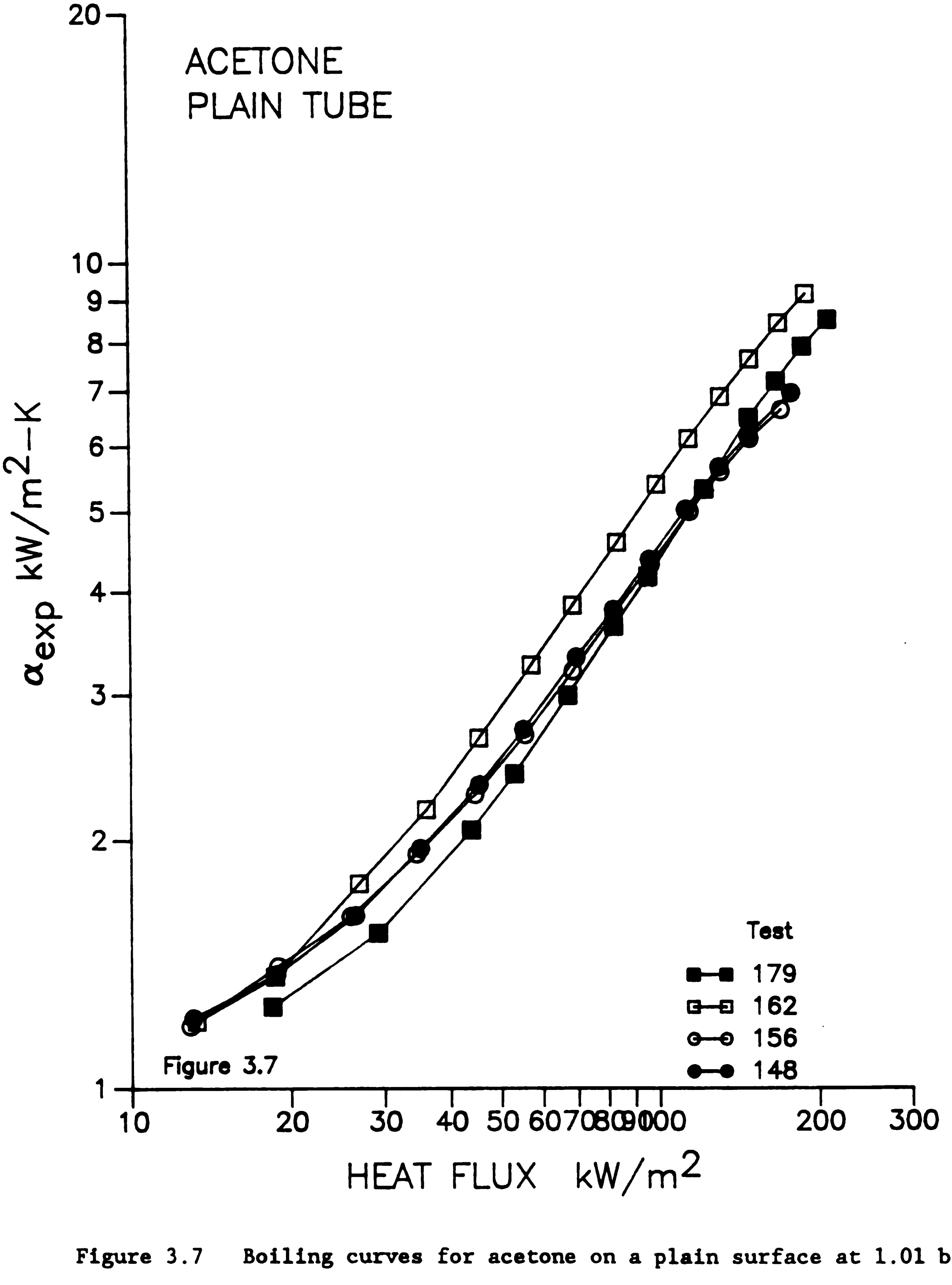


Figure 3.7 Boiling curves for acetone on a plain surface at 1.01 bar.

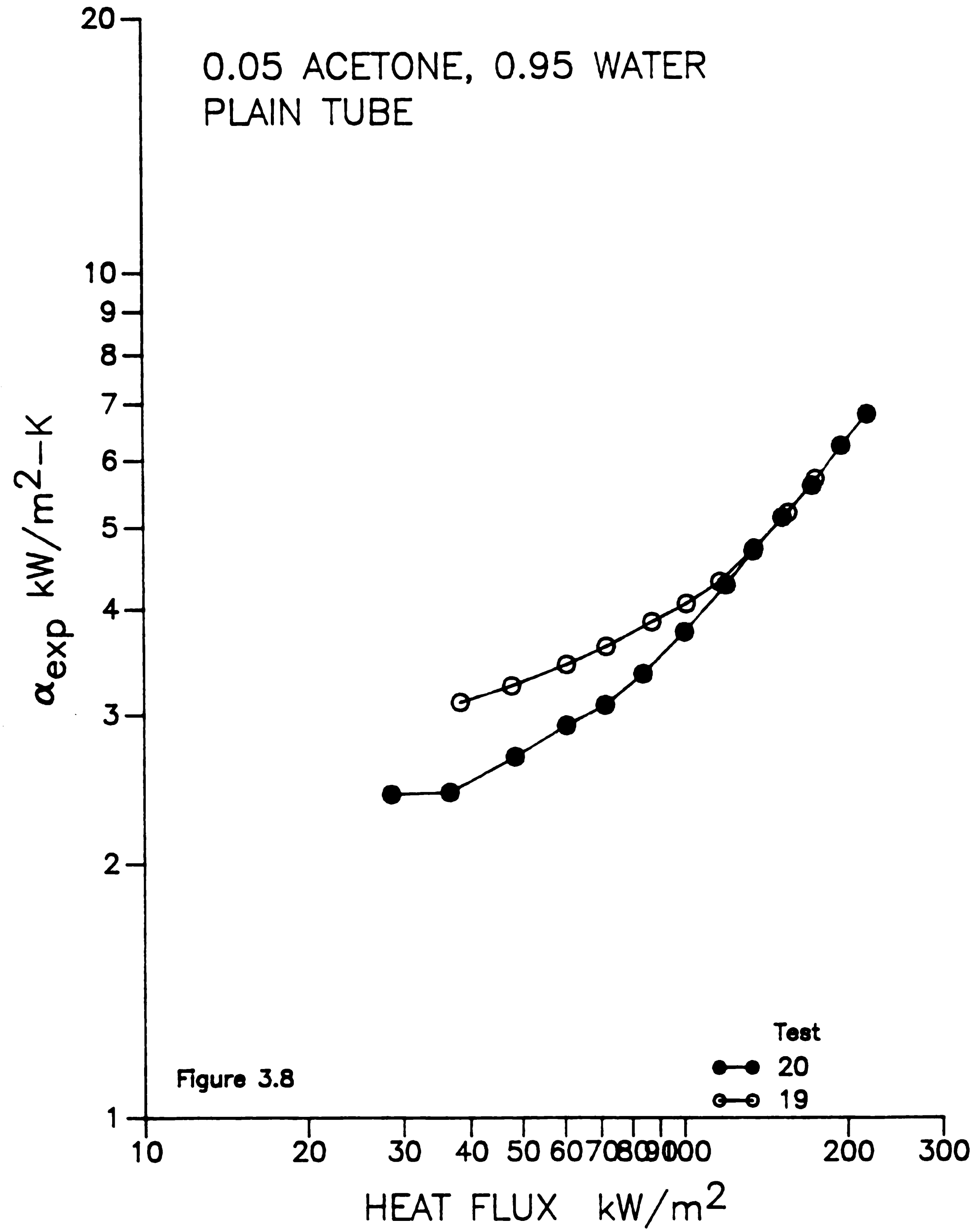


Figure 3.8 Boiling curves for 0.05 acetone, 0.95 water mole fraction mixtures.

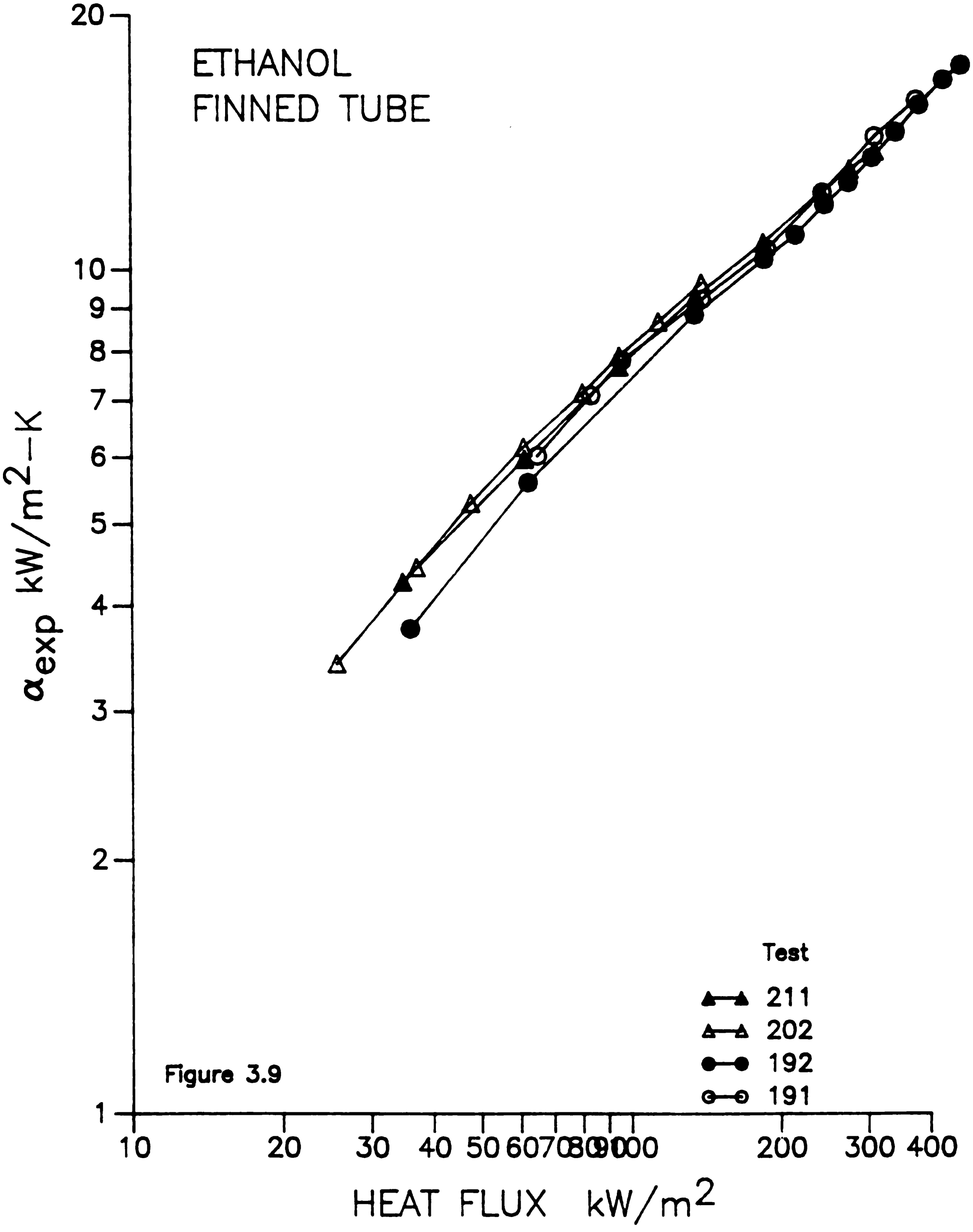


Figure 3.9 Boiling curves for ethanol on a finned surface at 1.01 bar. The fin outer diameter was used to determine the area on which the heat flux was based.

CHAPTER 4

MIXTURE THERMODYNAMIC AND TRANSPORT PROPERTIES

Correlations and predictive methods for nucleate pool boiling heat transfer coefficients depend on accurate estimates of pure component and mixture physical properties. This section discusses the thermodynamic and transport properties used in the calculation of multicomponent pool boling heat transfer coefficients. These properties include: liquid and vapor densities, differential heat of vaporization, liquid thermal conductivity, liquid viscosity, and liquid specific heat. Vapor-liquid phase equilibrium plays a vital role in multicomponent bubble growth and is also discussed in this chapter. Techniques used to estimate binary and multicomponent diffusion coefficients are described.

The methods used to estimate mixture physical properties were chosen based on their ability to reliably estimate the properties and on the capability of those methods to be extended to multicomponent mixtures. The methods chosen are applicable over the range temperatures and pressures for which experimental data were obtained. A complete listing of the physical properties used in this investigation are found in Appendix B.

4.1 VAPOR-LIQUID PHASE EQUILIBRIUM

The thermodynamics of mixtures defines the relationship between pressure, temperature and composition when two or more phases are in a state of equilibrium with each other. The Gibbs phase rule relates the number of independent intensive properties F, in a mixture with n components and p phases as:

$$F = n - p + 2 \qquad (4\text{-}1)$$

Thus, the temperature at which two phases can coexist in a binary mixture is uniquely determined by the pressure and the mole fraction of one of the components in one of the phases. A phase equilibrium diagram is used to show the relationship between temperature and the liquid phase mole fraction in a binary mixture at a given pressure. Figure 4.1 is an example of a phase equilibrium diagram for an ideal binary mixture. The saturation temperature is plotted on the vertical axis, and the liquid and vapor mole fractions of the more volatile component are plotted on the horizontal axis. The more volatile component is also referred to as the light component. The dew point curve represents the variation of equilibrium vapor mole fraction with saturation temperature, and the bubble point curve shows the dependence of the saturation temperature with liquid mole fraction.

An ideal mixture is one which conforms to Raoult's Law:

$$y_i = x_i(P_{vp_i}/P) \qquad (4\text{-}2)$$

Raoult's Law states that the equilibrium vapor mole fraction of any component is directly proportional to the liquid mole fraction and the ratio of the vapor pressure and the system pressure. Most mixture systems however, are not ideal. Aqueous mixtures in particular, are usually highly nonideal.

Figure 4.2 is the phase equilibrium diagram for a binary system that exhibits an azeotrope. At the azeotrope, the vapor and liquid equilibrium compositions are identical. Thus, a mixture with an azeotropic composition behaves as if it were a pure component. Mixtures systems which contain polar molecules are nonideal and the equilibrium vapor compositon cannot be estimated using Raoult's Law. Since water and the alcohols are both polar, their mixtures are nonideal, and other methods must be employed in order to determine the vapor-liquid equilibrium (VLE) compositions. Reid et al. (1987) discuss several methods that can be used to predict vapor-liquid equilibrium states.

The methods for predicting VLE compositions are complex, and all employ parameters that must be derived from experimental data. In order to avoid the introduction of uncertainty by choosing a particular VLE predictive method, only tabulated experimental VLE data were used in the calculations to be described in this document. Experimental VLE data for many mixture systems have been compiled by Behrens and Eckermann (1984), Hirata et al. (1975), Wichterle et al. (1973), and Chu (1950). It is important to point out, that experimental VLE data for mixtures with three or more components are relatively scarce. Tables 4-1 through 4-8 list the VLE data used for the mixture systems studied in this investigation. All of the VLE data reported in these tables was obtained from Behrens and Eckermann, except for Table 4-2, which was obtained from Chu. Binary phase equilibrium diagrams for acetone-water, methanol-water, ethanol-water, and 2-propanol-water are presented in Figures 4.3 through 4.6 respectively.

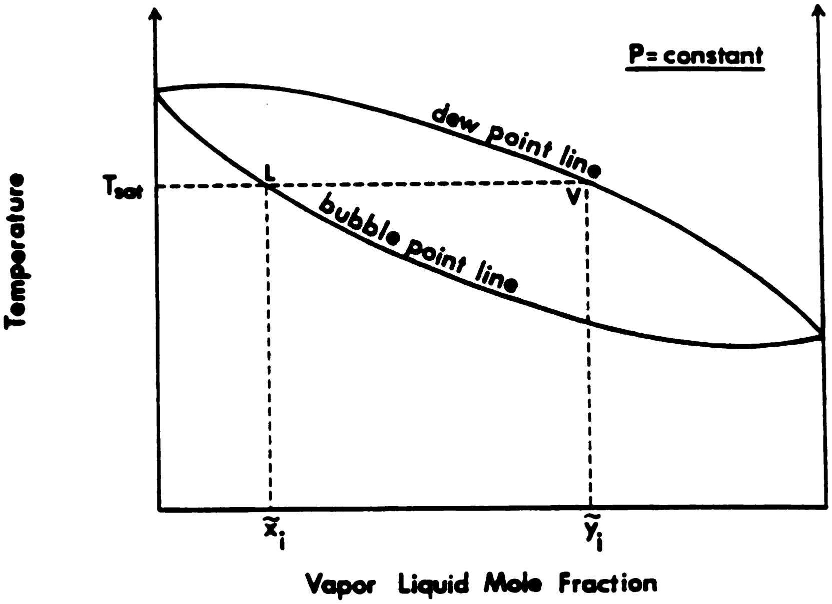


Figure 4.1 Vapor-liquid phase equilibrium diagram for an ideal non-azeotropic binary mixture.

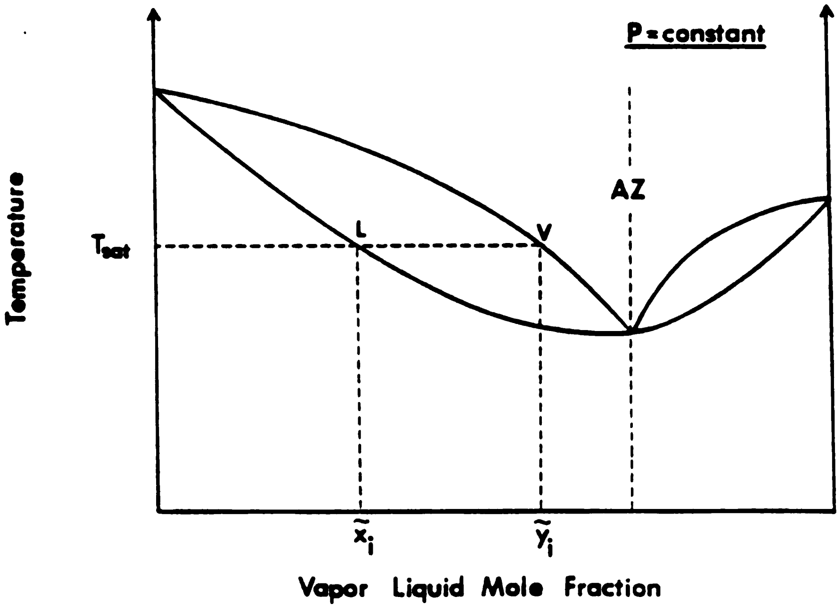


Figure 4.2 Vapor-liquid phase equilibrium diagram for an azeotropic binary mixture.

Table 4-1

Acetone(1)-Methanol(2)-Water(3)
Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	y_1	y_2	T_{sat}
1	0.1000	0.1000	0.6100	0.1300	70.0
2	0.1000	0.2000	0.5200	0.2400	70.0
3	0.1000	0.3000	0.4300	0.3550	69.4
4	0.1000	0.4000	0.3700	0.4500	68.8
5	0.1000	0.5000	0.3200	0.5400	68.0
6	0.1000	0.6000	0.2600	0.6300	66.5
7	0.1000	0.7000	0.2200	0.7100	65.0
8	0.1000	0.8000	0.1850	0.7800	63.5
9	0.2000	0.1000	0.7200	0.0700	65.0
10	0.2000	0.2000	0.6350	0.1800	65.5
11	0.2000	0.3000	0.5600	0.2800	65.5
12	0.2000	0.4000	0.5000	0.3700	64.5
13	0.2000	0.5000	0.4400	0.4700	63.5
14	0.2000	0.6000	0.3850	0.5500	62.5
15	0.2000	0.7000	0.3400	0.6250	61.0
16	0.3000	0.1000	0.7600	0.0650	62.8
17	0.3000	0.2000	0.7000	0.1500	62.7
18	0.3000	0.3000	0.6250	0.2550	62.3
19	0.3000	0.4000	0.5700	0.3450	61.5
20	0.3000	0.5000	0.5200	0.4150	60.5
21	0.3000	0.6000	0.4650	0.5000	59.5
22	0.4000	0.1000	0.7900	0.0600	61.5
23	0.4000	0.2000	0.7250	0.1550	60.8
24	0.4000	0.3000	0.6700	0.2420	60.0
25	0.4000	0.4000	0.6150	0.3220	59.4
26	0.4000	0.5000	0.5650	0.4020	58.4
27	0.5000	0.1000	0.8100	0.0650	60.0
28	0.5000	0.2000	0.7500	0.1600	59.4
29	0.5000	0.3000	0.7000	0.2320	58.6
30	0.5000	0.4000	0.6500	0.3170	57.6
31	0.6000	0.1000	0.8200	0.0800	59.1
32	0.6000	0.2000	0.7700	0.1630	58.3
33	0.6000	0.3000	0.7200	0.2450	57.3
34	0.7000	0.1000	0.8270	0.0950	58.2
35	0.7000	0.2000	0.7780	0.1840	57.2
36	0.8000	0.1000	0.8600	0.1000	57.2
37	0.0000	0.0000	0.0000	0.0000	100.0
38	0.0500	0.0000	0.6390	0.0000	77.0
39	0.1000	0.0000	0.7630	0.0000	69.1
40	0.2000	0.0000	0.8270	0.0000	64.3
41	0.3000	0.0000	0.8450	0.0000	62.4
42	0.4000	0.0000	0.8570	0.0000	61.2
43	0.5000	0.0000	0.8670	0.0000	60.2
44	0.6000	0.0000	0.8770	0.0000	59.3
45	0.7000	0.0000	0.8870	0.0000	58.4

Table 4.1, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
46	0.8000	0.0000	0.8980	0.0000	57.6
47	0.9000	0.0000	0.9270	0.0000	56.8
48	0.9500	0.0000	0.9620	0.0000	56.5
49	1.0000	0.0000	1.0000	0.0000	56.1
50	0.0000	0.0200	0.0000	0.1340	96.4
51	0.0000	0.0400	0.0000	0.2300	93.5
52	0.0000	0.0600	0.0000	0.3040	91.2
53	0.0000	0.0800	0.0000	0.3650	89.3
54	0.0000	0.1000	0.0000	0.4180	87.7
55	0.0000	0.1500	0.0000	0.5170	84.4
56	0.0000	0.2000	0.0000	0.5790	81.7
57	0.0000	0.3000	0.0000	0.6650	78.0
58	0.0000	0.4000	0.0000	0.7290	75.3
59	0.0000	0.5000	0.0000	0.7790	73.1
60	0.0000	0.6000	0.0000	0.8250	71.2
61	0.0000	0.7000	0.0000	0.8700	69.3
62	0.0000	0.8000	0.0000	0.9150	67.5
63	0.0000	0.9000	0.0000	0.9580	66.0
64	0.0000	0.9500	0.0000	0.9750	65.0
65	0.0000	1.0000	0.0000	1.0000	64.5
66	0.0480	0.9520	0.1400	0.8600	62.9
67	0.1760	0.8240	0.3170	0.6830	60.1
68	0.2800	0.7200	0.4200	0.5800	58.3
69	0.4000	0.6000	0.5160	0.4840	57.2
70	0.6000	0.4000	0.6560	0.3440	56.1
71	0.6760	0.3240	0.7100	0.2900	55.1
72	0.8000	0.2000	0.8000	0.2000	55.6
73	0.9500	0.0500	0.9400	0.0600	55.6
74	0.9820	0.0180	0.9760	0.0240	56.1

Table 4-2

Ethanol(1)-Ethyl Acetate(2)-Water(3)
Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	y_1	y_2	T_{sat}
1	0.8990	0.0160	0.8740	0.0360	77.6
2	0.8510	0.0150	0.8530	0.0240	78.1
3	0.7500	0.0240	0.7430	0.0550	77.5
4	0.5860	0.0080	0.6780	0.0250	79.1
5	0.8420	0.0480	0.8040	0.0960	77.0
6	0.6270	0.0330	0.6430	0.0910	77.4
7	0.7040	0.0480	0.6730	0.1100	76.7
8	0.7420	0.0620	0.6810	0.1400	76.2
9	0.8290	0.0920	0.7490	0.1640	75.8
10	0.4570	0.0040	0.6210	0.0200	80.0
11	0.5330	0.0150	0.6340	0.0560	78.8
12	0.8530	0.0530	0.7970	0.1200	76.6
13	0.6460	0.0950	0.5910	0.2010	75.4
14	0.7270	0.1970	0.6240	0.3010	73.7
15	0.4690	0.0570	0.5130	0.1760	76.4
16	0.5900	0.3270	0.5130	0.4060	72.4
17	0.5360	0.2820	0.4670	0.3680	72.4
18	0.4960	0.2130	0.4260	0.3500	73.0
19	0.3850	0.1130	0.3920	0.3000	74.4
20	0.2930	0.0570	0.3990	0.2590	76.0
21	0.2310	0.0240	0.4120	0.1860	77.6
22	0.6600	0.2530	0.5670	0.3460	72.5
23	0.6030	0.2230	0.5330	0.3190	72.7
24	0.5430	0.1660	0.4780	0.2880	73.6
25	0.4230	0.0850	0.4420	0.2500	75.2
26	0.3180	0.0390	0.4450	0.1740	76.4
27	0.2370	0.0170	0.4520	0.1150	78.8
28	0.4980	0.4050	0.4440	0.4440	71.6
29	0.4620	0.3500	0.4010	0.4310	71.5
30	0.4240	0.2880	0.3740	0.3860	72.0
31	0.8980	0.0220	0.8760	0.0500	77.0
32	0.3280	0.1430	0.3270	0.3450	73.6
33	0.2590	0.0800	0.3270	0.3070	74.8
34	0.1900	0.0360	0.3480	0.2550	76.4
35	0.1360	0.0140	0.3710	0.2060	78.9
36	0.0960	0.0040	0.3720	0.1250	82.4
37	0.0810	0.0020	0.3310	0.0380	85.4
38	0.3900	0.4720	0.3550	0.4900	71.2
39	0.3900	0.4130	0.3430	0.4690	71.3
40	0.3450	0.3360	0.3020	0.4420	71.5
41	0.2730	0.1880	0.2640	0.3980	72.3
42	0.1940	0.0960	0.2420	0.3840	72.8
43	0.1580	0.0460	0.2760	0.3540	73.4
44	0.1160	0.0200	0.2990	0.2840	76.3
45	0.0890	0.0050	0.3250	0.2120	82.0
46	0.2970	0.6280	0.3060	0.5790	71.4

Table 4-2, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
47	0.2820	0.5040	0.2630	0.5250	70.8
48	0.2540	0.3830	0.2200	0.4780	71.1
49	0.2220	0.2640	0.2120	0.4460	71.6
50	0.2080	0.2090	0.2030	0.4680	71.9
51	0.1600	0.1250	0.2080	0.4170	72.2
52	0.1830	0.7620	0.2360	0.6690	72.3
53	0.1730	0.6820	0.1910	0.5810	70.7
54	0.9690	0.0060	0.9730	0.0120	78.1
55	0.9500	0.0170	0.9400	0.0360	77.6
56	0.7790	0.1360	0.7060	0.2220	74.7
57	0.7000	0.1230	0.6520	0.2000	74.4
58	0.6630	0.1640	0.5750	0.2600	73.8
59	0.5460	0.1200	0.5200	0.1860	74.2
60	0.4950	0.1540	0.4600	0.2460	73.8
61	0.4330	0.1850	0.4070	0.2990	72.8
62	0.3830	0.2270	0.3380	0.3730	72.4
63	0.3100	0.2920	0.2800	0.4000	71.7
64	0.4020	0.5420	0.3990	0.5450	71.6
65	0.4990	0.4510	0.4800	0.4730	71.8
66	0.5800	0.3720	0.5350	0.4300	72.2
67	0.6670	0.2920	0.6090	0.3810	72.8
68	0.7170	0.2310	0.6600	0.3070	73.4
69	0.7900	0.1650	0.7390	0.2460	74.3
70	0.8540	0.1050	0.7800	0.1900	75.4
71	0.8900	0.0680	0.8350	0.1260	76.2
72	0.1890	0.4310	0.1620	0.5440	70.7
73	0.1490	0.3190	0.1520	0.5000	71.0
74	0.1000	0.7030	0.1020	0.6450	70.6
75	0.1900	0.7270	0.2270	0.6490	71.6
76	0.0650	0.8770	0.1040	0.7670	72.8
77	0.0620	0.8500	0.0760	0.7360	71.8
78	0.0780	0.8990	0.1070	0.8660	73.4
79	0.1910	0.5960	0.1800	0.6000	70.8
80	0.1170	0.3430	0.1400	0.5510	70.8
81	0.1840	0.2280	0.2040	0.4970	71.6
82	0.3480	0.3230	0.2980	0.4510	71.6
83	0.2860	0.1700	0.2800	0.4080	72.9
84	0.1560	0.1020	0.2300	0.3860	72.8
85	0.7930	0.1360	0.7100	0.2270	74.8
86	0.6900	0.1210	0.6210	0.2260	75.0
87	0.4270	0.1750	0.3860	0.3400	73.6
88	0.3810	0.2110	0.3410	0.3640	73.1
89	0.7820	0.1540	0.6930	0.2530	74.5
90	0.6630	0.2900	0.5710	0.3820	72.9
91	0.7520	0.1000	0.7520	0.1950	75.5
92	0.1340	0.7650	0.1640	0.6630	71.8
93	0.1490	0.6490	0.1520	0.6130	70.6
94	0.3540	0.3690	0.3030	0.4750	71.4
95	0.2440	0.5210	0.2240	0.5520	70.8
96	0.1860	0.5480	0.1690	0.5790	70.7

Table 4-2, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
97	0.0000	0.0000	0.0000	0.0000	100.0
98	0.0210	0.0000	0.1990	0.0000	94.3
99	0.0330	0.0000	0.2720	0.0000	91.9
100	0.0500	0.0000	0.3530	0.0000	90.0
101	0.0850	0.0000	0.4110	0.0000	87.3
102	0.1050	0.0000	0.4580	0.0000	86.1
103	0.1250	0.0000	0.4880	0.0000	85.2
104	0.1350	0.0000	0.4840	0.0000	84.7
105	0.3150	0.0000	0.5710	0.0000	81.8
106	0.3210	0.0000	0.5720	0.0000	81.6
107	0.4030	0.0000	0.6220	0.0000	80.4
108	0.5560	0.0000	0.6750	0.0000	79.5
109	0.6020	0.0000	0.6950	0.0000	79.2
110	0.6430	0.0000	0.7130	0.0000	79.1
111	0.6890	0.0000	0.7410	0.0000	78.6
112	0.8050	0.0000	0.8140	0.0000	78.3
113	0.9260	0.0000	0.9170	0.0000	78.3
114	0.9870	0.0000	0.9850	0.0000	78.2
115	1.0000	0.0000	1.0000	0.0000	78.4
116	0.0000	0.0006	0.0000	0.0405	98.9
117	0.0000	0.0011	0.0000	0.1256	96.2
118	0.0000	0.0049	0.0000	0.5910	86.5
119	0.0000	0.0086	0.0000	0.6680	76.2
120	0.0000	0.0459	0.0000	0.7140	70.6
121	0.0000	0.1440	0.0000	0.7025	70.6
122	0.0000	0.2690	0.0000	0.7060	70.5
123	0.0000	0.3540	0.0000	0.7090	70.5
124	0.0000	0.5140	0.0000	0.7100	70.5
125	0.0000	0.6900	0.0000	0.7070	70.5
126	0.0000	0.7750	0.0000	0.6990	70.5
127	0.0000	0.8737	0.0000	0.7650	71.5
128	0.0000	0.9444	0.0000	0.8650	73.4
129	0.0000	1.0000	0.0000	1.0000	77.1
130	0.9500	0.0500	0.8980	0.1020	76.6
131	0.9000	0.1000	0.8130	0.1870	75.5
132	0.8000	0.2000	0.6950	0.3050	73.9
133	0.7000	0.3000	0.6110	0.3890	72.8
134	0.6000	0.4000	0.5430	0.4570	72.1
135	0.5000	0.5000	0.4840	0.5160	71.8
136	0.4600	0.5400	0.4600	0.5400	71.8
137	0.4000	0.6000	0.4240	0.5760	71.9
138	0.3000	0.7000	0.3560	0.6440	72.2
139	0.2000	0.8000	0.2740	0.7260	73.0
140	0.1000	0.9000	0.1630	0.8370	74.7
141	0.0500	0.9500	0.0860	0.9140	76.0

Table 4-3

Methanol(1)-Ethanol(2)-Water(3)
Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	y_1	y_2	T_{sat}
1	0.7500	0.1410	0.8500	0.0960	68.1
2	0.7560	0.1420	0.8520	0.0960	68.1
3	0.3020	0.5900	0.4180	0.4900	74.2
4	0.5300	0.2300	0.6950	0.1800	71.7
5	0.2600	0.5200	0.3600	0.4700	75.0
6	0.0490	0.2480	0.1300	0.5120	81.2
7	0.3600	0.2930	0.5250	0.2900	74.5
8	0.2030	0.4750	0.3280	0.4700	76.3
9	0.2160	0.3100	0.3900	0.3650	77.2
10	0.4900	0.3600	0.6350	0.2900	71.9
11	0.1020	0.3680	0.1970	0.5100	79.0
12	0.2840	0.2960	0.4400	0.3550	75.8
13	0.0350	0.3500	0.0810	0.5540	80.5
14	0.0430	0.0620	0.1850	0.3100	83.0
15	0.0610	0.0330	0.2800	0.2200	87.5
16	0.1380	0.0410	0.4250	0.1500	83.0
17	0.2400	0.0600	0.5500	0.1600	79.0
18	0.0550	0.2550	0.1600	0.4850	81.0
19	0.0530	0.1450	0.1450	0.4300	82.7
20	0.0930	0.0980	0.3100	0.3000	82.7
21	0.1090	0.0810	0.3550	0.2500	82.7
22	0.0900	0.0800	0.3080	0.2850	83.5
23	0.0610	0.1420	0.1950	0.3950	82.5
24	0.1600	0.0370	0.5150	0.1050	82.2
25	0.1170	0.0980	0.3590	0.2730	81.0
26	0.0515	0.0670	0.2280	0.3160	82.8
27	0.1000	0.0960	0.3100	0.2950	82.5
28	0.1100	0.7200	0.1800	0.6800	76.5
29	0.1566	0.8306	0.2361	0.7537	75.8
30	0.2753	0.7143	0.3774	0.6136	73.9
31	0.3261	0.6595	0.4289	0.5601	72.9
32	0.3745	0.6116	0.0594	0.4833	71.8
33	0.3845	0.5983	0.5165	0.4734	72.1
34	0.4808	0.5028	0.6045	0.3862	71.1
35	0.4908	0.4895	0.6360	0.3487	70.9
36	0.5510	0.4276	0.6714	0.3173	70.1
37	0.5945	0.3847	0.6883	0.2981	69.8
38	0.6479	0.3303	0.7496	0.2389	68.9
39	0.6961	0.2817	0.7971	0.1899	68.1
40	0.7667	0.2113	0.8299	0.1578	67.7
41	0.7807	0.2020	0.8820	0.1096	66.8
42	0.7829	0.1996	0.8543	0.1369	67.1
43	0.0000	0.0000	0.0000	0.0000	100.0
44	0.0200	0.0000	0.1340	0.0000	96.4
45	0.0400	0.0000	0.2300	0.0000	93.5

Table 4-3, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
46	0.0600	0.0000	0.3040	0.0000	91.2
47	0.0800	0.0000	0.3650	0.0000	89.3
48	0.1000	0.0000	0.4180	0.0000	87.7
49	0.1500	0.0000	0.5170	0.0000	84.4
50	0.2000	0.0000	0.5790	0.0000	81.7
51	0.3000	0.0000	0.6650	0.0000	78.0
52	0.4000	0.0000	0.7290	0.0000	75.3
53	0.5000	0.0000	0.7790	0.0000	73.1
54	0.6000	0.0000	0.8250	0.0000	71.2
55	0.7000	0.0000	0.8700	0.0000	69.3
56	0.8000	0.0000	0.9150	0.0000	67.5
57	0.9000	0.0000	0.9580	0.0000	66.0
58	0.9500	0.0000	0.9750	0.0000	65.0
59	1.0000	0.0000	1.0000	0.0000	64.5
60	0.0000	0.0210	0.0000	0.1990	94.3
61	0.0000	0.0330	0.0000	0.2720	91.9
62	0.0000	0.0500	0.0000	0.3530	90.0
63	0.0000	0.0850	0.0000	0.4110	87.3
64	0.0000	0.1050	0.0000	0.4580	86.1
65	0.0000	0.1250	0.0000	0.4880	85.2
66	0.0000	0.1350	0.0000	0.4840	84.7
67	0.0000	0.3150	0.0000	0.5710	81.8
68	0.0000	0.3210	0.0000	0.5720	81.6
69	0.0000	0.4030	0.0000	0.6220	80.4
70	0.0000	0.5560	0.0000	0.6750	79.5
71	0.0000	0.6020	0.0000	0.6950	79.2
72	0.0000	0.6430	0.0000	0.7130	79.1
73	0.0000	0.6890	0.0000	0.7410	78.6
74	0.0000	0.8050	0.0000	0.8140	78.3
75	0.0000	0.9260	0.0000	0.9170	78.3
76	0.0000	0.9870	0.0000	0.9850	78.2
77	0.0000	1.0000	0.0000	1.0000	78.4
78	0.1340	0.8660	0.1830	0.8170	76.6
79	0.2420	0.7580	0.3260	0.6740	75.0
80	0.3200	0.6800	0.4280	0.5720	73.6
81	0.4010	0.5990	0.5290	0.4710	72.3
82	0.4350	0.5650	0.5660	0.4340	71.7
83	0.5420	0.4580	0.6760	0.3240	70.0
84	0.6520	0.3480	0.7590	0.2410	68.6
85	0.7280	0.2720	0.8130	0.1870	67.7
86	0.7900	0.2100	0.8580	0.1420	66.9
87	0.8140	0.1860	0.8750	0.1250	66.6
88	0.8730	0.1270	0.9190	0.0810	65.8
89	0.9100	0.0900	0.9370	0.0630	65.6

Table 4-4

Acetone(1)-2-Propanol(2)-Water(3)
Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	y_1	y_2	T_{sat}
1	0.0030	0.0120	0.1400	0.1780	90.0
2	0.0040	0.0750	0.0970	0.4050	82.0
3	0.0040	0.5900	0.0150	0.6140	80.0
4	0.0050	0.6900	0.0150	0.6850	80.0
5	0.0050	0.8020	0.0150	0.7700	80.0
6	0.0080	0.7440	0.0190	0.7150	80.0
7	0.0090	0.2430	0.1020	0.4640	80.0
8	0.0090	0.3860	0.0530	0.5300	80.0
9	0.0090	0.7660	0.0150	0.7440	80.0
10	0.0100	0.0080	0.2120	0.1020	90.0
11	0.0100	0.5200	0.0300	0.5900	80.0
12	0.0110	0.0740	0.2240	0.3250	80.0
13	0.0120	0.0620	0.1380	0.3720	82.0
14	0.0130	0.0720	0.2180	0.3360	80.0
15	0.0140	0.0440	0.2180	0.2930	82.0
16	0.0160	0.1510	0.1350	0.4350	80.0
17	0.0160	0.2780	0.0900	0.4800	80.0
18	0.0170	0.9410	0.0880	0.8580	80.0
19	0.0175	0.1750	0.1220	0.4480	80.0
20	0.0180	0.0450	0.2140	0.2920	82.0
21	0.0200	0.0190	0.3490	0.1530	82.0
22	0.0260	0.0200	0.4100	0.1420	80.0
23	0.0340	0.0360	0.4520	0.1650	77.0
24	0.0420	0.0190	0.5770	0.0780	75.0
25	0.0470	0.0220	0.5510	0.1010	75.0
26	0.0470	0.1780	0.2860	0.3440	77.0
27	0.0500	0.0400	0.5250	0.1400	73.0
28	0.0590	0.4660	0.1760	0.4780	77.0
29	0.0650	0.1300	0.3770	0.2660	75.0
30	0.0780	0.0950	0.4600	0.2110	73.0
31	0.0820	0.2940	0.3280	0.3420	75.0
32	0.0830	0.0360	0.6320	0.0860	70.0
33	0.0900	0.4800	0.2840	0.4210	75.0
34	0.1050	0.6100	0.2700	0.4960	75.0
35	0.1080	0.6750	0.2730	0.5310	75.0
36	0.1100	0.0500	0.6380	0.1080	69.0
37	0.1240	0.2900	0.4000	0.2960	73.0
38	0.1320	0.0530	0.6420	0.1090	68.0
39	0.1400	0.5800	0.3380	0.4560	73.0
40	0.1480	0.1140	0.5890	0.1570	69.0
41	0.1550	0.1500	0.5300	0.1940	70.0
42	0.1660	0.0240	0.7280	0.0410	66.0
43	0.1900	0.1200	0.6000	0.1500	68.0
44	0.1920	0.2810	0.4920	0.2550	70.0
45	0.1980	0.0340	0.7310	0.0490	65.0
46	0.2050	0.0680	0.6800	0.0970	66.0

Table 4-4, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
47	0.2120	0.1820	0.5370	0.2190	69.0
48	0.2260	0.5320	0.4770	0.3560	70.0
49	0.2270	0.5500	0.4740	0.3660	70.0
50	0.2360	0.3360	0.5200	0.2560	69.0
51	0.2460	0.0570	0.7370	0.0370	65.0
52	0.2530	0.1100	0.6520	0.1270	66.0
53	0.2620	0.4920	0.4970	0.3330	69.0
54	0.2660	0.2820	0.5600	0.2200	68.0
55	0.2690	0.0520	0.7470	0.0460	64.0
56	0.2940	0.4840	0.5450	0.3080	68.0
57	0.3240	0.1970	0.6400	0.1640	66.0
58	0.3440	0.1750	0.6870	0.1170	65.0
59	0.3560	0.0640	0.7450	0.0590	63.0
60	0.3760	0.4210	0.6160	0.2590	66.0
61	0.3820	0.2740	0.6390	0.1890	65.0
62	0.3850	0.1750	0.7020	0.1140	64.0
63	0.3890	0.2120	0.6740	0.1540	64.0
64	0.3990	0.4150	0.6570	0.2290	65.0
65	0.4100	0.0390	0.7660	0.0510	62.0
66	0.4150	0.4650	0.6730	0.2500	65.0
67	0.4360	0.3860	0.6830	0.2120	64.0
68	0.4380	0.3000	0.6790	0.1750	64.0
69	0.4480	0.1750	0.7160	0.1250	63.0
70	0.4580	0.0650	0.7700	0.0600	62.0
71	0.4600	0.2280	0.6980	0.1430	63.0
72	0.4660	0.3100	0.7050	0.1730	63.0
73	0.5020	0.1610	0.7460	0.0950	62.0
74	0.5230	0.0670	0.7990	0.0430	61.0
75	0.5240	0.2670	0.7310	0.1530	62.0
76	0.5510	0.2970	0.7400	0.1690	62.0
77	0.5690	0.0500	0.8260	0.0260	60.0
78	0.5850	0.1770	0.7780	0.1030	61.0
79	0.6200	0.2610	0.7950	0.1440	61.0
80	0.6250	0.1260	0.8000	0.0700	60.0
81	0.6520	0.0620	0.8370	0.0310	59.0
82	0.6730	0.2110	0.8380	0.1030	60.0
83	0.6990	0.1050	0.8550	0.0400	59.0
84	0.7360	0.1730	0.8600	0.0930	59.0
85	0.7570	0.0590	0.8650	0.0360	58.0
86	0.8080	0.1300	0.9010	0.0520	58.0
87	0.0000	0.0000	0.0000	0.0000	100.0
88	0.0500	0.0000	0.6390	0.0000	77.0
89	0.1000	0.0000	0.7630	0.0000	69.1
90	0.2000	0.0000	0.8270	0.0000	64.3
91	0.3000	0.0000	0.8450	0.0000	62.4
92	0.4000	0.0000	0.8570	0.0000	61.2
93	0.5000	0.0000	0.8670	0.0000	60.2
94	0.6000	0.0000	0.8770	0.0000	59.3
95	0.7000	0.0000	0.8870	0.0000	58.4
96	0.8000	0.0000	0.8980	0.0000	57.6

Table 4-4, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
97	0.9000	0.0000	0.9270	0.0000	56.8
98	0.9500	0.0000	0.9620	0.0000	56.5
99	1.0000	0.0000	1.0000	0.0000	56.1
100	0.0000	0.0023	0.0000	0.1723	96.5
101	0.0000	0.0067	0.0000	0.2038	95.4
102	0.0000	0.0130	0.0000	0.3190	92.7
103	0.0000	0.0322	0.0000	0.4230	88.2
104	0.0000	0.0410	0.0000	0.4627	86.7
105	0.0000	0.0470	0.0000	0.4809	86.0
106	0.0000	0.0717	0.0000	0.5162	84.1
107	0.0000	0.111	0.0000	0.5186	83.2
108	0.0000	0.2065	0.0000	0.5388	82.4
109	0.0000	0.2435	0.0000	0.5404	82.1
110	0.0000	0.2862	0.0000	0.5569	81.9
111	0.0000	0.3431	0.0000	0.5721	81.6
112	0.0000	0.3435	0.0000	0.5580	81.3
113	0.0000	0.5046	0.0000	0.5870	80.9
114	0.0000	0.6251	0.0000	0.6421	80.5
115	0.0000	0.6831	0.0000	0.6831	80.2
116	0.0000	0.7294	0.0000	0.7164	80.4
117	0.0000	0.7845	0.0000	0.7632	80.5
118	0.0000	0.8641	0.0000	0.8116	81.0
119	0.0000	1.0000	0.0000	1.0000	82.3

Table 4-5

Methanol(1)-2-Propanol(2)-Water(3)
Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	y_1	y_2	T_{sat}
1	0.0320	0.0130	0.1920	0.1310	89.6
2	0.0340	0.0250	0.1740	0.1590	88.5
3	0.0690	0.0250	0.2270	0.1710	85.9
4	0.1220	0.0390	0.3530	0.1560	82.9
5	0.1270	0.0200	0.4110	0.1140	83.2
6	0.1780	0.3350	0.2290	0.4210	78.8
7	0.2250	0.2510	0.3240	0.3380	78.1
8	0.2460	0.1310	0.3980	0.2020	78.1
9	0.2760	0.1460	0.4360	0.2280	77.8
10	0.3030	0.0310	0.6160	0.0600	77.2
11	0.3040	0.1940	0.4320	0.2600	77.0
12	0.3450	0.0650	0.6280	0.1060	75.2
13	0.3510	0.1960	0.4880	0.2390	76.0
14	0.3630	0.5360	0.4950	0.4130	75.3
15	0.3820	0.1900	0.5330	0.2130	75.1
16	0.4090	0.0910	0.6220	0.1250	74.9
17	0.4540	0.0840	0.6660	0.1030	74.0
18	0.4990	0.3640	0.6410	0.2630	72.8
19	0.5080	0.1370	0.6820	0.1270	72.9
20	0.6000	0.0960	0.7590	0.0780	71.5
21	0.6080	0.1200	0.7760	0.0870	71.1
22	0.6260	0.1370	0.7800	0.1020	70.7
23	0.6520	0.1270	0.8010	0.0900	70.3
24	0.7370	0.0910	0.8460	0.0700	69.0
25	0.7430	0.1910	0.8570	0.1100	68.6
26	0.8120	0.1430	0.8920	0.0870	67.4
27	0.0000	0.0000	0.0000	0.0000	100.0
28	0.0200	0.0000	0.1340	0.0000	96.4
29	0.0400	0.0000	0.2300	0.0000	93.5
30	0.0600	0.0000	0.3040	0.0000	91.2
31	0.0800	0.0000	0.3650	0.0000	89.3
32	0.1000	0.0000	0.4180	0.0000	87.7
33	0.1500	0.0000	0.5170	0.0000	84.4
34	0.2000	0.0000	0.5790	0.0000	81.7
35	0.3000	0.0000	0.6650	0.0000	78.0
36	0.4000	0.0000	0.7290	0.0000	75.3
37	0.5000	0.0000	0.7790	0.0000	73.1
38	0.6000	0.0000	0.8250	0.0000	71.2
39	0.7000	0.0000	0.8700	0.0000	69.3
40	0.8000	0.0000	0.9150	0.0000	67.5
41	0.9000	0.0000	0.9580	0.0000	66.0
42	0.9500	0.0000	0.9750	0.0000	65.0
43	1.0000	0.0000	1.0000	0.0000	64.5
44	0.0000	0.0023	0.0000	0.1723	96.5
45	0.0000	0.0067	0.0000	0.2038	95.4
46	0.0000	0.0130	0.0000	0.3190	92.7

Table 4-5, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
47	0.0000	0.0322	0.0000	0.4230	88.2
48	0.0000	0.0410	0.0000	0.4627	86.7
49	0.0000	0.0470	0.0000	0.4809	86.0
50	0.0000	0.0717	0.0000	0.5162	84.1
51	0.0000	0.1113	0.0000	0.5186	83.2
52	0.0000	0.2065	0.0000	0.5388	82.4
53	0.0000	0.2435	0.0000	0.5404	82.1
54	0.0000	0.2862	0.0000	0.5569	81.9
55	0.0000	0.3431	0.0000	0.5721	81.6
56	0.0000	0.3435	0.0000	0.5580	81.3
57	0.0000	0.5046	0.0000	0.5870	80.9
58	0.0000	0.6251	0.0000	0.6421	80.5
59	0.0000	0.6831	0.0000	0.6831	80.2
60	0.0000	0.7294	0.0000	0.7164	80.4
61	0.0000	0.7845	0.0000	0.7632	80.5
62	0.0000	0.8641	0.0000	0.8116	81.0
63	0.0000	1.0000	0.0000	1.0000	82.3

Table 4-6

Acetone(1)-2-Butanone(2)-Water(3)
Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	y_1	y_2	T_{sat}
1	0.7400	0.1140	0.8480	0.0520	58.3
2	0.6280	0.1320	0.7690	0.0880	59.9
3	0.6140	0.2600	0.7280	0.1630	62.1
4	0.5620	0.2320	0.6920	0.1540	62.5
5	0.5230	0.1050	0.7400	0.0830	61.8
6	0.4810	0.3630	0.6100	0.2370	65.8
7	0.4240	0.3630	0.5810	0.2440	66.8
8	0.4200	0.4030	0.5460	0.2820	66.7
9	0.4100	0.2530	0.6000	0.1660	64.9
10	0.4000	0.1690	0.6720	0.1390	63.8
11	0.3880	0.2440	0.6190	0.1850	65.0
12	0.3870	0.3740	0.5390	0.2730	67.2
13	0.3760	0.0860	0.7270	0.0940	63.9
14	0.2980	0.1070	0.6530	0.1370	64.7
15	0.2970	0.4950	0.4240	0.3660	67.8
16	0.2730	0.3030	0.4750	0.2860	67.3
17	0.2650	0.4140	0.4230	0.3330	67.8
18	0.2550	0.0540	0.6950	0.1030	64.6
19	0.2080	0.3530	0.3970	0.3440	68.3
20	0.1820	0.3960	0.3390	0.3790	68.4
21	0.1630	0.0500	0.6200	0.1480	66.2
22	0.1610	0.4570	0.2870	0.4340	71.2
23	0.1590	0.3150	0.3340	0.3860	69.9
24	0.1350	0.0550	0.6140	0.2020	66.8
25	0.1270	0.1780	0.3690	0.3520	67.5
26	0.1210	0.2530	0.2790	0.4060	69.7
27	0.1200	0.7850	0.1870	0.6400	72.3
28	0.1160	0.5740	0.1930	0.5150	78.3
29	0.1110	0.1200	0.3860	0.3320	67.8
30	0.0950	0.5030	0.1940	0.5280	71.4
31	0.0890	0.4200	0.0850	0.4870	71.3
32	0.0820	0.1390	0.2850	0.4200	69.8
33	0.0790	0.0930	0.3550	0.3580	69.4
34	0.0710	0.8990	0.1280	0.7610	77.0
35	0.0550	0.0390	0.5020	0.2410	73.1
36	0.0470	0.3690	0.1130	0.5610	72.9
37	0.0220	0.0800	0.1750	0.4860	79.5
38	0.0000	0.0000	0.0000	0.0000	100.0
39	0.0500	0.0000	0.6390	0.0000	77.0
40	0.1000	0.0000	0.7630	0.0000	69.1
41	0.2000	0.0000	0.8270	0.0000	64.3
42	0.3000	0.0000	0.8450	0.0000	62.4
43	0.4000	0.0000	0.8570	0.0000	61.2
44	0.5000	0.0000	0.8670	0.0000	60.2
45	0.6000	0.0000	0.8770	0.0000	59.3
46	0.7000	0.0000	0.8870	0.0000	58.4
47	0.8000	0.0000	0.8980	0.0000	57.6

Table 4-6, continued

No.	x_1	x_2	y_1	y_2	T_{sat}
48	0.9000	0.0000	0.9270	0.0000	56.8
49	0.9500	0.0000	0.9620	0.0000	56.5
50	1.0000	0.0000	1.0000	0.0000	56.1
51	0.0000	0.0480	0.0000	0.6440	73.9
52	0.0000	0.6690	0.0000	0.6580	73.3
53	0.0000	0.7310	0.0000	0.6760	73.4
54	0.0000	0.8000	0.0000	0.6970	73.6
55	0.0000	0.8420	0.0000	0.7240	74.0
56	0.0000	0.8640	0.0000	0.7480	74.3
57	0.0000	0.8840	0.0000	0.7690	74.8
58	0.0000	0.9130	0.0000	0.8080	75.6
59	0.0000	1.0000	0.0000	1.0000	79.6

Table 4-7

Cyclohexane(1)-Benzene(2)-2-Propanol(3)-2-Butanone(4)
Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	x_3	y_1	y_2	y_3	T_{sat}
1	0.0200	0.8580	0.0060	0.0280	0.8390	0.0150	78.40
2	0.0270	0.8410	0.0140	0.0410	0.8020	0.0380	77.80
3	0.0410	0.8020	0.0380	0.0530	0.7500	0.0900	76.40
4	0.0530	0.7500	0.0900	0.0710	0.6600	0.1800	74.20
5	0.0510	0.6790	0.1480	0.0660	0.5920	0.2410	73.10
6	0.1120	0.4990	0.3160	0.1510	0.4610	0.3340	71.00
7	0.1860	0.4210	0.3520	0.2350	0.3900	0.3430	70.20
8	0.0180	0.9560	0.0050	0.0250	0.9380	0.0170	79.20
9	0.0250	0.9380	0.0170	0.0360	0.8820	0.0610	77.90
10	0.0810	0.8360	0.0050	0.1040	0.8020	0.0110	77.80
11	0.1460	0.7180	0.0070	0.1810	0.6570	0.0140	76.80
12	0.2150	0.5830	0.0550	0.2530	0.4710	0.1340	73.20
13	0.2750	0.3540	0.2580	0.3010	0.3130	0.2910	70.10
14	0.0350	0.5460	0.0270	0.0480	0.5260	0.0420	76.70
15	0.0480	0.5260	0.0420	0.0710	0.4990	0.0710	75.90
16	0.0710	0.4990	0.0710	0.0970	0.4760	0.1070	74.90
17	0.0930	0.4580	0.1340	0.1620	0.4310	0.1420	74.00
18	0.2560	0.2650	0.2810	0.3280	0.2230	0.2860	70.10
19	0.3400	0.2250	0.2970	0.3850	0.1950	0.3020	69.50
20	0.0060	0.0750	0.0470	0.0140	0.1300	0.0260	78.80
21	0.0140	0.1300	0.0260	0.0260	0.1820	0.0350	78.20
22	0.0460	0.1560	0.1180	0.0900	0.1570	0.1430	75.80
23	0.1270	0.1810	0.1500	0.2080	0.1700	0.1720	73.40
24	0.2750	0.1680	0.1840	0.3560	0.1360	0.2020	70.60
25	0.3500	0.1350	0.1990	0.3970	0.1160	0.2190	69.90
26	0.0050	0.0160	0.2370	0.0150	0.0190	0.2620	77.50
27	0.0430	0.0640	0.3020	0.1040	0.0720	0.2970	75.10
28	0.1300	0.0720	0.2900	0.2280	0.0680	0.2640	72.50
29	0.3060	0.0840	0.2480	0.3900	0.0760	0.2310	70.10
30	0.3760	0.0830	0.2280	0.4300	0.0700	0.2310	69.50
31	0.0080	0.3640	0.3850	0.0170	0.3940	0.3850	73.70
32	0.0430	0.4790	0.3840	0.0700	0.4910	0.3680	71.90
33	0.0990	0.4760	0.3670	0.1380	0.4610	0.3610	71.00
34	0.2360	0.3840	0.3570	0.2670	0.3550	0.3580	69.80
35	0.0750	0.1820	0.2130	0.1460	0.1800	0.2340	73.90
36	0.1460	0.1800	0.2320	0.2300	0.1660	0.2370	72.40
37	0.7470	0.0760	0.0100	0.6030	0.0720	0.0440	72.50
38	0.5480	0.0530	0.0900	0.5210	0.0410	0.1380	70.00
39	0.5080	0.0200	0.1640	0.5060	0.0300	0.1840	69.40
40	0.4950	0.0200	0.1670	0.4910	0.0160	0.1980	69.60
41	0.4660	0.5100	0.0010	0.4580	0.4870	0.0120	76.50
42	0.4290	0.3870	0.0200	0.4200	0.3440	0.0400	73.80
43	0.4060	0.2040	0.1700	0.4110	0.1740	0.2190	70.40
44	0.4360	0.1310	0.2520	0.4470	0.1150	0.2720	69.20
45	0.4670	0.1160	0.2670	0.4790	0.0950	0.2850	69.10
46	0.7210	0.1130	0.1250	0.5890	0.0960	0.2590	70.10
47	0.6070	0.0910	0.2480	0.5310	0.0870	0.3130	69.20

Table 4-7, continued

No.	x_1	x_2	x_3	y_1	y_2	y_3	T_{sat}
48	0.5080	0.0770	0.3420	0.5160	0.0770	0.3290	69.10
49	0.4670	0.2550	0.2070	0.4580	0.2110	0.2690	69.60
50	0.0040	0.0050	0.9170	0.0160	0.0340	0.8450	80.20
51	0.0140	0.0340	0.8490	0.0520	0.0770	0.7360	78.10
52	0.0380	0.0710	0.7410	0.1060	0.1310	0.5980	75.90
53	0.1650	0.1910	0.4820	0.2700	0.2190	0.3780	70.90
54	0.2740	0.2050	0.3860	0.3530	0.2010	0.3330	70.00
55	0.3820	0.1780	0.3340	0.4120	0.1610	0.3330	69.20
56	0.0280	0.4270	0.4700	0.0490	0.4790	0.4140	72.10
57	0.0560	0.4940	0.4000	0.0840	0.5040	0.3760	71.30
58	0.1540	0.2480	0.5000	0.2460	0.2740	0.3960	70.70

Table 4-8

Methanol(1)-Ethanol(2)-Methyl Acetate(3)-Ethyl Acetate(4) Vapor-Liquid Equilibrium Data at 1.01 bar Pressure

No.	x_1	x_2	x_3	y_1	y_2	y_3	T_{sat}
1	0.2000	0.2000	0.2000	0.2597	0.1477	0.2795	65.30
2	0.2000	0.2000	0.4000	0.2409	0.1307	0.4928	62.20
3	0.2000	0.4000	0.2000	0.2180	0.2740	0.3178	67.00
4	0.4000	0.2000	0.2000	0.4094	0.1171	0.3011	66.80

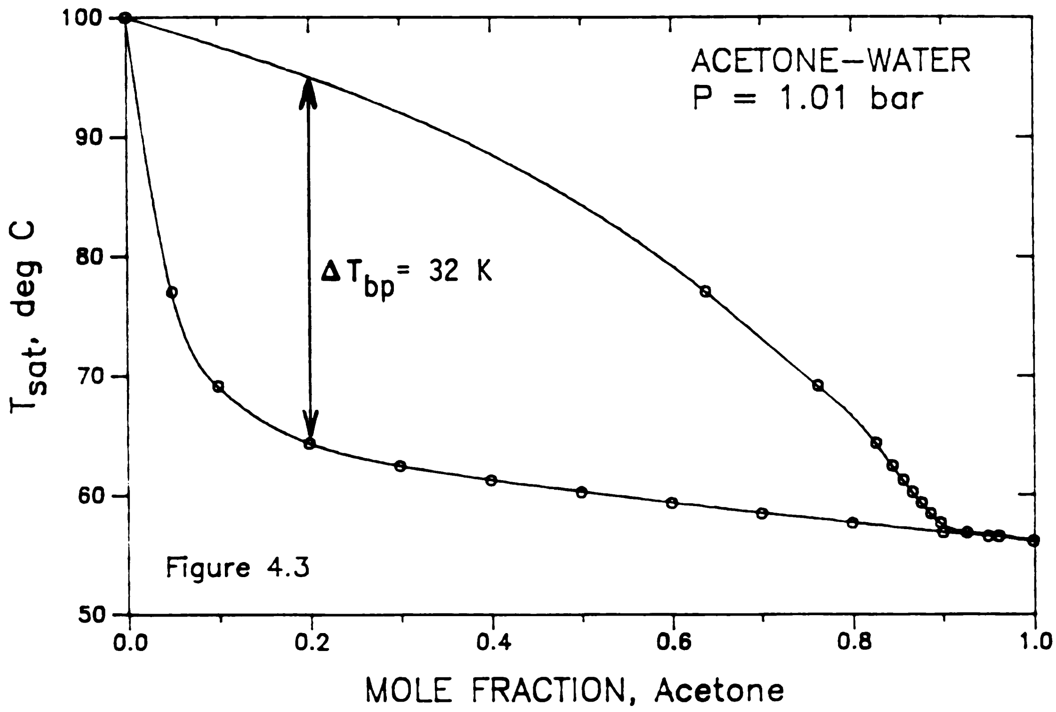


Figure 4.3 Acetone-water vapor-liquid equilibrium diagram at 1.01 bar.

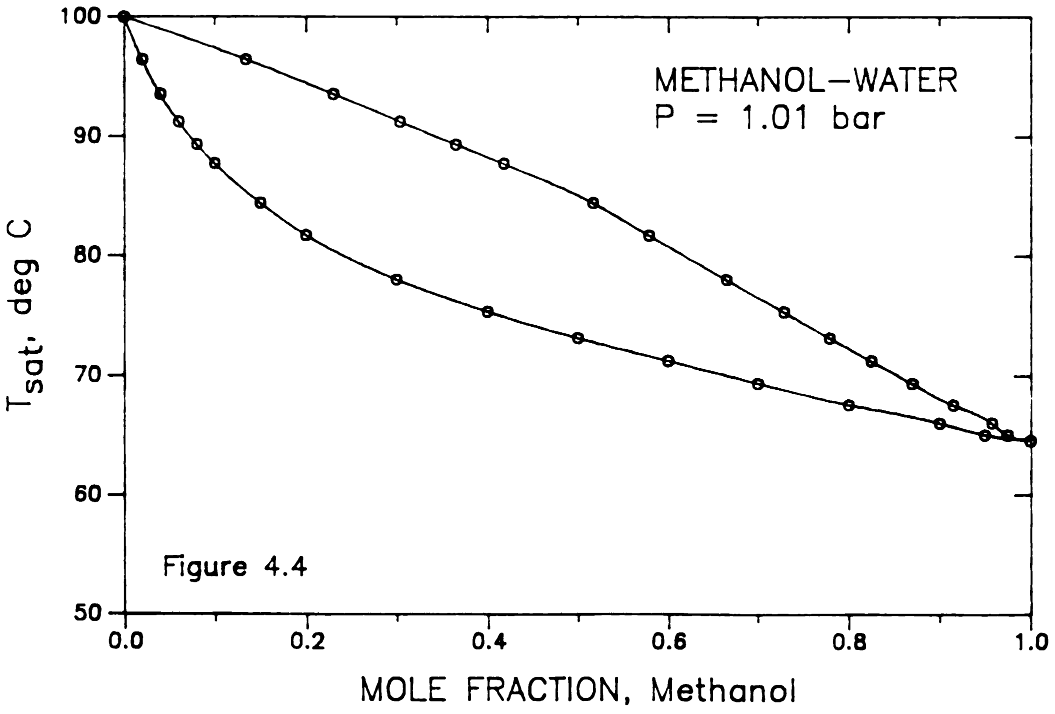


Figure 4.4 Methanol-water vapor-liquid equilibrium diagram at 1.01 bar.

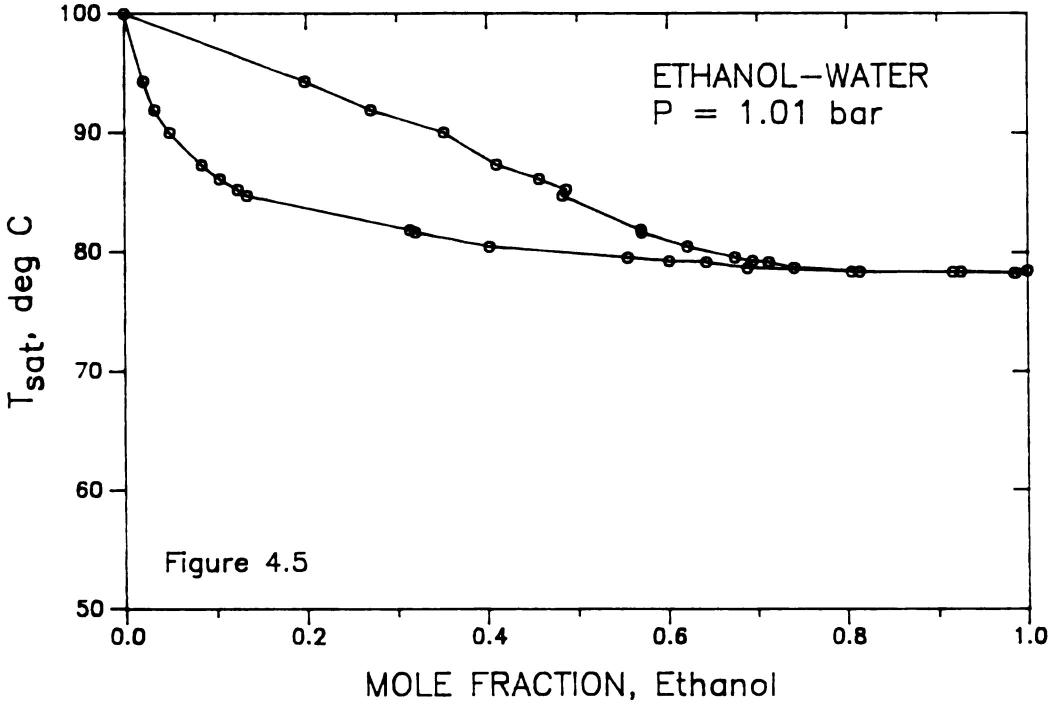


Figure 4.5 Ethanol-water vapor-liquid equilibrium diagram at 1.01 bar.

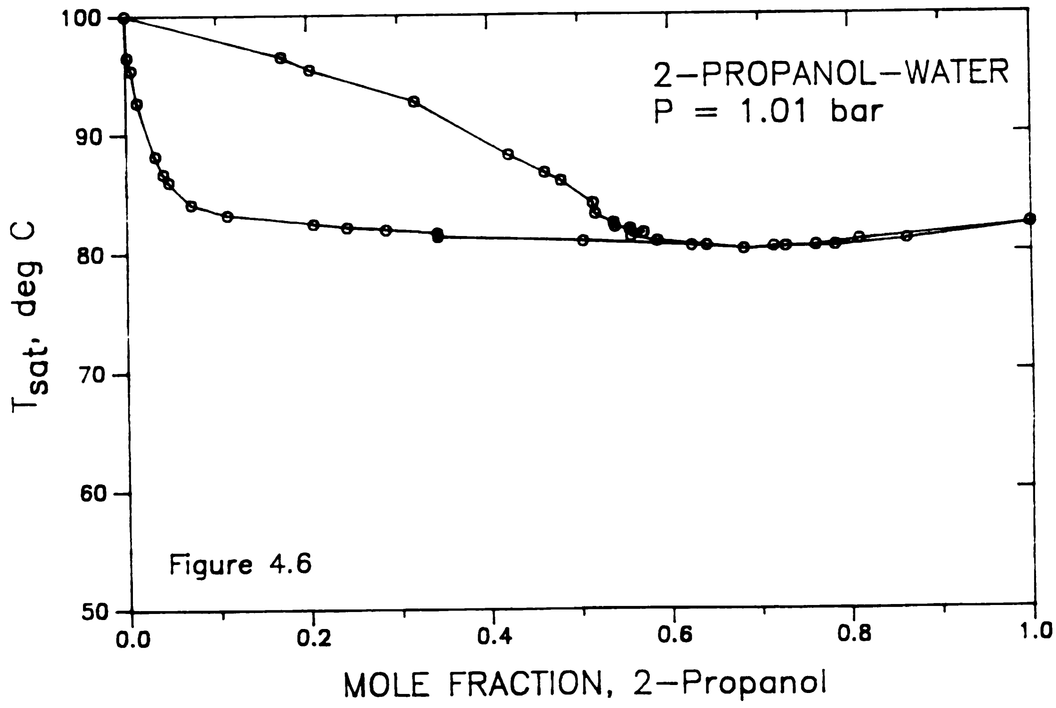


Figure 4.6 2-Propanol -water vapor-liquid equilibrium diagram at 1.01 bar.

4.2 BOILING RANGE

The boiling range ΔT_{bp}, is the difference between the dew point and the bubble point temperatures at the liquid phase mixture composition. Figure 4.3 is the phase equilibrium diagram for binary acetone - water mixtures. The boiling range for a mixture with a 0.20 mole fraction composition of acetone is shown in the figure to be $\Delta T_{bp} = 32°K$.

For a binary mixture system, the boiling range can be readily estimated from a phase equilibrium diagram. This estimation can be performed by generating continuous bubble and dew point curves from the existing experimental VLE data. The boiling range at a specified liquid composition is then identified as the difference in the dew point and bubble point temperatures. For mixtures with three or more components identification of ΔT_{bp} is more difficult since the limited number of experimental VLE data points makes it unlikely that equilibrium vapor composition of one liquid mixture is exactly the same as the liquid composition of another data point. Thus, more complex methods must be used to determine the boiling range in a multicomponent systems.

In the case of a ternary mixture, the boiling range can be conceptualized as the difference between saturation temperatures defined by bubble point and dew point surfaces. The saturation temperatures as a function of composition for each surface can then be determined by using an interpolation scheme using the available VLE data. The boiling range for binary and ternary mixtures in this study were determined by using the IMSL subroutine SURF to perform interpolation and smooth surface fitting for the VLE data. A listing of the computer program used to calculate ΔT_{bp} is contained in Appendix D.

4.3 MIXTURE PROPERTIES

This section describes the methods used to determine mixture physical properties. The physical properties of aqueous mixtures and many hydrocarbon mixtures vary nonlinearly with composition. Thus, the pure component properties and the mixture rules must be carefully chosen. Reid et al. (1987) describe a wide variety of methods to estimate the properties of pure components and their mixtures and provide a critical review of their accuracy. The methods chosen to estimate the physical properties in this study are those determined to be the most accurate of methods available for nonideal multicomponent liquid mixtures.

<u>Multifluid Corresponding States Method</u> The physical properties for a mixture are often estimated by determining the properties of the pure components at the mixture temperature, and combining the pure component properties using an appropriate mixing rule. The unknown properties of one fluid can be determined from the known properties of another fluid using the principle of corresponding states. A pure fluid is defined to be in corresponding states with a reference fluid if the compressibility Z and the reduced property $(\mathcal{P}\xi)$ of the fluids at the same reduced temperature T_R and reduced pressure P_R are given by:

$$Z = Z^{(o)} \tag{4-3}$$

and

$$(\mathcal{P}\xi) = (\mathcal{P}\xi)^R \tag{4-4}$$

In these expressions, $\mathcal{P}$ represents a physical property and ξ is a function of the critical parameters T_c, P_c, υ_c, and M.

Equations 4-3 and 4-4 are only valid however, for fluids with spherically symmetric molecules such as noble gases such that there is negligible intermolecular attraction.

The more general case of non-spherical molecules is treated by using the acentric factor ω and an expansion of Equation 4-3. This was first proposed by Pitzer et al. (1955) who suggested,

$$Z = Z^{(o)} + Z^{(1)} \tag{4-5}$$

where $Z^{(o)}$ is the compressibility of a spherical reference fluid and $Z^{(1)}$ is a complicated deviation function. The original proposal by Pitzer has been modified and extended by Lee and Kesler (1975) and more recently by Teja and Rice (1981). The generalized corresponding states principle proposed by Teja and Rice uses two non-spherical reference fluids and represents the compressibility as:

$$Z = Z^{(r1)} + \frac{\omega - \omega^{(r1)}}{\omega^{(r2)} - \omega^{(r1)}}[Z^{(r2)} - Z^{(r1)}] \tag{4-6}$$

For a binary mixture, the reference fluids (r1) and (r2) are the two pure components of interest. The method is extended to multicomponent fluids by replacing the reference fluid properties T_c, υ_c, Z_c, and ω by pseudocritical values defined by:

$$T_{cm}\upsilon_{cm} = \sum_i \sum_j x_i x_j T_{cij} \upsilon_{cij} \tag{4-7}$$

$$\upsilon_{cm} = \sum_i \sum_j x_i x_j \upsilon_{cij} \tag{4-8}$$

$$Z_{cm} = \sum_i x_i Z_{ci} \tag{4-9}$$

$$\omega_m = \sum_i x_i \omega_i \tag{4-10}$$

The cross-parameters T_{cij} and υ_{cij} are given by:

$$T_{cij}\upsilon_{cij} = (T_{cii}\upsilon_{cii}T_{cjj}\upsilon_{cjj})^{1/2} \tag{4-11}$$

$$\upsilon_{cij} = \eta_{ij}(\upsilon_{cii}^{1/3} + \upsilon_{cjj}^{1/3})^3/8 \tag{4-12}$$

where η_{ij} is a binary interaction coefficient which must be obtained from experiment. No additional coefficients are necessary to predict the properties of mixtures with three or more components.

A series of reference fluid interpolations are performed for a fluid mixture with *n* components. Components 1 and 2 are used to define a pseudo-component,

$$Z_{12} = Z_2 + \frac{\omega_{12} - \omega_2}{\omega_1 - \omega_2}[Z_1 - Z_2] \tag{4-13}$$

where,

$$\omega_{12} = \sum_1^2 x_i\omega_i \Big/ \sum_1^2 x_i \tag{4-14}$$

If the mixture contains a third component, another expansion is performed using the third component and the pseudo-component "12" as the reference fluids. Then,

$$Z_{123} = Z_3 + \frac{\omega_{123} - \omega_2}{\omega_{12} - \omega_2}[Z_{12} - Z_3] \tag{4-15}$$

where ω_{12} is defined by Eq. 4-14 and ω_{123} is given by:

$$\omega_{123} = \sum_1^3 x_i\omega_i \Big/ \sum_1^3 x_i \tag{4-16}$$

For a fourth component, the process is repeated using the fourth component and the pseudo-component "123" as the reference fluids.

In general, for *n* components, the expansion becomes:

$$Z_{12\ldots n} = Z_{12\ldots n-1} + \frac{\omega_{12\ldots n} - \omega_n}{\omega_{12\ldots n-1} - \omega_n}[Z_n - Z_{12\ldots n-1}] \tag{4-17}$$

with,

$$\omega_{12\ldots n} = \sum_1^n x_i\omega_i \Big/ \sum_1^n x_i \tag{4-18}$$

A similiar relationship can be written for other thermodynamic properties by starting with Eq. 4-4. The property of a mixture with *n* components is determined from:

$$(\mathcal{P}\xi)_{12\ldots n} = (\mathcal{P}\xi)_{12\ldots n-1} + \frac{\omega_{12\ldots n} - \omega_n}{\omega_{12\ldots n-1} - \omega_n}[(\mathcal{P}\xi)_n - (\mathcal{P}\xi)_{12\ldots n-1}] \qquad (4\text{-}19)$$

Liquid and Vapor Specific Volumes The Teja-Patel (1982) equation of state was used to estimate the specific volumes of pure vapors and their mixtures. This cubic equation of state has the following form:

$$P = \frac{\Re T}{v - b} - \frac{a(T)}{v(v + b) + c(v - b)} \qquad (4\text{-}20)$$

where $\Re$ is the universal gas constant, and a(T), b, and c are given by:

$$a(T) = \Omega_a(\Re^2 T_C{}^2/P_C)\varphi(T_R) \qquad (4\text{-}21)$$

$$b = \Omega_b(\Re T_C/P_C) \qquad (4\text{-}22)$$

$$c = \Omega_c(\Re T_C/P_C) \qquad (4\text{-}23)$$

where

$$\Omega_a = 3\zeta_C{}^2 + 3(1-2\zeta_C)\Omega_b + \Omega_b{}^2 + 1-3\zeta_C \qquad (4\text{-}24)$$

and Ω_b is the smallest root of the cubic equation:

$$\Omega_b{}^3 + (2-3\zeta_C)\Omega_b{}^2 + 3\zeta_C{}^2\Omega_b - \zeta_C{}^3 = 0 \qquad (4\text{-}25)$$

and where,

$$\Omega_c = 1 - 3\zeta_C \qquad (4\text{-}26)$$

The function $\varphi(T_R)$ is given by:

$$\varphi(T_R) = [1 + F(1 - T_R{}^{1/2})]^2 \qquad (4\text{-}27)$$

Saturated liquid density is found by choosing Ω_b as the largest root of Eq. 4-25. The parameters F and ζ_C have been correlated with the acentric factor, and are given by:

$$F = 0.452413 + 1.30982\omega - 0.295937\omega^2 \qquad (4\text{-}28)$$

$$\zeta_C = 0.329032 - 0.076799\omega + 0.0211947\omega^2 \qquad (4\text{-}29)$$

For water, benzene and several alcohols, Patel and Teja recommend the values listed in Table 4-9.

Table 4-9
Recommended Values for ζ_c and F.

Component	ζ_c	F
Water	0.269	0.689803
Benzene	0.310	0.704657
Methanol	0.272	0.972708
Ethanol	0.300	1.230395
1-Propanol	0.303	1.241347

The Patel-Teja equation of state can be extended to mixtures by replacing the constants a(T), b, and c as follows:

$$a_m(T) = \sum_i \sum_j x_i x_j a_{ij} \tag{4-30}$$

$$b_m = \sum_i x_i b_i \tag{4-31}$$

$$c_m = \sum_i x_i c_i \tag{4-32}$$

The cross-interaction term a_{ij} in Eq. 4-30 is evaluated using:

$$a_{ij} = (a_{ii} a_{jj})^{\frac{1}{2}} \tag{4-33}$$

Patel and Teja report that their equation of state provides accurate and consistent predictions of liquid and vapor densities for both pure components and mixtures. For pure component saturated liquid densities, they reported an absolute average deviation of 2.94% and 1.44% for the saturated vapor densities. For mixtures, the overall absolute deviation was reported as 2.05%. An important feature of this equation of state is that it can be used to predict the densities of mixtures containing polar substances. The Patel-Teja equation of state was therefore appropriate for prediction of the pure component and mixture vapor and liquid densities reported in this investigation. Figures 4.7 and 4.8 show saturated liquid and vapor densities for acetone-water, methanol-water, and ethanol-water binary mixtures.

Liquid Specific Volume Pure component liquid specific volumes at saturation were also estimated using the Modified Racket equation (1972):

$$v = (\mathcal{R}T_C/P_C)Z_{RA}^{\,n} \tag{4-34}$$

where $n = [1 + (1-T_r)^{2/7}]$ and Z_{RA} is a specified constant for each fluid. This equation was used to verify the values of saturated liquid density estimated using the Teja-Patel equation of state. Table 4-10 lists the values used for Z_{RA}.

The generalized corresponding states method proposed by Teja (1980) was used to estimate saturated liquid mixture specific volumes. For binary mixtures, the liquid specific volume is obtained from:

$$(Z_C v) = (Z_C v)^{(r1)} + \frac{\omega - \omega^{(r1)}}{\omega^{(r2)} - \omega^{(r1)}}[(Z_C v)^{(r2)} - (Z_C v)^{(r1)}] \tag{4-35}$$

For the more general case of a mixture with *n* components, Eqn. 4-19 is used with $\mathcal{P} = v$, and with $\xi = Z_C$.

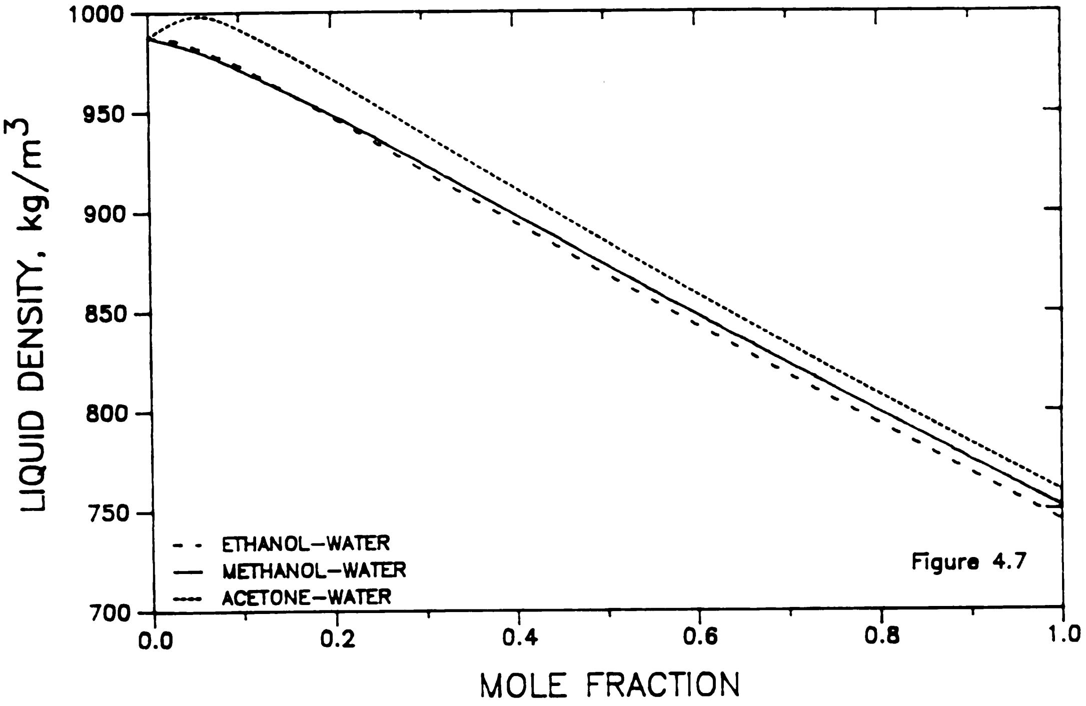


Figure 4.7 Saturated liquid densities predicted by the Teja-Patel equation of state at 1.01 bar.

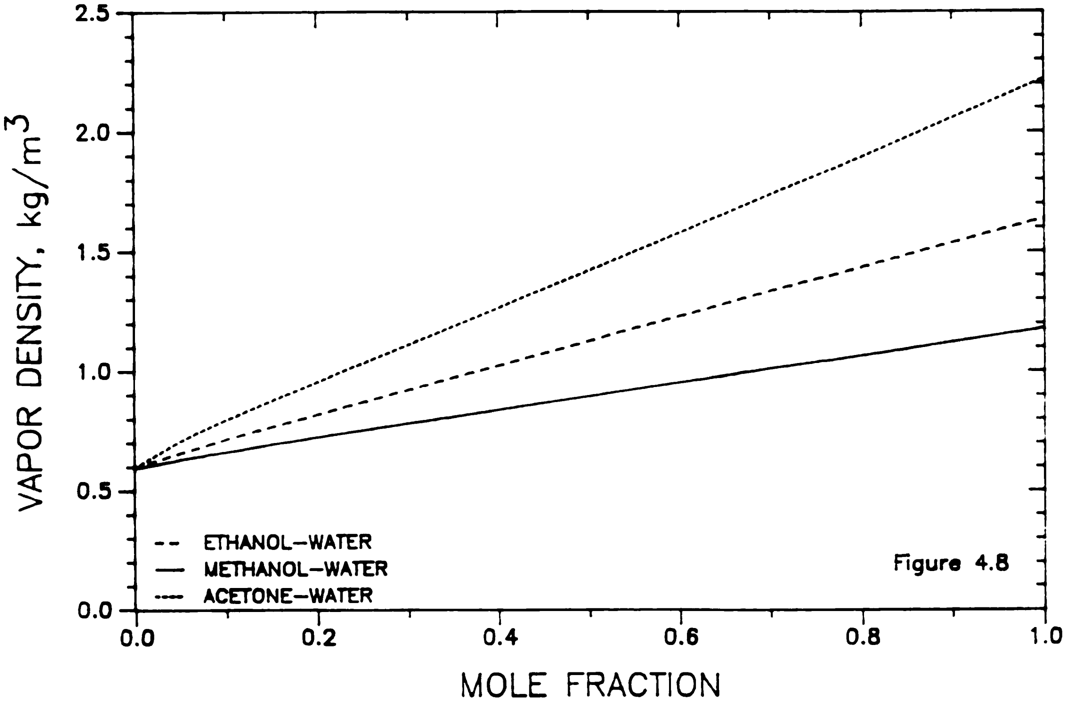


Figure 4.8 Saturated vapor densities predicted by the Teja-Patel equation of state at 1.01 bar.

Table 4-10
Pure Component Parameters Used in Property Estimation

Component	Formula	M	T_c (K)	P_c (bar)	v_c (m^3/kg)	Z_c	ω	Z_{RA}
Acetone	C3H6O	58.08	508.15	47.61	.0036630	0.239	0.309	0.2477
2-Butanone	C4H8O	72.11	535.60	41.53	.0037028	0.249	0.329	
Methanol	CH4O	32.04	513.15	79.50	.0036364	0.217	0.559	0.2334
Ethanol	C2H6O	46.07	516.25	63.90	.0035714	0.245	0.635	0.2502
Benzene	C2H6O	78.11	562.60	49.24	.0033157	0.273	0.212	0.2698
Water	H2O	18.02	647.30	221.29	.0031746	0.235	0.344	0.2338
1-Propanol	C3H8O	60.10	536.85	50.50	.0036630	0.249	0.624	0.2541
2-Propanol	C3H8O	60.10	508.75	53.70	.0036496	0.278	0.665	0.2493
Ethylene Glycol	C2H6O2	62.07	645.00	76.99	.0029967	0.270		0.2488
Cyclohexane	C6H12	84.16	554.15	40.75	.0036630	0.273	0.257	0.2729
Methyl Acetate	C3H6O2	74.08	506.80	46.87	.0030769	0.254	0.326	0.2552
Ethyl Acetate	C4H8O2	88.11	523.25	38.32	.0032500	0.252	0.362	0.2539

Table 4-11
Parameters for Calculation of Liquid Specific Heat

Component	A	B	C	D
Acetone	3.339	-1.031E-02	2.154E-05	0.000E-00
2-Butanone	2.299	0.000E-00	0.000E-00	0.000E-00
Methanol	3.509	-1.352E-02	3.473E-05	-7.070E-10
Ethanol	-1.465	4.001E-02	-1.585E-04	2.280E-07
Benzene	-6.199	6.472E-02	-1.829E-04	1.840E-07
Water	2.822	1.183E-02	-3.504E-05	3.600E-08
1-Propanol	-1.156	3.589E-02	1.432E-04	2.080E-07
2-Propanol	-1.964	1.961E-02	-1.297E-05	0.000E-00
Ethylene Glycol	4.430	-2.079E-02	4.738E-05	0.000E-00
Cyclohexane	-5.375	5.605E-02	-1.469E-04	1.350E-07
Methyl Acetate	2.597	-7.535E-03	1.658E-05	0.000E-00
Ethyl Acetate	1.323	2.786E-04	5.510E-07	0.000E-00

Enthalpy of Vaporization The enthalpy of a mixture can be expressed as:

$$H(T,P,x_i) = \sum x_i H_i(T,0,x_i) - H^D(T,P,x_i) \qquad (4\text{-}36)$$

where x_i represents either liquid or vapor mole fraction and where all $H_i(T,0,x_i)$ refer to the same reference state. The term $H^D(T,P,x_i)$ is referred to as the isothermal enthalpy departure and accounts for the difference between the mixture enthalpy at the pressure P, and the enthalpy of the mixture of ideal gases at zero pressure.

It is important to distinguish between two types of vaporization enthalpies when discussing mixtures. The *integral* latent heat is the difference between the enthalpies of the vapor and liquid at the same composition. The *differential* latent heat is the difference between the enthalpy of the liquid mixture and the enthalpy of the vapor mixture at the equilibrium compositions. Only the differential latent heat is of interest in vapor-liquid equilibrium calculations.

The isothermal enthalpy departure is determined from classical thermodynamics and an equation of state. From classical thermodynamics,

$$dH = d(P\upsilon) + \left[T\left(\frac{\partial P}{\partial T}\right)_{\upsilon} - P\right]_T dT \qquad (4\text{-}37)$$

The isothermal enthalpy departure is determined by integration of this expression from zero pressure to P. Using the Patel-Teja equation of state, the resulting expression for the enthalpy departure is:

$$\Lambda(H^D - H^o) = RT(Z-1) - \left[T\left(\frac{\partial a}{\partial T}\right) - a\right] \left[\frac{1}{2N}\ln\left(\frac{Z+M}{Z+Q}\right)\right] \qquad (4\text{-}38)$$

where Λ is a conversion factor and M, N, and Q are given by:

$$M = [\tfrac{1}{2}(b+c) - N](P/RT) \qquad (4\text{-}39)$$

$$N = [bc + \{\tfrac{1}{2}(b+c)\}^2]^{\frac{1}{2}} \qquad (4\text{-}40)$$

$$Q = [\tfrac{1}{2}(b+c) + N](P/RT) \qquad (4\text{-}41)$$

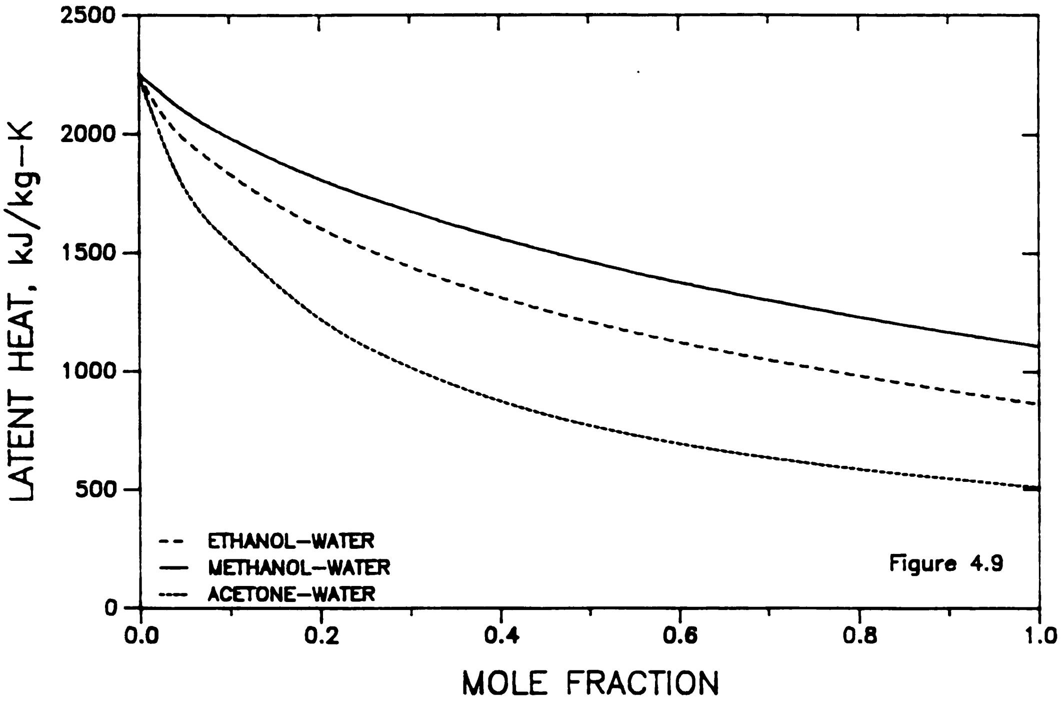


Figure 4.9 Differential latent heat at 1.01 bar for acetone-water, methanol-water and ethanol-water binary mixtures.

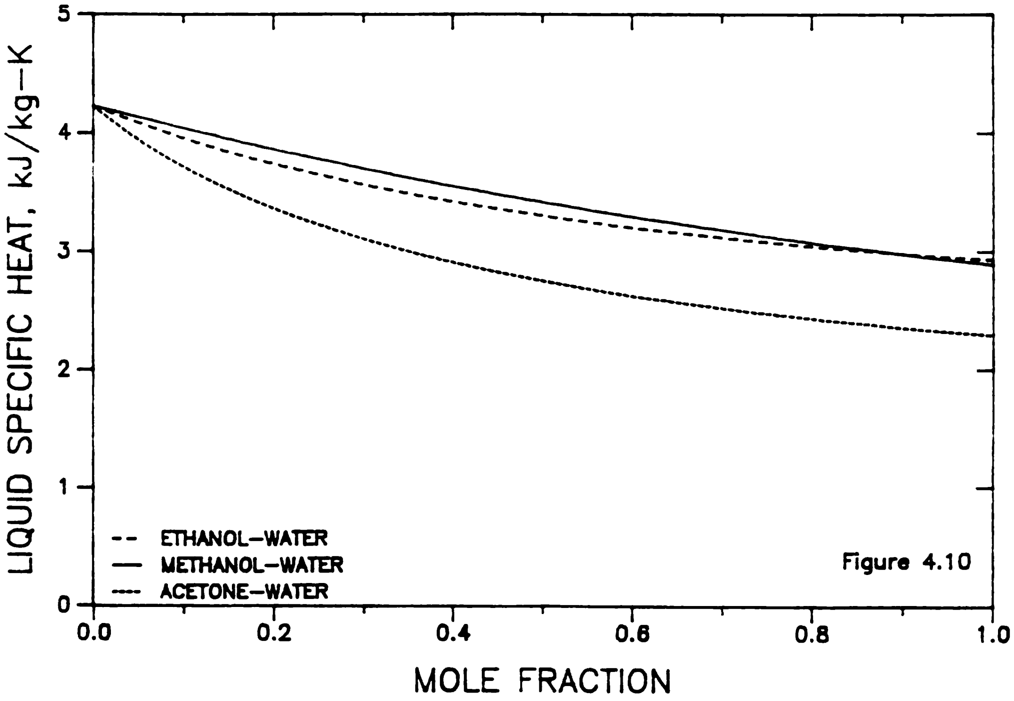


Figure 4.10 Liquid specific heat at 1.01 bar for acetone-water, methanol-water and ethanol-water binary mixtures.

Equations 4-21 through 4-23 are the appropriate expressions to use for a, b, and c for pure components, and Equations 4-30 through 4-32 are used in the case of mixtures. H^o represents the ideal gas enthalpy and can be estimated by integrating c_p from 0 K to the saturation temperature. Figure 4.9 shows the differential latent heat for acetone-water, methanol- water, and ethanol-water binary mixtures.

<u>Specific Heat</u> The specific heat capacity of pure liquid components was determined using the following expression:

$$c_p(T) = A + BT + CT^2 + DT^3 \qquad (4\text{-}42)$$

The values for A, B, C, and D were obtained from Miller et al.(1976) for water, benzene, methanol, ethanol, 1-propanol and cyclohexane. For other fluids, data for c_p at saturation temperatures ranging between 0° C and 130° C were obtained from Schlunder (1983), Washburn (1926), and Perry et al. (1984) and the method of least squares was used to determine A, B, and C. D was set equal to zero for these fluids. Table 4-11 lists the constants used for each fluid in Eqn. 4-42.

The specific heat capacity for liquid mixtures was determined using a method proposed by Teja (1983). For a binary mixture, liquid specific heat is determined from:

$$(c_p/R) = (c_p/R)^{(r1)} + \frac{\omega - \omega^{(r1)}}{\omega^{(r2)} - \omega^{(r1)}}[(c_p/R)^{(r2)} - (c_p/R)^{(r1)}] \qquad (4\text{-}43)$$

For the more general case of a mixture with *n* components, Eqn. 4-18 is used, with $\wp = c_p$ and $\xi = (1/R)$. Figure 4.10 shows liquid specific heats for acetone-water, methanol-water and ethanol-water mixtures.

Viscosity Pure component liquid viscosities were estimated using the following expression suggested by Yaws et al. (1976):

$$\ln \mu = A + B/T + CT + DT^2 \tag{4-44}$$

Values for the constants A, B, C, and D were obtained from Reid et al.(1987).

The viscosity of liquid mixtures was estimated using the method proposed by Teja and Rice (1981). The viscosity for a liquid mixture is estimated in a manner analogous to the generalized method of corresponding states. For a binary mixture, the viscosity is given by:

$$\ln(\mu\xi) = \ln(\mu\xi)^{(r1)} + \frac{\omega - \omega^{(r1)}}{\omega^{(r2)} - \omega^{(r1)}}[\ln(\mu\xi)^{(r2)} - \ln(\mu\xi)^{(r1)}] \tag{4-45}$$

where for viscosity ξ is given by:

$$\xi = v_c^{2/3} T_c^{-1/2} M^{-1/2} \tag{4-46}$$

The general expression for liquid viscosity in an *n* component mixture is:

$$\ln(\mu\xi)_{12\ldots n} = \ln(\mu\xi)_{12\ldots n-1} + \frac{\omega_{12\ldots n} - \omega_n}{\omega_{12\ldots n-1} - \omega_n}[\ln(\mu\xi)_n - \ln(\mu\xi)_{12\ldots n-1}] \tag{4-47}$$

Figure 4.11 shows the variation of liquid viscosity with composition in acetone-water, methanol-water, and ethanol-water mixtures.

Surface Tension The surface tension of a pure fluid decreases with increasing temperature, and can be estimated using:

$$\sigma = A - BT \tag{4-48}$$

Values for A and B were obtained from the compilation of experimental data for surface tension of liquids by Jasper (1972). Table 4-12 lists the values of A and B for the fluids used in this investigation.

Aqueous mixtures show pronounced nonlinear variation of surface tension with composition. The surface tension decreases dramatically upon the addition of an organic fluid. The corresponding states method

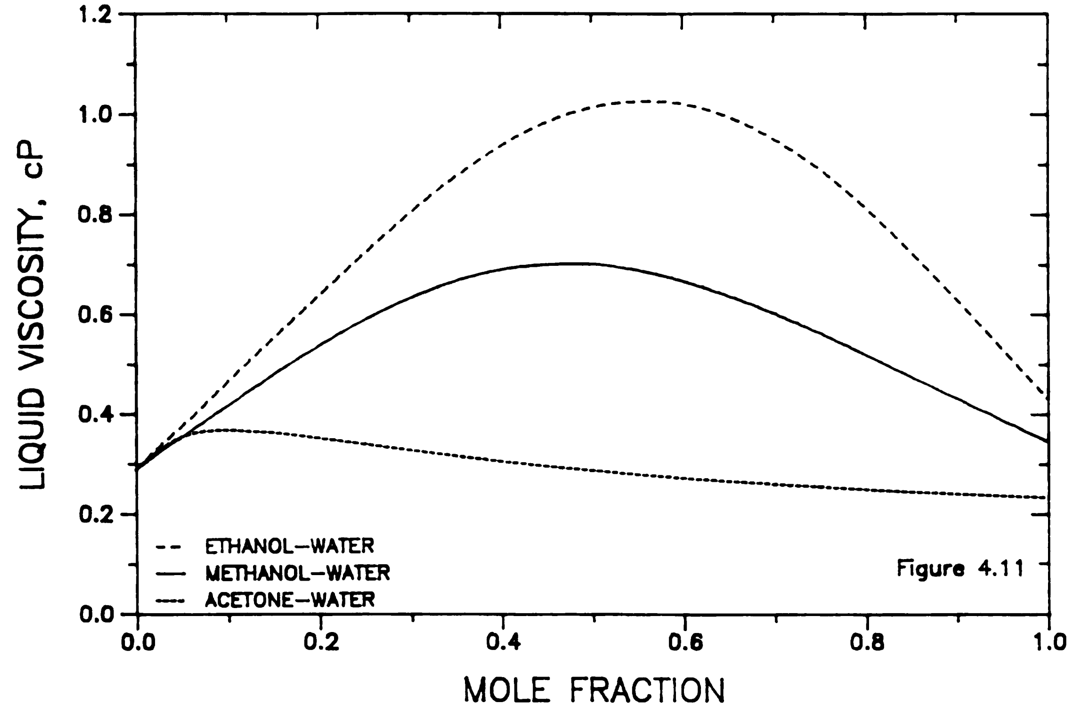


Figure 4.11 Liquid viscosities for acetone-water, methanol-water and ethanol-water binary mixtures.

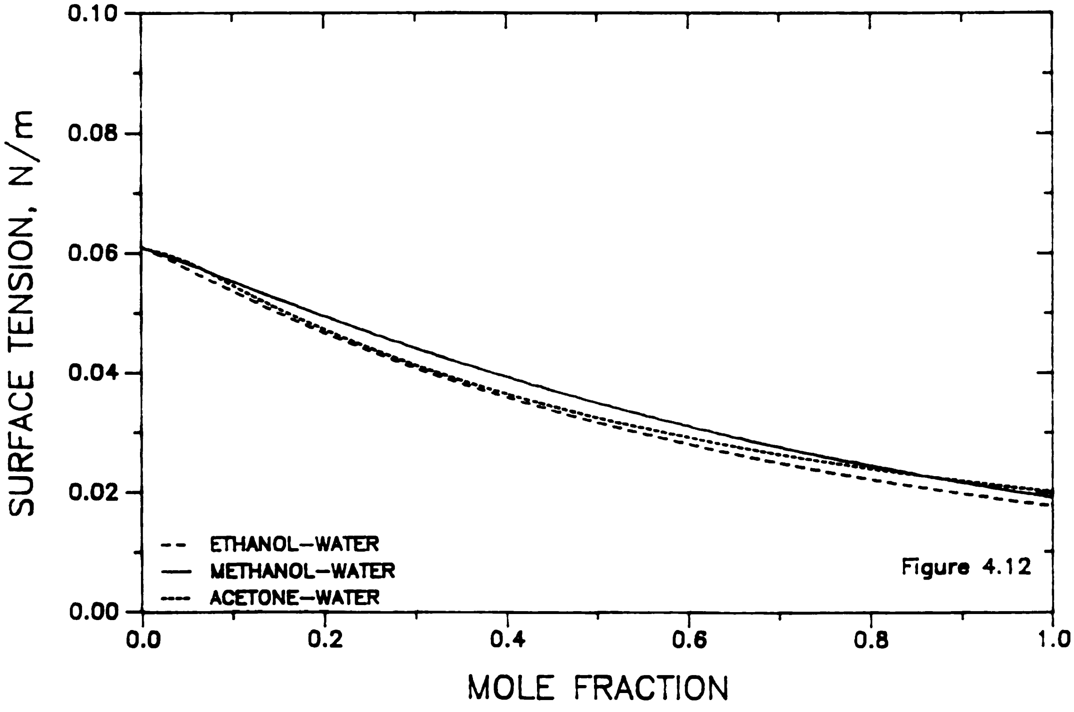


Figure 4.12 Surface tension for acetone-water, methanol-water and ethanol-water binary mixtures.

proposed by Rice and Teja (1982) was used to estimate the surface tension of liquid mixtures in this investigation. This method is currently the only method that that is capable of estimating the surface tension in mixtures with more than two components. For a binary mixture, σ is found from:

$$(\sigma\xi) = (\sigma\xi)^{(r1)} + \frac{\omega - \omega^{(r1)}}{\omega^{(r2)} - \omega^{(r1)}}[(\sigma\xi)^{(r2)} - (\sigma\xi)^{(r1)}] \qquad (4\text{-}49)$$

where for surface tension, ξ is given by:

$$\xi = T_c^{-1} v_c^{2/3} \qquad (4\text{-}50)$$

The general expression for surface tension in an n component mixture is:

$$(\sigma\xi)_{12\ldots n} = (\sigma\xi)_{12\ldots n\text{-}1} + \frac{\omega_{12\ldots n} - \omega_n}{\omega_{12\ldots n\text{-}1} - \omega_n}[(\sigma\xi)_n - (\sigma\xi)_{12\ldots n\text{-}1}] \qquad (4\text{-}51)$$

Figure 4.12 shows the surface tension for acetone-water, methanol-water, and ethanol water binary mixtures.

Table 4-12
Values of A and B for Use in Eq. 4-48.

Component	A	B
Acetone	26.26	0.1120
2-Butanone	26.77	0.1122
Methanol	24.00	0.0773
Ethanol	24.05	0.0832
Benzene	31.50	0.1287
Water	75.83	0.1477
1-Propanol	25.26	0.0777
2-Propanol	22.90	0.0789
Ethylene Glycol	50.21	0.0890
Cyclohexane	27.62	0.1188
Methyl Acetate	27.95	0.1289
Ethyl Acetate	26.29	0.1161

Liquid Thermal Conductivity Two methods were used to determine the thermal conductivity of pure liquid components. For water, benzene, methanol, ethanol, 1-propanol, 2-propanol, and cyclohexane, the thermal conductivity was estimated using (1976):

$$k(T) = A + BT + CT^2 \tag{4-52}$$

The values used for A and B in Eq. 4-52 are listed in Table 4-13.

Table 4-13
Values for A, B and C in Eq. 4-52.

Component	A	B	C
Methanol	0.3225	-4.785E-04	1.168E-07
Ethanol	0.2629	-3.847E-04	2.211E-07
Benzene	0.1776	4.773E-06	-3.781E-07
Water	-0.3838	5.254E-03	-6.369E-06
1-Propanol	0.1854	-3.366E-05	-2.215E-07
Cyclohexane	0.1068	-9.513E-05	-9.513E-05

Data for the thermal conductivity of acetone, 2-butanone, 2-propanol, ethylene glycol, methyl acetate, and ethyl acetate were not readily available and therefore the method of Latini (1977) was used instead of Eq. 4-52. Latini and coworkers suggested a correlation of the form:

$$k = \frac{\epsilon(1-T_R)^{0.38}}{T_R^{1/6}} \tag{4-53}$$

where,

$$\epsilon = \frac{A^* T_b^{\tau}}{M^{\beta} T_c^{\gamma}} \tag{4-54}$$

The parameters A^*, τ, β, and γ are listed in Table 4-14.

Table 4-14
Parameters used in Eq. 4-54

Component:	A^*	τ	β	γ
Acetone	3.83E-03	1.2	0.5	0.167
2-Butanone	3.83E-03	1.2	0.5	0.167
2-Propanol	3.93E-03	1.2	0.5	0.167
Ethylene Glycol	4.94E-01	0.0	1.0	-0.167
Methyl Acetate	4.15E-02	1.2	1.0	0.167
Ethyl Acetate	4.15E-02	1.2	1.0	0.167

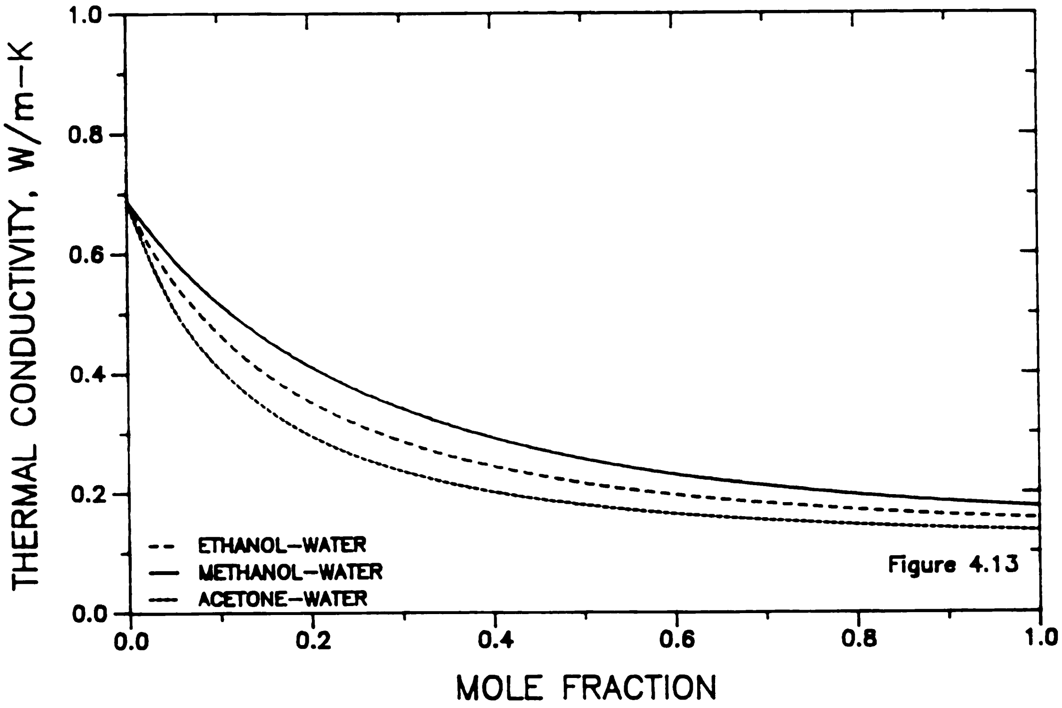


Figure 4.13 Liquid thermal conductivity for actone-water, methanol-water, and ethanol-water mixtures.

The Li (1976) method was used to estimate the thermal conductivity of liquid mixtures. This method estimates the conductivity of a multicomponent liquid mixture from:

$$k = \sum_i \sum_j \phi_i \phi_j k_{ij} \tag{4-55}$$

where

$$k_{ij} = 2(k_i^{-1} + k_j^{-1})^{-1} \tag{4-56}$$

and

$$\phi_i = x_i v_i \,/\, \sum x_j v_j \tag{4-57}$$

In these expressions, ϕ_i is the superficial volume fraction of component *i*, and v_i represents the molar volume of the pure component. Reid et al. (1987) have reviewed this and several other methods for estimating liquid thermal conductivity and found that the absolute error of the Li method rarely exceeds 5%. Figure 4.13 shows the liquid thermal conductivities for acetone-water, methanol-water, and ethanol-water binary mixtures.

4.4 MASS DIFFUSION COEFFICIENTS

The diffusion coefficient for a binary mixture of components 1 and 2 is defined by:

$$J_1 = -c\mathcal{D}_{12}\frac{dx_1}{dz} \tag{4-58}$$

where c is the total molar concentration and z is the direction in which diffusion occurs. The diffusion coefficient represents the proportionality between the molar flux of component 1 relative to a plane of no net molar flow, and the composition gradient.

Several methods have been proposed for estimation of binary and multicomponent diffusion coefficients in liquid mixtures, however none have been proven satisfactory. The most widely used correlation for the estimation of binary diffusion coefficients is the Wilke-Chang (1955) correlation. This technique was used to estimate binary mass diffusivities in this investigation. The Wilke-Chang correlation is:

$$\mathcal{D}_{12} = \frac{7.4\text{x}10^{-8}(\varphi M_2)^{½}T}{\mu_2 V_1^{0.6}} \qquad (4\text{-}59)$$

where, $\mathcal{D}_{12}$ = mutual diffusion coefficient of solute 1 at very low concentrations in solvent 2, cm^2/s
M_2 = molecular weight of solvent 2, gm/mol
T = temperature, K
μ_2 = viscosity of solvent 2, cP
V_1 = molar volume of solute 1 at its normal boiling point, cm^3/mol
φ = association factor (dimensionless)

Wilke and Chang recommend that the association factor φ be chosen as 2.6 if the solvent is water, 1.9 if it is methanol, 1.5 if it is ethanol, and 1.0 for other solvents. An average error of 10% was reported by Wilke and Chang for the 251 solute-solvent systems they tested.

Perkins and Geankoplis (1969) proposed a modification of the Wilke-Chang correlation in order to estimate multicomponent diffusion coefficients. Their new equation was proposed as:

$$\mathcal{D}_{1m} = \frac{7.4\text{x}10^{-8}(\varphi M_{23})^{½}T}{\mu_m V_1^{0.6}} \qquad (4\text{-}60)$$

The terms in the parentheses are determined using a linear mixing rule:

$$\varphi M_{23} = x_2\varphi_2 M_2 + x_3\varphi_3 M_3 \qquad (4\text{-}61)$$

No multicomponent experimental data is needed to apply this method.

CHAPTER 5

EXPERIMENTAL RESULTS

The objectives of the experimental part of this investigation were to: (1) obtain a suitable database of nucleate pool boiling heat transfer coefficients in multicomponent mixtures in order to evaluate existing predictive methods on plain tubes, (2) obtain nucleate pool boiling heat transfer coefficients in binary mixtures for a finned tube, and (3) obtain nucleate pool boiling heat transfer coefficients in a subcooled binary mixture on a plain tube. As described in the summary of previous studies on mixture boiling, there is currently a shortage of boiling data in mixtures with three or more components and very little information on subcooled mixture boiling. There are presently no data for mixture boiling on a finned surface. Thus, the data obtained and reported as part of this investigation provide valuable and unique information on the effects of multiple components, surface structure, and subcooling on nucleate pool boiling heat transfer coefficients.

This section presents the experimental data obtained in this investigation. Results for saturated mixture boiling on plain and finned surfaces and the results for subcooled boiling on a plain surface are discussed separately.

5.1 PLAIN TUBE EXPERIMENTAL RESULTS

Experimental data was obtained for six ternary and two quadrary mixture systems on a plain, smooth surface. The mixture systems were chosen on the basis of availability of vapor-liquid equilibrium data and the ability to estimate the thermal and transport properties. Table 5-1 lists the mixture systems investigated and the number of tests performed for each on a plain tube. Each experimental test was assigned a unique identification number to distinguish it from other tests. Table 5-2 lists each individual test for the plain surface by identification number, and lists the compositions, and test conditions. The acetone-methanol-water ternary system was chosen as the system for a comprehensive series of tests. This ternary system was chosen because the VLE data for it are readily available, and because Grigor'ev et al. (1968) and Stephan and Preusser (1978) also investigated this system. Since a large number of tests is required to perform a thorough examination of a particular multicomponent system, only the acetone-methanol- water system was examined in this way due to the prohibitive cost in time and materials. Other aqueous mixture systems were examined, but in the lesser detail. Since pool boiling heat transfer coefficients in dilute aqueous mixtures tend to be the most difficult to predict, more of these types of mixtures were tested in order to provide a severe test of the multicomponent boiling correlations to be considered later. Acetone was a component in several of these mixture systems because these systems behave very non-linearly and have relatively large boiling ranges. Figures 5.1 through 5.6 show the number of tests and relative compositions for the binary and ternary mixture systems examined in the investigation.

The boiling curves obtained for the acetone-methanol-water system at 1.01 bar are shown in Figures 5.7 through 5.10. The boiling curves are presented with the heat transfer coefficient as a function of heat flux, since this is representative of the way in which the tests were conducted. In these figures, the mixture effect on the nucleate boiling heat transfer coefficient is clearly evident. Figure 5.7 presents the boiling curves for acetone-water binary mixtures. The boiling curves for dilute mixtures lie well below those of the two pure component. Only the boiling curves for the two most concentrated acetone-water mixtures are bracketed by the boiling curves for acetone and water. The methanol-water mixtures shown in Figure 5.8 show a similar trend, with only the 0.05 and the 0.80 mole fraction methanol mixtures being bracketed by the pure component boiling curves. Figures 5.9 and 5.10 show the boiling curves for acetone-methanol-water ternary mixtures. Figure 5.9 shows the ternary boiling curves for dilute mixtures of acetone and methanol, and Figure 5.10 shows those with higher concentrations of acetone and methanol. In comparison, it can be seen that in general, the boiling curves for the dilute mixtures lie farther below the pure component boiling curves than do the more concentrated mixtures. This indicates that the dilute mixtures of acetone-methanol in water experience a larger degradation in their nucleate boiling heat transfer coefficients than do the more concentrated mixtures. Figure 5.11 shows the degradation in boiling heat transfer coefficients in acetone-water binary mixtures at several different heat flux levels. The maximum decrease in heat transfer coefficients occurred at a .20 mole fraction composition of acetone. Very little degradation occurs for more concentrated solutions of acetone. The maximum degradation in pool boiling heat transfer coefficients for methanol-water binary mixtures was found to occur at a composition of .30 mole fraction methanol, as shown in Figure 5.12. Figure 5.13 shows the nearly linear variation of pool boiling heat transfer coefficients in acetone-methanol binary mixtures. A shallow maximum is attained at an intermediate composition. Figures 5.11, 5.12 and 5.13 indicate that the diffusion of acetone or methanol through water causes a larger degradation in the nucleate boiling heat transfer coefficient than the diffusion of these two solutes through each other. The maximum degradation in the nucleate boiling heat transfer coefficients for the entire acetone-methanol-water system occurred for the binary aqueous mixture with .20 mole fraction acetone and for the ternary mixture with .15 acetone, .05 methanol, and .80 water. The magnitudes of the degradations for these two compositions are sufficiently close that it is not possible, due to the experimental uncertainty, to determine which represents the absolute minimum in heat transfer coefficient.

Figures 5.14 through 5.18 show the boiling curves for the additional binary and ternary mixtures for which experimental pool boiling heat transfer coefficients were measured. All mixtures show significant degradation in their heat transfer coefficients relative to those of the pure components. In the Figures 5.14 - 5.18, the mixtures with the lowest boiling heat transfer coefficients are dilute mixtures of the organic compounds, with the mole fraction of water usually 0.80 or larger.

Figure 5.19 presents the boiling curves for the four quadrary mixtures tested. The quadrary mixtures tested were all mixtures of light hydrocarbons, since VLE data for a four component aqueous system that could be safely investigated in the present facility could not be identified. The quadrary mixture boiling curves are shown with two of the pure component boiling curves, which enclose most of the other data points. This indicates that the degradation in heat transfer coefficients due to the mass transfer process in these mixtures is not large, similar to what was found for the acetone-methanol binary system. These four quadrary mixtures each had a narrow boiling range, which also indicates the likelyhood of a small mixture effect on the nucleate boiling heat transfer coefficient.

The effect of adding a third or fourth component to a mixture is difficult to precisely identify because the additional component changes both the vapor-liquid equilibrium composition and the mixture physical properties. Several investigators have found the largest degradation in the nucleate boiling heat transfer coefficient for many binary systems occurs near the composition at which $|y-x|$ is maximum.

To determine if this is also the case in multicomponent mixtures, the ratio α/α_{id} was plotted as a function of $|y-x|$ for the binary and ternary mixtures studied in this investigation. A linear mixing law was used to define α_{id}. These results for only the binary mixtures are shown in Figure 5.20 for $q"=100$ kW/m^2. Although there is a fair amount of scatter in the data, Figure 5.20 clearly indicates that for these binary mixtures, the largest degradations in heat transfer coefficients occur at large values of $|y-x|$. The value of α/α_{id} is seen in general to decrease as $|y-x|$ increases.

Note that for a binary mixture, one component is the light component, and the other is a heavy component. For a light component, $(y-x)>0$ and for a heavy component, $(y-x)<0$. The value of $|y-x|$ that is used in Figure 5.20 for binary mixtures is that for the light component. For a ternary mixture, it is possible for there to be two light and one heavy components or for there to be one light and two heavy components. For ternary mixtures, the degree of degradation in the heat transfer coefficients due to the mass diffusion process should also depend on the the thermodynamic requirement for a species to diffuse to the bubble interface in order to maintain equilibrium. Thus, one should expect the degradation of heat transfer coefficients in ternary mixtures to be a function of the sum of (y-x) for the light components in the mixture. Figure 5.21 shows for both binary and ternary mixtures, the degradation of heat transfer coefficients as the ratio α/α_{id} as a function of $\sum(y-x)$ for all $(y-x)>0$. The figure shows, that the larger the sum, the larger the degradation becomes. Presented in this manner, the ternary mixture data correlates closely with the binary mixture data.

The effect of an additional component on the nucleate boiling heat transfer coefficient, is thus seen to depend on the value of (y-x) for the additional component. If there is no change in the mixture physical properties, then adding a component in which (y-x) is positive will decrease the boiling heat transfer coefficient. If (y-x) is negative or zero for the additional component in the new mixture and there is no change in the physical properties, the boiling heat transfer coefficient will not change.

Table 5-1
Summary of Multicomponent Mixture Tests for a Plain Tube

Mixture System:	Mixtures Tested:
Acetone-Water	7
Methanol-Water	7
Acetone-Methanol	3
Acetone-Methanol-Water	15
Ethanol-Water	3
Methanol-Ethanol-Water	7
Methanol-Ethanol	1
Ethanol-Ethyl Acetate-Water	7
2-Propanol-Water	2
Acetone-2-Propanol-Water	4
Methanol-2-Propanol-Water	5
Acetone-2-Butanone-Water	5
Ethyl Acetate-Methyl Acetate-Ethanol-Methanol	1
2-Propanol-2-Butanone-Benzene-Ccylohexane	3

Table 5-2
List of Experimental Tests on Plain Surfaces

Test No.	Composition (by mole fraction)	P,bar	ΔT_{sub},K
01	1.0 acetone	1	0
02	1.0 acetone	3	0
03	1.0 acetone	.5	0
04	1.0 acetone	.5	0
05	1.0 acetone	5	0
19	.05 acetone, .95 water	1	0
20	.05 acetone, .95 water	1	0
21	.10 acetone, .90 water	1	0
22	.10 methanol, .90 water	1	0
23	.05 methanol, .95 water	1	0
24	.05 acetone, .05 methanol, .90 water	1	0
25	.10 acetone, .10 methanol, .80 water	1	0
26	1.0 acetone	1	0
27	1.0 acetone	.5	0
28	1.0 acetone	3	0
30	1.0 methanol	1	0
31	1.0 methanol	3	0
32	1.0 methanol	.5	0
33	1.0 methanol	1	20
34	1.0 water	1	0
35	1.0 water	3	0
36	1.0 water	.5	0
37	1.0 water	1	20
38	.33 acetone, .33 methanol, .34 water	1	0
41	.33 acetone, .33 methanol, .34 water	1	0
42	.33 acetone, .33 methanol, .34 water	1	20
43	.20 acetone, .80 water	1	0
44	.20 acetone, .80 water	1	0
46	.15 acetone, .05 methanol, .80 water	1	0

Table 5-2, continued
List of Experimental Tests on Plain Surfaces

Test No.	Composition (by mole fraction)	P,bar	ΔT_{sub},K
48	.05 acetone, .15 methanol, .80 water	1	0
50	.31 methanol, .69 water	1	0
51	.20 methanol, .80 water	1	0
53	.20 methanol, .80 water	1	0
54	.10 acetone, .20 methanol, .70 water	1	0
56	.20 acetone, .10 methanol, .70 water	1	0
57	.30 acetone, .70 water	1	0
59	.40 acetone, .60 water	1	0
61	.30 acetone, .10 methanol, .60 water	1	0
63	.20 acetone, .20 methanol, .60 water	1	0
67	.10 acetone, .30 methanol, .60 water	1	0
69	.40 methanol, .60 water	1	0
71	.10 acetone, .40 methanol, .50 water	1	0
73	.40 acetone, .10 methanol, .50 water	1	0
75	.60 acetone, .40 water	1	0
78	.20 acetone, .60 methanol, .20 water	1	0
80	.40 acetone, .20 methanol, .40 water	1	0
82	.60 methanol, .40 water	1	0
84	.80 methanol, .20 water	1	0
86	.60 acetone, .20 methanol, .20 water	1	0
88	.80 acetone, .20 water	1	0
90	.80 acetone, .20 methanol	1	0
92	.50 acetone, .50 methanol	1	0
94	.20 acetone, .80 methanol	1	0
96	.40 acetone, .20 methanol, .40 water	1	0
120	1.0 water	1	0
121	1.0 ethanol	1	0
122	1.0 ethyl acetate	1	0
123	.005 ethyl ace., .089 ethanol, .906 water	1	0
124	.036 ethyl ace., .190 ethanol, .774 water	1	0
125	.143 ethyl ace., .328 ethanol, .529 water	1	0
126	.092 ethyl ace., .829 ethanol, .079 water	1	0
128	.124 ethanol, .876 water	1	0
129	.014 ethyl ace., .136 ethanol, .850 water	1	0
130	.261 ethanol, .739 water	1	0
131	.057 ethyl ace., .469 ethanol, .474 water	1	0
132	.048 ethyl ace., .704 ethanol, .248 water	1	0
133	.573 ethanol, .427 water	1	0
134	1.0 methanol	1	0
135	.093 methanol, .098 ethanol, .809 water	1	0
136	.053 methanol, .145 ethanol, .802 water	1	0
137	.240 methanol, .060 ethanol, .700 water	1	0
138	.061 methanol, .033 ethanol, .906 water	1	0
139	.284 methanol, .296 ethanol, .420 water	1	0
140	.260 methanol, .520 ethanol, .220 water	1	0
141	.530 methanol, .230 ethanol, .240 water	1	0
142	.542 methanol, .458 ethanol	1	0

Table 5-2, continued
List of Experimental Tests on Plain Surfaces

Test No.	Composition (by mole fraction)	P,bar	ΔT_{sub},K
143	1.0 ethanol	1	0
144	1.0 methanol	1	0
145	1.0 water	1	0
155	1.0 methanol	1	0
156	1.0 acetone	1	0
157	1.0 water	1	0
160	1.0 water	1	0
161	1.0 2-propanol	1	0
162	1.0 acetone	1	0
163	.05 acetone, .04 2-propanol, .91 water	1	0
164	.011 acetone, .074 2-propanol, .915 water	1	0
165	.009 acetone, .243 2-propanol, .748 water	1	0
166	.06 2-propanol, .94 water	1	0
167	.15 2-propanol, .85 water	1	0
168	.018 acetone, .175, 2-propanol, .807 water	1	0
169	1.0 water	1	0
170	1.0 methanol	1	0
171	1.0 2-propanol	1	0
172	.122 methanol, .039 2-propanol, .839 water	1	0
173	.246 methanol, .131 2-propanol, .623 water	1	0
174	.225 methanol, .251 2-propanol, .524 water	1	0
175	.409 methanol, .091 2-propanol, .500 water	1	0
176	.303 methanol, .031 2-propanol, .666 water	1	0
178	1.0 2-butanone	1	0
179	1.0 acetone	1	0
180	.055 acetone, .039 2-butanone, .906 water	1	0
181	.163 acetone, .050 2-butanone, .787 water	1	0
182	.082 acetone, .139 2-butanone, .779 water	1	0
183	.022 acetone, .080 2-butanone, .898 water	1	0
184	.376 acetone, .086 2-butanone, .538 water	1	0
185	.074 2-butanone, .005 benzene, .004 cyclohexane, .917 2-propanol	1	0
186	.300 2-butanone, .500 benzene, .104 cyclohexane, .096 2-propanol	1	0
187	.119 2-butanone, .802 benzene, .041 cyclohexane, .038 2-propanol	1	0
188	.20 methyl acetate, .20 methanol, .20 ethyl acetate, .40 ethanol	1	0
189	1.0 water	1	0
213	1.0 water	1	0
214	1.0 water	1	10
215	1.0 water	1	20
216	1.0 ethanol	1	0
217	1.0 ethanol	1	10
218	.124 ethanol, .876 water	1	0
219	.124 ethanol, .876 water	1	10
220	.124 ethanol, .876 water	1	20
221	.261 ethanol, .739 water	1	0
222	.261 ethanol, .739 water	1	10
223	.573 ethanol, .427 water	1	0
224	.573 ethanol, .427 water	1	10

5.2 FINNED TUBE EXPERIMENTAL RESULTS

Finned tubes are commonly used to enhance heat transfer in boiling and condensation equipment. While boiling in mixtures on plain and porous surfaces has received a fair amount of attention, there are currently no experimental measurements of pool boiling heat transfer coefficients on finned surfaces. Experimental measurements of pool boiling heat transfer coefficients from a 19 fin/in. (750 fin/m) were obtained in acetone-water, methanol-water and ethanol-water binary mixtures at 1.01 bar. Heat transfer coefficients were also obtained for two ternary mixtures on this finned surface. Table 5-3 lists the experimental tests recorded for mixtures on the finned surface. Boiling curves on the finned tube are shown in Figures 5.22 through 5.25. The heat flux for the finned tube is based on fin outer diameter. The provides a more suitable basis for comparison between a finned tube and a plain tube that would occupy the same volume. Similar to the plain surface tube, the heat transfer coefficients in mixtures for the finned tube are significantly lower than those expected by a linear combination of the pure component heat transfer coefficients. Figure 5.26 shows the degradation of pool boiling heat transfer coefficients in acetone-water mixtures, Figure 5.27 in methanol-water mixtures, and Figure 5.28 in ethanol-water mixtures. The minimum in heat transfer coefficient in the acetone-water mixtures was found to occur near a .20 mole fraction composition of acetone, the same composition as was found for the plain tube. In the methanol-water mixtures however, the minimum point occurred at approximately 0.70 mole fraction methanol in comparison to the 0.30 mole fraction minimum found for the plain surface. The ethanol-water system showed a minimum in pool boiling heat transfer coefficients at approximately 0.20 mole fraction ethanol.

The effect of a third component on the nucleate boiling heat transfer coefficients for the finned tube is similar to that for the plain tube. Figure 5.29 shows α/α_{id} plotted against the sum of (y-x) for the light components of binary and two ternary mixtures at $q''=150$ kW/m^2 on the finned tube. The linear mixing law was used to define ideal heat transfer coefficient. As for the plain tube, the value of α/α_{id} decreases as $|y-x|$ increases for the finned tube.

Figure 5.30 compares the degradation in nucleate boiling heat transfer coefficients for three binary mixture system between the finned and the plain tubes at $q''=150$ kW/m^2. Although the heat transfer coefficients on the finned tube are in general larger than those on the plain tube, the degradation in the heat transfer coefficients due to physical properties and the mass transfer process are similar. The ratio α/α_{id} decreases to 0.4 for acetone-water mixtures on both tubes and to 0.5 for ethanol-water mixtures. The minimum of the ratio α/α_{id} for methanol-water mixtures is also 0.5, although the minima for each tube is at a different mole fraction. This implies that the enhancement in the heat transfer coefficients for the finned tube is principly a convective enhancement of the heat transfer.

Table 5-3
List of Experimental Tests on a Finned Surface

Test No.	Composition (by mole fraction)	P,bar	ΔT_{sub},K
97	1.0 water	1	0
98	.10 methanol, .90 water	1	0
99	.05 methanol, .95 water	1	0
100	.20 methanol, .80 water	1	0
101	.30 methanol, .70 water	1	0
102	.50 methanol, .50 water	1	0
103	1.0 methanol	1	0
104	.60 methanol, .40 water	1	0
105	.70 methanol, .30 water	1	0
106	.85 methanol, .15 water	1	0
107	.15 acetone, .85 water	1	0
108	.25 acetone, .75 water	1	0
109	.40 acetone, .60 water	1	0
110	.60 acetone, .40 water	1	0
111	1.0 acetone	1	0
112	.10 acetone, .10 methanol, .80 water	1	0
150	1.0 water	1	0
151	.20 acetone, .20 methanol, .80 water	1	0
190	1.0 water	1	0
191	1.0 ethanol	1	0
192	1.0 ethanol	1	0
193	.124 ethanol, .876 water	1	0
194	.261 ethanol, .739 water	1	0
195	.573 ethanol, .427 water	1	0
196	1.0 water	1	20
197	1.0 water	1	10
198	1.0 water	1	0
199	1.0 water	1	40
200	1.0 water	1	30
201	1.0 ethanol	1	20
202	1.0 ethanol	1	0
203	.124 ethanol, .876 water	1	0
204	.124 ethanol, .876 water	1	10
205	.124 ethanol, .876 water	1	20
206	.261 ethanol, .739 water	1	0
207	.261 ethanol, .739 water	1	10
208	.261 ethanol, .739 water	1	20
209	.573 ethanol, .427 water	1	0
210	.573 ethanol, .427 water	1	10
211	1.0 ethanol	1	0
212	1.0 ethanol	1	10
225	1.0 water	1	0
226	1.0 water	1	10

5.3 EFFECT OF SUBCOOLING ON PLAIN AND FINNED TUBES

The effect of subcooling on pool boiling heat transfer coefficients in ethanol-water mixtures was investigated. Table 5-2 lists the experimental tests performed on a plain surface with bulk liquid subcoolings. The facility could not maintain subcoolings of more than 20 K for ethanol-water mixtures. Figures 5.31 shows the variation of pool boiling heat transfer coefficients based on (T_w-T_b) in pure water and ethanol for several values of bulk liquid subcooling. As the subcooling increases, the heat transfer coefficients decrease for a given heat flux. Boiling curves for ethanol-water mixtures at constant subcooling of 10 K are shown in Figure 5.32. Figure 5.33 shows the degradation in pool boiling heat transfer coefficients with composition and subcooling. The effect of subcooling on the heat transfer coefficients is larger in the pure components than in the mixtures. For a subcooling of 10 K, the heat transfer coefficients in water and ethanol were reduced by 48% and 31% respectively. The heat transfer coefficient at 0.124 mole fraction ethanol decreased by 35%. Considering the decreases in the pure components, one would have expected a decrease at x=0.124 of approximately 44%. Thus, the effect of subcooling on the heat transfer coefficients in mixtures appears to be less than it is for the pure components. At 20 K, there is evidence that the heat transfer coefficients in the mixtures become linear with respect to the heat transfer coefficients in the pure components. These data for subcooled boiling in ethanol-water mixtures are in qualitative agreement with those of Sterman et al.(1966) for benzene-diphenyl mixtures. Sterman also found the effect of subcooling to be greater on pure components than their mixtures, but presented no explanation for this effect.

Subcooled pool boiling heat transfer coefficients were also measured in ethanol-water binary mixtures from a finned tube. Figure 5.34 shows the effect of subcooling from the finned tube on the pure components, and Figure 5.33 shows the boiling curves for ethanol-water mixtures with 10 K subcooling. Figure 5.36 shows the degradation in pool boiling heat transfer coefficients with composition and subcooling on the finned tube. Similar to the plain surface, the effect of subcooling is greater on the pure components than on the mixtures. In pure water, the nucleate boiling heat transfer coefficient decreased by 44% as the bulk liquid subcooling increased to 10 K. In pure ethanol, the reduction in the heat transfer coefficient for this same increase in subcooling was 37%. The decrease in α for a 0.124 mole fraction ethanol mixture was 40%, which is less than the 43% decrease that is predicted by a linear combination of the pure component reductions.

Figure 5.37 shows the variation of α/α_{id} with subcooling for both the plain and finned tubes at $q''=150$ kW/m^2. This data indicates that the effect of subcooling on both surfaces is similar, and that the degradation of nucleate pool boiling heat transfer coefficients decreases with increasing bulk liquid subcooling.

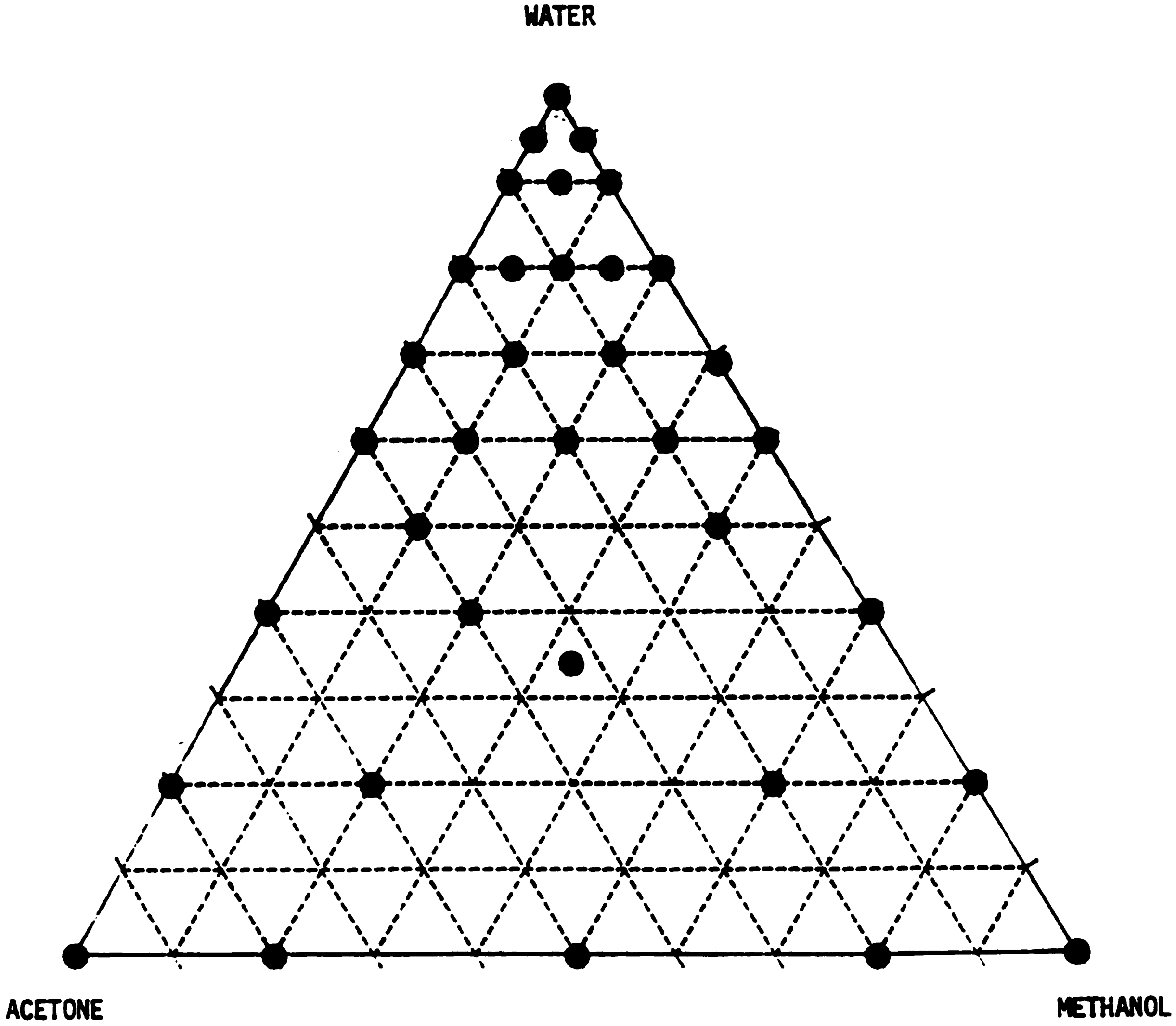


Figure 5.1 Acetone-Methanol-Water compositions tested at 1.01 bar.

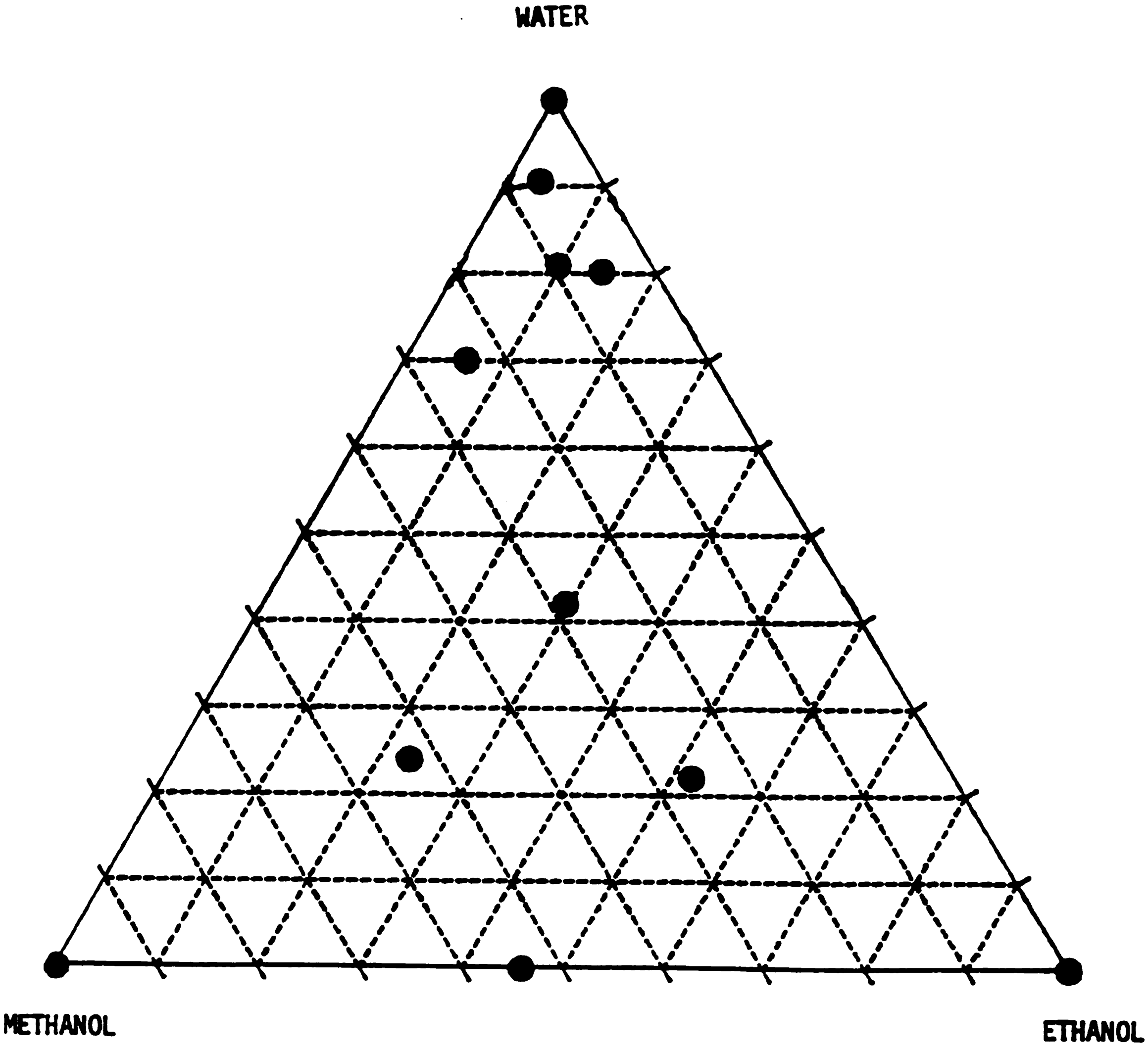


Figure 5.2 Methanol-Ethanol-Water compositions tested at 1.01 bar.

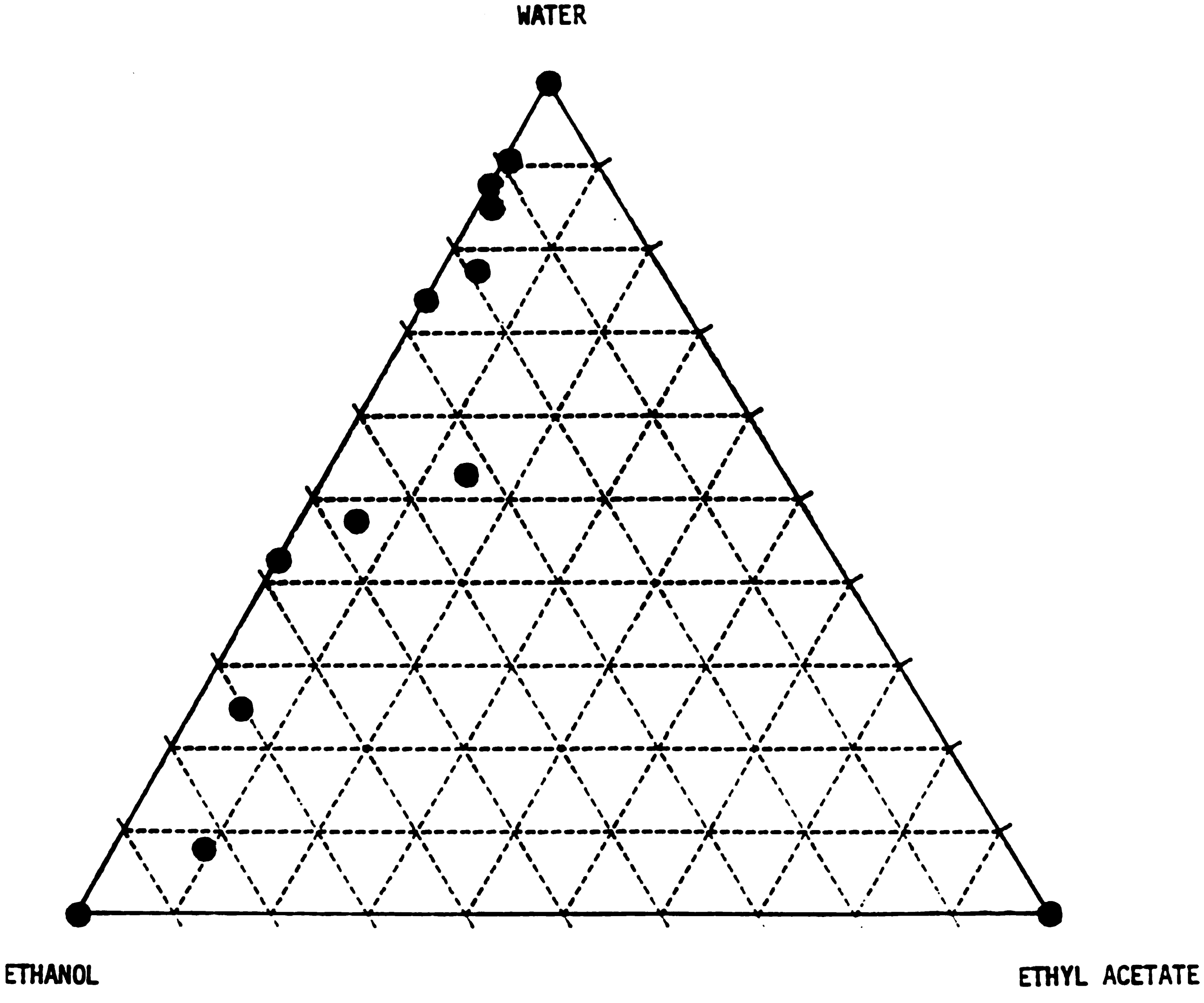


Figure 5.3 Ethanol-Ethyl Acetate-Water compositions tested at 1.01 bar.

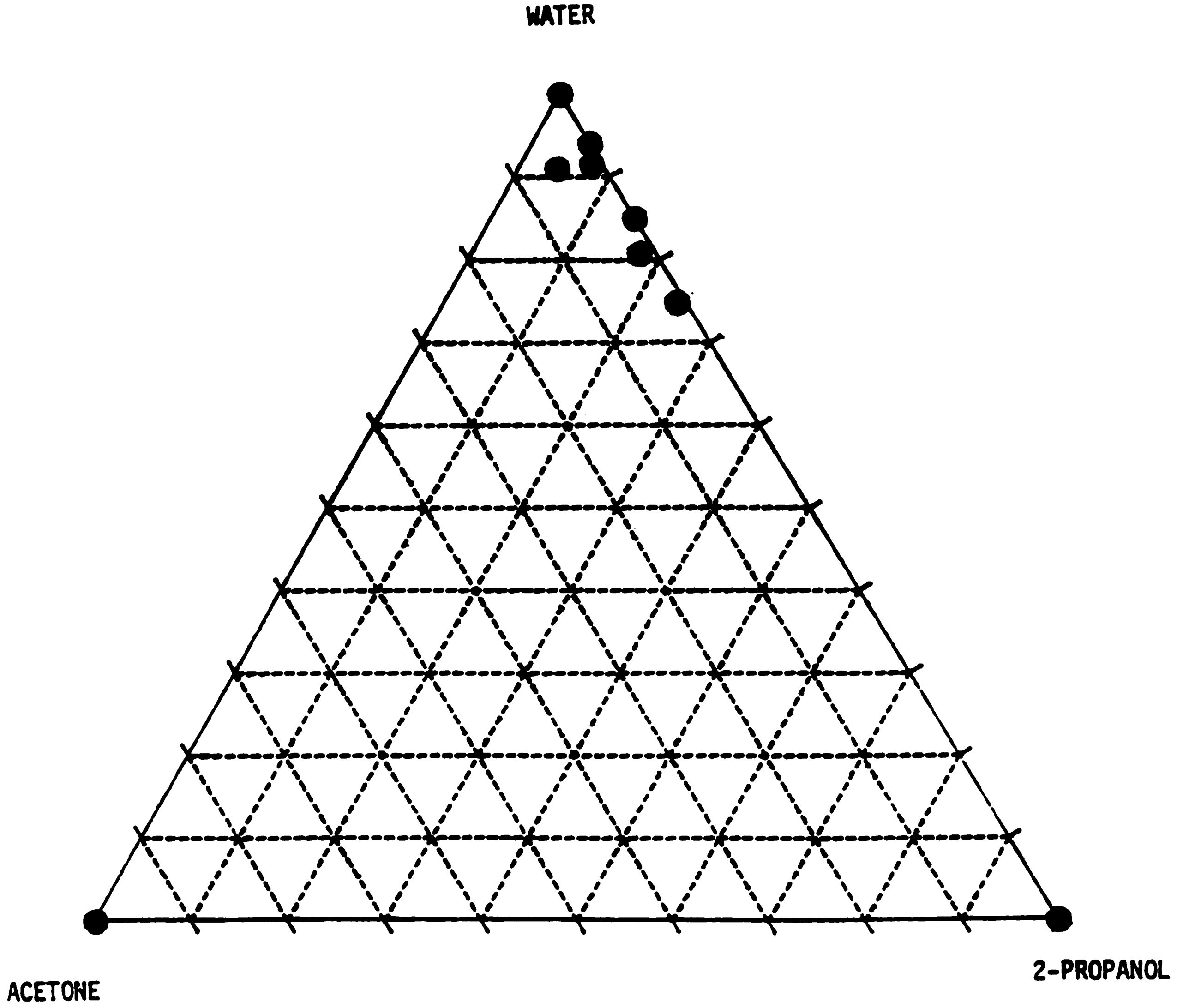


Figure 5.4 Acetone- 2-Propanol - Water compositions tested at 1.01 bar.

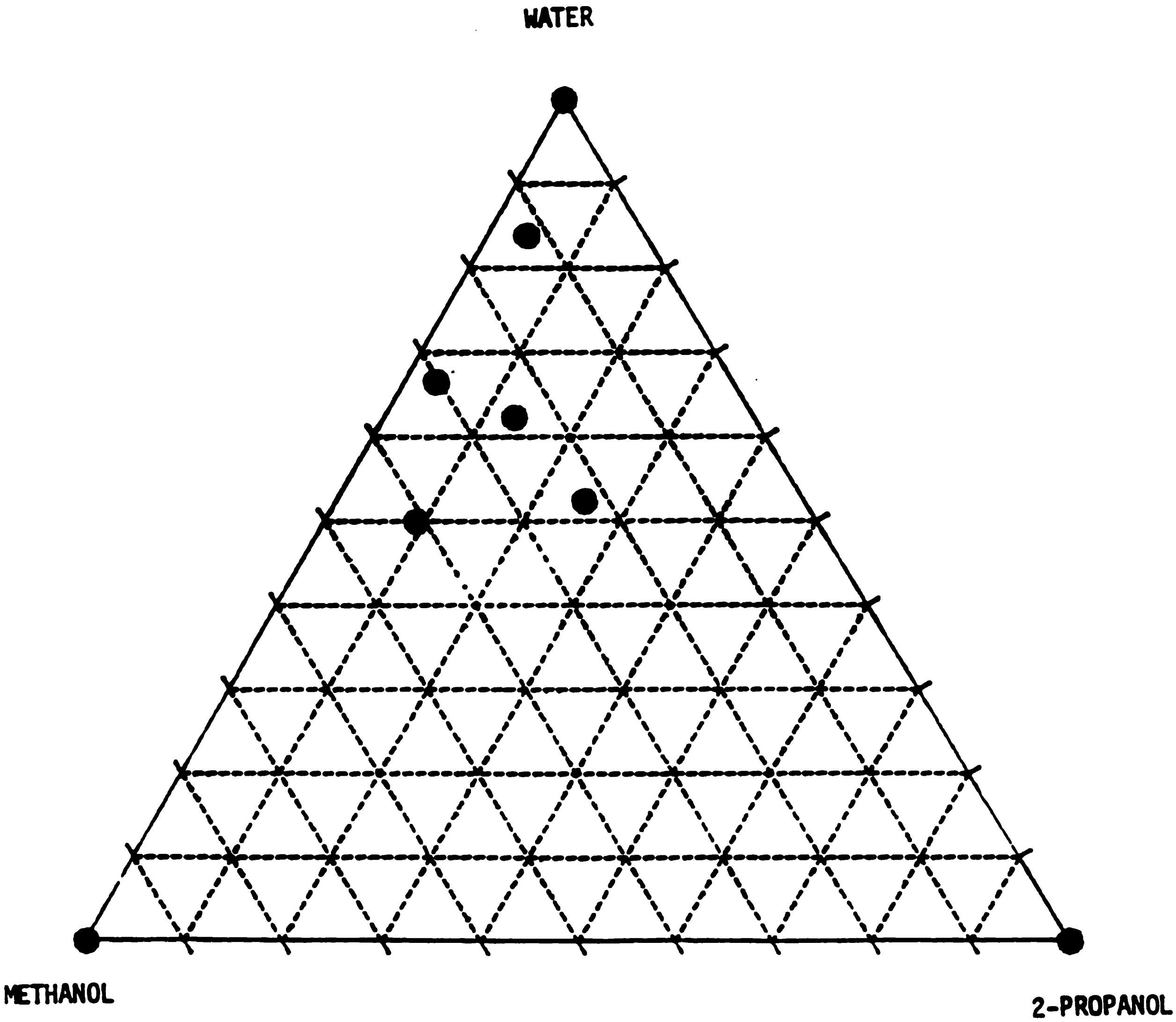


Figure 5.5 Methanol- 2-Propanol -Water compositions tested at 1.01 bar.

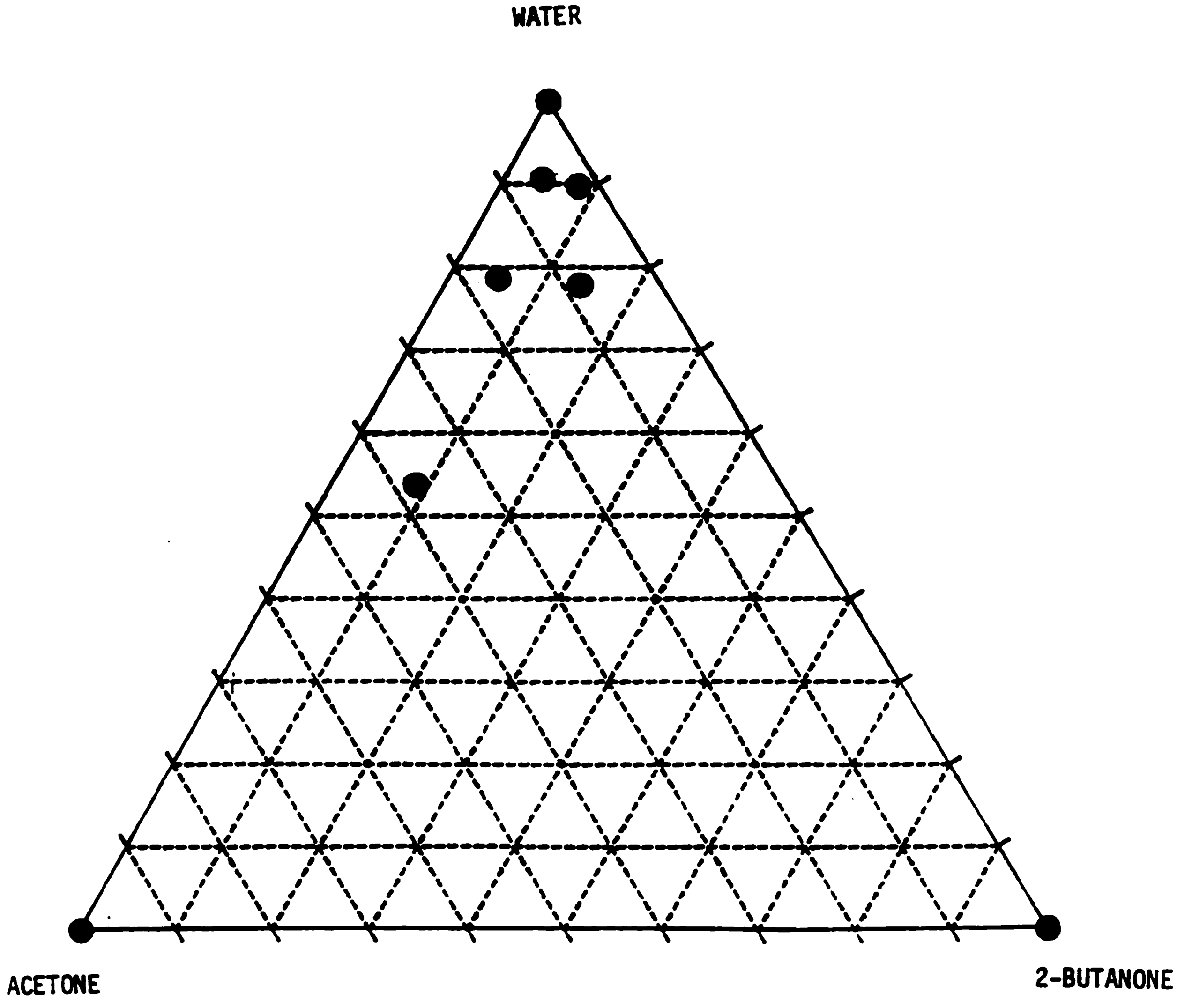


Figure 5.6 Acetone- 2-Butanone - Water compositions tested at 1.01 bar.

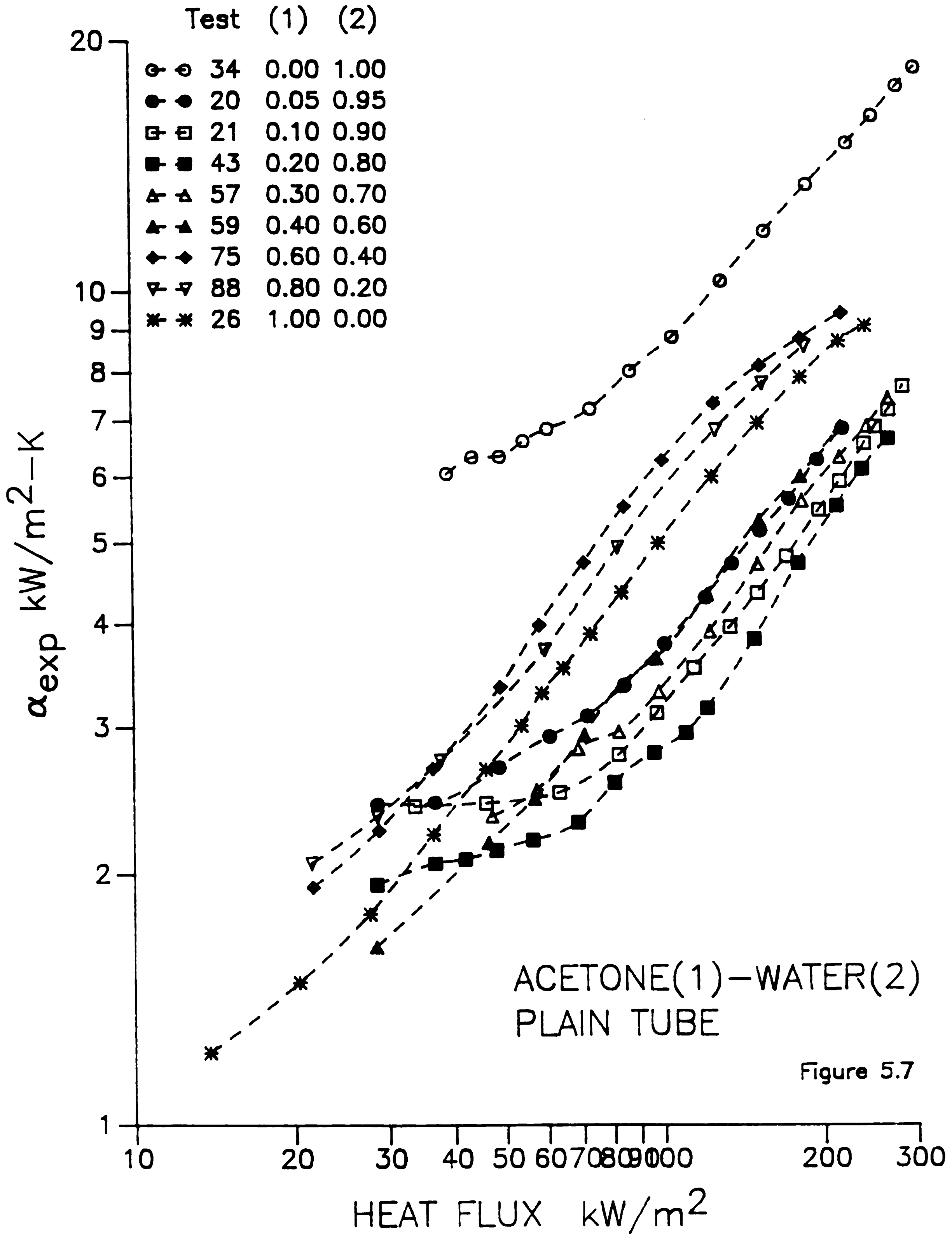


Figure 5.7 Boiling curves at 1.01 bar in acetone-water mixtures for a plain tube.

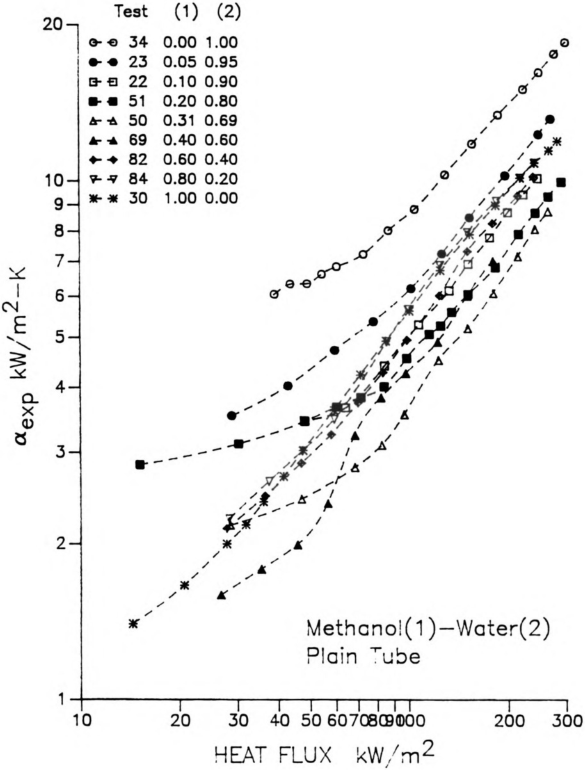


Figure 5.8 Boiling curves at 1.01 bar in methanol-water mixtures for a plain tube.

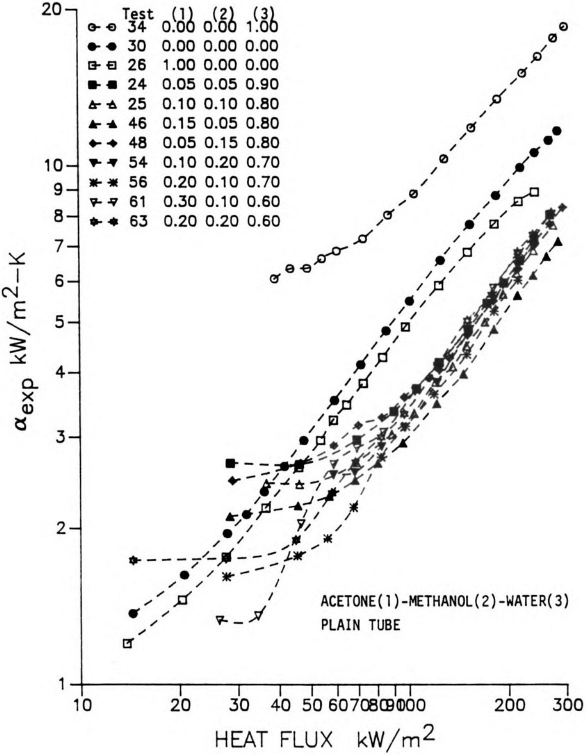


Figure 5.9 Boiling curves at 1.01 bar in acetone-methanol-water ternary mixtures in which the water mole fraction is greater than 0.5 for a plain tube.

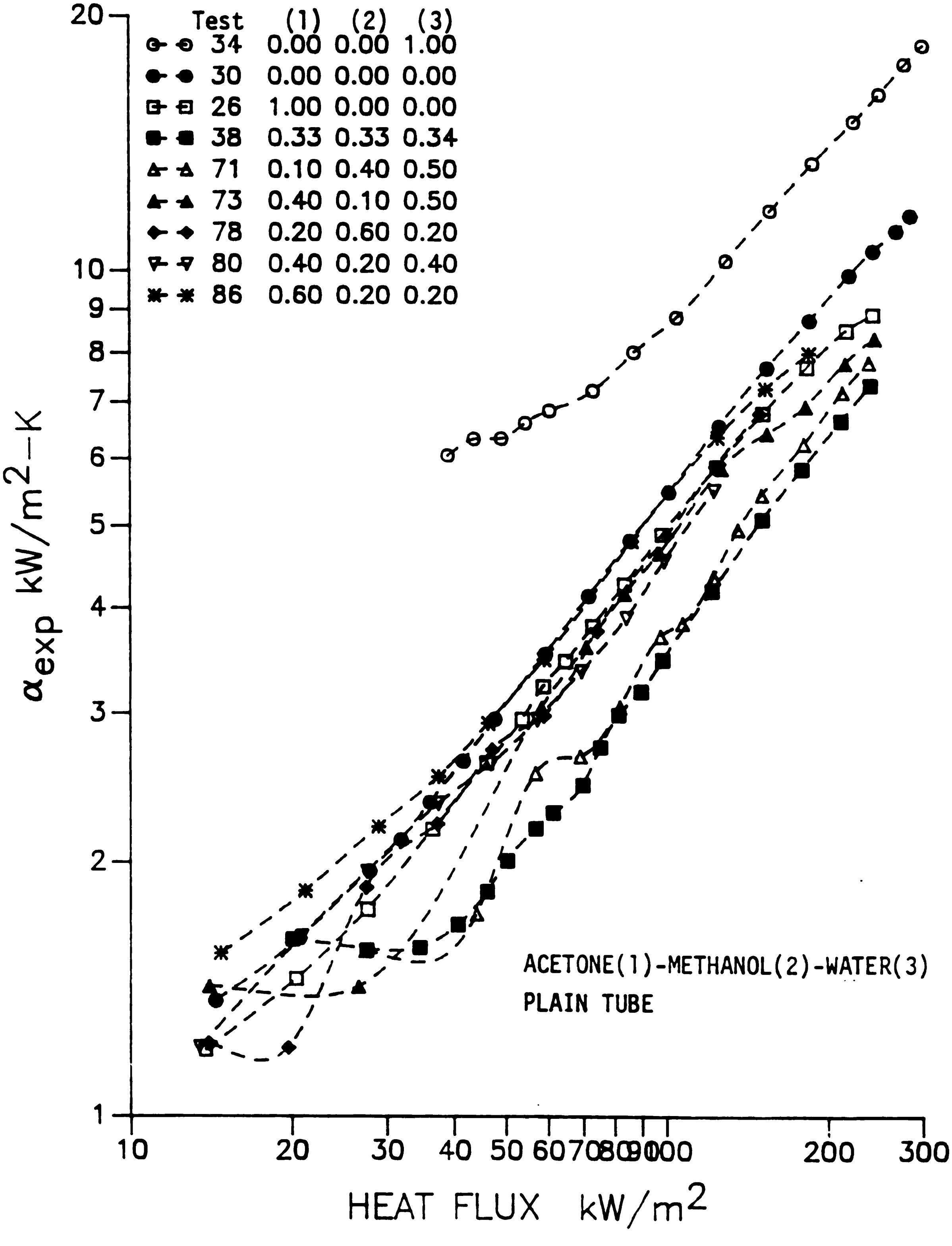


Figure 5.10 Boiling curves at 1.01 bar in acetone-methanol-water ternary mixtures for which the water mole fraction is less than or equal to 0.5 for a plain tube.

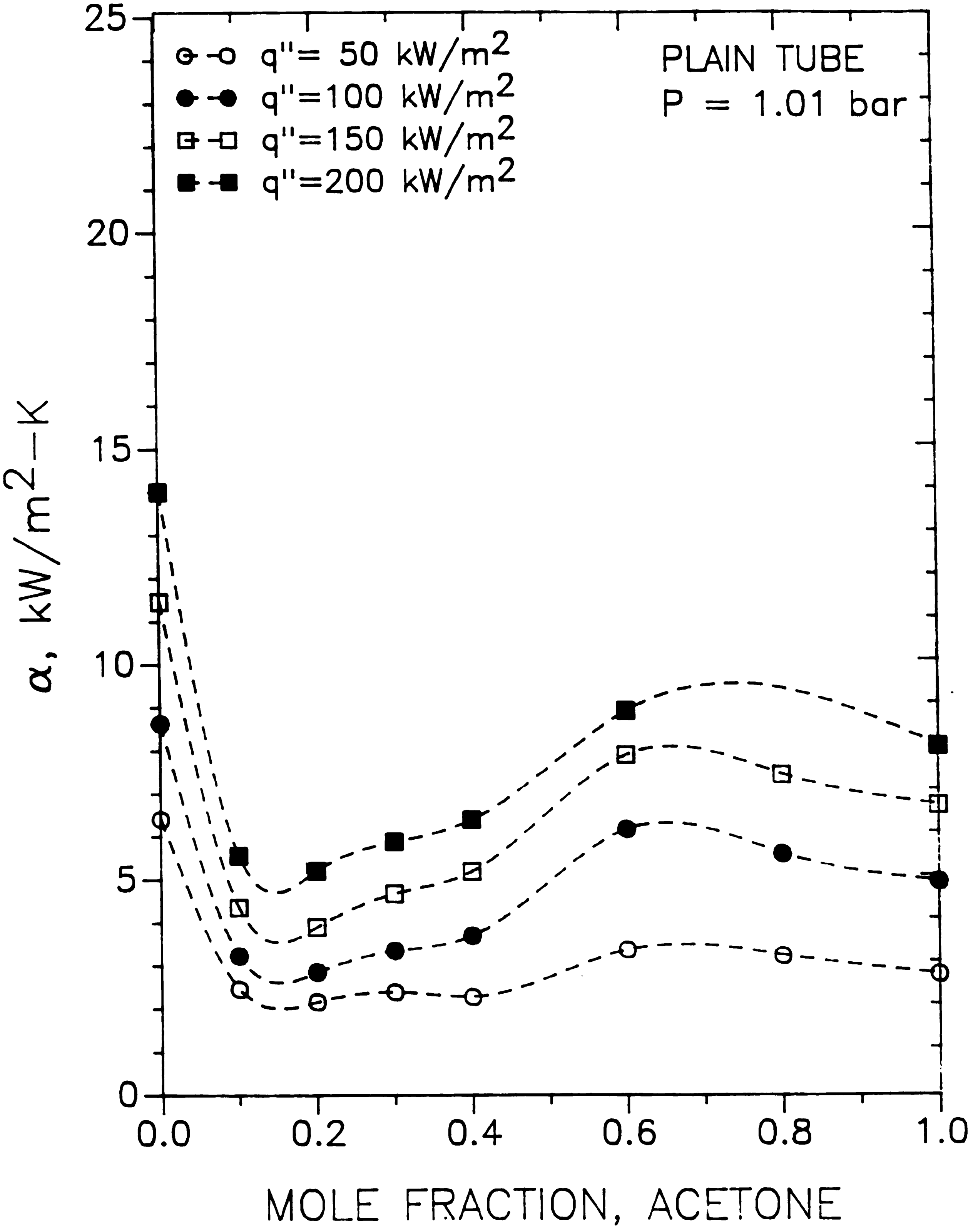


Figure 5.11 Pool boiling heat transfer coefficients in acetone-water binary mixtures at 1.01 bar for a plain tube.

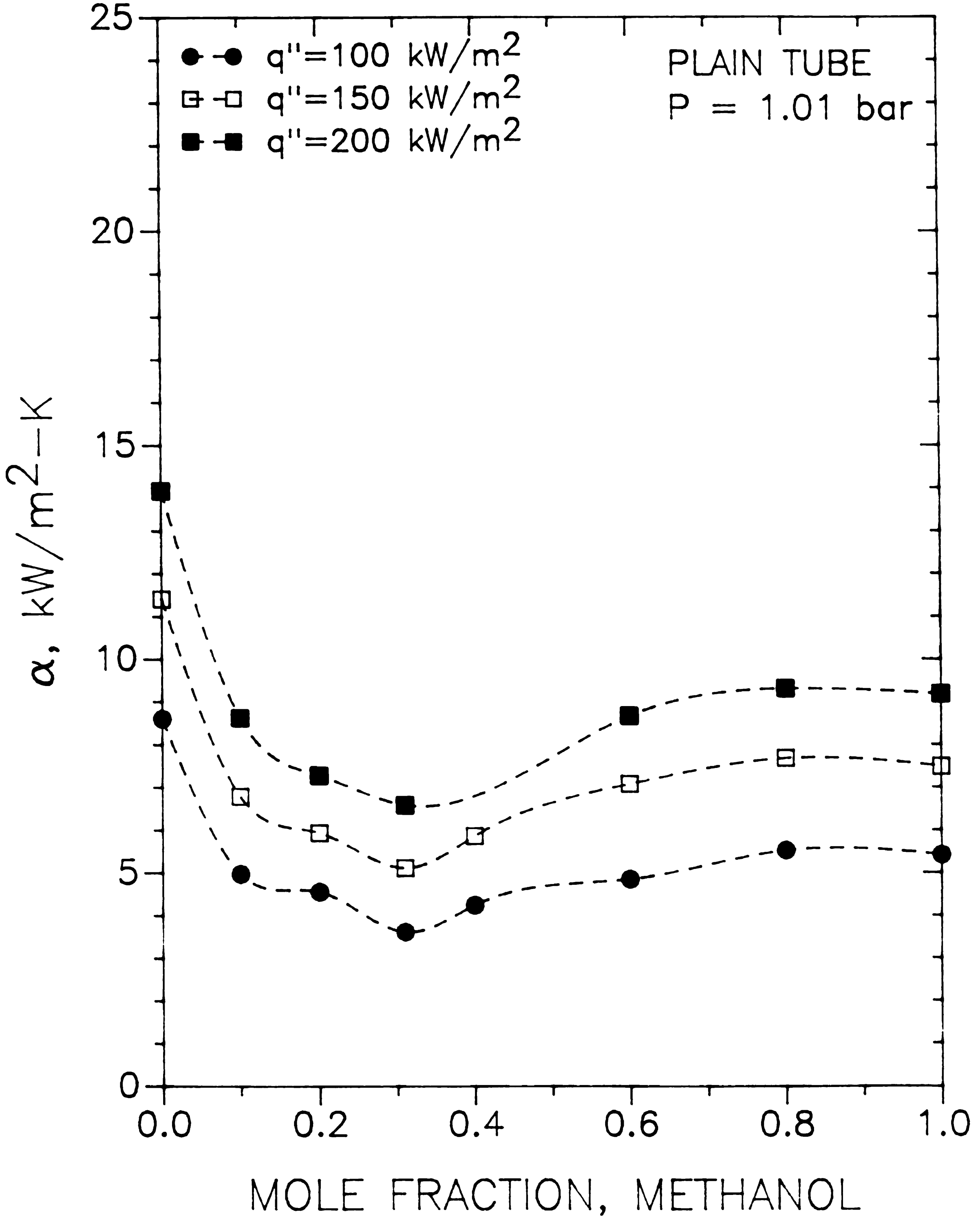


Figure 5.12 **Pool boiling heat transfer coefficients in methanol-water binary mixtures at 1.01 bar for a plain tube.**

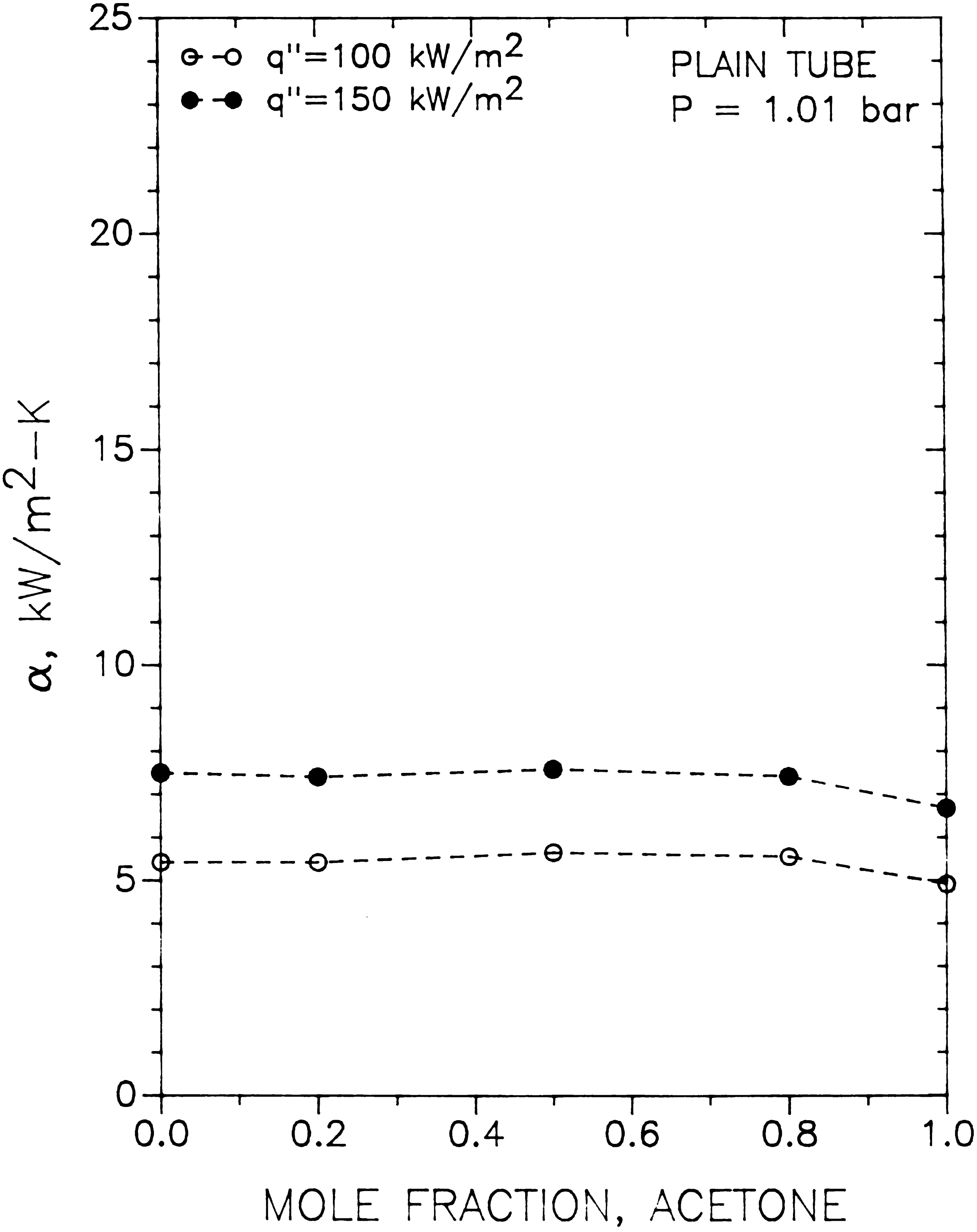


Figure 5.13 Variation in pool boiling heat transfer coefficients in acetone-methanol binary mixtures at 1.01 bar.

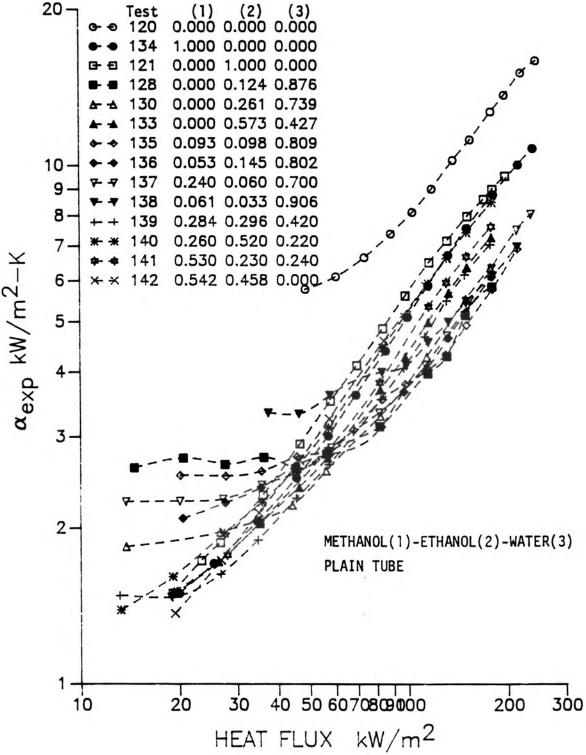


Figure 5.14 Boiling curves at 1.01 bar in methanol-ethanol-water ternary mixtures and ethanol-water binary mxtures for a plain tube.

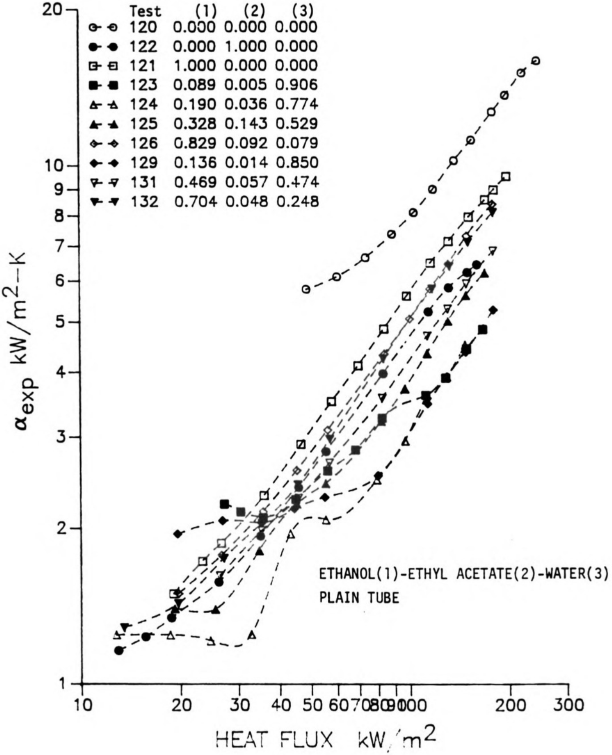


Figure 5.15 Boiling curves at 1.01 bar in ethanol- ethyl acetate-water ternary mixtures for a plain tube.

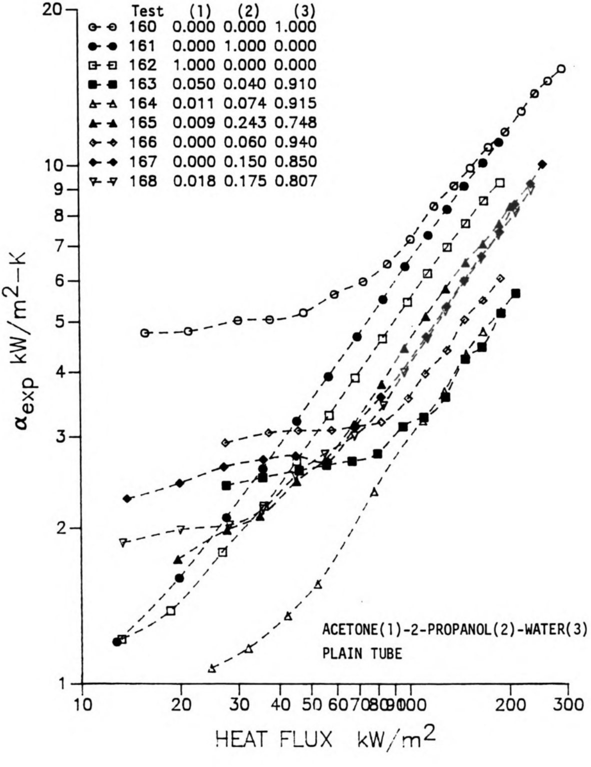


Figure 5.16 Boiling curves at 1.01 bar in acetone- 2-propanol- water mixtures for a plain tube.

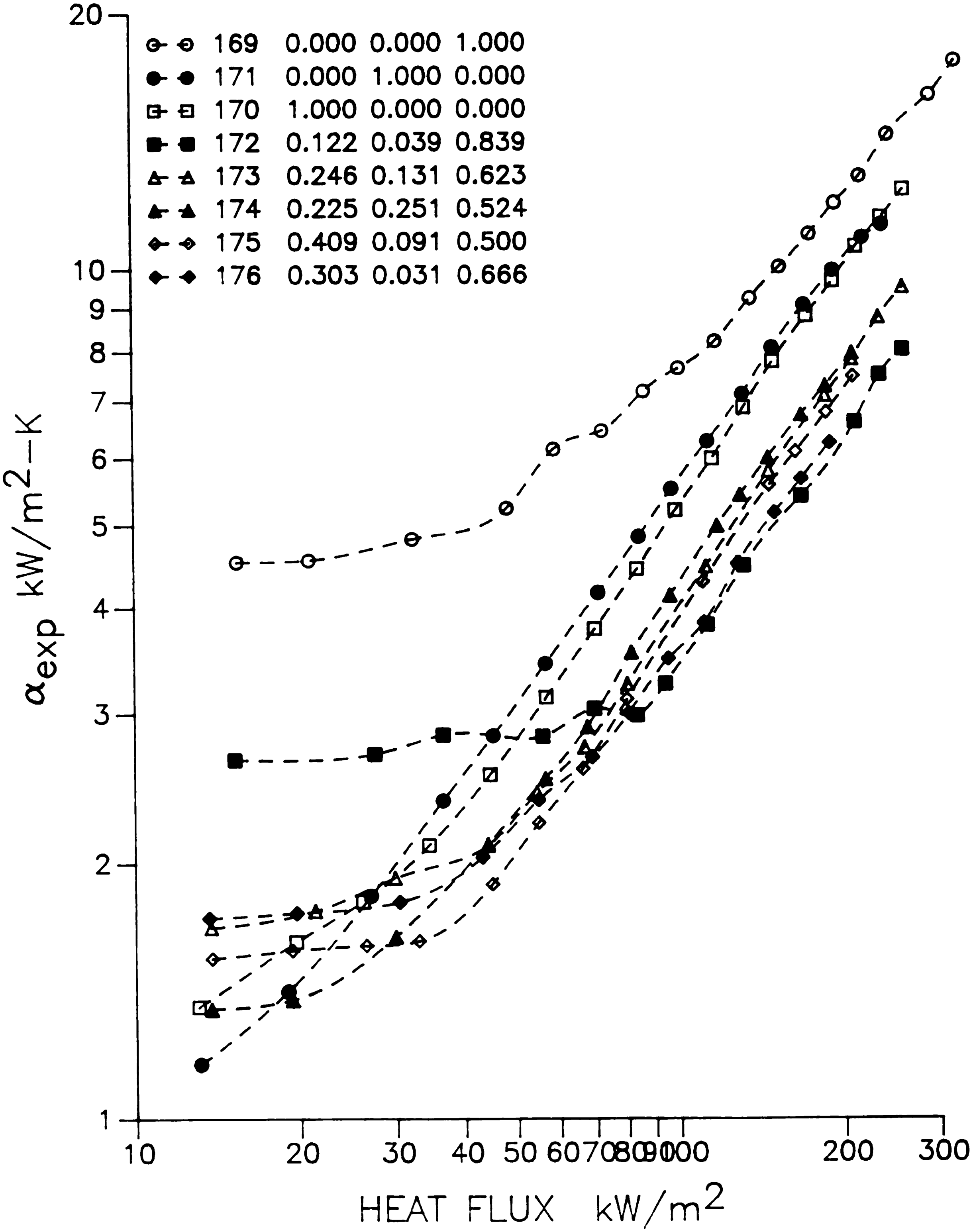


Figure 5.17 Boiling curves at 1.01 bar in methanol- 2-propanol -water ternary mixtures for a plain tube.

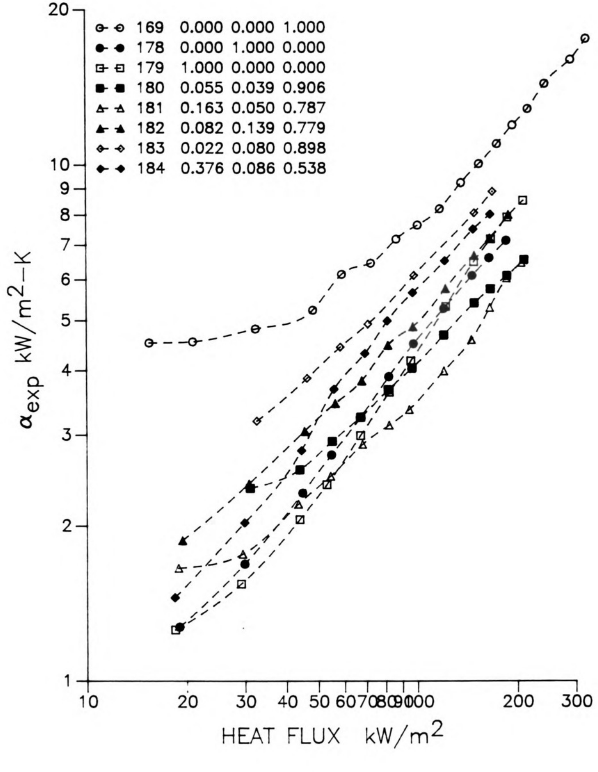


Figure 5.18 Boiling curves at 1.01 bar in acetone- 2-butanone -water ternary mixtures for a plain tube.

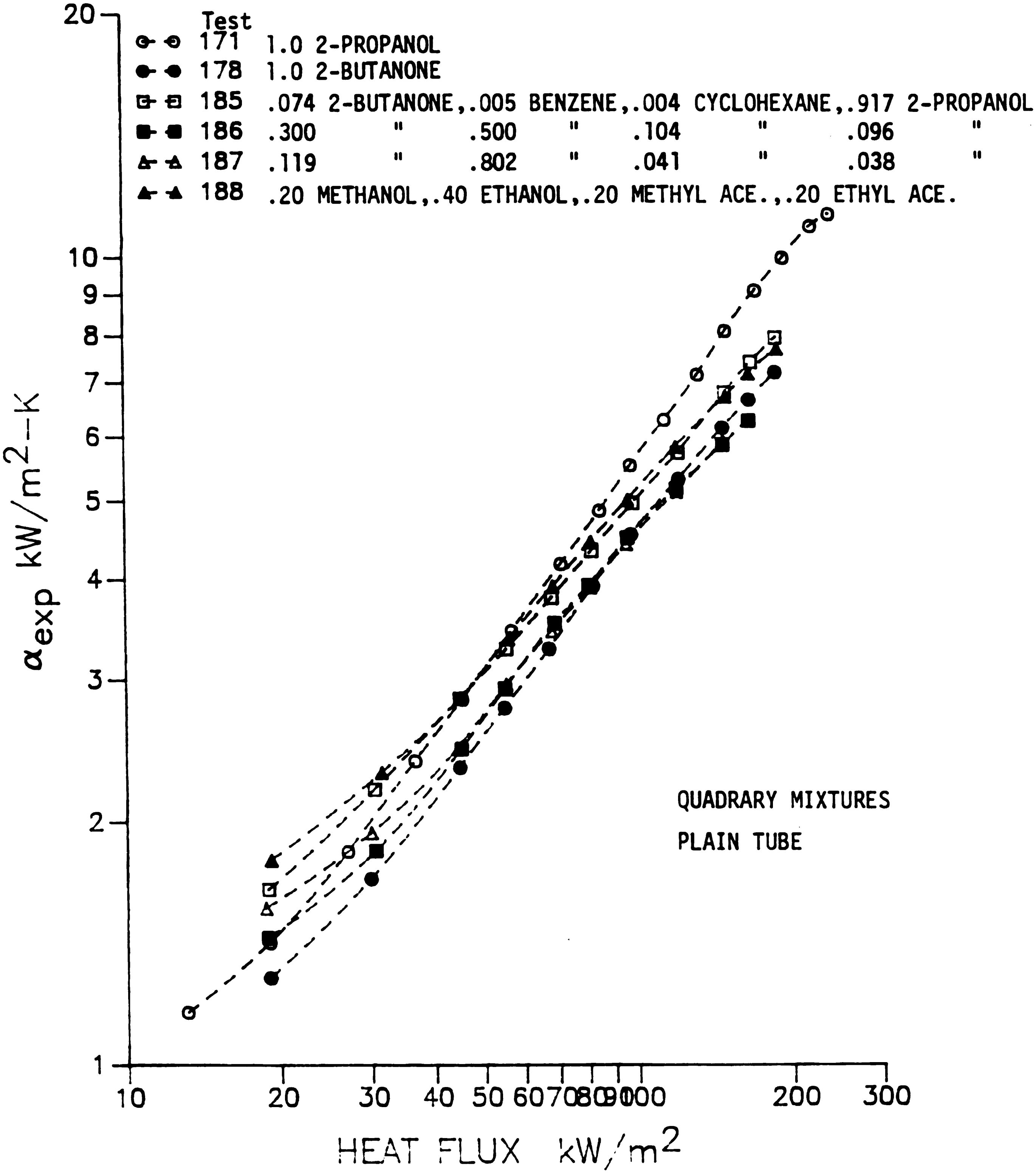


Figure 5.19 Boiling curves at 1.01 bar in quadrary mixtures for a plain tube.

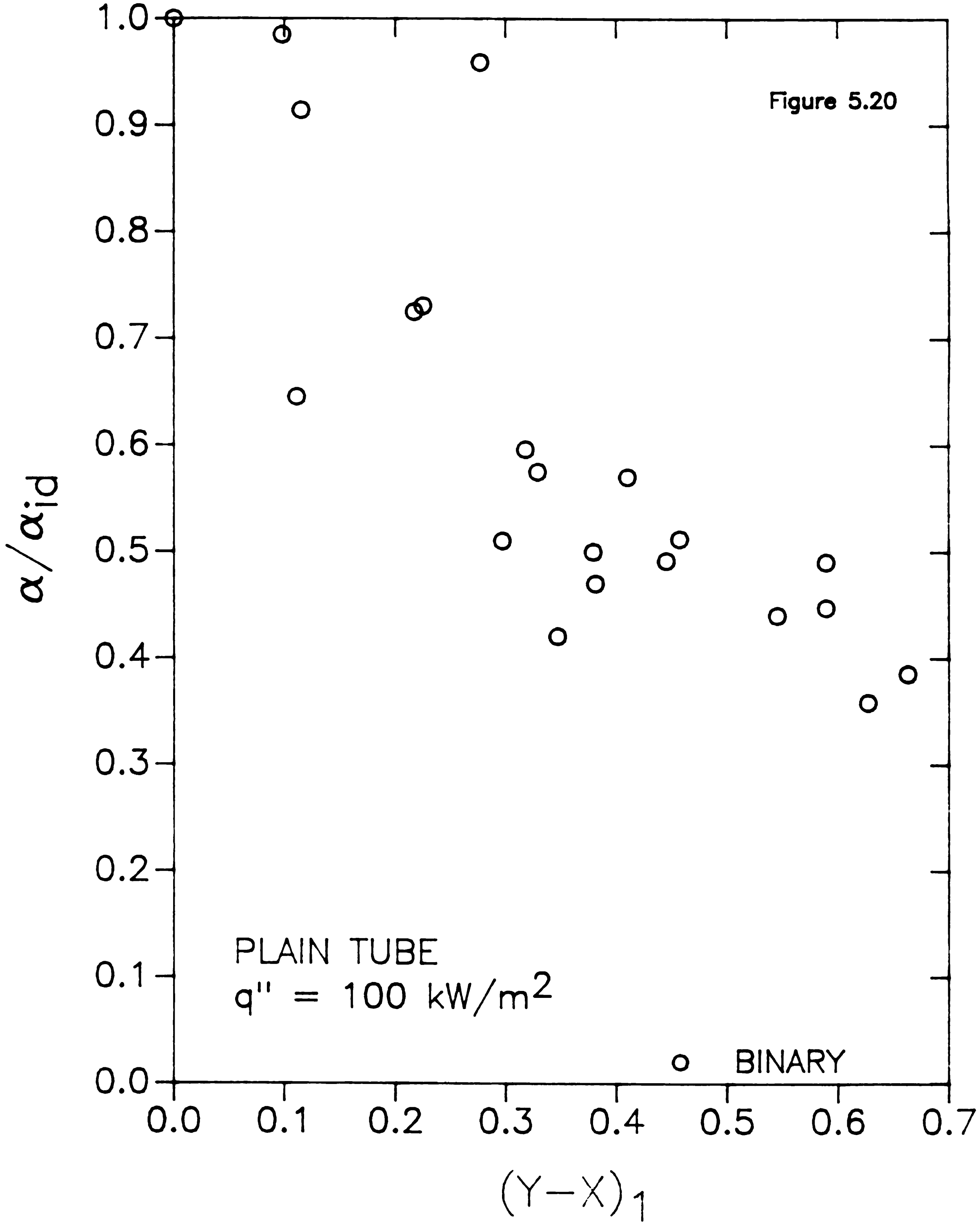


Figure 5.20 Degradation of binary mixture nucleate boiling heat transfer coefficients as a function of |y-x| of the light component.

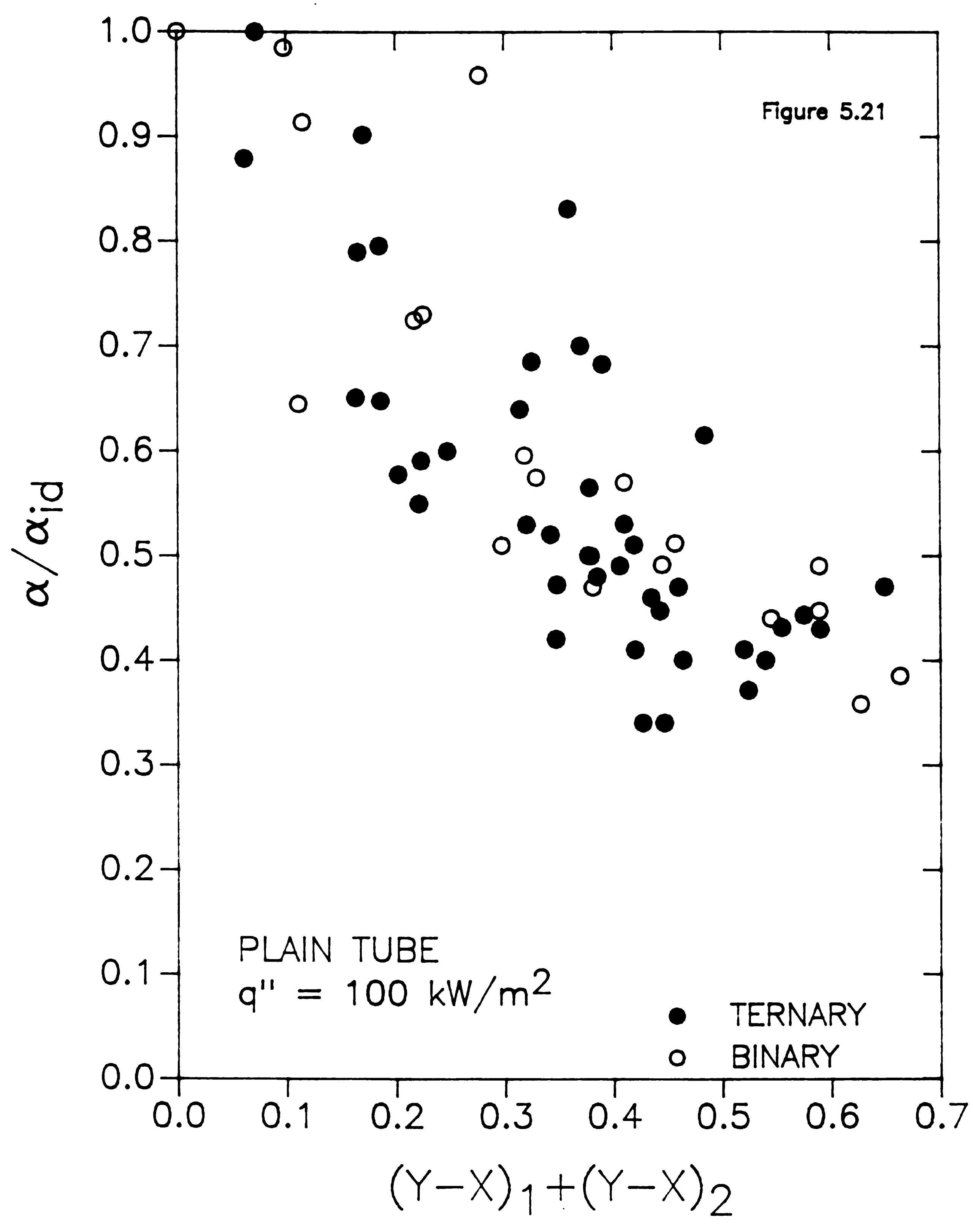


Figure 5.21 Degradation of binary and ternary nucleate boiling heat transfer coefficients as a function of |y-x| of the light components.

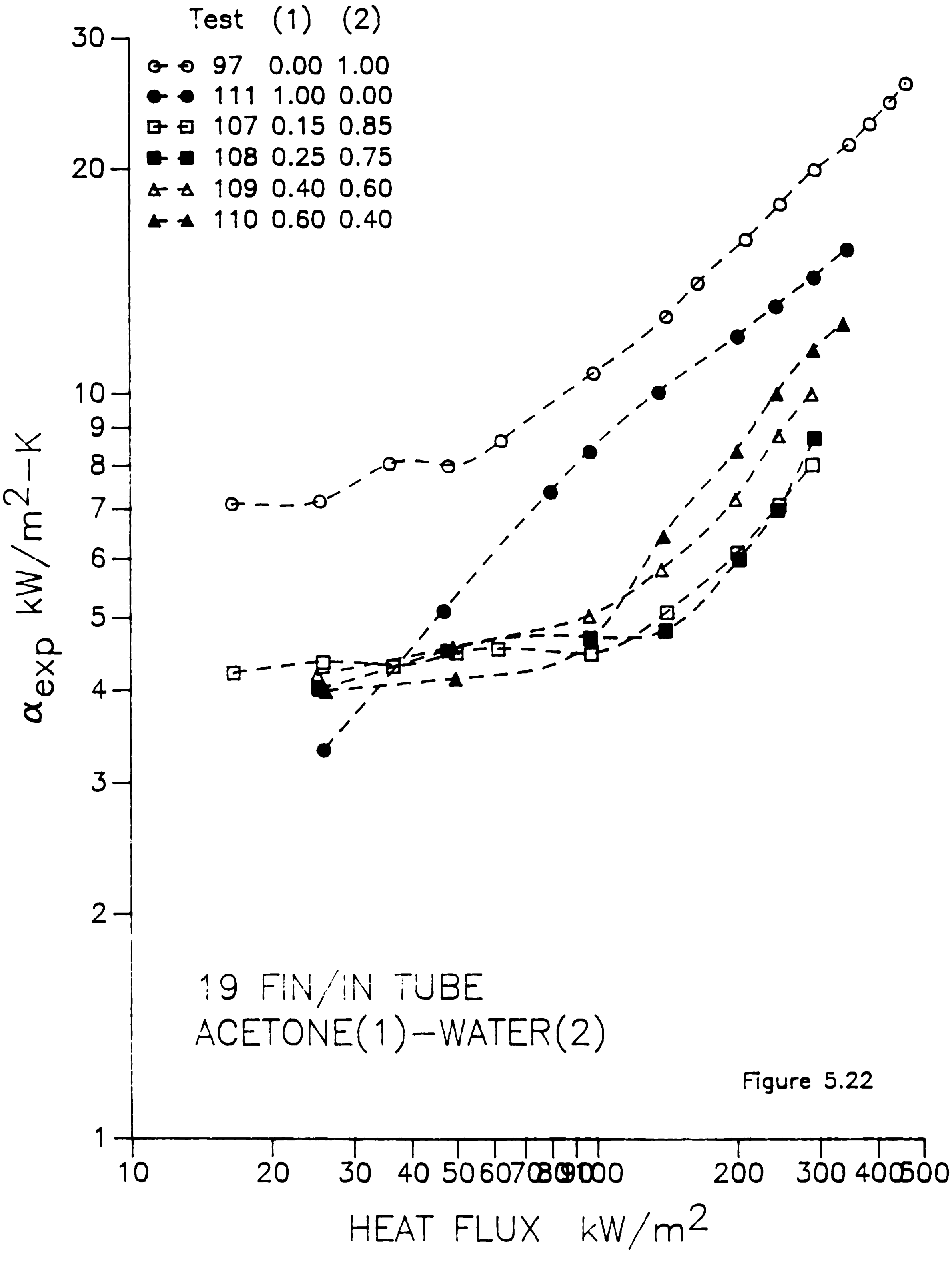


Figure 5.22 Boiling curves for a finned tube in acetone-water binary mixtures.

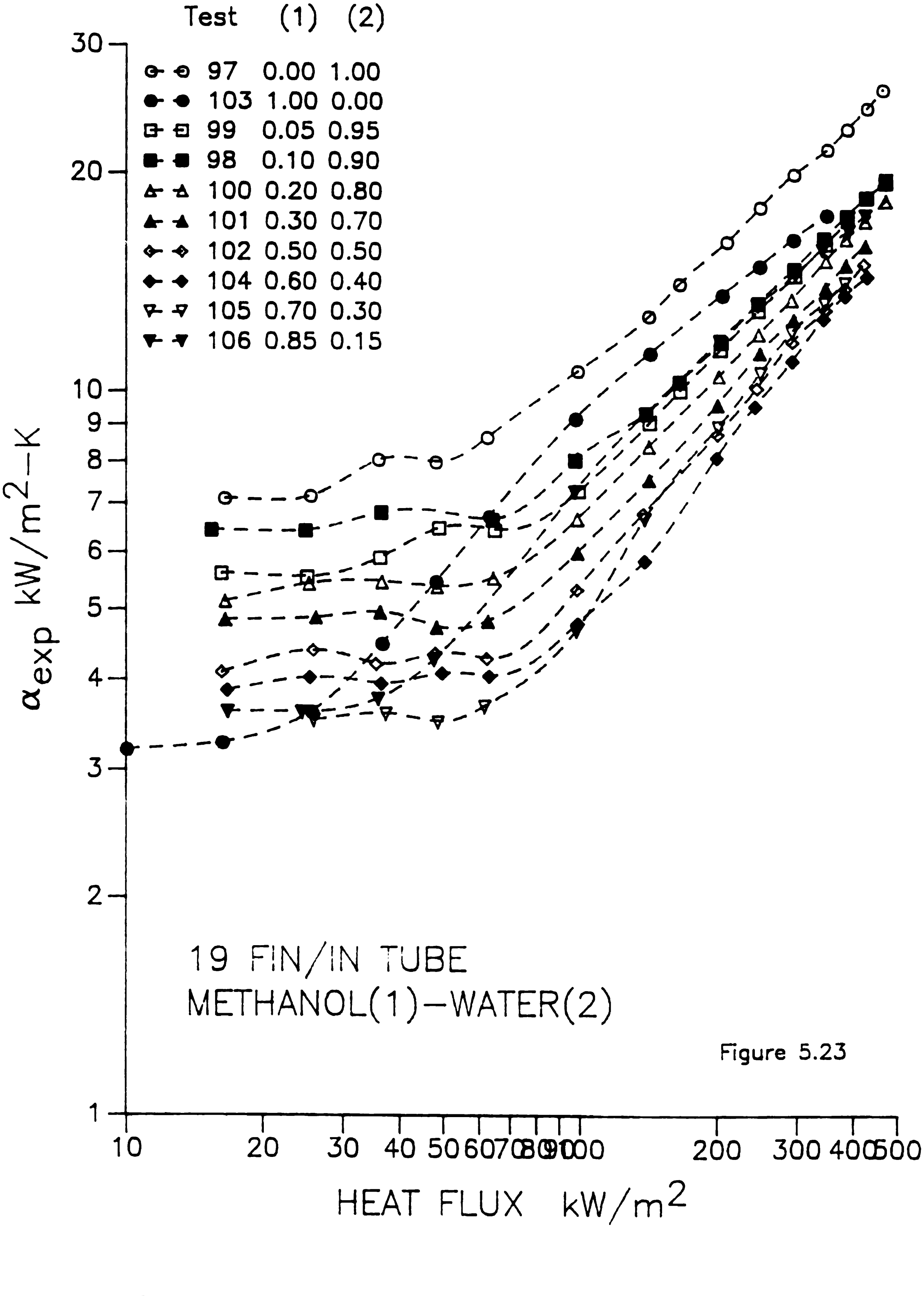


Figure 5.23 Boiling curves for a finned tube in methanol-water binary mixtures.

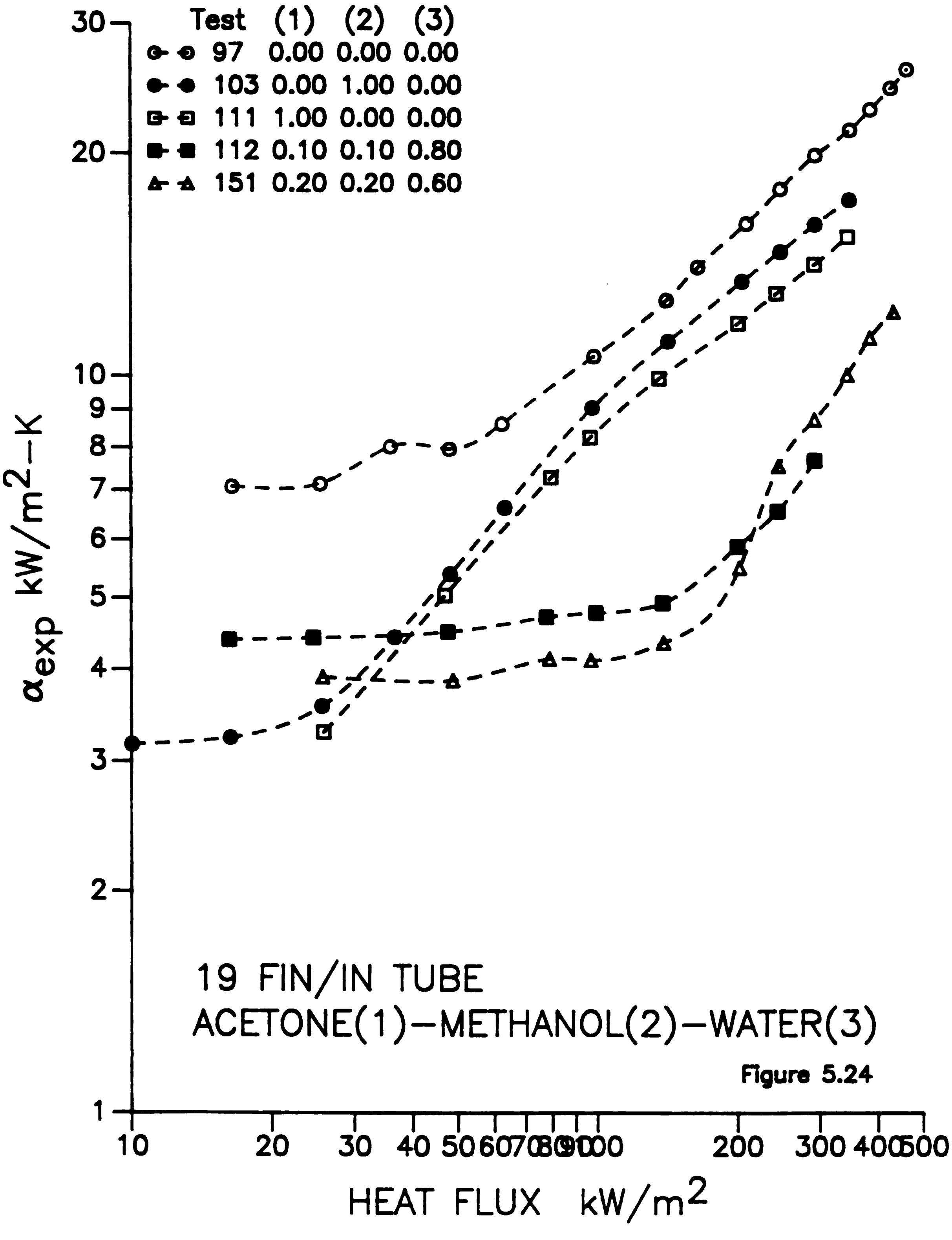


Figure 5.24 Boiling curves for a finned tube in acetone-methanol-water ternary mixtures.

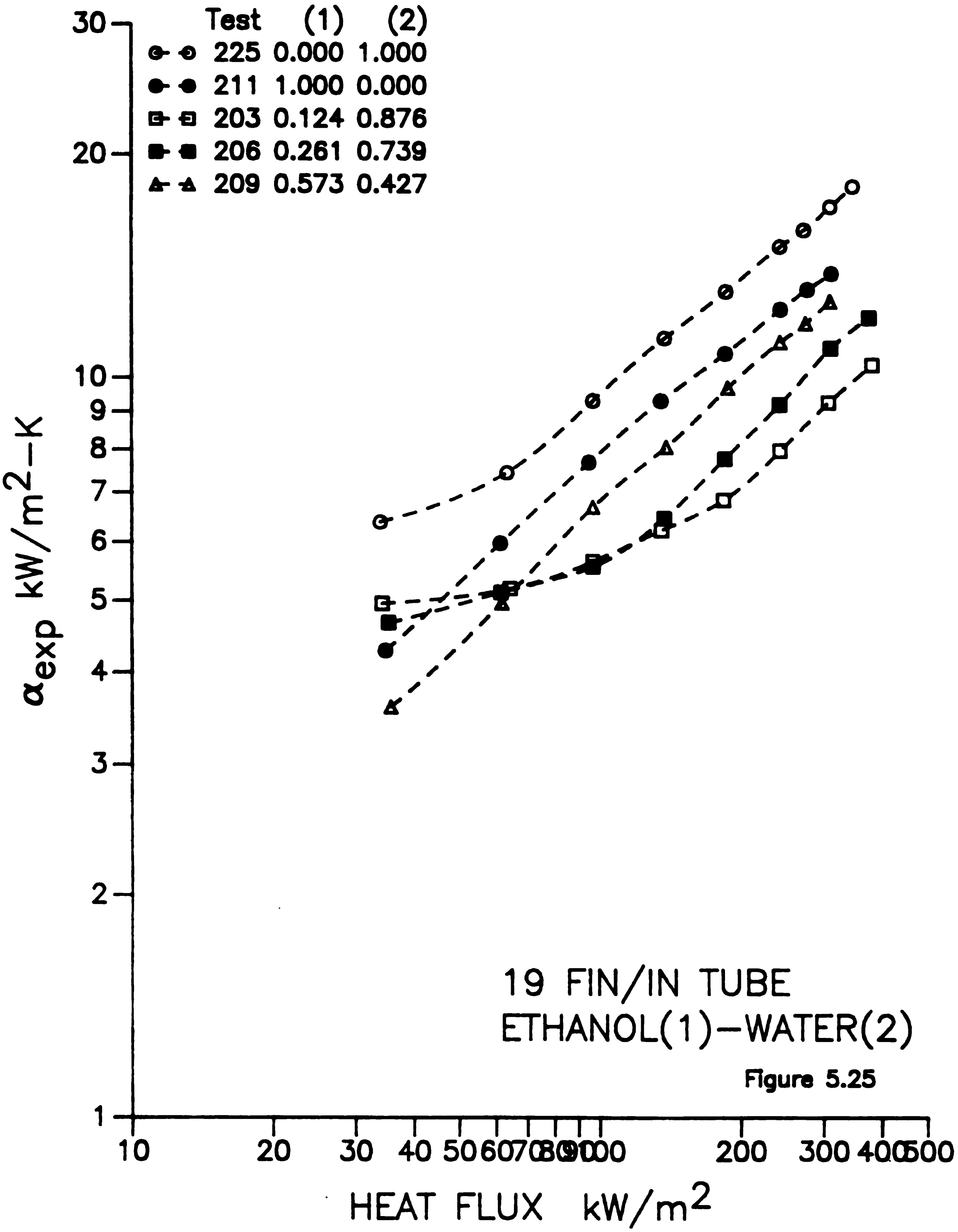


Figure 5.25 Boiling curves for a finned tube in ethanol-water binary mixtures.

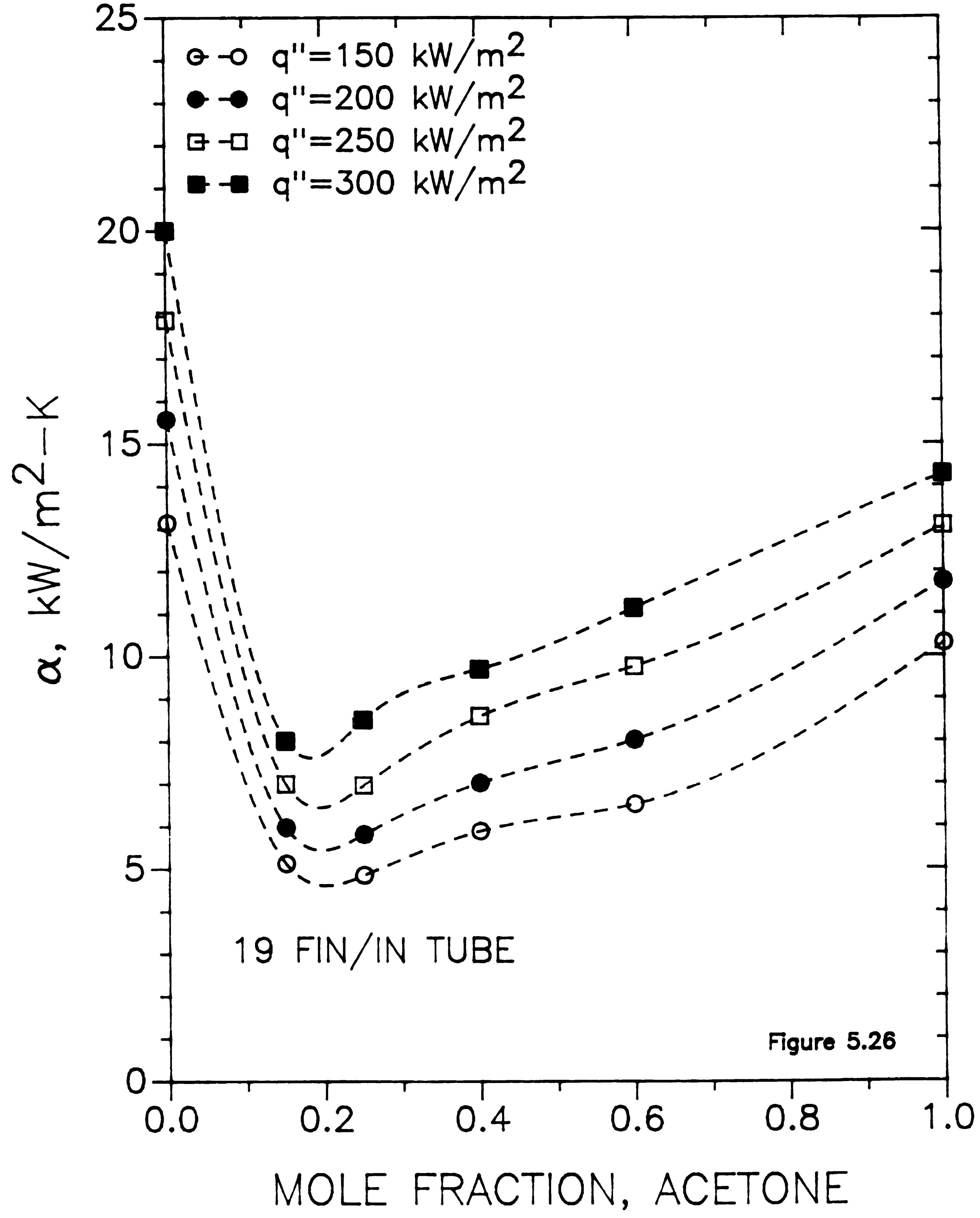


Figure 5.26 Pool boiling heat transfer coefficients for a finned tube in acetone-water binary mixtures.

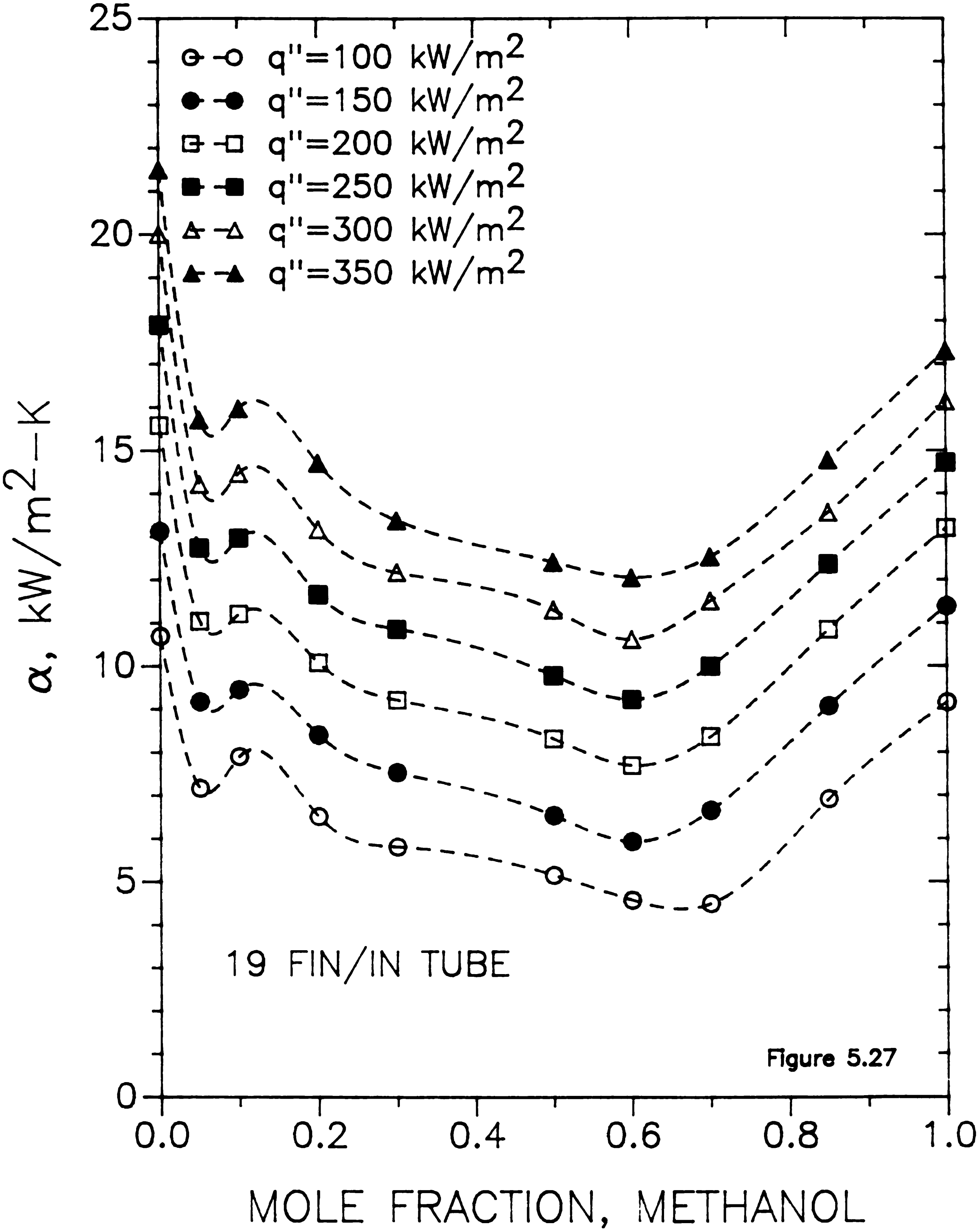


Figure 5.27 Pool boiling heat transfer coefficients for a finned tube in methanol-water binary mixtures.

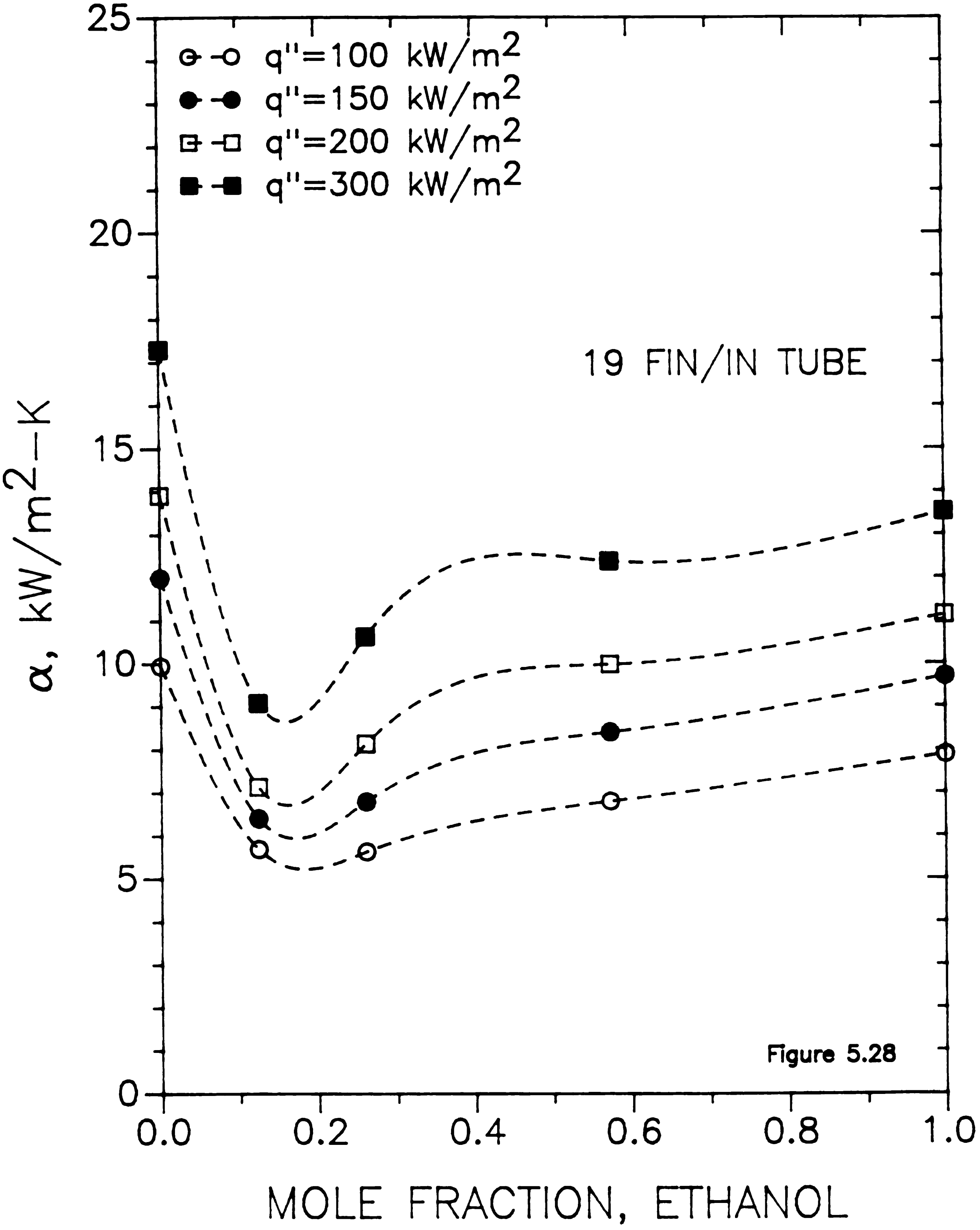


Figure 5.28 Pool boiling heat transfer coefficients for a finned tube in ethanol-water binary mixtures.

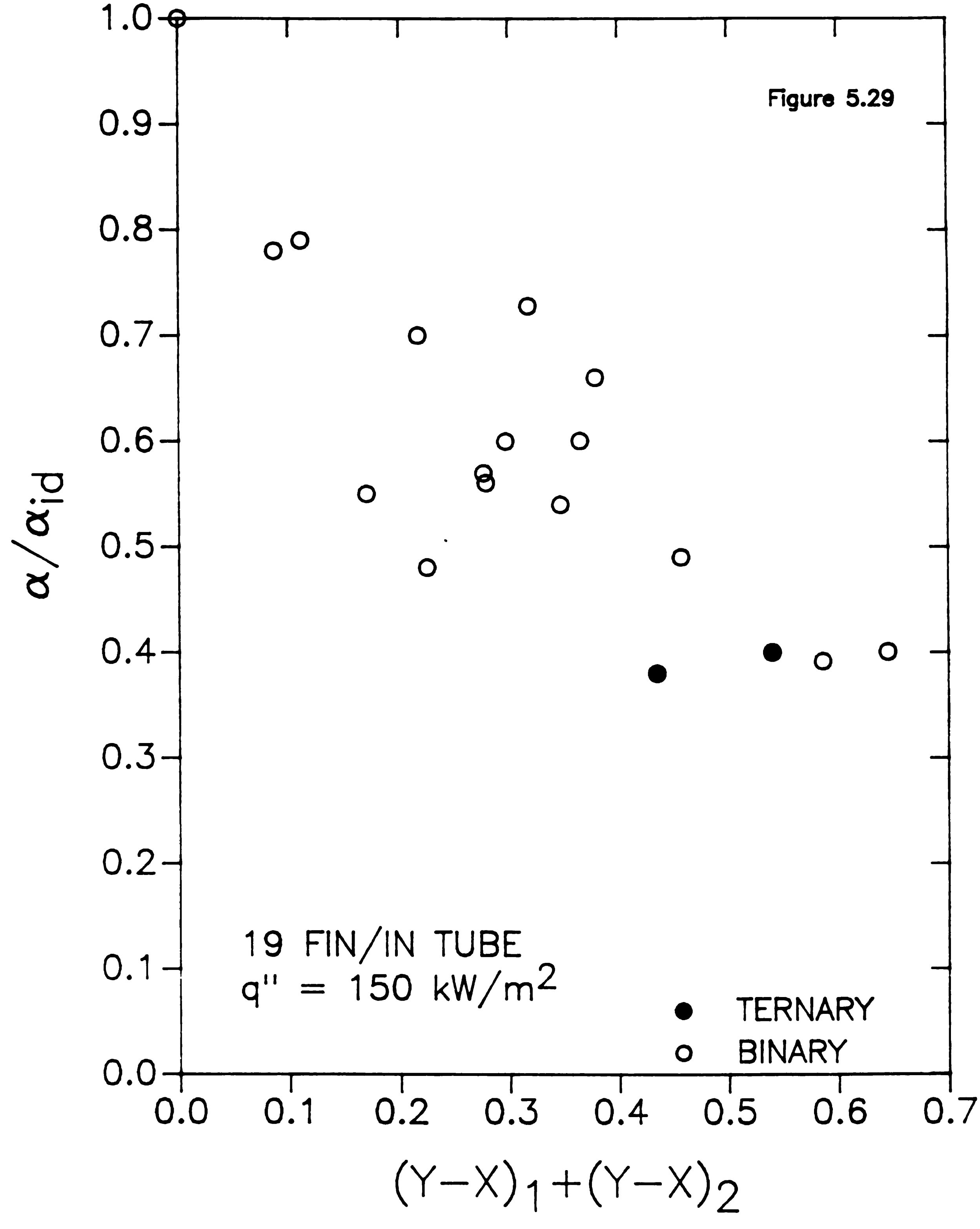


Figure 5.29 Degradation of nucleate pool boiling heat transfer coefficients in binary and ternary mixtures for a finned tube as a function of |y-x| of the light components.

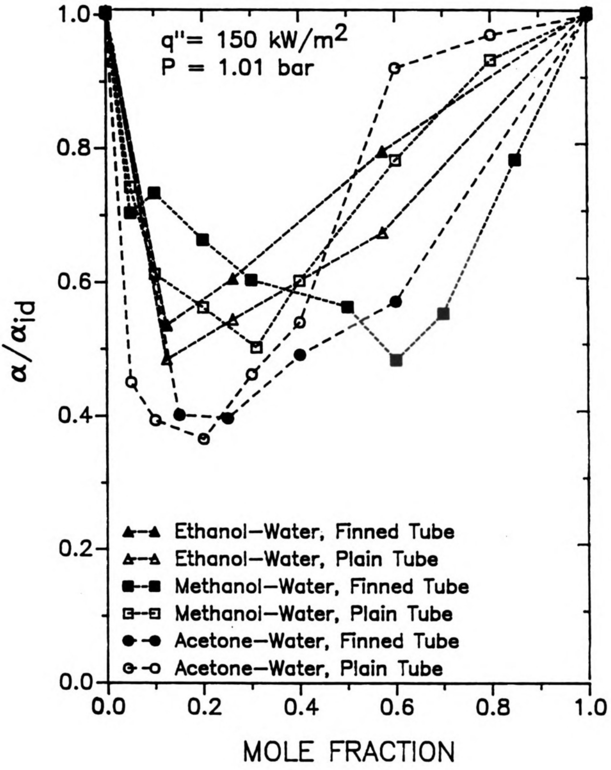


Figure 5.30 Comparison of the mixture boiling effect on pool boiling heat transfer coefficients for plain and finned tubes.

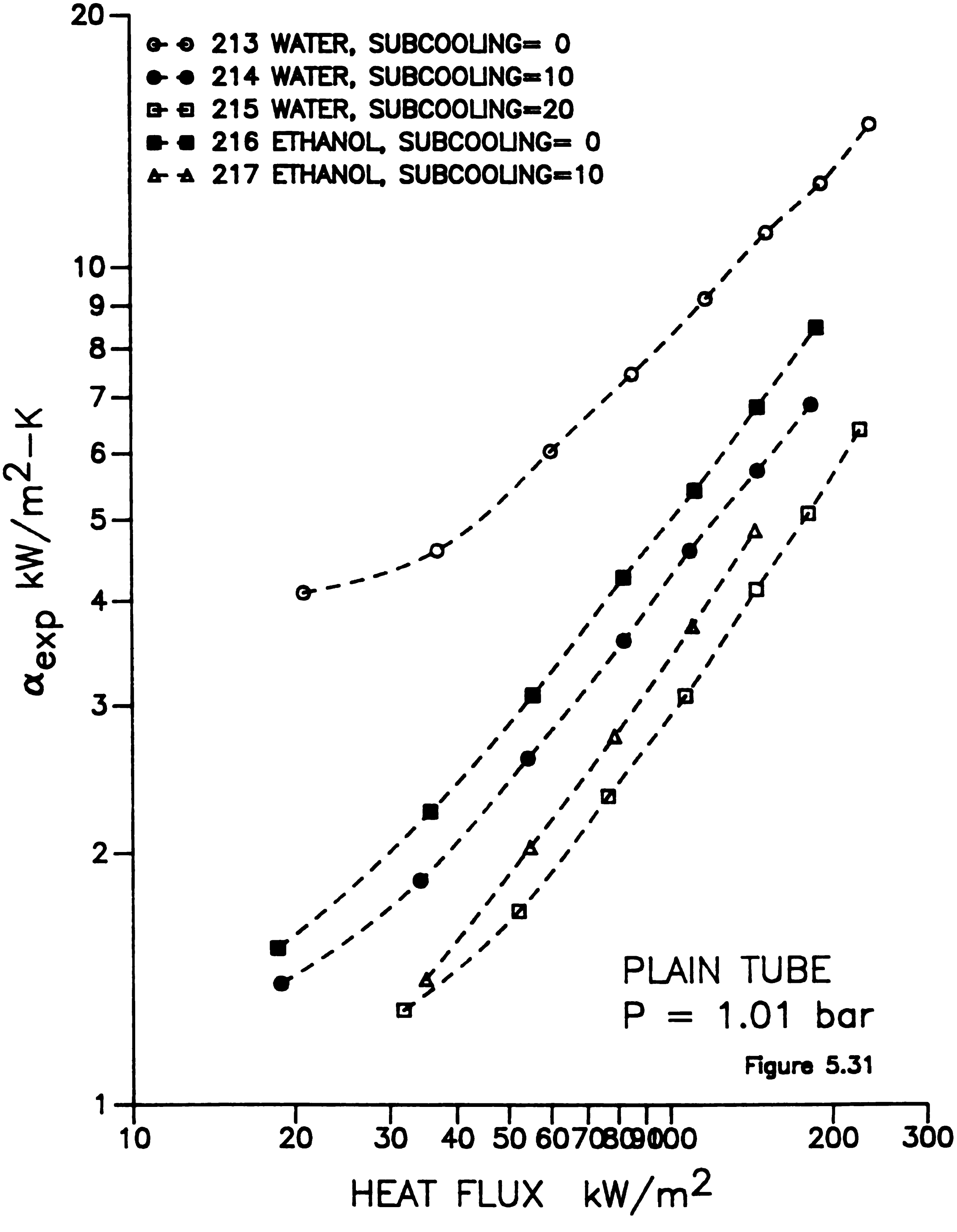


Figure 5.31 Subcooled boiling curves for pure water and pure ethanol from a plain tube.

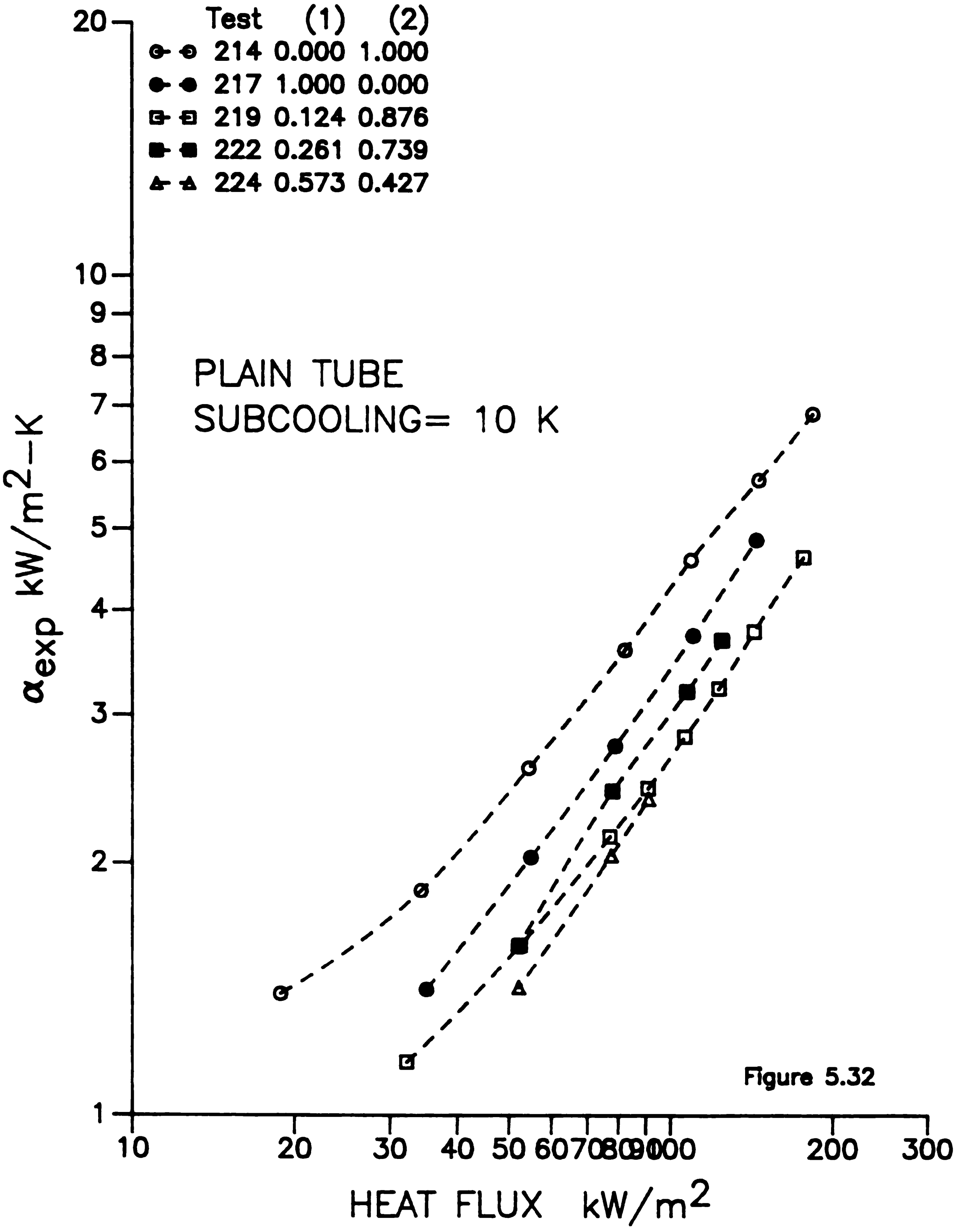


Figure 5.32 Subcooled boiling curves in ethanol-water mixtures on a plain surface at a constant subcooling of 10 K.

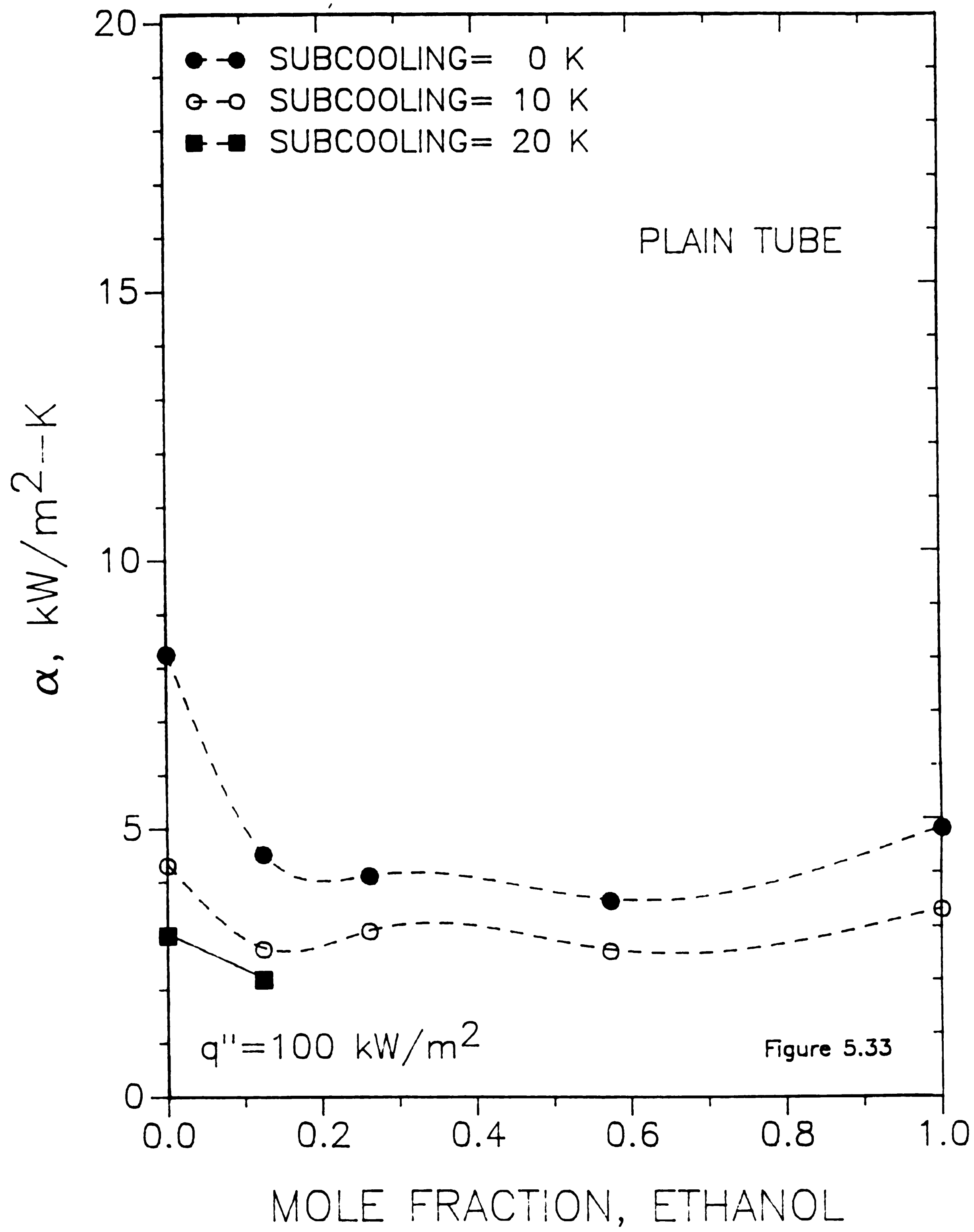


Figure 5.33 **Subcooled boiling heat transfer coefficients in ethanol-water binary mixtures.**

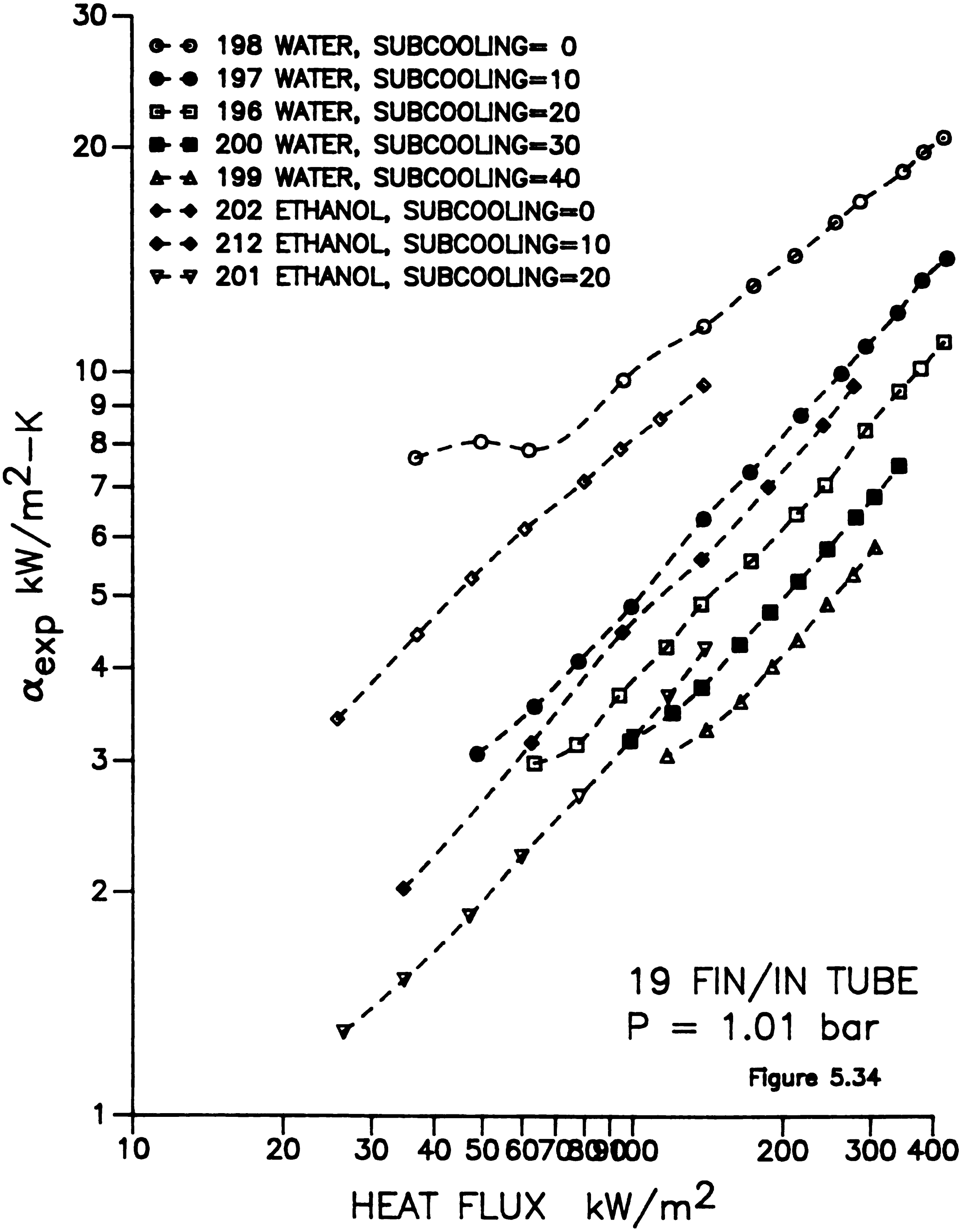


Figure 5.34 Subcooled pool boiling curves for pure water and ethanol for a finned tube.

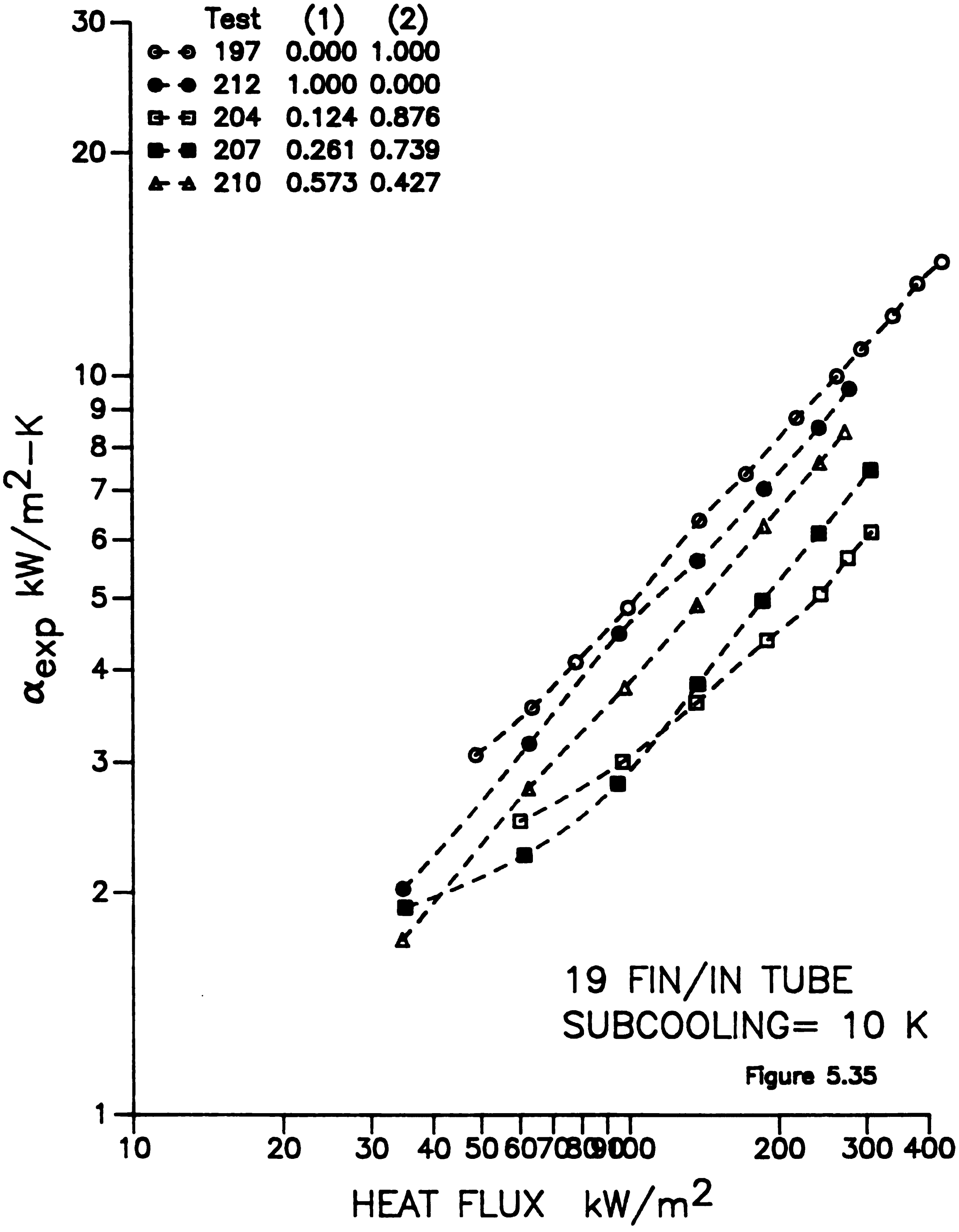


Figure 5.35 Subcooled boiling curves in ethanol-water mixtures from a finned tube at a constant subcooling of 10 K.

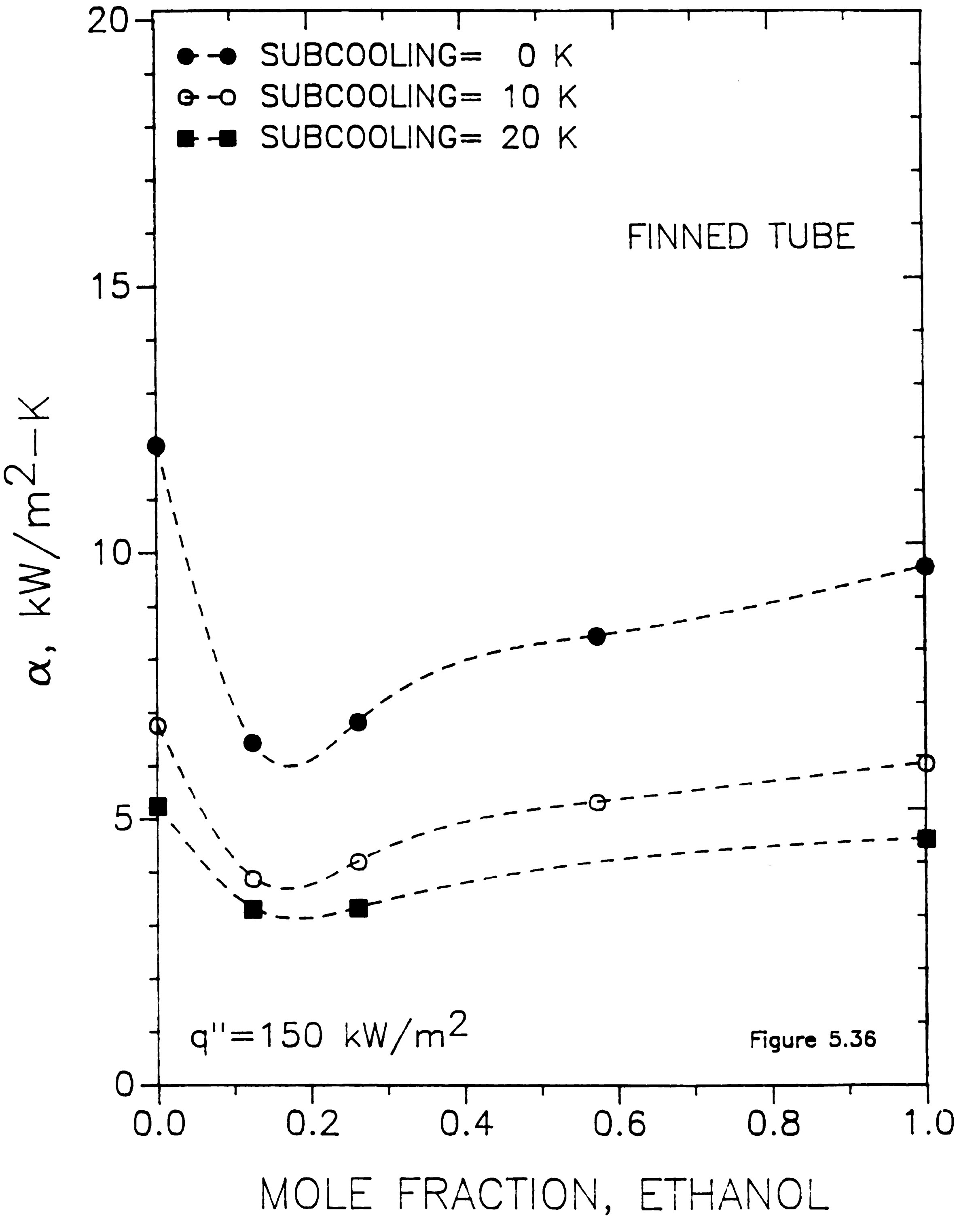


Figure 5.36 **Subcooled pool boiling heat transfer coefficients in ethanol-water mixtures for a finned tube.**

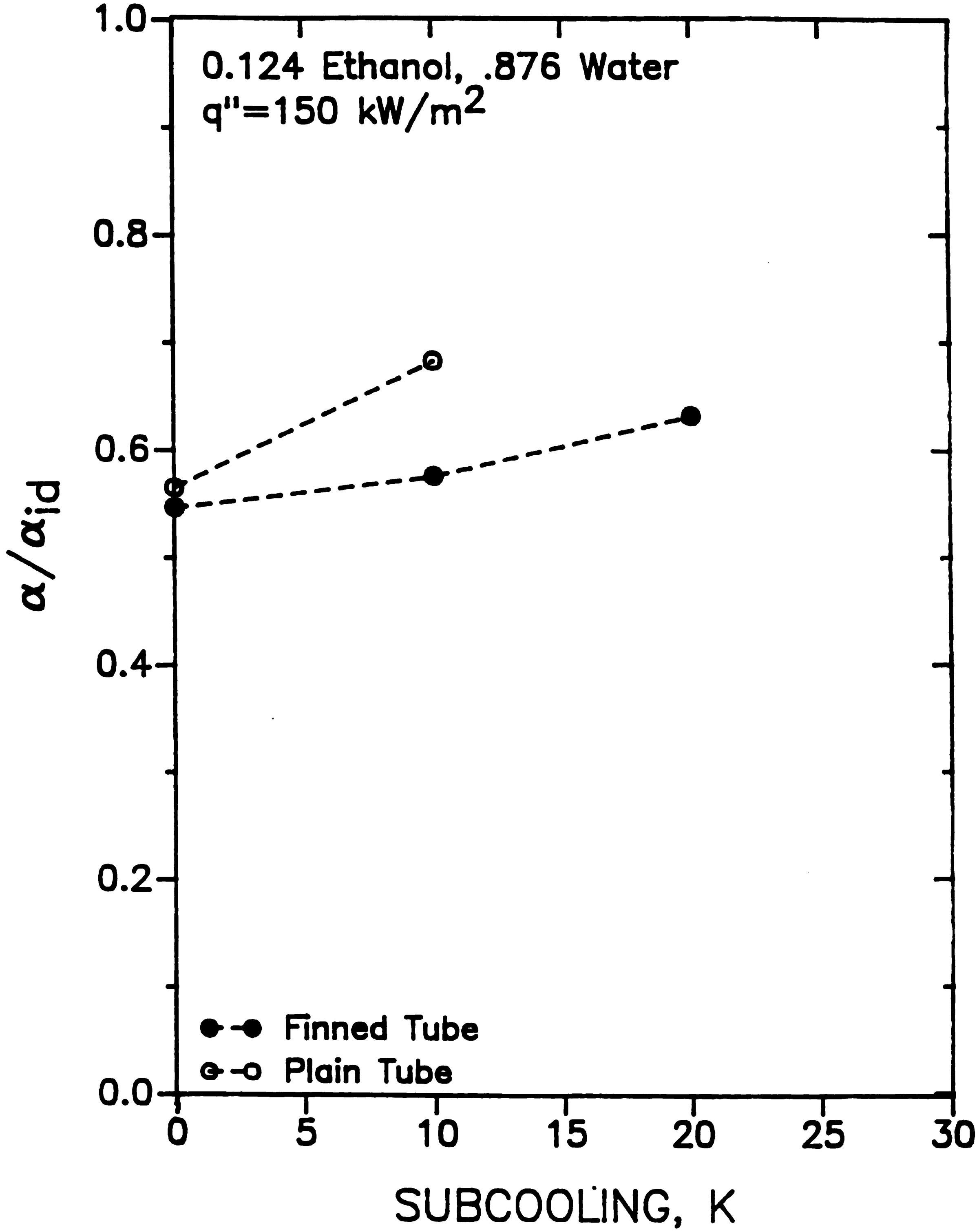


Figure 5.37 Degradation of 0.124 mole fraction ethanol heat transfer coefficients as a function of bulk liquid subcooling.

CHAPTER 6

PREDICTION OF POOL BOILING HEAT TRANSFER COEFFICIENTS IN MULTICOMPONENT MIXTURES

The objective of this section is to evaluate the existing correlations for pool boiling in multicomponent mixtures by comparing their predictions to the experimental data described in the previous chapter. Several predictive methods have been proposed for estimating boiling heat transfer coefficients in binary and multicomponent mixtures, but due to a lack of data for mixtures with three or more components, they have been tested only against binary mixture data. The correlations examined in this section are those that have been proposed as being applicable to multicomponent liquid mixtures. These correlations are those by Palen and Small (1964), two by Stephan and Preusser (1979), Schlunder (1986), and Thome and Shakir (1987). This section reviews each correlation, and compares their predictions to the experimental data. Two methods of calculating the ideal heat transfer coefficient are also examined.

6.1 CORRELATIONS EXAMINED

The five correlations considered in this chapter were discussed in Chapter 2, but are re-listed in this section for reference. The Palen-Small (1964) correlation is:

$$\alpha = \alpha_{id}\exp(-0.027\Delta T_{bp}) \tag{6-1}$$

where ΔT_{bp} is the boiling range, which is the difference in bubble point and dew point temperatures at the bulk liquid composition. This correlation was based on operating data from kettle reboilers for mixtures with wide boiling ranges.

Stephan and Preusser (1979) proposed two correlations for boiling in multicomponent mixtures. One of these correlations is an extension of the model proposed by Stephan and Korner (1969) and defines the wall superheat requirement as:

$$\Delta T = q''/\alpha = \Delta T_{id} + \Delta T^{E} \tag{6-2}$$

The ideal wall superheat is determined by a linear mixing law and the excess superheat is given by:

$$\Delta T^{E} = \sum_{i=1}^{i=n-1} K_{in}(y_i - x_i) \tag{6-3}$$

The coefficients K_{in} were determined from experiment and are listed for two ternary mixture systems at 1.01 bar in Table 2-1. The major problem associated with this method is its reliance on experimental data for each particular mixture system examined.

Stephan and Preusser also used a non-linear regression analysis and modified the Stephan and Abdelsalam correlation for use with multicomponent mixtures. Their correlation for multicomponent mixtures is:

$$\begin{aligned} Nu = (\alpha d/k_l) = {} & C\,(q''d/k_l T_s)^{0.674}(\rho_v/\rho_l)^{0.156}(\Delta h_v d^2/\kappa^2)^{0.371} \\ & (\kappa^2/\sigma d)^{0.350}(\mu c_p/k_l)^{-0.162} \\ & \left(1 + \sum (y_i - x_i)(\partial y_i/\partial x_i)_{x_j,p}\right)^{-0.0733} \end{aligned} \tag{6-4}$$

where the bubble departure diameter $d = 0.0146\gamma[2\sigma/g(\rho_l - \rho_v)]^{1/2}$ and $C = 0.100$.

The contact angle γ was assumed to be 35^o for all organic compounds and mixtures.

Schlunder (1986) proposed the following equation for nucleate pool boiling in multicomponent mixtures:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''} \left[\sum_{i=1}^{i=n-1} (T_{sn}-T_{si})(y_i-x_i)[1 - \exp(-B_0 q''/\rho \Delta h_v \beta_{1,im})] \right] \right\}^{-1} \tag{6-5}$$

The linear mixing law was used for the ideal heat transfer coefficient and a constant value of $\beta = 2\text{x}10^{-4}$ m/s was assumed for the mass transfer coefficient.

Thome and Shakir (1987) reconsidered some of the assumptions used in the derivation of the Schlunder equation, and proposed the following equation:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''} \Delta T_{bp} \left[1-\exp\left(\frac{-B_0 q''}{\rho \Delta h_v \beta_1}\right)\right] \right\}^{-1} \tag{6-6}$$

The Stephan-Abdelsalam correlation was recommended for calculation of the ideal heat transfer coefficient.

6.2 PREDICTION OF RESULTS FOR A PLAIN SURFACE

The five multicomponent mixture boiling correlations were used to estimate the nucleate pool boiling heat transfer coefficients for acetone-water and methanol-water binary mixtures and acetone- methanol-water ternary mixtures first. The comparison of the predicted and experimental values of the heat transfer coefficients are shown in Figures 6.1 through 6.15. The linear mixing law was used to calculate the ideal heat transfer coefficient in each of these comparisons. Table 6-1 lists the mean error and standard deviation associated with each correlation. From the Figures and the Table 6-1, it is clear that the general tendency is for the correlations to overpredict the mixture boiling heat transfer coefficient. All except the Palen-Small correlation for acetone-water mixtures overestimate the experimental heat transfer coefficient, especially at low heat flux levels.

To improve performance, consider the general form of most mixture boiling correlations:

$$\alpha = \alpha_{id}\Psi(x_i, y_i, T, P, q'', \mathcal{D}, \ldots) \tag{6-7}$$

where $\Psi(x_i, y_i, T, P, q'', \mathcal{D}, \ldots)$ is a function of thermodynamic variables and accounts for the degradation due to the mass transfer process, and α_{id} is the ideal heat transfer coefficient. Separate calculations are performed for $\Psi(x_i, y_i, T, P, q'', \mathcal{D}, \ldots)$ and α_{id}, and thus both terms represent a potential means of improving the overall estimation of mixture boiling heat transfer coefficients.

Table 6-1
Estimation of Experimental Heat Transfer Coefficients
Using the Linear Mixing Law for α_{id}

Correlation:	Eq.	Mixtures	Points	Ave.Error	Std.Dev.
Palen-Small	6-1	Acetone-Water	63	-5.8	18.5
		Methanol-Water	83	17.9	15.7
		Acetone-Methanol-Water	149	20.5	25.6
		Overall System	295	14.1	24.1
Stephan-Preusser	6-2	Acetone-Water	63	33.0	28.6
		Methanol-Water	83	28.8	20.4
		Acetone-Methanol-Water	149	45.1	25.1
		Overall System	295	37.9	25.7
Stephan-Preusser	6-4	Acetone-Water	63	62.6	44.3
		Methanol-Water	83	37.4	22.1
		Acetone-Methanol-Water	149	50.6	27.9
		Overall System	295	49.4	32.0
Schlunder	6-5	Acetone-Water	63	18.6	25.2
		Methanol-Water	83	24.2	19.8
		Acetone-Methanol-Water	149	24.1	19.9
		Overall System	295	23.0	21.2
Thome-Shakir	6-6	Acetone-Water	63	9.3	30.2
		Methanol-Water	83	24.9	20.3
		Acetone-Methanol-Water	149	26.8	27.8
		Overall System	295	22.5	27.3

6.3 USE OF A PURE COMPONENT CORRELATION FOR α_{id}

The ideal heat transfer coefficient is defined as the heat transfer coefficient required to support the same heat flux in a single component fluid with the appropriate mixture properties. Thus, the ideal heat transfer coefficient is intended to incorporate both the effect of non-linear property variation with mixture composition and the surface effect on the heat transfer coefficient. The linear mixing law retains the surface effect, assuming that the surface effect on heat transfer coefficients in mixtures is the same as it is for pure components, but does not take into account non-linear property variation.

Thome and Shakir (1987) found that the pure fluid correlation by Stephan and Abdelsalam (1980) provided an accurate representation of the nucleate pool boiling heat transfer coefficients in many pure hydrocarbons and at azeotropes. This correlation is given by:

$$Nu = \alpha d/k_l = 0.0546[(\rho_v/\rho_l)^{½}(q_l d/k_l T_s)]^{0.67} \\ [(\rho_l-\rho_v)/\rho_l]^{-4.33}[\Delta h_v d^2/\kappa_l{}^2]^{0.248} \qquad (6\text{-}8)$$

where the bubble departure diameter is $d = 0.0146\gamma[2\sigma/g(\rho_l-\rho_v)]^{½}$.

This correlation was developed using non-linear regression with data including different fluids and surfaces from many sources. Because it does not contain a term to explicitly model a surface effect, it is necessary to verify its applicability to a specific surface. To verify this correlation for the test sections with plain surfaces used in this investigation, Eq. 6-8 was used to predict the pool boiling heat transfer coefficients for several pure components. Figure 6.16 shows the comparison of Eq. 6-8 predictions with the experimental heat transfer coefficients in acetone and methanol for pressures ranging from 0.5 to 5 bar. The mean error was 0.5% and the standard deviation was 11.3%. Figure 6.17 shows the comparison against experimental data from acetone, methanol, ethanol, ethyl acetate, 2-butanone, 2-propanol, and the acetone- methanol azeotrope at 1.01 bar. For these components, the mean error was 6.6% and the standard deviation was 11.6%. These comparisons indicate that the Stephan-Abdelsalam correlation can adequately estimate the pure component pool boiling heat transfer coefficients for the fluids and plain surfaces used in this investigation.

The multicomponent mixture boiling correlations described by Equations 6-1 through 6-7 were again used to predict the heat transfer coefficients in acetone-methanol-water ternary system at 1.01 bar. In this comparison, however, the Stephan-Abdelsalam correlation was used to calculate α_{id}. Properties of the mixture at the liquid composition at saturation were used in the calculation of α_{id}. By using the Stephan-Abdelsalam correlation for α_{id}, the effect of non-linear property variation in the mixtures is taken into account. Table 6-2 lists the results of this comparison, and Figures 6.18 through 6.29 present the comparisons for each correlation. The Palen-Small, Stephan-Preusser (Eq. 6-2), Schlunder and Thome-Shakir correlations all show significant reductions in the standard deviation, indicating a reduction in the scatter in the predictions of the experimental data. The average error also significantly improves for the Stephan-Preusser (Eq. 6-2), Schlunder, and Thome-Shakir correlations. The average error for the Palen-Small correlation increases slightly. Since the Stephan-Abdelsalam correlation is not restricted to the range of heat fluxes spanned by the pure components, there is a small increase in the total number of points used in the two comparisons. There is only a minor change in the results using the Stephan-Preusser non-linear regression equation (Eq. 6-4) since it does not use an ideal heat transfer coefficient. The small change is due soley to an increase in the number of points used in calculating the statistics.

Table 6-2

Estimation of Experimental Heat Transfer Coefficients
Using the Stephan-Abdelsalam Correlation for α_{id}

Correlation:	Eq.	Mixtures	Points	Ave.Error	Std.Dev.
Palen-Small	6-1	Acetone-Water	68	-31.6	9.2
		Methanol-Water	84	-15.3	10.5
		Acetone-Methanol-Water	156	-8.3	18.7
		Overall System	308	-15.4	17.5
Stephan-Preusser	6-2	Acetone-Water	68	1.3	14.5
		Methanol-Water	84	-4.2	15.0
		Acetone-Methanol-Water	156	16.6	14.5
		Overall System	308	7.5	17.4
Stephan-Preusser	6-4	Acetone-Water	68	64.1	43.1
		Methanol-Water	84	37.5	22.0
		Acetone-Methanol-Water	156	51.5	27.6
		Overall System	308	50.5	31.8
Schlunder	6-5	Acetone-Water	68	-3.7	15.9
		Methanol-Water	84	-5.5	15.0
		Acetone-Methanol-Water	156	2.8	14.6
		Overall System	308	-0.9	15.4
Thome-Shakir	6-6	Acetone-Water	68	-10.7	18.9
		Methanol-Water	84	-5.3	14.5
		Acetone-Methanol-Water	156	4.2	19.2
		Overall System	308	-1.7	19.0

The acetone-methanol-water system clearly indicates that use of the Stephan-Abdelsalam correlation improves the prediction of those multicomponent mixture boiling correlations that use an ideal heat transfer coefficient. To test this effect further, the correlations were next used to predict the pool boiling heat transfer coefficients in several additional multicomponent mixture systems. Table 6-3 lists the comparison of the predictions of these correlations with experimental values for these additional systems using the linear mixing law, and Table 6-4 shows the same comparison using the Stephan-Abdelsalam correlation. Figures 6.30 through 6.50 show the prediction of each mixture in these additional systems with α_{id} calculated with the Stephan-Abdelsalam correlation. Similar to the acetone-methanol-water system, the standard deviation of all of the other mixture systems examined was reduced using the Stephan- Abdelsalam correlation rather than the linear mixing law for α_{id}. The mixture boiling heat transfer coefficients were also smaller when the Stephan-Abdelsalam correlation was used, and for the mixture systems tested reduced or eliminated the overestimation of the experimental heat transfer coefficients. The results again show that no correlation performs equally well for all mixture systams. The Palen-Small correlation performs remarkably well considering its simple form. For individual mixtures, however, the Palen Small correlation can be off by as much as 60%. The Stephan-Preusser correlation, Eq. 6-2, overestimates the ethanol-water and methanol-ethanol-water mixtures by approximately 20% with a 12.8% standard deviation, but is not applicable to most of the other systems tested. The non-linear regeression equation by Stephan and Preusser, Eq. 6-4, performs poorly. The Schlunder and Thome-Shakir correlations overestimate the mixture boiling heat transfer coefficients in most systems, and have standard deviations for all systems below 20%. The estimates of pool boiling heat transfer coefficients using the Schlunder and Thome-Shakir correlations are noted to exhibit a tendency to decrease with increasing heat flux. In many mixtures, such as those in Figures 6.25-6.29, the Schlunder and Thome-Shakir correlations overpredict the heat transfer coefficients at low heat flux, but underpredict them at high heat flux.

Table 6-3

Estimation of Experimental Heat Transfer Coefficients
Using the Linear Mixing Law for α_{id}

Correlation:	Eq.	Mixtures	Points	Ave.Error	Std.Dev.
Palen-Small	6-1	Ethanol-Water	14	*	*
		Methanol-Ethanol-Water	36	25.3	15.1
		Ethanol-Ethyl Acetate-Water	33	29.8	22.6
		Acetone-2-Propanol-Water	27	18.4	15.6
		2-Propanol-Water	10	*	*
		Methanol-2-Propanol-Water	36	32.3	10.7
		Acetone-2-Butanone-Water	43	-0.2	38.3
Stephan-Preusser	6-2	Ethanol-Water	14	*	*
		Methanol-Ethanol-Water	36	44.2	26.0
		Ethanol-Ethyl Acetate-Water	33	N/A	N/A
		Acetone-2-Propanol-Water	27	N/A	N/A
		2-Propanol-Water	10	N/A	N/A
		Methanol-2-Propanol-Water	36	N/A	N/A
		Acetone-2-Butanone-Water	43	N/A	N/A
Stephan-Preusser	6-4	Ethanol-Water	14	*	*
		Methanol-Ethanol-Water	36	46.0	27.9
		Ethanol-Ethyl Acetate-Water	33	42.6	38.6
		Acetone-2-Propanol-Water	27	64.7	43.9
		2-Propanol-Water	10	64.8	29.4
		Methanol-2-Propanol-Water	36	45.6	27.7
		Acetone-2-Butanone-Water	43	22.3	26.6
Schlunder	6-5	Ethanol-Water	14	*	*
		Methanol-Ethanol-Water	36	34.4	21.0
		Ethanol-Ethyl Acetate-Water	33	49.3	37.7
		Acetone-2-Propanol-Water	27	46.1	23.9
		2-Propanol-Water	10	*	*
		Methanol-2-Propanol-Water	36	41.4	17.1
		Acetone-2-Butanone-Water	43	6.9	19.0
Thome-Shakir	6-6	Ethanol-Water	14	*	*
		Methanol-Ethanol-Water	36	33.8	20.4
		Ethanol-Ethyl Acetate-Water	33	36.2	29.9
		Acetone-2-Propanol-Water	27	18.4	15.6
		2-Propanol-Water	10	*	*
		Methanol-2-Propanol-Water	36	36.9	16.5
		Acetone-2-Butanone-Water	43	8.7	35.0

* --- Insufficient data to perform calculation.

Table 6-4

Estimation of Experimental Heat Transfer Coefficients
Using the Stephan-Abdelsalam Correlation for α_{id}

Correlation:	Eq.	Mixtures	Points	Ave.Error	Std.Dev.
Palen-Small	6-1	Ethanol-Water	15	12.1	10.7
		Methanol-Ethanol-Water	45	3.1	8.8
		Ethanol-Ethyl Acetate-Water	39	12.1	8.7
		Acetone-2-Propanol-Water	32	-5.9	11.0
		2-Propanol-Water	15	-9.5	10.6
		Methanol-2-Propanol-Water	38	10.0	11.9
		Acetone-2-Butanone-Water	48	-33.3	22.9
Stephan-Preusser	6-2	Ethanol-Water	15	20.1	6.4
		Methanol-Ethanol-Water	45	22.3	12.8
		Ethanol-Ethyl Acetate-Water	39	N/A	N/A
		Acetone-2-Propanol-Water	32	N/A	N/A
		2-Propanol-Water	15	N/A	N/A
		Methanol-2-Propanol-Water	38	N/A	N/A
		Acetone-2-Butanone-Water	48	N/A	N/A
Stephan-Preusser	6-4	Ethanol-Water	15	48.3	35.0
		Methanol-Ethanol-Water	45	47.6	27.5
		Ethanol-Ethyl Acetate-Water	39	41.3	39.1
		Acetone-2-Propanol-Water	32	64.7	43.9
		2-Propanol-Water	15	53.9	32.2
		Methanol-2-Propanol-Water	38	45.3	27.6
		Acetone-2-Butanone-Water	48	25.1	27.1
Schlunder	6-5	Ethanol-Water	15	28.1	9.9
		Methanol-Ethanol-Water	45	13.4	11.4
		Ethanol-Ethyl Acetate-Water	39	29.8	17.1
		Acetone-2-Propanol-Water	32	21.1	18.5
		2-Propanol-Water	15	21.3	16.4
		Methanol-2-Propanol-Water	38	20.8	14.1
		Acetone-2-Butanone-Water	48	-18.0	12.3
Thome-Shakir	6-6	Ethanol-Water	15	22.3	8.3
		Methanol-Ethanol-Water	45	13.0	10.6
		Ethanol-Ethyl Acetate-Water	39	20.6	14.1
		Acetone-2-Propanol-Water	32	12.1	19.8
		2-Propanol-Water	15	7.4	17.1
		Methanol-2-Propanol-Water	38	18.9	14.5
		Acetone-2-Butanone-Water	48	-19.4	19.2

The Palen-Small, Schlunder, and Thome-Shakir correlations were also used to estimate the pool boiling heat transfer coefficients in the four quadrary mixtures tested. Table 6-5 lists these results, and predictions of individual tests are shown in Figures 6.51, 6.52 and 6.53. Since boiling curves were not obtained for all of the pure components of the quadrary mixtures, the Stephan-Abdelsalam correlation had to be used to calculate the ideal heat transfer coefficient. The Palen-Small correlation estimated all of the quadrary data points to within 30%, as did the Thome-Shakir correlation. The Schlunder equation estimated the heat transfer coefficients in three of the four mixtures to within 20%, but overestimated those of the remaining mixture by over 30%

Table 6-5

Estimation of Quadrary Mixture Pool Boiling Heat Transfer Coefficients

Correlation	Eq.	Points	Ave.Error	Std.Dev.
Palen-Small	6-1	41	9.6	8.0
Schlunder	6-5	41	15.0	13.4
Thome-Shakir	6-6	41	7.8	7.8

6.4 SUMMARY

The existing pool boiling correlations applicable to multicomponent mixtures were compared to experimental results from several aqueous ternary mixture systems. The Palen-Small, Schlunder, and Thome-Shakir correlations were found to generally provide predictions of the experimental heat transfer coefficients to within ±20% provided that the Stephan-Abdelsalam correlation for pure hydrocarbons using properties of the mixture was used to calculate the ideal heat transfer coefficient. Using the Stephan- Abdelsalam correlation instead of the linear mixing law to calculate α_{id} was found to significantly reduce the deviation about the average error for all of the correlations that used an ideal heat transfer coefficient. This indicates the importance of including the effect of mixture property variation in the estimation of mixture boiling heat transfer coefficients. The Palen-Small, Schlunder, and Thome-Shakir correlations were also used to predict the pool boiling heat transfer coefficients in four quadrary hydrocarbon mixtures and were found to estimate nearly all the data points to within 30% of the experimental values.

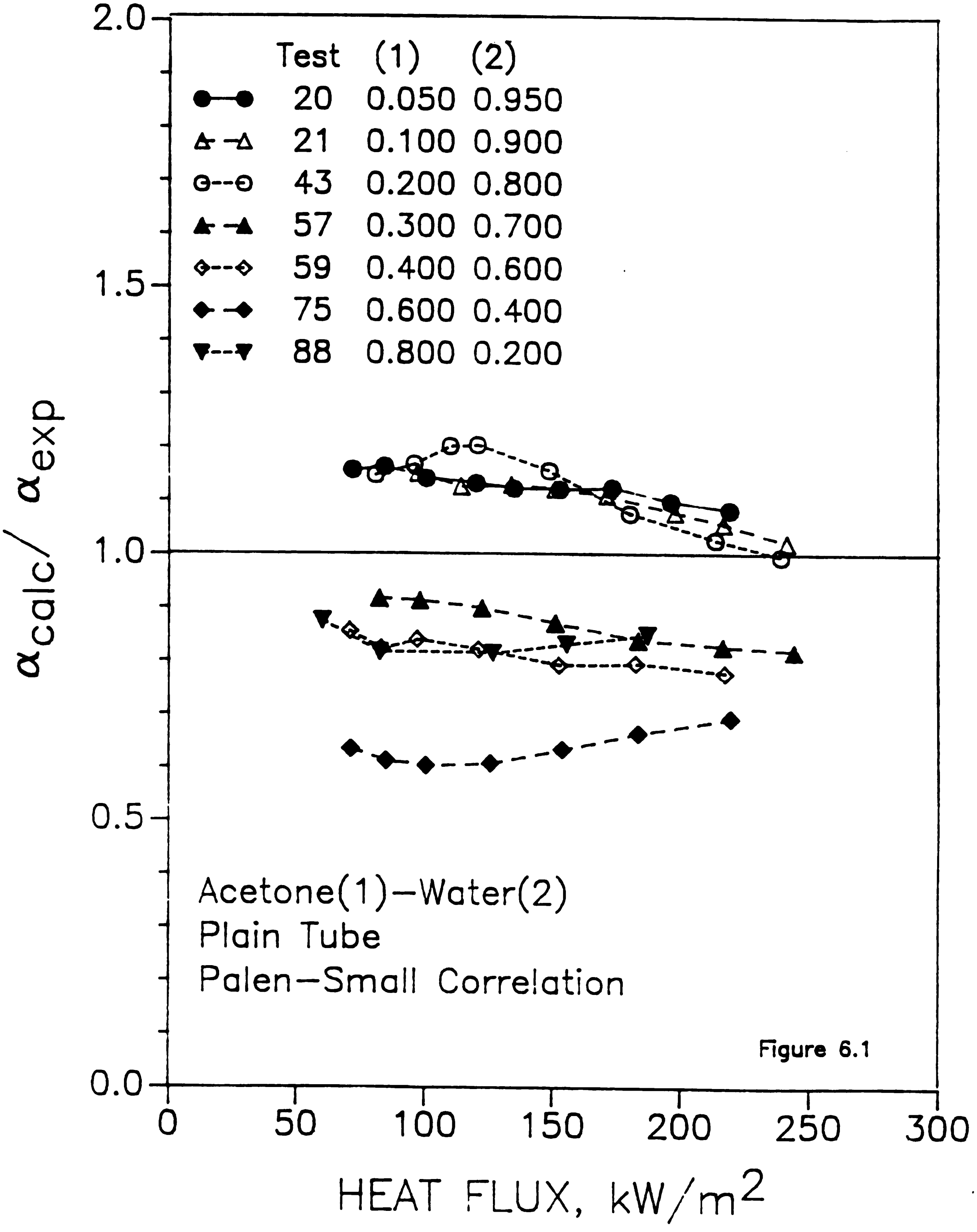


Figure 6.1 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in acetone-water binary mixtures. The linear mixing law was used to calculate α_{id}.

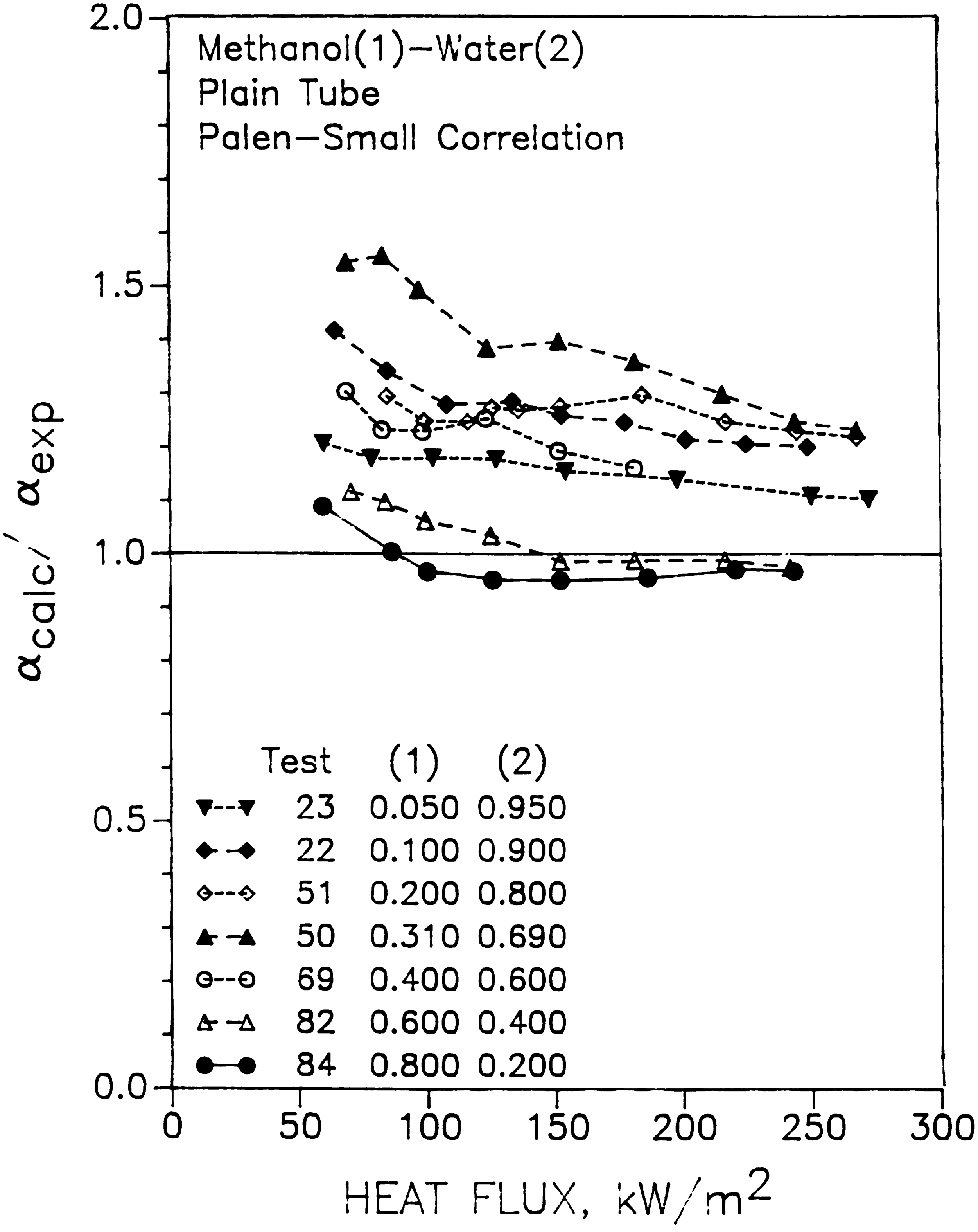


Figure 6.2 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in methanol-water binary mixtures. The linear mixing law was used to calculate α_{id}.

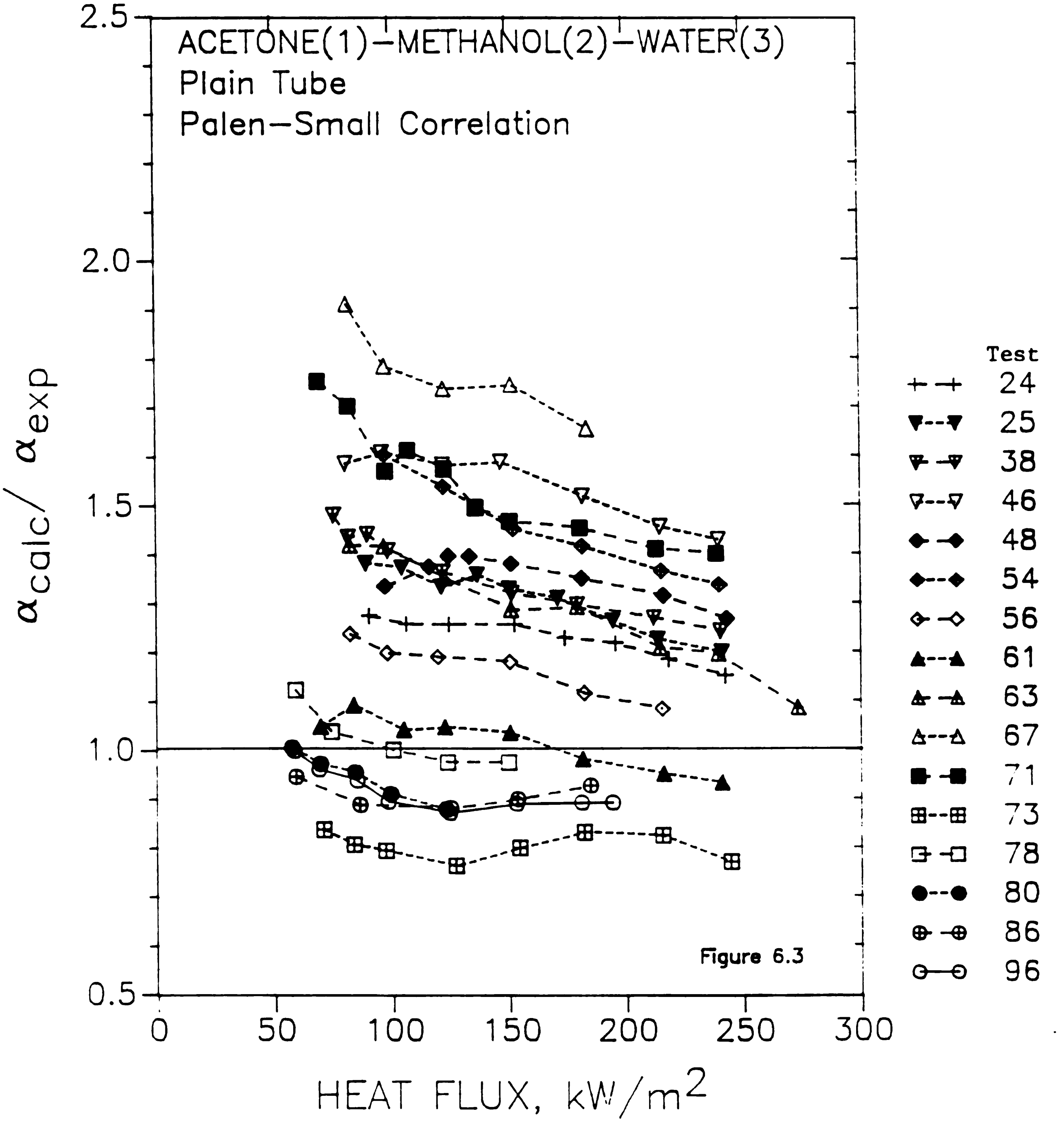


Figure 6.3 Comparison of the Palen-Small correlation, Eq. 6-1 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The linear mixing law was used to calculate α_{id}.

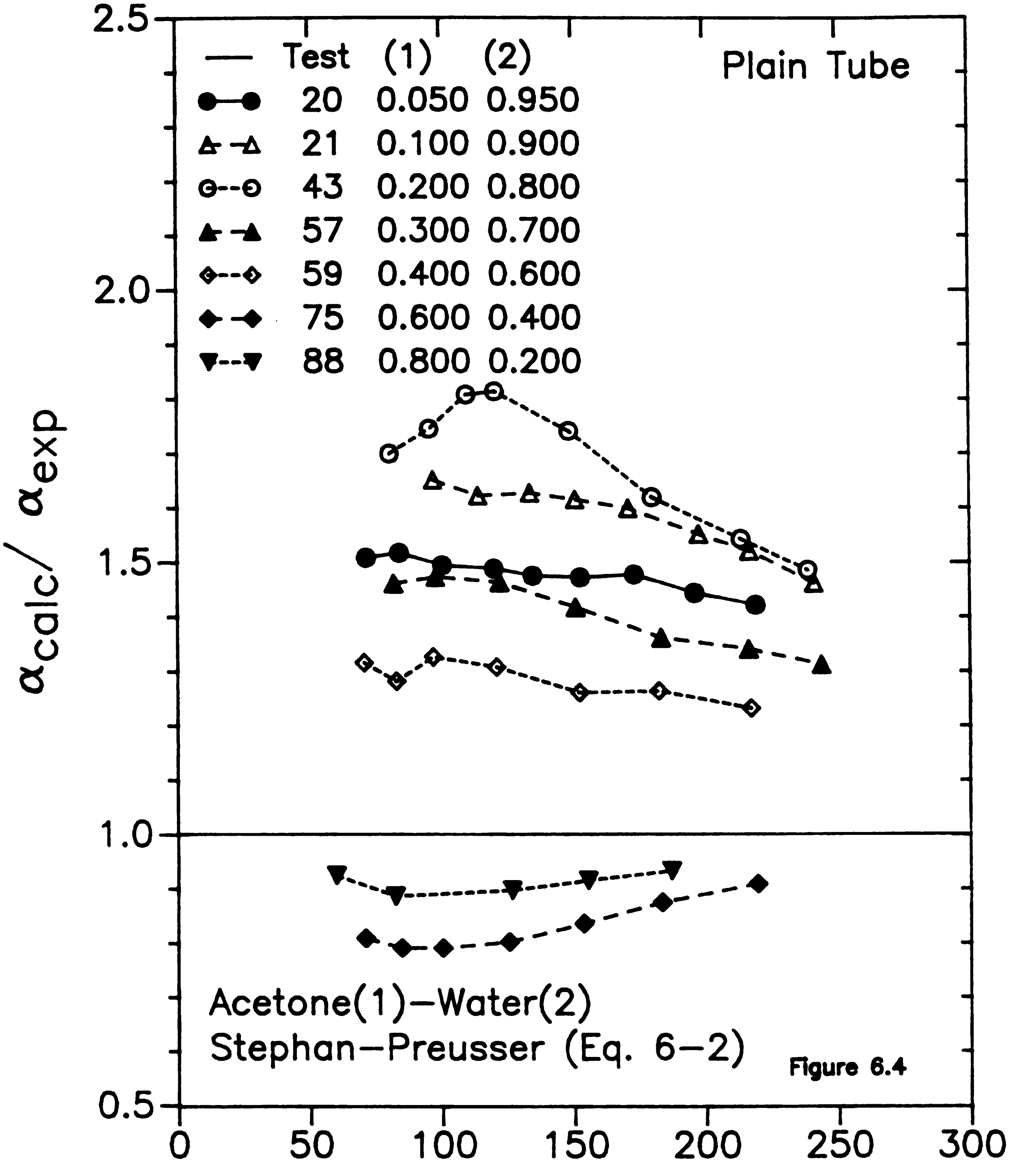


Figure 6.4 Comparison of the Stephan-Preusser correlation, Eq. 6-2, to experimental heat transfer coefficients in acetone-water binary mixtures. The linear mixing law was used to calculate α_{id}.

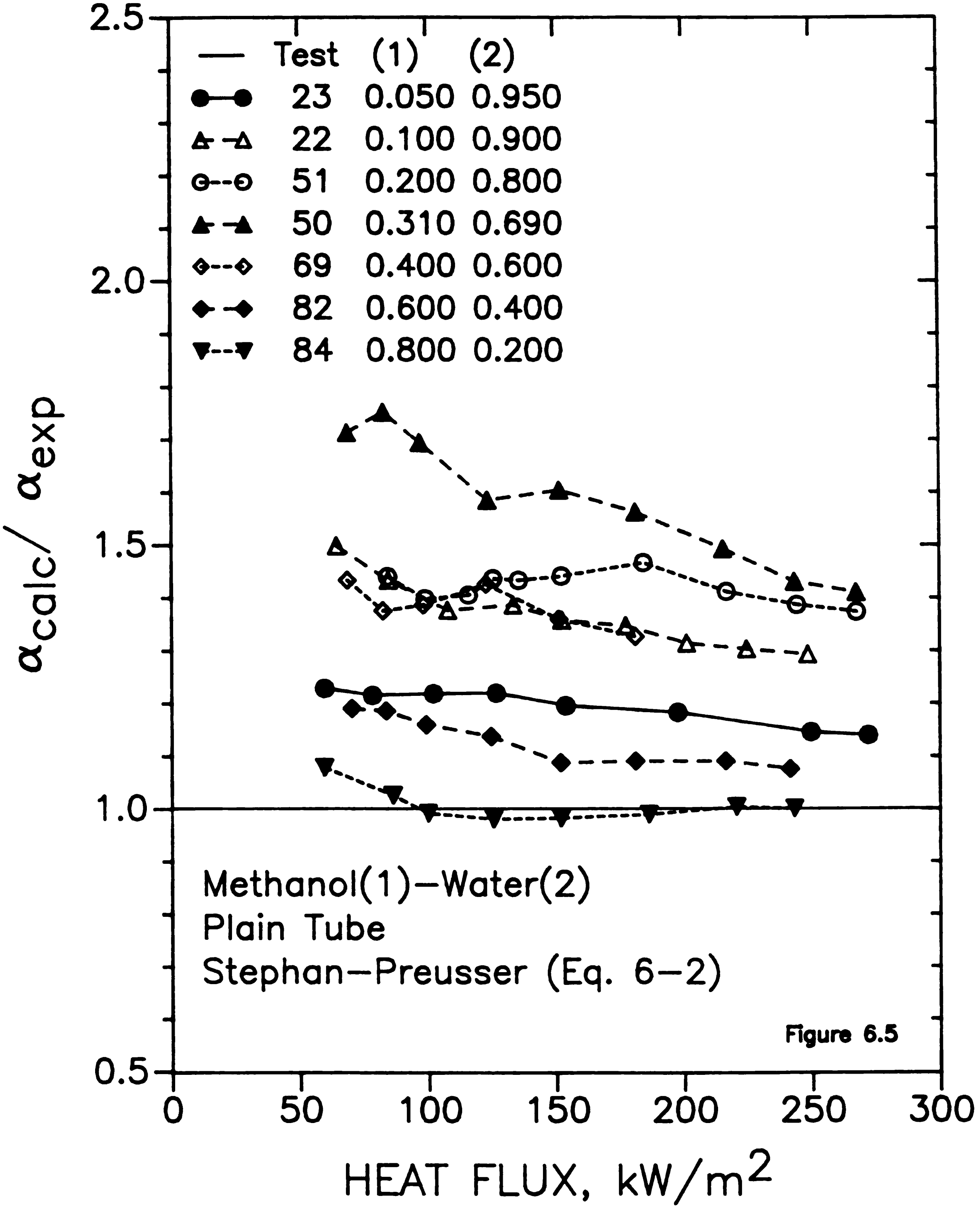


Figure 6.5 Comparison of the Stephan-Preusser correlation, Eq. 6-2 to experimental heat transfer coefficients in methanol-water binary mixtures. The linear mixing law was used to calculate α_{id}.

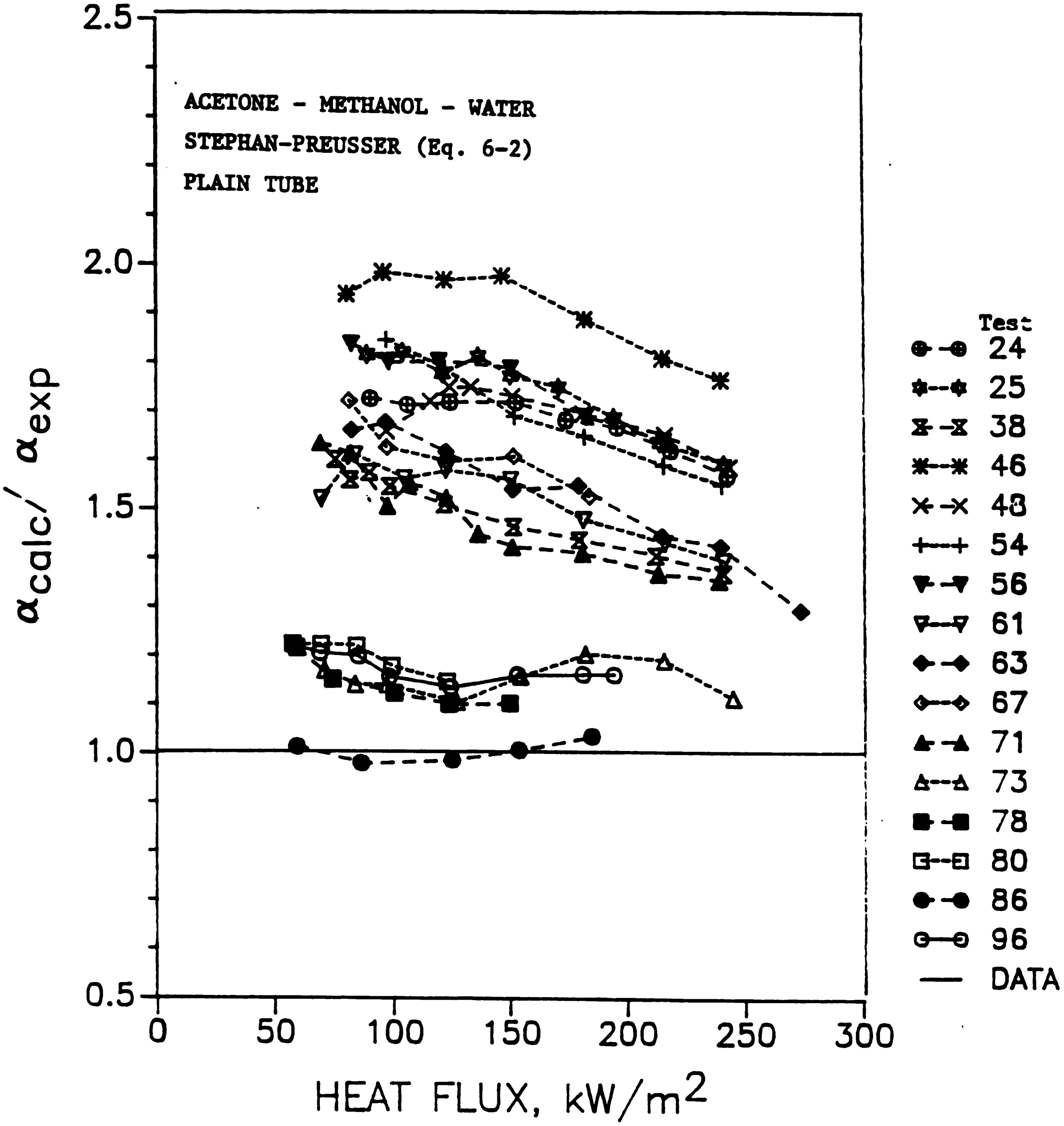


Figure 6.6 Comparison of the Stephan-Pruesser correlation, Eq. 6-2 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The linear mixing law was used to calculate α_{id}.

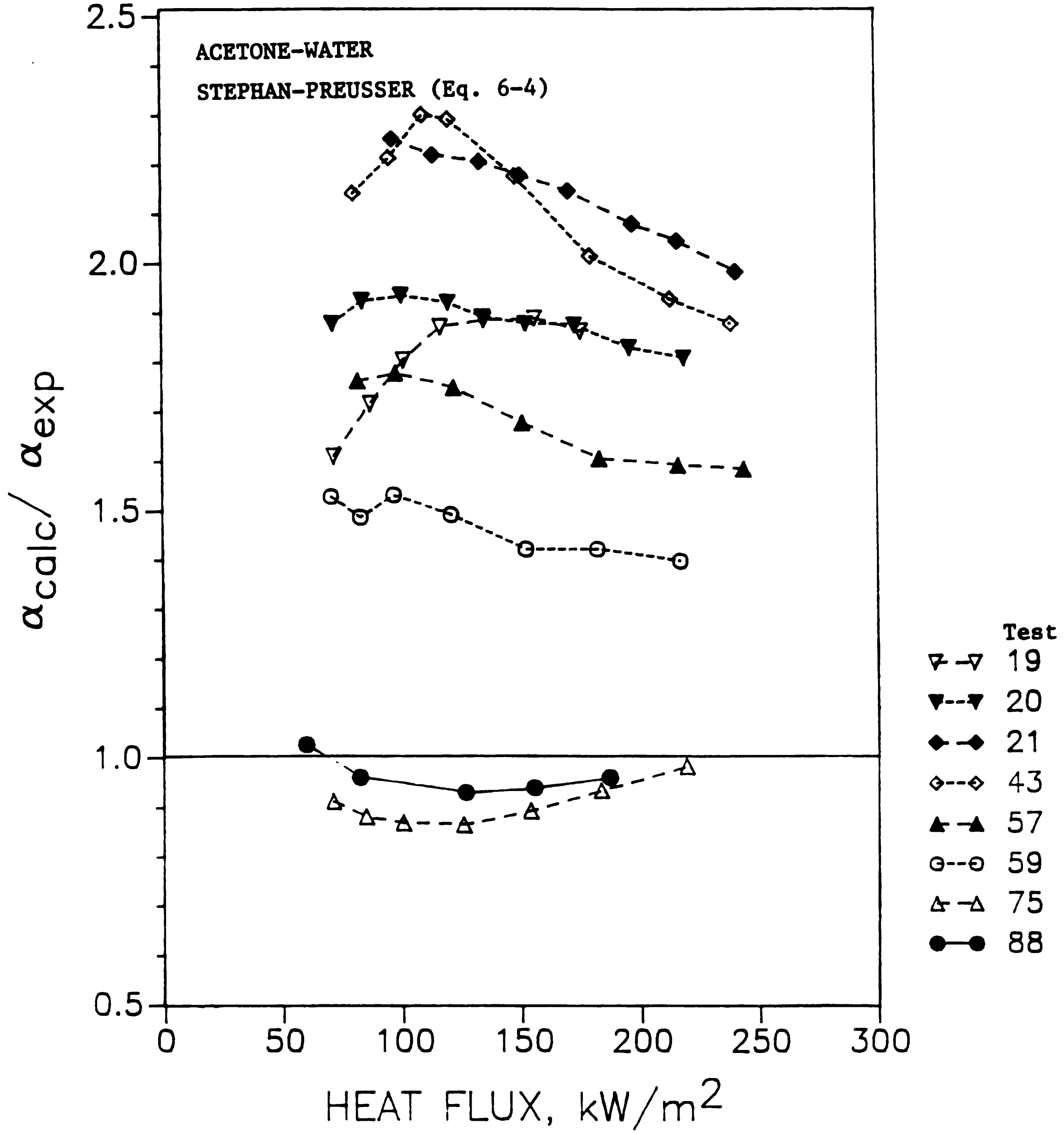


Figure 6.7 Comparison of the Stephan-Preusser correlation, Eq. 6-4, to experimental heat transfer coefficients in acetone-water binary mixtures.

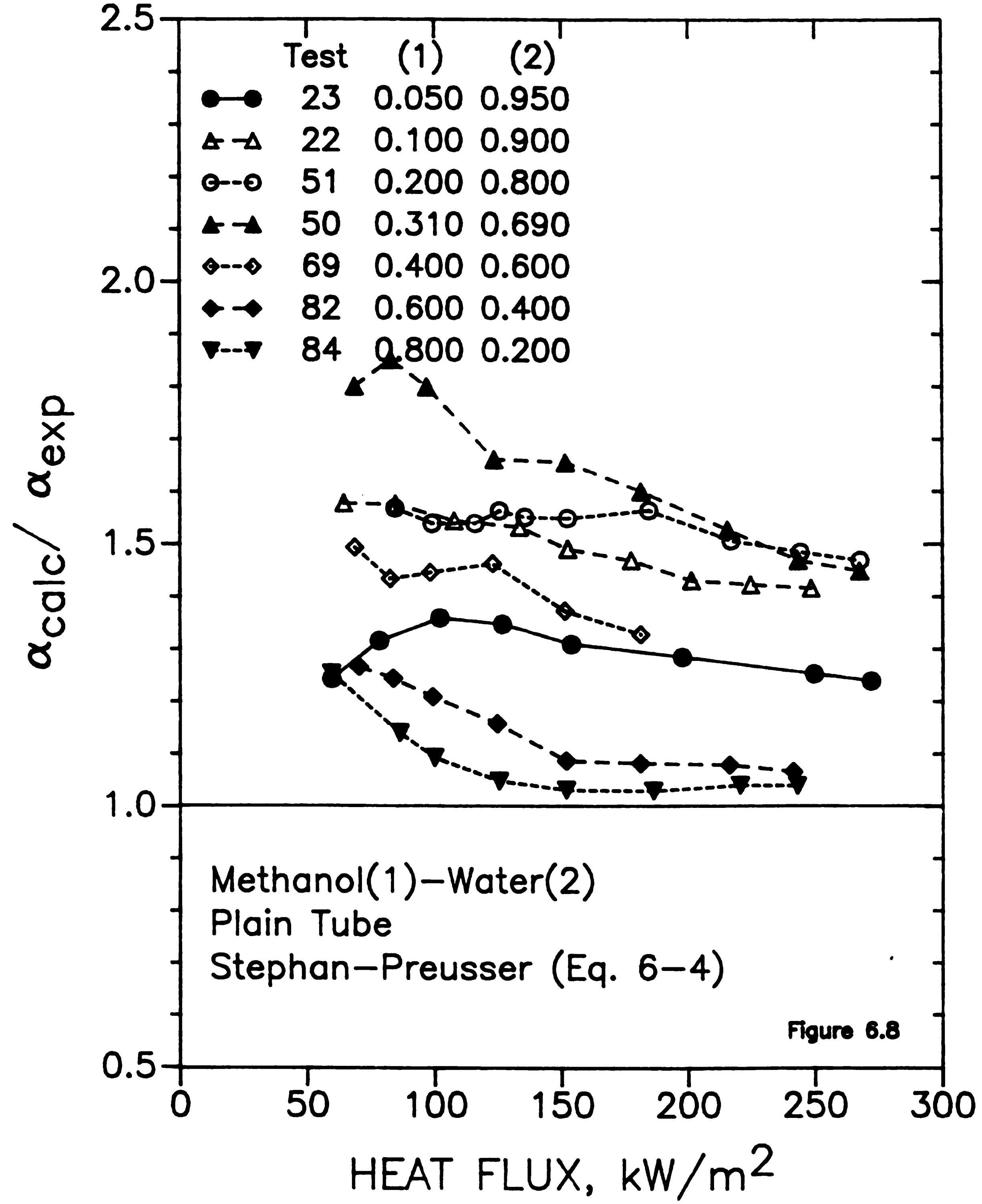


Figure 6.8 Comparison of the Stephan-Preusser correlation, Eq. 6-4 to experimental heat transfer coefficients in methanol-water binary mixtures.

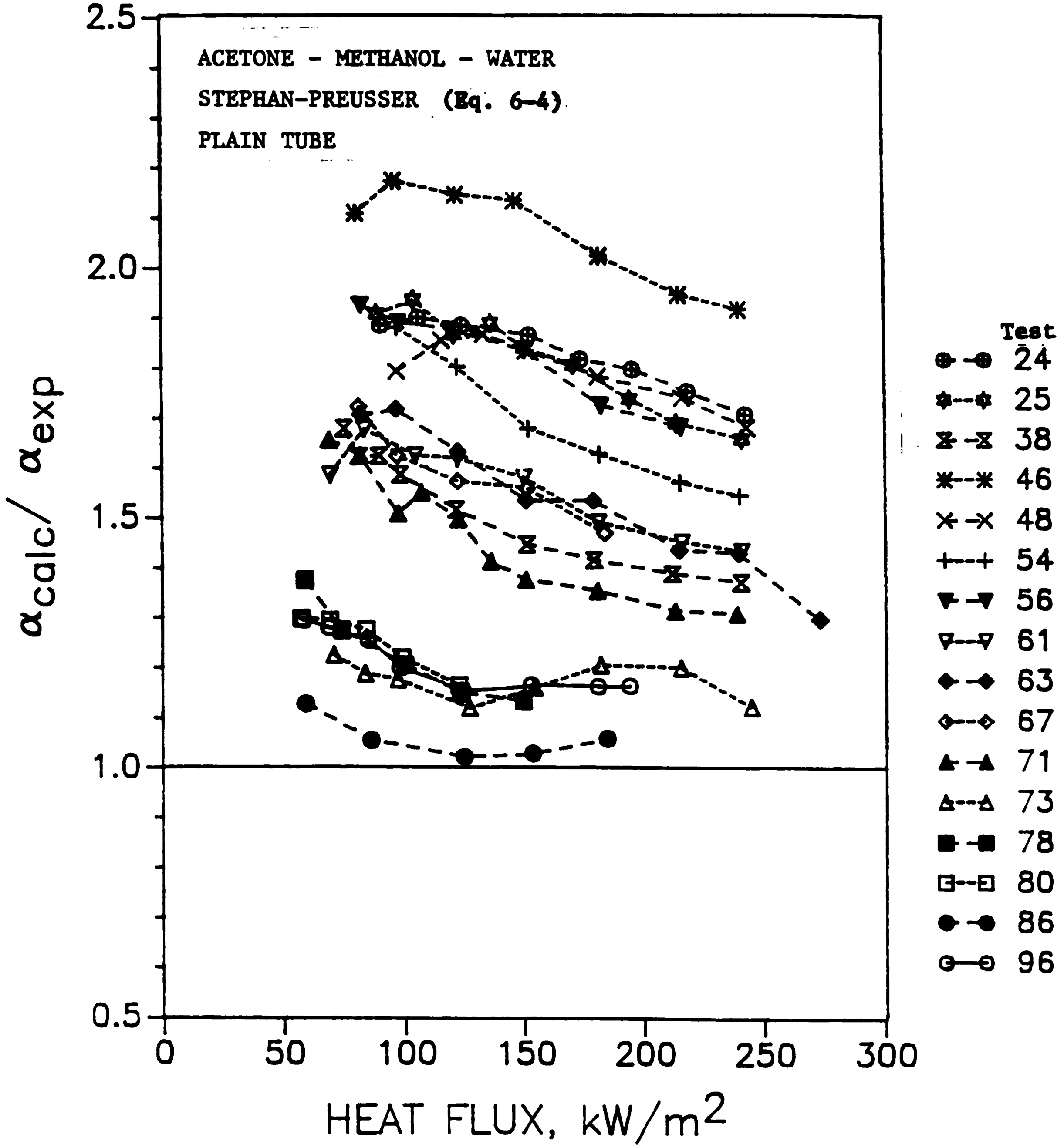


Figure 6.9 Comparison of the Stephan-Pruesser correlation, Eq. 6-4 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures.

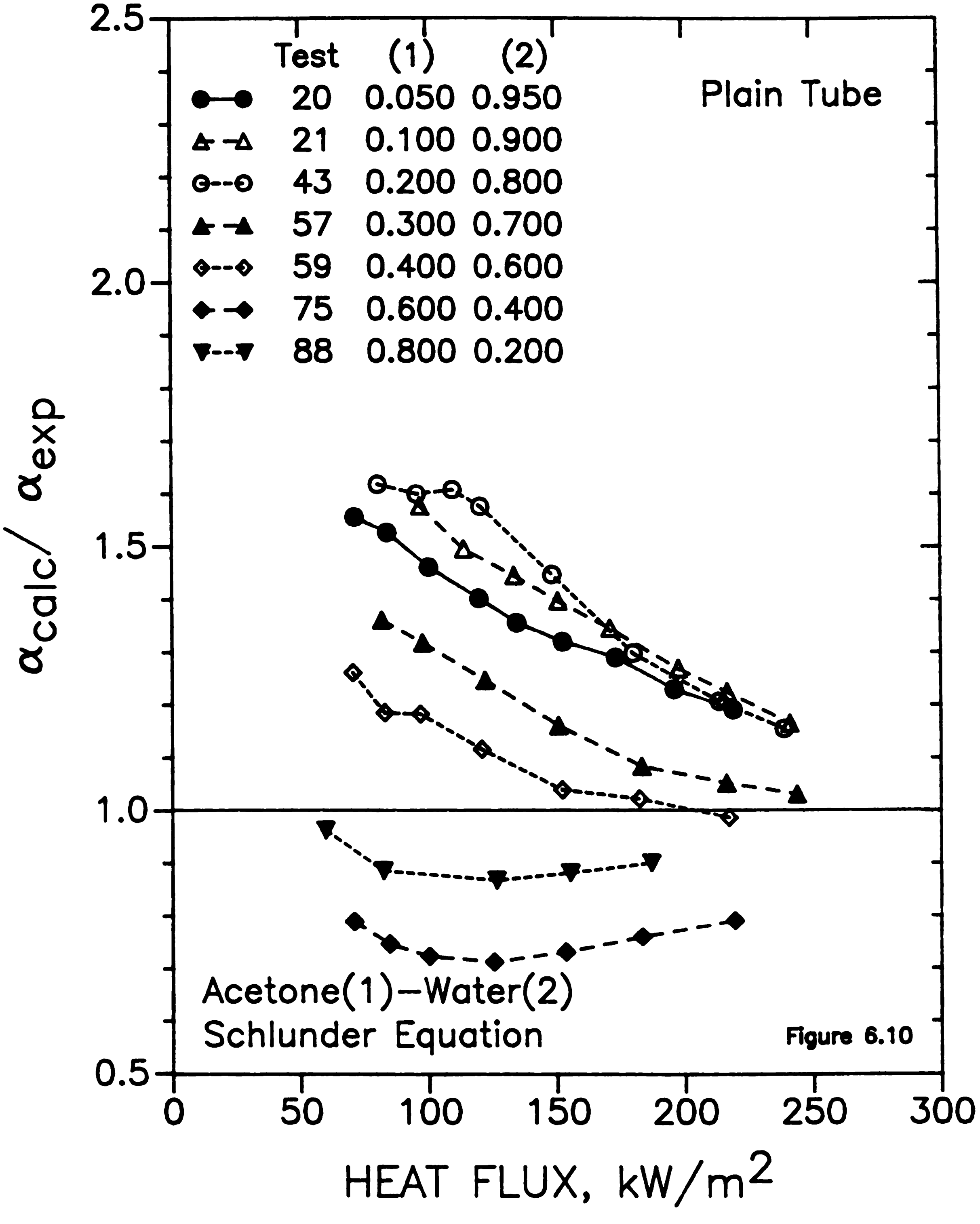


Figure 6.10 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in acetone-water binary mixtures. The linear mixing law was used to calculate α_{id}.

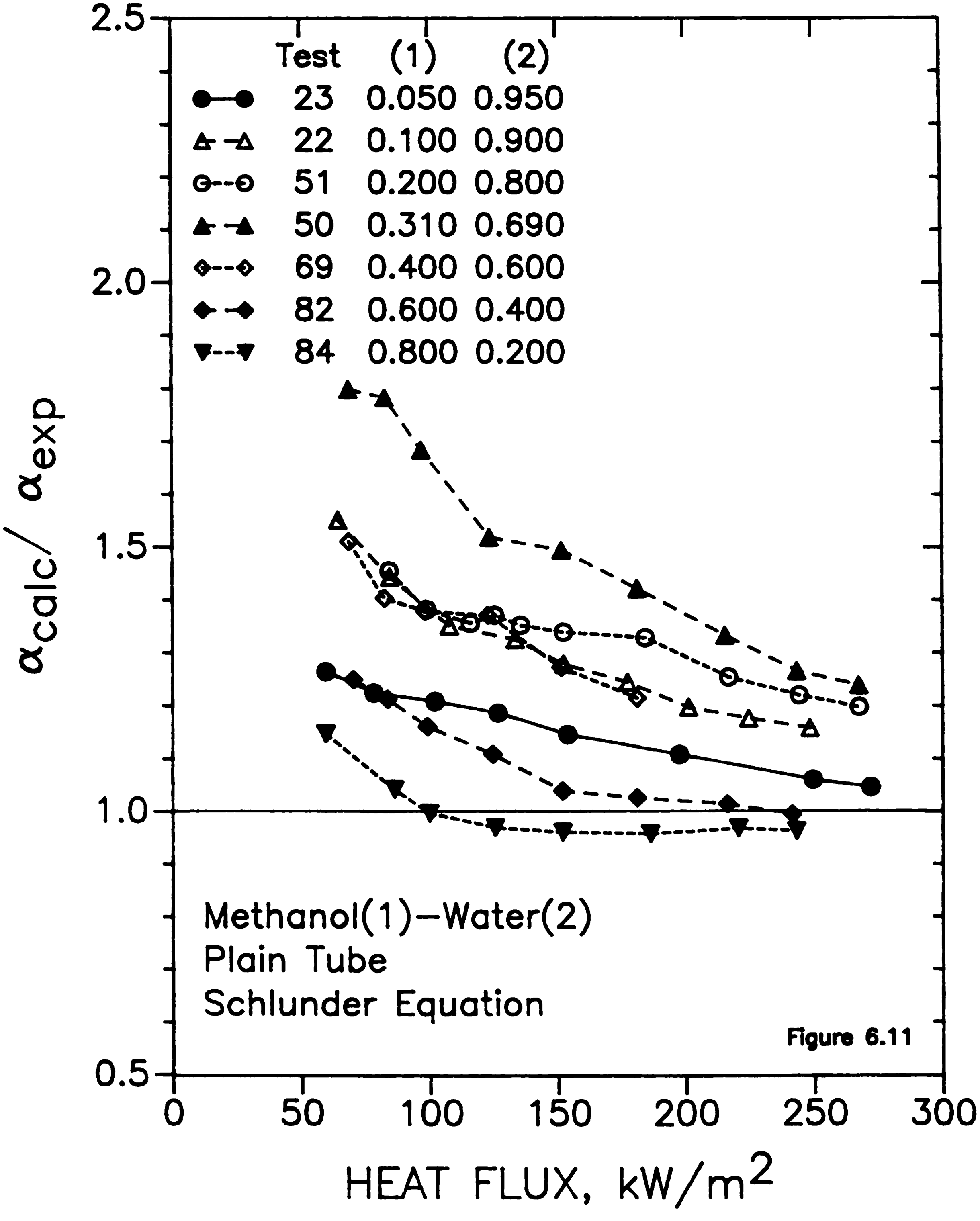


Figure 6.11 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in methanol-water binary mixtures. The linear mixing law was used to calculate α_{id}.

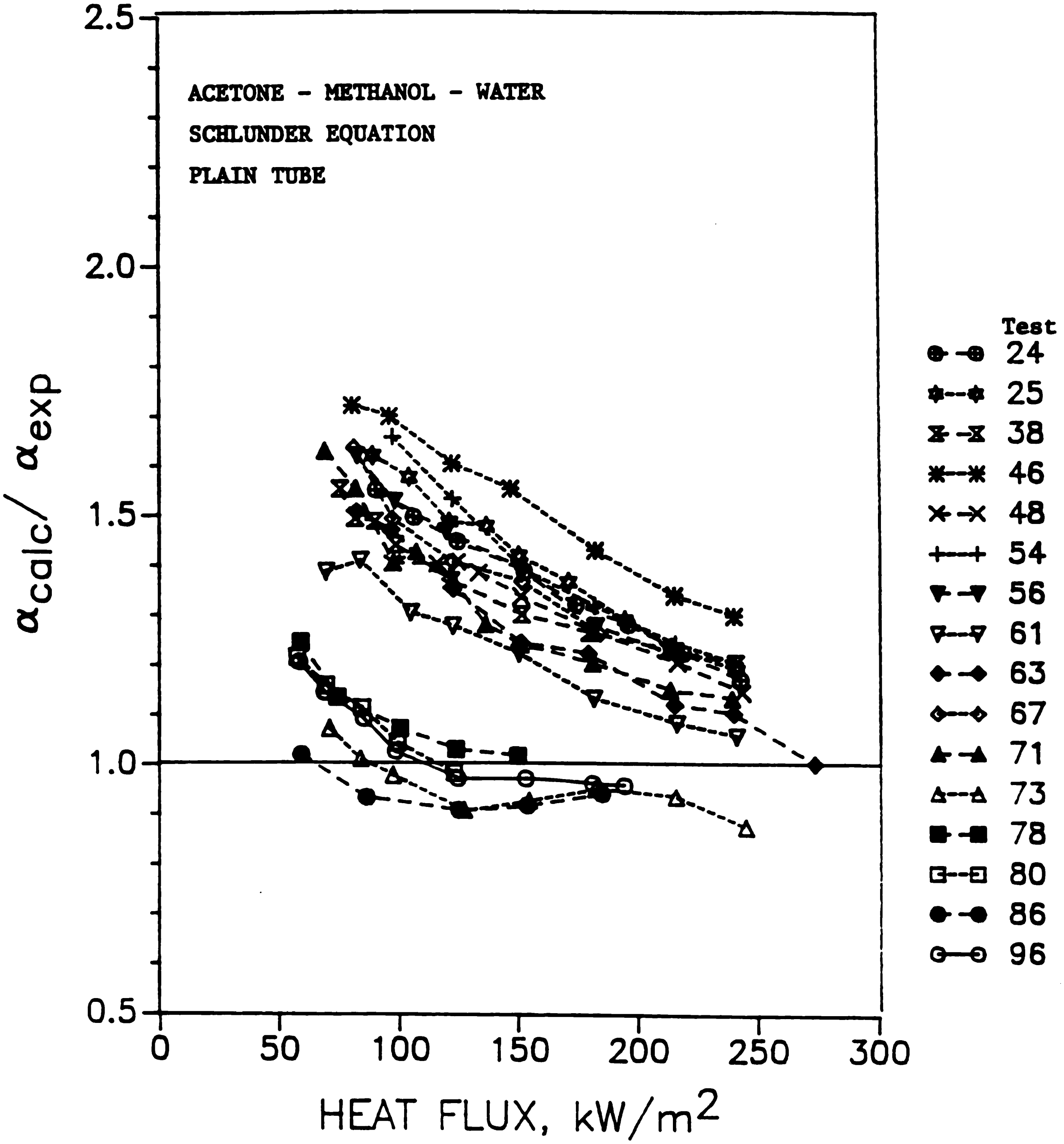


Figure 6.12 Comparison of the Schlunder equation, Eq. 6-5 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The linear mixing law was used to calculate α_{id}.

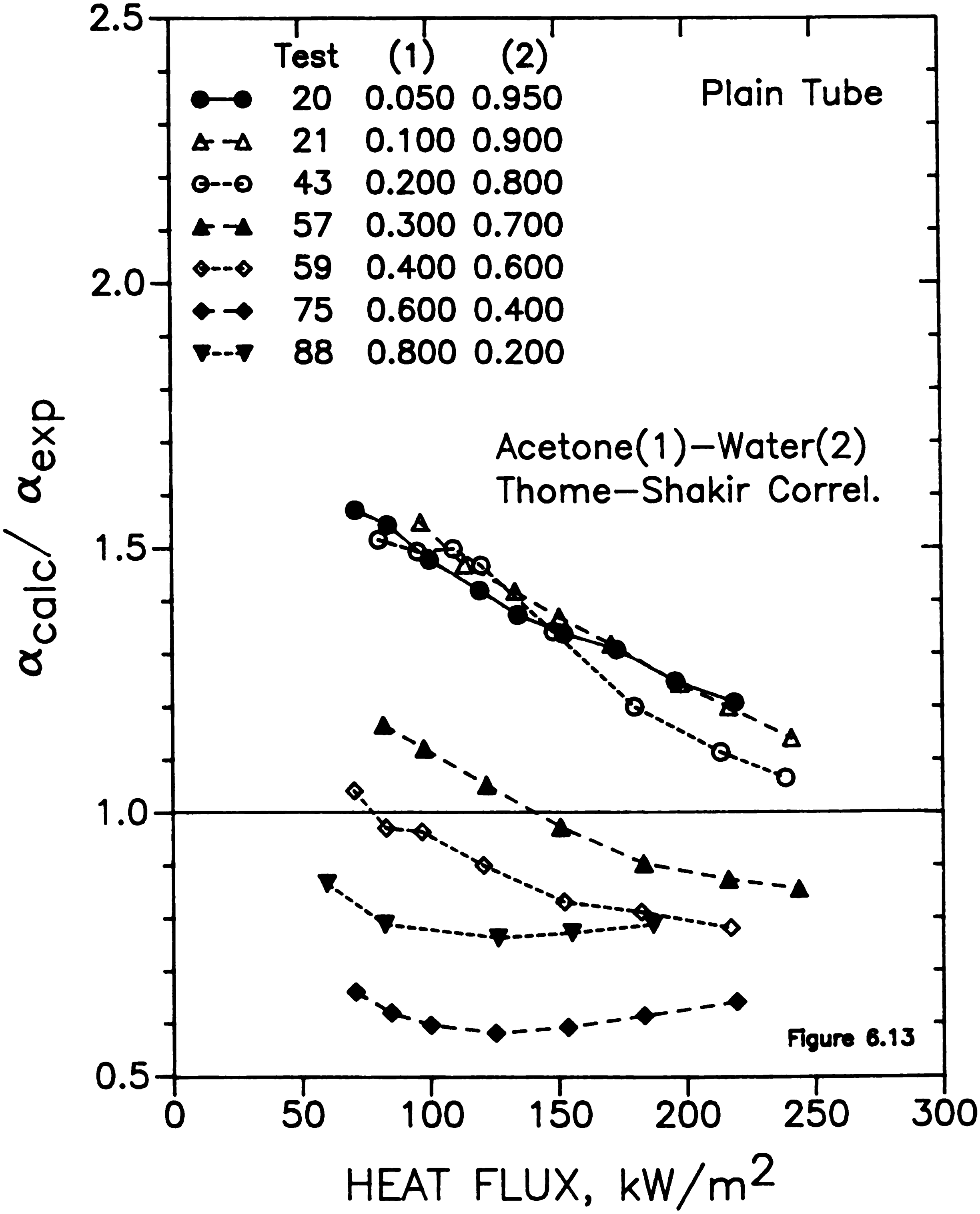


Figure 6.13 Comparison of the Thome-Shakir equation, Eq. 6-6, to experimental heat transfer coefficients in acetone-water binary mixtures. The linear mixing law was used to calculate α_{id}.

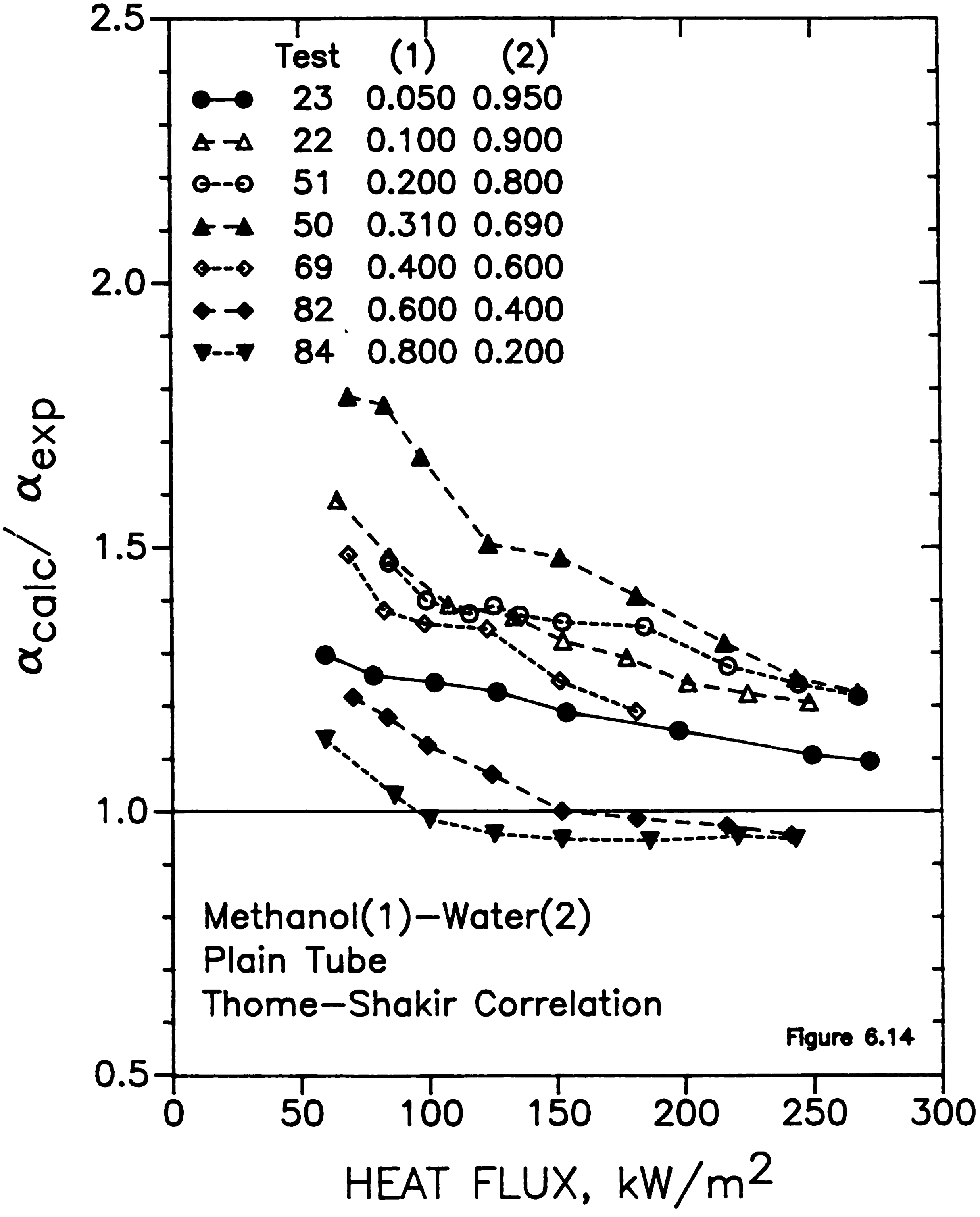


Figure 6.14 Comparison of the Thome-Shakir equation, Eq. 6-6, to experimental heat transfer coefficients in methanol-water binary mixtures. The linear mixing law was used to calculate α_{id}.

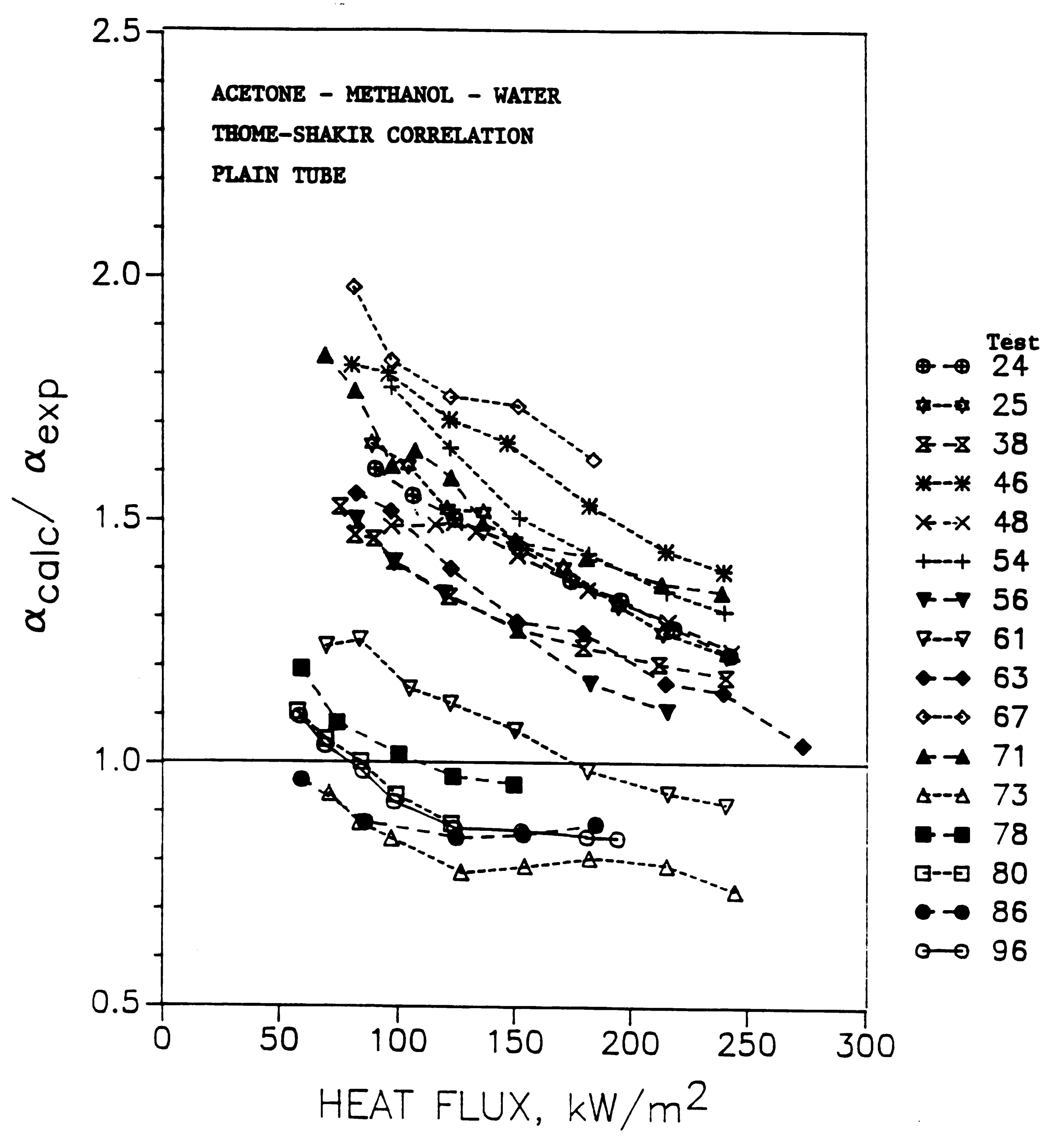


Figure 6.15 Comparison of the Thome-Shakir equation, Eq. 6-6 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The linear mixing law was used to calculate α_{id}.

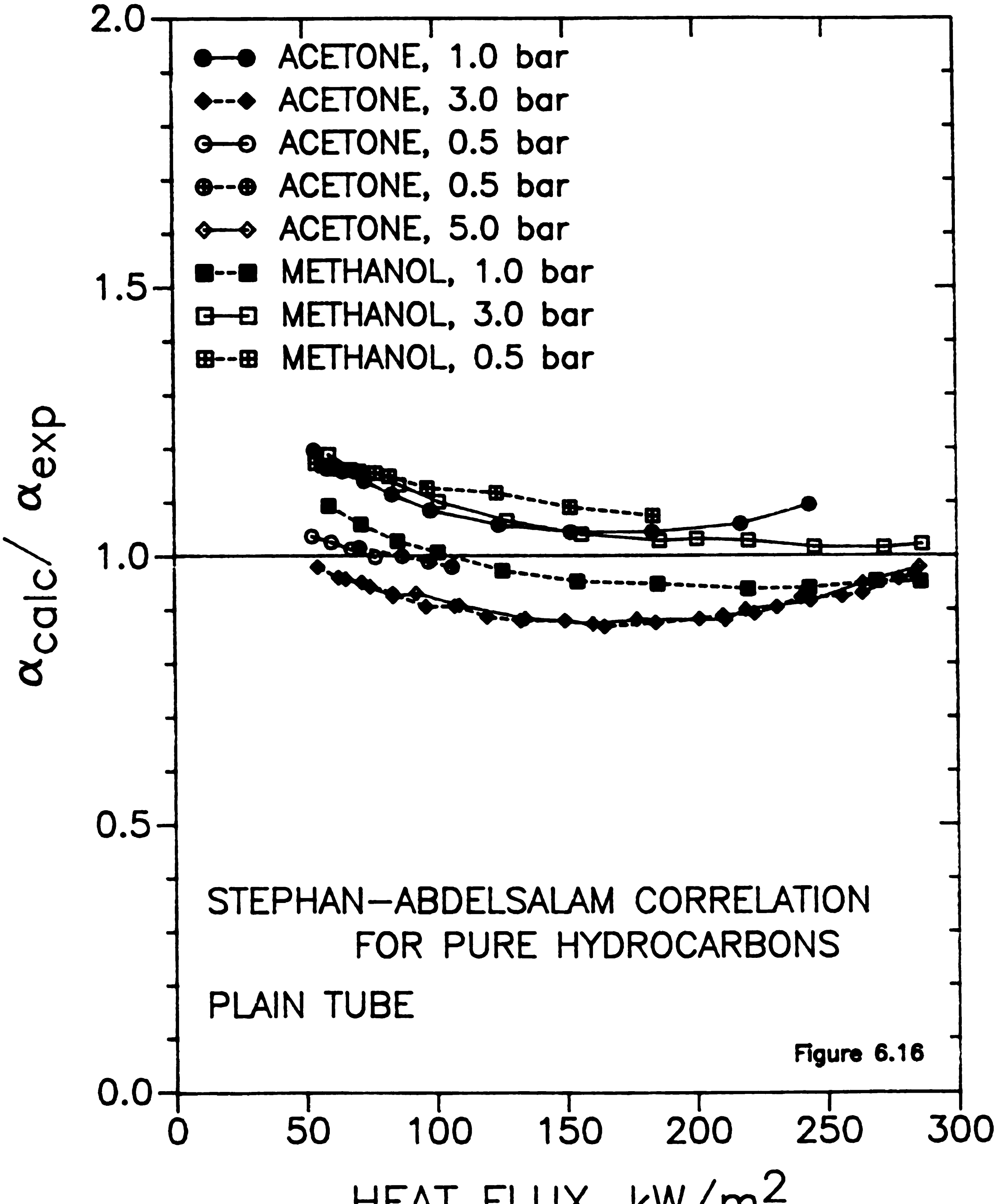


Figure 6.16 Comparison of the Stephan-Abdelsalam correlation, Eq. 6-8, to experimental heat transfer coefficients in acetone and methanol at pressures from 0.5 to 5 bar.

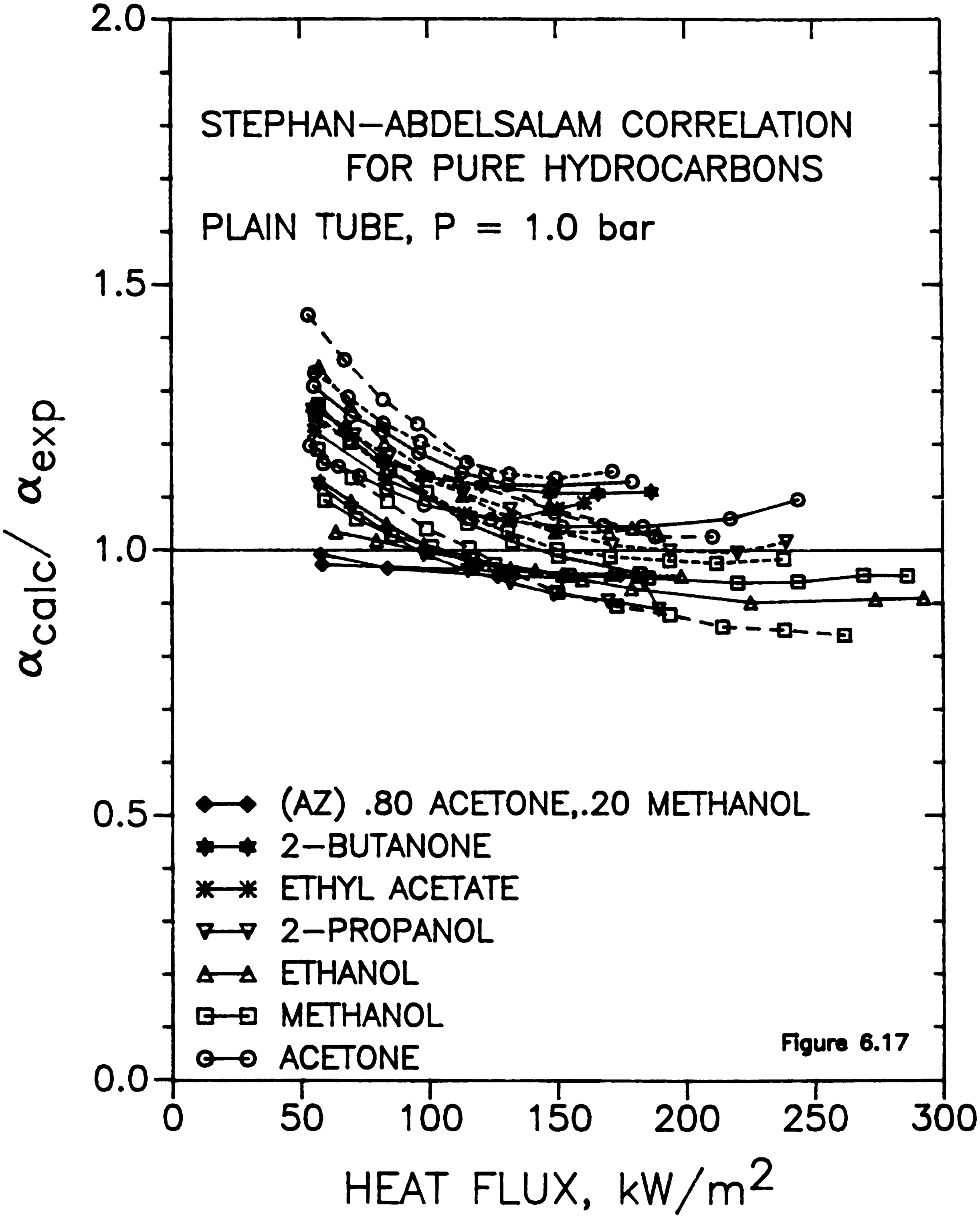


Figure 6.17 Comparison of the Stephan-Abdelsalam correlation, Eq. 6-8, to experimental heat transfer coefficients in several pure fluids at 1.01 bar.

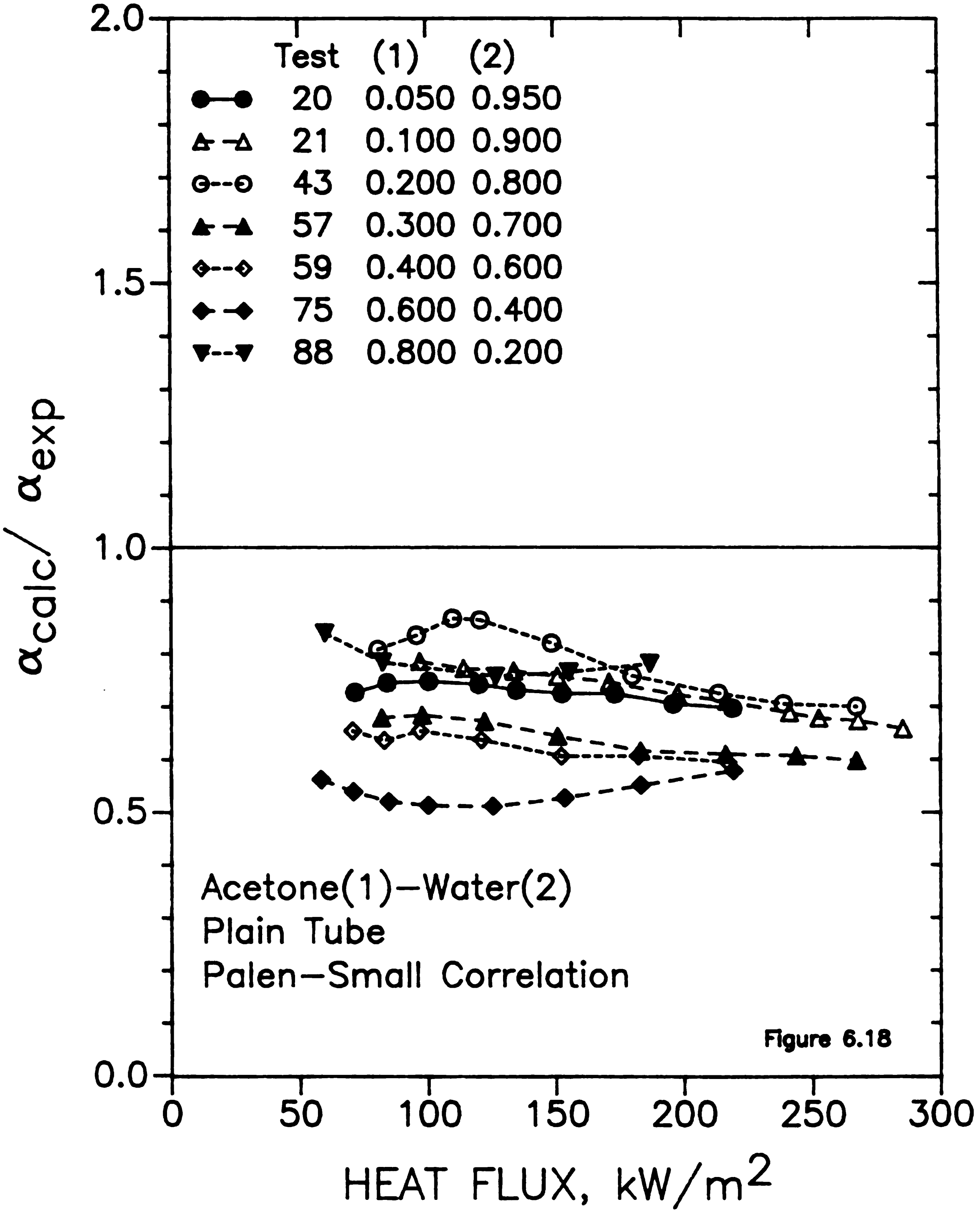


Figure 6.18 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in acetone-water binary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

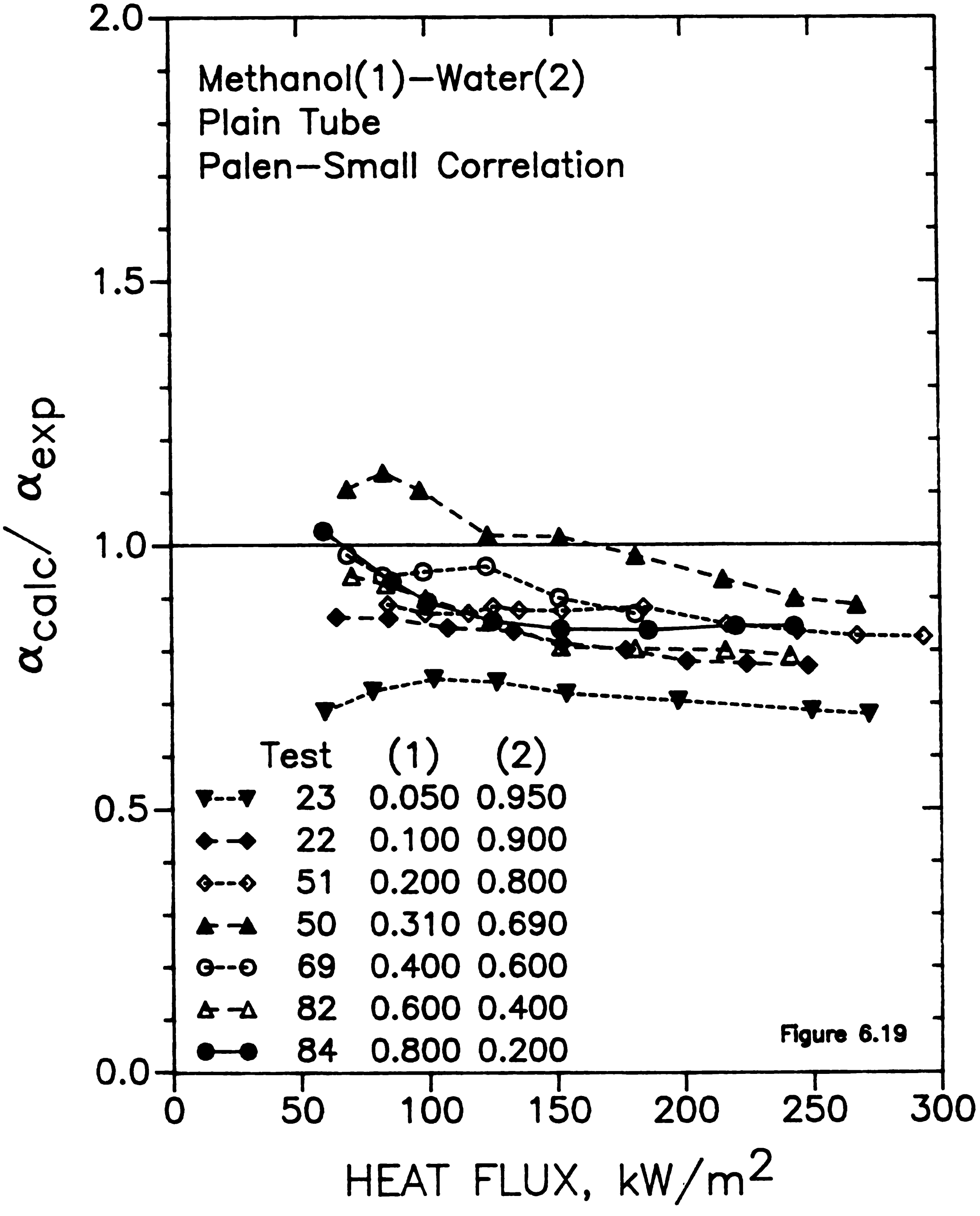


Figure 6.19 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in methanol-water binary mixtures. The Stephan-Abdelsalam correlation Eq. 6-8, was used to calculate α_{id}.

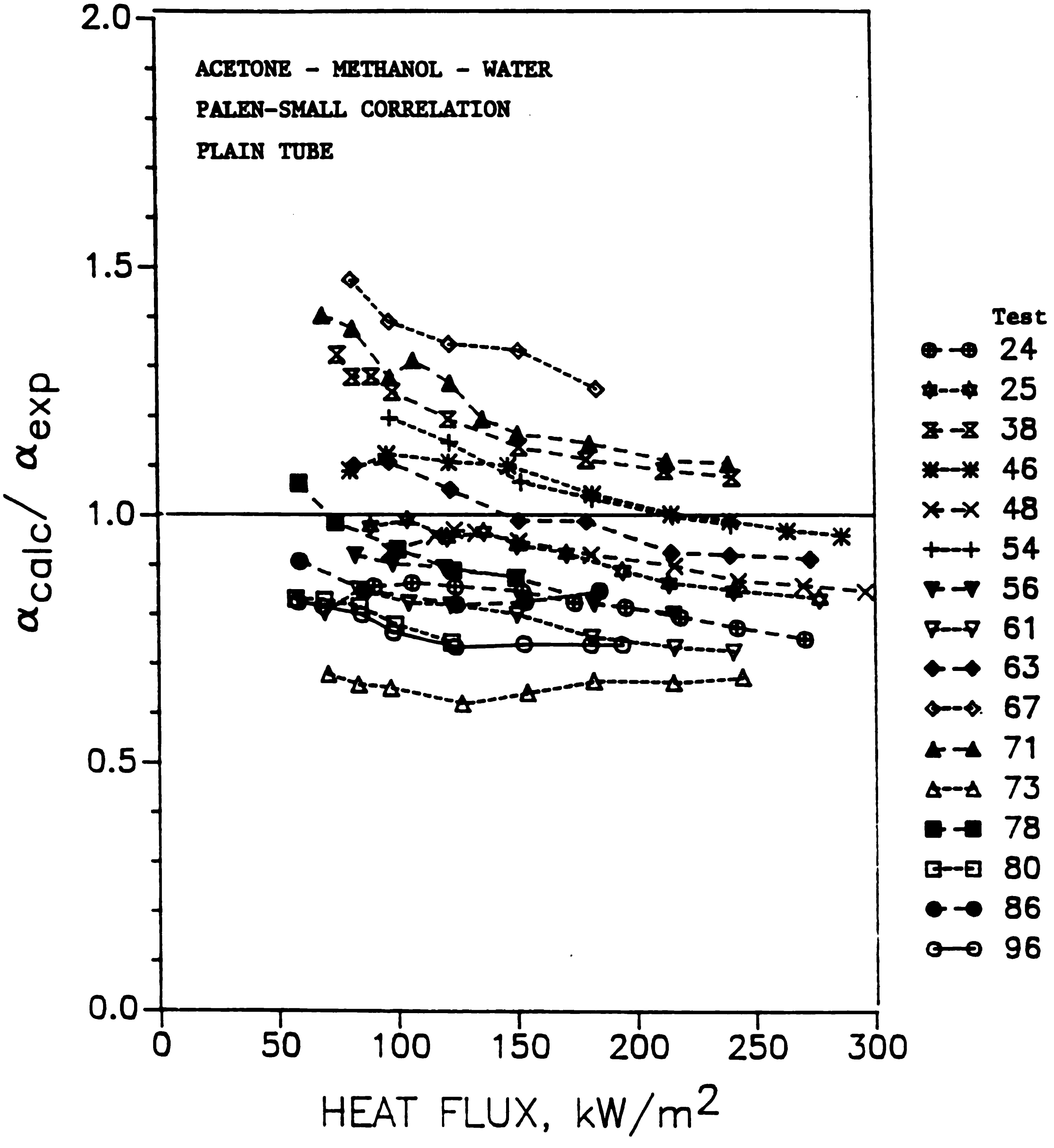


Figure 6.20 Comparison of the Palen-Small correlation, Eq. 6-1 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

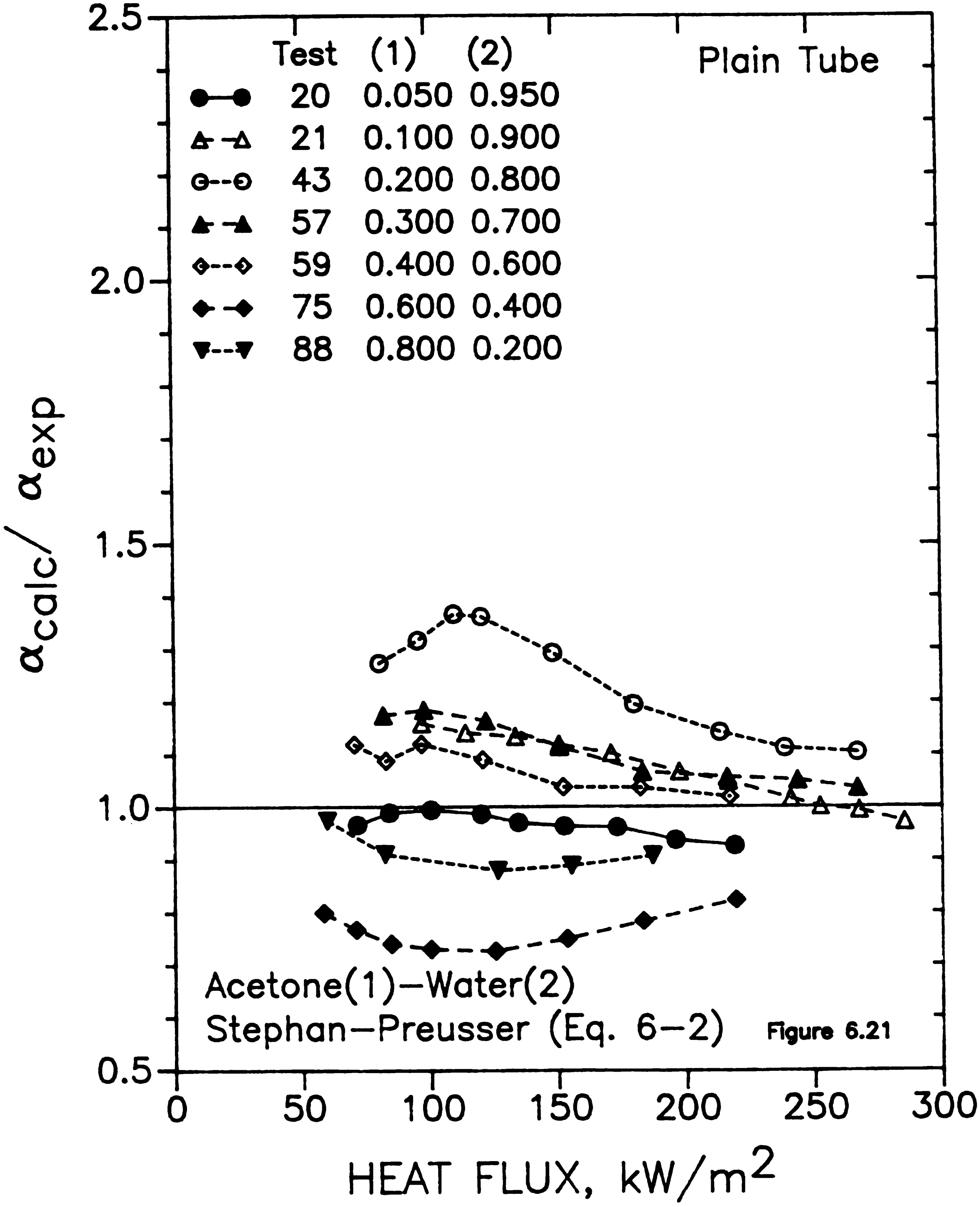


Figure 6.21 Comparison of the Stephan-Preusser correlation, Eq. 6-2, to experimental heat transfer coefficients in acetone-water binary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

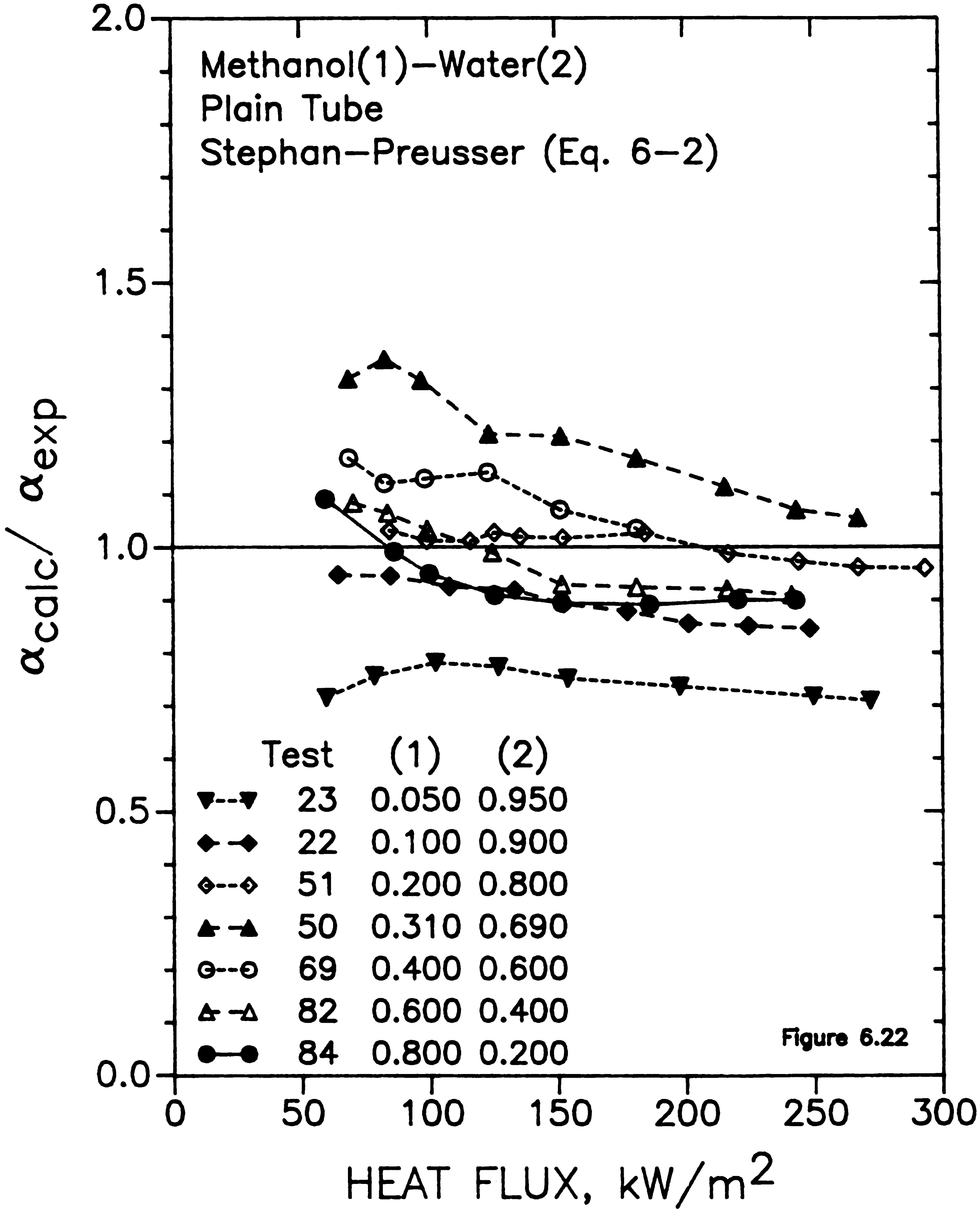


Figure 6.22 Comparison of the Stephan-Preusser correlation, Eq. 6-2 to experimental heat transfer coefficients in methanol-water binary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

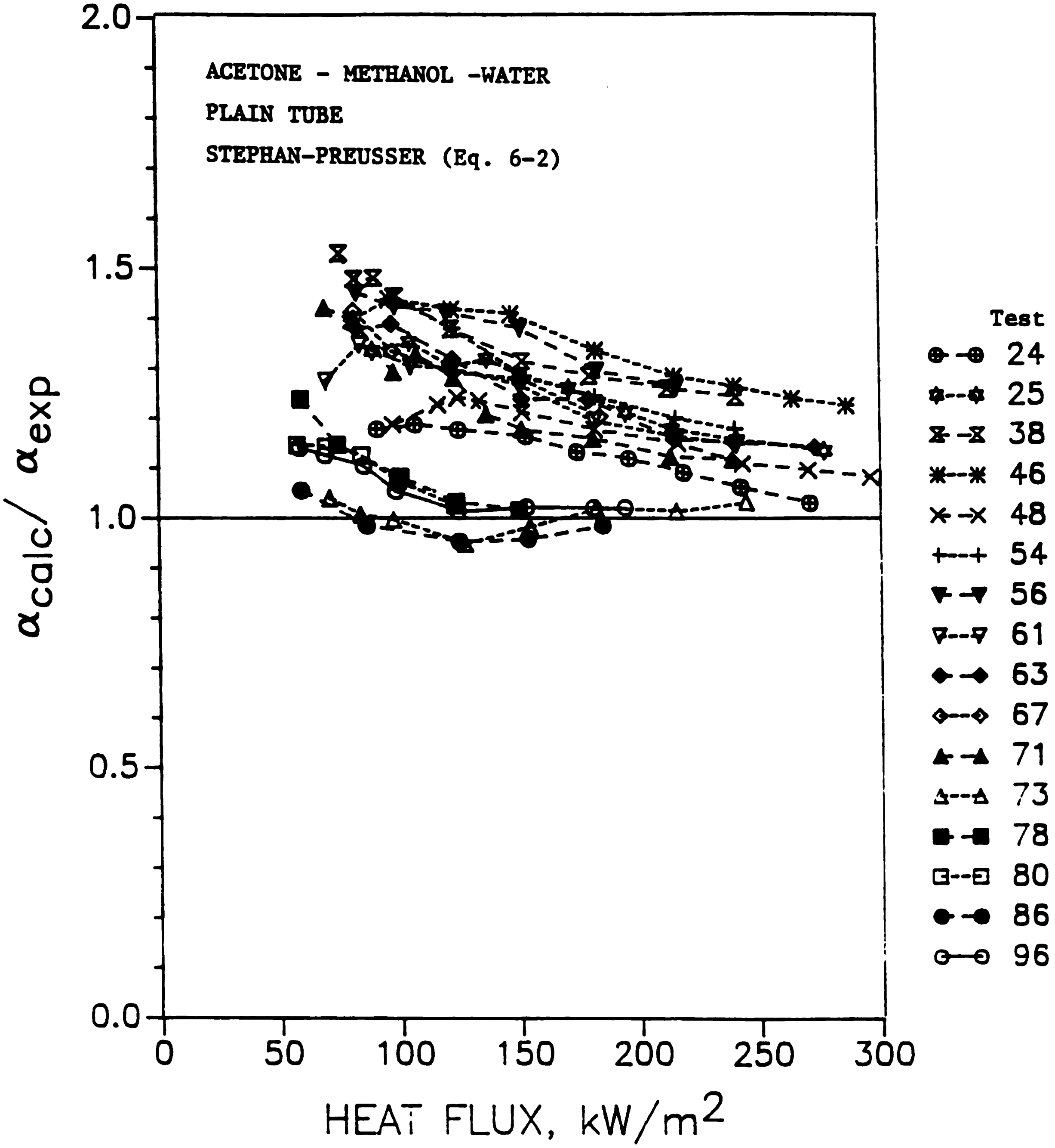


Figure 6.23 Comparison of the Stephan-Pruesser correlation, Eq. 6-2 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

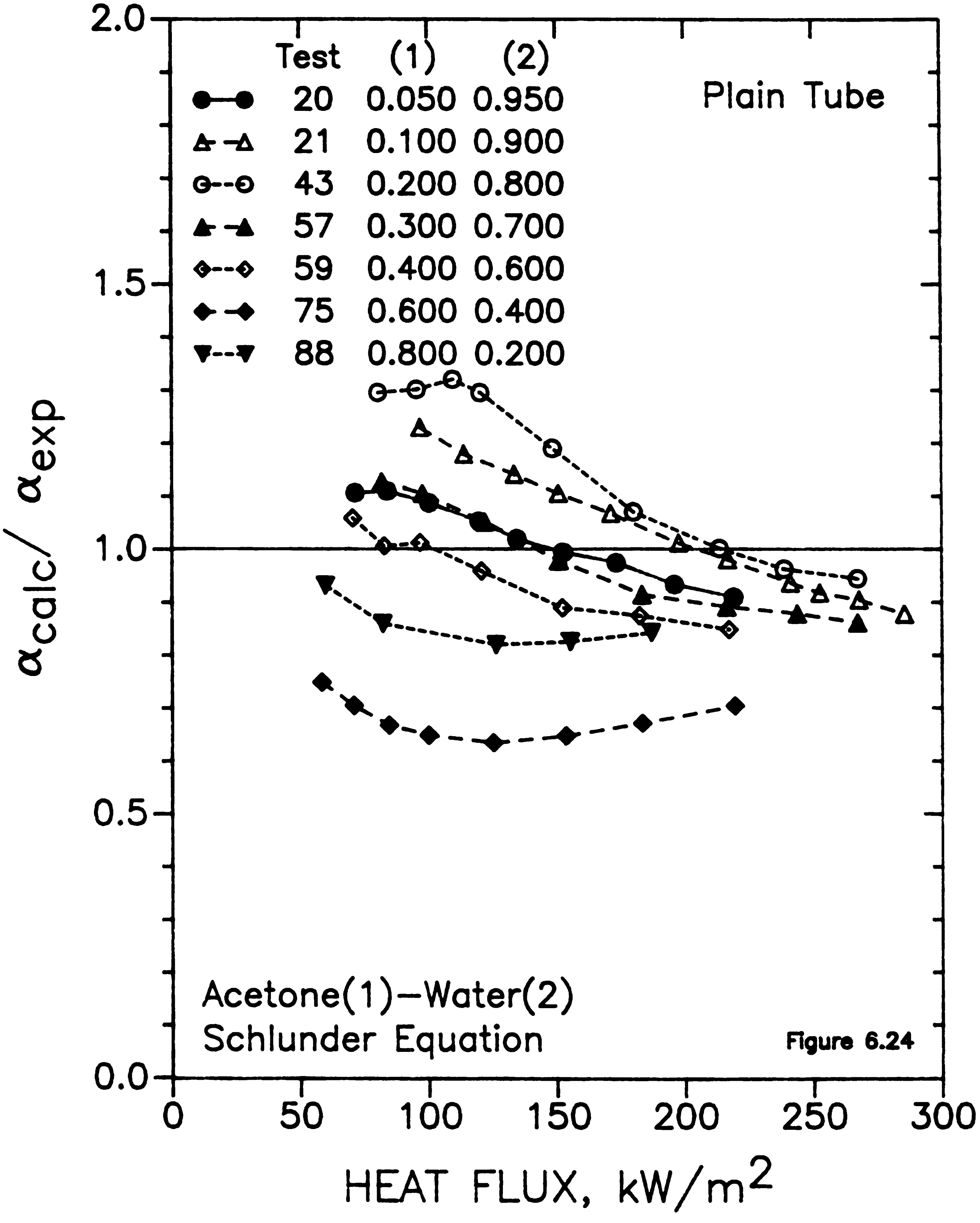


Figure 6.24 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in acetone-water binary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

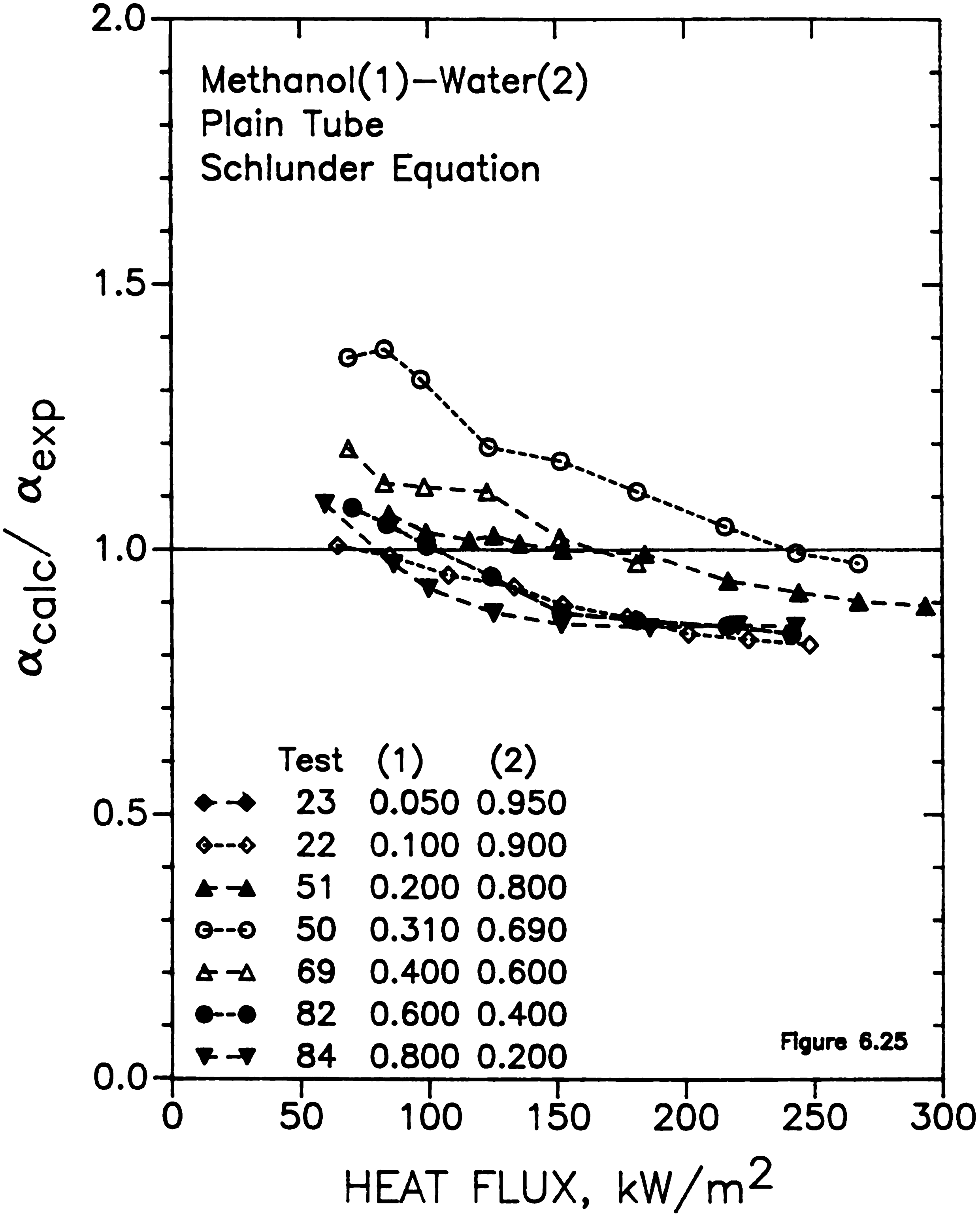


Figure 6.25 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in methanol-water binary mixtures. The Stephan-Abdelsalam correlation Eq. 6-8, was used to calculate α_{id}.

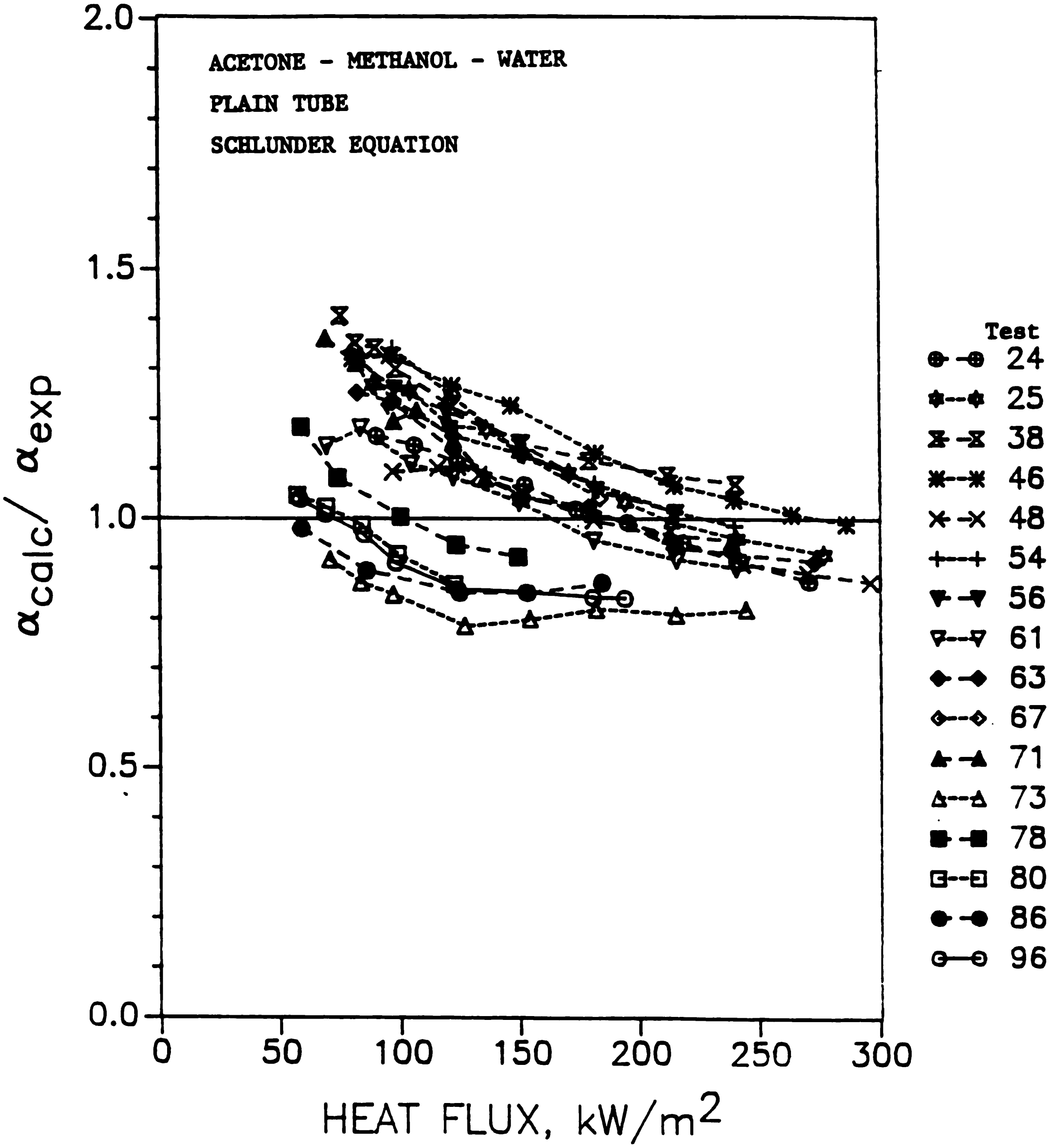


Figure 6.26 Comparison of the Schlunder equation, Eq. 6-5 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

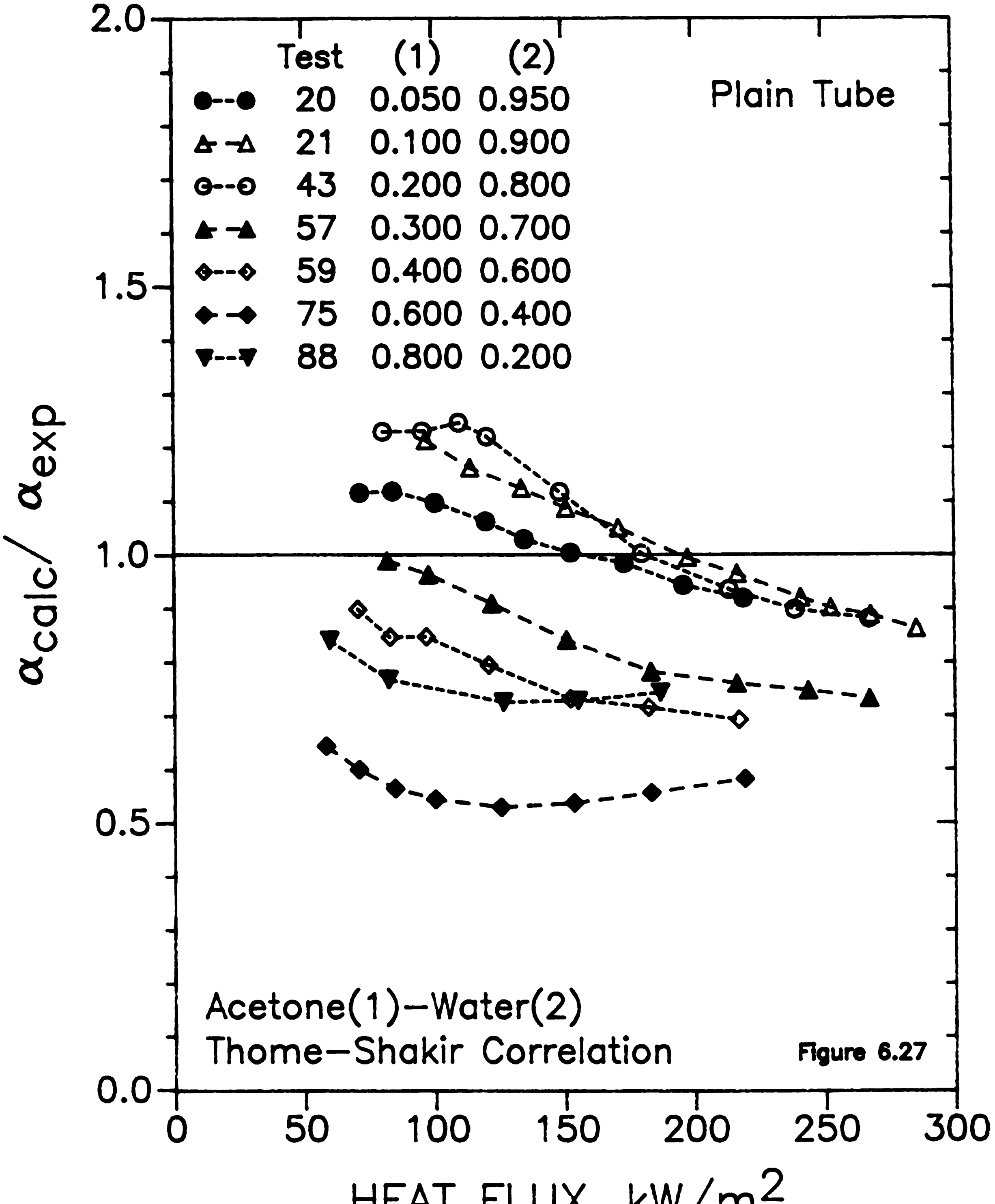


Figure 6.27 Comparison of the Thome-Shakir correlation, Eq. 6-6, to experimental heat transfer coefficients in acetone-water binary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

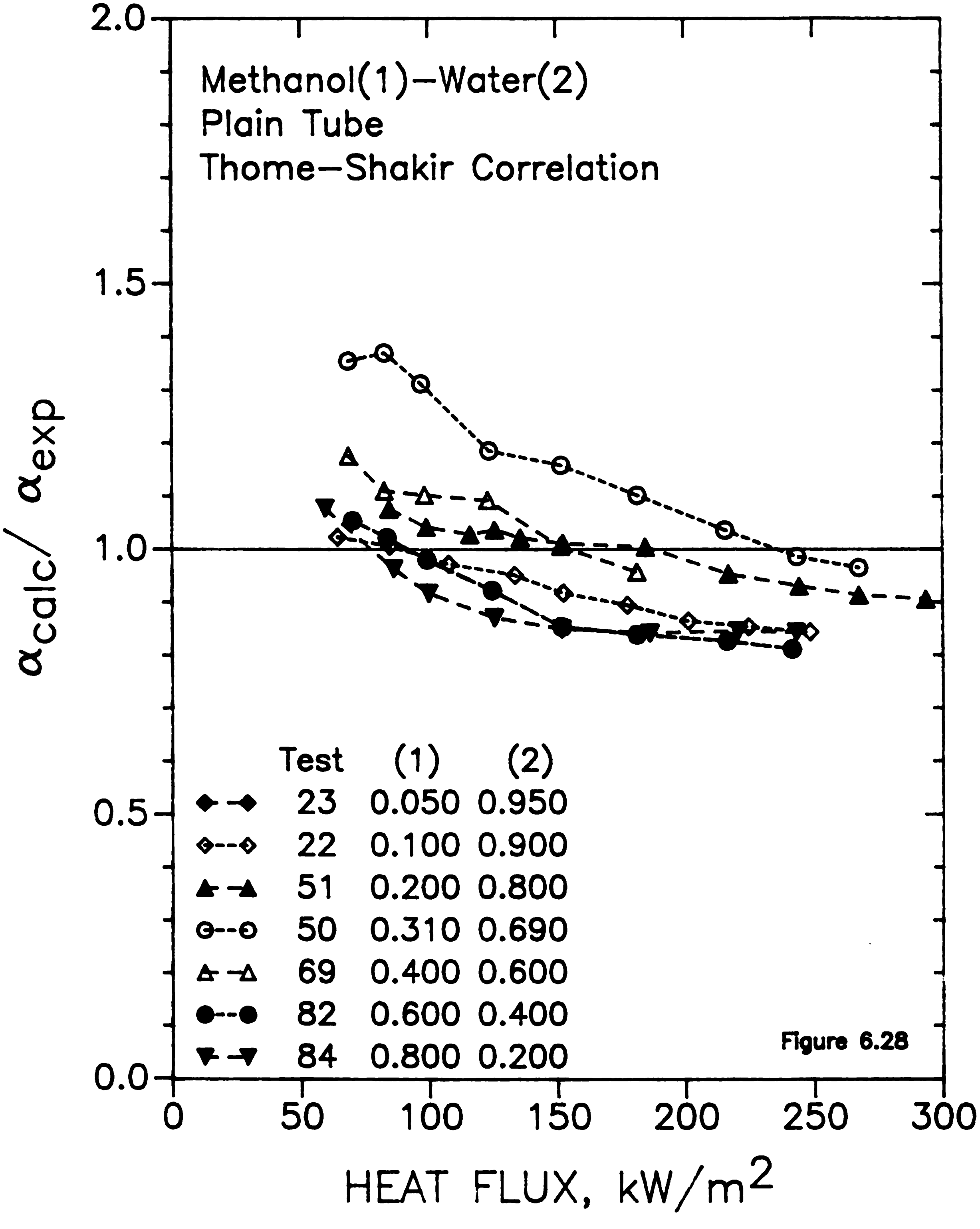


Figure 6.28 Comparison of the Thome-Shakir correlation, Eq. 6-6 to experimental heat transfer coefficients in methanol-water binary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.

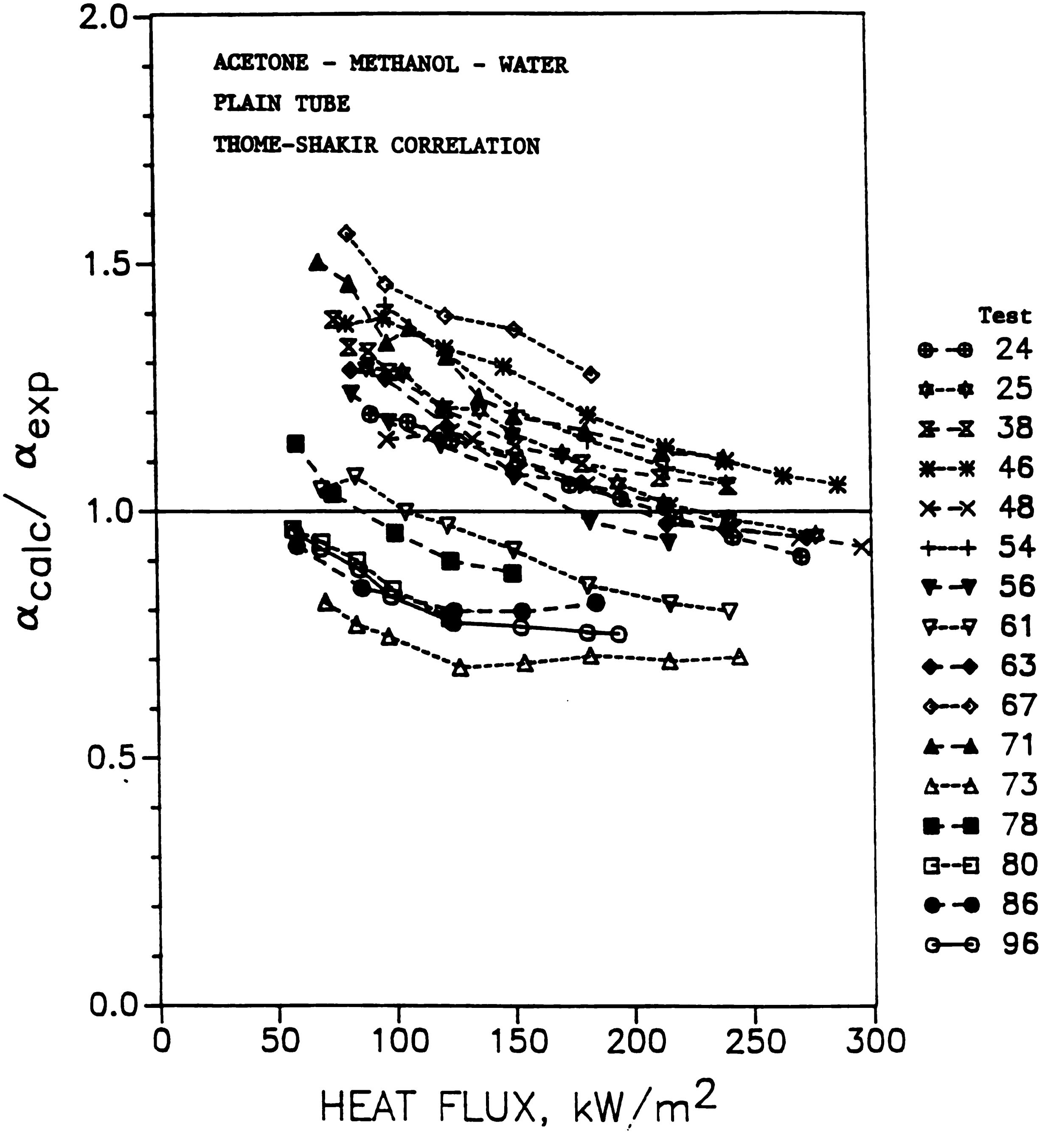
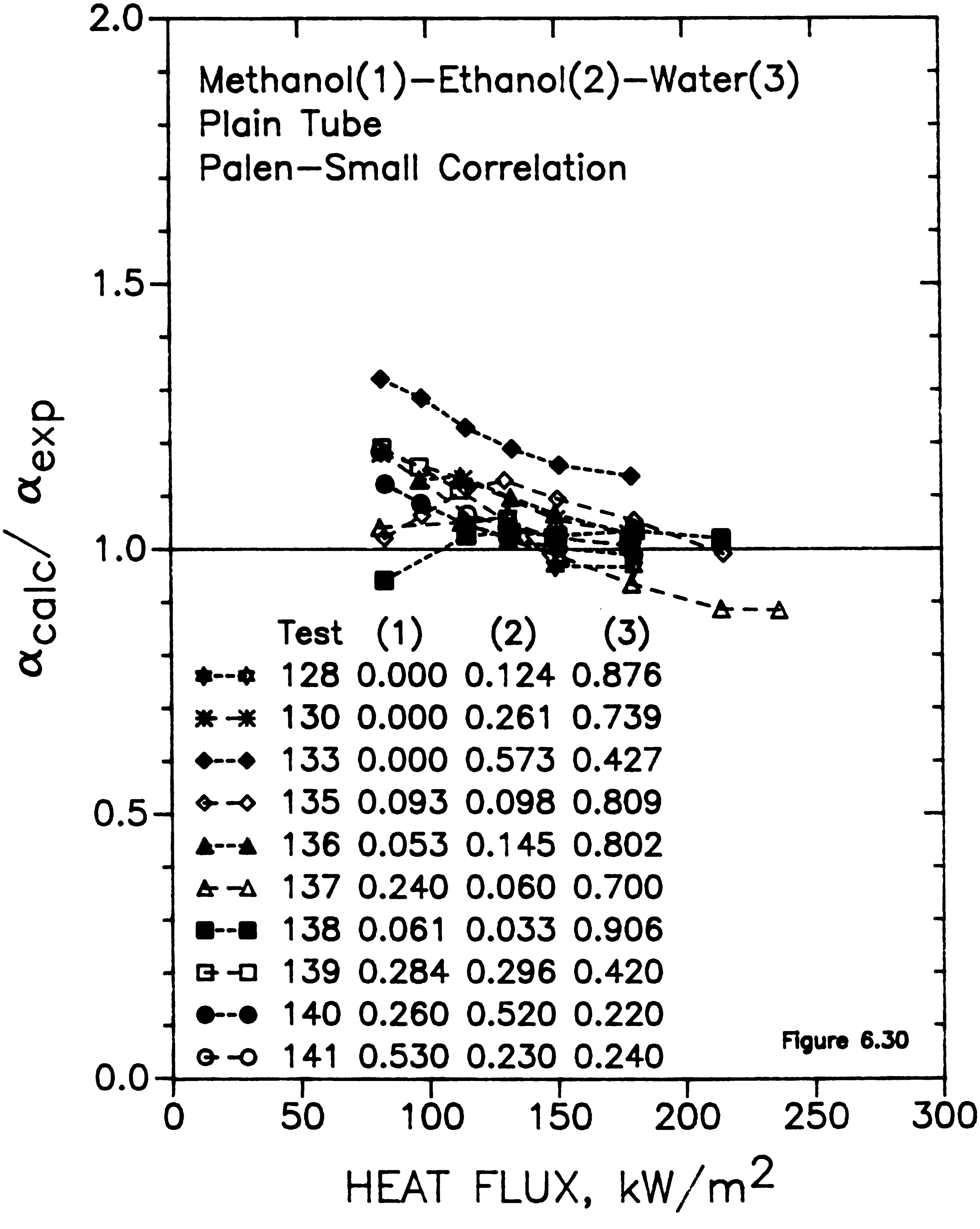


Figure 6.29 Comparison of the Thome-Shakir correlation, Eq. 6-6 to experimental heat transfer coefficients in acetone-methanol-water ternary mixtures. The Stephan-Abdelsalam correlation, Eq. 6-8, was used to calculate α_{id}.



Test	(1)	(2)	(3)
128	0.000	0.124	0.876
130	0.000	0.261	0.739
133	0.000	0.573	0.427
135	0.093	0.098	0.809
136	0.053	0.145	0.802
137	0.240	0.060	0.700
138	0.061	0.033	0.906
139	0.284	0.296	0.420
140	0.260	0.520	0.220
141	0.530	0.230	0.240

Figure 6.30 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in ethanol-water and methanol-ethanol-water mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

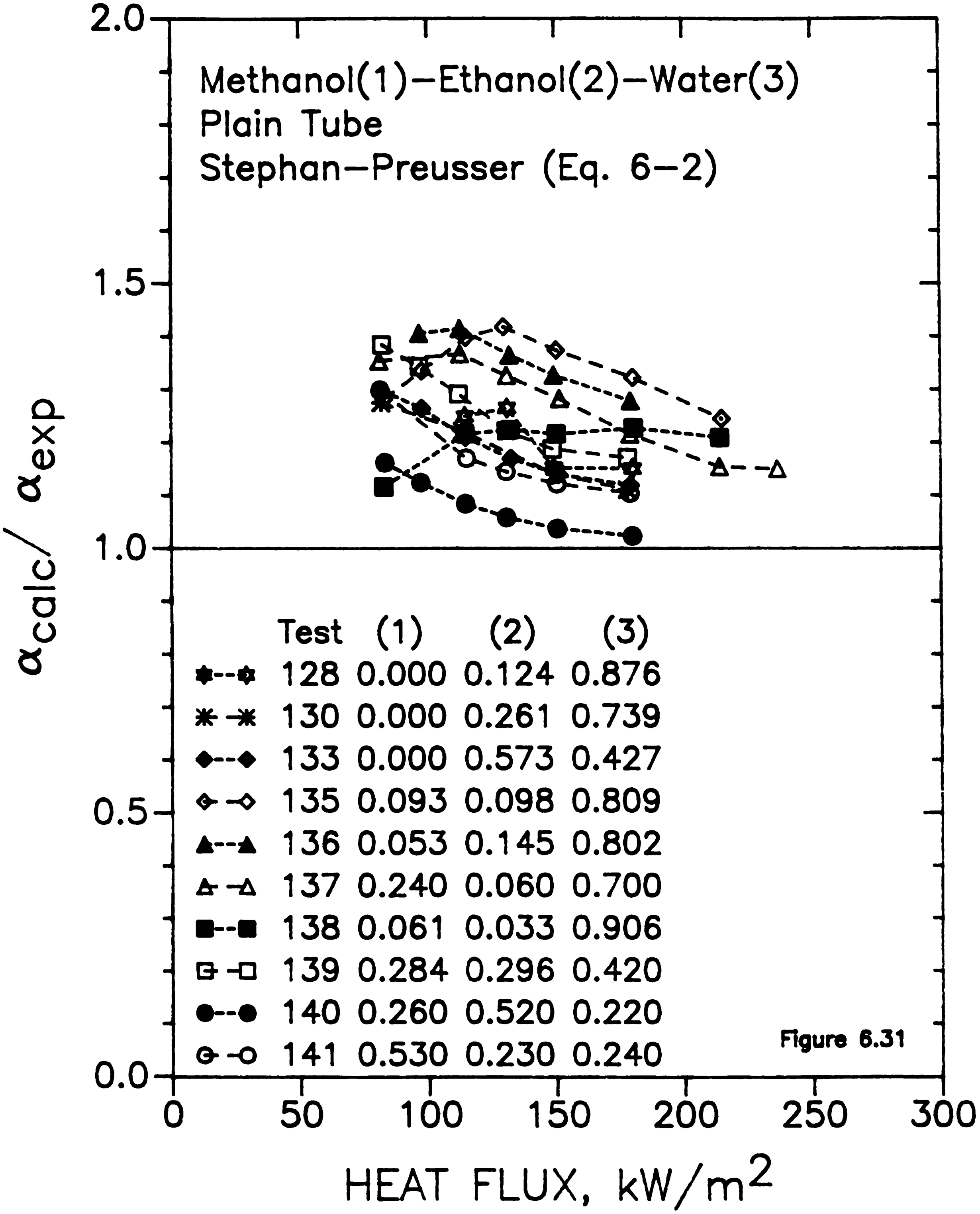


Figure 6.31 Comparison of the Stephan-Preusser correlation, Eq. 6-2, to experimental heat transfer coefficients in ethanol-water and methanol-ethanol-water mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

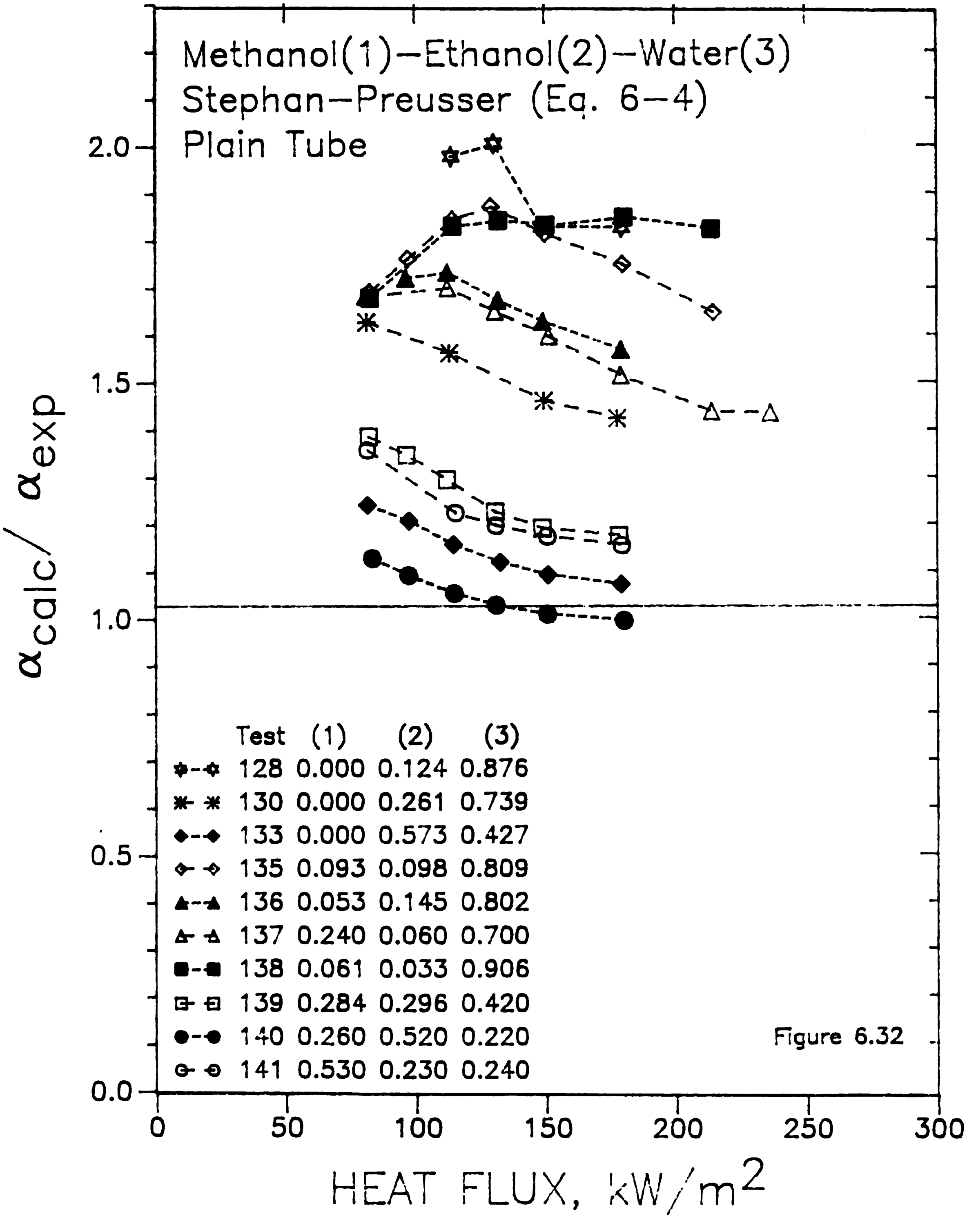


Figure 6.32 Comparison of the Stephan-Preusser correlation, Eq. 6-4, to experimental heat transfer coefficients in ethanol-water and methanol-ethanol-water mixtures.

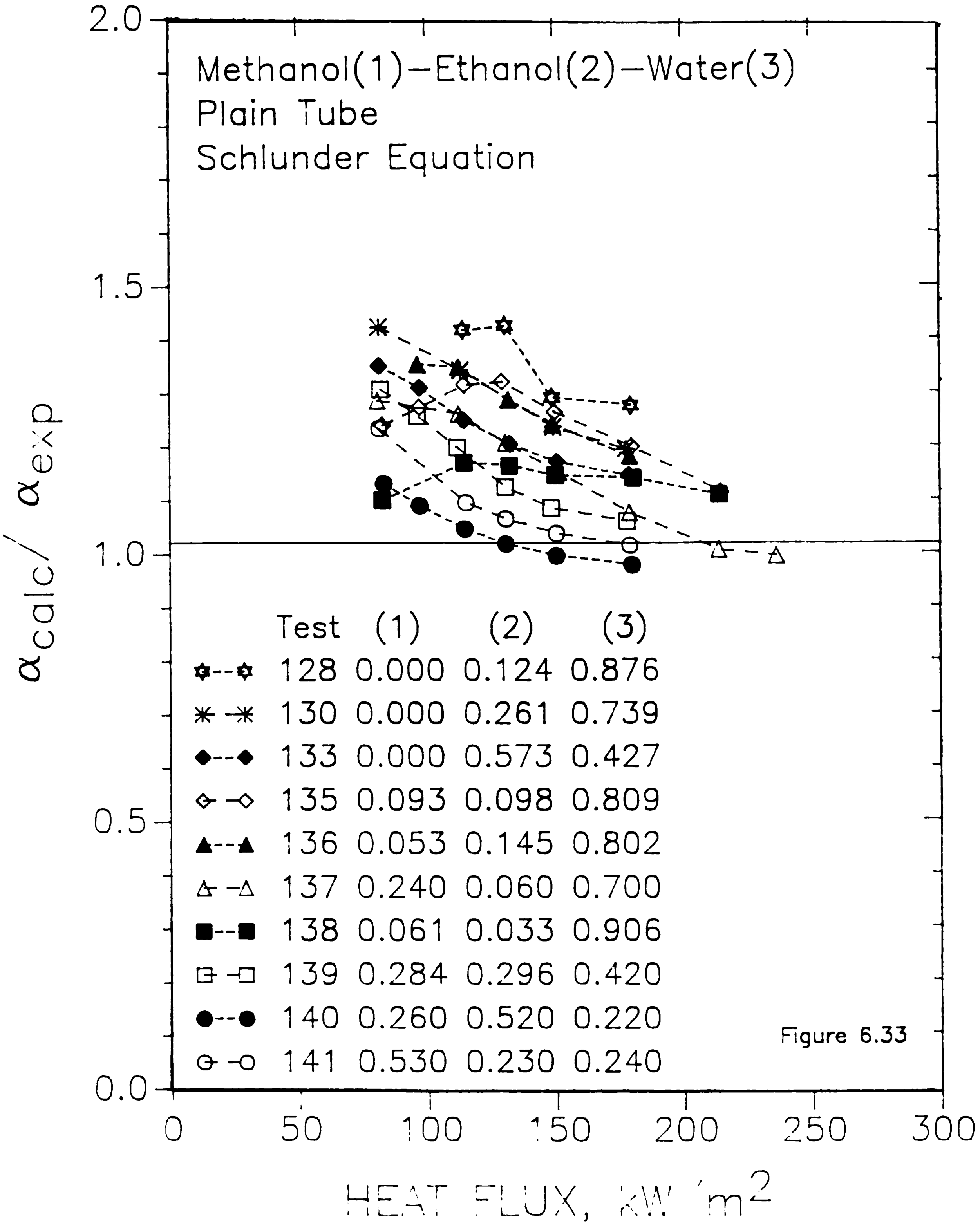


Figure 6.33 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in ethanol-water and methanol-ethanol-water mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

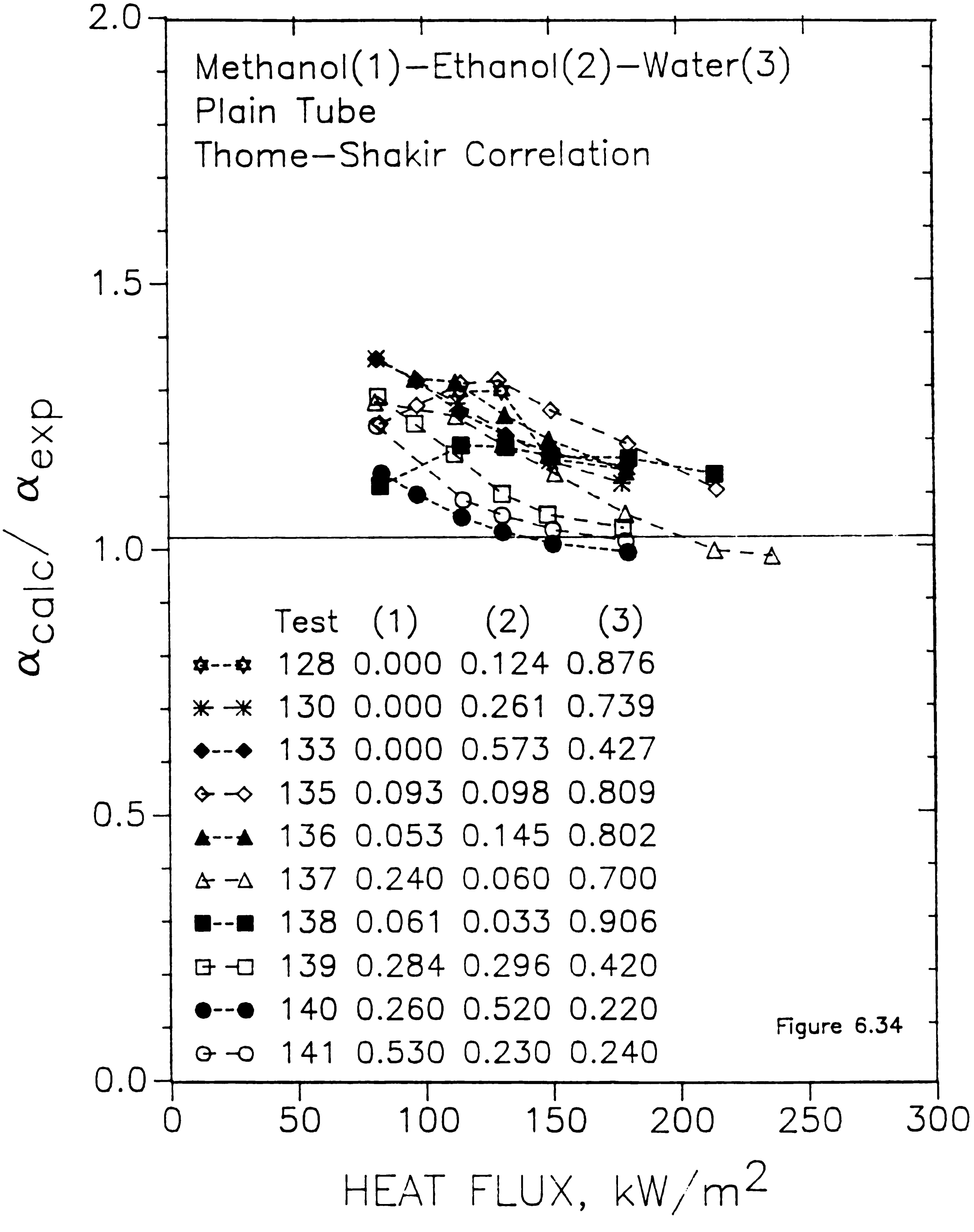


Figure 6.34 Comparison of the Thome-Shakir correlation, Eq. 6-5, to experimental heat transfer coefficients in ethanol-water and methanol-ethanol-water mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

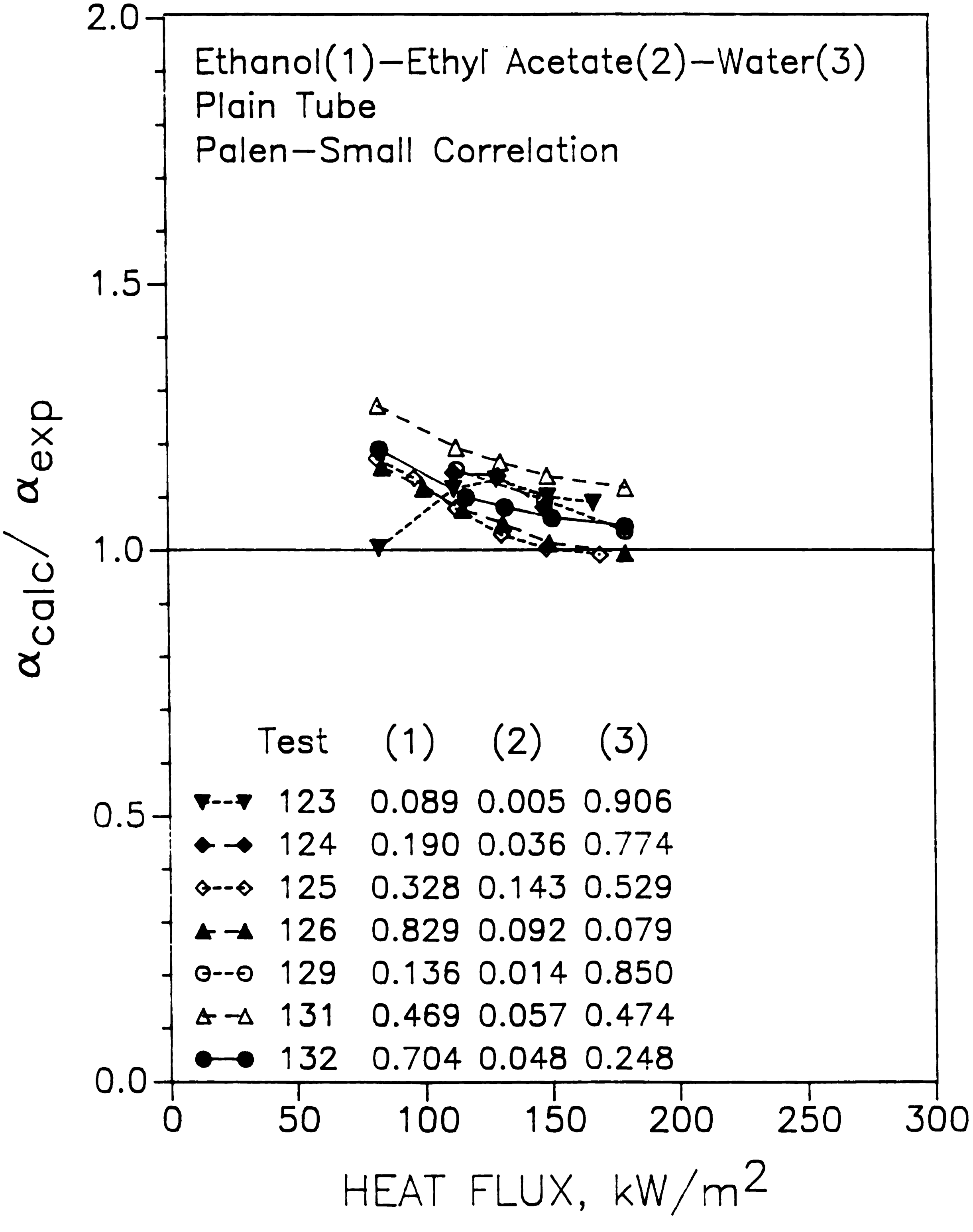


Figure 6.35 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in ethanol-ethyl acetate -water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

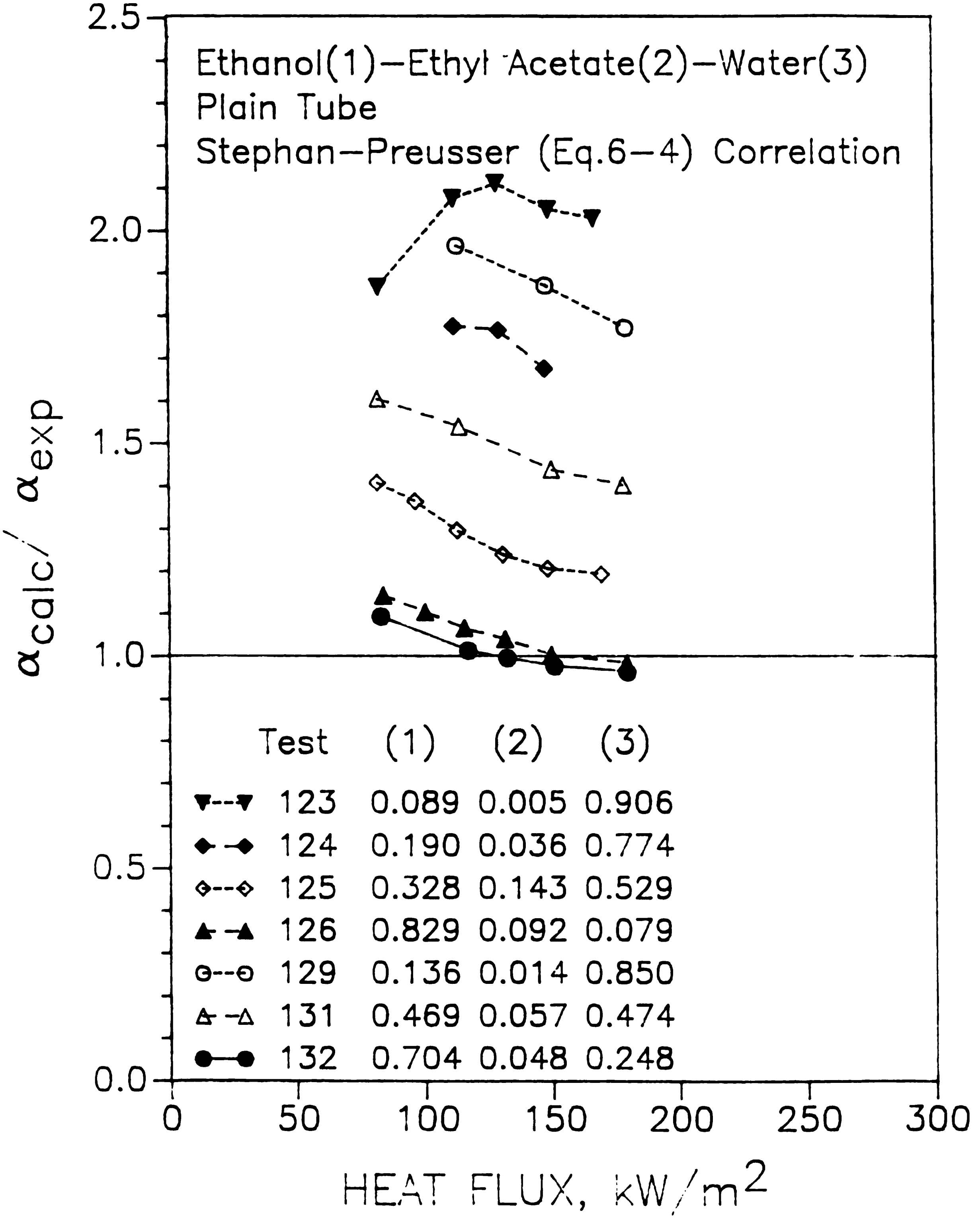


Figure 6.36 Comparison of the Stephan-Preusser correlation, Eq. 6-4, to experimental heat transfer coefficients in ethanol-ethyl acetate -water ternary mixtures.

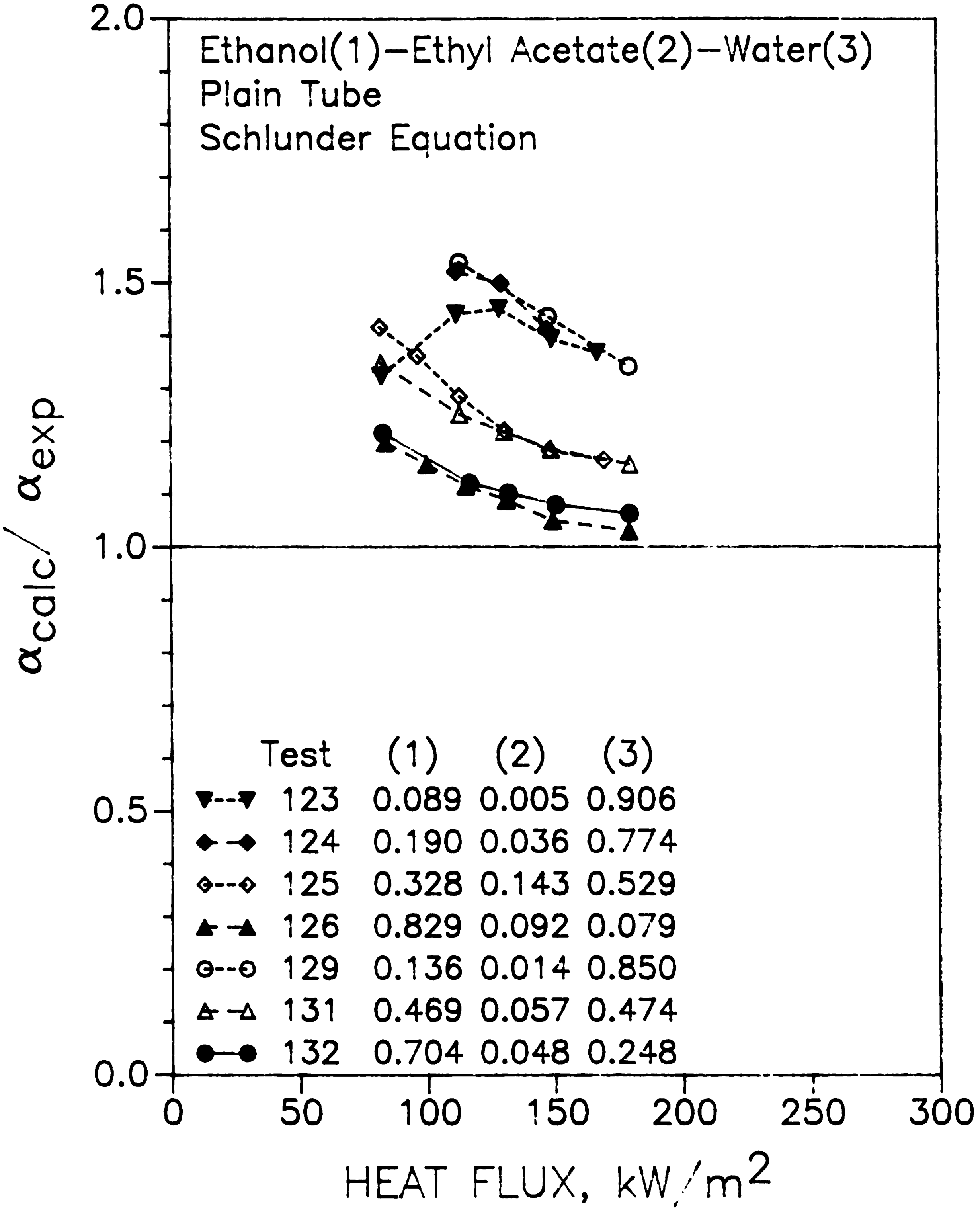


Figure 6.37 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in ethanol-ethyl acetate -water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

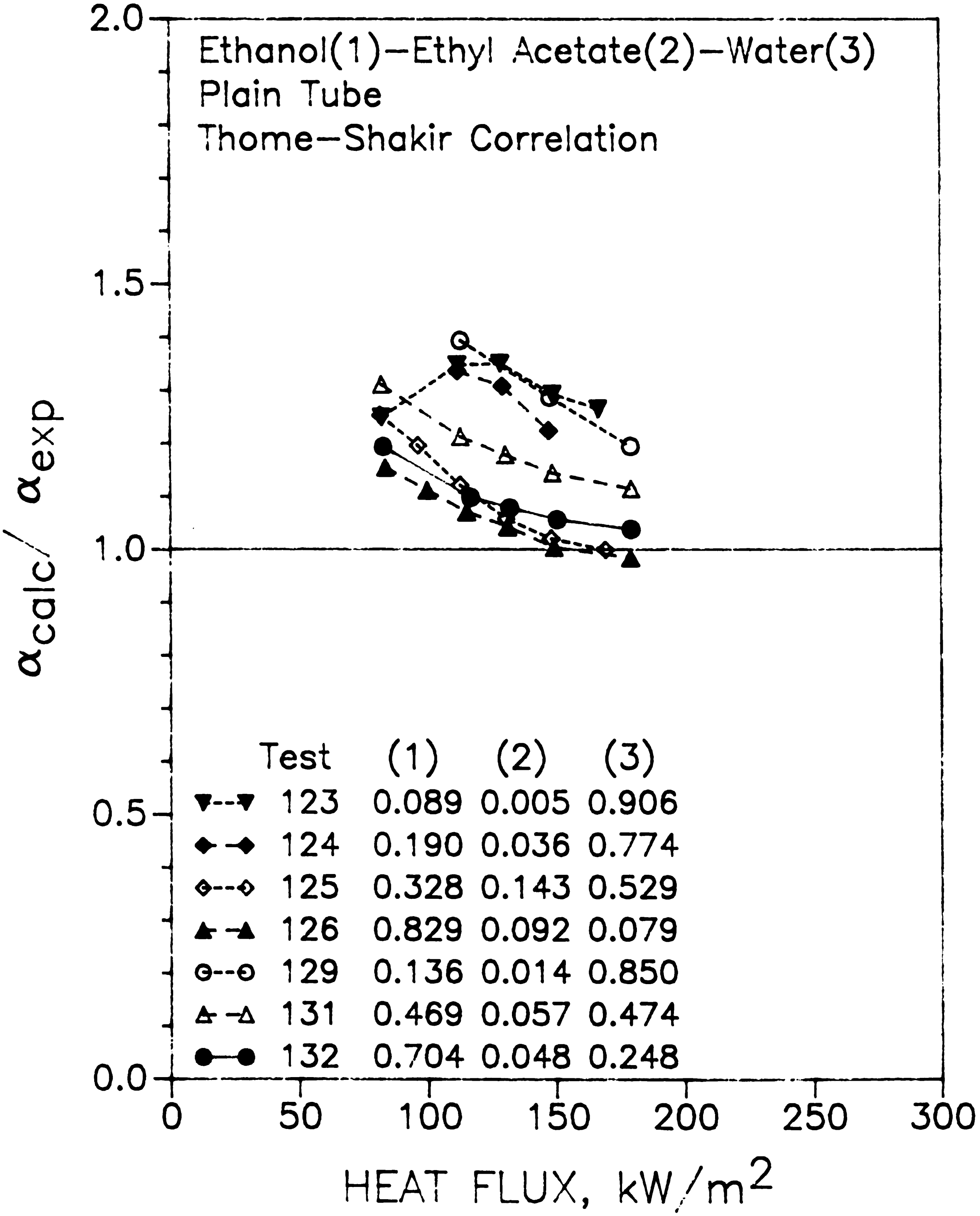


Figure 6.38 Comparison of the Thome-Shakir correlation, Eq. 6-6, to experimental heat transfer coefficients in ethanol-ethyl acetate -water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

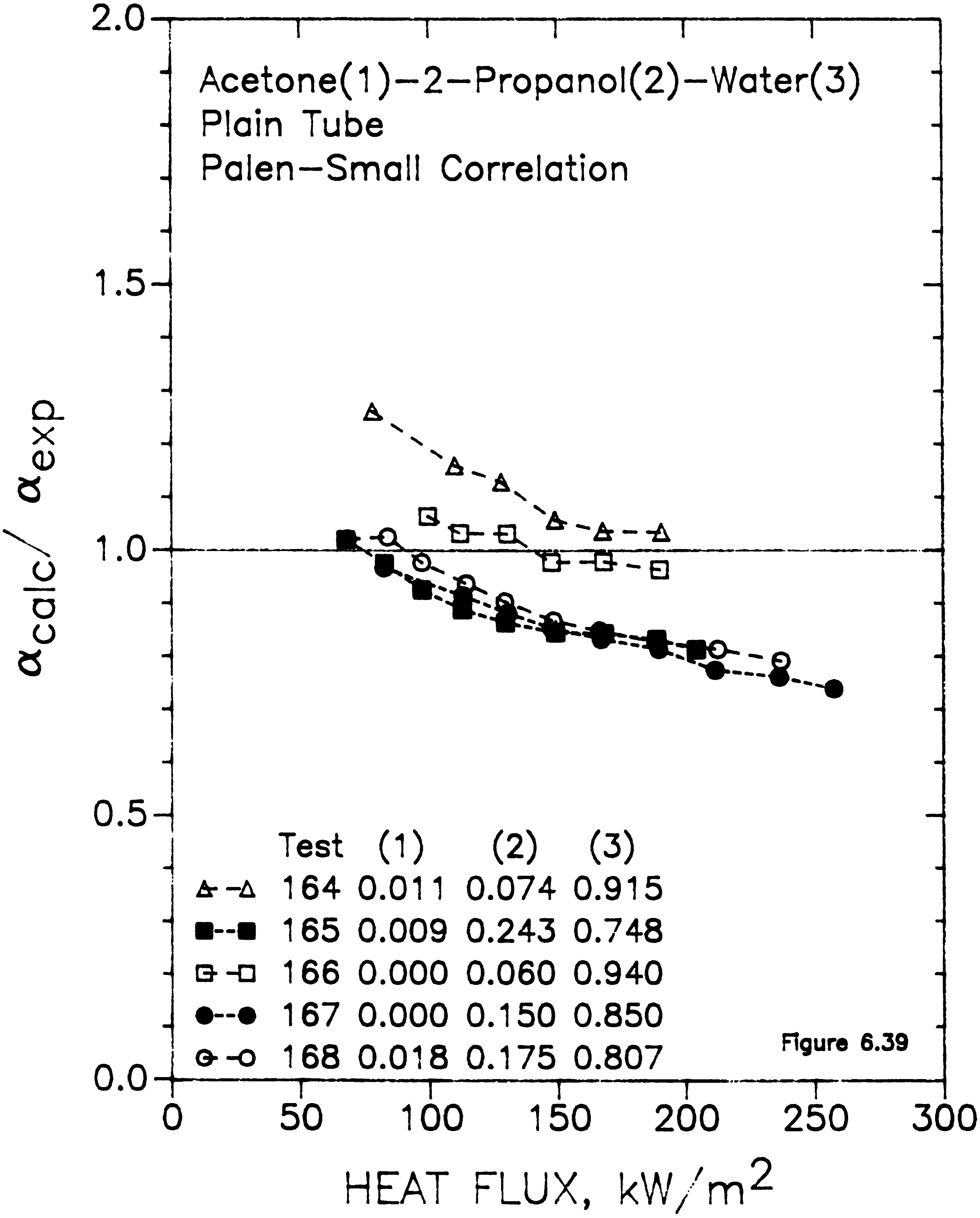


Figure 6.39 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in 2-propanol-water and acetone- 2-propanol - water mixtures. The Stephan- Abdelsalam correlation was used to calculate α_{id}.

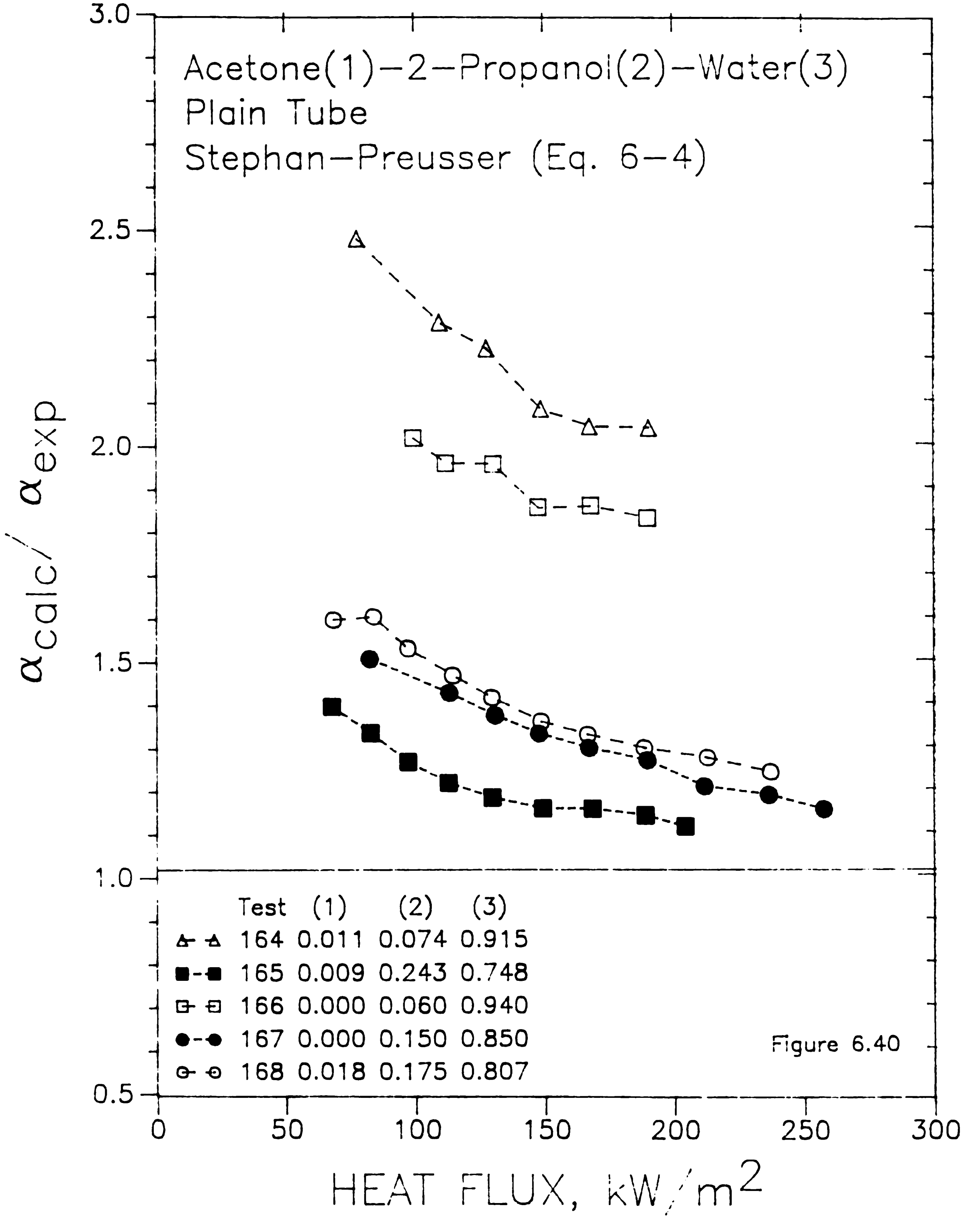


Figure 6.40 Comparison of the Stephan-Preusser correlation, Eq. 6-4, to experimental heat transfer coefficients in 2-propanol-water and acetone- 2-propanol - water mixtures.

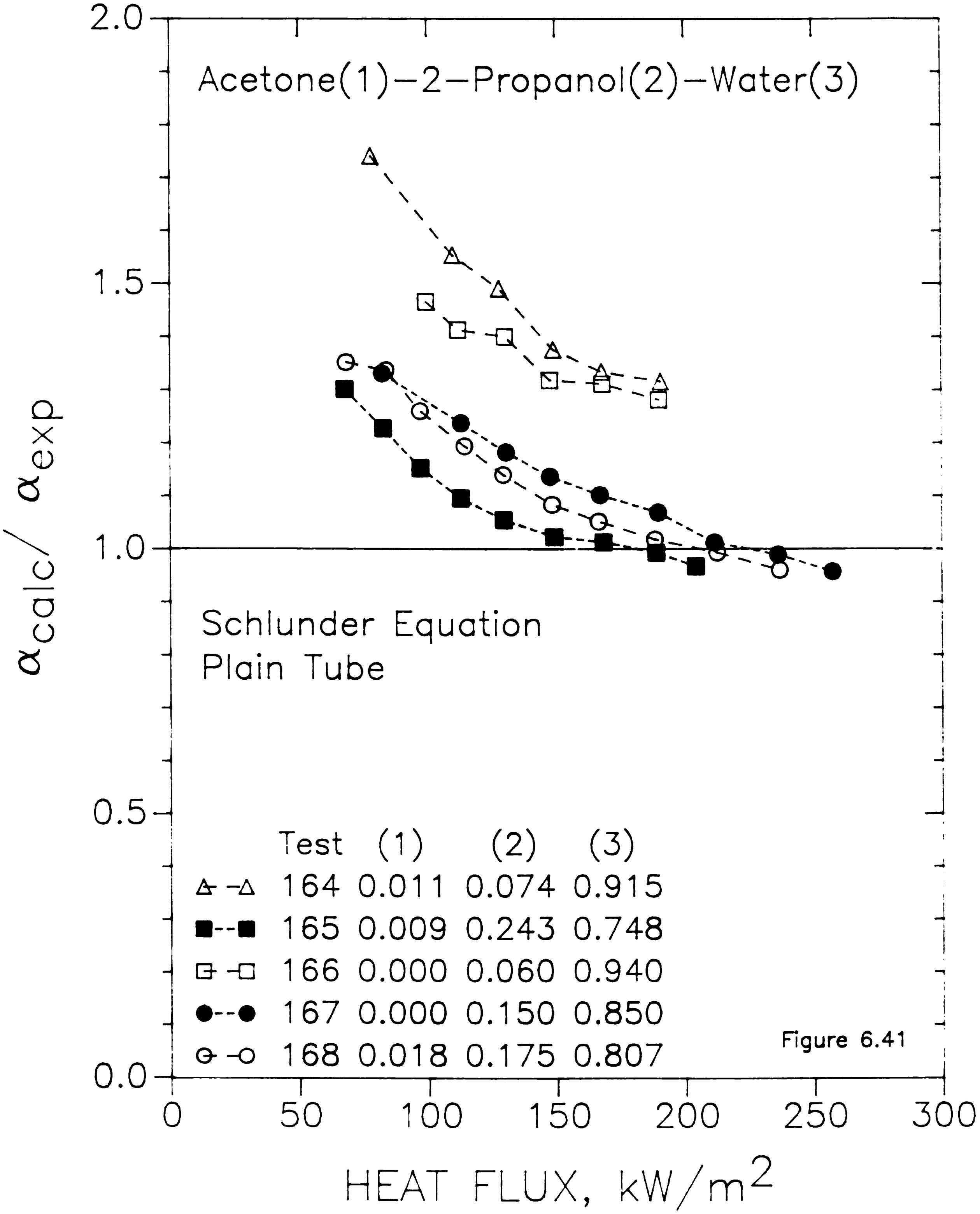


Figure 6.41 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in 2-propanol-water and acetone- 2-propanol - water mixtures. The Stephan- Abdelsalam correlation was used to calculate α_{id}.

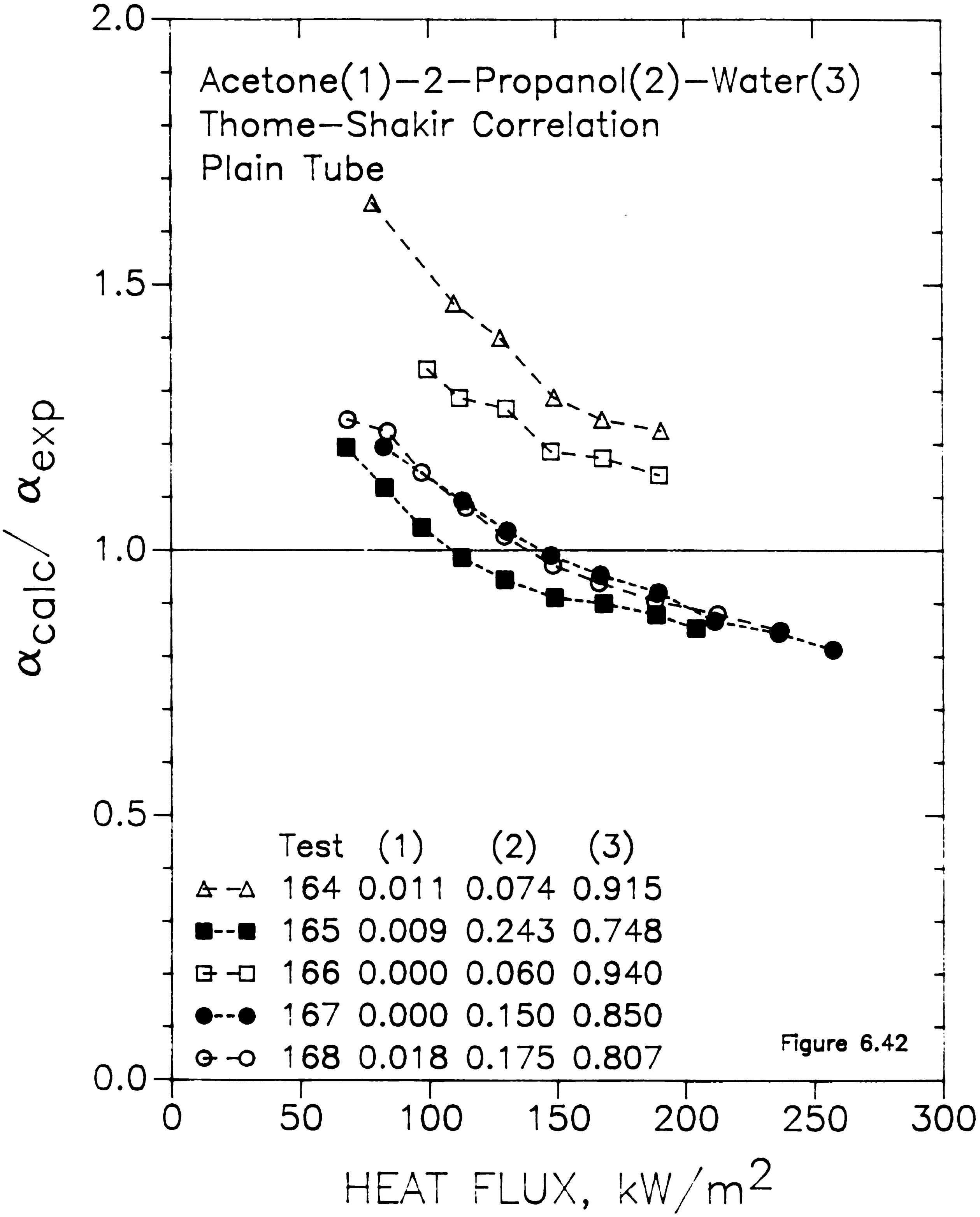


Figure 6.42 Comparison of the Thome-Shakir correlation, Eq. 6-6, to experimental heat transfer coefficients in 2-propanol-water and acetone- 2-propanol - water mixtures. The Stephan- Abdelsalam correlation was used to calculate α_{id}.

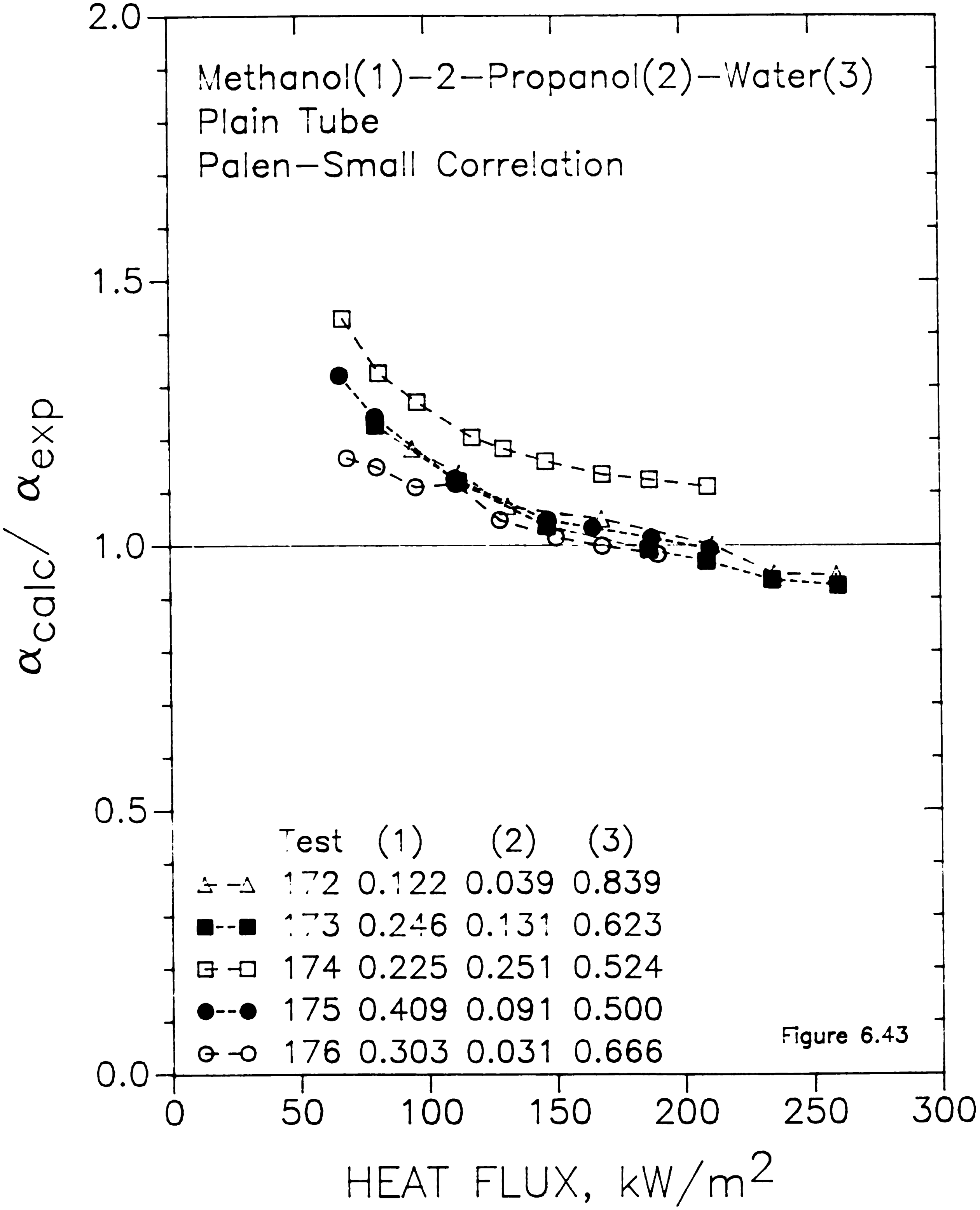


Figure 6.43 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in methanol-2-propanol - water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

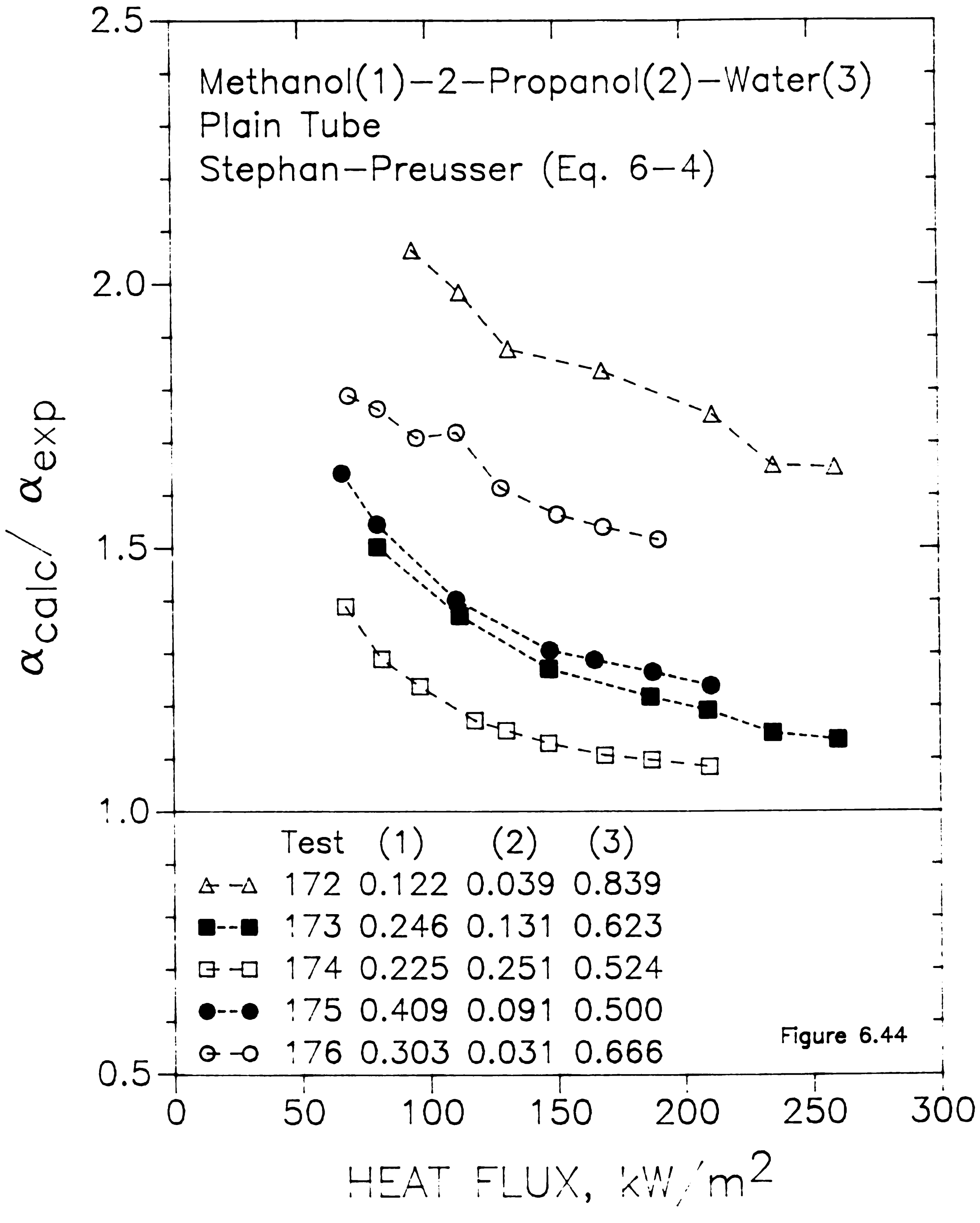


Figure 6.44 Comparison of the Stephan-Preusser correlation, Eq. 6-4, to experimental heat transfer coefficients in methanol-2-propanol - water ternary mixtures.

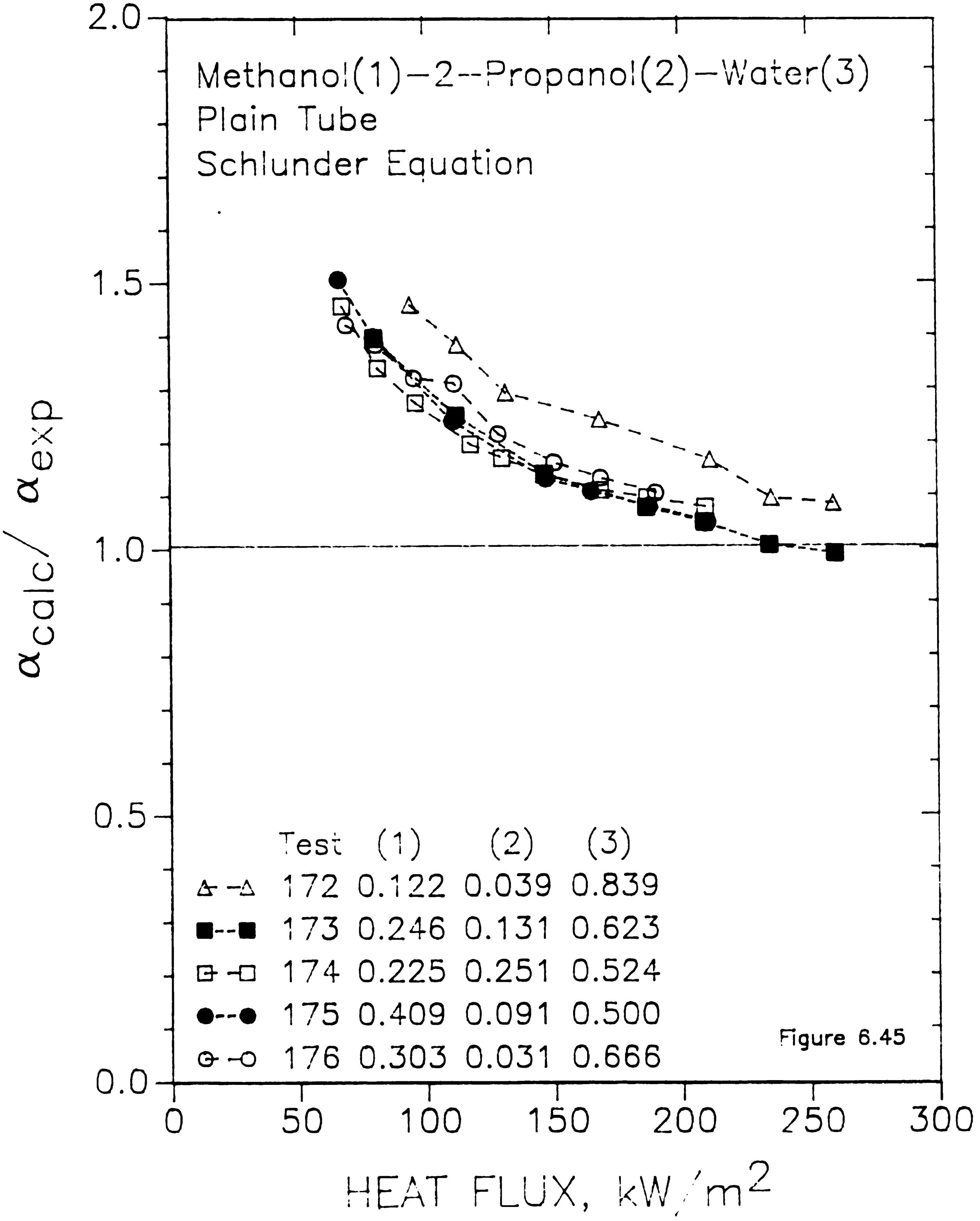


Figure 6.45 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in methanol-2-propanol - water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

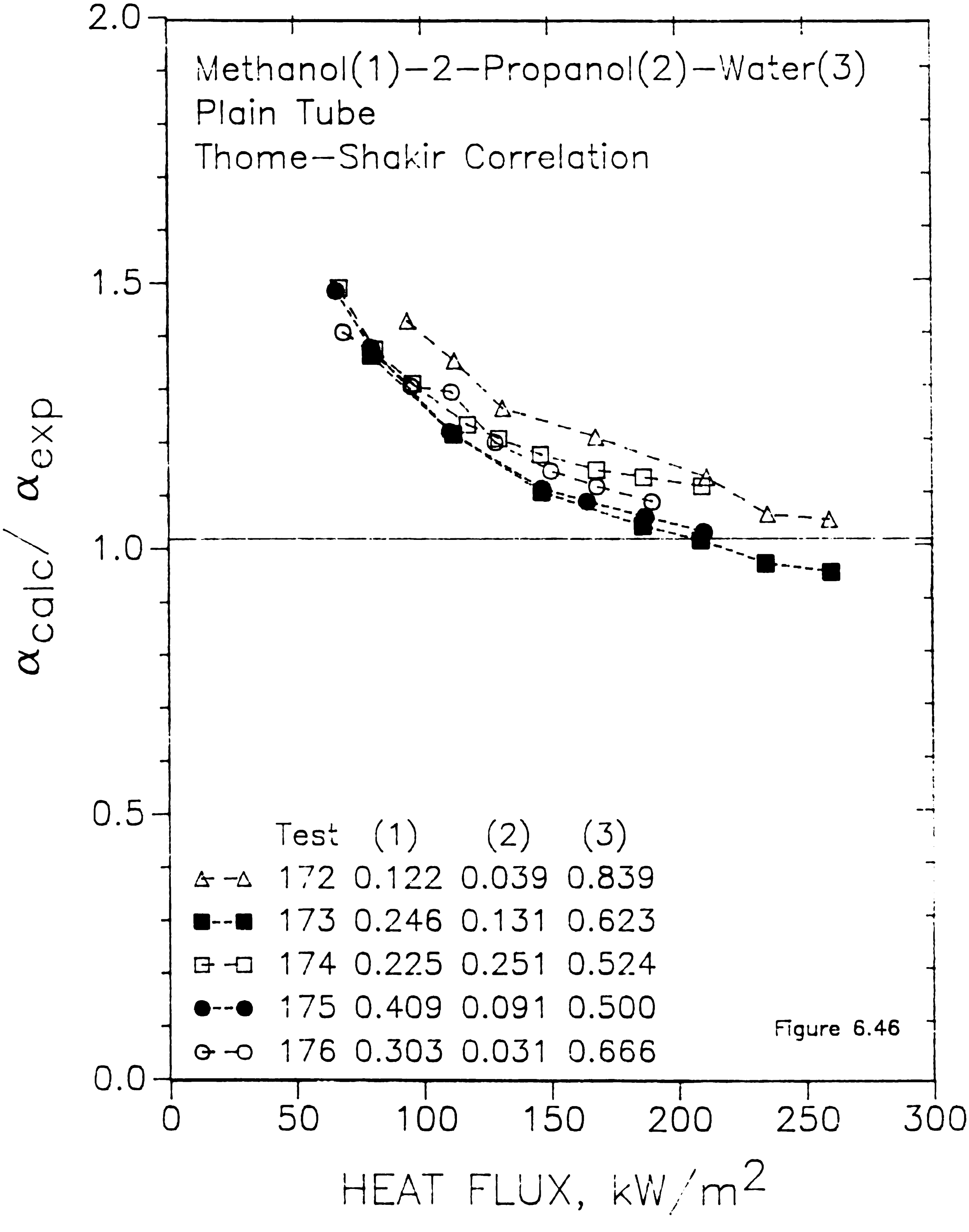


Figure 6.46 **Comparison of the Thome-Shakir correlation Eq. 6-6, to experimental heat transfer coefficients in methanol-2-propanol - water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.**

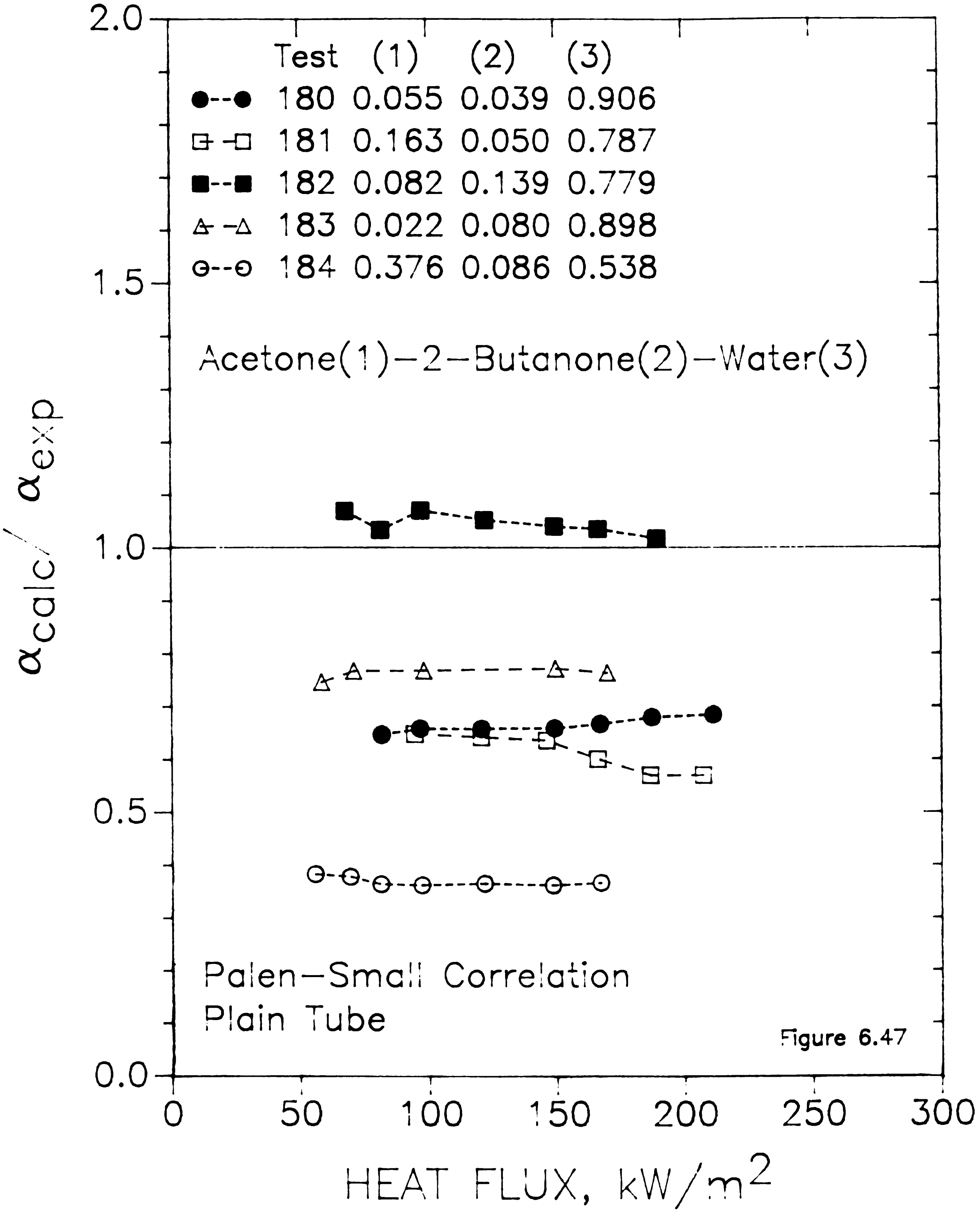


Figure 6.47 Comparison of the Palen-Small correlation, Eq. 6-1, to experimental heat transfer coefficients in acetone-2-butanone - water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

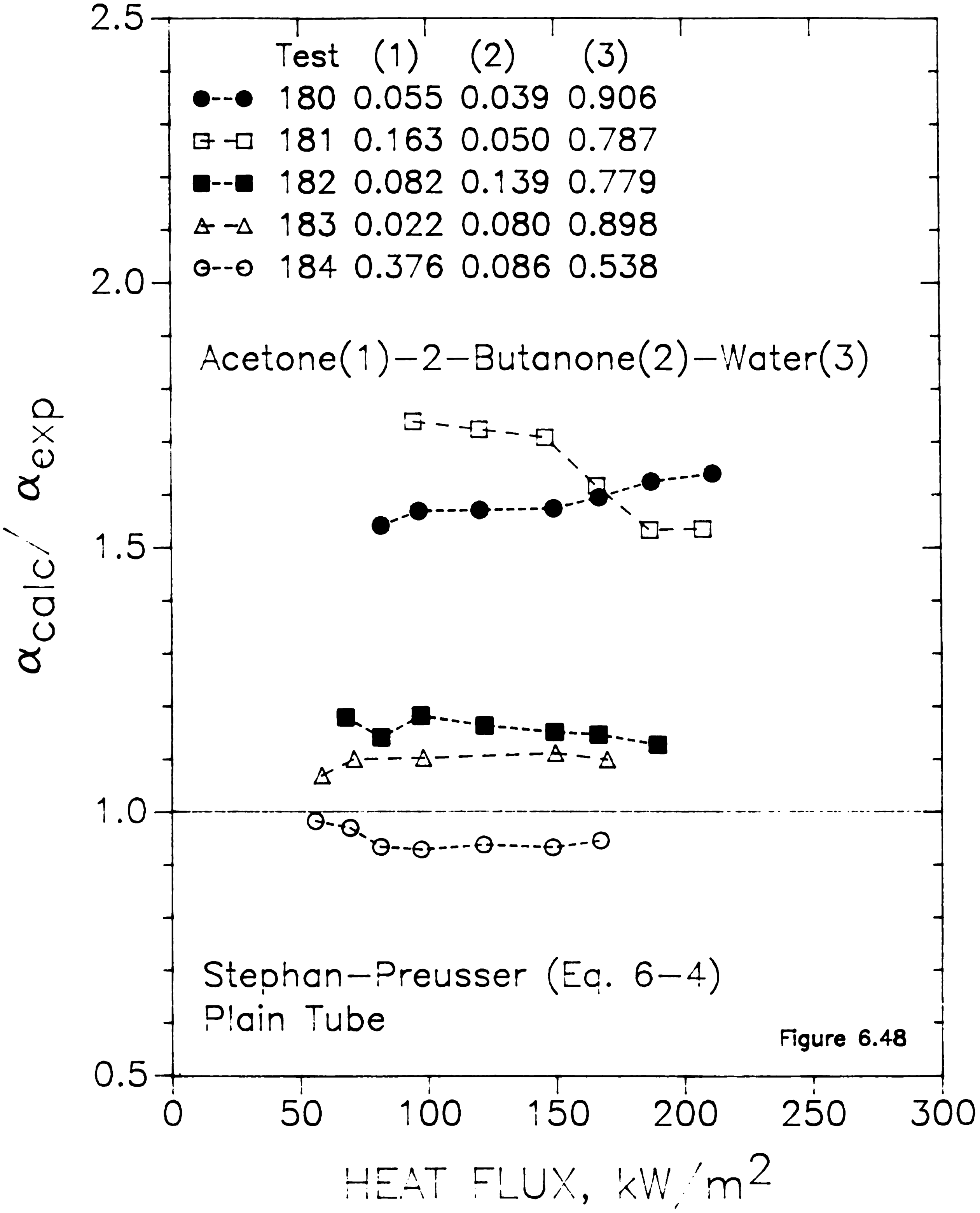


Figure 6.48 Comparison of the Stephan-Preusser correlation, Eq. 6-4, to experimental heat transfer coefficients in acetone-2-butanone - water ternary mixtures.

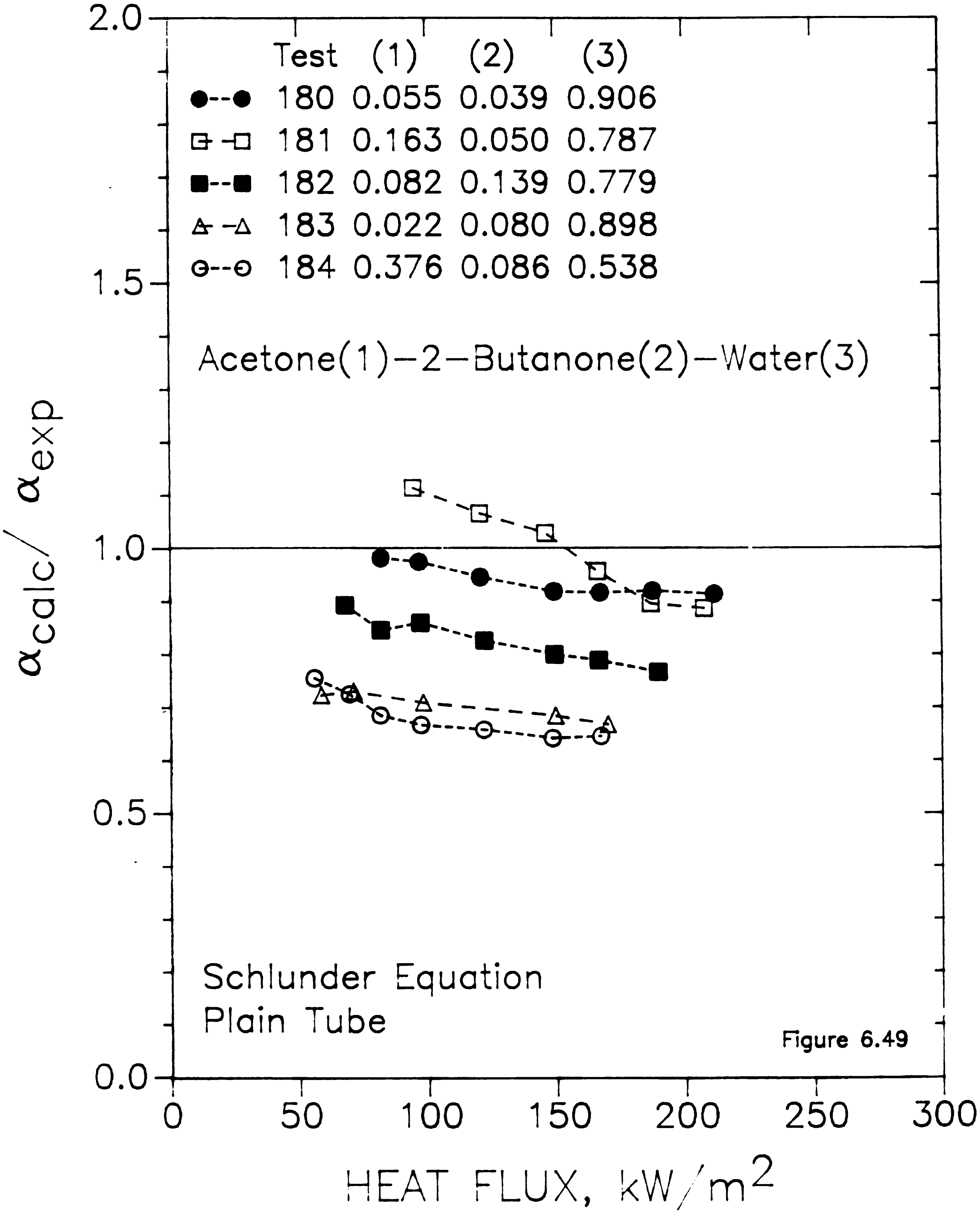


Figure 6.49 Comparison of the Schlunder equation, Eq. 6-5, to experimental heat transfer coefficients in acetone-2-butanone - water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

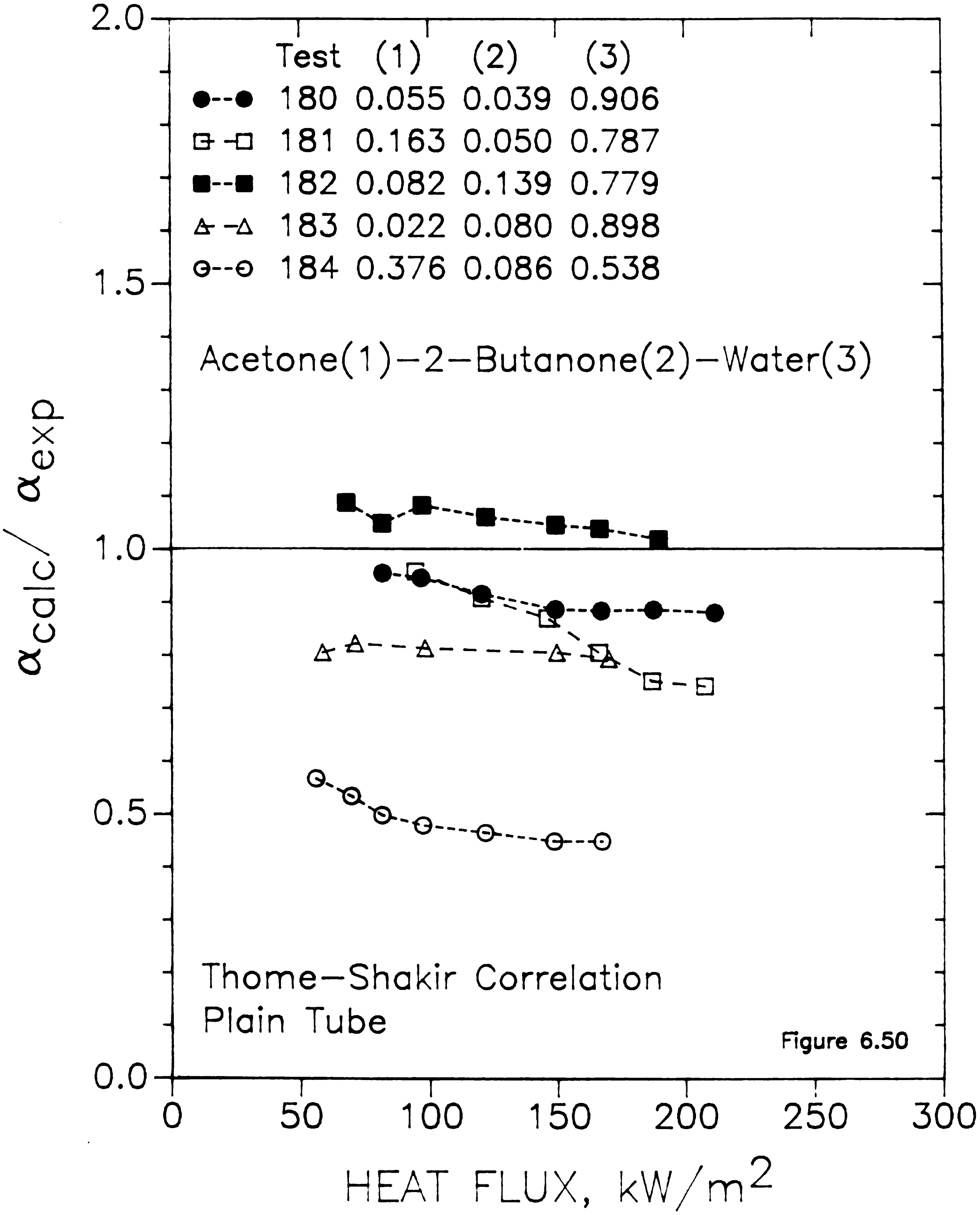


Figure 6.50 Comparison of the Thome-Shakir correlation, Eq. 6-6, to experimental heat transfer coefficients in acetone-2-butanone - water ternary mixtures. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

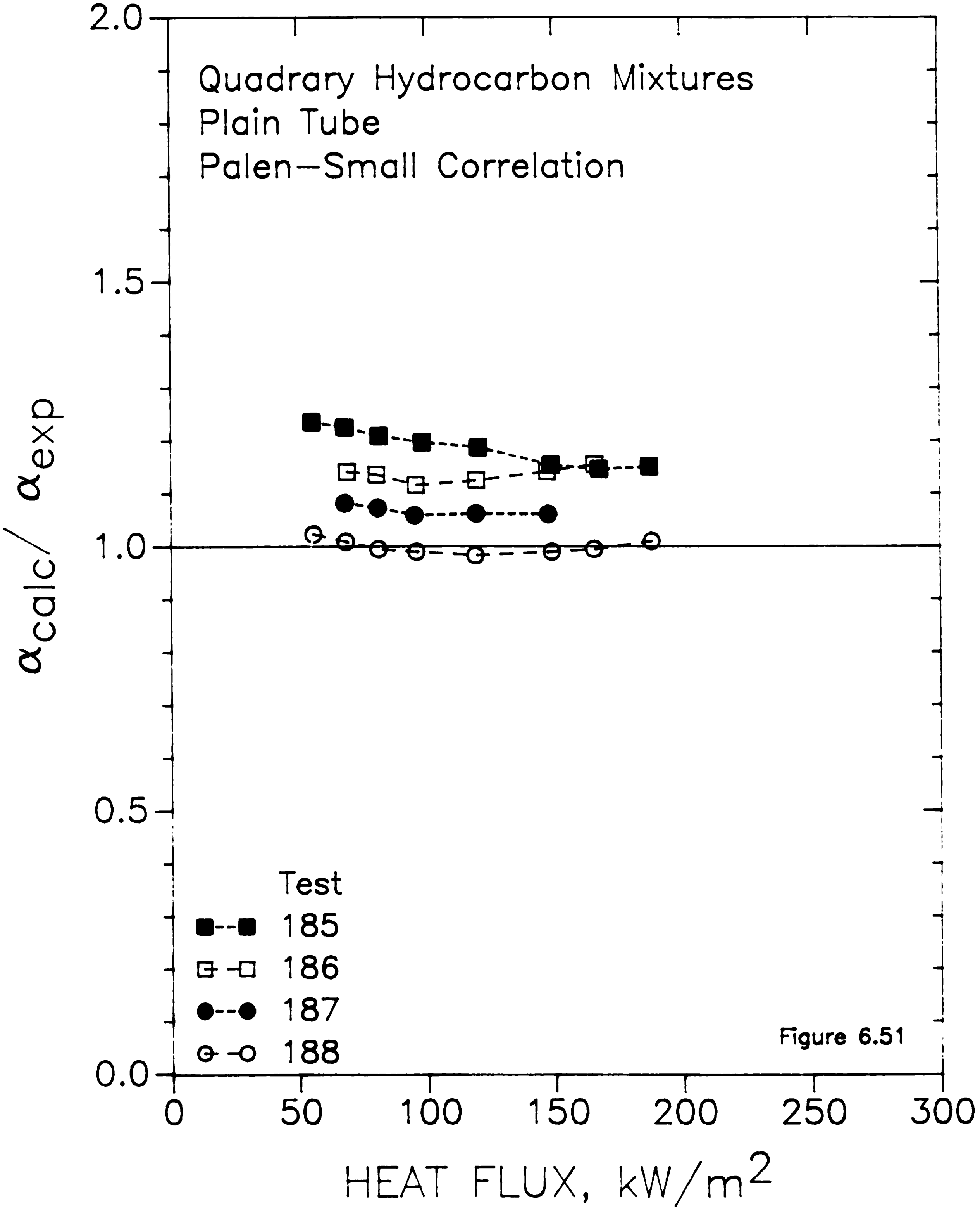


Figure 6.51 Comparison the Palen-Small correlation to experimental heat transfer coefficients from four quadrary mixtures of light hydrocarbons. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

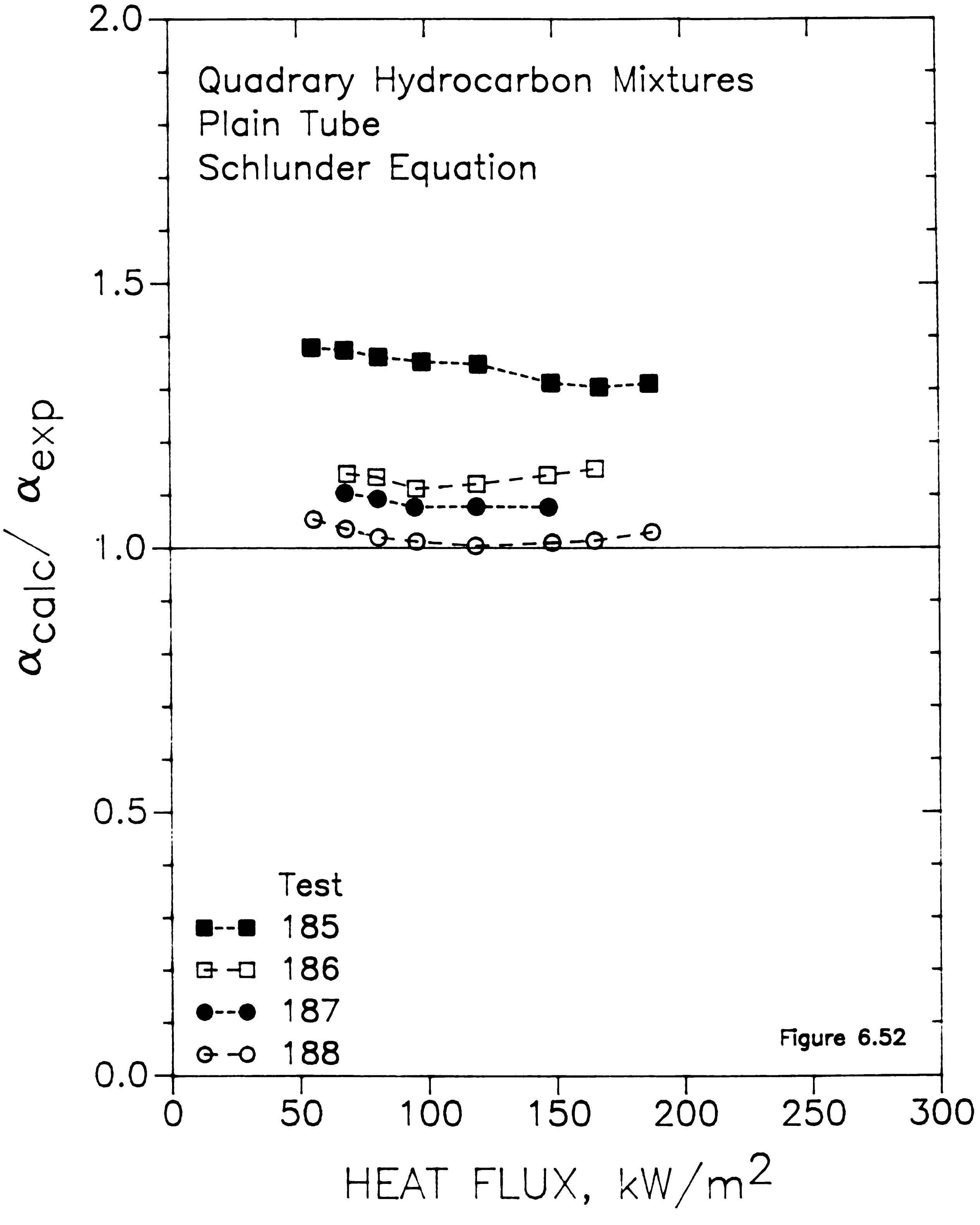


Figure 6.52 Comparison the Schlunder equation to experimental heat transfer coefficients from four quadrary mixtures of light hydrocarbons. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

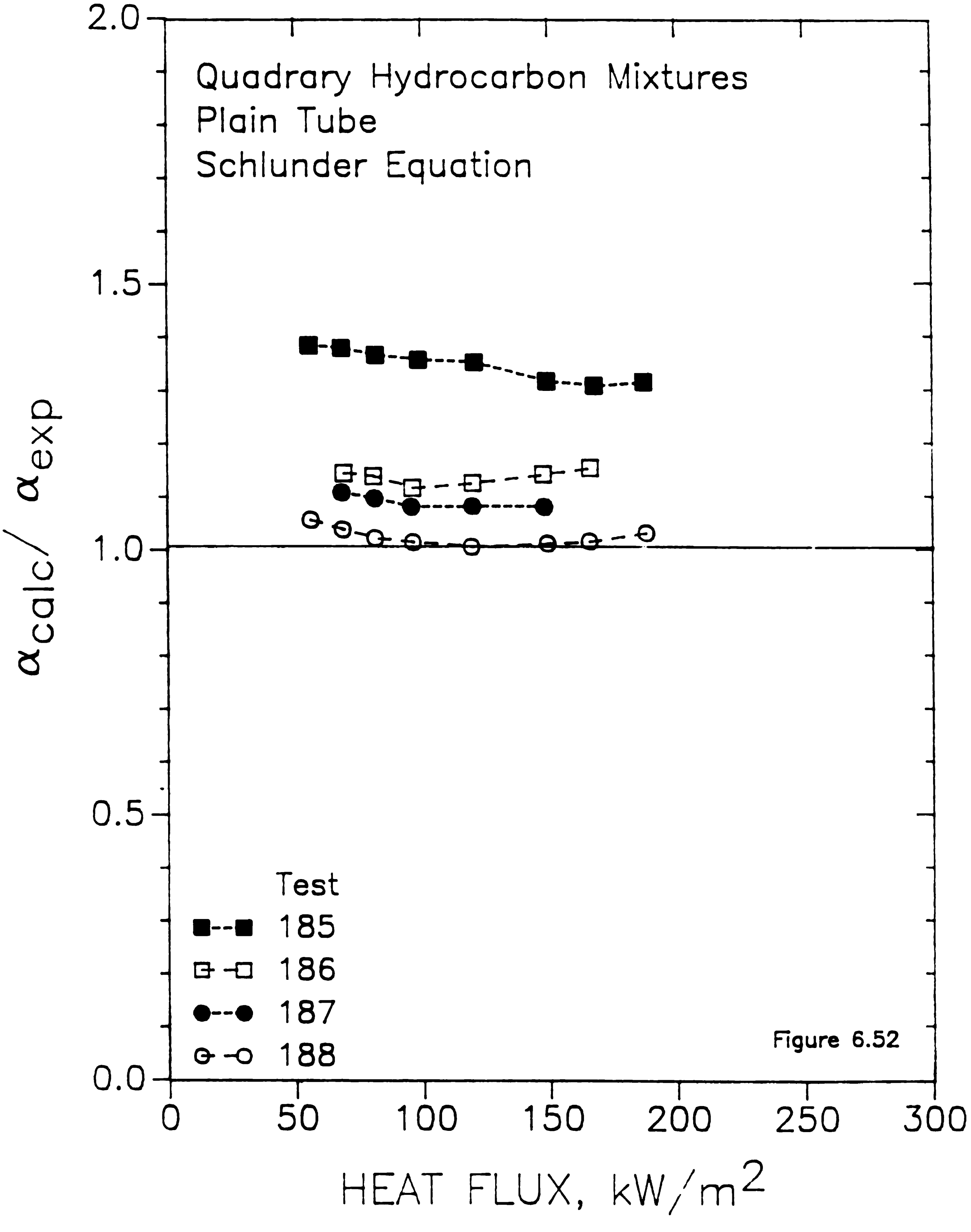


Figure 6.53 Comparison the Thome-Shakir correlation to experimental heat transfer coefficients from four quadrary mixtures of light hydrocarbons. The Stephan-Abdelsalam correlation was used to calculate α_{id}.

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CHAPTER 7

NEW MODEL FOR NUCLEATE POOL BOILING IN MULTICOMPONENT MIXTURES

The evaluation of existing multicomponent nucleate pool boiling correlations in the previous section identified the Schlunder and the Thome-Shakir correlations as the most reliable provided the Stephan-Abdelsalam correlation is used to calculate the ideal heat transfer coefficient. This section examines the underlying assumptions used in the derivation of these two mixture boiling correlations and presents a new model for nucleate pool boiling in multicomponent mixtures.

7.1 DERIVATION OF THE SCHLUNDER AND THOME-SHAKIR EQUATIONS

This section reviews the derivation of the Schlunder and Thome-Shakir correlations, and highlights the major assumptions used in their development. Both equations are based on the film theory of mass transfer, but differ in the manner in which the slope of the bubble point curve is approximated.

Bird et al. (1960) show that the steady state transport of a volatile component to an interface is given by:

$$\frac{r_1 - x_b}{r_1 - x_i} = \exp\left(-(N_1+N_2)\frac{\delta_{12}}{c\mathcal{D}_{12}}\right) \tag{7-1}$$

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where r_1 represents the relative boiling rate of component 1 and is:

$$r_1 = \frac{N_1}{\sum N_j} \tag{7-2}$$

For an equilibrium process, the relative boiling rate is $r_1 = y_i$. Thus,

$$\frac{y_i - x_b}{y_i - x_i} = \exp(-(N_1+N_2)\frac{\delta_{12}}{c\mathcal{D}_{12}}) \tag{7-3}$$

This expression can be rearranged to give the difference between the mole fractions in the bulk liquid and the interface. That is,

$$(x_b-x_i) = (y_i-x_i)\ [\ 1 - \exp(-(N_1+N_2)\frac{\delta_{12}}{c\mathcal{D}_{12}})] \tag{7-4}$$

If $\alpha = q''/(T_w-T_b)$ and $\alpha_{id} = q''/(T_i-T_b)$ are defined, the ratio of these two quantities can be expressed as:

$$\frac{\alpha}{\alpha_{id}} = \left[1 + \frac{(T_i-T_b)}{(T_w-T_i)} \right]^{-1} \tag{7-5}$$

or,

$$\frac{\alpha}{\alpha_{id}} = \frac{1}{1 + (\alpha_{id}/q'')(T_i-T_b)} \tag{7-6}$$

The term (T_i-T_b) represents the temperature difference between the interface and the bulk liquid, and is the unknown to be determined. Schlunder approximated this quantity as:

$$(T_i-T_b) \approx - \frac{dT}{dx}\ (x_b-x_i) \tag{7-7}$$

Substituting for (x_b-x_i), this equation becomes,

$$(T_i-T_b) \approx - \frac{dT}{dx}\ (y_i-x_i)[\ 1 - \exp(-\Psi)\ ] \tag{7-8}$$

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where,

$$\Psi = -(N_1+N_2)\frac{\delta_{12}}{c\mathcal{D}_{12}} \tag{7-9}$$

Schlunder further simplified Eq. 7-8 by assuming,

$$\frac{dT}{dx} \approx \frac{T_{s1}-T_{s2}}{1.0 - 0.0} = T_{s1}-T_{s2} \tag{7-10}$$

and,

$$(y_i-x_i) \approx (y_b-x_b) \tag{7-11}$$

With these approximations, Eq. 7-8 becomes,

$$(T_i-T_b) \approx (T_{s2}-T_{s1})(y_b-x_b)[\ 1 - \exp(-\Psi)\ ] \tag{7-12}$$

Substitution of Eq. 7-12 into Eq 7-6 for (T_i-T_b) yields the Schlunder equation, Eq. 2-39. Figure 7.1 shows the terms used in this derivation. Clearly, Schlunder's approximation of the slope of the bubble point curve does not match the actual slope except at one composition. For aqueous mixtures, this slope can be a strong function of composition. The assumptions given by Eqs. 7-10 and 7-11 can be greatly in error at very low and at very high mole fraction compositions of the light component.

Thome and Shakir improved the Schlunder equation by providing a more accurate approximation of the slope of the bubble point curve. They also approximated the temperature difference across the thermal layer surrounding a bubble using,

$$(T_i-T_b) \approx -\frac{dT}{dx}(x_b-x_i) \tag{7-13}$$

The boiling range is the difference in temperature between the dew point and the bubble point at the bulk liquid composition as shown in Figure 7.2. Thome and Shakir used the boiling range to approximate Eq. 7-13 as,

$$(T_i-T_b) \approx \frac{\Delta T_{bp}}{(y_i-x_i)}(x_b-x_i) \tag{7-14}$$

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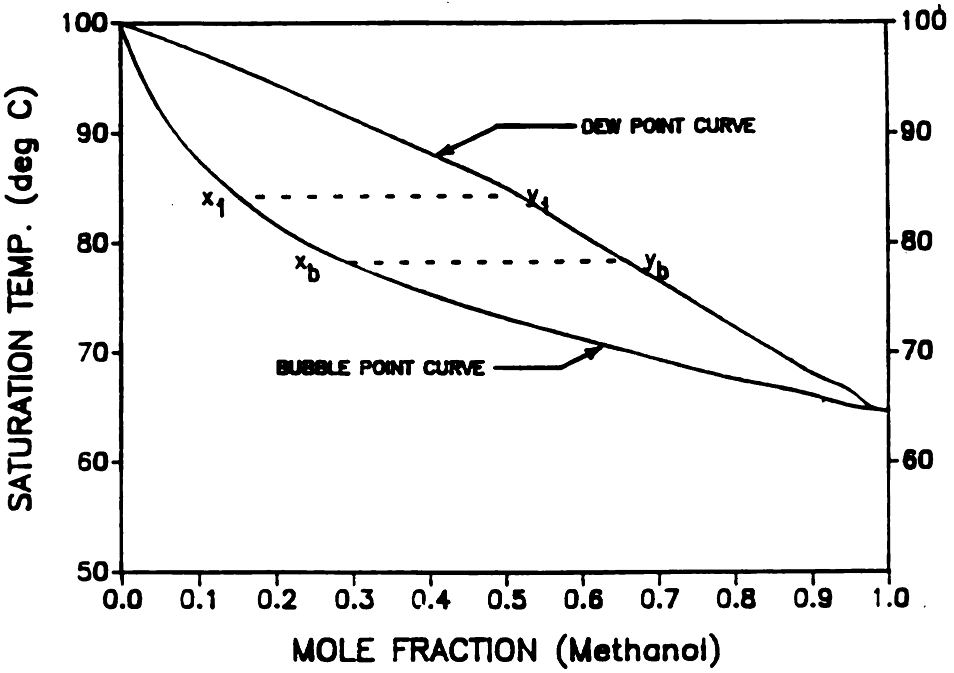

Figure 7.1 Approximation of the slope of the bubble point curve in the Schlunder equation.

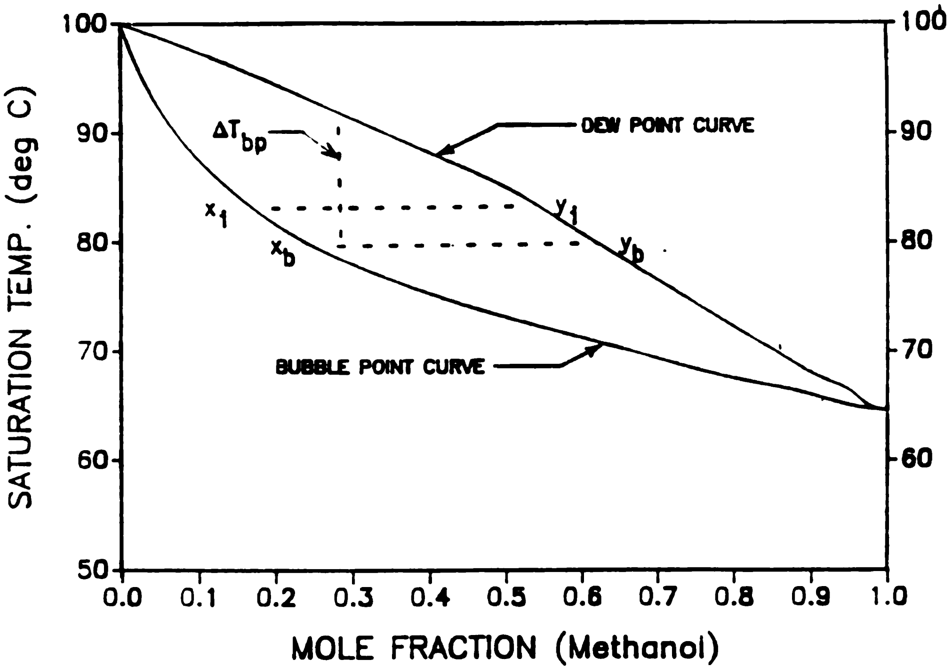

Figure 7.2 Approximation of the slope of the bubble point curve in the Thome-Shakir equation.

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Substituting Eq. 7-14 into Eq. 7-13 approximates the temperature difference across the interface as,

$$(T_i - T_b) \approx \Delta T_{bp}[\ 1 - \exp(-\Psi)\ ] \tag{7-15}$$

Substituting Eq. 7-15 into Eq. 7-6 gives the Thome-Shakir mixture boiling correlation, Eq. 2-41.

The term Ψ, given by Eq. 7.9, is derived from the interfacial heat and mass transfer to the growing bubble. Both Schlunder and Thome and Shakir approximate this term in the same fashion in order to eliminate the binary mass diffusivity $\mathcal{D}_{12}$, and the thickness of the concentration layer δ_{12}. The mass diffusivity can be related to a mass transfer coefficient using Fick's Law:

$$-c\mathcal{D}_{12}\frac{dx}{dz} = \beta\Delta c \tag{7-16}$$

Recalling that $\Delta c = c\Delta x$, and approximating dx/dz as $-\Delta x/\delta_{12}$ yields,

$$\frac{\delta_{12}}{\mathcal{D}_{12}} = \frac{1}{\beta} \tag{7-17}$$

Assuming the rate of heat transfer is determined by the rate of mass transfer, Schlunder equated the heat and mass as,

$$B_o q'' = M\Delta h_v(N_1+N_2) \tag{7-18}$$

where B_0 is a scaling factor. Substituting Eq. 7-17, Eq. 7-18 and the definition, $\rho = cM$ into Eq. 7-9 results in,

$$\Psi = (N_1+N_2)\frac{\delta_{12}}{c\mathcal{D}_{12}} = \frac{B_o q''}{\rho\Delta h_v\beta} \tag{7-19}$$

Schlunder recommended the values of B_0 and β to be B_0=1.0 and β=2x10^{-4} m/s.

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The validity of approximating the slope of the bubble point curve as suggested by Schlunder and Thome and Shakir can be assessed by testing these correlations against one that uses the exact value of (dT/dx). This correlation for binary mixtures, assuming $(y_i-x_i)=(y_b-x_b)$, is:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''}\left[\left(\frac{dT}{dx}\right)(y-x)\left[1-\exp\left(\frac{B_0 q''}{\rho \Delta h_v \beta}\right)\right]\right]\right\}^{-1} \qquad (7\text{-}20)$$

Eq. 7-20 was used to estimate the nucleate boiling heat transfer coefficients in binary mixtures of acetone and water and compared to the experimental data obtained for that system at 1.01 bar. Values of (dT/dx) were obtained from an acetone-water binary vapor-liquid equilibrium diagram. Table 7-1 lists the results of comparisons of Eq. 7-20 and Eq. 2-39 with experimental data. The linear mixing law was used to evaluate the ideal heat transfer coefficient.

Table 7-1

Evaluation of Approximations for dT/dx in Acetone-Water Binary Mixtures

Method:	Eq.	Ave.Error	Std.Dev.
Schlunder with $dT/dx = T_{s1}-T_{s2}$	2-39	-9.7	36.1
Schlunder with exact dT/dx	7-20	26.9	29.7

Although the mean error has improved, the standard deviation has increased. This indicates that use of the actual value of the slope of the bubble point curve tends to increase the scatter in the prediction of experimental data. If a correlation accurately models a physical process, then providing more accurate parameters for that correlation in place of approximations should improve the results. Table 7-1 shows that accuracy improvement does not occur in the case of the Schlunder and Thome-Shakir equations. This indicates that the term within the exponential may not be an accurate model.

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7.2 NEW MODEL FOR INTERFACIAL TRANSPORT

This section considers the approximations used to estimate Ψ, which models the heat and mass transfer at the bubble interface. For a multicomponent system, Eq. 7-9 is written as:

$$\Psi = \sum N_j \frac{\delta_{12}}{c\mathcal{D}_{12}} \tag{7-21}$$

Since the mass diffusivity is generally an order of magnitude lower than the thermal diffusivity, assume that the rate of heat transfer is limited by the rate of mass transfer to the bubble interface. Similar to Schlunder, equate the heat transfer rate and the mass transfer rate by,

$$M \, \Delta h_v \sum N = q''_{\ell} \tag{7-22}$$

Two important distinctions between this expression and Eq. 7-18 must be made however. In this expression, the scaling factor B_0 is not used. Physically, the term B_0 in Eq. 7-18 represents the fraction of energy that is used as latent heat as opposed to energy used as sensible heat. In Eq. 7-22, we assume that all of the heat transferred to the interface is used to generate vapor, and thus, superheating of the vapor does not occur. A second important difference between Eq. 7-22 and 7-18 is interpretation of the heat transfer term. Schlunder assumes that all of the heat transfer is due to phase change at the bubble interface. A large proportion of the overall heat transfer however, is due to the thermal stripping mechanism. Thus, the heat transfer term in Eq. 7-22 is denoted as q''_{ℓ} to represent only the energy transfer as latent heat.

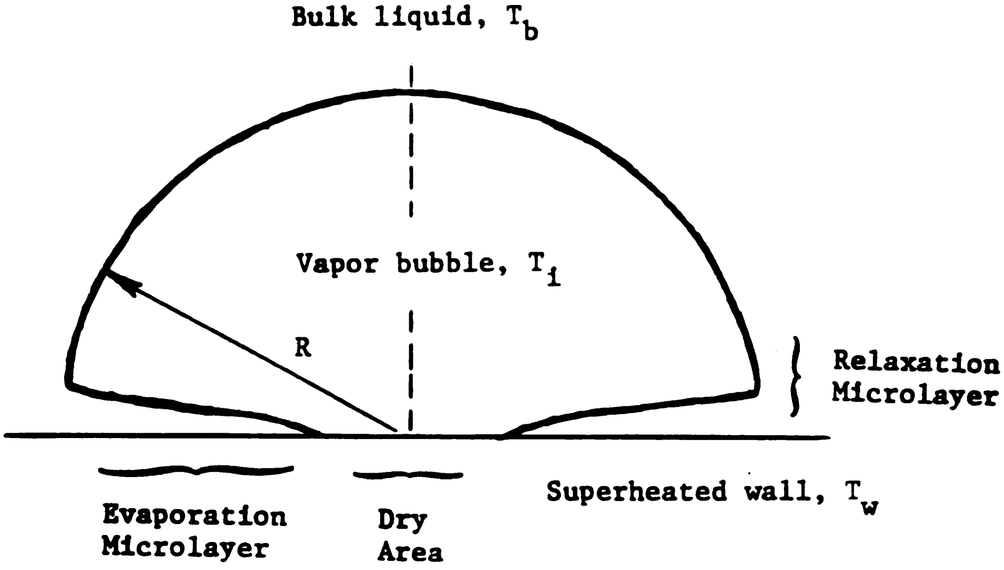

Figure 7.3 Evaporation and relaxation microlayers during growth of a bubble near a heated surface.

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Heat transfer to the bubble can be considered as occurring in two regions. The evaporation microlayer is the thin film of liquid that becomes trapped beneath a growing bubble. The relaxation microlayer is the region surrounding the bubble in the thermal boundary layer of the wall that is above the bulk saturation temperature. Figure 7.3 shows the location of these regions relative to a growing bubble. Both regions contribute to the overall bubble growth. The heat transport to the bubble can be expressed as:

$$q''_{\ell} = k \frac{T_{TE}-T_i}{\delta_{TE}} \qquad (7\text{-}23)$$

where T_{TE} represents an effective temperature for conduction across an effective thermal length, δ_{TE}, to the bubble interface. This effective thickness is comprised of contributions from both the evaporation microlayer and the relaxation microlayer. At the evaporation microlayer, the effective temperature for conduction is the wall surface temperature T_w, and in the relaxation microlayer close to the wall it is between T_w and T_b. Considering the quantity $(T_{TE}-T_i)$ to be comprised of separate evaporation microlayer and relaxation microlayer contributions, Eq. 7-23 can be written as:

$$q''_{\ell} = \frac{k}{\delta_{TE}}\{f(T_w-T_i) + (1-f)(T_{b1}-T_i)\} \qquad (7\text{-}24)$$

Assuming a linear temperature profile and a bubble size equal to or greater than the thermal boundary layer thickness on the wall, Eq. 7-24 becomes:

$$q''_{\ell} = \frac{k}{\delta_{TE}}\{f(T_w-T_i) + (1-f)(\frac{(T_w+T_b)}{2} - T_i)\} \qquad (7\text{-}25)$$

$$= \frac{k}{\delta_{TE}}\{f(T_w-T_i) + \frac{1-f}{2}[(T_w-T_i)+(T_b-T_i)]\} \qquad (7\text{-}26)$$

$$= \frac{k}{\delta_{TE}}(\frac{1+f}{2}(T_w-T_i) + \frac{1-f}{2}(T_b-T_i) \qquad (7\text{-}27)$$

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The possible values for f are from 0 to 1. A value of $f = 1$ implies that the evaporation microlayer is responsible for all of the heat transfer while a value of $f = 0$ implies that all of the heat transfer occurs in the relaxation microlayer. Since most of the heat and mass transfer during bubble growth occurs in the evaporation microlayer and in the relaxation microlayer near the wall, a value of $f \approx 1$ is assumed in Eq. 7-27 so that:

$$q''_{\ell} = k \frac{T_w - T_i}{\delta_{TE}} \tag{7-28}$$

By definition, the overall heat rate of heat transfer can be expressed in terms of the ideal heat transfer coefficient as:

$$q'' = \alpha_{id}(T_w - T_i) \tag{7-29}$$

Again recalling that $c = \rho/M$, and substituting Equations 7-22, 7-24 and 7-25 into Eq. 7-21, a new expression for Ψ is obtained:

$$\Psi = \frac{kq''}{\rho \Delta h_v \mathcal{D}_{12} \alpha_{id}} \left(\frac{\delta_{12}}{\delta_{TE}}\right) \tag{7-30}$$

The effective thickness of the concentration layer δ_{12}, and the effective thermal length scale δ_{TE} depend on transport phenomena in both the evaporation microlayer, and the relaxation microlayer and are functions of time as the bubble grows. Average values of these terms around the bubble are used here. The concentration layer around a bubble grows according to $\delta_{12} = (\kappa t)^{1/2}$ and the thermal layer around the bubble grows as $\delta_{TE} = (\mathcal{D} t)^{1/2}$. The ratio of these two length scales can be expressed as:

$$\frac{\delta_{TE}}{\delta_{12}} = \frac{(\kappa t)^{1/2}}{(\mathcal{D}_{12} t)^{1/2}} = \sqrt{(\kappa/\mathcal{D}_{12})} = \sqrt{Le} \tag{7-31}$$

where Le is the Lewis number at a particular liquid composition.

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Substituting $(Le)^{1/2}$ for $(\delta_{TE}/\delta_{12})$ in Eq. 7-30 results in:

$$\Psi = \frac{kq''}{\rho \Delta h_v \mathcal{D}_{12} \alpha_{id} (Le)^{1/2}} \qquad (7\text{-}32)$$

The new correlation for binary mixtures is:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''} \left[\left(\frac{dT}{dx}\right)(y_b - x_b) \left[1 - \exp\left(\frac{-kq''}{\rho \Delta h_v \mathcal{D}_{12} \alpha_{id} (Le)^{1/2}}\right)\right] \right] \right\}^{-1} \qquad (7\text{-}33)$$

Unlike the semi-empirical Schlunder and Thome-Shakir correlations, this expression does not contain any unknown parameters. Eq. 7-33 is generally valid for all mixtures and the heat transfer coefficient depends on the heat flux and thermodynamic properties. Because the mass diffusivity appears explicitly however, Eq. 7-33 is not practical for use as a design tool. Its main value is as a tool to validate simpler correlations for use with a wide variety of mixture systems.

Figure 7.4 shows a comparison of Eq. 7-33 with acetone-water and ethanol- water binary mixtures using the Stephan- Abdelsalam correlation with mixture properties for the ideal heat transfer coefficient. The binary mass diffusion coefficients used in the new expression for this system were the experimental values reported by Tyn and Calus (1975). Compared to the experimental heat transfer coefficients from the acetone-water and ethanol-water binary mixtures, the mean error was 9.0% and the standard deviation was 31.7%. For these same mixtures, the Schlunder equation had a mean error of 2.0% with a standard deviation of 21.0% and the Thome-Shakir correlation had a mean error of -5.2% and standard deviation of 23.4%. Thus, although the new correlation for binary mixtures given by Eq. 7-33 does not appear to perform as well as the Schlunder or Thome-Shakir correlations for these particular mixtures, there are

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there are some superior aspects to the new model. Figure 7.5 shows the variation of heat transfer coefficients with composition for the new model, the Schlunder equation and the Thome-Shakir correlation in acetone- water mixtures at 150 kW/m^2. The new model captures the shape of the curve passing through the experimental data points better than the Schlunder and Thome-Shakir correlations, but underestimates the heat transfer coefficients at the most dilute composition and overestimates them at the compositions where the maximum degradation occurs. Figure 7.6 presents the same comparison for ethanol-water mixtures. All three equations overestimate the heat transfer coefficients for these mixtures.


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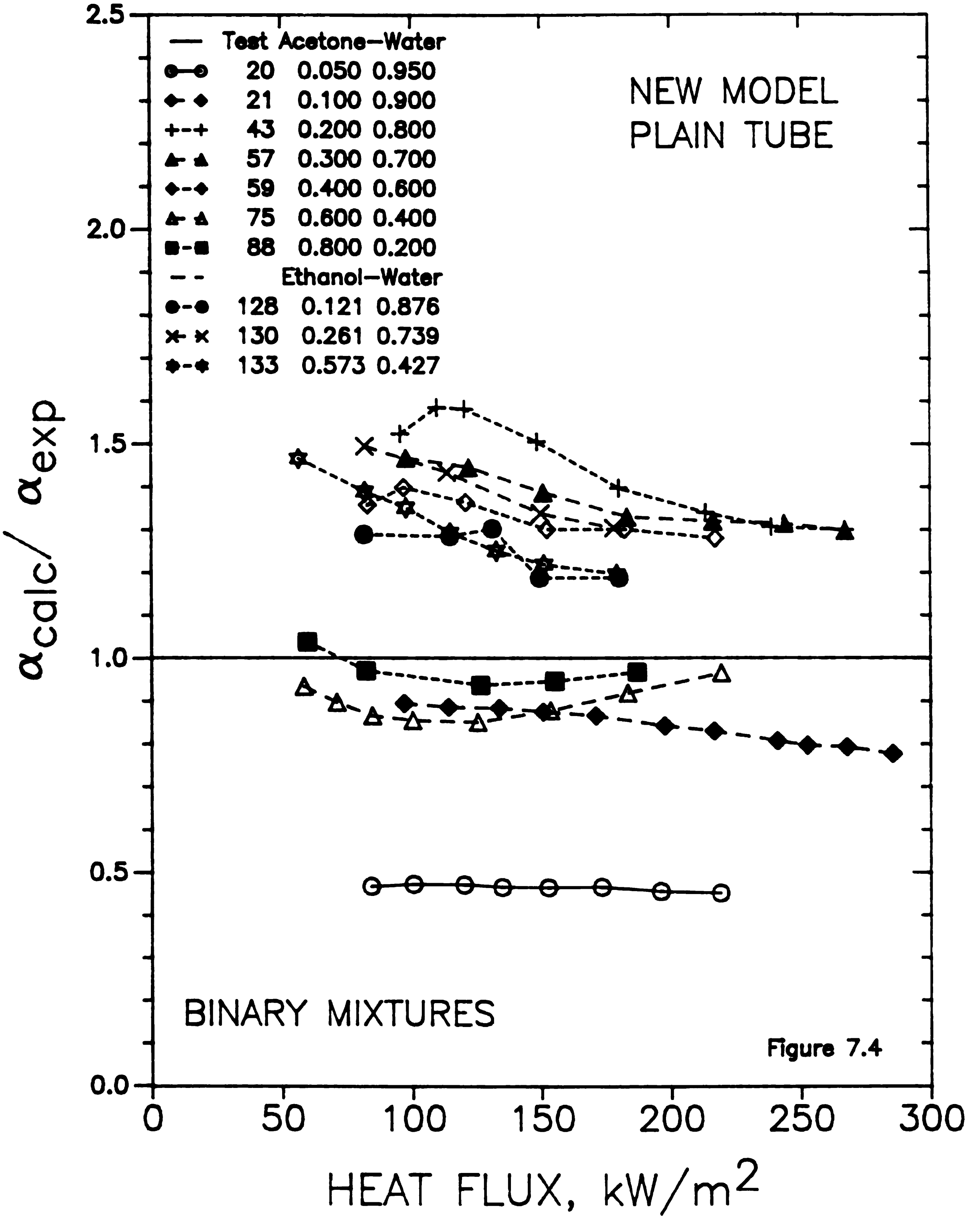

Figure 7.4 Comparison of the new model, Eq. 7-33 with acetone-water and ethanol-water binary mixture data. The Stephan-Abdelsalam correlation was used for α_{id}.


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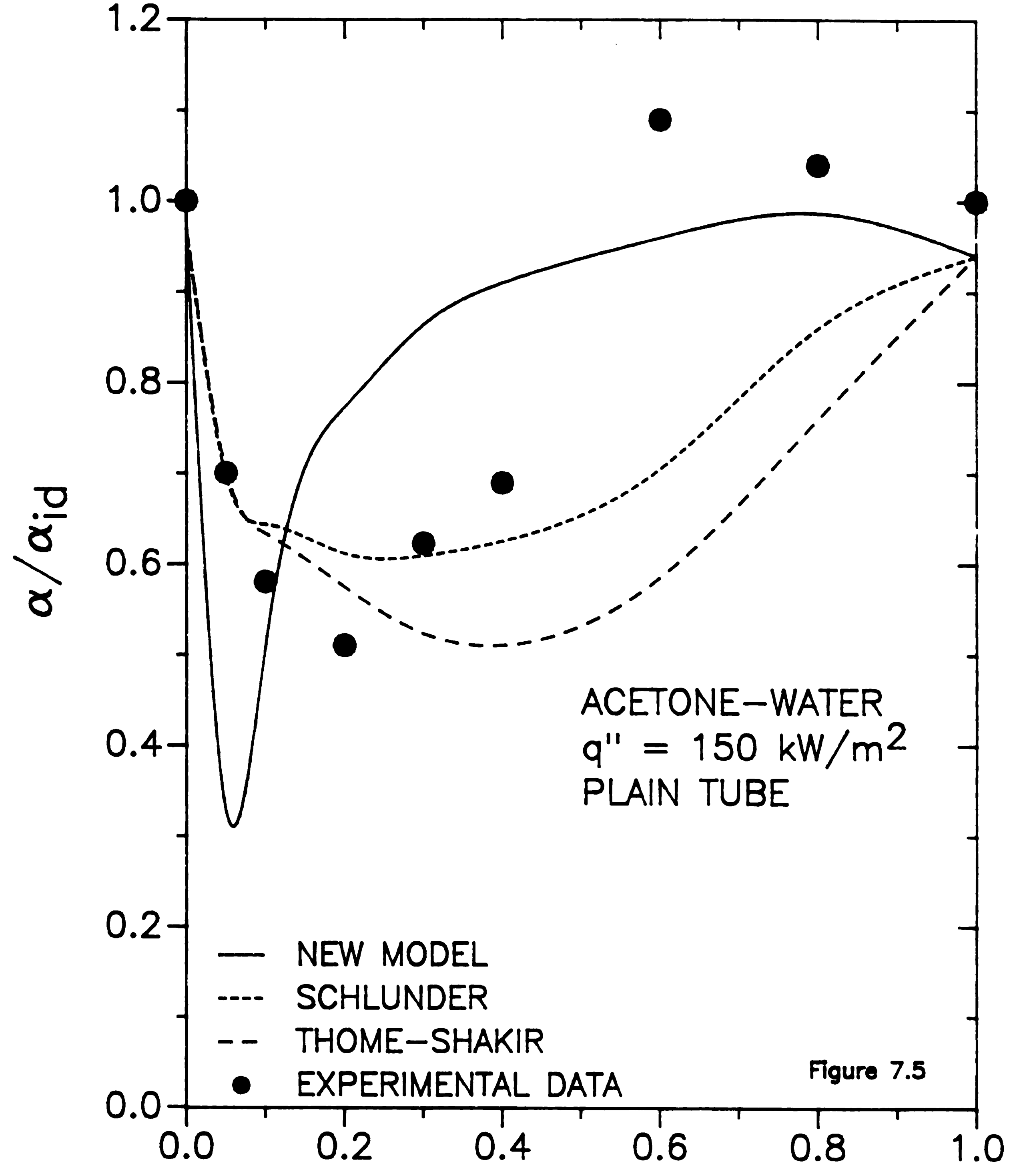
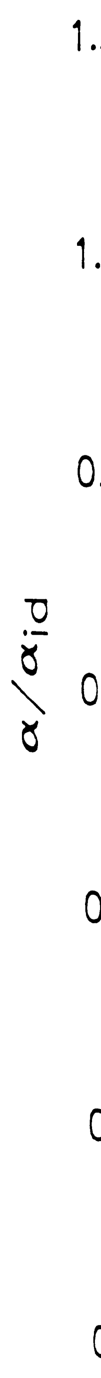


Figure 7.5 Estimation of boiling heat transfer coefficients at q"=150 kW/m^2 for acetone-water mixtures. The Stephan-Abdelsalam correlation was used for α_{id}.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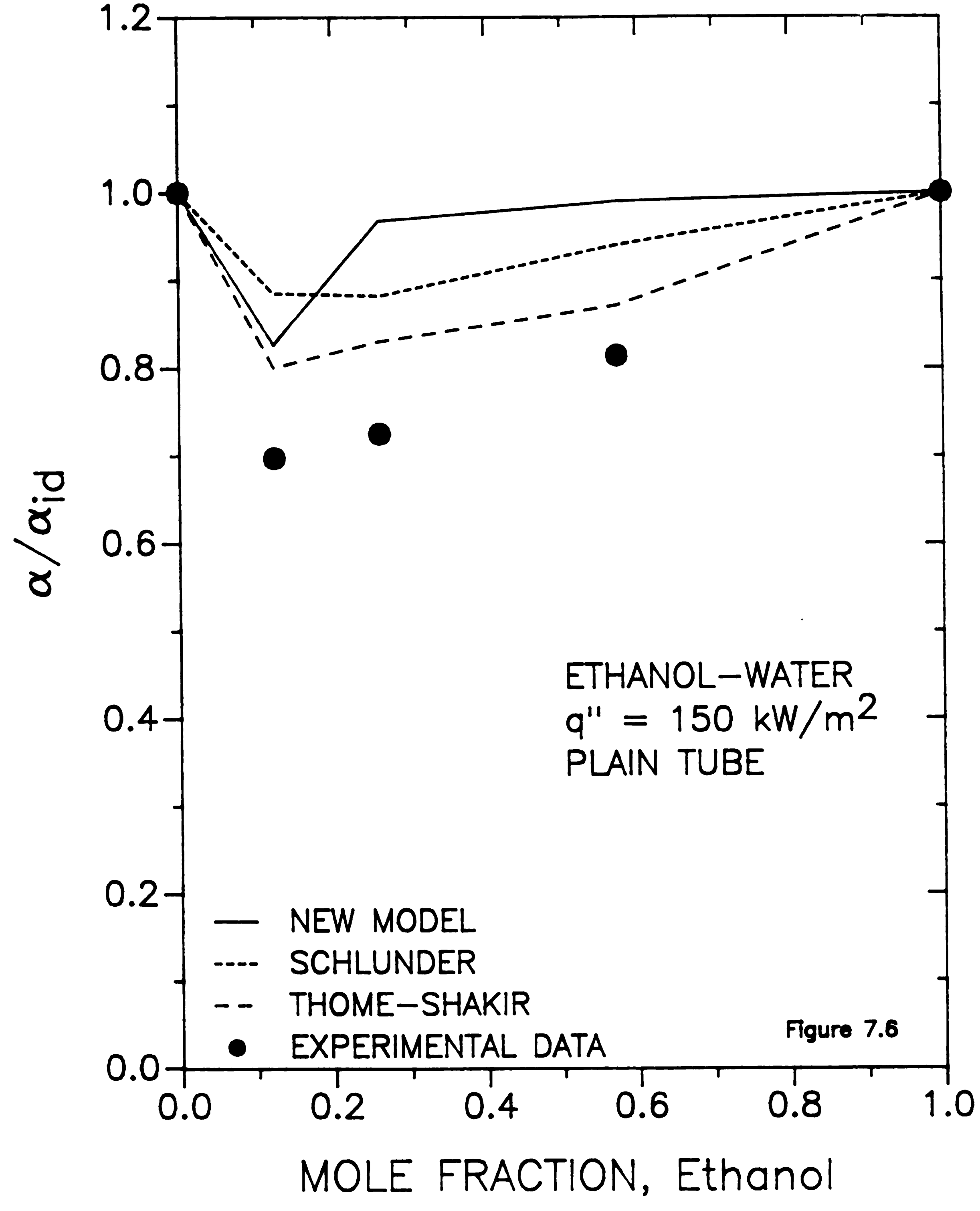

Figure 7.6 Estimation of boiling heat transfer coefficients at $q''=150\ kW/m^2$ for ethanol-water mixtures. The Stephan-Abdelsalam correlation was used for α_{id}.

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7.3 DERIVATION OF A NEW MODEL FOR MULTICOMPONENT MIXTURES

This section derives a new model for nucleate pool boiling heat transfer coefficients in multicomponent mixtures. Although the formulation is general, specific equations for a ternary mixture system are presented. The film theory of mass transfer is used to model the transport of the lightest component in the mixture to the interface. The flux of component *i* in a multicomponent mixture is given by:

$$N_i = x_i \sum_j^n N_j - c \sum_j^{n-1} D_{ij} \frac{dx_j}{dz} \tag{7-34}$$

where z represents distance from the bubble interface as shown in Figure 7.7, c is the liquid concentration, and D_{ij} are multicomponent diffusion coefficients.

It is important to point out the notation representing binary and multicomponent diffusion coefficients. The binary mass diffusion coefficient is denoted as $\mathcal{D}_{12}$ and used to relate the diffusion of the solute "1" through the solvent "2". Multicomponent diffusion coefficients are defined to represent mass diffusion in mixtures with three or more components. One component must be chosen as the solvent. The flux of component "1" due to its own gradient is represented by D_{11}. The flux of "1" due to the gradient in the mixture of component "2" is denoted by D_{12}. In general, the diffusion terms are not symmetric, and $D_{ij} \neq D_{ji}$. From matrix notation, the diagonal terms (D_{ii}) are called the "main-term" diffusion coefficients and the off-diagonal terms ($D_{ij,i\neq j}$) are called the "cross-term" diffusion coefficients. Cussler (1976) notes that the cross-term diffusion coefficients are often less than 10% of the main-term coefficients.

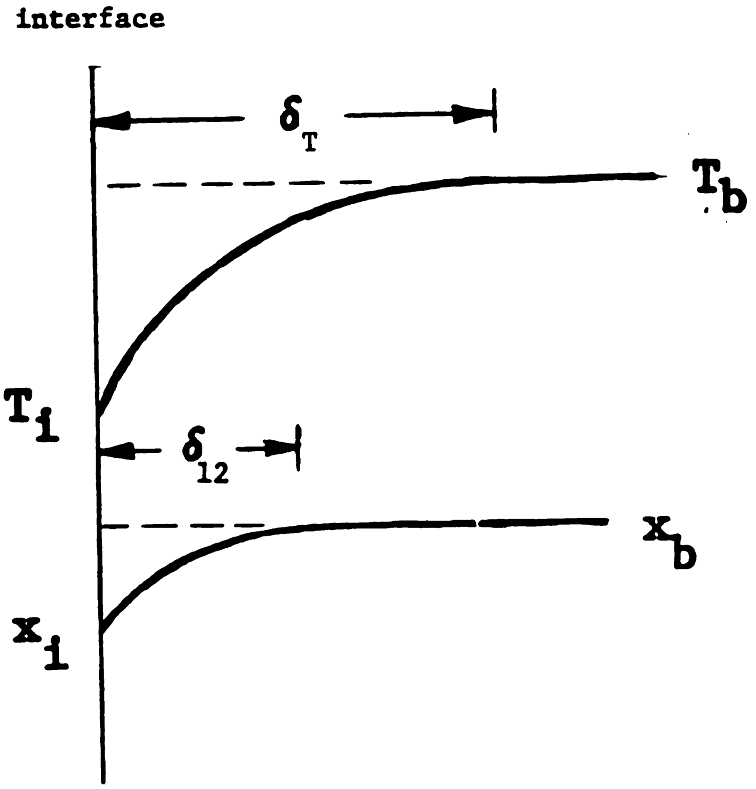

Figure 7.7 Diffusion to a vapor-liquid interface.

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For a ternary mixture, we can write Eq. 7-34 as a system of equations as:

$$N_1 = x_1(N_1+N_2+N_3) - c(D_{11}x_1' + D_{12}x_2') \qquad (7\text{-}35)$$

$$N_2 = x_2(N_1+N_2+N_3) - c(D_{21}x_1' + D_{22}x_2') \qquad (7\text{-}36)$$

where the ' denotes differentiation with respect to position.
By adding $-x_{10}(N_1+N_2+N_3)$ to each side of Eq. 7-35 and $-x_{20}(N_1+N_2+N_3)$ to each side of Eq. 7-36, and since $x_{10}'= 0$ and $x_{20}'= 0$ we can obtain:

$$N_1-x_{10}(N_1+N_2+N_3) = (x_1-x_{10})(N_1+N_2+N_3)-c[D_{11}(x_1-x_{10})'+D_{12}(x_2-x_{20})'] \qquad (7\text{-}37)$$

$$N_2-x_{20}(N_1+N_2+N_3) = (x_2-x_{20})(N_1+N_2+N_3)-c[D_{21}(x_1-x_{10})'+D_{22}(x_2-x_{20})'] \qquad (7\text{-}38)$$

Let $X_1'= (x_1-x_{10})'$ and $X_2'= (x_2-x_{20})'$ and expressing these equations in matrix form they become:

$$c\begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix}\begin{bmatrix} X_1' \\ X_2' \end{bmatrix} = (N_1+N_2+N_3)\begin{bmatrix} X_1 \\ X_2 \end{bmatrix}\begin{bmatrix} N_1-X_{10}(N_1+N_2+N_3) \\ N_2-X_{20}(N_1+N_2+N_3) \end{bmatrix} \qquad (7\text{-}39)$$

Solving this expression for $\begin{bmatrix} X_1' \\ X_2' \end{bmatrix}$ yields:

$$\begin{bmatrix} X_1' \\ X_2' \end{bmatrix} = \underline{A}\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} - \underline{b} \qquad (7\text{-}40)$$

where,

$$\underline{A} = (N_1+N_2+N_3)\underline{D}^{-1}/c = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \qquad (7\text{-}41)$$

$$\underline{b} = \underline{D}^{-1}/c\begin{bmatrix} N_1-X_{10}(N_1+N_2+N_3) \\ N_2-X_{20}(N_1+N_2+N_3) \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \qquad (7\text{-}42)$$

and the matrix of diffusion coefficients and its inverse are:

$$\underline{D} = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \qquad (7\text{-}43)$$

$$\underline{D}^{-1} = \frac{\begin{bmatrix} D_{22} & -D_{12} \\ -D_{21} & D_{11} \end{bmatrix}}{\det(\underline{D})} \qquad (7\text{-}44)$$

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To solve this system of simultaneous differential equations, first determine the eigenvalues and eigenvectors of $\underline{A}$. The eigenvalues of $\underline{A}$ are:

$$\psi_{1,2} = \frac{1}{2}\{(A_{11}+A_{22}) \pm \sqrt{(A_{11}-A_{22})^2+A_{12}A_{21}}\ \} \qquad (7\text{-}45)$$

and the eigenvectors are:

$$\underline{u}_1 = \begin{bmatrix} 1 \\ \dfrac{A_{11}-\psi_1}{-A_{12}} \end{bmatrix} \qquad \underline{u}_2 = \begin{bmatrix} \dfrac{-A_{12}}{A_{11}-\psi_2} \\ 1 \end{bmatrix} \qquad (7\text{-}46)$$

The homogeneous solution of Eq. 7-40 can be expressed as:

$$\underline{X}_h(z) = C_1\underline{u}_1\exp(\psi_1 z) + C_1\underline{u}_2\exp(\psi_2 z) \qquad (7\text{-}47)$$

For the particular solution, assume:

$$\underline{X}_p(z) = \underline{d} = \begin{bmatrix} d_1 \\ d_2 \end{bmatrix} \qquad (7\text{-}48)$$

Substitution into Eq. 7-40 and solution for values of the coefficients of $\underline{d}$, gives:

$$d_1 = \frac{\begin{bmatrix} b_1 & A_{12} \\ b_2 & A_{22} \end{bmatrix}}{\det(\underline{A})} = \frac{A_{22}b_1 - A_{12}b_2}{A_{11}A_{22} - A_{12}A_{21}} \qquad (7\text{-}49)$$

$$d_2 = \frac{\begin{bmatrix} A_{11} & b_1 \\ A_{21} & b_2 \end{bmatrix}}{\det(\underline{A})} = \frac{A_{11}b_2 - A_{21}b_1}{A_{11}A_{22} - A_{12}A_{21}} \qquad (7\text{-}50)$$

The general solution to Eq. 7-40 is given by:

$$\underline{X}(z) = C_1\underline{u}_1\exp(\psi_1 z) + C_1\underline{u}_2\exp(\psi_2 z) + \underline{d} \qquad (7\text{-}51)$$

Using the boundary condition $x_j(z=0) = x_{j0}$, the constants C_1 and C_2 are determined to be:

$$C_1 = \frac{\begin{bmatrix} -d_1 & -A_{12}/(A_{11}-\psi_2) \\ -d_2 & 1 \end{bmatrix}}{\det(\Phi)} \qquad C_2 = \frac{\begin{bmatrix} 1 & -d_1 \\ -(A_{11}-\psi_1)/A_{12} & -d_2 \end{bmatrix}}{\det(\Phi)} \qquad (7\text{-}52a,b)$$

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$$\det(\Phi) = \frac{A_{11}-\psi_1}{A_{11}-\psi_2} \tag{7-53}$$

Substituting Eqs. 7-49 and 7-50 for d_1 and d_2, C_1 and C_2 become:

$$C_1 = \frac{-b_1\det(\underline{A}) + \psi_2(A_{22}b_1 - A_{12}b_2)}{(\psi_1-\psi_2)\det(\underline{A})} \tag{7-54}$$

$$C_2 = \frac{-b_1\det(\underline{A}) + \psi_1(A_{22}b_1 - A_{12}b_2)}{(\psi_1-\psi_2)\det(\underline{A})}\left(\frac{A_{11}-\psi_2}{A_{12}}\right) \tag{7-55}$$

An expression for $X_1(z) = x_1(z) - x_{10}$ can now be written as:

$$X_1(z) = C_1u_{11}\exp(\psi_1) + C_2u_{12}\exp(\psi_2) + d_1 \tag{7-56}$$

or,

$$x_1(z)-x_{10} = \frac{-b_1\det(\underline{A}) + \psi_2(A_{22}b_1 - A_{12}b_2)}{(\psi_1-\psi_2)\det(\underline{A})}\exp(\psi_1 z)$$
$$- \frac{-b_1\det(\underline{A}) + \psi_1(A_{22}b_1 - A_{12}b_2)}{(\psi_1-\psi_2)\det(\underline{A})}\exp(\psi_2 z) + \frac{(A_{22}b_1-A_{12}b_2)}{\det(\underline{A})} \tag{7-57}$$

To simplify this expression note that:

$$\det(\underline{A}) = \left[\frac{\sum N}{c}\right]^2 \frac{1}{\det(\underline{D})} \tag{7-58}$$

$$A_{22} = \frac{\sum N}{c\det(\underline{D})}D_{11} \qquad A_{12} = -\frac{\sum N}{c\det(\underline{D})}D_{12} \tag{7-59a,b}$$

Then,

$$\frac{A_{22}b_1 - A_{12}b_2}{c\det(\underline{A})} = \frac{(N_1 - x_{10}\sum N)}{\sum N} \tag{7-60}$$

With these substitutions, Eq. 7-57 becomes,

$$x_1(z)-x_{10} = \frac{-b_1 + \psi_2(N_1-x_{10}\sum N)/\sum N}{(\psi_1-\psi_2)}\exp(\psi_1 z) - \frac{-b_1 + \psi_1(N_1-x_{10}\sum N)/\sum N}{(\psi_1-\psi_2)}\exp(\psi_2 z)$$
$$+ \frac{(N_1-x_{10}\sum N)}{\sum N} \tag{7-61}$$

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Dividing through by $(N_1-x_{10}\sum N)/\sum N$ we obtain,

$$\frac{(x_1(z)-x_{10})\sum N}{(N_1-x_{10}\sum N)} = 1 + \frac{-b_1\sum N + \psi_2(N_1-x_{10}\sum N)}{(N_1-x_{10}\sum N)(\psi_1-\psi_2)}\exp(\psi_1 z) - \frac{-b_1\sum N + \psi_2(N_1-x_{10}\sum N)}{(N_1-x_{10}\sum N)(\psi_1-\psi_2)}\exp(\psi_2 z) \qquad (7\text{-}62)$$

Solving Eq. 7-42 for b_1 obtain:

$$b_1 = \frac{[D_{22}(N_1-x_{10}\sum N) - D_{12}(N_2-x_{10}\sum N)]}{c\ \det(\underline{D})} \qquad (7\text{-}63)$$

Substituting Eq. 7-63 into 7-64 and rearranging obtain:

$$\frac{N_1-x_1(z)\sum N}{N_1-x_{10}\sum N} = \left[\frac{D_{22}\sum N}{c\ \det(\underline{D})} - D_{12}\frac{(N_2-x_{20}\sum N)}{(N_1-x_{10}\sum N)}\frac{\sum N}{c\ \det(\underline{D})} - \psi_2\right]\frac{\exp(\psi_1 z)}{(\psi_1-\psi_2)} - \left[\frac{D_{22}\sum N}{c\ \det(\underline{D})} - D_{12}\frac{(N_2-x_{20}\sum N)}{(N_1-x_{10}\sum N)}\frac{\sum N}{c\ \det(\underline{D})} - \psi_1\right]\frac{\exp(\psi_2 z)}{(\psi_1-\psi_2)} \qquad (7\text{-}64)$$

The eigenvalues of $\underline{A}$ are related to the eigenvalues of the diffusion matrix $\underline{D}$ by:

$$\psi_1 = \frac{\sum N}{c\ \det(\underline{D})}\lambda_1 \qquad \psi_2 = \frac{\sum N}{c\ \det(\underline{D})}\lambda_2 \qquad (7\text{-}65a,b)$$

and then,

$$\psi_1 - \psi_2 = \frac{\sum N}{c\ \det(\underline{D})}(\lambda_1-\lambda_2) \qquad (7\text{-}66)$$

Substituting Eqs. 7-65 and 7-66 into Eq. 7-64, results in the expression:

$$\frac{N_1-x_1(z)\sum N}{N_1-x_{10}\sum N} = \left[D_{22} - D_{12}\frac{(N_2-x_{20}\sum N)}{(N_1-x_{10}\sum N)} - \lambda_2\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_1 z\}}{(\lambda_1-\lambda_2)} - \left[D_{22} - D_{12}\frac{(N_2-x_{20}\sum N)}{(N_1-x_{10}\sum N)} - \lambda_1\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_2 z\}}{(\lambda_1-\lambda_2)} \qquad (7\text{-}67)$$

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Next, apply the boundary condition at the edge of the diffusion shell for the lightest component in the mixture. At $z = \delta_1$, $x = x_1$ so,

$$\frac{N_1 - x_1(z)\sum N}{N_1 - x_{10}\sum N} = \left[D_{22} - D_{12}\frac{(N_2 - x_{20}\sum N)}{(N_1 - x_{10}\sum N)} - \lambda_2\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_1\delta_1\}}{(\lambda_1 - \lambda_2)}$$
$$- \left[D_{22} - D_{12}\frac{(N_2 - x_{20}\sum N)}{(N_1 - x_{10}\sum N)} - \lambda_1\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_2\delta_1\}}{(\lambda_1 - \lambda_2)} \tag{7-68}$$

The relative boiling rates of components 1 and 2 are defined as:

$$r_1 = \frac{N_1}{\sum N} \qquad r_2 = \frac{N_2}{\sum N} \tag{7-69a,b}$$

Using these definitions, Eq. 7-68 becomes:

$$\frac{r_1 - x_1}{r_1 - x_{10}} = \left[D_{22} - D_{12}\frac{(r_2 - x_{20})}{(r_1 - x_{10})} - \lambda_2\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_1\delta_1\}}{(\lambda_1 - \lambda_2)}$$
$$- \left[D_{22} - D_{12}\frac{(r_2 - x_{20})}{(r_1 - x_{10})} - \lambda_1\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_2\delta_1\}}{(\lambda_1 - \lambda_2)} \tag{7-70}$$

Using the assumption that $r_1 = y_{10}$ and $r_2 = y_{20}$, Eq. 7-70 becomes:

$$\frac{y_{10} - x_1}{y_{10} - x_{10}} = \left[D_{22} - D_{12}\frac{(y_{20} - x_{20})}{(y_{10} - x_{10})} - \lambda_2\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_1\delta_1\}}{(\lambda_1 - \lambda_2)}$$
$$- \left[D_{22} - D_{12}\frac{(y_{20} - x_{20})}{(y_{10} - x_{10})} - \lambda_1\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_2\delta_1\}}{(\lambda_1 - \lambda_2)} \tag{7-71}$$

Solving this expression for $(x_1 - x_{10})$ results in:

$$x_1 - x_{10} = (y_{10} - x_{10})\left\{1 - \left[D_{22} - D_{12}\frac{(y_{20} - x_{20})}{(y_{10} - x_{10})} - \lambda_2\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_1\delta_1\}}{(\lambda_1 - \lambda_2)}\right.$$
$$\left. + \left[D_{22} - D_{12}\frac{(y_{20} - x_{20})}{(y_{10} - x_{10})} - \lambda_1\right]\frac{\exp\{[\sum N/c\det(\underline{D})]\lambda_2\delta_1\}}{(\lambda_1 - \lambda_2)}\right\} \tag{7-72}$$

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Eq. 7-72 is the expression for a ternary mixture corresponding to Eq. 7-4 for a binary mixture. The derivation for a multicomponent mixture continues in the same way as for a binary mixture. Recalling Eq. 7-6,

$$\frac{\alpha}{\alpha_{id}} = \frac{1}{1 + (\alpha_{id}/q")(T_i - T_b)} \tag{7-73}$$

As before, one can approximate the interfacial temperature difference as:

$$(T_i - T_b) \approx - \frac{dT}{dx}(x_1 - x_{10}) \tag{7-74}$$

Replacing $(x_1 - x_{10})$ in this expression by Eq. 7-72 and substituting it into Eq. 7-73 results in a new model for ternary mixtures including cross diffusion terms:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 - \frac{\alpha_{id}}{q"}\left(\frac{dT}{dx}\right)(y_1 - x_1)\left[1 - \left\{ D_{22} - D_{12}\left(\frac{y_2 - x_2}{y_1 - x_1}\right) - \lambda_2 \right\} \frac{\exp(-\Psi_1)}{\lambda_1 - \lambda_2} + \left\{ D_{22} - D_{12}\left(\frac{y_2 - x_2}{y_1 - x_1}\right) - \lambda_1 \right\} \frac{\exp(-\Psi_2)}{\lambda_1 - \lambda_2} \right]\right\}^{-1} \tag{7-75}$$

where,

$$\Psi_1 = - \frac{\sum N}{c \det(\underline{D})} \lambda_1 \delta_1 \tag{7-76}$$

and,

$$\Psi_2 = - \frac{\sum N}{c \det(\underline{D})} \lambda_2 \delta_1 \tag{7-77}$$

For a ternary mixture, the expressions corresponding to Eq. 7-32 are:

$$\Psi_1 = \frac{k q" \lambda_1}{\rho \Delta h_v \det(\underline{D}) \alpha_{id} (Le)^{1/2}} \tag{7-78}$$

and,

$$\Psi_2 = \frac{k q" \lambda_2}{\rho \Delta h_v \det(\underline{D}) \alpha_{id} (Le)^{1/2}} \tag{7-79}$$

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Eq. 7-75 represents a new expression for nucleate pool boiling in ternary mixtures that does not require any empirical fitting parameters or mass transfer coefficients. It is a completely theoretical expression in which there are no undefined or unknown parameters that must be determined by experiment. This aspect distinguishes it from all other multicomponent mixture boiling correlations. No other available expression for multicomponent pool boiling includes multicomponent diffusion terms. Thus, Eq. 7-75 is more generally applicable than other mixture boiling correlations.

An equation neglecting the cross-term diffusion coefficients can be determined by considering the limit of Eq. 7-75 as D_{12} approaches zero in the matrix of diffusion coefficients. As $D_{12} \rightarrow 0$, $\lambda_1 \rightarrow D_{11}$, $\lambda_2 \rightarrow D_{22}$, and $\det(\underline{D}) \rightarrow D_{11}D_{22}$. Eq. 7-75 then becomes:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''} \left[(\frac{dT}{dx})(y_1 - x_1)[1 - \exp(\frac{-kq''}{\rho \Delta h_v D_{11} \alpha_{id} (Le)^{\frac{1}{2}}})] \right] \right\}^{-1} \tag{7-80}$$

This equation could also be derived by assuming $D_{ij} = 0$ for $i \neq j$ in Eq. 7-32. The resulting system of multicomponent diffusion equations are immediately de-coupled, and Eq. 7-80 is found. The expression for binary mixtures, Eq. 7-31, is repeated here for comparative purposes:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''} \left[(\frac{dT}{dx})(y_b - x_b)[1 - \exp(\frac{-kq''}{\rho \Delta h_v \mathcal{D}_{12} \alpha_{id} (Le)^{\frac{1}{2}}})] \right] \right\}^{-1} \tag{7-81}$$

It is readily seen that these two expressions are identical with the exception that the binary mass diffusivity $\mathcal{D}_{12}$, is replaced by the multicomponent mass diffusion coefficient for the lightest component D_{11}. In comparison to the Schlunder equation Eq. 6-5, it is apparent that the

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that the summation sign does not appear in the new expression. This implies that a more appropriate expression for multicomponent mixtures using Schlunder's approximations is:

$$\frac{\alpha}{\alpha_{id}} = \left\{ 1 + \frac{\alpha_{id}}{q''}\left[(T_{sn}-T_{s1})(y_1-x_1)[1-\exp(\frac{-B_0 q''}{\rho \Delta h_v \beta_1})] \right]\right\}^{-1} \qquad (7\text{-}82)$$

The slope of the bubble point curve is approximated by the difference in saturation temperatures of the heaviest component T_{sn}, and the saturation temperature of the most volatile component T_{s1}. That is, the quantity $(T_{sn}-T_{s1})$ is the difference between the highest and lowest saturation temperatures of the pure components in the mixture. The mass transfer coefficient β is that for the transfer of the lightest component through the mixture. Since Schlunder assumes β to be $\beta = 2\text{x}10^{-4}$ m/s for all mixture systems, this value should also be appropriate for Eq. 7-82, although as in Schlunder and Thome-Shakir correlations this terms represents a potential source of error.

7.4 COMPARISON OF THE NEW EQUATIONS WITH EXPERIMENT

This section compares the new correlation for multicomponent mixtures without cross term diffusion coefficients, Eq. 7-80, and the modified version of the Schlunder equation for multicomponent mixtures, Eq. 7-82 to experimental results. A brief parametric study on the effect of diffusive cross terms on multicomponent boiling heat transfer coefficients is also carried out using Eq. 7-75.

A major problem in applying any expression using binary or multicomponent diffusion coefficients is the lack of reliable values for them. Limited experimental data is available for several binary mixture

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systems such as acetone-water and ethanol-water. The predictive methods by Wilke-Chang (1955) for binary mass diffusivities and by Perkins and Geankoplis (1969) for multicomponent mass diffusion coefficients are strictly valid only for infinite dilution of the diffusing solute. In practice they are applied at concentrations of up to 0.10 mole fraction of the diffusing component. Therefore, to examine the new correlation for multicomponent mixtures, Eq. 7-80 was used to estimate the nucleate pool boiling heat transfer coefficients in mixtures in which the mole fraction of the light component was less than 0.10. Figure 7.8 shows the results of the prediction of multicomponent boiling heat transfer coefficients by Eq. 7-80 for 11 such dilute aqueous mixtures. For these mixtures, the average error was 11.4% with a standard deviation of 22.9%. In comparison for these same 11 mixtures, the Schlunder equation had an average error of 22.2% and standard deviation of 20.6%, and the Thome-Shakir correlation had an average error of 17.7% with a standard deviation of 17.2%. Thus, the new correlation predicted these mixtures with a lower average error but with a slightly larger standard deviation than the two semi-empirical expressions. The new correlation does not exhibit the tendency to shift from an overprediction to an underprediction of the mixture boiling heat transfer coefficients as the heat flux increases.

The effect of cross diffusion terms on the boiling heat transfer coefficients was investigated using Eq. 7-75. Since there are currently no reliable methods available to estimate the magnitude of the cross term diffusion coefficients in liquids, only parametric effects can be explored. Two different ternary mixtures were used for the parametric study. Test no. 67 had a bulk liquid composition of 0.10 acetone, 0.30 methanol and 0.60 water by mole fraction. The corresponding equilibrium vapor composition is 0.430 acetone, 0.355 methanol, and 0.215 water.

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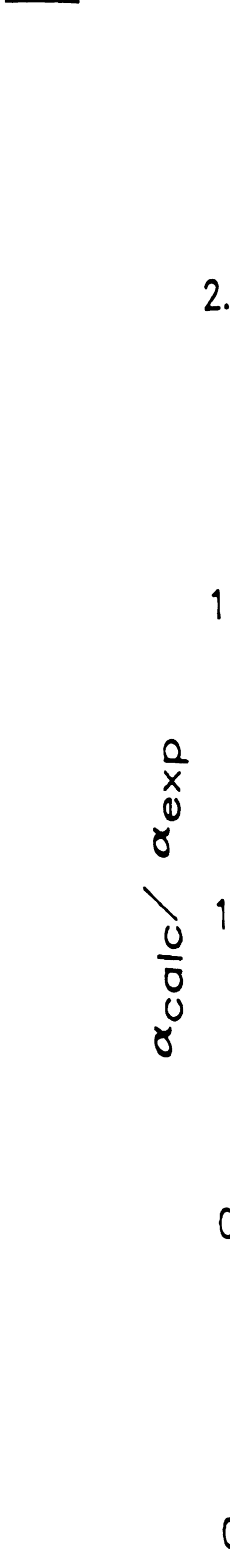
Thus, in this particular mixture, both acetone and methanol are light components. That is, the equilibrium vapor compositions for both of these components are greater than the liquid compositions. In Eq. 7-75 then, (y_2-x_2) is a positive quantity. The effect of including cross terms in the calculation of multicomponent pool boiling heat transfer coefficients was investigated by assuming the product of the cross terms to be a given fraction of the main diagonal diffusion coefficients. Figure 7.9 shows the variation in the heat transfer coefficients as the size of the cross terms are increased. The cross terms are seen to have little effect on the heat transfer coefficients until they become greater than 50% of the main diagonal terms. As the cross terms increase, value of the mixture boiling heat transfer coefficients decrease. For this test, the calculated heat transfer coefficients became very close to the experimental values when the cross terms were assumed to be the same size as the main diagonal terms in the diffusion matrix.

Figure 7.10 shows a similar parametric study but for a mixture in which there was one light and two heavy components. Test no. 78 had the composition 0.20 acetone, 0.60 methanol, and 0.20 water by mole fraction. The equilibrium vapor composition for this mixture is 0.395 acetone, 0.550 methanol, and 0.065 water. In this mixture, acetone is a light component, but methanol and water are heavy components and thus the quantity (y_2-x_2) is negative in Eq. 7-75. In Figure 7.10, the effect of including the cross-term diffusion coefficients is to decrease the boiling heat transfer coefficients. As in Figure 7.9, the cross-term diffusion coefficients have only a small effect on the heat transfer coefficients until they approach values that are 50% of the main-term diffusion coefficients.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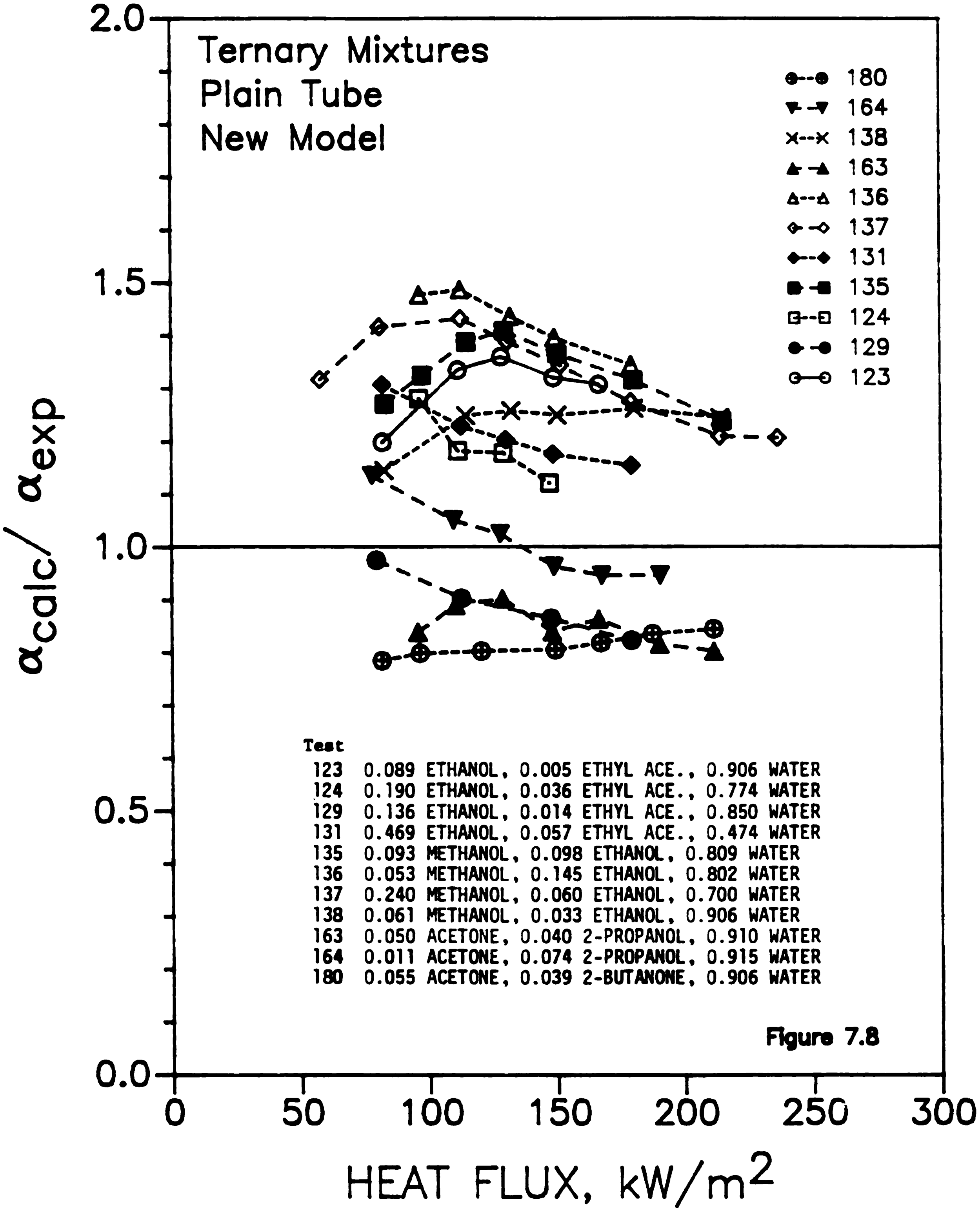

Figure 7.8 Comparison of the new correlation for multicomponent mixture boiling, Eq. 7-80, with experimental data.

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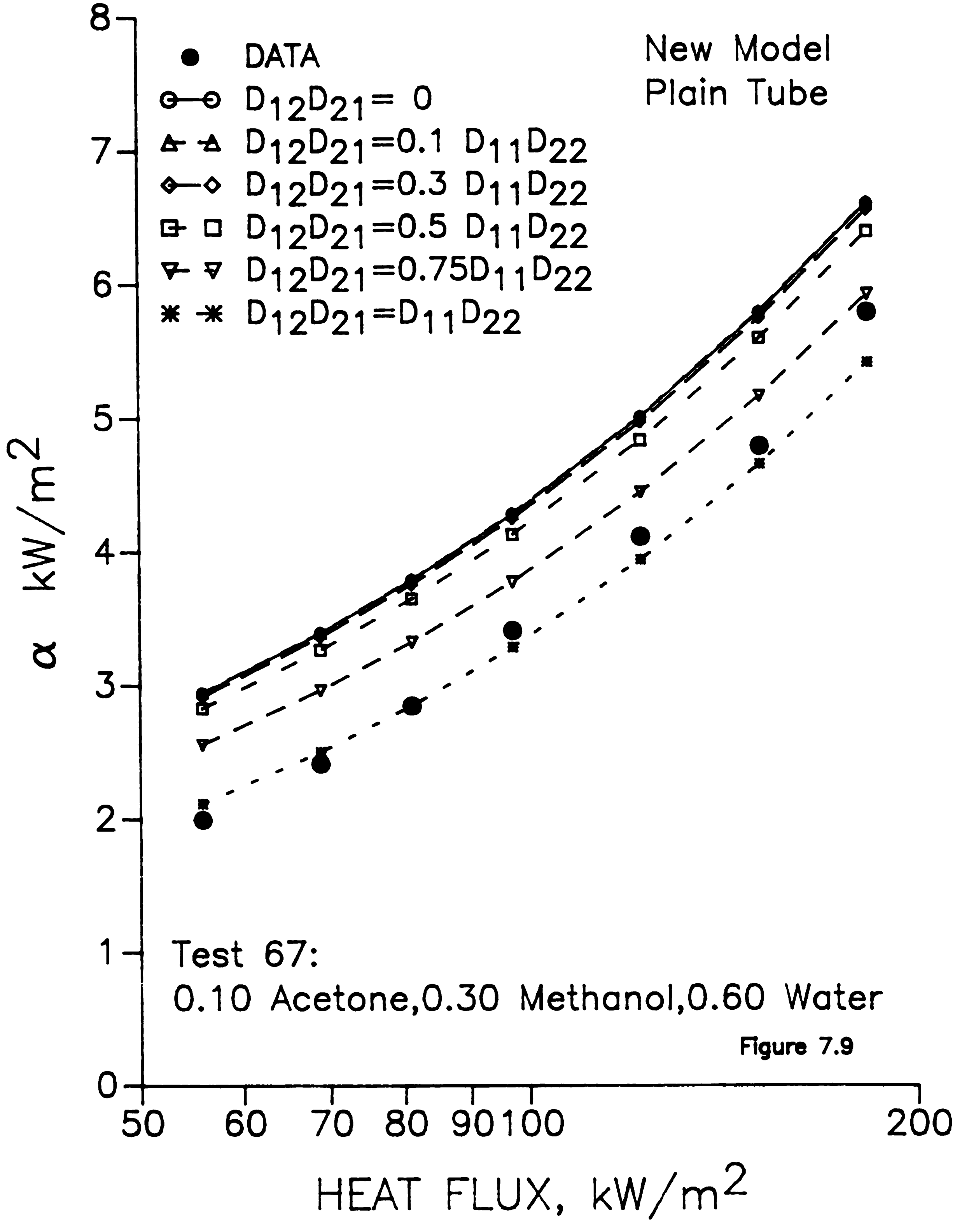

Figure 7.9 Effect of cross diffusion terms on the boiling heat transfer coefficient. Test No. 67

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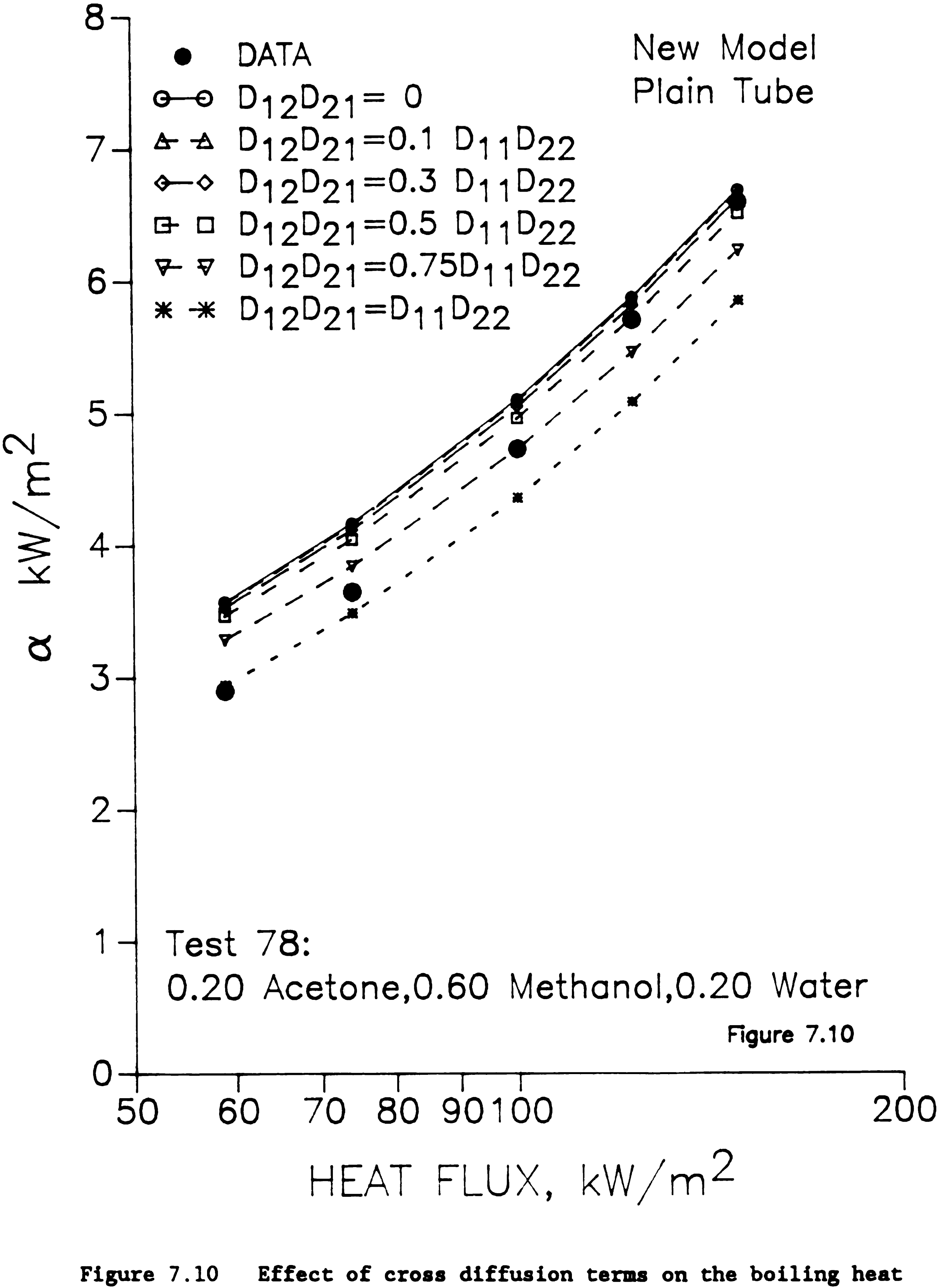

Figure 7.10 Effect of cross diffusion terms on the boiling heat transfer coefficient. Test No. 78

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The revised form of Schlunder's equation for multicomponent mixtures, Eq. 7-80, was examined by comparing its prediction of boiling heat transfer coefficients with experimental results for acetone-methanol- water ternary mixtures. The average error for these mixtures was 2.9% with a standard deviation of 15.4%. From Table 6-2, the estimation of the heat transfer coefficients for these mixtures using Eq. 6-5, was had a 2.8% average error and a standard deviation of 14.6%. The simplified expression given by Eq. 7-80 is thus seen to calculate mixture boiling heat transfer coefficients with nearly the same accuracy as the expression proposed by Schlunder. The Stephan-Abdelsalam correlation was used to calculate α_{id} in both of these comparisons.

7.5 SUMMARY

Pool boiling in multicomponent mixtures was investigated by reconsidering the assumptions that were used in the development of the Schlunder and Thome-Shakir equations, and by deriving a new correlation for boiling in multicomponent mixtures that includes the cross-term diffusion coefficients. A new expression relating the heat and mass transfer at a bubble interface was also derived that retains the mass diffusivity as a parameter and is used as part of the new correlation. The new correlation derived in this chapter is generally applicable to miscible mixtures and does not require any empirical constants. The new model for mixture boiling was compared to experimental data for binary and ternary aqueous mixtures and was found to predict the nucleate boiling heat transfer coefficents to the same order of accuracy as the existing empirical and semi-empirical correlations. In comparison to experimental values from dilute aqueous ternary mixtures, the new

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correlation provided estimates of the nucleate boiling heat transfer coefficients that had less average error than the Schlunder and Thome-Shakir correlations. The new correlation did not exhibit the tendency to overpredict the heat transfer coefficients at low heat flux and underpredict them at high heat flux as the Schlunder and Thome-Shakir correlations were often found to do.

The new correlation was also used to investigate the influence of cross-term diffusion coefficients on multicomponent pool boiling heat transfer coefficients. The cross-term diffusion coefficients were found to decrease the multicomponent pool boiling heat transfer coefficients. The effect of the cross-term diffusion coefficients was found to be minor until the cross-terms were at least 50% of the main-term diffusion coefficients.

The derivation for the new correlation suggests a simplifcation to the Schlunder equation for multicomponent mixtures. This simplifcation was tested by comparing predictions of pool boiling heat transfer coefficients for acetone-methanol-water mixtures to their experimental values. The comparison showed that the simplified expression provided estimates of the heat transfer coefficients without a significant loss of accuracy.

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CHAPTER 8

CONCLUSIONS

The following conclusions are supported by the experimental and theoretical work performed in this investigation:

(1) Experimental measurements of pool boiling heat transfer coefficients in several new ternary and quadrary mixtures were obtained. The multicomponent heat transfer coefficients were found to be significantly lower than those estimated by a linear combination of the heat transfer coefficients in the pure components composing the mixture.

(2) The ideal heat transfer coefficient should be calculated using an appropriate pool boiling correlation that includes the effect of fluid physical properties. The Stephan-Abdelsalam correlation was found to estimate pool boiling heat transfer coefficients for several pure fluids and azeotropic mixtures at pressures from 0.5 to 5 bar with an average error of 6.6% and a standard deviation of 11.6% for a plain surface. Predictions of multicomponent pool boiling heat transfer coefficients for all correlations considered were significantly improved by using the Stephan- Abdelsalam correlation with mixture properties rather than the linear mixing law to calculate α_{id}.

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(3) For each of the binary, ternary, and quadrary mixture systems tested, the Schlunder and Thome-Shakir correlations estimated experimental nucleate pool boiling heat transfer coefficients with average errors no greater than 30%. To obtain this accuracy, the Stephan-Abdelsalam correlation with mixture properties was used to calculate α_{id}.

(4) A new correlation for boiling in multicomponent mixtures that includes cross-term diffusion coefficients was derived based on the film theory of mass transfer. A new expression relating the heat and mass transfer at a bubble interface was also derived that retains the mass diffusivity as a parameter and is used as part of the new correlation. The new correlation is general and does not require any empirical constants. This aspect makes this new correlation unique with regard to all other existing multicomponent pool boiling correlations. The new correlation was found to predict the experimental nucleate boiling heat transfer coefficients in dilute aqueous ternary mixtures from several mixture systems with an average error of less than 12%.

(5) The new correlation was used to investigate the effect of cross-term diffusion coefficients on multicomponent pool boiling heat transfer coefficients. The cross-term diffusion coefficients were found to decrease the multicomponent pool boiling heat transfer coefficients. The effect of the cross-term diffusion coefficients was not significant until the cross-terms were at least 50% of the main-term diffusion coefficients.

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(6) Experimental measurements of nucleate pool boiling heat transfer coefficients on a 19 fin/in. tube were obtained for three binary mixture systems and two ternary mixtures. The magnitude of the degradation in mixture boiling heat transfer coefficients for the finned tube was approximately the same as for a plain tube. The pool boiling heat transfer coefficients for the finned tube were larger than those for the plain tube indicating that the enhancement in heat transfer coefficients for the finned tube is convective. No previous investigations have measured mixture boiling heat transfer coefficients for a finned tube.

(7) The effect of an additional component in a mixture was found to depend on the difference between the vapor and liquid equilibrium compositions for that component. Positive values of (y-x) for the additional component decrease the nucleate pool boiling heat transfer coefficient assuming that the mixture physical properties do not change. In general for a multicomponent mixture, the degradation in heat transfer coefficients increase with the sum of (y-x) for the light components in the mixture.

AN EXPERIMENTAL AND THEORETICAL INVESTIGATION OF MULTICOMPONENT POOL BOILING ON SMOOTH AND FINNED SURFACES

Volume II

By

Stephen Matthew Bajorek

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Mechanical Engineering

1988

APPENDIX A

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APPENDIX A

CALCULATION OF HEAT TRANSFER COEFFICIENTS FROM EXPERIMENTAL DATA

This section describes the calculations performed in order to determine pool boiling heat transfer coefficients from the data obtained from the test facility. The test sections used in this investigation are shown in Figures 3.3 through 3.5. Figure A.1 shows location of the thermocouples and nomenclature used in the calculations. The smooth surface test sections each had four thermocouples (T_1, T_2, T_3, T_4) in the tube wall near the middle of the heated length of the test section. The wall surface temperature was estimated by extrapolating the average readings of these four interior thermocouples. The power supplied to the cartridge heater was determined from readings of the voltage V, and current I, applied to the test section. Losses away from the heated length of the test section were estimated by two thermocouples (T_5, T_6) located at the end of the tube.

The test section surface temperature is estimated by assuming one dimensional radial heat conduction through the tube wall. Between the thermocouple location and the wall the rate of heat transfer is given by:

$$q = \frac{(T_t - T_w)}{\frac{1}{(2\pi k_w L_b)} \ln(\frac{r_o}{r_t})} \qquad \text{(A 1)}$$

where T_t is the average temperature of the thermocouples in the center of the test section. Solving Eq. A.1 for T_w one obtains:

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$$T_w = T_t - q\left(\frac{1}{2\pi k_w L_b}\right)\ln\left(\frac{r_o}{r_t}\right) \qquad (A.2)$$

The wall superheat is given by:

$$\Delta T = T_w - T_b \qquad (A.3)$$

where the bulk liquid temperature T_b is the average temperatures from the two thermocouples located in the bulk liquid.

The experimental heat transfer coefficient is given by:

$$\alpha = \frac{q''}{\Delta T} \qquad (A.4)$$

where the surface heat flux is defined as:

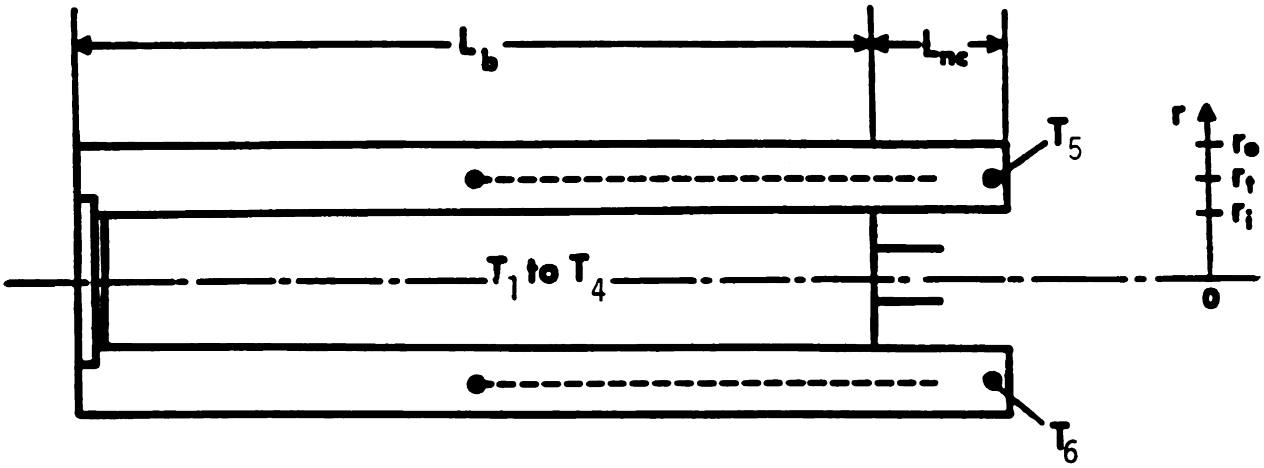
$$q'' = \frac{q}{2\pi k_w L} \qquad (A.5)$$

A first approximation of α and ΔT, the entire surface of the test section $(L=L_b+L_{nc})$ was assumed to be at a uniform temperature T_w and the rate of heat transfer from the surface to be $q = VI$. The losses from the length L_{nc} were then estimated using this value of α with the expression:

$$q_{loss} = -k_w\pi(r_o^2-r_i^2)\left(\frac{\Delta T_c}{L_{nc}}\right) + 2\pi r_o L_{nc}\alpha\Delta T_{nc} \qquad (A.6)$$

where $\Delta T_c = T_w-T_{loss}$ and $\Delta T_{nc} = 0.5(T_w-T_{loss})$. T_{loss} represents the average temperature of the thermocouples in the unheated segment of the boiling tube.

A new value of $q = VI - q_{loss}$ is substituted into Eq. A.2 and revised values for α and ΔT are obtained. For the corrected value of q'', the heated length L_b was used for L in Eq. A.5.



Dimensions: (mm)

	Plain Tube #1	Plain Tube #2	19 fin/in Tube
r_i	6.3	4.8	4.7
r_t	8.7	7.1	5.9
r_o	11.1	9.5	8.0
r_{fin}	N/A	N/A	9.5
L_b	76.2	50.8	50.8
L_{nc}	12.7	19.0	31.7

Figure A.1 Thermocouple locations and nomenclature for calculation of wall superheats and heat transfer coefficients.

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Program PBDATA is the first of three main computer programs used to process data and evaluate mixture boiling correlations. The three main programs in the series are PBDATA, MIXPROP, and MIXBOIL. PBDATA processes thermocouple readings and power measurements and calculates wall superheats and heat transfer coefficients. MIXPROP calculates thermodynamic and transport properties for a liquid mixture. MIXBOIL uses the processed data from PBDATA and the properties from MIXPROP and compares several boiling correlations to the experimental data. Each of the programs assumes a common indexing scheme for pure components and test sections. Table A-1 lists the components presently assumed by this code series.

Table A-1
Component List for Programs PBDATA and MIXPROP

No.	Component	Formula	Mol.Wt.	Normal Boiling Point, deg K
1	Acetone	C3H6O	58.08	329.25
2	2-Butanone	C4H8O	72.11	352.70
3	Methanol	CH4O	32.04	337.85
4	Ethanol	C2H6O	46.07	351.45
5	Benzene	C6H6	78.11	353.25
6	Water	H2O	18.02	373.15
7	1-Propanol	C3H8O	60.10	370.95
8	2-Propanol	C3H8O	60.10	355.65
9	Ethylene Glycol	C2H6O2	60.10	470.00
10	Cyclohexane	C6H12	84.16	353.87
11	not assigned			
12	Methyl Acetate	C3H6O2	74.08	330.30
13	Ethyl Acetate	C4H8O2	88.11	350.25
14	not assigned			
15	Ammonia	H3N	17.03	239.75

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      O
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   10 F
      R
      R
   15 F
      F
      F
   20
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```

Program PBDATA calculates the wall superheats and heat transfer coefficients from the measurements obtained from the boiling facility. The calculations performed by PBDATA were described in Appendix A. The program reads from file PBDATA.INP, which contains the filenames for the individual test results to be processed. The data file containing the test results included a unique test identification number, the components by index number and their mole fractions, and the test measurements. PBDATA writes one output file that lists the input and the processed results, and another file for plotting purposes. Table A-2 is a listing of PBDATA.

Table A-2
Listing of Program PBDATA

```
      PROGRAM PBDATA
      COMMON/XDATA/ IDNUM,IDATE,ISURF,ICOMP(5),FRAC(5),NPTS
      COMMON/XDATA/ VOLTS(40),AMPS(40),P(40)
      COMMON/XDATA/ TB(2,40),TC(4,40),TE(4,40)
      COMMON/XOUTP/ DELT(40),QLOSS(40),ALPHA(40),TWALL(40),FLUX(40)
      COMMON/XOUTP/ TCVAR1(40),TCVAR2(40)
      CHARACTER*20 INPFIL, DATFIL, SDFFIL
C
      JIN  = 1
      JINP = 2
      JDAT = 3
      JSDF = 4
      JBAN = 5
C
      OPEN(JIN,FILE='PBDATA.INP',STATUS='OLD')
      OPEN(JBAN,FILE='PBDATA.TXT',STATUS='NEW')
      READ(JIN,10)
   10 FORMAT( )
      READ(JIN,10)
      READ(JIN,15) NFILES
   15 FORMAT(3X,I3)
      READ(JIN,10)
      DO 900 IFILE=1,NFILES
      READ(JIN,20) INPFIL, DATFIL, SDFFIL
   20 FORMAT(3A20)
      WRITE(*,25) INPFIL
   25 FORMAT(/,10X,'BEGIN DATA REDUCTION FOR FILE ',A20)
      OPEN(JINP,FILE=INPFIL,STATUS='OLD')
      OPEN(JDAT,FILE=DATFIL,STATUS='NEW')
      OPEN(JSDF,FILE=SDFFIL,STATUS='NEW')
```

```
C
      CALL
C
      PI-
      TWOP
C *** Test
      IF (
      GO T
C
 130  CON
C *** ISU
       RI-
       RT-
       RO-
       ZLB
       ZL
       ZL
       CON
       DO
       WA
       Q
       TC
       TB
       TL
       TV
       DO
       TV
 133   CO
        T
        T
        T
        D
        F
        A
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C
      CALL INPUT(JINP)
C
      PI= 3.141593
      TWOPI= 6.283185
C *** Tests with IDNUM greater than 1000 are for flat disk test sections.
      IF (IDNUM.GE.1000) GO TO 1000
      GO TO (130,140,150,160,170,170,130,130) ISURF
C
 130  CONTINUE
C *** ISURF = 1,7,8  Smooth Tube - See section B.2, pg. 101 Shakir
      RI=  0.00630
      RT=  0.00870
      RO=  0.01110
      ZLB= 0.07620
      ZLNC=0.01270
      ZL = ZLB + ZLNC
      CONDCU= 391.0
      DO 135 I=1,NPTS
      WATTS = VOLTS(I)*AMPS(I)
      Q = WATTS
      TCAVE=(TC(1,I)+TC(2,I)+TC(3,I)+TC(4,I))/4.
      TBAVE=(TB(1,I)+TB(2,I))/2.
      TLAVE=(TE(1,I)+TE(2,I))/2.
      TVAR = 0.
      DO 133 J=1,4
      TVAR = TVAR + (TCAVE - TC(J,I))**2
 133  CONTINUE
      TCVAR1(I)= SQRT(TVAR)
      TCVAR2(I)= 100.*TCVAR1(I)/(TCAVE-TBAVE)
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDCU*ZLB))*ALOG(RO/RT)
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RO*ZL)
      ALPHA(I)= FLUX(I)/DELT(I)
      DELTL= TCAVE - TLAVE
      DELTM= TLAVE - TBAVE
      QLOSS(I)= CONDCU*PI*(RO*RO-RI*RI)*DELTL/(0.5*ZL) +
     &          ALPHA(I)*TWOPI*RO*ZLNC*DELTM
      Q = Q - QLOSS(I)
      QLOSS(I)= 100.*QLOSS(I)/WATTS
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDCU*ZLB))*ALOG(RO/RT)
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RO*ZLB)
      ALPHA(I)= FLUX(I)/DELT(I)
 135  CONTINUE
      GO TO 200
 140  CONTINUE
      ISURF = 2, High Flux  (Bajorek)
      RO= 0.009335
      RC= 0.008382
      RT= 0.007798
      RI= 0.004763
      ZLB= 0.0508
      ZLNC= 0.041625
      ZL= ZLB + ZLNC
      CONDHF= 242.0
```

```
      DO 14
      WATTS
      Q - W
      TCAVE
      TBAVE
      TLAVE
      TVAR
      DO 14
      TVAR
143   CONTI
      TCVAR
      TCVAR
      TWAL
      DELT
      FLUX
      ALPH
      DELT
      DELT
      QLOS
     &
      Q -
      QLOS
      TWAL
      DELT
      FLUX
      ALPH
145   CONT
      GO
150   CONT
      ISU
      RI
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      RO
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      ZLB
      ZL
      ZL
      CON
      DO
      WAT
      Q -
      TCA
      TBA
      TVA
      DO
      TVA
153   CON
      TCV
      TCV
      TWA
      DEL
      FLU
      ALP
      DEL
      QLO
      Q -
      QLO
      TWA
```

```
      DO 145 I=1,NPTS
      WATTS = VOLTS(I)*AMPS(I)
      Q = WATTS
      TCAVE=(TC(1,I)+TC(2,I)+TC(3,I)+TC(4,I)+2.*(TE(2,I)+TE(4,I)))/8.
      TBAVE=(TB(1,I)+TB(2,I))/2.
      TLAVE=(TE(1,I)+TE(3,I))/2.
      TVAR = 0.
      DO 143 J=1,4
      TVAR = TVAR + (TCAVE - TC(J,I))**2
 143  CONTINUE
      TCVAR1(I)= SQRT(TVAR)
      TCVAR2(I)= 100.*TCVAR1(I)/(TCAVE-TBAVE)
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDHF*ZLB))*ALOG(RO/RT)
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RO*ZL)
      ALPHA(I)= FLUX(I)/DELT(I)
      DELTL= (TE(2,I)+TE(4,I))/2. - TLAVE
      DELTM= TLAVE - TBAVE
      QLOSS(I)= CONDHF*PI*(RO*RO-RI*RI)*DELTL/(0.5*ZLNC) +
     &          ALPHA(I)*TWOPI*RO*ZLNC*DELTM
      Q = Q - QLOSS(I)
      QLOSS(I)= 100.*QLOSS(I)/WATTS
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDHF*ZLB))*ALOG(RO/RT)
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RO*ZLB)
      ALPHA(I)= FLUX(I)/DELT(I)
 145  CONTINUE
      GO TO 200
 150  CONTINUE
      ISURF = 3, Finned Tube, 19 Fins per Inch
      RI   = 0.00470
      RT   = 0.00591
      RO   = 0.00800
      RFIN = 0.009535
      ZLB  = 0.0508
      ZLNC = 0.03175
      ZL   = ZLB + ZLNC
      CONDCU = 391.0
      DO 155 I=1,NPTS
      WATTS = VOLTS(I)*AMPS(I)
      Q = WATTS
      TCAVE=(TC(1,I)+TC(2,I)+TC(3,I)+TC(4,I))/4.
      TBAVE=(TB(1,I)+TB(2,I))/2.
      TVAR = 0.
      DO 153 J=1,4
      TVAR = TVAR + (TCAVE - TC(J,I))**2
 153  CONTINUE
      TCVAR1(I)= SQRT(TVAR)
      TCVAR2(I)= 100.*TCVAR1(I)/(TCAVE-TBAVE)
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDCU*ZLB))*ALOG(RO/RT)
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RFIN*ZL)
      ALPHA(I)= FLUX(I)/DELT(I)
      DELTM= 0.5 * DELT(I)
      QLOSS(I)=  ALPHA(I)*TWOPI*RO*ZLNC*DELTM
      Q = Q - QLOSS(I)
      QLOSS(I)=  100.*QLOSS(I)/WATTS
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDCU*ZLB))*ALOG(RO/RT)
```

```
      DELT
      FLUX
      ALPH
155   CONT
      GO T
160   CONT
      ISUR
      GO T
170   CONT
      ISU
      RI=
      RT=
      RO=
      ZLB
      ZLN
      ZL
      CON
      DO
      WAT
      Q =
      TC
      TB
      TL
      TV
      DO
      TV
173   CO
      TC
      TC
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      DE
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      AL
      DE
      DE
      QL
     &
      Q
      Q
      T
      D
      F
      A
175   C
      G
1000  C
C *** F
      C
      R
      R
      A
      A
      T
      P
      A
      Z
      Z
```

```
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RFIN*ZLB)
      ALPHA(I)= FLUX(I)/DELT(I)
  155 CONTINUE
      GO TO 200
  160 CONTINUE
      ISURF = 4, High Flux  (Heinz)
      GO TO 200
  170 CONTINUE
      ISURF = 5,6   Smooth Tube - 0.75 in. OD  (Bajorek)
      RI=  0.47625E-02
      RT=  0.71438E-02
      RO=  0.95250E-02
      ZLB= 0.05080
      ZLNC=0.01905
      ZL = 0.03810 + 0.05080
      CONDCU= 391.0
      DO 175 I=1,NPTS
      WATTS = VOLTS(I)*AMPS(I)
      Q = WATTS
      TCAVE=(TC(1,I)+TC(2,I)+TC(3,I)+TC(4,I))/4.
      TBAVE=(TB(1,I)+TB(2,I))/2.
      TLAVE=(TE(3,I)+TE(4,I))/2.
      TVAR = 0.
      DO 173 J=1,4
      TVAR = TVAR + (TCAVE - TC(J,I))**2
  173 CONTINUE
      TCVAR1(I)= SQRT(TVAR)
      TCVAR2(I)= 100.*TCVAR1(I)/(TCAVE-TBAVE)
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDCU*ZLB))*ALOG(RO/RT)
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RO*ZL)
      ALPHA(I)= FLUX(I)/DELT(I)
      DELTL= TCAVE - (TE(1,I)+TE(2,I))/2.
      DELTM= ((TE(1,I)+TE(2,I))/2. + TLAVE)/2. - TBAVE
      QLOSS(I)= CONDCU*PI*(RO*RO-RI*RI)*DELTL/(0.00635) +
     &          ALPHA(I)*TWOPI*RO*ZLNC*DELTM
      Q = Q - QLOSS(I)
      QLOSS(I)= 100.*QLOSS(I)/WATTS
      TWALL(I)= TCAVE - Q*(1./(TWOPI*CONDCU*ZLB))*ALOG(RO/RT)
      DELT(I)= TWALL(I) - TBAVE
      FLUX(I)= Q/(TWOPI*RO*ZLB)
      ALPHA(I)= FLUX(I)/DELT(I)
  175 CONTINUE
      GO TO 200
 1000 CONTINUE
C *** FLAT DISK TEST SECTIONS
      CONDCU = 391.0
      RI = 0.0127
      RO = 0.0159
      AI = 0.507E-03
      AO = 0.792E-03
      THICK = 0.8E-03
      PERIM = 2. * TWOPI * RI + 2. * THICK
      AX = TWOPI * RI * THICK
      ZLB  = RO - RI
      ZLNC = 5.
```

```
      ZL =
      D1 =
      D2 =
      D3 =
      DO 1
      STC
      SX2
      SX
      STCX
      S2X
      TWAL
      TBAV
      DELT
      WATT
      QLOS
      FLU
      ALP
      QLOS
      TCV
      TCV
 1050 CO
      GO
  200 CO
C
      CA
      CA
      WR
  225 FO
      WR
  226 FO
      IF
      CL
      CL
      CL
  900 CO
      CL
      WR
  950 FO
      ST
      EN
C *****
      SU
      WR
      WR
      WR
      WR
      WR
      WR
      WR
      WR
      WR
      WR
      WR
      WR
   10 FO
   20 FO
     &
```

```
      ZL - ZLNC * PERIM / CONDCU / AX
      D1 - 0.001
      D2 - 0.005
      D3 - 0.009
      DO 1050 I - 1, NPTS
      STC - TC(1,I) + TC(2,I) + TC(3,I)
      SX2 - D1*D1 + D2*D2 + D3*D3
      SX  - D1 + D2 + D3
      STCX- TC(1,I)*D1 + TC(2,I)*D2 + TC(3,I)*D3
      S2X - SX * SX
      TWALL(I) - (STC*SX2 - SX*STCX) / (3.*SX2 - S2X)
      TBAVE - (TB(1,I) + TB(2,I))/2.
      DELT(I) - TWALL(I) - TBAVE
      WATTS - VOLTS(I) * AMPS(I)
      QLOSS(I) - SQRT(ZLNC*PERIM*CONDCU*AX)*DELT(I)*TANH(ZL)
      FLUX(I) - (WATTS - QLOSS(I)) / AI
      ALPHA(I)- FLUX(I)/DELT(I)
      QLOSS(I)- 100.*QLOSS(I)/WATTS
      TCVAR1(I) - 0.
      TCVAR2(I) - 0.
 1050 CONTINUE
      GO TO 200
 200  CONTINUE
C
      CALL OUTPUT(JDAT)
      CALL SDFOUT(JSDF)
      WRITE(*,225) DATFIL
 225  FORMAT(10X,'OUTPUT FILE IS ',A20)
      WRITE(*,226) SDFFIL
 226  FORMAT(10X,'PLOT FILE IS   ',A20)
      IF(IFILE.EQ.NFILES) CALL BANNER(JBAN) C
      CLOSE(JINP)
      CLOSE(JDAT)
      CLOSE(JSDF)
 900  CONTINUE
      CLOSE(JBAN)
      WRITE(*,950)
 950  FORMAT(/,1X,'Normal termination of Program PBDATA')
      STOP
      END
C *******************************************************************
      SUBROUTINE BANNER(N)
      WRITE(N,10)
      WRITE(N,20)
      WRITE(N,30)
      WRITE(N,40)
      WRITE(N,50)
      WRITE(N,60)
      WRITE(N,60)
      WRITE(N,80)
      WRITE(N,90)
      WRITE(N,100)
      WRITE(N,110)
      WRITE(N,120)
  10  FORMAT(/)
  20  FORMAT(15X,'PPPPPP',3X,'BBBBBB',3X,'DDDDDD',4X,'AAA',4X,'TTTTTTTT',
     &        5X,'AAA')
```

```
 30  FORM
   &
 40  FORM
   &
 50  FORM
   &
 60  FORM
   &
 80  FORM
   &
 90  FORM
100  FORM
110  FORM
120  FORM
     WRIT
     WRIT
     WRIT
     WRIT
     WRI
     WRI
     WRI
     WRI
     WRI
     WRI
     WRI
     WRI
     WRI
     WRI
     WRI
     WRI
200  FO
210  FO
220  FO
230  FO
240  FO
250  FO
260  FO
270  FO
280  FO
290  FO
300  FO
310  FO
320  FO
330  FO
340  FO
350  FO
     WR
     WR
     WR
     WR
     WR
     WR
     WR
     WR
     WR
     WR
     WR
     WR
```

```
 30  FORMAT(15X,'PP   PP',2X,'BB   BB',2X,'DD   DD',3X,'AA AA',3X,
    &       'T  TT  T',3X,'AA AA')
 40  FORMAT(15X,'PP   PP',2X,'BB   BB',2X,'DD   DD',2X,'AA   AA',2X,
    &       'T  TT  T',2X,'AA   AA')
 50  FORMAT(15X,'PPPPPP',3X,'BBBBBB',3X,'DD   DD',2X,'AAAAAAA',5X,'TT',
    &       5X,'AAAAAAA')
 60  FORMAT(15X,'PP',7X,'BB   BB',2X,'DD   DD',2X,'AA   AA',5X,'TT',
    &       5X,'AA   AA')
 80  FORMAT(15X,'PP',7X,'BBBBBB',3X,'DDDDDD',3X,'AA   AA',4X,'TTTT',
    &       4X,'AA   AA')
 90  FORMAT( )
100  FORMAT(15X,46HPROGRAM PBDATA  --- Revised:  May     03, 1988)
110  FORMAT(30X,' --- Written by S. M. Bajorek')
120  FORMAT( )
     WRITE(N,200)
     WRITE(N,210)
     WRITE(N,220)
     WRITE(N,230)
     WRITE(N,240)
     WRITE(N,250)
     WRITE(N,260)
     WRITE(N,270)
     WRITE(N,280)
     WRITE(N,290)
     WRITE(N,300)
     WRITE(N,310)
     WRITE(N,320)
     WRITE(N,330)
     WRITE(N,340)
     WRITE(N,350)
200  FORMAT(15X,'COMPONENT INDEX:')
210  FORMAT(15X,' 1 - ACETONE    ')
220  FORMAT(15X,' 2 - 2-BUTANONE ')
230  FORMAT(15X,' 3 - METHANOL   ')
240  FORMAT(15X,' 4 - ETHANOL    ')
250  FORMAT(15X,' 5 - BENZENE    ')
260  FORMAT(15X,' 6 - WATER      ')
270  FORMAT(15X,' 7 - 1-PROPANOL ')
280  FORMAT(15X,' 8 - 2-PROPANOL ')
290  FORMAT(15X,' 9 - ETHYLENE GLYCOL')
300  FORMAT(15X,'10 - CYCLOHEXANE')
310  FORMAT(15X,'11 - unassigned')
320  FORMAT(15X,'12 - METHYL ACETATE')
330  FORMAT(15X,'13 - ETHYL ACETATE')
340  FORMAT(15X,'14 - unassigned')
350  FORMAT(15X,'15 - AMMONIA')
     WRITE(N,120)
     WRITE(N,500)
     WRITE(N,510)
     WRITE(N,520)
     WRITE(N,530)
     WRITE(N,540)
     WRITE(N,550)
     WRITE(N,560)
     WRITE(N,570)
     WRITE(N,580)
     WRITE(N,120)
     WRITE(N,700)
```

```
      WRITE
      WRITE
500   FORMA
510   FORMA
520   FORMA
530   FORMA
540   FORM
550   FORM
560   FORM
570   FORM
580   FORM
700   FORM
710   FORM
720   FORM
      RET
      END
C *******
      SUB
      COM
      COM
      COM
      REA
 1    FOR
      REA
10    FOR
      REA
      REA
20    FOR
      REA
      REA
30    FOR
      REA
      REA
40    FOR
      REA
      DO
      IF
      REA
     &
     &
      GO
45    CO
      REA
     &
     &
50    CO
60    FO
70    FO
C
      RE
      EN
C ******
      SU
      CO
      CO
      CO
      CO
      CO
```

```
      WRITE(N,710)
      WRITE(N,720)
 500  FORMAT(15X,'SURFACE INDEX:')
 510  FORMAT(15X,' 1 - SMOOTH TUBE      Shakir')
 520  FORMAT(15X,' 2 - HIGH FLUX TUBE   Bajorek')
 530  FORMAT(15X,' 3 - FINNED TUBE      Bajorek')
 540  FORMAT(15X,' 4 - HIGH FLUX TUBE   Heinz')
 550  FORMAT(15X,' 5 - SMOOTH TUBE      Bajorek')
 560  FORMAT(15X,' 6 - SMOOTH TUBE      Bajorek')
 570  FORMAT(15X,' 7 - SMOOTH TUBE      Shakir')
 580  FORMAT(15X,' 8 - SMOOTH TUBE      Shakir')
 700  FORMAT(14X,'101 - SMOOTH CU FLAT DISK')
 710  FORMAT(14X,'102 - SMOOTH CU FLAT DISK')
 720  FORMAT(14X,'103 - 1.25 IN SI WAFER')
      RETURN
      END
C *****************************************************************
      SUBROUTINE INPUT(J)
      COMMON/XDATA/ IDNUM,IDATE,ISURF,ICOMP(5),FRAC(5),NPTS
      COMMON/XDATA/ VOLTS(40),AMPS(40),P(40)
      COMMON/XDATA/ TB(2,40),TC(4,40),TE(4,40) C
      READ(J,1)
   1  FORMAT( )
      READ(J,10) IDNUM,IDATE,ISURF
  10  FORMAT(10X,I5,9X,I6,10X,I5)
      READ(J,1)
      READ(J,20) ICOMP(1),ICOMP(2),ICOMP(3),ICOMP(4),ICOMP(5)
  20  FORMAT(5I15)
      READ(J,1)
      READ(J,30) FRAC(1),FRAC(2),FRAC(3),FRAC(4),FRAC(5)
  30  FORMAT(5E15.5)
      READ(J,1)
      READ(J,40) NPTS
  40  FORMAT(10X,I5)
      READ(J,1)
      DO 50 N-1,NPTS
      IF(IDNUM.GE.1000) GO TO 45
      READ(J,60) VOLTS(N),AMPS(N),TC(1,N),TC(2,N),TC(3,N),TC(4,N),
     &          TB(1,N),TB(2,N),TE(1,N),TE(2,N),TE(3,N),TE(4,N),
     &          P(N)
      GO TO 50
  45  CONTINUE
      READ(J,70) VOLTS(N),AMPS(N),TC(1,N),TC(2,N),TC(3,N),TC(4,N),
     &          TB(1,N),TB(2,N),TE(1,N),TE(2,N),TE(3,N),TE(4,N),
     &          P(N)
  50  CONTINUE
  60  FORMAT(F5.1,1X,F4.2,10F6.1,F5.1)
  70  FORMAT(F5.2,F5.2,10F6.1,F5.1)
C
      RETURN
      END
C *****************************************************************
      SUBROUTINE OUTPUT(J)
      COMMON/XDATA/ IDNUM,IDATE,ISURF,ICOMP(5),FRAC(5),NPTS
      COMMON/XDATA/ VOLTS(40),AMPS(40),P(40)
      COMMON/XDATA/ TB(2,40),TC(4,40),TE(4,40)
      COMMON/XOUTP/ DELT(40),QLOSS(40),ALPHA(40),TWALL(40),FLUX(40)
      COMMON/XOUTP/ TCVAR1(40),TCVAR2(40)
```

```
C
      WRI
    5 FOR
      WRI
   10 FOR
      WRI
   20 FOR
     &
      WRI
   30 FOR
      WRI
   40 FOR
     &
      WRI
   50 FOR
      WRI
   60 FOR
      WRI
   70 FOR
      WRI
   80 FOR
     &
     &
C
      DO
      WRI
     &
     &
  100 CON
  110 FOR
      WRI
  120 FOR
     &
C
      DO
      WRI
     &
  130 CON
  140 FOR
C
      RET
      END
C ******
      SUB
      COM
      COM
      COM
      COM
      COM
C
      DO
      WRI
   10 CON
   20 FOR
C
      RET
      END
```

```
C
      WRITE(J,5)
    5 FORMAT(10X,'IDNUM',11X,'DATE',8X,'SURFACE')
      WRITE(J,10) IDNUM,IDATE,ISURF
   10 FORMAT(10X,I5,9X,I6,10X,I5)
      WRITE(J,20)
   20 FORMAT(6X,'COMPONENT',6X,'COMPONENT',6X,'COMPONENT',
     &        6X,'COMPONENT',6X,'COMPONENT')
      WRITE(J,30) ICOMP(1),ICOMP(2),ICOMP(3),ICOMP(4),ICOMP(5)
   30 FORMAT(5I15)
      WRITE(J,40)
   40 FORMAT(7X,'FRACTION',7X,'FRACTION',7X,'FRACTION',
     &        7X,'FRACTION',7X,'FRACTION')
      WRITE(J,50) FRAC(1),FRAC(2),FRAC(3),FRAC(4),FRAC(5)
   50 FORMAT(5E15.5)
      WRITE(J,60)
   60 FORMAT(11X,'NPTS')
      WRITE(J,70) NPTS
   70 FORMAT(10X,I5) C
      WRITE(J,80)
   80 FORMAT(/,9X,'V',4X,'I',2X,'TC-1',2X,'TC-2',2X,'TC-3',2X,'TC-4',
     &        2X,'TB-1',2X,'TB-2',2X,'TE-1',2X,'TE-2',2X,'TE-3',
     &        2X,'TE-4',4X,'P')
C
      DO 100 N=1,NPTS
      WRITE(J,110) VOLTS(N),AMPS(N),TC(1,N),TC(2,N),TC(3,N),TC(4,N),
     &           TB(1,N),TB(2,N),TE(1,N),TE(2,N),TE(3,N),TE(4,N),
     &           P(N)
  100 CONTINUE
  110 FORMAT(5X,F5.1,1X,F4.1,10F6.1,F5.1)
      WRITE(J,120)
  120 FORMAT(/,2X,'NO',1X,' SUPERHEAT',2X,'HEAT FLUX',5X,'ALPHA',
     &        5X,'QLOSS',5X,'TWALL',4X,'TCVAR1',4X,'TCVAR2')
C
      DO 130 N=1,NPTS
      WRITE(J,140) N,DELT(N),FLUX(N),ALPHA(N),QLOSS(N),TWALL(N),
     &             TCVAR1(N),TCVAR2(N)
  130 CONTINUE
  140 FORMAT(2X,I2,1X,F10.1,1X,4F10.1,F10.2,F10.1)
C
      RETURN
      END
C ********************************************************************
      SUBROUTINE SDFOUT(J)
      COMMON/XDATA/ IDNUM,IDATE,ISURF,ICOMP(5),FRAC(5),NPTS
      COMMON/XDATA/ VOLTS(40),AMPS(40),P(40)
      COMMON/XDATA/ TB(2,40),TC(4,40),TE(4,40)
      COMMON/XOUTP/ DELT(40),QLOSS(40),ALPHA(40),TWALL(40),FLUX(40)
      COMMON/XOUTP/ TCVAR1(40),TCVAR2(40)
C
      DO 10 N=1,NPTS
      WRITE(J,20) DELT(N),FLUX(N),ALPHA(N)
   10 CONTINUE
   20 FORMAT(5X,F10.4,5X,F10.1,5X,F10.1)
C
      RETURN
      END
```

APPENDIX B

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APPENDIX B

CALCULATION OF MIXTURE THERMODYNAMIC PROPERTIES

Program MIXPROP generates the thermodynamic and transport properties for mixtures and pure components. Chapter 4 of this document describes the calculations performed by MIXPROP. Program MIXPROP reads from file MIXPROP.INP which contains the test identification number, components by index number, the vapor-liquid equilibrium compositions, and the test temperature and pressure. Multiple test cases can be considered, and all information can be written to a file suitable for use by MIXBOIL for evaluation of the mixture boiling correlations. Sample input to MIXPROP is shown in Table B-1. Table B-2 is a listing of Program MIXPROP.

Table B-1
Sample Input to Program MIXPROP

```
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              1              3              6              0              0
       FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
     .10000E+00     .10000E+00     .80000E+00     .00000E+00     .00000E+00
     .61000E+00     .13000E+00     .26000E+00     .00000E+00     .00000E+00
          PTEST          TBAVE
          14.70          70.00
          IDUMP           IEND
              0              1
```

```
      PRC
C *****
C *** Th
C *** li
C ***
C *** Pr
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C *** T
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C ***
C *****
      C
     &
      C
      C
      C
     &
C ***
C ***
C ***
C ***
C ***
C ***
C ***
```

Table B-2
Listing of Program MIXPROP

```
      PROGRAM MIXPROP
C  *************************************************************************
C  *** This program calculates thermodynamic properties for multicomponent *
C  *** liquid mixtures.  Up to 5 pure components are permitted.            *
C  ***                                                                     *
C  *** Property index is IPROP.   IPROP = 1 Saturation Temperature         *
C  ***                            IPROP = 2 Conductivity                   *
C  ***                            IPROP = 3 Kinematic Viscosity            *
C  ***                            IPROP = 4 Specific Heat                  *
C  ***                            IPROP = 5 Surface Tension                *
C  ***                            IPROP = 6 Liquid Density                 *
C  ***                            IPROP = 7 Vapor Density                  *
C  ***                            IPROP = 8 Vaporization Enthalpy          *
C  *** The component index is ICOMP.                                       *
C  ***                            ICOMP =  1 Acetone                       *
C  ***                            ICOMP =  2 2-Butanone                    *
C  ***                            ICOMP =  3 Methanol                      *
C  ***                            ICOMP =  4 Ethanol                       *
C  ***                            ICOMP =  5 Benzene                       *
C  ***                            ICOMP =  6 Water                         *
C  ***                            ICOMP =  7 1-Propanol                    *
C  ***                            ICOMP =  8 2-Propanol                    *
C  ***                            ICOMP =  9 Ethylene Glycol               *
C  ***                            ICOMP = 10 Cyclohexane                   *
C  ***                            ICOMP = 11 not assigned                  *
C  ***                            ICOMP = 12 Methyl Acetate                *
C  ***                            ICOMP = 13 Ethyl Acetate                 *
C  ***                            ICOMP = 14 not assigned                  *
C  ***                            ICOMP = 15 Ammonia                       *
C *************************************************************************
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C ***
C *** NMAX IS THE MAXIMUM NUMBER OF COMPONENTS ALLOWED (5)
C *** NCOMP IS THE NUMBER OF COMPONENTS
C *** IDUMP > 0 WRITES DEBUG PRINTOUT, IDUMP = 0 IS DEFAULT
C *** ITAPE = 1 SAVES DATA IN FILE MIXPROP.DAT
C *** RU IS THE UNIVERSAL GAS CONSTANT (BAR * M**3)/(KG-MOL * K)
C ***
      NMAX  = 5
      IDUMP = 0
      PI = 3.141593
      RU = 0.8314E-01
      JIN  = 1
      JOUT = 2
      OPEN(JIN,FILE='MIXPROP.INP',STATUS='OLD')
      OPEN(JOUT,FILE='MIXPROP.OUT',STATUS='NEW')
      OPEN(JDAT,FILE='MIXPROP.DAT',STATUS='NEW')
```

```
   10 CONT
      DO 2
      PROI
   20 CONT
      CALI
      WRIT
   50  FC
C
      CAL
      PRO
      WRI
  100  FO
C
      CAL
      PRO
      WRI
  200  FC
C
      CAI
      PRC
      WRI
  300  FC
C
      CAI
      PRC
      WRI
  400  F
C
      CA
      PR
      WR
  500  F
C
      CA
      PR
      WR
  600  F
C
      CA
      PR
      PR
      WR
  700  F
C
      CA
      PR
      WR
C      V
      VM
C      V
C
      CA
      PR
      PR
      WR
  800  F
```

```
  10  CONTINUE
      DO 20 I = 1, 12
      PROP(I) = 0.0
  20  CONTINUE
      CALL INPUT(IEND)
      WRITE(*,50)
    50  FORMAT(/,1X,'INPUT FILE READ',/)
C
      CALL TSAT(TBP)
      PROP(1) = TBP
      WRITE(*,100) TBP
  100  FORMAT(1X,'TBP    =',E12.5)
C
      CALL CONDMIX(TBP,COND)
      PROP(2) = COND
      WRITE(*,200) COND
  200  FORMAT(1X,'COND   =',E12.5)
C
      CALL VISCMIX(TBP,VISMIX)
      PROP(3) = VISMIX
      WRITE(*,300) VISMIX
  300  FORMAT(1X,'VISMIX =',E12.5)
C
      CALL CPMIX(TBP,CPL)
      PROP(4) = CPL
      WRITE(*,400) CPL
  400  FORMAT(1X,'CPL    =',E12.5)
C
      CALL SURFTM(TBP,SIGMA)
      PROP(5) = SIGMA
      WRITE(*,500) SIGMA
  500  FORMAT(1X,'SIGMA  =',E12.5)
C
      CALL SPECVL(TBP,VMIXL,DENSL)
      PROP(6) = VMIXL
      WRITE(*,600) 1./VMIXL
  600  FORMAT(1X,'DENSL  =',E12.5,'  USING MODIFIED RACKETT EQN')
C
      CALL TEJA(TBP,VMIXG,DENSG,VMIXL,DENSL,0)
      PROP(7) = VMIXG
      PROP(9) = VMIXL
      WRITE(*,700) 1./VMIXG, 1./VMIXL
  700  FORMAT(1X,'DENSG  =',E12.5,'  DENSL  =',E12.5,' USING TEJA EOS')
C
      CALL TEJA(TBP,VMIXG,DENSG,VMIXL,DENSL,1)
      PROP(10) = VMIXG
      WRITE(*,700) 1./VMIXG, 1./VMIXL
C      VMIXL = PROP(6)
      VMIXL = PROP(9)
       VMIXG = PROP(10)
C
      CALL DELHV(TBP,VMIXL,VMIXG,HVKJKG,HVMOL)
      PROP(8) = HVKJKG
      PROP(11)= HVMOL
      WRITE(*,800) HVKJKG
  800  FORMAT(1X,'HVDIFF =',E12.5)
```

```
C
      CA
      WR
  900  F
C
      CA
      CA
C
      IF
      WR
  999  FO
C
      ST
      E
C *****
      S
C
C *** T
C
       C
     &
       C
       C
       C
     &
C
       E

C
       C
   10  C
C ***  
       C
   20  C
C ***  


       C
   30  C
C ***  


       C
   40  C
C ***  
       C
    50
```

```
C
      CALL MDIFF(TBP,VISMIX,VMIXL)
      WRITE(*,900) DIJ(1),DIJ(2),DIJ(3)
  900  FORMAT(1X,'D11    =',E12.5,'  D22 = ',E12.5,'  D33 = ',E12.5)
C
      CALL OUTPUT
      CALL SAVER(IEND)
C
      IF(IEND.EQ.0) GO TO 10
      WRITE(*,999)
 999  FORMAT(//,1X,'NORMAL TERMINATION OF PROGRAM MIXPROP')
C
      STOP
      END
C ***************************************************************************
      SUBROUTINE BIC(I,J,ETA1,ETA2,IPROP)
C
C *** This subroutine generates the binary interaction coefficients.
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      ETA1 = 1.000
       ETA2 = 1.000
C
      GO TO (10,20,30,40,50,60,70,80) IPROP
  10  CONTINUE
C *** IPROP = 1   TSAT     Saturation Temperature
      GO TO 99
  20  CONTINUE
C *** IPROP = 2            Conductivity
      IF (I.EQ.4.AND.J.EQ.6) ETA1 = 1.40
      IF (I.EQ.6.AND.J.EQ.4) ETA1 = 1.40
      IF (I.EQ.7.AND.J.EQ.6) ETA1 = 1.40
      IF (I.EQ.6.AND.J.EQ.7) ETA1 = 1.40
      GO TO 99
  30  CONTINUE
C *** IPROP = 3   VISCMIX  Kinematic Viscosity
      IF (I.EQ.3.AND.J.EQ.6) ETA1 = 1.34
      IF (I.EQ.6.AND.J.EQ.3) ETA1 = 1.34
      IF (I.EQ.4.AND.J.EQ.6) ETA1 = 1.36
      IF (I.EQ.6.AND.J.EQ.4) ETA1 = 1.36
      IF (I.EQ.7.AND.J.EQ.6) ETA1 = 1.37
      IF (I.EQ.6.AND.J.EQ.7) ETA1 = 1.37
      IF (I.EQ.15.AND.J.EQ.6) ETA1 = 1.37
      IF (I.EQ.6.AND.J.EQ.15) ETA1 = 1.37
      GO TO 99
  40  CONTINUE
C *** IPROP = 4            Specific Heat
      GO TO 99
   50  CONTINUE
```

```
C *** IPROP
      GO TO
   60 CONTI
C *** IPROP
      GO TO
   70 CONTI
C *** IPROP
      IF (I
      IF (I
      IF (I
      IF (I
      GO T
   80 CONTI
C *** IPRO
      IF (
      IF (
      IF (
      IF (
      GO T
C ***
   99 CONT
      RETU
      END
C ********
      BLOC
C ***
C *** This
C *** comp
C *** Comp
C *** (4)
C *** (8)
C *** (11)
C *** (14)
C ***
      COMM
     &
      DATA
     &
     &
      DATA
     &
     &
      DATA
     &
     &
      DATA
     &
     &
      DATA
     &
     &
      DATA
     &
     &
      DATA
```

```
C *** IPROP = 5           Surface Tension
      GO TO 99
  60  CONTINUE
C *** IPROP = 6   VSPECL   Liquid Specific Volume
      GO TO 99
  70  CONTINUE
C *** IPROP = 7   VSPECG   Vapor Specific Volume
      IF (I.EQ.3.AND.J.EQ.6) ETA1 = 1.083
      IF (I.EQ.6.AND.J.EQ.3) ETA1 = 1.083
      IF (I.EQ.4.AND.J.EQ.6) ETA1 = 1.075
      IF (I.EQ.6.AND.J.EQ.4) ETA1 = 1.075
      GO TO 99
  80  CONTINUE
C *** IPROP = 8           Vaporization Enthalpy
      IF (I.EQ.3.AND.J.EQ.6) ETA1 = 1.083
      IF (I.EQ.6.AND.J.EQ.3) ETA1 = 1.083
      IF (I.EQ.4.AND.J.EQ.6) ETA1 = 1.075
      IF (I.EQ.6.AND.J.EQ.4) ETA1 = 1.075
      GO TO 99
C ***
  99  CONTINUE
      RETURN
      END
C **************************************************************************
      BLOCK DATA
C ***
C *** This section returns parameters at the critical point for
C *** component K.  Units are: TC in K, PC in bar, VC in m**3/kg.
C *** Components are: (1) Acetone, (2) 2-Butanone, (3) Methanol,
C *** (4) Ethanol, (5) Benzene, (6) Water, (7) 1-Propanol,
C *** (8) 2-Propanol, (9) Ethylene Glycol, (10) Cyclohexane
C *** (11) not assigned, (12) Methyl Acetate, (13) Ethyl Acetate,
C *** (14) not assigned, (15) Ammonia.
C ***
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DATA TCRIT/ 508.15,  535.60,  513.15,  516.25,  562.60,
     &            647.30,  536.85,  508.75,  645.00,  554.15,
     &               0.0,  506.80,  523.25,     0.0,  405.50/
      DATA PCRIT/ 47.610,  41.533,  79.500,  63.900,  49.240,
     &            221.29,  50.500,  53.700,  76.988,  40.750,
     &               0.0,  46.870,  38.320,     0.0, 113.500/
      DATA VCRIT/.36630E-02,.37028E-02,.36364E-02,.35714E-02,.33157E-02,
     &          .31746E-02,.36630E-02,.36496E-02,.29967E-02,.36630E-02,
     &                 0.0,.30769E-02,.32500E-02,        0.0,.42569E-02/
      DATA ZCRIT/  0.239,   0.249,   0.217,   0.245,   0.273,
     &             0.235,   0.249,   0.278,   0.270,   0.273,
     &               0.0,   0.254,   0.252,     0.0,   0.244/
      DATA OMEGA/  0.304,   0.320,   0.559,   0.635,   0.212,
     &             0.344,   0.624,   0.665,   1.171,   0.257,
     &               0.0,   0.326,   0.362,     0.0,   0.250/
      DATA WM   /  58.10,  72.107,  32.000,  46.100,  78.108,
     &            18.015,  60.100,  60.100,  62.069,  84.132,
     &               0.0,  74.080,  88.100,     0.0,  17.032/
      DATA BP   / 329.25,  352.70,  337.85,  351.45,  353.25,
```

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     &
      &
C
C     RET
      EN
C *******
      SU
C
      CO
     &
      CO
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     &
C
      IP
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   10 C
      V
      D
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      C
      V
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      I
   20
      D
      I





   25
     &
   26
     &
   27
```

```
     &            373.15,  370.95,  355.65,  470.00,  353.87,
     &              0.00,  330.30,  350.25,    0.00,  239.75/
C
C     RETURN
      END
C ***********************************************************************
      SUBROUTINE CONDMIX(TBP,CONDM)
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      IPROP - 2
      CONDM - 0.0
      TEMP - TBP
      IF(NCOMP.GT.1) GO TO 10
      II - ICOMP(1)
      CALL CONDPUR(IPROP,II,TEMP,CONDM)
      GO TO 99
   10 CONTINUE
      VTOT - 0.
      DO 15 I - 1, NCOMP
      II - ICOMP(I)
      TRI - TBP/TCRIT(II)
      CALL VLIQUID(II,TRI,VL)
      VTOT - VTOT + FRACX(I) * VL*WM(II)/1000.
   15 CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,20) VTOT
   20 FORMAT(1X,'CONDMIX:',' VTOT-',E10.4)
      DO 40 I - 1, NCOMP
      DO 30 J - 1, NCOMP
      II - ICOMP(I)
      TRI - TBP/TCRIT(II)
      CALL VLIQUID(II,TRI,VLI)
      PHII - (FRACX(I) * VLI*WM(II)/1000.)/VTOT
      CALL CONDPUR(IPROP,II,TEMP,CONDI)
      JJ - ICOMP(J)
      TRJ - TBP/TCRIT(JJ)
      CALL VLIQUID(JJ,TRJ,VLJ)
      PHIJ - (FRACX(J) * VLJ*WM(JJ)/1000.)/VTOT
      CALL CONDPUR(IPROP,JJ,TBP,CONDJ)
      CONDIJ - 2./(1./CONDI + 1./CONDJ)
      CONDM - CONDM + PHII*PHIJ*CONDIJ
      IF(IDUMP.NE.IPROP) GO TO 30
      WRITE(JOUT,25) II, TRI, PHII, CONDI
   25 FORMAT(1X,'CONDMIX:',' II-',I2,' TRI-',E10.4,' PHII-',E10.4,
     &          ' CONDI-',E10.4)
      WRITE(JOUT,26) JJ, TRJ, PHIJ, CONDJ
   26 FORMAT(1X,'CONDMIX:',' JJ-',I2,' TRJ-',E10.4,' PHIJ-',E10.4,
     &          ' CONDJ-',E10.4)
      WRITE(JOUT,27) CONDIJ, CONDM
   27 FORMAT(1X,'CONDMIX:',' CONDIJ-',E10.4,' CONDM-',E10.4)
```

```
  30  CONTINUE
   40  CONTINUE
C
  99  CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,100) CONDM
 100  FORMAT(1X,'CONDMIX:',' CONDM=',E10.4)
      RETURN
      END
C ***************************************************************************
      SUBROUTINE CONDPUR(IPROP,I,TEMP,CONDP)
C ***
C *** CALCULATE LIQUID THERMAL CONDUCTIVITY FOR PURE COMPONENTS
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DIMENSION A(15), B(15), C(15), ASTAR(15), B1(15)
      DATA A / 0.000E+00, 0.000E+00, 3.225E-01, 2.629E-01, 1.776E-01,
     &        -3.838E-01, 1.854E-01, 0.000E+00, 0.000E+00, 1.626E-01,
     &         0.000E+00, 0.000E+00, 0.000E+00, 0.000E+00, 1.068E+00/
      DATA B / 0.000E+00, 0.000E+00,-4.785E-04,-3.847E-04, 4.773E-06,
     &         5.254E-03,-3.366E-05, 0.000E+00, 0.000E+00,-9.513E-05,
     &         0.000E+00, 0.000E+00, 0.000E+00, 0.000E+00,-1.577E-03/
      DATA C / 0.000E+00, 0.000E+00, 1.168E-07, 2.211E-07,-3.781E-07,
     &        -6.369E-06,-2.215E-07, 0.000E+00, 0.000E+00,-9.513E-05,
     &         0.000E+00, 0.000E+00, 0.000E+00, 0.000E+00,-1.229E-06/
      DATA ASTAR / 3.83E-03,3.83E-03,3.39E-03,3.39E-03,3.46E-02,
     &             4.94E-01,3.39E-03,3.39E-03,4.94E-01,3.10E-02,
     &             0.00E+00,4.15E-02,4.15E-02,0.00E+00,4.94E-01/
      DATA B1 / 4*0.5,1.0,3*0.5,2*1.0,0.0,2*1.0,0.0,1.0 /
C
      A1 = 1.2
      IF(ASTAR(I).GT.0.1) A1 = 0.0
      C1 = 0.167
       IF(ASTAR(I).GT.0.1) C1 = -0.167
C
      CONDP = 0.0
      CONDP = A(I) + B(I)*TEMP + C(I)*TEMP**2
      IF(CONDP.GT.0.) GO TO 99
      CONDP = ASTAR(I)*BP(I)**A1 / ( WM(I)**B1(I) * TCRIT(I)**C1 )
      TR = TEMP/TCRIT(I)
      CONDP = CONDP*(1.-TR)**0.38/TR**(1./6.)
  99  CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,100) I, TEMP, TR, CONDP
 100  FORMAT(1X,'CONDPUR:',' I=',I2,' TEMP=',E10.4,' TR=',E10.4,
     &          ' CONDP=',E10.4)
      RETURN
      END
C ***************************************************************************
      SUBROUTINE CPMIX(TBP,CP)
C ***
C *** This subroutine calculates bulk liquid mixture specific heat.
```

```
C ***
      COMMON/I
     &
      COMMON/C
      COMMON/T
      COMMON/F
     &
C
      IPROP =
      CP = 0.C
       KCOMP =
C
      II = ICC
      CALL PSU
      R = RU*
      TEMP =
      CALL CP
      RI = RU
      CIRI =
       CPSUR =
C
      IF(IDUM
   10  FORMAT
C
      IF(NCOM
C ***
C *** MULTICO
      OMI = O
   20 CONTINU
C *** CALCULA
      Z2 = 0.
      Z3 = 0.
      DO 30 L
      NN = IC
      Z2 = Z2
      Z3 = Z3
   30 CONTINU
      OMPSU =

      JJ = IC
      TEMP =
      CALL CP
      RJ = RU
      CJRJ =
       OMJ =
C

        CPSUI
C

      IF(IDU
   40 FORMAT
     &  E10
      OMI =
      CIRI =
      KCOMP
      IF(KCO
```

```
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      IPROP = 4
      CP = 0.0
       KCOMP = 1
C
      II = ICOMP(KCOMP)
      CALL PSUMIX(0,IPROP,VCM,TCM,WMCM,ZCM)
      R = RU*100./WMCM
      TEMP = TBP
      CALL CPPUR(IPROP,II,TEMP,CPI)
      RI = RU*100./WM(II)
      CIRI = CPI / RI
       CPSUR = CIRI
C
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) II, RI, CPI
   10  FORMAT(1X,'CPMIX:',' II=',I2,' RI=',E10.4,' CPI=',E10.4)
C
      IF(NCOMP.EQ.1) GO TO 99
C ***
C *** MULTICOMPONENT MIXTURE - NCOMP.GE.1
      OMI = OMEGA(II)
  20  CONTINUE
C *** CALCULATE A NEW PSEUDO ACCENTRIC FACTOR
      Z2 = 0.
      Z3 = 0.
      DO 30 LL = 1, KCOMP+1
      NN = ICOMP(LL)
      Z2 = Z2 + FRACX(LL) * OMEGA(NN)
      Z3 = Z3 + FRACX(LL)
  30  CONTINUE
      OMPSU = Z2/Z3

      JJ = ICOMP(KCOMP+1)
      TEMP = TBP
      CALL CPPUR(IPROP,JJ,TEMP,CPJ)
      RJ = RU*100./WM(JJ)
      CJRJ = CPJ / RJ
       OMJ = OMEGA(JJ)
C
        CPSUR =  CIRI + ((OMPSU-OMI)/(OMJ-OMI)) * (CJRJ-CIRI)
C
      IF(IDUMP.EQ.IPROP)WRITE(JOUT,40)KCOMP,CIRI,OMI,JJ,CJRJ,OMJ,CPSUR
  40  FORMAT(1X,'CPMIX:',' KCOMP=',I2,' CIRI=',E10.4,' OMI=',
     &  E10.4,' JJ=',I2,' CJRJ=',E10.4,' OMJ=',E10.4,' CPSUR=',E10.4)
      OMI = OMPSU
      CIRI = CPSUR
      KCOMP = KCOMP + 1
      IF(KCOMP.LT.NCOMP) GO TO 20
```

```
 99


 100
C


C ****

C ***
C ***
C ***
C ***

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C



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C



C ****

C ***
C ***
C ***

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```
  99  CONTINUE
      CP = CPSUR * R
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,100) R, CP
 100   FORMAT(1X,'CPMIX:',' R=',E10.4,' CP=',E10.4)
C
      RETURN
      END
C ************************************************************************
      SUBROUTINE CPPUR(IPROP,I,T,CP)
C ***
C *** This subroutine calculates pure component liquid specific heat.
C *** CP is returned in units of kJ/kg-K
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      DIMENSION A(15), B(15), C(15), D(15)
      DATA A /  3.339,  2.299,  3.509, -1.465, -6.199,
     &          2.822, 19.010, -1.964,  4.430, -5.375,
     &          0.000,  2.597,  1.323,  0.000,  0.000/
      DATA B / -1.031E-02, 0.0, -1.352E-02, 4.001E-02, 6.472E-02,
     &          1.183E-02,-0.9554E-01,1.961E-02,-2.079E-02,5.605E-02,
     &          0.0, -7.535E-03, 2.786E-04, 0.0, 0.0/
      DATA C /  2.154E-05, 0.0, 3.473E-05, -1.585E-04,-1.829E-04,
     &        -3.504E-05,1.425E-04,-1.297E-05,4.738E-05,-1.469E-04,
     &          0.0, 1.658E-05, 5.510E-06, 0.0, 0.0/
      DATA D /  0.0, 0.0, -7.070E-10, 2.280E-07, 1.840E-07,
     &          3.60E-08, 0.0, 0.0, 0.0, 1.350E-07,
     &          0.0, 0.0, 0.0, 0.0, 0.0/
C
      CP = A(I) + B(I)*T + C(I)*T*T + D(I)*T*T*T
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) I, T, CP
   10  FORMAT(1X,'CPPUR:',' I=',I2,' T=',E10.4,' CP=',E10.4)
C
      RETURN
      END
C ************************************************************************
      SUBROUTINE DELHV(TBP,VMIXL,VMIXG,HVKJKG,HVMOL)
C ***
C *** CALCULATE THE DIFFERENTIAL LATENT HEAT OF VAPORIZATION
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DIMENSION F(15), PSI(15), CPVAPA(15), CPVAPB(15),
     &          CPVAPC(15), CPVAPD(15)
      DATA PSI / 0.285,0.273,0.271,0.300,0.310,0.269,0.303,
     &           0.323,0.2955,0.0,0.0,0.300,0.298,0.0,0.282/
```

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     &
     &
C
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  5
C ***
C  ***
C ***
        &
        &
```

```
      DATA F   / 0.713, 0.720, 0.905, 1.23034, 0.704657, 0.689803,
     &             1.241347, 1.297, 1.345, 0.0, 0.0, 0.780, 0.866,
     &           0.0, 1.42559 /
      DATA CPVAPA/ 6.301E+00,1.094E+01,2.115E+01,9.014E+00,-3.392E+01,
     &             3.224E+01,2.470E+00,3.243E+01,3.570E+01,-5.454E+01,
     &             0.000E+00,1.655E+01,7.235E+00,0.000E+00,2.731E+01/
      DATA CPVAPB/ 2.606E-01,3.559E-01,7.092E-02,2.141E-01,4.739E-01,
     &             1.924E-03,3.325E-01,1.885E-01,2.483E-01,6.113E-01,
     &             0.000E+00,2.245E-01,4.072E-01,0.000E+00,2.383E-02/
      DATA CPVAPC/ -1.253E-04,-1.900E-04,2.587E-05,-8.390E-05,
     &          -3.017E-04,1.055E-05,-1.855E-04,6.406E-05,-1.497E-04,
     &          -2.523E-04,0.0,-4.342E-05,-2.092E-04,0.0,1.707E-05 /
      DATA CPVAPD/ 2.038E-08,3.920E-08,-2.852E-08,1.373E-09,
     &           7.130E-08,-3.596E-09,4.296E-08,-9.261E-08,3.010E-08,
     &           1.321E-08,0.0,2.914E-08,2.855E-08,0.0,-1.185E-08 /
C
      IPROP = 8
      HOL = 0.0
      HOV = 0.0
      HVKJKG = 0.0
      HVMOL = 0.0
      DO 5 I = 1, NCOMP
      K = ICOMP(I)
      IF(PSI(K).GT.0.) GO TO 5
      PSI(K) = 0.329032 - 0.076799*OMEGA(K) + 0.211947*OMEGA(K)**2
      F(K) = 0.452413 + 1.30982*OMEGA(K) - 0.295937*OMEGA(K)**2
      ATHIRD = 1./3.
      IF(PSI(K).GT.ATHIRD) PSI(K) = ATHIRD
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,4) K, PSI(K), F(K)
   4  FORMAT(1X,'DELHV:',' K=',I2,' PSI=',E10.4,' F=',E10.4)
   5  CONTINUE
C ***
C *** CALCULATE THE ENTHALPY DEPARTURE FOR THE LIQUID MIXTURE
C ***
      AM = 0.
      BM = 0.
      CM = 0.
      FPSU = 0.
      WAPSU = 0.
      DO 30 I = 1, NCOMP
      II = ICOMP(I)
      B = 2. - 3. * PSI(II)
      C = 3. * PSI(II) * PSI(II)
      D = -1. * PSI(II) * PSI(II) * PSI(II)
      CALL ROOT3(IPROP,B,C,D,WBI,0)
      WAI = 3.*PSI(II)*PSI(II) + 3.*(1.-2.*PSI(II))*WBI +
     &     WBI*WBI + 1. - 3.*PSI(II)
      WCI = 1. - 3.*PSI(II)
      AMI = WAI*RU*RU*TCRIT(II)*TCRIT(II) *
     &     (1.+F(II)*(1.-SQRT(TBP/TCRIT(II))))**2 / PCRIT(II)
      AMIJ =0.
      DO 20 J = 1, NCOMP
      JJ = ICOMP(J)
      IF(I.EQ.J) GO TO 10
      B = 2. - 3. * PSI(JJ)
```

```
     C
     D
     C
     W
    &
     W
     A
    &
     C
     A
     G
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     A
 15  C
     A
 20  C
     E
     C
     I
     W
 30  C

 35  I
    &
C



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    &




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 40

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    &

 41
    &
C ***




    &
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```
      C = 3. * PSI(JJ) * PSI(JJ)
      D = -1. * PSI(JJ) * PSI(JJ) * PSI(JJ)
      CALL ROOT3(IPROP,B,C,D,WBJ,0)
      WAJ = 3.*PSI(JJ)*PSI(JJ) + 3.*(1.-2.*PSI(JJ))*WBJ +
     &     WBJ*WBJ + 1. - 3.*PSI(JJ)
      WCJ = 1. - 3.*PSI(JJ)
      AMJ = WAJ*RU*RU*TCRIT(JJ)*TCRIT(JJ) *
     &     (1.+F(JJ)*(1.-SQRT(TBP/TCRIT(JJ))))**2 / PCRIT(JJ)
      CALL BIC(II,JJ,ETA1,ETA2,IPROP)
      AMIJ = ETA1 * SQRT(AMI*AMJ)
      GO TO 15
  10  CONTINUE
      AMIJ = AMI
  15  CONTINUE
      AM = AM + FRACX(I)*FRACX(J)*AMIJ
  20  CONTINUE
      BM = BM + FRACX(I)*WBI*RU*TCRIT(II) / PCRIT(II)
      CM = CM + FRACX(I)*WCI*RU*TCRIT(II) / PCRIT(II)
      FPSU = FPSU + FRACX(I)*F(II)
      WAPSU = WAPSU + FRACX(I)*WAI
  30  CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,35) AM,BM,CM,FPSU
  35  FORMAT(1X,'DELHV:',' AM=',E10.4,' BM=',E10.4,' CM=',E10.4,
     &          ' FPSU=',E10.4)
C
      ZN = SQRT( BM*CM + 0.25*(BM+CM)**2 )
      ZM = (0.5*(BM+CM)-ZN) * (PTEST/RU/TBP)
      ZQ = (0.5*(BM+CM)+ZN) * (PTEST/RU/TBP)
      CALL PSUMIX(0,IPROP,VCM,TCM,WMCM,ZCM)
      PCM = ZCM*RU*TCM/VCM/WMCM
      DADT = -(WAPSU*RU*RU*TCM*FPSU/PCM) * (1.+FPSU *
     &        (1.-SQRT(TBP/TCM))) / SQRT(TBP/TCM)
      FF = 100.
      Z = PTEST*VMIXL*WMCM/(RU*TBP)
      HDEPL = FF * ( RU*TBP*(Z-1.) - (TBP*DADT-AM)*
     &            (ALOG((Z+ZM)/(Z+ZQ))/(2.*ZN)) ) / WMCM
      HDEPL1 = RU*TBP*(Z-1.)
      HDEPL2 = TBP*DADT-AM
      HDEPL3 = ALOG((Z+ZM)/(Z+ZQ))
      HDEPL4 = 2.*ZN
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,40) ZN,ZM,ZQ,TCM,PCM,
     &                                  DADT,Z,HDEPL
  40  FORMAT(1X,'DELHV:',' ZN=',E10.4,' ZM=',E10.4,' ZQ=',E10.4,
     &      ' TCM=',E10.4,' PCM=',E10.4,' DADT=',E10.4,' Z=',E10.4,
     &      ' HDEPL=',E10.4)
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,41) HDEPL1,HDEPL2,HDEPL3,HDEPL4
  41  FORMAT(1X,'DELHV:',' HDEPL1=',E10.4,' HDEPL2=',E10.4,' HDEPL3=',
     &       E10.4,' HDEPL4=',E10.4)
C *** CALCULATE THE IDEAL GAS ENTHALPY (LET TREF = 0.0 K)
      TREF = 0.0
      DO 45 I = 1,NCOMP
      II = ICOMP(I)
      HI = CPVAPA(II)*(TBP-TREF)+CPVAPB(II)*(TBP**2-TREF**2)/2. +
     &   CPVAPC(II)*(TBP**3-TREF**3)/3.+CPVAPD(II)*(TBP**4-TREF**4)/4.
      H0L = H0L + FRACX(I)*HI
```

```
      HOV
   45 CON
      HOL
      IF(
   50 FOR
      HVM
C ***
C  *** NO
C ***
      AM
      BM
      CM
      FP
      WA
      DO
      II
      B
      C
      D
      CA
      WA
     &
       W
       A
     &
        A
        D
        J
        I



      &


      &


   60

   65

   70



   80

   85
C
```

```
      HOV = HOV + FRACY(I)*HI
  45  CONTINUE
      HOL = HOL/WMCM
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,50) HOL
  50  FORMAT(1X,'DELHV:',' HOL=',E10.4)
      HVMOLL= HDEPL * WMCM / 1000.
C ***
C  *** NOW CALCULATE THE VAPOR PHASE ENTHALPY DEPARTURE
C ***
      AM = 0.
      BM = 0.
      CM = 0.
      FPSU = 0.
      WAPSU = 0.
      DO 80 I = 1, NCOMP
      II = ICOMP(I)
      B = 2. - 3. * PSI(II)
      C = 3. * PSI(II) * PSI(II)
      D = -1. * PSI(II) * PSI(II) * PSI(II)
      CALL ROOT3(IPROP,B,C,D,WBI,0)
      WAI = 3.*PSI(II)*PSI(II) + 3.*(1.-2.*PSI(II))*WBI +
     &     WBI*WBI + 1. - 3.*PSI(II)
      WCI = 1. - 3.*PSI(II)
      AMI = WAI*RU*RU*TCRIT(II)*TCRIT(II) *
     &     (1.+F(II)*(1.-SQRT(TBP/TCRIT(II))))**2 / PCRIT(II)
      AMIJ =0.
      DO 70 J = 1, NCOMP
      JJ = ICOMP(J)
      IF(I.EQ.J) GO TO 60
      B = 2. - 3. * PSI(JJ)
      C = 3. * PSI(JJ) * PSI(JJ)
      D = -1. * PSI(JJ) * PSI(JJ) * PSI(JJ)
      CALL ROOT3(IPROP,B,C,D,WBJ,0)
      WAJ = 3.*PSI(JJ)*PSI(JJ) + 3.*(1.-2.*PSI(JJ))*WBJ +
     &     WBJ*WBJ + 1. - 3.*PSI(JJ)
      WCJ = 1. - 3.*PSI(JJ)
      AMJ = WAJ*RU*RU*TCRIT(JJ)*TCRIT(JJ) *
     &     (1.+F(JJ)*(1.-SQRT(TBP/TCRIT(JJ))))**2 / PCRIT(JJ)
      CALL BIC(II,JJ,ETA1,ETA2,IPROP)
      AMIJ = ETA1 * SQRT(AMI*AMJ)
      GO TO 65
  60  CONTINUE
      AMIJ = AMI
  65  CONTINUE
      AM = AM + FRACY(I)*FRACY(J)*AMIJ
  70  CONTINUE
      BM = BM + FRACY(I)*WBI*RU*TCRIT(II) / PCRIT(II)
      CM = CM + FRACY(I)*WCI*RU*TCRIT(II) / PCRIT(II)
      FPSU = FPSU + FRACY(I)*F(II)
      WAPSU = WAPSU + FRACY(I)*WAI
  80  CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,85) AM,BM,CM,FPSU
  85  FORMAT(1X,'DELHV:',' AM=',E10.4,' BM=',E10.4,' CM=',E10.4,
     &          ' FPSU=',E10.4)
C
```

```
      ZN = SQRT( BM*CM + 0.25*(BM+CM)**2 )
      ZM = (0.5*(BM+CM)-ZN) * (PTEST/RU/TBP)
      ZQ = (0.5*(BM+CM)+ZN) * (PTEST/RU/TBP)
      CALL PSUMIX(1,IPROP,VCM,TCM,WMCM,ZCM)
      PCM = ZCM*RU*TCM/VCM/WMCM
      DADT = -(WAPSU*RU*RU*TCM*FPSU/PCM) * (1.+FPSU *
      &        (1.-SQRT(TBP/TCM))) / SQRT(TBP/TCM)
C *** CONVERSION FACTOR FF TO PUT INTO KJ/KG-MOL
      FF = 100.
      Z = PTEST*VMIXG*WMCM/(RU*TBP)
      HDEPV = FF * ( RU*TBP*(Z-1.) - (TBP*DADT-AM)*
     &            (ALOG((Z+ZM)/(Z+ZQ))/(2.*ZN)) ) / WMCM
      HDEPV1 = RU*TBP*(Z-1.)
      HDEPV2 = TBP*DADT-AM
      HDEPV3 = ALOG((Z+ZM)/(Z+ZQ))
      HDEPV4 = 2.*ZN
      HVMOLV= HDEPV * WMCM / 1000.
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,90) ZN,ZM,ZQ,TCM,PCM,
     &                                  DADT,Z,HDEPV
  90  FORMAT(1X,'DELHV:',' ZN=',E10.4,' ZM=',E10.4,' ZQ=',E10.4,
     &      ' TCM=',E10.4,' PCM=',E10.4,' DADT=',E10.4,' Z=',E10.4,
     &      ' HDEPV=',E10.4)
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,91) HDEPV1,HDEPV2,HDEPV3,HDEPV4
  91  FORMAT(1X,'DELHV:',' HDEPV1=',E10.4,' HDEPV2=',E10.4,' HDEPV3=',
     &       E10.4,' HDEPV4=',E10.4)
      HOV = HOV/WMCM
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,95) HOV
  95  FORMAT(1X,'DELHV:',' HOV=',E10.4)
C ***
      HVKJKG = (HDEPV - HDEPL) + (HOV-HOL)
      HVMOL  = HVMOLV - HVMOLL
C ***
      RETURN
      END
C ***************************************************************************
      SUBROUTINE INPUT(IEND)
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      READ(JIN,1)
    1 FORMAT( )
      READ(JIN,10) IDNUM, ITAPE
      READ(JIN,1)
      READ(JIN,10) (ICOMP(I),I=1,NMAX)
  10  FORMAT(5I15)
      READ(JIN,1)
      READ(JIN,20) (FRACX(I),I=1,NMAX)
      READ(JIN,20) (FRACY(I),I=1,NMAX)
  20  FORMAT(5E15.5)
      READ(JIN,1)
```

```
      READ(JIN,30) PTEST,TBAVE
      READ(JIN,1)
   30 FORMAT(5X,F10.4,5X,F10.4)
      READ(JIN,40) IDUMP, IEND
   40 FORMAT(13X,I2,13X,I2)
C *** CONVERT TBAVE FROM DEG C TO DEG K
      TBAVE = TBAVE + 273.15
C *** CONVERT PTEST FROM PSIA TO BAR
      PTEST = PTEST * 1.01325 / 14.696
C
C *** DETERMINE THE NUMBER OF COMPONENTS
      NCOMP = 0
      DO 60 I=1,NMAX
      IF (ICOMP(I)) 60,60,50
   50 NCOMP = NCOMP + 1
   60 CONTINUE
C *** CHECK FRAC ARRAYS
      FXTOT = 0.
      FYTOT = 0.
      DO 70 I=1,NCOMP
      FXTOT = FXTOT + FRACX(I)
      FYTOT = FYTOT + FRACY(I)
   70 CONTINUE
      IF(FXTOT.NE.1.0) WRITE(JOUT,80)
      IF(FYTOT.NE.1.0) WRITE(JOUT,80)
      IF(FXTOT.NE.1.0) WRITE(*,80)
      IF(FYTOT.NE.1.0) WRITE(*,80)
    80 FORMAT(1X,'WARNING - PROBLEM IN FRAC ARRAY AS INPUT')
C
      RETURN
      END
C ****************************************************************************
      SUBROUTINE MDIFF(TBP,VISMIX,VMIXL)
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DIMENSION ASSOC(15)
      DATA ASSOC / 1.0,1.0,1.9,1.5,1.0,2.6,9*1.0 /
C ***
C *** CALCULATE THE MASS DIFFUSIVITY BY WILKE-CHANG METHOD
C ***
      DO 10 I = 1,NMAX-1
      DIJ(I) = 0.0
   10 CONTINUE
      IF(NCOMP.EQ.1) GO TO 90
      WMIX = 0.0
      DO 20 I = 1, NCOMP
      II = ICOMP(I)
      WMIX = WMIX + FRACX(I)*WM(II)
   20 CONTINUE
      VISC = 1000. * VISMIX
```

```
      IF(IDUMP.EQ.9) WRITE(JOUT,25) WMIX, VISC, TBP
   25  FORMAT(1X,'MDIFF: ','WMIX=',E10.4,' VISC=',E10.4,' TBP=',E10.4)
C
      DO 50 I = 1, NCOMP-1
      II = ICOMP(I)
      ASSOCM = 0.
      DO 40 J = 1, NCOMP
      JJ = ICOMP(J)
      IF(I.EQ.J) GO TO 30
      ASSOCM = ASSOCM + FRACX(J) * ASSOC(JJ) * WM(JJ)
   30 CONTINUE
   40 CONTINUE
      ASSOCM = ASSOCM/(1.-FRACX(I))
      TR = BP(II)/TCRIT(II)
      CALL VLIQUID(II,TR,VMOL)
      VMOL = 1000. * WM(II) * VMOL
      DIJ(I) = 7.4E-08*SQRT(ASSOCM)*TBP / (VISC*VMOL**0.6)
      IF(IDUMP.EQ.9) WRITE(JOUT,45) ASSOCM, VMOL, DIJ(I)
   45 FORMAT(1X,'MDIFF: ','ASSOCM=',E10.4,' VMOL=',E10.4,' DIJ=',E10.4)
   50 CONTINUE
C
   90 CONTINUE
      RETURN
      END
C ***************************************************************************
      SUBROUTINE OUTPUT
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C ***
      WRITE(JOUT,10)
   10 FORMAT(//,10X,'OUTPUT FILE FROM PROGRAM MIXPROP',/)
      IF(ITAPE.EQ.1) WRITE(JOUT,15) IDNUM
   15 FORMAT(10X,'IDNUM = ',I5)
      WRITE(JOUT,20) (ICOMP(I),I=1,NMAX)
   20 FORMAT(10X,'ICOMP = ',5I7)
      WRITE(JOUT,30) (FRACX(I),I=1,NMAX)
   30 FORMAT(10X,'FRACX = ',5F7.3)
      WRITE(JOUT,35) (FRACY(I),I=1,NMAX)
   35 FORMAT(10X,'FRACY = ',5F7.3)
      WRITE(JOUT,40) TBAVE
   40 FORMAT(10X,'TBAVE = ',F7.1,' K')
      WRITE(JOUT,50) PTEST
   50 FORMAT(10X,'PTEST = ',F7.1,' BAR')
      WRITE(JOUT,60) IDUMP
   60 FORMAT(10X,'IDUMP = ',I5)
      WRITE(JOUT,70) NCOMP
   70 FORMAT(10X,'NCOMP = ',I5)
C
      WRITE(JOUT,100) PROP(1)
  100 FORMAT(/,1X,'TBP   =',E12.5,' DEG K')
```

```
      WRITE(JOUT,110) PROP(2)
  110 FORMAT(1X,'COND  =',E12.5,' W/M-K')
      WRITE(JOUT,120) PROP(3)
  120 FORMAT(1X,'VISMIX=',E12.5,' N-S/M**2')
      WRITE(JOUT,125) 1000.*PROP(3)
  125 FORMAT(1X,'VISMIX=',E12.5,' CP')
      WRITE(JOUT,130) PROP(4)
  130 FORMAT(1X,'CPL   =',E12.5,' KJ/KG-K')
      WRITE(JOUT,140) PROP(5)
  140 FORMAT(1X,'SIGMA =',E12.5,' N/M')
      WRITE(JOUT,150) PROP(6)
  150 FORMAT(1X,'VMIXL =',E12.5,' M**3/KG',5X,'USING MODIFIED RACKETT')
      WRITE(JOUT,155) 1./PROP(6)
  155 FORMAT(1X,'DENSL =',E12.5,' KG/M**3',5X,'USING MODIFIED RACKETT')
      WRITE(JOUT,160) PROP(7)
  160 FORMAT(1X,'VMIXG =',E12.5,' M**3/KG',5X,'USING TEJA-PATEL')
      WRITE(JOUT,165) 1./PROP(7)
  165 FORMAT(1X,'DENSG =',E12.5,' KG/M**3',5X,'USING TEJA-PATEL')
      WRITE(JOUT,170) PROP(8)
  170 FORMAT(1X,'HVDIFF=',E12.5,' KJ/KG')
C
      WRITE(JOUT,175) PROP(11)
  175 FORMAT(1X,'HVDIFF=',E12.5,' KJ/MOL')
      WRITE(JOUT,180) PROP(9)
  180 FORMAT(1X,'VMIXL =',E12.5,' M**3/KG',5X,'USING TEJA-PATEL')
      WRITE(JOUT,185) 1./PROP(9)
  185 FORMAT(1X,'DENSL =',E12.5,' KG/M**3',5X,'USING TEJA-PATEL')
      WRITE(JOUT,190) PROP(10)
  190 FORMAT(1X,'VMIXG =',E12.5,' M**3/KG',5X,'AT VLE VAPOR',
     &                   1X,'MOL FRACTION')
C
      IF(NCOMP.GT.1) WRITE(JOUT,200) (DIJ(I),I=1,NCOMP-1)
  200 FORMAT(1X,'DIJ   =',4E12.5,' CM**2/S')
      WRITE(JOUT,900)
  900 FORMAT( )
      RETURN
      END
C *************************************************************************
      SUBROUTINE PSUMIX(IFRAC,IPROP,VCM,TCM,WMCM,ZCM)
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DIMENSION FRAC(5)
C ***
C ***     Calculate the mixture pseudocritical values.
C ***     Use liquid mole fractions if IFRAC = 0
C ***     Use vapor mole fractions if IFRAC = 1
C ***
      IF(NCOMP.EQ.1) GO TO 150
      DO 300 K = 1, NMAX
      FRAC(K) = FRACX(K)
```

```
      IF(IFRAC.EQ.1) FRAC(K) = FRACY(K)
  300 CONTINUE
C
      VCM = 0.
      TCMVCM = 0.
      WMCM = 0.
      ZCM = 0.
      OMCM = 0.
      DO 20 I=1,NCOMP
      DO 10 J=1,NCOMP
      II = ICOMP(I)
      JJ = ICOMP(J)
      CALL BIC(II,JJ,ETA1,ETA2,IPROP)
      TCI = TCRIT(II)
      VCI = VCRIT(II)
      TCJ = TCRIT(JJ)
       VCJ = VCRIT(JJ)
C
      VCIJ = VCI
      TCIJ = TCI * VCI
      IF(I.EQ.J) GO TO 5
      VCIJ = ( VCI**(1./3.) + VCJ**(1./3.) )**3 / 8.
      TCIJ = ETA1 * SQRT(TCI*VCI*TCJ*VCJ)
    5 CONTINUE
      Z1 = FRAC(I)*FRAC(J)*VCIJ
      VCM = VCM + FRAC(I)*FRAC(J)*VCIJ
      Z2 = FRAC(I)*FRAC(J)*TCIJ
       TCMVCM = TCMVCM + FRAC(I)*FRAC(J)*TCIJ
C
   10 CONTINUE
   20 CONTINUE
       TCM = TCMVCM/VCM
C
      DO 70 KK = 1,NCOMP
      II = ICOMP(KK)
      WMCM = WMCM + FRAC(KK)*WM(II)
      ZCM  = ZCM  + FRAC(KK)*ZCRIT(II)
      OMCM = OMCM + FRAC(KK)*OMEGA(II)
   70 CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,71) ZCM, OMCM
   71  FORMAT(1X,'PSUMIX:',' ZCM=',E10.4,' OMCM=',E10.4)
C ***
C *** Calculate pseudocritical values ZPSU and OMPSU
C ***
      KCOMP = 0
   75 CONTINUE
      OMOLD = OMPSU
      ZPOLD = ZPSU
      KCOMP = KCOMP + 1
      ILOWER = ICOMP(KCOMP)
      IUPPER = ICOMP(KCOMP+1)
      IF(KCOMP.EQ.1) OMOLD = OMEGA(ILOWER)
       IF(KCOMP.EQ.1) ZPOLD = ZCRIT(ILOWER)
C
      Z1 = 0.
```

```
C

C



C

1

1
C





C

2



C

C
C
C
C
C



C



C
```

```
      Z2 = 0.
      DO  90 K = 1, KCOMP + 1
      I = ICOMP(K)
      Z1 = Z1 + FRAC(K)*OMEGA(I)
      Z2 = Z2 + FRAC(K)
   90 CONTINUE
      OMPSU = Z1/Z2
C
      ZPSU = ZCRIT(IUPPER) + ((OMPSU-OMEGA(IUPPER))/
      &      (OMOLD-OMEGA(IUPPER))) * (ZPOLD-ZCRIT(IUPPER))
C
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,95) KCOMP, IUPPER, ILOWER,
     &                OMPSU, OMOLD, ZPSU, ZPOLD
   95 FORMAT(1X,'PSUMIX:',' KCOMP=',I2,' ILOWER=',I2,' IUPPER=',I2,
     &       ' OMPSU=',E10.4,' OMOLD=',E10.4,' ZPSU=',E10.4,
     &       ' ZPOLD=',E10.4)
C
      IF((KCOMP+1).LT.NCOMP) GO TO 75
  100 CONTINUE
      IF(NCOMP.GT.1) GO TO 190
  150 CONTINUE
C *** FOR SINGLE COMPONENT RETURN CRITICAL POINT VALUES
      II = ICOMP(1)
      TCM = TCRIT(II)
      VCM = VCRIT(II)
      WMCM = WM(II)
      ZCM = ZCRIT(II)
   190 CONTINUE
C
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,200) IPROP,VCM,TCM,WMCM,ZCM
  200 FORMAT(1X,'PSUMIX:',' IPROP=',I2,' VCM=',E10.4,' TCM=',E10.4,
     &       ' WMCM=',E10.4,' ZCM=',E10.4)
      RETURN
      END
C ************************************************************************
      SUBROUTINE ROOT3(IPROP,B,C,D,WB,IFLAG)
C ***
C *** SOLVE FOR POSITIVE ROOTS OF A CUBIC EQUATION
C  ***    IFLAG = 1  MAXIMUM POSITIVE ROOT
C  ***    IFLAG = 0  MINIMUM POSITIVE ROOT
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      COMPLEX*8   I, Y1, Y2, Y3
C
      I = (0.0,1.0)
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,5) IPROP,B,C,D, IFLAG
    5 FORMAT(1X,'ROOT3:',' IPROP=',I2,' B=',E10.4,' C=',E10.4,
     &         ' D=',E10.4,' IFLAG=',I2)
C
      P = (3.*C - B*B)/3.
```

```
      Q = (27.*D - 9.*B*C + 2.*B**3)/27.
      R = (P/3.)**3 + (Q/2.)**2
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) P,Q,R
   10 FORMAT(1X,'ROOT3:',' P=',E10.4,' Q=',E10.4,' R=',E10.4)
      IF(R.LT.0.) GO TO 20
      CC = -Q/2.+SQRT(R)
      IF(CC.LT.0.) AA = - (-CC)**(1./3.)
      IF(CC.GE.0.) AA =   (CC)**(1./3.)
      CC = -Q/2.-SQRT(R)
      IF(CC.LT.0.) BB = - (-CC)**(1./3.)
      IF(CC.GE.0.) BB =   (CC)**(1./3.)
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,15) AA,BB
   15 FORMAT(1X,'ROOT3:',' AA=',E10.4,' BB=',E10.4)
      Y1 = AA + BB - B/3.
      Y2 = -(AA+BB)/2. + I*(SQRT(3.)/2)*(AA-BB) - B/3.
      Y3 = -(AA+BB)/2. - I*(SQRT(3.)/2)*(AA-BB) - B/3.
      GO TO 30
   20 CONTINUE
      PHI = ACOS( SQRT( 0.25*Q*Q/(-P**3/27.) )  )
      Y1 = 2.*SQRT(-P/3.)*COS(PHI/3.)
      Y2 = 2.*SQRT(-P/3.)*COS((PHI+2.*PI)/3.)
      Y3 = 2.*SQRT(-P/3.)*COS((PHI+4.*PI)/3.)
      IF(Q.LT.0.) GO TO 25
      Y1 = -Y1
      Y2 = -Y2
      Y3 = -Y3
   25 CONTINUE
      Y1 = Y1 - B/3.
      Y2 = Y2 - B/3.
      Y3 = Y3 - B/3.
   30 CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,35) Y1,Y2,Y3
   35 FORMAT(1X,'ROOT3:',' Y1=',2(E10.4,1X),' Y2=',2(E10.4,1X),
     &           ' Y3=',2(E10.4,1X))
C ***
C  *** DETERMINE THE MINIMUM POSITIVE REAL ROOT IF IFLAG = 0
C  *** DETERMINE THE MAXIMUM POSITIVE REAL ROOT IF IFLAG = 1
C ***
      ROOTA = 0.
      ROOTB = 0.
      ROOTC = 0.
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,40) AIMAG(Y1),AIMAG(Y2),AIMAG(Y3)
   40 FORMAT(1X,'Y1IMAG=',E10.4,' Y2IMAG=',E10.4,' Y3IMAG=',E10.4)
      IF(AIMAG(Y1).EQ.0.) ROOTA = AMAX1(REAL(Y1),0.0)
      IF(AIMAG(Y2).EQ.0.) ROOTB = AMAX1(REAL(Y2),0.0)
      IF(AIMAG(Y3).EQ.0.) ROOTC = AMAX1(REAL(Y3),0.0)
      WB = 1.0E+10
      IF(ROOTA.GT.0.) WB = AMIN1(WB,ROOTA)
      IF(ROOTB.GT.0.) WB = AMIN1(WB,ROOTB)
       IF(ROOTC.GT.0.) WB = AMIN1(WB,ROOTC)
C
      IF(IFLAG.EQ.1) WB = AMAX1(ROOTA,ROOTB,ROOTC)
      CHECK = WB**3 + B*WB**2 + C*WB + D
      IF(ABS(CHECK).GT.0.5E-02) WRITE(JOUT,50) WB, CHECK
      IF(CHECK.GE.1.0E+10) WRITE(JOUT,50) WB, CHECK
```

```
  50  FORMAT(1X,'WARNING - BAD VALUE FROM ROOT3',5X,'WB=',E10.4,
     &          5X,'CHECK=',E10.4)
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,60) WB, CHECK, IPROP
  60  FORMAT(1X,'ROOT3:',' WB=',E10.4,'  CHECK=',E10.4,' IPROP=',I2)
      RETURN
      END
C *************************************************************************
      SUBROUTINE SAVER(IEND)
C ***
C *** This subroutine saves selected properties and writes them to
C *** file MIXPROP.DAT .  The order in which they are written are
C *** appropriate for file THERMOD.DAT, which is used by Program MIXBOIL.
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DIMENSION Z1(250),Z2(250),Z3(250),Z4(250),Z5(250),
     &          Z6(250),Z7(250),Z8(250),YMX1(250),YMX2(250),
     &          YMX3(250),YMX4(250),YMX5(250),D11(250),
     &          D22(250),D33(250),D44(250)
C
      IF(ITAPE.EQ.0) GO TO 200
C
      Z1(IDNUM) = PROP(1)
      Z2(IDNUM) = PROP(2)
      Z3(IDNUM) = PROP(3)
      Z4(IDNUM) = PROP(4)
      Z5(IDNUM) = PROP(5)
      Z6(IDNUM) = 1./PROP(6)
      Z7(IDNUM) = 1./PROP(7)
      Z8(IDNUM) = PROP(8)
      YMX1(IDNUM) = FRACY(1)-FRACX(1)
      YMX2(IDNUM) = FRACY(2)-FRACX(2)
      YMX3(IDNUM) = FRACY(3)-FRACX(3)
      YMX4(IDNUM) = FRACY(4)-FRACX(4)
      YMX5(IDNUM) = FRACY(5)-FRACX(5)
      D11(IDNUM) = DIJ(1)
      D22(IDNUM) = DIJ(2)
      D33(IDNUM) = DIJ(3)
       D44(IDNUM) = DIJ(4)
C
      IF(IEND.EQ.0) GO TO 200
      IDMAX = 250
      WRITE(JDAT,5)
   5  FORMAT(' C *** THERMOD.DAT --- THERMAL PROPERTY DATA')
      WRITE(JDAT,10)
  10  FORMAT(' C *** TSAT - DEG C')
      WRITE(JDAT,*) (Z1(I),I=1,IDMAX)
      WRITE(JDAT,20)
  20  FORMAT(' C *** COND - W/m-K')
      WRITE(JDAT,*) (Z2(I),I=1,IDMAX)
      WRITE(JDAT,30)
```

```
   30 FORMAT(' C *** VISC - N-s/m**2')
      WRITE(JDAT,*) (Z3(I),I=1,IDMAX)
      WRITE(JDAT,40)
   40 FORMAT(' C *** CP - kJ/kg-K')
      WRITE(JDAT,*) (Z4(I),I=1,IDMAX)
      WRITE(JDAT,50)
   50 FORMAT(' C *** SIGMA - N/m')
      WRITE(JDAT,*) (Z5(I),I=1,IDMAX)
      WRITE(JDAT,60)
   60 FORMAT(' C *** RHOL - kg/m**3')
      WRITE(JDAT,*) (Z6(I),I=1,IDMAX)
      WRITE(JDAT,70)
   70 FORMAT(' C *** RHOG - kg/m**3')
      WRITE(JDAT,*) (Z7(I),I=1,IDMAX)
      WRITE(JDAT,80)
   80 FORMAT(' C *** DELHV - kJ/kg')
      WRITE(JDAT,*) (Z8(I),I=1,IDMAX)
      WRITE(JDAT,90)
   90 FORMAT(' C *** YMX1')
      WRITE(JDAT,*) (YMX1(I),I=1,IDMAX)
      WRITE(JDAT,100)
  100 FORMAT(' C *** YMX2')
      WRITE(JDAT,*) (YMX2(I),I=1,IDMAX)
      WRITE(JDAT,110)
  110 FORMAT(' C *** YMX3')
      WRITE(JDAT,*) (YMX3(I),I=1,IDMAX)
      WRITE(JDAT,120)
  120 FORMAT(' C *** YMX4')
      WRITE(JDAT,*) (YMX4(I),I=1,IDMAX)
      WRITE(JDAT,130)
  130 FORMAT(' C *** YMX5')
      WRITE(JDAT,*) (YMX5(I),I=1,IDMAX)
      WRITE(JDAT,140)
  140 FORMAT(' C *** D11')
      WRITE(JDAT,*) (D11(I),I=1,IDMAX)
      WRITE(JDAT,150)
  150 FORMAT(' C *** D22')
      WRITE(JDAT,*) (D22(I),I=1,IDMAX)
      WRITE(JDAT,160)
  160 FORMAT(' C *** D33')
      WRITE(JDAT,*) (D33(I),I=1,IDMAX)
      WRITE(JDAT,170)
  170 FORMAT(' C *** D44')
       WRITE(JDAT,*) (D44(I),I=1,IDMAX)
C
      WRITE(*,190)
  190 FORMAT(/,' MIXPROP.DAT FILE WRITTEN')
  200 CONTINUE
C
      RETURN
      END
C **********************************************************************
      SUBROUTINE TEJA(TBP,VMIXG,DENSG,VMIXL,DENSL,IFRAC)
C ***
C *** This subroutine calculates mixture vapor specific volume and
```

```
C  *** liquid specific volume using Teja-Patel equation of state.
C ***    IFRAC = 0 uses liquid mole fractions.
C ***    IFRAC = 1 uses vapor mole fractions.
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DIMENSION F(15), PSI(15), FRAC(5)
      DATA PSI / 0.285,0.273,0.271,0.300,0.310,0.269,0.303,
     &           0.323,0.2955,0.0,0.0,0.300,0.298,0.0,0.282/
      DATA F   / 0.713, 0.720, 0.905, 1.23034, 0.704657, 0.689803,
     &           1.241347, 1.297, 1.345, 0.0, 0.0, 0.780, 0.866,
     &           0.0, 1.42559 /
C
      IPROP = 7
      VMIXG = 0.0
      DENSG = 0.0
      VMIXL = 0.0
       DENSL = 0.0
C
      DO 5 I = 1, NCOMP
      K = ICOMP(I)
      IF(PSI(K).GT.0.) GO TO 5
      PSI(K) = 0.329032 - 0.076799*OMEGA(K) + 0.211947*OMEGA(K)**2
      F(K) = 0.452413 + 1.30982*OMEGA(K) - 0.295937*OMEGA(K)**2
   5  CONTINUE
C
      DO 300 K = 1, NMAX
      FRAC(K) = FRACX(K)
      IF(IFRAC.EQ.1) FRAC(K) = FRACY(K)
 300  CONTINUE
C
      AM = 0.
      BM = 0.
      CM = 0.
      DO 30 I = 1, NCOMP
      II = ICOMP(I)
      B = 2. - 3. * PSI(II)
      C = 3. * PSI(II) * PSI(II)
      D = -1. * PSI(II) * PSI(II) * PSI(II)
      CALL ROOT3(IPROP,B,C,D,WBI,0)
      WAI = 3.*PSI(II)*PSI(II) + 3.*(1.-2.*PSI(II))*WBI +
     &     WBI*WBI + 1. - 3.*PSI(II)
      WCI = 1. - 3.*PSI(II)
      AMI = WAI*RU*RU*TCRIT(II)*TCRIT(II) *
     &     (1.+F(II)*(1.-SQRT(TBP/TCRIT(II))))**2 / PCRIT(II)
      AMIJ =0.
      DO 20 J = 1, NCOMP
      JJ = ICOMP(J)
      IF(I.EQ.J) GO TO 10
      B = 2. - 3. * PSI(JJ)
      C = 3. * PSI(JJ) * PSI(JJ)
```

```
      D = -1. * PSI(JJ) * PSI(JJ) * PSI(JJ)
      CALL ROOT3(IPROP,B,C,D,WBJ,0)
      WAJ = 3.*PSI(JJ)*PSI(JJ) + 3.*(1.-2.*PSI(JJ))*WBJ +
     &     WBJ*WBJ + 1. - 3.*PSI(JJ)
      WCJ = 1. - 3.*PSI(JJ)
      AMJ = WAJ*RU*RU*TCRIT(JJ)*TCRIT(JJ) *
     &     (1.+F(JJ)*(1.-SQRT(TBP/TCRIT(JJ))))**2 / PCRIT(JJ)
      CALL BIC(II,JJ,ETA1,ETA2,IPROP)
      AMIJ = ETA1 * SQRT(AMI*AMJ)
      GO TO 15
   10 CONTINUE
      AMIJ = AMI
   15 CONTINUE
      AM = AM + FRAC(I)*FRAC(J)*AMIJ
   20 CONTINUE
      BM = BM + FRAC(I)*WBI*RU*TCRIT(II) / PCRIT(II)
      CM = CM + FRAC(I)*WCI*RU*TCRIT(II) / PCRIT(II)
   30 CONTINUE
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,35) AM,BM,CM
    35 FORMAT(1X,'TEJA:',' AM=',E10.4,' BM=',E10.4,' CM=',E10.4)
C
      B = CM - RU*TBP/PTEST
      C = AM/PTEST - BM*BM - 2.*BM*CM - RU*TBP*(BM+CM)/PTEST
      D = BM*BM*CM + RU*TBP*BM*CM/PTEST - AM*BM/PTEST
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,40) B,C,D
   40 FORMAT(1X,'TEJA:',' B=',E10.4,' C=',E10.4,' D=',E10.4)
      CALL ROOT3(IPROP,B,C,D,VMIXG,1)
      CALL PSUMIX(0,IPROP,VCM,TCM,WMCM,ZCM)
      VMIXG = VMIXG/WMCM
      DENSG = 1./VMIXG
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,45) VMIXG, WMCM, DENSG, IFRAC
   45 FORMAT(1X,'TEJA:',' VMIXG=',E10.4,' WMCM=',E10.4,' DENSG=',
     &           E10.4,' IFRAC=',I2)
C
      CALL ROOT3(IPROP,B,C,D,VMIXL,0)
      VMIXL = VMIXL/WMCM
      DENSL = 1./VMIXL
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,50) VMIXL, WMCM, DENSL, IFRAC
   50 FORMAT(1X,'TEJA:',' VMIXL=',E10.4,' WMCM=',E10.4,' DENSL=',
     &           E10.4,' IFRAC=',I2)
C
      RETURN
      END
C ***********************************************************************
      SUBROUTINE SPECVL(TBP,VMIXL,DENSL)
C
C     This subroutine calculates mixture liquid specific volume.
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
```

```
      IPROP = 6
      KCOMP = 1
      II = ICOMP(KCOMP)
       JJ = ICOMP(KCOMP+1)
C
      CALL PSUMIX(0,IPROP,VCM,TCM,WMCM,ZCM)
      TRI = TBP/TCM
      CALL VLIQUID(II,TRI,VI)
            VRI=  VI/VCRIT(II)
C ***
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) II, TRI, TCM, VI, VRI
 10   FORMAT(1X,'SPECVL:',' II=',I2,' TRI=',E10.4,' TCM=',E10.4,
     &           ' VI=',E10.4,' VRI=',E10.4)
C ***
      VMIXL = VI
      IF(NCOMP.EQ.1) GO TO 99
C
      TRJ = TBP/TCM
      CALL VLIQUID(JJ,TRJ,VJ)
      VRJ= VJ/VCRIT(JJ)
C ***
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,20) JJ, TRJ, TCM, VJ, VRJ
 20   FORMAT(1X,'SPECVL:',' JJ=',I2,' TRJ=',E10.4,' TCM=',E10.4,
     &           ' VJ=',E10.4,' VRJ=',E10.4)
C ***
C
      Z2 = FRACX(KCOMP)*OMEGA(II) + FRACX(KCOMP+1)*OMEGA(JJ)
      Z3 = FRACX(KCOMP) + FRACX(KCOMP+1)
      OMPSU = Z2/Z3
C
      ZPSU = ZCRIT(JJ) + ((OMPSU-OMEGA(JJ))/
     &        (OMEGA(II)-OMEGA(JJ))) * (ZCRIT(II)-ZCRIT(JJ))
C
      VRPSU = (ZCRIT(JJ)*VRJ + ((OMPSU-OMEGA(JJ))/
     &         (OMEGA(II)-OMEGA(JJ))) * (ZCRIT(II)*VRI-
     &          ZCRIT(JJ)*VRJ)) / ZPSU
C ***
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,30) OMPSU, ZPSU, VRPSU
 30   FORMAT(1X,'SPECVL:',' OMPSU=',E10.4,' ZPSU=',E10.4,
     &        ' VRPSU=',E10.4)
C ***
      VRPSUN = VRPSU
       IF(NCOMP.LE.2) GO TO 55
C
      DO 50 KCOMP = 3, NCOMP
      II = ICOMP(KCOMP)
      ZCI = ZCRIT(II)
      OMI = OMEGA(II)
      TRI = TBP/TCM
      CALL VLIQUID(II,TRI,VI)
      VRI= VI/VCRIT(II)
C ***
       IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) II, TRI, TCM, VI, VRI
C ***
      Z2 = 0.
```

```
      Z3 = 0.
      DO 60 L = 1, KCOMP
      LL = ICOMP(L)
      Z2 = Z2 + FRACX(L)*OMEGA(LL)
      Z3 = Z3 + FRACX(L)
  60  CONTINUE
      OMPSUN = Z2/Z3
C
       ZPSUN = ZCI + ((OMPSUN-OMI)/(OMPSU-OMI))*(ZPSU-ZCI)
C
      VRPSUN = (ZPSU*VRPSU+((OMPSUN-OMI)/(OMPSU-OMI))*
     &         (ZCI*VRI-ZPSU*VRPSU))/ZPSUN
C ***
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,35) KCOMP,OMPSUN,ZPSUN,VRPSUN
  35  FORMAT(1X,'SPECVL:',' KCOMP=',I3,' OMPSUN=',E10.4,' ZPSUN=',
     &       E10.4,' VRPSUN=',E10.4)
C ***
C
  50  CONTINUE
   55  CONTINUE
C
       VMIXL = VRPSUN * VCM
C ***
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,40) VMIXL, VRPSUN, VCM
  40  FORMAT(1X,'SPECVL:',' VMIXL=',E10.4,' VRPSUN=',E10.4,' VCM=',
     &          E10.4)
C ***
  99  CONTINUE
      DENSL = 1./VMIXL
      RETURN
      END
C ***************************************************************************
      SUBROUTINE SURFTM(TBP,SIGMA)
C ***
C *** This subroutine calculates the mixture surface tension.
C *** Reference: Rice,P., and Teja,A.S., "A Generalized Corresponding-
C *** States Method for the Prediction of Surface Tension of Pure
C *** Liquids and Liquid Mixtures," J. Colloid and Interfactial Sci.,
C *** Vol. 86, No. 1, March 1982.
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      IPROP = 5
       KCOMP = 1
C
      II = ICOMP(KCOMP)
      CALL PSUMIX(0,IPROP,VCM,TCM,WMCM,ZCM)
      E = (VCM*WMCM*1000.)**(2./3.) / TCM
      TEMP = TBP
      CALL SURFTP(IPROP,II,TEMP,SIGMA)
```

```
      EI = (VCRIT(II)*WM(II)*1000.)**(2./3.) / TCRIT(II)
      SIEI = EI * SIGMA
       SPSUE = SIEI
C
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) II, EI, SIGMA
   10  FORMAT(1X,'SURFTM:',' II=',I2,' EI=',E10.4,' SIGMA=',E10.4)
C
      IF(NCOMP.EQ.1) GO TO 99
C ***
C *** MULTICOMPONENT MIXTURE - NCOMP.GE.1
      OMI = OMEGA(II)
  20  CONTINUE
C *** CALCULATE A NEW PSEUDO ACCENTRIC FACTOR
      Z2 = 0.
      Z3 = 0.
      DO 30 LL = 1, KCOMP+1
      NN = ICOMP(LL)
      Z2 = Z2 + FRACX(LL) * OMEGA(NN)
      Z3 = Z3 + FRACX(LL)
  30  CONTINUE
      OMPSU = Z2/Z3

      JJ = ICOMP(KCOMP+1)
      TEMP = TBP
      CALL SURFTP(IPROP,JJ,TEMP,SIGMA)
      EJ = (VCRIT(JJ)*WM(JJ)*1000.)**(2./3.) / TCRIT(JJ)
      SJEJ = EJ * SIGMA
      OMJ = OMEGA(JJ)
C
        SPSUE =  SIEI + ((OMPSU-OMI)/(OMJ-OMI)) * (SJEJ-SIEI)
C
      IF(IDUMP.EQ.IPROP)WRITE(JOUT,40)KCOMP,SIEI,OMI,JJ,SJEJ,OMJ,SPSUE
  40  FORMAT(1X,'SURFTM:',' KCOMP=',I2,' SIEI=',E10.4,' OMI=',
     &   E10.4,' JJ=',I2,' SJEJ=',E10.4,' OMJ=',E10.4,' SPSUE=',E10.4)
      OMI = OMPSU
      SIEI = SPSUE
      KCOMP = KCOMP + 1
      IF(KCOMP.LT.NCOMP) GO TO 20
  99  CONTINUE
      SIGMA = SPSUE / E
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,100) E, SIGMA
  100  FORMAT(1X,'SURFTM:',' E=',E10.4,' SIGMA=',E10.4)
C
      RETURN
      END
C *************************************************************************
      SUBROUTINE SURFTP(IPROP,I,TEMP,SIGMA)
C ***
C *** This subroutine calculates the surface tension of a pure substance.
C *** SIGMAP is returned in units of N/M. Reference: Jasper,J.J.,"The
C *** Surface Tension of Pure Liquid Compounds," J.Phys.Chem.Ref.Data,
C *** Vol. 1, No. 4, 1972.
C ***
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
```

```
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      DIMENSION A(15), B(15)
      DATA  A  / 26.26, 26.77, 24.00, 24.05, 31.50,
     &           75.83, 25.26, 22.90, 50.21, 27.62,
     &            0.00, 27.95, 26.29,  0.00, 26.08/
      DATA  B  / 0.1120, 0.1122, 0.0773, 0.0832, 0.1287,
     &           0.1477, 0.0777, 0.0789, 0.0890, 0.1188,
      &           0.0000, 0.1289, 0.1161, 0.0000, -0.2299/
C
      T = TEMP - 273.15
      IF(TEMP.LT.0.) WRITE(JOUT,10)
  10  FORMAT(1X,'SURFTP:',5X,'WARNING - TEMP TOO LOW')
      SIGMA = ( A(I) - B(I)*T ) / 1000.
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,20) I, T, SIGMA
   20  FORMAT(1X,'SURFTP:',' I=',I2,' T=',E10.4,' SIGMA=',E10.4)
C
      RETURN
      END
C ****************************************************************************
      SUBROUTINE TSAT(TBP)
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      IPROP = 1
       TBP = TBAVE
C
      RETURN
      END
C ****************************************************************************
      SUBROUTINE VISCMIX(TBP,VISMIX)
C
C *** This subroutine calculates the liquid mixture viscosity.
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      IPROP = 3
      KCOMP = 1
      II = ICOMP(KCOMP)
      CALL PSUMIX(0,IPROP,VCM,TCM,WMCM,ZCM)
      E = WMCM**(-0.5) * (VCM*WMCM*1000.)**(2./3.) * TCM**(-0.5)
      TEMP = TBP * TCRIT(II) / TCM
```

```
      CALL V
      EI = W
     &    T
      VIEI =
       VPSUE
C
      IF(IDU
   10  FORMA
C
      IF(NCO
C ***
C *** MULTIC
      OMI =
   20 CONTIN
C *** CALCUL
      Z2 = 0
      Z3 = 0
      DO 30
      NN = I
      Z2 = Z
      Z3 = Z
   30 CONTIN
      OMPSU

      JJ = I
      TEMP =
      CALL V
      EJ = W
     &    T
      VJEJ =
      OMJ =
C
      VPSUE
     &
C
      IF(IDU
   40 FORMA
     &  E1
      OMI =
      VIEI =
      KCOMP
      IF(KC
   99 CONTIN
      VISMI
      IF(IDU
  100 FORMA
      RETUR
      END
C *********
      SUBROU
C
C *** This
C *** VISCO
C

      COMMO
```

```
      CALL VISCPUR(IPROP,II,TEMP,VISCO)
      EI = WM(II)**(-0.5) * (VCRIT(II)*WM(II)*1000.)**(2./3.) *
     &     TCRIT(II)**(-0.5)
      VIEI = EI * VISCO * 1000.
       VPSUE = VIEI
C
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) II, EI, VISCO
   10  FORMAT(1X,'VISCMIX:',' II=',I2,' EI=',E10.4,' VISCO=',E10.4)
C
      IF(NCOMP.EQ.1) GO TO 99
C ***
C *** MULTICOMPONENT MIXTURE - NCOMP.GE.1
      OMI = OMEGA(II)
  20  CONTINUE
C *** CALCULATE A NEW PSEUDO ACCENTRIC FACTOR
      Z2 = 0.
      Z3 = 0.
      DO 30 LL = 1, KCOMP+1
      NN = ICOMP(LL)
      Z2 = Z2 + FRACX(LL) * OMEGA(NN)
      Z3 = Z3 + FRACX(LL)
  30  CONTINUE
      OMPSU = Z2/Z3

      JJ = ICOMP(KCOMP+1)
      TEMP = TBP * TCRIT(JJ) / TCM
      CALL VISCPUR(IPROP,JJ,TEMP,VISCO)
      EJ = WM(JJ)**(-0.5) * (VCRIT(JJ)*WM(JJ)*1000.)**(2./3.) *
     &     TCRIT(JJ)**(-0.5)
      VJEJ = EJ * VISCO * 1000.
      OMJ = OMEGA(JJ)
C
      VPSUE = EXP( LOG(VIEI) + ((OMPSU-OMI)/(OMJ-OMI)) *
     &             (LOG(VJEJ)-LOG(VIEI)) )
C
      IF(IDUMP.EQ.IPROP)WRITE(JOUT,40) KCOMP,VIEI,OMI,JJ,VJEJ,OMJ,VPSUE
  40  FORMAT(1X,'VISCMIX:',' KCOMP=',I2,' VIEI=',E10.4,' OMI=',
     &   E10.4,' JJ=',I2,' VJEJ=',E10.4,' OMJ=',E10.4,' VPSUE=',E10.4)
      OMI = OMPSU
      VIEI = VPSUE
      KCOMP = KCOMP + 1
      IF(KCOMP.LT.NCOMP) GO TO 20
  99  CONTINUE
      VISMIX = VPSUE / E / 1000.
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,100) E, VISMIX
 100  FORMAT(1X,'VISCMIX:',' E=',E10.4,' VISMIX=',E10.4)
      RETURN
      END
C ***************************************************************************
      SUBROUTINE VISCPUR(IPROP,I,T,VISCO)
C
C *** This subroutine calculates the pure component liquid viscosity.
C *** VISCO is returned with units N-s/m**2.
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
```

```
     &
      COMMO
      COMMO
      COMMO
     &
C
      DIMEN
      DATA
     &
     &
      DATA
     &
     &
      DATA
     &
     &
      DATA
     &
     &
C
      VISCO
C ***
      IF(ID
   10 FORMA
C ***
      RETUR
      END

C *********
      SUBR
C
C     This
C
      COMM
     &
      COMM
      COMM
      COMM
     &
      DIME
      DATA
     &
     &
C
C *** CAL
C
      IF(Z
      ZRA(
   10 CONT
      VL
      VL
C
      RETU
      END
```

```
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
C
      DIMENSION A(15), B(15), C(15), D(15)
      DATA A /-4.033E+00,-4.213E+00,-3.935E+01,-6.210E+00, 4.612E+00,
     &       -2.471E+01,-1.228E+01,-8.114E+00,-7.811E+00,-4.398E+00,
     &        0.000E+00,-4.200E+00,-4.171E+00, 0.000E+00,-1.978E+01/
      DATA B / 8.456E+02, 9.759E+02, 4.826E+03, 1.614E+03, 1.489E+02,
     &        4.209E+03, 2.666E+03, 2.624E+03, 3.143E+03, 1.380E+03,
     &        0.000E+00, 9.409E+02, 9.841E+02, 0.000E+03, 2.018E+03/
      DATA C / 0.000E+00, 0.000E+00, 1.091E-01, 6.180E-03,-2.544E-02,
     &        4.527E-02, 2.008E-02, 0.000E+00, 0.000E+00,-1.550E-03,
     &        0.000E+00, 0.000E+00, 0.000E+00, 0.000E+00, 6.173E-02/
      DATA D / 0.000E+00, 0.000E+00,-1.127E-04,-1.132E-05, 2.222E-05,
     &       -3.376E-05,-2.233E-05, 0.000E+00, 0.000E+00, 1.157E-06,
      &        0.000E+00, 0.000E+00, 0.000E+00, 0.000E+00,-8.317E-05/
C
      VISCO = EXP( A(I) + B(I)/T + C(I)*T + D(I)*T*T ) / 1000.
C ***
      IF(IDUMP.EQ.IPROP) WRITE(JOUT,10) I, T, VISCO
  10  FORMAT(1X,'VISCPUR:',' I=',I2,' T=',E10.4,' VISCO=',E10.4)
C ***
      RETURN
      END

C *********************************************************************
      SUBROUTINE VLIQUID(I,TR,VL)
C
C     This subroutine calculates the pure liquid specific volume.
C
      COMMON/INFO / ICOMP(5),FRACX(5),FRACY(5),PTEST,TBAVE,IDUMP,
     &              IDNUM,ITAPE
      COMMON/CALCV/ NMAX, NCOMP, PI, RU, PROP(12), DIJ(4)
      COMMON/TAPES/ JIN, JOUT, JDAT
      COMMON/PURES/ TCRIT(15), PCRIT(15), VCRIT(15), ZCRIT(15),
     &              OMEGA(15), WM(15), BP(15)
      DIMENSION ZRA(15)
      DATA ZRA / 0.24494, 0.23580, 0.23230, 0.25041, 0.26967,
     &           0.23380, 0.25272, 0.24962, 0.24880, 0.27290,
      &               0.0, 0.25520, 0.25390,     0.0, 0.24650/
C
C  *** CALCULATE PURE COMPONENT SPEC. VOL. USING MODIFIED RACKET EQN.
C
      IF(ZRA(I).GT.0.) GO TO 10
      ZRA(I) = 0.29056 - 0.08775*OMEGA(I)
  10  CONTINUE
      VL = (1. + (1.-TR)**(2./7.))
      VL = (RU*TCRIT(I)/WM(I)/PCRIT(I))*ZRA(I)**VL
C
      RETURN
      END
```

APPENDIX C

multico
to the
by St
docume
from
input
follow

NF
IP

I
Q

Q

B
B

C
D

APPENDIX C

EVALUATION OF MIXTURE BOILING CORRELATIONS

Program MIXBOIL calculates heat transfer coefficients for several multicomponent mixture boiling correlations, and compares those values to the experimental values. The correlations are the Palen-Small, two by Stephan- Preusser, Thome-Shakir, Bennet-Chen, and the new correlation documented in Chapter 7. MIXBOIL requires as input the output files from PBDATA, property information from MIXPROP, and instructions from an input file, MIXBOIL.INP. The input file MIXPROP.INP supplies the following values:

NFILES - Number of tests to be evaluated.

IPURE - Determines calculation for ideal heat transfer coefficient. Use IPURE = 0 for linear mixing law, IPURE = 1 to use Stephan-Abdelsalam correlation.

IPRINT - Flag for debug printout. Use IPRINT = 0 for no extra print.

QLOW - Lower end of range of heat flux for statistical evaluation. (W/m^2)

QHIGH - Upper end of range of heat flux for statistical evaluation. (W/m^2)

BO - Value of B_0 in Schlunder equation.

BETA - Value of mass transfer coefficient in Schlunder equation. (m/s)

CANGLE - Contact angle to be used in Stephan-Abdelsalam correlation.

DIAM - Tube diameter, m. Used only in Bennet-Chen correlation.

VEXPC

XTERM

ZA,ZB,ZC

Table C-1
of Progra
experimenta
appropriate
component.
test stor
file S20DA

```
[BAJC
[BAJC
[BAJC
[BAJC
[BAJC
[BAJC
[BAJC
```

VEXPC - Volumetric expansion coefficient, K^{-1}. Used only in Bennet-Chen correlation.

XTERM - Fraction diffusion cross terms are of main term diagonal.

ZA,ZB,ZC,ZN - Values to be used in new correlation for the ratio $(\delta_{TE}/\delta_{12})=ZA*K^{ZN}+ZB*K+ZC$, where K is the vapor-liquid equilibrium constant of the first component. For the Lewis number representation, set ZA=0, ZB=0, and ZC=1.

Table C-1 shows a sample MIXBOIL.INP file, and Table C-2 is the listing of Program MIXBOIL. The sample input file is setup to evaluate two experimental tests. Each data file for a mixture is followed by the appropriate number of files containing the results for each pure component. The following sample input will evaluate a ternary mixture test stored in file S24DAT.DAT and then a binary mixture test stored in file S20DAT.DAT.

Table C-1
Sample MIXBOIL.INP Input File.

```
           NFILES          IPRINT           IPURE
                2               0               1
             QLOW           QHIGH            BETA              BO
       7.5000E+04      5.0000E+05      2.0000E-04      1.0000E+00
            XTERM          CANGLE            DIAM           VEXPC
       0.0000E+00      3.5000E+01      2.2200E-02      1.0000E-03
               ZA              ZN              ZB              ZC
       0.0000E+00      0.0000E+00      0.0000E+00      1.0000E+00
[BAJOREK.PBDATA.DAT]S24DAT.DAT                     DATFIL-1
[BAJOREK.PBDATA.DAT]S26DAT.DAT                     PURFIL
[BAJOREK.PBDATA.DAT]S30DAT.DAT                     PURFIL
[BAJOREK.PBDATA.DAT]S34DAT.DAT                     PURFIL
[BAJOREK.PBDATA.DAT]S20DAT.DAT                     DATFIL-2
[BAJOREK.PBDATA.DAT]S26DAT.DAT                     PURFIL
[BAJOREK.PBDATA.DAT]S34DAT.DAT                     PURFIL
```

```
      P
C ***
C  ***
C ***
      C
     &
     &
      C
      C
      C
      C
      C
      C
C ***

C ***



C ***



C ***

    1

    5

    6


C ***

C ***



   10

C
```

Table C-2
Listing of Program MIXBOIL

```
      PROGRAM MIXBOIL
C ***
C  *** This program evaluates mixture boiling data.
C ***
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
      CHARACTER*35 DATFIL, PURFIL
C *** MAXIMUM NUMBER OF COMPONENTS PER MIXTURE IS NMAX = 5
      NMAX = 5
C *** MAXIMUM NUMBER OF DATA POINTS PER FILE IS NDIM = 50
      NDIM   = 50
      QFLUX  = 0.
       IERROR = 0
C *** TAPES:
      JIN  = 1
      JOUT = 2
      JPLT = 3
      JDAT = 5
C *** MIXBOIL.INP LISTS THE FILES WITH DATA TO BE EXAMINED
      OPEN(JIN,FILE='MIXBOIL.INP',STATUS='OLD')
      READ(JIN,1)
   1  FORMAT( )
      READ(JIN,1)
      READ(JIN,5) NFILES, IPRINT, IPURE
   5  FORMAT(10X,I5,10X,I5,10X,I5)
      READ(JIN,1)
      READ(JIN,6) QLOW, QHIGH, BETA, BO
   6  FORMAT(4E15.4)
      READ(JIN,1)
      READ(JIN,6) XTERM, CANGLE, DIAM, VEXPC
      READ(JIN,1)
      READ(JIN,6) ZA, ZN, ZB, ZC
C *** MIXBOIL.OUT IS FOR PRINTED OUTPUT
       OPEN(JOUT,FILE='MIXBOIL.OUT',STATUS='NEW')
C *** MIXBOIL.PLT IS FOR PLOTTING
      OPEN(JPLT,FILE='MIXBOIL.PLT',STATUS='NEW')
      CALL HEADER(QLOW,QHIGH,BETA,BO,XTERM,CANGLE,DIAM,VEXPC,ZA,
     &            ZN,ZB,ZC)
      DO 900 IFILE=1,NFILES
      READ(JIN,10) DATFIL
  10  FORMAT(A35)
      WRITE(*,11) DATFIL
      WRITE(JOUT,11) DATFIL
   11  FORMAT(//,5X,'BEGIN CALCULATION FOR FILE ',A35)
C
      KUNIT = 10
      OPEN(KUNIT,FILE=DATFIL,STATUS='OLD')
      KARRAY = 1
      CALL INPUT(KUNIT,KARRAY)
```

```
C
C *** HOW M
      NCOMP
      DO 20
      IF (I
 15   NCOMP
 20   CONTI
        IF(
C
C  *** READ
C
      DO 25
      READ(
      WRITE
 12   FORMA
      KUNIT
      OPEN(
      KARRA
      CALL
 25   CONTI
  26   CONT
C
C  *** CALC
C
      CALL
      TSAT
      COND
      VISC
      CP
      SIGMA
      RHOL
      RHOG
      DELH
      DTBP
      IF(TS
      CALL
      IF(V
      CALL
C *** DETE
      CALL
C  ***
C *** START
      DO 8
      QFLU
C ***
C *** CALC
C ***
      CALL
     &
      IF(A
       IF(
C ***
C  *** CAL
C ***
      CALL
```

```
 C
 C ***  HOW MANY COMPONENTS IN THIS MIXTURE ?
        NCOMP - 0
        DO 20 I-1,NMAX
        IF (ICOMP(I)) 20,20,15
   15   NCOMP - NCOMP + 1
   20   CONTINUE
          IF(NCOMP.EQ.1) GO TO 26
C
C   *** READ THE ASSOCIATED PURE COMPONENT DATA FILES:
C
        DO 25 I-1,NCOMP
        READ(JIN,10) PURFIL
        WRITE(*,12) PURFIL
  12    FORMAT(/,5X,'READING PURFIL ',A35)
        KUNIT - KUNIT + 1
        OPEN(KUNIT,FILE-PURFIL,STATUS-'OLD')
        KARRAY - KARRAY + 1
        CALL INPUT(KUNIT,KARRAY)
  25    CONTINUE
   26    CONTINUE
C
C   *** CALCULATE MIXTURE PROPERTIES ***
C
        CALL THERMOD(P1,P2,P3,P4,P5,P6,P7,P8,P9)
        TSATM- P1
        COND - P2
        VISC - P3
        CP   - P4
        SIGMA- P5
        RHOL - P6
        RHOG - P7
        DELHV- P8
        DTBP - P9
        IF(TSATM.LE.0.0) IERROR - 1
        CALL ABORT(QFLUX)
        IF(VLE(1).GE.1.0) IERROR - 2
        CALL ABORT(QFLUX)
C ***   DETERMINE IF DATA POINT IS NATURAL CONVECTION OR NUCLEATE BOILING
        CALL NATCONV
C   ***                    ********************************************
C ***   START DATA ANALYSIS:
        DO 800 IDATA - 1, NPTS(1)
        QFLUX - QQ(IDATA,1)
C ***
C ***   CALCULATE THE IDEAL H.T.C.
C ***
        CALL AIDEAL(IDATA,QFLUX,TSATM,COND,VISC,CP,SIGMA,
       &                 RHOL,RHOG,DELHV,CANGLE)
        IF(A(1).LE.0.) GO TO 790
         IF(NCOMP.EQ.1) GO TO 795
C ***
C   *** CALCULATE BOILING H.T.C. WITH SCHLUNDER CORRELATION
C ***
        CALL SCHLDR(IDATA,QFLUX,BETA,BO,RHOL,DELHV,ASCH)
```

```
C ***
C  *** CALC
C ***
     CALL
     IF(A
      IF(
C ***
C  *** CALC
C ***
     CALL
    &
C ***
C *** CALC
C ***
     CALL
C ***
C *** CALC
C ***
     CALL
C ***
C  *** CAL
C ***
     CALL
    &
C ***
C *** CALC
C ***
     CALL
    &
     GO T
  790 CONT
     IERR
      CAL
C
  795 CONT
C ***
C  *** ST
C ***
     ACA
     ACA
     ACA
     ACA
     ACA
     ACA
     ACA
     ACA
  800 CON
C
     CAL
C  ***
C *** PRI
C ***
     CAL
    &
C ***
```

```
C ***
C   *** CALCULATE BOILING H.T.C. WITH STEPHAN-PREUSSER KIN METHOD
C ***
      CALL STEPRU(IDATA,QFLUX,ASP)
      IF(ASP.LE.0.) IERROR = 4
       IF(IDATA.EQ.1) CALL ABORT(QFLUX)
C ***
C   *** CALCULATE BOILING H.T.C. WITH STEPHAN-PREUSSER NU CORRELATION
C ***
      CALL STEPAB(IDATA,QFLUX,TSATM,COND,VISC,CP,SIGMA,
     &            RHOL,RHOG,DELHV,CANGLE,ASA)
C ***
C *** CALCULATE BOILING H.T.C. WITH THOME BOILING RANGE MODEL
C ***
      CALL THOME(IDATA,QFLUX,BETA,BO,RHOL,DELHV,DTBP,ATHOM)
C ***
C *** CALCULATE BOILING H.T.C. WITH PALEN-SMALL CORRELATION
C ***
      CALL PALSML(IDATA,QFLUX,DTBP,APS)
C ***
C   *** CALCULATE BOILING H.T.C. USING BENNET-CHEN (FINNED and HIGH FLUX)
C ***
      CALL BENCHN(IDATA,QFLUX,TSATM,COND,VISC,CP,SIGMA,
     &            RHOL,RHOG,DELHV,DTBP,BETA,DIAM,VEXPC,ASCH,ABC)
C ***
C *** CALCULATE BOILING H.T.C. USING THE NEW MODEL
C ***
      CALL NEWMOD(IDATA,ZA,ZN,ZB,ZC,QFLUX,BO,XTERM,COND,CP,RHOL,
     &            DELHV,DTBP,ANM)
      GO TO 795
  790 CONTINUE
      IERROR = 3
       CALL ABORT(QFLUX)
C
  795 CONTINUE
C ***
C   *** STORE CALCULATIONS FOR PRINTING:
C ***
      ACALC(IDATA,1) = A(1)
      ACALC(IDATA,2) = ASCH
      ACALC(IDATA,3) = ASP
      ACALC(IDATA,4) = ASA
      ACALC(IDATA,5) = ATHOM
      ACALC(IDATA,6) = APS
      ACALC(IDATA,7) = ABC
      ACALC(IDATA,8) = ANM
  800 CONTINUE
C
      CALL STATS(QLOW,QHIGH)
C  ***                          **************************************
C *** PRINT CALCULATION RESULTS:
C ***
      CALL OUTPUT(TSATM,COND,VISC,CP,SIGMA,RHOL,RHOG,DELHV,
     &            DTBP,IFILE)
C ***
```

```
      WRIT
 130   FOR
C
 900  CONT
      CLOS
      CLOS
       CLO
C
      WRIT
 999  FOR
      STOP
      END
C ********
      SUBR
C
C *** Reac
C
      COMM
     &
     &
      COMM
      COMM
      COMM
      COMM
C
      REA
   1  FOR
      WRIT
    5  FO
C
      REA
      WRIT
  15  FOR
  20  FOR
      IF(
      REA
      REA
  30  FOR
      REA
      REA
  40  FOR
      GO
  45  DO
      REA
  46  CON
  47  REA
      REA
  50  FOR
C
  55  ISK
      DO
      REA
  60  CON
      DO
      REA
```

```
      WRITE(*,130) DATFIL
  130  FORMAT(/,5X,'CALCULATION COMPLETED FOR FILE ',A35)
C
 900  CONTINUE
      CLOSE(JIN)
      CLOSE(JOUT)
       CLOSE(JPLT)
C
      WRITE(*,999)
 999  FORMAT(//,5X,'NORMAL TERMINATION OF PROGRAM MIXBOIL')
      STOP
      END
C ********************************************************************
      SUBROUTINE INPUT(JUNIT,JARRAY)
C
C *** Read the data in a *DAT.DAT output file from PBDATA.
C
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      READ(JUNIT,1)
    1 FORMAT( )
      WRITE(*,5) JUNIT,JARRAY
    5  FORMAT(/,5X,'JUNIT =',I4,5X,'JARRAY =',I4)
C
      READ(JUNIT,20) IDNUM(JARRAY),ISURF(JARRAY)
      WRITE(*,15) IDNUM(JARRAY),ISURF(JARRAY)
   15 FORMAT(/,5X,'IDNUM =',I4,5X,'ISURF =',I5)
   20 FORMAT(10X,I5,25X,I5)
      IF(JARRAY.GT.1) GO TO 45
      READ(JUNIT,1)
      READ(JUNIT,30) (ICOMP(I),I=1,NMAX)
   30 FORMAT(5I15)
      READ(JUNIT,1)
      READ(JUNIT,40) (FRAC(I),I=1,NMAX)
   40 FORMAT(5E15.5)
      GO TO 47
   45 DO 46 I=1,4
      READ(JUNIT,1)
   46 CONTINUE
   47 READ(JUNIT,1)
      READ(JUNIT,50) NPTS(JARRAY)
   50 FORMAT(10X,I5,25X,I5)
C
   55 ISKIP = NPTS(JARRAY) + 4
      DO 60 I=1,ISKIP
      READ(JUNIT,1)
   60 CONTINUE
      DO 80 I= 1, NPTS(JARRAY)
      READ(JUNIT,70) DELT(I,JARRAY),QQ(I,JARRAY),ALPHA(I,JARRAY)
```

```
 70  FORM
 80  CONTI
      CLOS
C
     RETU
C*********
       SUBR
    &
C
     COMM
    &
    &
      COMM
      COMM
      COMM
      COMM
C
      WRIT
 500  FORM
      WRIT
 510  FORM
      WRIT
 515  FORM
      WRIT
 520  FORM
      WRIT
 530  FORM
      WRIT
 535  FORM
      WRIT
 540  FORM
      WRIT
 545  FORM
      WRIT
 550  FORM
      WRIT
 560  FOR
      WRI
 570  FOR
      WRI
 580  FOR
      WRI
 590  FOR
    &
C
      RET
      END
C ******
       SU
C
      CO
    &
    &
      CO
```

```
  70  FORMAT(5X,F10.1,1X,2F10.1)
  80  CONTINUE
       CLOSE(JUNIT)
C
      RETURN
                END
C************************************************************************
      SUBROUTINE HEADER(QLOW,QHIGH,BETA,BO,XTERM,CANGLE,DIAM,VEXPC,
     &                  ZA,ZN,ZB,ZC)
C
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      WRITE(JOUT,500)
 500  FORMAT(///,10X,'MIXBOIL INPUT LISTING:',/)
      WRITE(JOUT,510) NFILES
 510  FORMAT(10X,'NFILES =',I5)
      WRITE(JOUT,515) IPURE
 515  FORMAT(10X,'IPURE  =',I5)
      WRITE(JOUT,520) IPRINT
 520  FORMAT(10X,'IPRINT =',I5)
      WRITE(JOUT,530) QLOW
 530  FORMAT(10X,'QLOW   =',F10.1,'  W/M**2')
      WRITE(JOUT,535) QHIGH
 535  FORMAT(10X,'QHIGH  =',F10.1,'  W/M**2')
      WRITE(JOUT,540) BO
 540  FORMAT(10X,'BO     =',F10.4)
      WRITE(JOUT,545) BETA
 545  FORMAT(10X,'BETA   =',E10.4,'  M/SEC')
      WRITE(JOUT,550) CANGLE
 550  FORMAT(10X,'CANGLE =',F10.1,'  DEGREES')
      WRITE(JOUT,560) DIAM
 560  FORMAT(10X,'DIAM   =',E10.4,'  M')
      WRITE(JOUT,570) VEXPC
 570  FORMAT(10X,'VEXPC  =',E10.4,'  PER DEG K')
      WRITE(JOUT,580) XTERM * 100.
 580  FORMAT(10X,'XTERM  =',F10.1,'  %')
      WRITE(JOUT,590) ZA,ZB,ZC,ZN
 590  FORMAT(10X,'NEW MODEL COEFF:  A=',F5.2,3X,'B=',F5.2,3X,
     &       'C=',F5.2,5X,'N=',F5.2)
C
      RETURN
      END
C ***********************************************************************
      SUBROUTINE STATS(QLOW,QHIGH)
C
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
```

```
      COMM
      COMM
      COMM
C
      DO 3
      ISKI
      STAT
      STAT
       DO
C  *** STA
C *** STAT
      IF(Q
      ISKI
      GO T
   15 CONT
      STAT
   10 CONT
      STAT
      DO 2
      IF(
      IF(
      STAT
   20 CONT
      STAT
     &
      STAT
   30 CONT
C
      RETU
      END
C *******
      SUB
C
      COMM
     &
     &
      COMM
      COMM
      COMM
      COMM
C
      WRIT
   10 FORM
      WRIT
   15 FOR
      WRIT
   16 FOR
      WRIT
   20 FOR
      WRIT
   40 FOR
      WRIT
   50 FOR
      WRIT
   60 FOR
```

```
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      DO 30 J - 1, 10
      ISKIP - 0
      STAT(1,J) - 0.
      STAT(2,J) - 0.
       DO 10 I - INCIP(1), NPTS(1)
C  *** STAT(1,N) IS THE AVE. ERROR
C *** STAT(2,N) IS THE STD. DEVIATION
      IF(QQ(I,1).GE.QLOW.AND.QQ(I,1).LE.QHIGH) GO TO 15
      ISKIP - ISKIP + 1
      GO TO 10
  15  CONTINUE
      STAT(1,J) - STAT(1,J)+(ACALC(I,J)-ALPHA(I,1))/ALPHA(I,1)
  10  CONTINUE
      STAT(1,J) - STAT(1,J)/FLOAT((NPTS(1)-ISKIP+1))
      DO 20 I - INCIP(1), NPTS(1)
      IF(QQ(I,1).LT.QLOW)  GO TO 20
      IF(QQ(I,1).GT.QHIGH) GO TO 20
      STAT(2,J)-STAT(2,J)+((ACALC(I,J)-ALPHA(I,1))/ALPHA(I,1))**2
  20  CONTINUE
      STAT(2,J) - STAT(2,J) - (FLOAT((NPTS(1)-ISKIP+1))) *
     &            STAT(1,J)*STAT(1,J)
      STAT(2,J) - SQRT( STAT(2,J)/FLOAT(NPTS(1)-ISKIP) )
  30  CONTINUE
C
      RETURN
      END
C ***************************************************************************
      SUBROUTINE OUTPUT(P1,P2,P3,P4,P5,P6,P7,P8,P9,IFILE)
C
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      WRITE(JOUT,10) IDNUM(1)
  10  FORMAT(//,5X,'CALCULATION FOR FILE IDNUM',I5,/)
      WRITE(JOUT,15) (ICOMP(I),I-1,NMAX)
  15  FORMAT(10X,'ICOMP - ',5I7)
      WRITE(JOUT,16) (FRAC(I),I-1,NMAX)
  16  FORMAT(10X,'FRAC  - ',5F7.3)
      WRITE(JOUT,20)
  20  FORMAT(/,10X,'THERMODYNAMIC PROPERTIES:')
      WRITE(JOUT,40) P1
  40  FORMAT(10X,'TSAT  - ',F5.1,2X,'DEG K')
      WRITE(JOUT,50) P2
  50  FORMAT(10X,'COND  - ',F7.4,2X,'W/M-K')
      WRITE(JOUT,60) P3
  60  FORMAT(10X,'VISC  - ',E10.4,2X,'N-S/M**2')
```

```
      WRITE
   70 FORMA
      WRITE
   80 FORMA
      WRITE
   90 FORMA
      WRITE
  100 FORMA
      WRITE
  110 FORMA
      WRITE
  115 FORMA
C
      WRITE
  120 FORM
      WRITE
  130 FORM
      WRITE
  140 FORM
      WRIT
  150 FORM
C
      WRIT
  230 FORM
      DO 2
      WRIT
  240 FORM
  250 CONT
      WRIT
  180 FORM
     &
     &
      C -
C *** WRIT
      DO 2
      WRIT
     &
     &
     &
      WRIT
     &
     &
     &
  190 FORM
  200 CONT
      WRIT
  205 FORM
      WRIT
      DO
      IF(
      WRI
     &
     &
     &
     &
```

```
      WRITE(JOUT,70) P4
  70  FORMAT(10X,'CP    = ',F7.3,2X,'KJ/KG-K')
      WRITE(JOUT,80) P5
  80  FORMAT(10X,'SIGMA = ',E10.4,2X,'N/M')
      WRITE(JOUT,90) P6
  90  FORMAT(10X,'RHOL  = ',F6.1,2X,'KG/M**3')
      WRITE(JOUT,100) P7
 100  FORMAT(10X,'RHOG  = ',F6.3,2X,'KG/M**3')
      WRITE(JOUT,110) P8
 110  FORMAT(10X,'DELHV = ',F7.1,2X,'KJ/KG')
      WRITE(JOUT,115) P9
 115  FORMAT(10X,'DTBP  = ',F6.1,2X,'DEG K')
C
      WRITE(JOUT,120) (VLE(I),I=1,NMAX)
 120  FORMAT(10X,'Y-X  =',5E12.4)
      WRITE(JOUT,130) (DYDX(I),I=1,NMAX)
 130  FORMAT(10X,'DYDX =',5E12.4)
      WRITE(JOUT,140) (DTDX(I),I=1,NMAX)
 140  FORMAT(10X,'DTDX =',5E12.4)
      WRITE(JOUT,150) (DIJ(I),I=1,NCOMP-1)
 150  FORMAT(10X,'DIJ  =',4E12.4)
C
      WRITE(JOUT,230)
 230  FORMAT(//,4X,'JARRAY',5X,'IDNUM',6X,'NPTS',6X,'TSAT')
      DO 250 I= 1, NMAX+1
      WRITE(JOUT,240) I, IDNUM(I), NPTS(I), TSAT(I)
 240  FORMAT(5X,I5,5X,I5,5X,I5,5X,F5.1)
 250  CONTINUE
      WRITE(JOUT,180)
 180  FORMAT(/,2X,'IDATA'3X,' HEAT FLUX',5X,'ALPHA',
     &       4X,'AIDEAL',6X,'ASCH',7X,'ASP',7X,'ASA',
     &       4X,'ATHOME',4X,'APALEN',3X,'ABENCHN',3X,'ANEWMOD')
      C = 1000.
C *** WRITE HEAT FLUX IN kW/m**2 AND ALPHA IN kW/m**2-C
      DO 200 I=1,NPTS(1)
      WRITE(JOUT,190) I,QQ(I,1)/C,ALPHA(I,1)/C,ACALC(I,1)/C,
     &             ACALC(I,2)/C,ACALC(I,3)/C,ACALC(I,4)/C,
     &             ACALC(I,5)/C,ACALC(I,6)/C,ACALC(I,7)/C,
     &             ACALC(I,8)/C
      WRITE(JPLT,190) IDNUM(1),QQ(I,1)/C,ALPHA(I,1)/C,ACALC(I,1)/C,
     &             ACALC(I,2)/C,ACALC(I,3)/C,ACALC(I,4)/C,
     &             ACALC(I,5)/C,ACALC(I,6)/C,ACALC(I,7)/C,
     &             ACALC(I,8)/C
 190  FORMAT(4X,I3,3X,10F10.3)
 200  CONTINUE
      WRITE(JOUT,205)
 205  FORMAT(/,2X,'RATIOS WITH AIDEAL:')
      WRITE(JOUT,180)
      DO 220 I=1,NPTS(1)
      IF(ACALC(I,1).LE.0.) ACALC(I,1) = 1.0
      WRITE(JOUT,210) I,QQ(I,1)/C,ALPHA(I,1)/ACALC(I,1),
     &                ACALC(I,1)/ACALC(I,1),ACALC(I,2)/ACALC(I,1),
     &                ACALC(I,3)/ACALC(I,1),ACALC(I,4)/ACALC(I,1),
     &                ACALC(I,5)/ACALC(I,1),ACALC(I,6)/ACALC(I,1),
     &                ACALC(I,7)/ACALC(I,1),ACALC(I,8)/ACALC(I,1)
```

```
 210  FORM
  220  CON
C
      WRIT
 300  FORM
      WRIT
 305  FORM
      IF(N
 307  FORM
      IF(N
      WRIT
 310  FORM
      WRIT
 315  FORM
      WRIT
 320  FORM
      WRIT
 325  FORM
      WRIT
 330  FORM
      WRIT
 335  FORM
      WRIT
 340  FORM
  350  CON
C
      WRIT
  900  FOR
C
      RETU
      END
C ********
      SUBR
C ***
C *** Call
C ***
      COMM
     &
     &
      COMM
      COMM
      COMM
      COMM
C
      IF(I
      GO T
  10  WRIT
  11  FORM
      GO T
  20  WRIT
  21  FORM
      GO T
  30  WRIT
  31  FORM
      WRIT
```

```
 210  FORMAT(5X,I2,3X,F10.3,9F10.4)
  220  CONTINUE
C
      WRITE(JOUT,300)
 300  FORMAT(//,10X,'STATISTICAL SUMMARY:')
      WRITE(JOUT,305)
 305  FORMAT(/,35X,' AVE ERROR','   STD DEV')
      IF(NCOMP.EQ.1) WRITE(JOUT,307) 100.*STAT(1,1), 100.*STAT(2,1)
 307  FORMAT(10X,'STEP-ABDEL PURE HYDRO',4X,2F10.1)
      IF(NCOMP.EQ.1) GO TO 350
      WRITE(JOUT,310) 100.*STAT(1,2), 100.*STAT(2,2)
 310  FORMAT(10X,'SCHLUNDER ',15X,2F10.1)
      WRITE(JOUT,315) 100.*STAT(1,3), 100.*STAT(2,3)
 315  FORMAT(10X,'STEPHAN-PREUSSER KIN',5X,2F10.1)
      WRITE(JOUT,320) 100.*STAT(1,4), 100.*STAT(2,4)
 320  FORMAT(10X,'STEPHAN-PREUSSER  NU',5X,2F10.1)
      WRITE(JOUT,325) 100.*STAT(1,5), 100.*STAT(2,5)
 325  FORMAT(10X,'THOME     ',15X,2F10.1)
      WRITE(JOUT,330) 100.*STAT(1,6), 100.*STAT(2,6)
 330  FORMAT(10X,'PALEN-SMALL',14X,2F10.1)
      WRITE(JOUT,335) 100.*STAT(1,7), 100.*STAT(2,7)
 335  FORMAT(10X,'BENNET-CHEN',14X,2F10.1)
      WRITE(JOUT,340) 100.*STAT(1,8), 100.*STAT(2,8)
 340  FORMAT(10X,'NEW MODEL  ',14X,2F10.1)
  350  CONTINUE
C
      WRITE(JOUT,900) IDNUM(1)
  900  FORMAT(//,10X,'END OF STATISTICS FOR FILE IDNUM ',I3)
C
      RETURN
      END
C **********************************************************************
      SUBROUTINE ABORT(QF)
C ***
C *** Called because of suspected error.
C ***
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      IF(IERROR.LE.0) GO TO 99
      GO TO (10,20,30,40) IERROR
  10  WRITE(JOUT,11)
  11  FORMAT(10X,'WARNING - PROBLEM WITH THERMAL PROPERTIES')
      GO TO 99
  20  WRITE(JOUT,21)
  21  FORMAT(10X,'WARNING - PROBLEM WITH VLE DATA')
      GO TO 99
  30  WRITE(JOUT,31)
  31  FORMAT(10X,'WARNING - QFLUX WITHOUT UPPER BOUND')
      WRITE(JOUT,32) QF
```

```
 32  FOR
     GO
 40  CON
     WRI
 41  FOR
     GO
C
  99  CON
      IER
      RET
      END
C ******
      SU
C ***
C *** Th
C ***
       CO
      &
      &
       C
       C
       C
       C
       D
       D
       D
       D
       D
       D
C



     1





C
```

```
   32  FORMAT(10X,'QFLUX =',F10.1)
       GO TO 99
   40  CONTINUE
       WRITE(JOUT,41)
   41  FORMAT(10X,'WARNING - STEPHAN-PREUSSER METHOD NOT APPLICABLE')
       GO TO 99
C
   99  CONTINUE
       IERROR = 0
       RETURN
       END
C ***********************************************************************
       SUBROUTINE THERMOD(P1,P2,P3,P4,P5,P6,P7,P8,P9)
C ***
C *** Thermodynamic properties.
C ***
       COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
      &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
      &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
       COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
       COMMON/IDEAL/ A(6), DT(6), INCIP(6)
       COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
       COMMON/CALC/ ACALC(50,10), STAT(2,10)
       DIMENSION TSATT(250), COND(250), VISC(250), CP(250)
       DIMENSION SIGMA(250), RHOL(250), RHOG(250), DELHV(250)
       DIMENSION YMX1(250), YMX2(250), YMX3(250), YMX4(250), YMX5(250)
       DIMENSION DTBP(250), D11(250), D22(250), D33(250), D44(250)
       DIMENSION DY1DX1(250), DY2DX2(250), DY3DX3(250), DY4DX4(250)
       DIMENSION DY5DX5(250), DT1DX1(250), DT2DX2(250), DT3DX3(250)
       DIMENSION DT4DX4(250), DT5DX5(250)
C
       IMAX = 250
       JUNIT = JDAT
       OPEN(JUNIT,FILE='THERMOD.DAT',STATUS='OLD')
       READ(JUNIT,1)
    1  FORMAT( )
       READ(JUNIT,1)
       READ(JUNIT,*) (TSATT(I),I=1,IMAX)
       READ(JUNIT,1)
       READ(JUNIT,*) (COND(I),I=1,IMAX)
       READ(JUNIT,1)
       READ(JUNIT,*) (VISC(I),I=1,IMAX)
       READ(JUNIT,1)
       READ(JUNIT,*) (CP(I),I=1,IMAX)
       READ(JUNIT,1)
       READ(JUNIT,*) (SIGMA(I),I=1,IMAX)
       READ(JUNIT,1)
       READ(JUNIT,*) (RHOL(I),I=1,IMAX)
       READ(JUNIT,1)
       READ(JUNIT,*) (RHOG(I),I=1,IMAX)
       READ(JUNIT,1)
       READ(JUNIT,*) (DELHV(I),I=1,IMAX)
       READ(JUNIT,1)
C
       READ(JUNIT,*) (YMX1(I),I=1,IMAX)
```

```
      READ(JUNIT,1)
      READ(JUNIT,*) (YMX2(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (YMX3(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (YMX4(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (YMX5(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (D11(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (D22(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (D33(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (D44(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DTBP(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DY1DX1(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DY2DX2(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DY3DX3(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DY4DX4(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DY5DX5(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DT1DX1(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DT2DX2(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DT3DX3(I),I=1,IMAX)
      READ(JUNIT,1)
      READ(JUNIT,*) (DT4DX4(I),I=1,IMAX)
      READ(JUNIT,1)
       READ(JUNIT,*) (DT5DX5(I),I=1,IMAX)
C
      I = IDNUM(1)
      P1 = TSATT(I)
      P2 = COND(I)
      P3 = VISC(I)
      P4 = CP(I)
      P5 = SIGMA(I)
      P6 = RHOL(I)
      P7 = RHOG(I)
      P8 = DELHV(I)
      P9 = DTBP(I)
C *** Convert mass diffusivity from cm**2/s to m**2/s
      DIJ(1) = D11(I) * 1.0E-04
      DIJ(2) = D22(I) * 1.0E-04
      DIJ(3) = D33(I) * 1.0E-04
      DIJ(4) = D44(I) * 1.0E-04
      VLE(1) = YMX1(I)
```

```
      VLE(2) = YMX2(I)
      VLE(3) = YMX3(I)
      VLE(4) = YMX4(I)
      VLE(5) = YMX5(I)
      DYDX(1) = DY1DX1(I)
      DYDX(2) = DY2DX2(I)
      DYDX(3) = DY3DX3(I)
      DYDX(4) = DY4DX4(I)
      DYDX(5) = DY5DX5(I)
      DTDX(1) = DT1DX1(I)
      DTDX(2) = DT2DX2(I)
      DTDX(3) = DT3DX3(I)
      DTDX(4) = DT4DX4(I)
      DTDX(5) = DT5DX5(I)
      TSAT(1) = TSATT(I)
C
      IF(NCOMP.EQ.1) GO TO 20
      DO 10 I = 1, NCOMP + 1
      ID = IDNUM(I)
      TSAT(I) = TSATT(ID)
  10  CONTINUE
  20  CONTINUE
       CLOSE(JUNIT)
C
      RETURN
      END
C *********************************************************************
      SUBROUTINE NATCONV
C ***
C *** Determine where the boiling incipient point.
C ***
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      DO 10 I = 1, NCOMP+1
      INCIP(I) = 2
  10  CONTINUE
C
      RETURN
      END
C *********************************************************************
      SUBROUTINE AIDEAL(IDATA,QFLUX,TSATM,COND,VISC,CP,SIGMA,
     &                  RHOL,RHOG,DELHV,CANGLE)
C ***
C *** Calculate the "ideal" boiling heat transfer coefficient.
C ***
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
```

```
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      A(1) = 0.0
      DT(1) = 0.0
      IF(IPURE.GE.1) GO TO 40
      IF(NCOMP.EQ.1) GO TO 40
      DO 20 J = 2, NCOMP+1
      DO 10 I = 1, NPTS(J)
      IF(QFLUX.GE.QQ(I,J)) IBELOW = I
       IF(QFLUX.GE.QQ(I,J)) IABOVE = IBELOW + 1
C *** CHECK TO SEE IF QQ(IABOVE,J) EXISTS:
      IF(QQ(IABOVE,J).LE.0.0) GO TO 5
      GO TO 10
    5 CONTINUE
      A(1) = 0.0
      DT(1) = 0.0
      RETURN
   10 CONTINUE
      RATIO = (QFLUX-QQ(IBELOW,J))/(QQ(IABOVE,J)-QQ(IBELOW,J))
      A(J) = ALPHA(IBELOW,J)+RATIO*(ALPHA(IABOVE,J)-ALPHA(IBELOW,J))
      DT(J) = DELT(IBELOW,J) + RATIO*(DELT(IABOVE,J)-DELT(IBELOW,J))
   20 CONTINUE
      A(1) = 0.0
      DT(1) = 0.0
      DO 30 K = 1, NCOMP
      A(1) = A(1) + FRAC(K)*A(K+1)
      DT(1) = DT(1) + FRAC(K)*DT(K+1)
   30 CONTINUE
      GO TO 90
   40 CONTINUE
C *** PURE COMPONENT CORRELATION, NCOMP = 1 or IPURE > 0
      CALL PURBOIL(IDATA,QFLUX,TSATM,COND,VISC,CP,SIGMA,
     &             RHOL,RHOG,DELHV,CANGLE,APURB)
      A(1) = APURB
      DT(1) = QFLUX/APURB
      IF(IPRINT.EQ.1) WRITE(JOUT,50) A(1), DT(1)
   50 FORMAT(/,1X,'AIDEAL: A1=',E10.4,5X,'DT1=',E10.4)
C
   90 CONTINUE
      RETURN
      END
C **********************************************************************
      SUBROUTINE SCHLDR(IDATA,QFLUX,BETA,B0,RHOL,DELHV,ASCH)
C ***
C *** SCHLUNDER CORRELATION FOR MULTICOMPONENT MIXTURES
C ***
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
```

```
C
      ASCH - 0.0
      IF(RHOL.EQ.0.) GO TO 20
      IF(DELHV.EQ.0.) GO TO 20
      Z1 - 1. - EXP(-B0*QFLUX/(1000.*RHOL*DELHV*BETA))
      DO 10 I - 2, NCOMP
      ASCH - ASCH + (TSAT(NCOMP+1)-TSAT(I))*VLE(I-1) * Z1
CCC USE FOR REAL DTDX      ASCH - ASCH - DTDX(I-1)*VLE(I-1) * Z1
   10 CONTINUE
CC       ASCH - ASCH + (TSAT(NCOMP+1)-TSAT(2))*VLE(1) * Z1
      ASCH - A(1)/(1. + A(1)*ASCH/QFLUX)
C
   20 CONTINUE
      RETURN
      END
C ***********************************************************************
      SUBROUTINE STEPRU(IDATA,QFLUX,ASP)
C ***
C *** STEPHAN AND PREUSSER METHOD USING KIN COEFFICIENTS
C *** VALID ONLY FOR ACTONE-METHANOL-WATER OR FOR
C *** METHANOL-ETHANOL-WATER MIXTURES
C ***
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      DIMENSION BIN(6,6)
      DATA BIN / 12*0.0,1.19,5*0.0,2*0.0,1.39,3*0.0,6*0.0,
     &           0.81,0.0,0.56,0.71,2*0.0 /
C
      ASP - 0.
      DTX - 0.
      DO 10 I - 1, NMAX
      J - ICOMP(I)
      IF(J.EQ.2) GO TO 90
      IF(J.EQ.5) GO TO 90
      IF(J.GT.6) GO TO 90
   10 CONTINUE
      GO TO (90,20,30,90,90) NCOMP
   20 CONTINUE
C *** BINARY MIXTURE
      I - ICOMP(1)
      J - ICOMP(2)
      DTX - DT(1)*(BIN(I,J)*VLE(1))
      GO TO 60
   30 CONTINUE
C *** TERNARY MIXTURE
      DO 40 I - 1, NMAX
      J - ICOMP(I)
      IF(J.EQ.4) GO TO 50
   40 CONTINUE
```

```
C *** ACETONE-METHANOL-WATER MIXTURE
      DTX = DT(1)*(0.58*VLE(1) + 0.54*VLE(2))
      GO TO 60
  50  CONTINUE
C *** METHANOL-ETHANOL-WATER MIXTURE
      DTX = DT(1)*(0.31*VLE(1) + 0.23*VLE(2))
  60  CONTINUE
      DTSP = DT(1) + DTX
      ASP = QFLUX/DTSP
  90  CONTINUE
      RETURN
      END
C ************************************************************************
      SUBROUTINE STEPAB(IDATA,QFLUX,TSATM,COND,VISC,CP,SIGMA,
     &                  RHOL,RHOG,DELHV,CANGLE,ASA)
C ***
C *** STEPHAN AND PREUSSER CORRELATION BASED ON EXTENSION OF
C *** STEPHAN AND ABDULSALAM PURE COMPONENT CORRELATION
C *** PROGRAM DYIDXI USED TO DETERMINE PARTIAL DERIVATIVES
C ***
      COMMON/DATA/ IDNUM(6), ISURF(6), ICOMP(5), FRAC(5),
     &             NPTS(6), DELT(50,6), QQ(50,6), ALPHA(50,6),
     &             NFILES, NMAX, NCOMP, NDIM, IERROR, IPRINT, IPURE
      COMMON/TAPES/ JIN, JOUT, JPLT, JDAT
      COMMON/IDEAL/ A(6), DT(6), INCIP(6)
      COMMON/PROP/ TSAT(6), VLE(5), DYDX(5), DTDX(5), DIJ(4)
      COMMON/CALC/ ACALC(50,10), STAT(2,10)
C
      ASA = 0.0
      C = TSATM*COND*VISC*CP*SIGMA*RHOL*RHOG*DELHV*CANGLE
      IF(C.EQ.0.) GO TO 90
      C = 0.100
      G = 9.81
      TDIFF = COND/RHOL/CP/1000.
       DO = 0.0146*CANGLE*SQRT(2.*SIGMA/(G*(RHOL-RHOG)))
C
      IF(IPRINT.EQ.4)      WRITE(2,24) CANGL,SIGMA,RHOL,RHOG
      IF(IPRINT.EQ.4)      WRITE(*,24) CANGL,SIGMA,RHOL,RHOG
  24  FORMAT(10X,'CANGL=',F8.3,' SIGMA=',F10.4,' RHOL=',F10.4,
     &            ' RHOG=',F10.4)
      IF(IPRINT.EQ.4)      WRITE(2,21) DO
      IF(IPRINT.EQ.4)      WRITE(*,21) DO
  21  FORMAT(10X,'DO =',E12.5)
C
      SUM = 0.
      DO 10 I = 1, NCOMP-1
      SUM = SUM + VLE(I)*DYDX(I)
   10  CONTINUE
C
      IF(IPRINT.EQ.4)      WRITE(2,23) SUM
      IF(IPRINT.EQ.4)      WRITE(*,23) SUM
  23  FORMAT(10X,'SUM =',F10.3)
C
      Z1 = (QFLUX*DO/COND/TSATM)**0.674
C
```

APPENDIX D

APPENDIX D

CALCULATION OF BOILING RANGE AND SLOPE OF BUBBLE POINT CURVE

Program DTBP calculates the boiling range ΔT_{bp} for binary and ternary mixtures. Vapor-liquid equilibrium data is required as input. The input file DTBP.INP supplies the program with the name of the file containing the VLE data and the compositions at which the boiling range is to be calculated.

Table D-1
Listing of Program DTBP

```
      PROGRAM DTBP
C ***
C *** ESTIMATE THE BOILING RANGE FOR A TERNARY MIXTURE
C ***
      COMMON /WORKSP/ RWKSP
      REAL RWKSP(5312)
      DIMENSION X1DAT(200), X2DAT(200), X3DAT(200), TSATM(200)
      DIMENSION Y1DAT(200), Y2DAT(200), Y3DAT(200), FDATA(200)
      DIMENSION XYDATA(2,200), XOUT(1), YOUT(1), SUR(1,1)
      DIMENSION IDNUM(100), BR(100)
      CHARACTER*15 DATFIL
C
      CALL IWKIN(5312)
      JIN  = 1
      JOUT = 2
      JDAT = 3
      ICOUNT = 0
      OPEN(JIN,FILE='DTBP.INP',STATUS='OLD')
      OPEN(JOUT,FILE='DTBP.OUT',STATUS='NEW')
      READ(JIN,1)
    1 FORMAT( )
      READ(JIN,1)
      READ(JIN,10) DATFIL
```

```
   10  FORMAT(A15)
       OPEN(JDAT,FILE=DATFIL,STATUS='OLD')
       READ(JIN,1)
       READ(JIN,20) NDATA
   20  FORMAT(10X,I5)
       READ(JIN,1)
       READ(JIN,25) IBR, ITOT
   25  FORMAT(10X,I5,10X,I5)
       READ(JIN,1)
   26  CONTINUE
       ICOUNT = ICOUNT + 1
       READ(JIN,30) IDNUM(ICOUNT), X1, X2, TSAT
   30  FORMAT(10X,I5,2F10.4,F10.1)
       WRITE(*,35)
   35  FORMAT(//,10X,'PROGRAM DTBP - BOILING RANGE CALCULATIONS',//)
       WRITE(*,27) IDNUM(ICOUNT)
   27  FORMAT(/,10X,'FILE IDNUM = ',I3)
       WRITE(*,36) X1
   36  FORMAT(10X,'LIQUID MOL FRACTION COMPONENT 1 IS',F7.4)
       WRITE(*,37) X2
   37  FORMAT(10X,'LIQUID MOL FRACTION COMPONENT 2 IS',F7.4)
       X3 = 1.0 - X1 -X2
       WRITE(*,38) X3
   38  FORMAT(10X,'LIQUID MOL FRACTION COMPONENT 3 IS',F7.4)
C
       IF(ICOUNT.GT.1) GO TO 56
       PSUMO = 0.0
       WRITE(*,39) DATFIL
   39  FORMAT(//,10X,'BEGIN READ OF VLE DATA FILE ',A15)
       READ(JDAT,1)
       READ(JDAT,1)
       DO 50 I = 1, NDATA
       READ(JDAT,40) J,X1DAT(J),X2DAT(J),Y1DAT(J),
     &              Y2DAT(J),TSATM(J)
   40  FORMAT(I3,4F10.4,F10.1)
       X3DAT(J) = 1.0 - X1DAT(J) - X2DAT(J)
       Y3DAT(J) = 1.0 - Y1DAT(J) - Y2DAT(J)
       YMX1 = Y1DAT(J) - X1DAT(J)
       YMX2 = Y2DAT(J) - X2DAT(J)
       YMX3 = Y3DAT(J) - X3DAT(J)
       PSUM = AMAX1(YMX1,0.0)+AMAX1(YMX2,0.0)+AMAX1(YMX3,0.0)
       IF(PSUM.GT.PSUMO) JSAV = J
       PSUM = AMAX1(PSUM,PSUMO)
       PSUMO= PSUM
   50  CONTINUE
       WRITE(*,55)
   55  FORMAT(10X,'READ COMPLETED')
   56  CONTINUE
C ***
C  *** IBR = 0  DO ONLY LIGH COMPONENT SUM
C  *** IBR = 1  DO ONLY BOILING RANGE CALC
C *** IBR = 2  DO BOTH CALCULATIONS
C ***
       IF(IBR.EQ.1) GO TO 95
       IF(ICOUNT.GT.1) GO TO 93
C
```

```
      WRITE(JOUT,60) PSUM
      WRITE(*,60) PSUM
   60 FORMAT(//,10X,'MAX SUM LIGHT COMPONENT Y-X = ',F7.4)
      WRITE(JOUT,70) X1DAT(JSAV)
      WRITE(*,70) X1DAT(JSAV)
   70 FORMAT(15X,'MOL FRAC COMP 1 = ',F7.4)
      WRITE(JOUT,80) X2DAT(JSAV)
      WRITE(*,80) X2DAT(JSAV)
   80 FORMAT(15X,'MOL FRAC COMP 2 = ',F7.4)
      WRITE(JOUT,90) X3DAT(JSAV)
      WRITE(*,90) X3DAT(JSAV)
   90 FORMAT(15X,'MOL FRAC COMP 3 = ',F7.4)
   93 CONTINUE
      IF(IBR.EQ.0) GO TO 890
   95 CONTINUE
C ***
C *** PERFORM BOILING RANGE CALCULATION
C ***
      DO 100 I = 1, NDATA
      XYDATA(1,I) = Y1DAT(I)
      XYDATA(2,I) = Y2DAT(I)
      FDATA(I) = TSATM(I)
  100 CONTINUE
C
      NXOUT = 1
      NYOUT = 1
      LDSUR = NXOUT
      XOUT(1)  = X1
       YOUT(1)  = X2
C
      CALL SURF(NDATA,XYDATA,FDATA,NXOUT,NYOUT,XOUT,YOUT,
     &          SUR,LDSUR)
C
      BR(ICOUNT) = SUR(1,1) - TSAT
      WRITE(*,110) BR(ICOUNT)
  110 FORMAT(10X,'BOILING RANGE = ',F6.1)
C
      IF(ICOUNT.LT.ITOT) GO TO 26
C
C       WRITE(JOUT,200)
C 200  FORMAT(1H1)
      WRITE(JOUT,35)
      WRITE(JOUT,210)
  210 FORMAT(10X,'IDNUM','  BOILING RANGE')
      DO 230 I = 1, ITOT
      WRITE(JOUT,220) IDNUM(I), BR(I)
  220 FORMAT(10X,I5,5X,F10.1)
  230 CONTINUE
      WRITE(JOUT,240) DATFIL
  240 FORMAT(///,10X,'VLE DATA FILE USED WAS ',A15)
  890 CONTINUE
      WRITE(*,900)
  900 FORMAT(/,10X,'NORMAL TERMINATION OF PROGRAM DTBP')
      STOP
      END
```

Program DYIDXI was used to determine the slope of the bubble point curve (dT/dx) and the value of (dy/dx) at the bulk liquid composition for binary and ternary mixtures.

Table D-2

Listing of Program DYIDXI

```
      PROGRAM DYIDXI C ***

C  *** ESTIMATE THE PARTIAL DERIVATIVE dy/dx FOR TERNARY VLE DATA
C ***
      COMMON /WORKSP/ RWKSP
      INTEGER   JIN, JOUT, JDAT, I, J, NXOUT, NYOUT, ITOT
      INTEGER   NDATA, NXDATA, NYDATA, LDSUR, LDF
      INTEGER   IXDER, IYDER, IDNUM(25)
      REAL      X1DAT(200), X2DAT(200), X3DAT(200), TSATM(200)
      REAL      Y1DAT(200), Y2DAT(200), Y3DAT(200), FDATA(200)
      REAL      XYDATA(2,200), XOUT(51), YOUT(51), SUR(51,51)
      REAL      X1(25), X2(25), X3(25), TSAT(25), RWKSP(7838)
      REAL      XDATA(51), YDATA(51), FFDATA(51,51), X, Y, Q
      LOGICAL   CHECK
      INTRINSIC FLOAT
      EXTERNAL  SURF, QD2DR, IWKIN
      CHARACTER*15 DATFIL
C
      CALL IWKIN(7838)
      NXOUT = 51
      NYOUT = 51
      LDSUR = NXOUT
      LDF   = NXOUT
      JIN   = 1
      JOUT  = 2
      JDAT  = 3
      OPEN(JIN,FILE='DYIDXI.INP',STATUS='OLD')
      OPEN(JOUT,FILE='DYIDXI.OUT',STATUS='NEW')
      READ(JIN,1)
    1 FORMAT( )
      READ(JIN,1)
      READ(JIN,10) DATFIL
   10 FORMAT(A15)
      OPEN(JDAT,FILE=DATFIL,STATUS='OLD')
      READ(JIN,1)
      READ(JIN,20) NDATA
   20 FORMAT(10X,I5)
```

```
      READ(JIN,1)
       READ(JIN,25) ITYPE, ITOT, IPRINT
C ***
C  ***    ITYPE = 1, CALCULATE DY1DX1
C  ***    ITYPE = 2, CALCULATE DY2DX2
C  ***    ITYPE = 3, CALCULATE DT1DX1
C  ***    ITYPE = 4, CALCULATE DT2DX2
C ***
  25  FORMAT(10X,I5,5X,I5,5X,I5)
      READ(JIN,1)
      DO 35 I = 1, ITOT
      READ(JIN,30) IDNUM(I), X1(I), X2(I), TSAT(I)
  30  FORMAT(10X,I5,2F10.4,F10.1)
  35  CONTINUE
      WRITE(*,40)
      WRITE(JOUT,40)
   40  FORMAT(//,10X,'PROGRAM DYIDXI - VLE DERIVATIVE CALCULATIONS',//)
C
      WRITE(*,41) DATFIL
  41  FORMAT(//,10X,'BEGIN READ OF VLE DATA FILE ',A15)
      READ(JDAT,1)
      READ(JDAT,1)
      DO 50 I = 1, NDATA
      READ(JDAT,45) J,X1DAT(J),X2DAT(J),Y1DAT(J),
     &              Y2DAT(J),TSATM(J)
  45  FORMAT(I3,4F10.4,F10.1)
      X3DAT(J) = 1.0 - X1DAT(J) - X2DAT(J)
      Y3DAT(J) = 1.0 - Y1DAT(J) - Y2DAT(J)
  50  CONTINUE
      WRITE(*,55)
   55  FORMAT(10X,'READ COMPLETED')
C ***
C  *** GENERATE SURFACE:  Z = F(X1,X2)
C ***
      DO 60 I = 1, NDATA
      XYDATA(1,I) = X1DAT(I)
      XYDATA(2,I) = X2DAT(I)
      IF(ITYPE.EQ.1) FDATA(I) = Y1DAT(I)
      IF(ITYPE.EQ.2) FDATA(I) = Y2DAT(I)
      IF(ITYPE.GE.3) FDATA(I) = TSATM(I)
  60  CONTINUE
C
      DO 70  I = 1, NXOUT
      XOUT(I)  = FLOAT(I-1)/FLOAT(NXOUT-1)
  70  CONTINUE
      DO 80  I = 1, NYOUT
      YOUT(I)  = FLOAT(I-1)/FLOAT(NYOUT-1)
  80  CONTINUE
C
      CALL SURF(NDATA,XYDATA,FDATA,NXOUT,NYOUT,XOUT,YOUT,
     &          SUR,LDSUR)
C
      IF(IPRINT.EQ.0) GO TO 90
      WRITE(JOUT,84)
      WRITE(*,84)
  84  FORMAT(16X,'XOUT',6X,'YOUT',7X,'SUR')
```

```
      DO 90 I = 1, NYOUT
      DO 90 J = 1, NXOUT
      WRITE(JOUT,85) XOUT(J), YOUT(I), SUR(J,I)
      WRITE(*,85) XOUT(J), YOUT(I), SUR(J,I)
   85 FORMAT(10X,3F10.4)
   90 CONTINUE
      IXDER = 0
      IYDER = 0
      IF(ITYPE.EQ.1) IXDER = 1
      IF(ITYPE.EQ.2) IYDER = 1
      IF(ITYPE.EQ.3) IXDER = 1
      IF(ITYPE.EQ.4) IYDER = 1
      NXDATA = NXOUT
      NYDATA = NYOUT
      DO 100 I = 1, NXDATA
      XDATA(I) = XOUT(I)
  100 CONTINUE
      DO 110 I = 1, NYDATA
      YDATA(I) = YOUT(I)
  110 CONTINUE
C
      DO 130 I = 1, NYDATA
      DO 130 J = 1, NXDATA
      FFDATA(J,I) = SUR(J,I)
  130 CONTINUE
      CHECK = .TRUE.
      WRITE(JOUT,135) ITYPE, IXDER, IYDER
  135  FORMAT(//,10X,'ITYPE=',I2,'    IXDER=',I2,'     IYDER=',I2)
C
      DO 200 I = 1, ITOT
      X = X1(I)
      Y = X2(I)
      Q = QD2DR(IXDER,IYDER,X,Y,NXDATA,XDATA,NYDATA,YDATA,
     &          FFDATA,LDF,CHECK)
      IF(ITYPE.EQ.1) WRITE(JOUT,141) IDNUM(I), X, Y, Q
  141 FORMAT(10X,'IDNUM=',I3,'   X1=',F7.4,'   X2=',F7.4,
     &       '   DYIDXI=',E12.5)
      IF(ITYPE.EQ.2) WRITE(JOUT,142) IDNUM(I), X, Y, Q
  142 FORMAT(10X,'IDNUM=',I3,'   X1=',F7.4,'   X2=',F7.4,
     &       '   DY2DX2=',E12.5)
      IF(ITYPE.EQ.3) WRITE(JOUT,143) IDNUM(I), X, Y, Q
  143 FORMAT(10X,'IDNUM=',I3,'   X1=',F7.4,'   X2=',F7.4,
     &       '   DT1DX1=',E12.5)
      IF(ITYPE.EQ.4) WRITE(JOUT,144) IDNUM(I), X, Y, Q
  144 FORMAT(10X,'IDNUM=',I3,'   X1=',F7.4,'   X2=',F7.4,
     &       '   DT2DX2=',E12.5)
  200 CONTINUE
      WRITE(JOUT,240) DATFIL
  240 FORMAT(///,10X,'VLE DATA FILE USED WAS ',A15)
  890 CONTINUE
      WRITE(*,900)
  900 FORMAT(/,10X,'NORMAL TERMINATION OF PROGRAM DYIDXI')
      STOP
      END
```

APPENDIX E

APPENDIX E

LIST OF PHYSICAL PROPERTIES

This section lists the physical properties used in the evaluation of each experimental test. The properties were calculated using the programs MIXPROP, DTBP and DYIDXI, and the vapor-liquid equilibrium data obtained from the Tables listed in Chapter 4. The information contained in the following Tables are listed as follows:

IDNUM - Test identification number.

TSAT - Saturation temperature at 1.01 bar, K.

RHOL - Liquid density, kg/m^3.

RHOG - Equilibrium vapor density, kg/m^3.

COND - Thermal conductivity, W/m-K.

CP - Liquid specific heat, kJ/kg-K.

VISC - Viscosity, cP.

SIGMA - Surface tension, N/m.

DELHV - Differential latent heat, kJ/kg.

DTBP - Boiling range, K.

D11,D22 - Diffusion coefficient, cm^2/s.

YMX1,YMX2,YMX3,YMX4 - Difference of vapor and liquid mole fractions for components 1,2,3,4 respectively.

DY1DX1,DY2DX2,DY3DX3 - Partial derivatives (dy/dx) for components 1-3

DT1DX1,DT2DX2,DT3DX3 - Partial derivatives (dT/dx) for components 1-3

Table E-1
List of Physical Properties I

IDNUM	TSAT	RHOL	RHOG	COND	CP	VISC	SIGMA	DELHV
1	329.3	759.3	2.218	.1347	2.279	.2311	.1998E-01	506.2
2	363.0	714.6	6.431	.1224	2.435	.1820	.1619E-01	473.0
3	312.0	780.7	1.179	.1408	2.219	.2665	.2191E-01	520.6
4	312.0	780.7	1.179	.1408	2.219	.2665	.2191E-01	520.6
5	383.9	684.8	10.31	.1143	2.556	.1604	.1386E-01	449.2
19	350.1	998.3	.7048	.5131	3.946	.3543	.5857E-01	1782.0
20	350.1	998.3	.7048	.5131	3.946	.3543	.5857E-01	1782.0
21	342.3	991.8	.7943	.4101	3.715	.3688	.5469E-01	1547.0
22	360.9	971.5	.6628	.5178	4.038	.4168	.5530E-01	1985.0
23	366.0	980.7	.6296	.5927	4.134	.3524	.5823E-01	2096.0
24	347.3	958.4	.7360	.4566	3.856	.4142	.5548E-01	1716.0
25	343.1	940.3	.8432	.3419	3.571	.4497	.4849E-01	1456.0
26	329.3	759.3	2.218	.1347	2.279	.2311	.1998E-01	506.2
27	311.0	782.0	1.183	.1411	2.216	.2689	.2203E-01	521.4
28	338.0	748.0	7.035	.1316	2.315	.2162	.1899E-01	491.5
30	337.6	751.6	1.178	.1743	2.876	.3437	.1901E-01	1105.0
31	367.8	710.5	3.401	.1623	3.199	.2600	.1669E-01	1040.0
32	321.9	772.0	.6254	.1806	2.732	.4002	.2024E-01	1135.0
33	317.6	777.3	1.257	.1823	2.696	.4176	.2056E-01	1141.0
34	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
35	406.8	947.3	1.691	.6995	4.259	.2157	.5610E-01	2173.0
36	354.5	1009.0	.3178	.6783	4.216	.3567	.6382E-01	2298.0
37	353.1	1011.0	.6284	.6773	4.21	.3625	.6401E-01	2303.0
38	333.8	852.8	1.336	.1772	2.783	.4128	.2806E-01	892.6
41	333.8	852.8	1.336	.1772	2.783	.4128	.2806E-01	892.6
42	313.8	877.0	1.427	.1846	2.691	.5276	.3024E-01	917.4
43	337.5	966.8	.9540	.2955	3.362	.3511	.4727E-01	1222.0
44	354.9	946.7	.9057	.2915	3.402	.2895	.4489E-01	1196.0
46	349.0	921.1	.8751	.3149	3.482	.3572	.4666E-01	1325.0
48	349.0	921.1	.8751	.3149	3.482	.3572	.4666E-01	1325.0
50	350.9	921.5	.7868	.3342	3.680	.6406	.4357E-01	1663.0
51	354.9	948.8	.7235	.4111	3.859	.5367	.4947E-01	1808.0
53	354.9	948.8	.7235	.4111	3.859	.5367	.4947E-01	1808.0
54	343.1	924.7	.8944	.2930	3.442	.5209	.4312E-01	1375.0
56	338.1	918.3	1.004	.2600	3.251	.4155	.4219E-01	1174.0
57	334.0	941.1	1.114	.2360	3.099	.3318	.4145E-01	1017.0
59	333.5	912.8	1.267	.2005	2.903	.3068	.3650E-01	873.3
61	336.0	900.3	1.160	.2147	3.016	.3756	.3702E-01	986.2
63	338.6	902.1	1.055	.2330	3.153	.4637	.3768E-01	1126.0
67	342.5	902.5	.9473	.2573	3.324	.5708	.3841E-01	1305.0
69	348.8	898.3	.8368	.2904	3.549	.6871	.3919E-01	1560.0
71	342.0	877.8	1.000	.2306	3.216	.5876	.3422E-01	1241.0
73	334.6	884.2	1.316	.1870	2.834	.3409	.3278E-01	854.6
75	332.5	858.6	1.576	.1627	2.620	.2705	.2908E-01	691.6
78	335.6	811.1	1.275	.1749	2.812	.4360	.2418E-01	971.1
80	334.0	867.0	1.372	.1767	2.765	.3660	.2961E-01	836.1
82	344.4	848.2	.9497	.2288	3.289	.6661	.3098E-01	1374.0
84	340.8	799.3	1.063	.1945	3.067	.5176	.2437E-01	1228.0
86	331.5	836.5	1.690	.1520	2.518	.2989	.2395E-01	675.7
88	331.3	807.3	1.891	.1445	2.425	.2467	.2382E-01	583.2
90	328.8	760.6	2.018	.1394	2.340	.2540	.1990E-01	574.9
92	329.9	760.2	1.708	.1483	2.467	.2892	.1963E-01	707.3

Table E-1,continued
List of Physical Properties I

IDNUM	TSAT	RHOL	RHOG	COND	CP	VISC	SIGMA	DELHV
94	332.9	757.3	1.393	.1615	2.663	.3253	.1931E-01	904.0
96	334.0	867.0	1.372	.1767	2.765	.3660	.2961E-01	836.1
97	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
98	360.9	971.5	.6628	.5178	4.038	.4168	.5530E-01	1985.0
99	366.0	980.7	.6296	.5927	4.134	.3524	.5823E-01	2096.0
100	354.9	948.8	.7235	.4111	3.859	.5367	.4947E-01	1808.0
101	351.1	924.0	.781	.3400	3.695	.6329	.4408E-01	1674.0
102	346.3	873.3	.8937	.2549	3.412	.7005	.3487E-01	1461.0
103	337.6	751.6	1.178	.1743	2.876	.3437	.1901E-01	1105.0
104	344.4	848.2	.9497	.2288	3.289	.6661	.3098E-01	1374.0
105	342.5	823.6	1.007	.2093	3.174	.6007	.2750E-01	1298.0
106	340.4	786.7	1.091	.1883	3.021	.4719	.2289E-01	1195.0
107	337.8	981.5	.8791	.3428	3.521	.3689	.5100E-01	1370.0
108	336.5	952.9	1.031	.2612	3.224	.3377	.4407E-01	1108.0
109	335.5	910.5	1.259	.1998	2.908	.3004	.3624E-01	870.6
110	332.5	858.6	1.576	.1627	2.620	.2705	.2908E-01	691.6
111	329.3	759.3	2.218	.1347	2.279	.2311	.1998E-01	506.2
112	373.1	906.3	.7734	.3349	3.665	.3181	.4453E-01	1401.0
120	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
121	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4
122	350.3	830.2	3.178	.1314	2.097	.2563	.1734E-01	363.6
123	355.1	886.5	.7244	.4686	3.926	.4733	.5456E-01	1794.0
124	349.5	888.0	.9147	.3124	3.506	.6479	.4465E-01	1414.0
125	346.8	890.5	1.333	.2000	2.941	.7133	.3154E-01	960.6
126	349.0	857.4	1.707	.1560	2.789	.5542	.1916E-01	812.8
128	358.5	967.5	.7393	.4328	3.898	.5056	.5196E-01	1770.0
129	352.0	887.3	.7998	.3887	3.746	.5610	.5018E-01	1627.0
130	355.5	931.3	.8806	.3076	3.625	.7387	.4296E-01	1500.0
131	349.5	876.5	1.249	.2007	3.099	.9141	.3023E-01	1069.0
132	349.9	862.4	1.463	.1710	2.957	.8305	.2326E-01	943.9
133	352.5	849.7	1.200	.1992	3.219	1.026	.2891E-01	1143.0
134	337.6	751.6	1.178	.1743	2.876	.3437	.1901E-01	1105.0
135	355.9	915.8	.7651	.3858	3.807	.5737	.4853E-01	1705.0
136	355.9	899.1	.7917	.3674	3.768	.6066	.4753E-01	1651.0
137	352.1	916.4	.8086	.3265	3.663	.6608	.4331E-01	1609.0
138	360.6	943.6	.6763	.5069	4.021	.4254	.5514E-01	1920.0
139	349.0	858.1	1.076	.2120	3.248	.8318	.2996E-01	1239.0
140	348.1	835.6	1.294	.1778	3.045	.7257	.2328E-01	1061.0
141	344.9	819.7	1.148	.1894	3.081	.6325	.2468E-01	1163.0
142	343.9	748.1	1.392	.1634	2.874	.3867	.1826E-01	977.0
143	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4
144	337.6	751.6	1.178	.1743	2.876	.3437	.1901E-01	1105.0
145	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
150	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
151	338.6	902.1	1.055	.2330	3.153	.4637	.3768E-01	1126.0
155	337.6	751.6	1.178	.1743	2.876	.3437	.1901E-01	1105.0
156	329.3	759.3	2.218	.1347	2.279	.2311	.1998E-01	506.2
157	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
160	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
161	355.6	818.3	2.109	.1196	3.370	.4790	.1639E-01	621.5
162	329.3	759.3	2.218	.1347	2.279	.2311	.1998E-01	506.2
163	346.1	919.5	.7735	.4312	3.858	.3898	.5489E-01	1631.0

Table E-1,continued
List of Physical Properties I

IDNUM	TSAT	RHOL	RHOG	COND	CP	VISC	SIGMA	DELHV
164	353.1	905.5	.7531	.4448	3.981	.3869	.5425E-01	1707.0
165	353.1	909.6	1.000	.2594	3.737	.4520	.4109E-01	1249.0
166	356.6	995.5	.7097	.4986	4.070	.3698	.5632E-01	1854.0
167	354.6	981.0	.8462	.3486	3.899	.4136	.4816E-01	1514.0
168	353.1	907.6	.9116	.3042	3.792	.4229	.4512E-01	1374.0
169	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
170	337.6	751.6	1.178	.1743	2.876	.3437	.1901E-01	1105.0
171	355.6	818.3	1.109	.1196	3.370	.4790	.1639E-01	621.5
172	356.0	949.2	.7399	.4142	3.914	.4781	.5050E-01	1768.0
173	351.3	908.6	.9491	.2543	3.604	.6346	.3766E-01	1360.0
174	351.3	898.8	1.118	.2039	3.519	.6426	.3217E-01	1144.0
175	348.0	881.3	.9801	.2310	3.445	.6937	.3341E-01	1321.0
176	356.0	911.2	.8169	.3053	3.677	.5977	.4100E-01	1558.0
178	352.8	825.5	2.581	.1283	2.299	.2354	.1784E-01	442.9
179	329.3	759.3	2.218	.1347	2.279	.2311	.1998E-01	506.2
180	346.3	950.7	.7959	.4152	3.705	.3568	.5412E-01	1532.0
181	339.4	930.5	.9935	.2827	3.300	.3431	.4568E-01	1167.0
182	343.0	948.4	1.040	.2724	3.236	.3340	.4399E-01	1108.0
183	352.6	965.1	.8126	.3974	3.638	.3313	.5196E-01	1467.0
184	337.0	895.7	1.391	.1834	2.796	.2887	.3318E-01	783.2
185	353.4	878.6	2.163	.1210	3.238	.4828	.1669E-01	591.9
186	345.5	859.8	2.742	.1288	2.143	.3395	.2021E-01	424.8
187	349.5	906.9	2.769	.1310	2.021	.3215	.2088E-01	411.4
188	340.1	781.1	2.108	.1495	2.356	.3518	.1828E-01	610.2
189	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
190	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
191	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4
192	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4
193	358.5	967.5	.7393	.4328	3.898	.5056	.5196E-01	1770.0
194	355.5	931.3	.8806	.3076	3.625	.7387	.4296E-01	1500.0
195	352.5	849.7	1.200	.1992	3.219	1.026	.2891E-01	1143.0
196	353.1	1011.0	.6284	.6773	4.215	.3625	.6401E-01	2303.0
197	363.1	999.3	.6106	.6843	4.221	.3223	.6254E-01	2283.0
198	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
199	333.1	1033.0	.6672	.6597	4.205	.4765	.6697E-01	2347.0
200	343.1	1022.0	.6472	.6691	4.210	.4127	.6549E-01	2327.0
201	331.5	769.5	1.741	.1597	2.686	.5848	.1920E-01	892.8
202	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4
203	358.5	967.5	.7393	.4328	3.89	.5056	.5196E-01	1770.0
204	348.5	979.0	.7612	.4316	3.858	.5824	.5329E-01	1794.0
205	338.5	990.3	.7844	.4298	3.823	.6802	.5462E-01	1813.0
206	355.5	931.3	.8806	.3076	3.625	.7387	.4296E-01	1500.0
207	345.5	942.9	.9071	.3086	3.561	.8639	.4417E-01	1520.0
208	335.5	954.3	.9352	.3093	3.505	1.025	.4538E-01	1539.0
209	352.5	849.7	1.200	.1992	3.219	1.026	.2891E-01	1143.0
210	342.5	861.7	1.237	.2015	3.122	1.204	.2991E-01	1161.0
211	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4
212	341.5	757.1	1.686	.1573	2.794	.4998	.1836E-01	876.2
213	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
214	363.1	999.3	.6106	.6843	4.221	.3223	.6254E-01	2283.0
215	353.1	1011.0	.6284	.6773	4.215	.3625	.6401E-01	2303.0
216	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4

Table E-1,continued
List of Physical Properties I

IDNUM	TSAT	RHOL	RHOG	COND	CP	VISC	SIGMA	DELHV
217	351.5	744.4	1.635	.1550	2.917	.4297	.1753E-01	859.4
218	358.5	967.5	.7393	.4328	3.898	.5056	.5196E-01	1770.0
219	348.5	979.0	.7612	.4316	3.858	.5824	.5329E-01	1794.0
220	338.5	990.3	.7844	.4298	3.823	.6802	.5462E-01	1813.0
221	355.5	931.3	.8806	.3076	3.625	.7387	.4296E-01	1500.0
222	345.5	942.9	.9071	.3086	3.561	.8639	.4417E-01	1520.0
223	352.5	849.7	1.200	.1992	3.219	1.026	.2891E-01	1143.0
224	342.5	861.7	1.237	.2015	3.122	1.204	.2991E-01	1161.0
225	373.1	987.7	.5939	.6899	4.228	.2898	.6106E-01	2255.0
226	363.1	999.3	.6106	.6843	4.221	.3223	.6254E-01	2283.0

Table E-2
List of Physical Properties II

IDNUM	YMX1	YMX2	YMX3	YMX4	DTBP	D11	D22
1	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
2	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
3	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
4	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
5	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
19	.5890	-.5890	.0000	.0000	.2500E+02	.2730E-04	.0000E+00
20	.5890	-.5890	.0000	.0000	.2500E+02	.2730E-04	.0000E+00
21	.6630	-.6630	.0000	.0000	.3040E+02	.1600E-04	.0000E+00
22	.3180	-.3180	.0000	.0000	.9500E+01	.4616E-04	.0000E+00
23	.2170	-.2170	.0000	.0000	.5900E+01	.5538E-04	.0000E+00
24	.5500	.0400	-.5900	.0000	.2300E+02	.3170E-04	.4499E-04
25	.5100	.0300	-.5400	.0000	.2190E+02	.2910E-04	.4123E-04
26	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
27	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
28	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
30	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
31	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
32	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
33	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
34	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
35	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
36	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
37	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
38	.2210	-.0200	-.2010	.0000	.9700E+01	.3249E-04	.4560E-04
41	.2210	-.0200	-.2010	.0000	.9700E+01	.3249E-04	.4560E-04
42	.2210	-.0200	-.2010	.0000	.9700E+01	.2389E-04	.3354E-04
43	.6270	-.6270	.0000	.0000	.3210E+02	.1180E-04	.0000E+00
44	.6270	-.6270	.0000	.0000	.1470E+02	.4598E-04	.0000E+00
46	.4880	.0360	-.5240	.0000	.1920E+02	.3698E-04	.5308E-04
48	.4880	.0360	-.5240	.0000	.1920E+02	.3698E-04	.5308E-04
50	.3610	-.3610	.0000	.0000	.1330E+02	.2921E-04	.0000E+00
51	.3790	-.3790	.0000	.0000	.1270E+02	.3526E-04	.0000E+00
53	.3790	-.3790	.0000	.0000	.1270E+02	.3526E-04	.0000E+00
54	.4200	.0400	-.4600	.0000	.1580E+02	.2552E-04	.3566E-04
56	.5200	-.0300	-.4900	.0000	.2650E+02	.3110E-04	.4454E-04
57	.5450	-.5450	.0000	.0000	.3390E+02	.1140E-04	.0000E+00
59	.4570	-.4570	.0000	.0000	.3160E+02	.1350E-04	.0000E+00
61	.4600	-.0350	-.4250	.0000	.2560E+02	.3426E-04	.4957E-04
63	.4350	-.0200	-.4150	.0000	.1660E+02	.2840E-04	.4010E-04
67	.3300	.0550	-.3850	.0000	.6000E+01	.2361E-04	.3255E-04
69	.3290	-.3290	.0000	.0000	.1270E+02	.2707E-04	.0000E+00
71	.2700	.0500	-.3200	.0000	.6800E+01	.2324E-04	.3165E-04
73	.3900	-.0400	-.3500	.0000	.2300E+02	.3773E-04	.5507E-04
75	.2770	-.2770	.0000	.0000	.2060E+02	.2060E-04	.0000E+00
78	.1850	-.0500	-.1350	.0000	.8600E+01	.3195E-04	.4345E-04
80	.3250	-.0450	-.2800	.0000	.1770E+02	.3589E-04	.5149E-04
82	.2250	-.2250	.0000	.0000	.9600E+01	.2757E-04	.0000E+00
84	.1150	-.1150	.0000	.0000	.4600E+01	.3511E-04	.0000E+00
86	.1700	-.0370	-.1330	.0000	.8500E+01	.4460E-04	.6425E-04
88	.0980	-.0980	.0000	.0000	.8400E+01	.3700E-04	.0000E+00
90	.0000	.0000	.0000	.0000	.0000E+00	.5533E-04	.0000E+00
92	.0860	-.0860	.0000	.0000	.7000E+00	.4876E-04	.0000E+00

Table E-2,continued
List of Physical Properties II

IDNUM	YMX1	YMX2	YMX3	YMX4	DTBP	D11	D22
94	.1408	-.1408	.0000	.0000	.2300E+01	.4375E-04	.0000E+00
96	.3250	-.0450	-.2800	.0000	.1770E+02	.3589E-04	.5149E-04
97	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
98	.3180	-.3180	.0000	.0000	.9500E+01	.4616E-04	.0000E+00
99	.2170	-.2170	.0000	.0000	.5900E+01	.5538E-04	.0000E+00
100	.3790	-.3790	.0000	.0000	.1270E+02	.3526E-04	.0000E+00
101	.3650	-.3650	.0000	.0000	.1330E+02	.2959E-04	.0000E+00
102	.2790	-.2790	.0000	.0000	.1190E+02	.2636E-04	.0000E+00
103	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
104	.2250	-.2250	.0000	.0000	.9600E+01	.2757E-04	.0000E+00
105	.1700	-.1700	.0000	.0000	.7200E+01	.3040E-04	.0000E+00
106	.0865	-.0865	.0000	.0000	.3300E+01	.3846E-04	.0000E+00
107	.6450	-.6450	.0000	.0000	.3230E+02	.1390E-04	.0000E+00
108	.5860	-.5860	.0000	.0000	.3230E+02	.1160E-04	.0000E+00
109	.4570	-.4570	.0000	.0000	.3080E+02	.1350E-04	.0000E+00
110	.2770	-.2770	.0000	.0000	.2070E+02	.2060E-04	.0000E+00
111	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
112	.5100	.0300	-.5400	.0000	.2190E+02	.4474E-04	.6338E-04
120	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
121	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
122	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
123	.2070	.2360	-.4430	.0000	.1500E+02	.2362E-04	.3204E-04
124	.1890	.1580	-.3770	.0000	.1580E+02	.1740E-04	.2343E-04
125	.2020	-.0010	-.2010	.0000	.1060E+02	.1630E-04	.2257E-04
126	.0720	-.0800	.0080	.0000	.1100E+01	.2326E-04	.3256E-04
128	.3466	-.3466	.0000	.0000	.1460E+02	.2320E-04	.0000E+00
129	.1920	.2350	-.4270	.0000	.1650E+02	.1998E-04	.2692E-04
130	.2972	-.2972	.0000	.0000	.9900E+01	.1660E-04	.0000E+00
131	.1190	.0440	-.1630	.0000	.5000E+01	.1311E-04	.1704E-04
132	.0620	-.0310	-.0310	.0000	.1400E+01	.1510E-04	.1918E-04
133	.1109	-.1109	.0000	.0000	.2200E+01	.2160E-04	.0000E+00
134	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
135	.2170	.2020	-.4190	.0000	.1240E+02	.3392E-04	.2683E-04
136	.0920	.2850	-.3770	.0000	.1140E+02	.3240E-04	.2522E-04
137	.3100	.1000	-.4100	.0000	.1390E+02	.2895E-04	.2355E-04
138	.2190	.1870	-.4060	.0000	.1020E+02	.4559E-04	.3646E-04
139	.1560	.0590	-.2150	.0000	.7800E+01	.2448E-04	.1892E-04
140	.1000	-.0500	-.0500	.0000	.2000E+01	.2956E-04	.2203E-04
141	.1650	-.0500	-.1150	.0000	.4900E+01	.3228E-04	.2550E-04
142	.1340	-.1340	.0000	.0000	.1400E+01	.5762E-04	.0000E+00
143	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
144	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
145	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
150	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
151	.4350	-.0200	-.4150	.0000	.1660E+02	.2840E-04	.4010E-04
155	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
156	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
157	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
160	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
161	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
162	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
163	.4750	.1000	-.5750	.0000	.2460E+02	.3352E-04	.3436E-04

Table E-2,continued
List of Physical Properties II

IDNUM	YMX1	YMX2	YMX3	YMX4	DTBP	D11	D22
164	.2130	.2510	-.4640	.0000	.1830E+02	.3461E-04	.3515E-04
165	.0930	.2210	-.3140	.0000	.1380E+02	.3031E-04	.3009E-04
166	.4450	-.4450	.0000	.0000	.1550E+02	.3709E-04	.0000E+00
167	.4100	-.4100	.0000	.0000	.1560E+02	.3298E-04	.0000E+00
168	.1045	.2730	-.3775	.0000	.1550E+02	.3211E-04	.3219E-04
169	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
170	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
171	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
172	.2310	.1170	-.3480	.0000	.1260E+02	.3997E-04	.2918E-04
173	.1520	.0710	-.2230	.0000	.8700E+01	.3023E-04	.2217E-04
174	.0990	.0870	-.1860	.0000	.4000E+01	.3046E-04	.2194E-04
175	.2130	.0340	-.2470	.0000	.9400E+01	.2733E-04	.2055E-04
176	.3130	.0290	-.3420	.0000	.1280E+02	.3197E-04	.2395E-04
178	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
179	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
180	.4470	.2020	-.6490	.0000	.2640E+02	.3681E-04	.3386E-04
181	.4570	.0980	-.5550	.0000	.3370E+02	.3770E-04	.3498E-04
182	.2030	.2810	-.4840	.0000	.1700E+01	.4006E-04	.3599E-04
183	.1530	.4060	-.5590	.0000	.5000E+01	.4081E-04	.3700E-04
184	.3510	.0080	-.3590	.0000	.3600E+02	.4541E-04	.4242E-04
185	.0310	.0290	.0120	-.0720	.2100E+01	.2878E-04	.2748E-04
186	-.0390	-.0230	.0260	.0360	.1000E+01	.4510E-04	.4158E-04
187	-.0120	-.0520	.0120	.0520	.2200E+01	.4850E-04	.4441E-04
188	.1178	.0180	-.0098	-.1260	.2400E+01	.4262E-04	.6530E-04
189	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
190	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
191	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
192	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
193	.3466	-.3466	.0000	.0000	.1460E+02	.2320E-04	.0000E+00
194	.2972	-.2972	.0000	.0000	.9900E+01	.1660E-04	.0000E+00
195	.1109	-.1109	.0000	.0000	.2200E+01	.2160E-04	.0000E+00
196	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
197	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
198	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
199	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
200	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
201	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
202	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
203	.3466	-.3466	.0000	.0000	.1460E+02	.2320E-04	.0000E+00
204	.3466	-.3466	.0000	.0000	.1460E+02	.1800E-04	.0000E+00
205	.3466	-.3466	.0000	.0000	.1460E+02	.1600E-04	.0000E+00
206	.2972	-.2972	.0000	.0000	.9900E+01	.1660E-04	.0000E+00
207	.2972	-.2972	.0000	.0000	.9900E+01	.1400E-04	.0000E+00
208	.2972	-.2972	.0000	.0000	.9900E+01	.1000E-04	.0000E+00
209	.1109	-.1109	.0000	.0000	.2200E+01	.2160E-04	.0000E+00
210	.1109	-.1109	.0000	.0000	.2200E+01	.1900E-04	.0000E+00
211	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
212	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
213	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
214	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
215	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
216	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00

Table E-2,continued
List of Physical Properties II

IDNUM	YMX1	YMX2	YMX3	YMX4	DTBP	D11	D22
217	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
218	.3466	-.3466	.0000	.0000	.1460E+02	.2320E-04	.0000E+00
219	.3466	-.3466	.0000	.0000	.1460E+02	.1800E-04	.0000E+00
220	.3466	-.3466	.0000	.0000	.1460E+02	.1600E-04	.0000E+00
221	.2972	-.2972	.0000	.0000	.9900E+01	.1660E-04	.0000E+00
222	.2972	-.2972	.0000	.0000	.9900E+01	.1400E-04	.0000E+00
223	.1109	-.1109	.0000	.0000	.2200E+01	.2160E-04	.0000E+00
224	.1109	-.1109	.0000	.0000	.2200E+01	.1900E-04	.0000E+00
225	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00
226	.0000	.0000	.0000	.0000	.0000E+00	.0000E+00	.0000E+00

Table E-3
List of Physical Properties III

IDNUM	DYDX1	DYDX2	DYDX3	DTDX1	DTDX2	DTDX3
1	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
19	.5900E+01	.0000E+00	.0000E+00	-.2683E+03	.0000E+00	.0000E+00
20	.5900E+01	.0000E+00	.0000E+00	-.2683E+03	.0000E+00	.0000E+00
21	.7600E+00	.0000E+00	.0000E+00	-.8850E+02	.0000E+00	.0000E+00
22	.2500E+01	.0000E+00	.0000E+00	-.7450E+02	.0000E+00	.0000E+00
23	.3700E+01	.0000E+00	.0000E+00	-.1144E+03	.0000E+00	.0000E+00
24	.7500E+01	.2240E+01	.0000E+00	-.2389E+03	.3370E+02	.0000E+00
25	.3530E+01	.1470E+01	.0000E+00	-.1153E+03	-.5500E+01	.0000E+00
26	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
27	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
28	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
30	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
31	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
32	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
33	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
34	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
35	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
36	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
37	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
38	.5000E+00	.9100E+00	.0000E+00	-.2490E+02	-.8300E+01	.0000E+00
41	.5000E+00	.9100E+00	.0000E+00	-.2490E+02	-.8300E+01	.0000E+00
42	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
43	.4000E+00	.0000E+00	.0000E+00	-.2450E+02	.0000E+00	.0000E+00
44	.4000E+00	.0000E+00	.0000E+00	-.2450E+02	.0000E+00	.0000E+00
46	.2800E+00	.5400E+00	.0000E+00	-.3210E+02	.4000E+00	.0000E+00
48	.2800E+00	.5400E+00	.0000E+00	-.3210E+02	.4000E+00	.0000E+00
50	.7000E+00	.0000E+00	.0000E+00	-.2990E+02	.0000E+00	.0000E+00
51	.1000E+01	.0000E+00	.0000E+00	-.4770E+02	.0000E+00	.0000E+00
53	.1000E+01	.0000E+00	.0000E+00	-.4770E+02	.0000E+00	.0000E+00
54	.3110E+01	.1170E+01	.0000E+00	-.8280E+02	-.1300E+02	.0000E+00
56	.9200E+00	.9600E+00	.0000E+00	-.4140E+02	.5600E+01	.0000E+00
57	.1000E+00	.0000E+00	.0000E+00	-.1450E+02	.0000E+00	.0000E+00
59	.1200E+00	.0000E+00	.0000E+00	-.1050E+02	.0000E+00	.0000E+00
61	.3500E+00	.7800E+00	.0000E+00	-.1910E+02	.1800E+01	.0000E+00
63	.1060E+01	.1020E+01	.0000E+00	-.3900E+02	.8000E+00	.0000E+00
67	.2880E+01	.9900E+00	.0000E+00	-.6600E+02	-.9400E+01	.0000E+00
69	.5600E+00	.0000E+00	.0000E+00	-.2420E+02	.0000E+00	.0000E+00
71	.2300E+01	.8700E+00	.0000E+00	-.6140E+02	-.9800E+01	.0000E+00
73	.2400E+00	.8800E+00	.0000E+00	-.1400E+02	-.9800E+01	.0000E+00
75	.1000E+00	.0000E+00	.0000E+00	-.9100E+01	.0000E+00	.0000E+00
78	.1040E+01	.1040E+01	.0000E+00	-.3520E+02	-.1270E+02	.0000E+00
80	.2800E+00	.2800E+00	.0000E+00	-.1670E+02	-.6100E+01	.0000E+00
82	.4500E+00	.0000E+00	.0000E+00	-.1870E+02	.0000E+00	.0000E+00
84	.4600E+00	.0000E+00	.0000E+00	-.1520E+02	.0000E+00	.0000E+00
86	.1400E+00	.1400E+00	.0000E+00	-.1190E+02	-.9400E+01	.0000E+00
88	.1400E+00	.1400E+00	.0000E+00	-.8300E+01	.0000E+00	.0000E+00
90	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
92	.6900E+00	.0000E+00	.0000E+00	-.3600E+01	.0000E+00	.0000E+00

Table E-3,continued
List of Physical Properties III

IDNUM	DYDX1	DYDX2	DYDX3	DTDX1	DTDX2	DTDX3
94	.1000E+01	.0000E+00	.0000E+00	-.1860E+02	.0000E+00	.0000E+00
96	.2800E+00	.8800E+00	.0000E+00	-.1670E+02	-.6100E+01	.0000E+00
97	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
98	.2500E+01	.0000E+00	.0000E+00	-.7450E+02	.0000E+00	.0000E+00
99	.3700E+01	.0000E+00	.0000E+00	-.1144E+03	.0000E+00	.0000E+00
100	.1000E+01	.0000E+00	.0000E+00	-.4740E+02	.0000E+00	.0000E+00
101	.7300E+00	.0000E+00	.0000E+00	-.3000E+02	.0000E+00	.0000E+00
102	.4700E+00	.0000E+00	.0000E+00	-.2000E+02	.0000E+00	.0000E+00
103	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
104	.4500E+00	.0000E+00	.0000E+00	-.1870E+02	.0000E+00	.0000E+00
105	.4500E+00	.0000E+00	.0000E+00	-.1930E+02	.0000E+00	.0000E+00
106	.4400E+00	.0000E+00	.0000E+00	-.1400E+02	.0000E+00	.0000E+00
107	.6700E+00	.0000E+00	.0000E+00	-.4370E+02	.0000E+00	.0000E+00
108	.1500E+00	.0000E+00	.0000E+00	-.1880E+02	.0000E+00	.0000E+00
109	.1200E+00	.0000E+00	.0000E+00	-.1050E+02	.0000E+00	.0000E+00
110	.1000E+00	.0000E+00	.0000E+00	-.9100E+01	.0000E+00	.0000E+00
111	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
112	.3530E+01	.1470E+01	.0000E+00	-.1153E+03	-.5500E+01	.0000E+00
120	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
121	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
122	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
123	.1550E+01	.5570E+01	.0000E+00	-.8400E+02	-.1579E+03	.0000E+00
124	.5460E+01	.8500E+00	.0000E+00	-.1597E+03	.1350E+02	.0000E+00
125	.8900E+00	.7600E+00	.0000E+00	-.1800E+02	.4300E+01	.0000E+00
126	.1410E+01	.1050E+01	.0000E+00	-.2370E+02	-.2300E+01	.0000E+00
128	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
129	.1170E+02	.7900E+00	.0000E+00	-.3420E+03	.1010E+02	.0000E+00
130	.7400E+00	.0000E+00	.0000E+00	-.7200E+01	.0000E+00	.0000E+00
131	.2220E+01	.5800E+00	.0000E+00	-.5090E+02	-.1900E+01	.0000E+00
132	.2020E+01	.7000E+00	.0000E+00	-.3370E+02	-.1900E+01	.0000E+00
133	.4300E+00	.0000E+00	.0000E+00	-.5900E+01	.0000E+00	.0000E+00
134	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
135	.1910E+01	.1000E+01	.0000E+00	-.4930E+02	-.2280E+02	.0000E+00
136	.4270E+01	.2480E+01	.0000E+00	-.3800E+02	-.4700E+02	.0000E+00
137	.6300E+00	.2090E+01	.0000E+00	-.1890E+02	-.1070E+02	.0000E+00
138	.3140E+01	.4590E+01	.0000E+00	-.3630E+02	-.1221E+03	.0000E+00
139	.1040E+01	.6600E+00	.0000E+00	-.1970E+02	-.6700E+01	.0000E+00
140	.5900E+00	.6800E+00	.0000E+00	-.1930E+02	-.3700E+01	.0000E+00
141	.7400E+00	.7700E+00	.0000E+00	-.1810E+02	-.4600E+01	.0000E+00
142	.9000E+00	.0000E+00	.0000E+00	-.1410E+02	.0000E+00	.0000E+00
143	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
144	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
145	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
150	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
151	.1060E+01	.1020E+01	.0000E+00	-.3900E+02	.8000E+00	.0000E+00
155	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
156	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
157	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
160	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
161	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
162	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
163	.5010E+01	.2840E+01	.0000E+00	-.1868E+03	-.2200E+01	.0000E+00

Table E-3,continued
List of Physical Properties III

IDNUM	DYDX1	DYDX2	DYDX3	DTDX1	DTDX2	DTDX3
164	.1662E+02	-.3040E+01	.0000E+00	-.3089E+03	-.1297E+03	.0000E+00
165	.9890E+01	.7000E-01	.0000E+00	-.2039E+03	-.1020E+02	.0000E+00
166	.1299E+02	.0000E+00	.0000E+00	-.2248E+03	.0000E+00	.0000E+00
167	.1269E+02	.0000E+00	.0000E+00	-.2704E+03	.0000E+00	.0000E+00
168	.6320E+01	.6800E+00	.0000E+00	-.1323E+03	.4200E+01	.0000E+00
169	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
170	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
171	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
172	.2150E+01	.3800E+00	.0000E+00	-.1850E+02	.2390E+02	.0000E+00
173	.1580E+01	.1370E+01	.0000E+00	-.1600E+02	-.6000E+01	.0000E+00
174	.1170E+01	.6300E+00	.0000E+00	-.1560E+02	-.7000E+00	.0000E+00
175	.7700E+00	.1090E+01	.0000E+00	-.1710E+02	.3000E+00	.0000E+00
176	.1030E+01	.1790E+01	.0000E+00	-.3120E+02	-.1950E+02	.0000E+00
178	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
179	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
180	.6010E+01	.5860E+01	.0000E+00	-.1249E+03	-.1151E+03	.0000E+00
181	.5500E+00	.2380E+01	.0000E+00	-.2700E+02	.1090E+02	.0000E+00
182	.2800E+01	.1470E+01	.0000E+00	-.1070E+03	.8300E+01	.0000E+00
183	.6840E+01	-.7000E-01	.0000E+00	.1031E+03	.1748E+03	.0000E+00
184	.4300E+00	.9200E+00	.0000E+00	-.1340E+02	.1650E+02	.0000E+00
185	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
186	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
187	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
188	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
189	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
190	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
191	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
192	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
193	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
194	.7400E+00	.0000E+00	.0000E+00	-.7200E+01	.0000E+00	.0000E+00
195	.4300E+00	.0000E+00	.0000E+00	-.5900E+01	.0000E+00	.0000E+00
196	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
197	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
198	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
199	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
200	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
201	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
202	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
203	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
204	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
205	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
206	.7400E+00	.0000E+00	.0000E+00	-.7200E+01	.0000E+00	.0000E+00
207	.7400E+00	.0000E+00	.0000E+00	-.7200E+01	.0000E+00	.0000E+00
208	.7400E+00	.0000E+00	.0000E+00	-.7200E+01	.0000E+00	.0000E+00
209	.4300E+00	.0000E+00	.0000E+00	-.5900E+01	.0000E+00	.0000E+00
210	.4300E+00	.0000E+00	.0000E+00	-.5900E+01	.0000E+00	.0000E+00
211	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
212	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
213	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
214	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
215	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
216	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

Table E-3,continued
List of Physical Properties III

IDNUM	DYDX1	DYDX2	DYDX3	DTDX1	DTDX2	DTDX3
217	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
218	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
219	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
220	.1660E+01	.0000E+00	.0000E+00	-.4560E+02	.0000E+00	.0000E+00
221	.7400E+00	.0000E+00	.0000E+00	-.7200E+01	.0000E+00	.0000E+00
222	.7400E+00	.0000E+00	.0000E+00	-.7200E+01	.0000E+00	.0000E+00
223	.4300E+00	.0000E+00	.0000E+00	-.5900E+01	.0000E+00	.0000E+00
224	.4300E+00	.0000E+00	.0000E+00	-.5900E+01	.0000E+00	.0000E+00
225	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
226	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

APPENDIX F

APPENDIX F

EXPERIMENTAL DATA

This section contains the experimental data obtained in this investigation. The following data is listed in order by the test identification number. The components and surface type are designated by the index numbers described in Appendix A and used by the series of computer programs that evaluated the data. For reference, these indicies are:

Components:

Index:	Component:
1	Acetone
2	2-Butanone
3	Methanol
4	Ethanol
5	Benzene
6	Water
7	1-Propanol
8	2-Propanol
9	Ethylene Glycol
10	Cyclohexane
11	not used
12	Methyl Acetate
13	Ethyl Acetate
14	not used
15	Ammonia

Surfaces:

Index:	Surface Type:
1	Plain Tube (#1)
2	High Flux
3	19 Fin/In.
4	High Flux
5	Plain Tube (#2)
6	Plain Tube (#2)
7	Plain Tube (#1)
8	Plain Tube (#1)

(A different surface index for the same tube design denotes a similar but not identical surface finish.)

The units for the headings which follow are:

SUPERHEAT - deg K
HEAT FLUX - W/m^2
ALPHA - W/m^2-K

```
       IDNUM          DATE         SURFACE
           1         12186               1
   COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
           1             0               0               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.10000E+01   0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX    ALPHA
           1        2.0     2080.6   1047.8
           2        7.2     8433.2   1176.7
           3        9.5    13429.2   1412.5
           4       10.8    20376.3   1880.8
           5       11.8    27525.3   2330.7
           6       12.3    36158.3   2945.7
           7       13.0    51189.9   3931.3
           8       13.7    68294.1   5002.2
           9       14.3    90298.4   6303.3
          10       15.0   113548.0   7575.1
          11       16.4   150367.6   9149.2
          12       17.6   183044.6  10424.5
          13       19.1   216224.0  11332.7

       IDNUM          DATE         SURFACE
           2         40886               1
   COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
           1             0               0               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.10000E+01   0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
        NPTS
          28
          NO  SUPERHEAT  HEAT FLUX    ALPHA
           1        8.1    13129.1   1619.0
           2        9.0    19272.5   2137.4
           3        9.4    23751.4   2523.9
           4        9.8    27762.5   2823.4
           5       10.0    31743.4   3180.6
           6       10.2    36512.8   3571.8
           7       10.4    41220.1   3948.3
           8       10.6    47346.7   4446.7
           9       10.9    54953.9   5032.4
          10       11.2    62982.4   5628.8
          11       11.6    71903.2   6210.5
          12       11.9    83691.2   7035.1
          13       12.2    96456.8   7933.7
          14       12.6   107444.3   8522.7
          15       12.8   119744.4   9375.7
          16       13.1   132728.0  10126.5
          17       13.6   149714.3  10976.5
          18       13.9   164913.5  11856.2
          19       14.5   184662.9  12693.5
          20       15.1   201450.7  13335.1
          21       15.4   210510.3  13652.6
          22       15.8   222620.0  14103.0
          23       16.2   231205.4  14271.1
          24       16.7   240516.3  14370.7
          25       17.1   256170.8  14956.0
```

```
      IDNUM          DATE       SURFACE
          3         40986             1
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
          1             0             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
       NPTS
         10
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1       14.1    18350.2    1301.6
          2       15.9    27339.8    1718.3
          3       16.8    32762.8    1947.5
          4       17.2    37266.7    2161.4
          5       17.8    41727.3    2342.7
          6       18.4    46601.2    2528.9
          7       19.1    52789.6    2769.7
          8       19.7    60251.1    3061.0
          9       20.2    67928.4    3357.8
         10       20.8    77050.9    3710.2
```

```
      IDNUM          DATE       SURFACE
          4         61386             1
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
          1             0             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
       NPTS
         11
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        8.0     8035.3    1008.3
          2       13.6    14285.6    1052.3
          3       14.6    20017.8    1370.0
          4       16.6    24723.0    1493.5
          5       17.0    29260.5    1724.0
          6       17.6    34309.0    1945.2
          7       18.6    42692.6    2300.9
          8       20.6    71002.9    3449.4
          9       21.7    87458.3    4031.2
         10       22.3    97479.2    4376.0
         11       22.7   106457.1    4692.1
```

```
      IDNUM          DATE        SURFACE
          5         41086              1
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1             0              0              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        2.8     2306.8     828.6
          2        5.2     4629.7     887.3
          3        6.4    10102.3    1577.2
          4        7.1    15590.3    2198.2
          5        7.7    22023.6    2861.1
          6        8.4    33649.7    4009.6
          7        9.3    47786.5    5141.4
          8        9.7    65711.0    6777.4
          9       10.0    75007.8    7514.9
         10       10.1    83708.9    8250.4
         11       10.6    92709.1    8780.3
         12       10.9   109152.0   10041.5
         13       11.3   134571.6   11862.5
         14       11.9   160437.0   13493.0
         15       12.4   177451.8   14313.3
         16       13.1   211383.1   16120.1
         17       13.6   219237.4   16169.5
         18       14.3   244090.5   17055.1
         19       15.2   264167.6   17353.2
         20       16.1   285842.0   17728.7

      IDNUM          DATE        SURFACE
         19         72486              1
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1             6              0              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.50000E-01   0.95000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         17
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.8     3613.5    2064.9
          2        3.0     7253.3    2438.2
          3        4.4    12386.0    2790.1
          4        5.5    15216.3    2781.9
          5        6.5    18816.0    2874.9
          6        7.8    21681.7    2797.6
          7        9.6    29358.9    3051.2
          8       12.4    38390.1    3099.9
          9       14.8    47877.1    3241.8
         10       17.6    60589.7    3436.6
         11       19.9    71784.1    3611.1
         12       22.6    87294.7    3863.2
         13       24.9   101221.4    4061.0
         14       27.1   116798.4    4311.1
         15       28.6   135220.1    4721.4
         16       30.1   156430.8    5202.5
         17       30.8   175802.4    5706.2
```

```
      IDNUM           DATE        SURFACE
         20          72586              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.50000E-01    0.95000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        4.3     9244.7    2144.4
          2        6.4    14662.4    2282.6
          3        8.9    21442.5    2415.6
          4       11.8    28529.2    2417.2
          5       15.1    36667.4    2428.9
          6       18.1    48554.1    2676.8
          7       20.8    60556.4    2914.0
          8       23.2    71423.4    3081.1
          9       25.0    84029.3    3355.3
         10       26.7   100364.1    3761.7
         11       28.1   119966.6    4273.8
         12       28.7   134738.1    4691.7
         13       29.7   152581.4    5138.3
         14       30.9   173195.4    5604.6
         15       31.4   196023.5    6248.9
         16       32.2   219013.0    6810.0
         17       29.5   173301.2    5869.4
         18       26.9   134054.3    4983.8


      IDNUM           DATE        SURFACE
         21          72886              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+00    0.90000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        4.2     9630.5    2315.9
          2       19.0    45935.7    2416.7
          3       25.4    63247.3    2486.4
          4       29.7    81932.2    2760.2
          5       31.3    96907.2    3095.6
          6       32.5   114006.0    3506.6
          7       34.1   133704.0    3926.7
          8       35.0   150755.3    4312.5
          9       35.9   171031.2    4765.1
         10       36.5   197619.4    5420.4
         11       36.9   216660.7    5867.3
         12       37.1   252586.1    6812.3
         13       37.5   267860.6    7133.9
         14       33.9   241134.6    7111.6
         15       31.8   214755.7    6760.8
         16       29.5   174293.0    5914.3
         17       26.8   134300.2    5007.2
         18       24.2    98480.4    4066.3
         19       23.0    82905.7    3604.3
         20       21.1    63514.9    3015.8
```

```
        IDNUM          DATE       SURFACE
           22         72986             1
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            3             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
  0.10000E+00   0.90000E+00   0.00000E+00   0.00000E+00   0.00000E+00
         NPTS
           20
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        1.8     5483.5    2984.9
            2        4.8    14879.2    3085.6
            3        9.1    28440.2    3141.4
            4       14.0    47982.3    3429.0
            5       17.7    64345.1    3629.2
            6       19.4    84653.0    4371.6
            7       20.5   107749.7    5248.5
            8       21.9   133471.3    6108.0
            9       22.2   152512.0    6871.4
           10       23.0   177466.9    7725.1
           11       23.3   201204.6    8632.3
           12       24.0   224566.4    9348.4
           13       24.7   248396.6   10053.7
           14       22.7   202326.5    8932.5
           15       20.9   152748.8    7310.8
           16       18.2   108141.8    5933.0
           17       16.8    84890.2    5049.1
           18       12.8    48304.8    3776.5
           19        8.4    28555.8    3408.6
           20        4.7    14857.6    3163.0

        IDNUM          DATE       SURFACE
           23         73086             1
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            3             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
  0.50000E-01   0.95000E+00   0.00000E+00   0.00000E+00   0.00000E+00
         NPTS
           20
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        1.8     5527.9    3093.8
            2        4.3    15184.7    3494.8
            3        8.2    28835.1    3516.2
            4       10.7    42882.0    4015.8
            5       12.7    59577.9    4704.9
            6       14.7    78293.5    5341.2
            7       16.5   102112.1    6181.6
            8       17.6   126721.7    7210.9
            9       18.2   153917.1    8463.7
           10       19.4   197633.8   10209.3
           11       20.4   249646.4   12253.5
           12       20.7   272058.5   13131.2
           13       20.3   249612.0   12312.1
           14       19.1   198087.4   10395.6
           15       18.0   155258.0    8624.9
           16       15.9   101708.4    6388.1
           17       13.0    61118.9    4691.6
           18       10.4    42715.6    4115.3
           19        7.6    28573.0    3758.4
           20        4.4    15243.3    3449.0
```

```
      IDNUM           DATE        SURFACE
         24          73186              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              3              6              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.50000E-01    0.50000E-01    0.90000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        2.4     5363.9    2200.2
          2        3.9     9387.9    2400.9
          3        6.1    14685.2    2398.2
          4       10.8    28471.6    2629.4
          5       17.7    46238.4    2615.3
          6       23.8    69317.9    2916.1
          7       27.3    90135.1    3307.5
          8       29.0   106016.1    3659.9
          9       30.2   124189.3    4106.6
         10       32.0   152358.9    4761.8
         11       32.5   173808.4    5344.2
         12       33.4   195466.6    5848.2
         13       33.8   218353.3    6462.1
         14       34.0   242308.1    7121.6
         15       34.2   270856.8    7913.6
         16       32.7   244991.7    7502.3
         17       29.7   195100.2    6574.4
         18       27.5   154297.8    5604.1
         19       24.2   105307.6    4343.2
         20       21.0    70487.8    3350.6

      IDNUM           DATE        SURFACE
         25          80186              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              3              6              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+00    0.10000E+00    0.80000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        9.5    20982.8    2207.6
          2       15.2    36560.2    2397.8
          3       19.3    46134.7    2386.6
          4       26.3    69069.1    2629.0
          5       29.8    88731.1    2978.9
          6       31.8   104062.5    3271.9
          7       32.2   120908.7    3753.3
          8       33.9   136319.1    4020.4
          9       34.1   150078.3    4406.0
         10       34.9   170763.1    4897.3
         11       35.0   194237.9    5548.6
         12       35.1   213672.7    6088.0
         13       35.8   240826.3    6725.2
         14       36.8   277001.2    7530.4
         15       33.5   239439.6    7143.4
         16       32.2   220542.6    6849.2
         17       28.5   170245.8    5974.0
         18       26.6   136763.3    5145.5
         19       23.8    98022.6    4123.4
         20       21.2    69810.6    3286.4
```

```
       IDNUM          DATE       SURFACE
          26         82186             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           1             0             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          17
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        7.5     8546.3    1137.1
           2       11.6    13781.6    1185.0
           3       14.2    20370.7    1438.7
           4       15.9    27635.8    1739.9
           5       16.8    36487.2    2165.7
           6       17.8    46036.2    2592.6
           7       18.4    53700.8    2921.9
           8       18.4    58829.0    3198.4
           9       18.9    64740.1    3425.0
          10       19.3    72868.6    3766.6
          11       19.8    83575.3    4221.6
          12       20.3    98252.6    4835.1
          13       21.4   124386.3    5808.4
          14       22.6   152025.8    6727.2
          15       24.1   183463.8    7626.5
          16       25.8   217361.7    8425.9
          17       27.7   243803.3    8797.2


       IDNUM          DATE       SURFACE
          27         82286             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           1             0             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          17
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        4.7     5042.4    1075.1
           2        8.0     8577.0    1070.0
           3       12.1    13728.7    1134.1
           4       16.0    19819.7    1239.7
           5       18.4    27177.9    1478.1
           6       20.2    35272.8    1747.8
           7       21.2    43898.2    2068.6
           8       22.0    53530.6    2429.9
           9       22.5    58336.3    2590.2
          10       23.1    64464.3    2796.2
          11       23.6    71627.1    3031.2
          12       24.0    78265.7    3256.5
          13       24.4    82372.9    3382.1
          14       25.3    97470.0    3852.4
          15       26.6   122893.2    4624.4
          16       28.0   151475.6    5414.2
          17       29.0   173654.8    5993.5
```

```
       IDNUM          DATE       SURFACE
          28         82586             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           1             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          19
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        5.1     5089.7     1000.0
           2        9.0     8611.5      952.6
           3        9.8    14466.8     1476.2
           4       10.7    21240.3     1979.9
           5       11.5    28387.6     2478.5
           6       12.2    37525.9     3078.3
           7       13.3    48780.3     3678.0
           8       14.0    59677.9     4266.6
           9       14.7    72017.0     4890.2
          10       15.4    84502.2     5499.5
          11       16.0   101160.4     6312.5
          12       16.8   124557.1     7397.1
          13       17.7   153699.1     8702.2
          14       18.6   184779.9     9909.3
          15       19.9   220526.8    11067.9
          16       20.6   245978.5    11941.4
          17       21.3   259098.8    12145.4
          18       21.9   272617.1    12468.5
          19       22.4   286563.8    12797.0

       IDNUM          DATE       SURFACE
          30         82986             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           3             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          20
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        1.9     2042.9     1069.1
           2        6.7     9049.7     1348.2
           3       10.6    14377.6     1362.7
           4       12.8    20660.4     1616.4
           5       14.3    27843.5     1942.7
           6       15.1    31843.7     2115.2
           7       15.4    36037.2     2340.0
           8       15.9    41574.7     2620.9
           9       16.2    47684.7     2939.8
          10       16.9    59310.2     3511.6
          11       17.4    71586.3     4113.0
          12       17.9    85613.4     4780.8
          13       18.6   101139.9     5452.1
          14       19.3   125748.2     6530.6
          15       20.2   154479.1     7654.5
          16       21.3   185473.1     8700.6
          17       22.4   220127.2     9848.0
          18       23.2   243720.2    10521.3
          19       24.2   269331.0    11112.3
          20       24.7   286253.1    11591.4
```

```
      IDNUM           DATE        SURFACE
         31          82986              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        4.1     4894.7     1203.8
          2        7.2     8803.4     1220.3
          3       10.8    13683.7     1266.4
          4       10.0    20396.4     2037.8
          5       10.7    24273.5     2261.8
          6       11.1    28331.4     2545.7
          7       11.8    37725.7     3186.5
          8       12.5    48654.1     3903.7
          9       13.0    59402.7     4573.2
         10       13.4    72727.3     5408.4
         11       14.0    86315.7     6164.1
         12       14.3   101400.9     7066.9
         13       15.0   127614.2     8511.9
         14       15.6   156199.5     9984.2
         15       16.4   186212.9    11363.4
         16       16.8   200508.7    11907.9
         17       17.3   220382.0    12719.9
         18       17.8   245624.0    13837.0
         19       18.3   272356.5    14849.3
         20       18.8   286760.5    15280.3

      IDNUM           DATE        SURFACE
         32          90286              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        3.9     4979.5     1279.9
          2        9.6    13702.8     1426.6
          3       12.2    20323.1     1664.5
          4       15.2    27713.1     1828.2
          5       16.7    31597.6     1888.5
          6       17.7    35625.6     2015.2
          7       19.2    40341.5     2101.6
          8       20.2    45873.2     2270.1
          9       20.9    49380.3     2364.6
         10       21.5    54373.0     2526.2
         11       21.9    57545.0     2633.4
         12       22.3    62049.1     2783.0
         13       22.9    67706.2     2955.7
         14       23.2    70970.8     3057.9
         15       23.8    77151.7     3242.8
         16       24.2    82607.3     3413.0
         17       25.1    97146.1     3877.6
         18       26.9   123545.7     4593.5
         19       28.1   151849.8     5403.9
         20       29.5   183758.9     6233.5
```

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      IDNUM          DATE        SURFACE
         33         90286              1
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3             0              0              0              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         14
         NO   SUPERHEAT   HEAT FLUX      ALPHA
          1        26.2     11942.3      455.9
          2        30.9     14882.8      480.9
          3        35.2     17282.3      491.2
          4        40.5     20367.1      502.8
          5        42.4     21405.3      504.5
          6        38.0     24856.2      654.9
          7        36.2     29747.0      822.4
          8        36.0     31541.9      877.2
          9        36.3     34081.8      937.9
         10        39.3     44269.4     1125.9
         11        40.2     55554.0     1382.3
         12        40.0     65941.1     1647.7
         13        39.9     78961.4     1977.5
         14        39.8     95133.2     2389.3
```

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      IDNUM          DATE        SURFACE
         34         90386              1
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          6             0              0              0              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO   SUPERHEAT   HEAT FLUX      ALPHA
          1         4.2     15072.7     3613.9
          2         4.4     21814.9     4930.9
          3         4.8     25344.2     5308.0
          4         5.3     29947.9     5631.6
          5         6.0     35718.8     5950.2
          6         6.5     39038.6     6047.8
          7         6.9     43656.9     6328.9
          8         7.8     49167.6     6336.1
          9         8.2     54539.2     6612.6
         10         8.9     60554.9     6837.6
         11        10.1     73074.6     7221.1
         12        10.9     87145.6     8015.4
         13        11.9    104801.2     8806.7
         14        12.6    129746.9    10274.8
         15        13.3    156955.7    11788.3
         16        14.0    188271.9    13402.1
         17        14.9    224557.1    15023.6
         18        15.5    250842.3    16193.7
         19        15.9    279746.4    17577.3
         20        16.3    302285.5    18506.1
```

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       IDNUM          DATE       SURFACE
          35         90386             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           6             0             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          20
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        4.1    14493.3    3492.6
           2        4.8    18236.9    3820.2
           3        5.2    21790.0    4190.9
           4        5.6    25321.6    4501.7
           5        6.0    29015.9    4796.6
           6        6.4    34415.3    5409.5
           7        6.6    38201.4    5756.9
           8        7.1    43679.4    6153.8
           9        7.4    48309.9    6536.4
          10        8.4    60812.6    7279.1
          11        9.0    73692.3    8219.7
          12        9.6    86647.1    9001.6
          13       10.6   103205.7    9772.1
          14       11.5   129281.7   11211.8
          15       12.5   156704.5   12520.1
          16       13.2   190003.2   14436.9
          17       13.9   223151.7   16075.3
          18       14.4   249240.8   17367.2
          19       14.9   277871.8   18645.1
          20       15.2   303288.5   19917.3

       IDNUM          DATE       SURFACE
          36         90486             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           6             0             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          20
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        4.3    21142.4    4912.5
           2        5.2    26049.4    5038.7
           3        6.0    29784.0    4989.8
           4        6.3    33531.5    5286.3
           5        7.1    38971.8    5523.6
           6        8.0    43966.2    5481.4
           7        8.6    49743.3    5780.1
           8        9.4    54745.3    5795.4
           9       10.0    60612.9    6057.8
          10       10.7    66103.3    6182.0
          11       11.1    71163.4    6435.6
          12       11.9    80176.6    6711.9
          13       12.6    86091.6    6857.4
          14       13.3   100204.5    7516.1
          15       12.9   129258.9   10034.8
          16       16.7   157686.5    9437.0
          17       17.8   188164.6   10571.9
          18       19.0   226345.8   11922.6
          19       20.4   255592.6   12555.3
          20       21.3   286148.1   13421.0
```

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          IDNUM           DATE        SURFACE
             37          90586              1
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              6              0              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
              9
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1       19.9    18460.8     927.8
              2       23.7    24220.0    1020.5
              3       24.8    25425.6    1026.3
              4       27.3    29091.8    1064.7
              5       29.4    34839.5    1186.7
              6       29.8    38592.3    1294.7
              7       30.0    44211.7    1472.8
              8       29.2    50677.3    1734.1
              9       28.0    57740.8    2060.3
```

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          IDNUM           DATE        SURFACE
             38          91086              1
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              1              3              6              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.33333E+00    0.33333E+00    0.33333E+00    0.00000E+00    0.00000E+00
           NPTS
             20
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        3.8     5533.4    1461.2
              2        9.1    14380.9    1580.2
              3       12.6    20021.6    1593.9
              4       17.8    27491.3    1547.9
              5       22.1    34498.2    1558.4
              6       24.5    40631.2    1660.5
              7       25.4    46081.9    1817.4
              8       25.4    50274.5    1977.2
              9       26.3    56832.1    2158.3
             10       27.2    61229.0    2253.0
             11       28.6    69588.5    2429.4
             12       27.9    75164.0    2693.6
             13       27.7    81377.2    2941.8
             14       28.6    89637.8    3136.4
             15       28.7    98277.2    3418.9
             16       29.5   121597.0    4127.7
             17       30.2   151123.1    5011.6
             18       31.2   179202.3    5746.3
             19       32.3   211903.4    6558.6
             20       33.2   240353.1    7231.3
```

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       IDNUM          DATE        SURFACE
          41         91186              1
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           1             3              6              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.33333E+00   0.33333E+00    0.33333E+00    0.00000E+00    0.00000E+00
        NPTS
          16
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        4.1     4944.3     1208.6
           2       11.4    14163.9     1245.0
           3       21.4    27084.9     1263.4
           4       25.1    44953.6     1788.2
           5       27.1    56963.2     2103.4
           6       28.7    66867.7     2332.9
           7       28.4    71762.3     2531.0
           8       28.3    75087.3     2652.7
           9       28.9    83059.0     2876.4
          10       29.3    89199.0     3043.5
          11       29.4    97675.3     3319.5
          12       30.0   121072.1     4034.0
          13       30.6   149430.8     4876.7
          14       31.5   180654.4     5739.5
          15       33.0   216276.9     6548.0
          16       34.1   249037.7     7313.3
```

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       IDNUM          DATE        SURFACE
          42         91286              1
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           1             3              6              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.33333E+00   0.33333E+00    0.33333E+00    0.00000E+00    0.00000E+00
        NPTS
          11
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1       12.0     4712.0      392.1
           2       19.2     8516.0      444.3
           3       26.4    12322.9      467.0
           4       34.8    17165.4      493.9
           5       46.1    24298.1      526.7
           6       57.1    31024.8      543.5
           7       50.5    37233.6      737.0
           8       51.3    42176.0      822.0
           9       51.3    53638.9     1046.0
          10       50.4    66300.9     1315.7
          11       49.3    80635.2     1636.7
```

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      IDNUM           DATE        SURFACE
         43          91586              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.20000E+00    0.80000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         17
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        3.3     5736.5    1746.1
          2        7.9    14358.0    1828.9
          3       14.8    28395.4    1921.4
          4       18.0    36682.5    2035.5
          5       20.3    41852.8    2060.6
          6       22.7    47934.0    2112.2
          7       25.9    56142.2    2170.9
          8       30.0    68480.2    2280.7
          9       31.6    80440.0    2544.1
         10       34.6    95613.7    2764.3
         11       37.6   109725.8    2918.9
         12       38.6   120510.5    3120.7
         13       39.3   148554.4    3782.6
         14       38.7   180044.5    4654.7
         15       39.1   213521.2    5457.7
         16       39.5   238779.8    6041.5
         17       40.7   267251.8    6566.1
```

```
      IDNUM           DATE        SURFACE
         44          91586              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.20000E+00    0.80000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         11
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        7.5    14837.5    1965.9
          2       21.5    45532.7    2121.7
          3       31.7    81148.3    2558.8
          4       34.7    97621.6    2815.3
          5       38.1   120481.1    3162.9
          6       37.5   148667.5    3959.5
          7       38.5   180480.3    4687.6
          8       39.2   215274.9    5493.6
          9       40.5   237347.9    5859.2
         10       40.6   264870.2    6529.0
         11       41.0   280379.8    6840.9
```

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       IDNUM           DATE        SURFACE
          46          91686              1
   COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
           1              3              6              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
 0.15000E+00    0.50000E-01    0.80000E+00    0.00000E+00    0.00000E+00
        NPTS
          15
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        2.9     5421.5     1894.0
           2        7.3    14627.1     1990.4
           3       13.7    28318.8     2062.7
           4       21.1    45625.6     2163.9
           5       25.2    56848.9     2257.5
           6       28.2    68357.0     2423.8
           7       30.7    80242.4     2614.2
           8       33.5    95775.0     2857.9
           9       35.8   121848.8     3405.3
          10       37.8   146657.2     3881.3
          11       38.4   181775.6     4728.5
          12       39.0   214797.1     5502.1
          13       39.8   239600.0     6013.6
          14       40.3   263672.5     6542.5
          15       40.9   286323.3     6992.9
```

```
       IDNUM           DATE        SURFACE
          48          91786              1
   COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
           1              3              6              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
 0.50000E-01    0.15000E+00    0.80000E+00    0.00000E+00    0.00000E+00
        NPTS
          17
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        2.5     5548.1     2209.0
           2        6.4    15160.3     2379.9
           3       12.0    28860.1     2409.9
           4       17.9    46618.2     2607.6
           5       20.9    58842.5     2816.4
           6       22.7    70127.8     3083.9
           7       25.9    82749.2     3191.5
           8       27.8    96893.6     3491.0
           9       30.4   115828.6     3807.2
          10       31.5   124053.8     3942.3
          11       32.1   133151.2     4154.0
          12       32.8   150978.7     4602.2
          13       33.8   181199.4     5353.5
          14       35.0   216060.8     6176.6
          15       35.1   243017.2     6924.7
          16       35.9   270316.3     7523.3
          17       36.5   296055.3     8105.0
```

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        IDNUM           DATE        SURFACE
           50          91886              1
    COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
            3              6              0              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.31180E+00    0.68820E+00    0.00000E+00    0.00000E+00    0.00000E+00
         NPTS
           13
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        2.9     5458.2     1858.3
            2        7.2    14658.1     2036.2
            3       13.3    28491.1     2141.7
            4       19.6    47073.5     2404.8
            5       24.8    68600.7     2766.1
            6       27.1    82815.5     3052.9
            7       27.8    97019.9     3495.7
            8       27.7   123490.8     4454.8
            9       29.6   151607.9     5130.3
           10       30.3   181379.0     5991.9
           11       30.6   215481.9     7051.2
           12       30.6   243328.7     7960.5
           13       31.1   267509.3     8601.6
```

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        IDNUM           DATE        SURFACE
           51          91986              1
    COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
            3              6              0              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.20000E+00    0.80000E+00    0.00000E+00    0.00000E+00    0.00000E+00
         NPTS
           20
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        2.2     5989.3     2774.6
            2        5.4    15178.5     2813.4
            3        9.8    30298.9     3086.9
            4       14.2    48280.8     3408.2
            5       16.6    60296.9     3630.6
            6       18.9    71671.7     3786.3
            7       21.2    84399.9     3973.4
            8       22.0    98988.6     4506.6
            9       23.1   115970.3     5015.4
           10       24.1   125571.8     5209.0
           11       24.5   135677.3     5529.6
           12       25.4   152312.9     5985.6
           13       27.3   184442.6     6743.9
           14       27.8   216830.5     7813.6
           15       28.4   244233.0     8588.9
           16       29.0   267606.0     9236.0
           17       29.8   293563.1     9852.9
           18       24.5   185846.8     7581.0
           19       21.5   126233.2     5884.5
           20       18.5    84114.9     4548.4
```

```
      IDNUM           DATE        SURFACE
         53          92286              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.20000E+00    0.80000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
          8
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        6.1    15233.5    2509.8
          2       20.0    47987.2    2397.2
          3       25.0    83484.3    3336.4
          4       25.3    99477.4    3930.0
          5       25.6   125933.9    4918.5
          6       27.2   152664.9    5608.7
          7       28.4   184660.5    6502.6
          8       29.5   216644.5    7343.5
```

```
      IDNUM           DATE        SURFACE
         54          92386              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              3              6              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+00    0.20000E+00    0.70000E+00    0.00000E+00    0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        2.9     5610.7    1944.0
          2        7.3    15234.0    2088.4
          3       20.1    47459.3    2364.5
          4       23.7    58521.1    2469.7
          5       27.3    68168.4    2494.4
          6       29.5    82451.7    2796.9
          7       31.9    96954.0    3043.7
          8       32.9   122128.0    3714.3
          9       32.9   151960.9    4619.0
         10       33.8   181577.3    5373.0
         11       34.5   215238.1    6241.2
         12       35.1   239892.4    6836.3
         13       30.9   184202.5    5965.9
         14       26.9   122514.8    4549.8
         15       24.0    83966.9    3495.8
         16       22.6    69230.9    3060.4
         17       21.1    58248.9    2761.0
         18       18.9    45613.8    2409.0
```

```
       IDNUM          DATE       SURFACE
          56         92486             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           1             3             6             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.20000E+00   0.10000E+00   0.70000E+00   0.00000E+00   0.00000E+00
        NPTS
          12
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        3.8     5185.4     1368.5
           2        9.2    14175.6     1536.3
           3       17.7    27590.5     1562.4
           4       26.4    45389.1     1716.9
           5       30.2    56023.8     1852.8
           6       31.8    67530.6     2126.4
           7       30.9    82061.7     2659.4
           8       32.1    97885.0     3049.6
           9       34.0   119539.9     3516.1
          10       35.8   150249.9     4192.7
          11       35.9   182181.0     5079.6
          12       36.9   215483.6     5834.2
```

```
       IDNUM          DATE       SURFACE
          57         92586             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           1             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.30000E+00   0.70000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          14
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        3.4     5471.7     1591.9
           2        8.5    14536.7     1705.3
           3       16.0    27951.0     1746.2
           4       20.3    47022.1     2313.5
           5       23.0    57174.9     2482.7
           6       24.6    68545.4     2783.5
           7       28.1    81904.0     2916.4
           8       30.0    97780.2     3256.8
           9       31.8   122167.6     3847.2
          10       32.6   150903.2     4628.0
          11       33.3   183298.5     5511.5
          12       34.8   216361.1     6216.6
          13       36.0   243781.1     6769.1
          14       36.6   267326.2     7303.8
```

```
      IDNUM           DATE        SURFACE
         59         100186              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.40000E+00    0.60000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        3.7     5165.0     1400.0
          2        9.4    14299.7     1517.0
          3       17.6    28316.7     1606.2
          4       21.7    46355.4     2140.7
          5       23.5    56720.1     2418.0
          6       24.5    70521.9     2879.9
          7       25.1    82860.0     3300.9
          8       27.2    96878.5     3561.1
          9       28.5   120905.6     4244.0
         10       29.3   152304.8     5203.1
         11       31.0   182394.6     5876.4
         12       32.3   217154.7     6723.4
         13       30.0   183352.5     6115.4
         14       24.7   122772.9     4980.5
         15       20.6    84461.4     4092.0
         16       17.7    57876.4     3260.7
         17       16.2    46024.4     2839.8
         18       13.5    28938.6     2135.7


      IDNUM           DATE        SURFACE
         61         100286              1
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              3              6              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.30000E+00    0.10000E+00    0.60000E+00    0.00000E+00    0.00000E+00
       NPTS
         19
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        4.3     5198.2     1198.0
          2       11.2    13778.5     1232.5
          3       20.5    26272.0     1283.5
          4       26.2    34397.4     1311.0
          5       23.6    46564.3     1972.8
          6       22.8    58639.6     2566.9
          7       25.1    69286.5     2760.9
          8       28.2    83512.3     2959.1
          9       29.4   104624.7     3558.5
         10       30.8   122231.9     3968.0
         11       32.2   150025.6     4664.6
         12       32.3   181171.9     5613.9
         13       33.3   215836.0     6489.9
         14       34.0   240647.1     7070.4
         15       30.7   182186.0     5936.3
         16       25.1   123884.5     4927.2
         17       21.3    84515.2     3969.6
         18       17.7    57876.4     3260.7
         19       13.8    27928.3     2026.5
```

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     IDNUM         DATE      SURFACE
        63       100386            1
 COMPONENT    COMPONENT    COMPONENT    COMPONENT    COMPONENT
         1            3            6            0            0
  FRACTION     FRACTION     FRACTION     FRACTION     FRACTION
0.20000E+00  0.20000E+00  0.60000E+00  0.00000E+00  0.00000E+00
      NPTS
        19
        NO SUPERHEAT  HEAT FLUX     ALPHA
         1       3.4     5018.8    1480.3
         2       8.6    14400.3    1669.5
         3      16.3    27508.0    1684.0
         4      24.5    44878.1    1828.8
         5      25.7    57924.2    2251.7
         6      26.5    68480.0    2584.0
         7      28.4    82058.0    2886.1
         8      30.2    96696.6    3201.2
         9      31.0   122352.3    3949.6
        10      31.2   150905.4    4839.6
        11      33.0   179027.0    5431.3
        12      32.7   214768.8    6559.9
        13      33.8   239477.8    7091.7
        14      34.9   273167.2    7819.1
        15      27.3   181649.7    6643.2
        16      23.7   122152.5    5163.9
        17      20.5    84058.5    4101.7
        18      17.8    58606.8    3288.9
        19      13.1    27603.3    2113.7

     IDNUM         DATE      SURFACE
        67       100786            1
 COMPONENT    COMPONENT    COMPONENT    COMPONENT    COMPONENT
         1            3            6            0            0
  FRACTION     FRACTION     FRACTION     FRACTION     FRACTION
0.10000E+00  0.30000E+00  0.60000E+00  0.00000E+00  0.00000E+00
      NPTS
        19
        NO SUPERHEAT  HEAT FLUX     ALPHA
         1       1.8     2347.4    1280.1
         2       3.5     5121.4    1457.2
         3       5.8     8810.6    1515.4
         4       9.0    13834.0    1545.0
         5      12.8    20087.4    1571.0
         6      17.1    27012.3    1578.4
         7      21.2    34996.5    1648.2
         8      26.6    44085.1    1654.5
         9      28.0    55777.8    1991.0
        10      28.5    68869.2    2412.3
        11      28.5    81133.1    2847.9
        12      28.5    97181.4    3412.5
        13      29.7   122338.9    4115.2
        14      31.6   151367.9    4793.4
        15      31.7   183708.9    5794.4
        16      25.8   123522.5    4783.9
        17      22.3    82893.9    3725.3
        18      18.7    57394.9    3072.9
        19      10.5    28325.9    2696.7
```

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      IDNUM         DATE      SURFACE
         69       100886            1
  COMPONENT    COMPONENT    COMPONENT    COMPONENT    COMPONENT
          3            6            0            0            0
    FRACTION     FRACTION     FRACTION     FRACTION     FRACTION
0.40000E+00  0.60000E+00  0.00000E+00  0.00000E+00  0.00000E+00
       NPTS
         19
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        1.7     2186.1     1278.5
          2        3.4     5089.3     1501.4
          3        9.3    14428.8     1547.3
          4       17.0    26626.9     1564.8
          5       20.2    35426.0     1755.5
          6       23.4    45697.6     1956.3
          7       24.1    56631.7     2349.1
          8       21.6    68620.9     3180.5
          9       22.0    82502.0     3753.6
         10       23.5    98251.0     4186.2
         11       25.6   122882.4     4809.5
         12       25.7   151353.5     5900.0
         13       26.3   181218.4     6884.8
         14       21.8   123402.1     5668.0
         15       18.4    84679.3     4592.3
         16       15.6    57726.7     3712.2
         17       11.6    28644.4     2474.3
         18       10.1    21774.4     2150.7
         19        7.9    14143.0     1789.8

      IDNUM         DATE      SURFACE
         71       101086            1
  COMPONENT    COMPONENT    COMPONENT    COMPONENT    COMPONENT
          1            3            6            0            0
    FRACTION     FRACTION     FRACTION     FRACTION     FRACTION
0.10000E+00  0.40000E+00  0.50000E+00  0.00000E+00  0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        3.6     5151.0     1415.4
          2        9.8    14156.8     1451.7
          3       17.7    27211.8     1538.5
          4       25.9    43998.5     1700.7
          5       22.7    56772.4     2497.4
          6       26.3    68841.5     2615.2
          7       27.3    81707.7     2991.9
          8       26.8    97339.1     3628.4
          9       28.5   107007.2     3759.9
         10       28.7   122435.2     4265.6
         11       28.0   135964.0     4854.2
         12       28.2   150646.9     5335.8
         13       29.5   180632.8     6128.2
         14       30.2   213036.1     7059.6
         15       31.2   238733.3     7658.1
         16       26.9   179632.5     6675.9
         17       22.5   122215.3     5436.7
         18       18.8    84280.0     4473.0
         19       16.2    57328.1     3532.6
         20       12.7    28600.0     2260.5
```

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       IDNUM          DATE        SURFACE
          73        101386              1
   COMPONENT     COMPONENT      COMPONENT     COMPONENT     COMPONENT
           1             3              6             0             0
     FRACTION      FRACTION       FRACTION      FRACTION      FRACTION
 0.40000E+00   0.10000E+00    0.50000E+00   0.00000E+00   0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        3.7     4933.1    1318.7
           2       10.1    13973.2    1389.9
           3       19.1    26526.5    1389.4
           4       18.9    46451.2    2457.2
           5       19.6    58238.2    2975.6
           6       20.1    70585.5    3514.0
           7       20.5    83421.4    4059.8
           8       21.4    96952.2    4534.8
           9       22.2   126802.8    5705.9
          10       24.6   154170.1    6277.6
          11       26.9   181918.6    6764.8
          12       28.3   215416.1    7609.1
          13       30.0   244551.0    8142.6
```

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       IDNUM          DATE        SURFACE
          75        101486              1
   COMPONENT     COMPONENT      COMPONENT     COMPONENT     COMPONENT
           1             6              0             0             0
     FRACTION      FRACTION       FRACTION      FRACTION      FRACTION
 0.60000E+00   0.40000E+00    0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          14
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        4.1     5429.9    1312.4
           2        9.5    14179.2    1492.2
           3       11.4    21568.4    1887.7
           4       13.0    28756.3    2207.6
           5       13.9    36455.9    2618.4
           6       15.0    49064.9    3279.6
           7       15.0    58261.6    3891.4
           8       15.3    70829.7    4618.8
           9       15.7    84610.6    5392.7
          10       16.4   100146.0    6122.4
          11       17.5   125421.4    7153.6
          12       19.3   153576.3    7941.7
          13       21.4   183399.7    8557.5
          14       23.9   219434.1    9178.5
```

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         IDNUM           DATE        SURFACE
            78         101687              1
     COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
             1              3              6              0              0
      FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
   0.20000E+00    0.60000E+00    0.20000E+00    0.00000E+00    0.00000E+00
          NPTS
            19
            NO  SUPERHEAT  HEAT FLUX      ALPHA
             1        4.5     4942.8     1094.6
             2        7.8     9064.3     1167.7
             3       11.9    14028.9     1181.1
             4       16.8    19667.8     1169.7
             5       15.1    27429.0     1812.3
             6       17.2    37186.9     2156.7
             7       17.8    47100.1     2638.8
             8       20.3    58863.1     2897.1
             9       20.3    74072.6     3651.1
            10       21.2   100131.0     4732.7
            11       21.6   123390.0     5706.8
            12       22.7   149536.8     6597.5
            13       16.0    60110.9     3748.9
            14       13.2    38645.2     2920.4
            15       11.6    28724.2     2475.9
            16        9.9    20568.8     2076.0
            17        8.3    14400.3     1745.4
            18        6.4     9507.3     1495.0
            19        4.8     6468.8     1353.2

         IDNUM           DATE        SURFACE
            80         101786              1
     COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
             1              3              6              0              0
      FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
   0.40000E+00    0.20000E+00    0.40000E+00    0.00000E+00    0.00000E+00
          NPTS
            12
            NO  SUPERHEAT  HEAT FLUX      ALPHA
             1        4.4     5079.1     1163.6
             2        7.7     9178.4     1186.4
             3       11.5    13408.4     1167.8
             4       13.2    20818.6     1579.4
             5       14.6    27506.1     1885.9
             6       16.5    37385.2     2270.4
             7       18.5    46851.0     2528.9
             8       20.0    57216.5     2856.6
             9       21.3    69309.3     3258.5
            10       22.3    84068.2     3766.7
            11       22.5    99049.2     4404.1
            12       23.0   122690.0     5328.2
```

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      IDNUM          DATE         SURFACE
         82        102186               1
  COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
          3             6               0               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
0.60000E+00   0.40000E+00     0.00000E+00     0.00000E+00     0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        3.4     5100.7     1482.9
          2        5.7     8799.4     1553.5
          3        8.3    14199.8     1710.4
          4       11.2    20600.1     1842.2
          5       13.3    27784.1     2095.7
          6       15.1    36467.4     2419.4
          7       16.8    47086.8     2798.7
          8       18.3    58146.0     3177.7
          9       19.2    70272.8     3657.4
         10       20.0    83656.6     4183.6
         11       20.5    99245.0     4832.1
         12       21.2   124652.2     5883.2
         13       21.2   151905.6     7157.1
         14       22.4   181157.3     8097.5
         15       23.6   216292.1     9153.6
         16       24.2   241456.3     9975.5
         17       17.6   124849.1     7099.1
         18       13.6    59803.0     4409.8
         19       10.6    29110.0     2746.6
         20        9.2    21243.8     2308.3

      IDNUM          DATE         SURFACE
         84        102886               1
  COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
          3             6               0               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
0.80000E+00   0.20000E+00     0.00000E+00     0.00000E+00     0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        1.9     2635.7     1382.3
          2        3.6     5456.8     1531.8
          3        5.9     9271.1     1568.5
          4        8.7    13911.6     1607.6
          5       11.1    20638.8     1862.3
          6       13.0    28264.7     2181.8
          7       14.6    37514.4     2575.6
          8       16.1    47514.5     2947.3
          9       17.5    59443.7     3389.3
         10       18.0    86190.1     4787.3
         11       18.1    99900.1     5516.6
         12       18.7   125436.7     6705.2
         13       19.6   151825.8     7756.1
         14       20.9   186217.5     8915.4
         15       22.3   220422.4     9884.2
         16       23.0   242986.9    10567.2
         17       17.8   126425.1     7102.3
         18       14.0    58345.7     4176.1
         19       10.5    28509.3     2720.9
         20        9.2    21224.9     2318.9
```

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         IDNUM          DATE       SURFACE
            86        103086             1
     COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
             1             3             6             0             0
      FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
   0.60000E+00   0.20000E+00   0.20000E+00   0.00000E+00   0.00000E+00
          NPTS
            13
            NO  SUPERHEAT  HEAT FLUX      ALPHA
             1        2.1     2533.9     1231.6
             2        4.1     5197.4     1271.0
             3        7.1     9349.7     1310.3
             4        9.8    14693.4     1503.4
             5       11.9    21162.7     1781.6
             6       13.6    28868.6     2122.6
             7       15.4    37377.4     2432.4
             8       16.4    46248.6     2814.9
             9       17.6    58890.7     3352.2
            10       18.6    85977.0     4627.3
            11       20.3   124658.0     6136.9
            12       21.9   153363.0     7006.3
            13       23.9   184599.4     7716.3
```

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         IDNUM          DATE       SURFACE
            88        103186             1
     COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
             1             6             0             0             0
      FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
   0.80000E+00   0.20000E+00   0.00000E+00   0.00000E+00   0.00000E+00
          NPTS
            16
            NO  SUPERHEAT  HEAT FLUX      ALPHA
             1        2.1     2566.6     1218.0
             2        4.0     5381.8     1332.9
             3        6.6     9339.3     1418.2
             4        8.6    14568.5     1689.2
             5       10.7    21491.7     2008.3
             6       12.5    28590.2     2286.8
             7       14.1    37728.9     2668.4
             8       16.5    59661.8     3618.6
             9       17.1    82193.9     4797.8
            10       19.1   126464.3     6629.7
            11       20.6   155217.6     7534.3
            12       22.4   186949.4     8352.7
            13       15.6    59305.1     3804.1
            14       11.9    28347.1     2381.3
            15       10.2    21222.6     2090.2
            16        8.2    14370.5     1747.0
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         IDNUM          DATE       SURFACE
            90        110386             1
     COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
             1             3             0             0             0
      FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
   0.80000E+00   0.20000E+00   0.00000E+00   0.00000E+00   0.00000E+00
          NPTS
            17
            NO  SUPERHEAT  HEAT FLUX      ALPHA
             1        2.2     2571.0     1178.2
             2        3.7     4843.6     1321.0
             3        5.6     8548.3     1522.2
             4        7.8    14273.0     1829.6
             5        9.8    20475.7     2082.3
             6       11.9    27454.6     2314.9
             7       13.6    36326.4     2676.2
             8       14.7    46473.2     3155.3
             9       15.5    57735.5     3724.7
            10       17.1    83904.4     4915.4
            11       19.3   126878.4     6583.4
            12       20.4   151985.3     7450.7
            13       21.4   174428.2     8134.3
            14       15.2    58301.1     3823.8
            15       11.4    28228.3     2480.6
            16        9.4    20243.7     2151.3
            17        7.5    13905.5     1847.0


         IDNUM          DATE       SURFACE
            92        110586             1
     COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
             1             3             0             0             0
      FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
   0.50000E+00   0.50000E+00   0.00000E+00   0.00000E+00   0.00000E+00
          NPTS
            20
            NO  SUPERHEAT  HEAT FLUX      ALPHA
             1        2.0     2545.0     1283.8
             2        3.5     4869.9     1384.9
             3        5.6     8750.9     1551.7
             4        7.4    14285.4     1923.7
             5        8.5    17444.0     2057.2
             6        9.7    21433.9     2215.0
             7       11.1    26293.2     2364.9
             8       11.7    28295.6     2417.5
             9       12.4    31417.5     2542.3
            10       13.5    36642.8     2715.0
            11       14.8    45457.0     3079.6
            12       15.6    58217.5     3732.5
            13       16.9    84704.3     5000.5
            14       17.6    98106.7     5567.5
            15       18.7   123272.4     6601.8
            16       19.9   153627.2     7705.4
            17       21.2   185863.1     8750.8
            18       15.0    58513.7     3908.6
            19       11.1    28570.4     2585.0
            20        8.8    20123.4     2277.5
```

```
       IDNUM          DATE       SURFACE
          94        110686             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           1             3             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.20000E+00   0.80000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          16
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        1.7     2008.9    1157.1
           2        3.4     4614.8    1360.1
           3        5.8     8420.0    1441.4
           4        7.4    13264.6    1784.5
           5        9.4    20123.0    2138.3
           6       11.4    27524.3    2417.7
           7       13.4    36481.3    2728.0
           8       16.3    58478.3    3588.6
           9       17.7    84462.9    4774.4
          10       19.4   122932.9    6345.0
          11       20.4   152992.1    7502.6
          12       21.5   186541.2    8662.3
          13       15.0    58176.4    3866.1
          14       10.6    27406.2    2576.9
          15        9.0    20501.8    2282.2
          16        7.4    14069.3    1913.5
```

```
       IDNUM          DATE       SURFACE
          95        110786             1
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           1             3             0             0             0
    FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.20000E+00   0.80000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        2.2     2264.0    1036.5
           2        4.4     5351.5    1205.8
           3        5.9     9031.1    1521.0
           4        7.1    14121.1    2002.3
           5        9.1    20660.7    2281.2
           6       10.6    27555.9    2609.6
           7       12.2    58708.6    4804.7
           8       12.6    83564.4    6607.4
           9       13.7   125063.8    9105.5
          10       14.3   155582.7   10861.7
          11       14.8   185160.0   12536.7
          12       15.8   242524.0   15327.6
          13       16.6   278761.3   16795.8
```

```
       IDNUM            DATE          SURFACE
          96          101586                1
   COMPONENT       COMPONENT        COMPONENT        COMPONENT        COMPONENT
           1               3                6                0                0
     FRACTION        FRACTION         FRACTION         FRACTION         FRACTION
 0.40000E+00     0.20000E+00      0.40000E+00      0.00000E+00      0.00000E+00
        NPTS
          20
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        4.7     5313.4     1121.4
           2        8.3     9409.7     1132.3
           3       12.1    14084.1     1166.1
           4       17.0    20401.4     1199.5
           5       14.6    28238.6     1936.8
           6       16.5    35448.3     2154.3
           7       18.7    45566.1     2432.2
           8       20.0    58186.9     2902.4
           9       20.9    68713.9     3283.9
          10       22.0    84850.1     3858.9
          11       22.0    98023.4     4451.1
          12       22.9   124087.6     5420.6
          13       24.7   152802.9     6181.8
          14       26.1   180764.7     6932.5
          15       26.7   194001.3     7263.7
          16       21.9   127587.8     5814.6
          17       18.2    83220.8     4579.0
          18       16.0    58491.5     3651.0
          19       12.6    28088.1     2232.6
          20       10.9    20010.1     1829.6

       IDNUM            DATE          SURFACE
          97          120486                3
   COMPONENT       COMPONENT        COMPONENT        COMPONENT        COMPONENT
           6               0                0                0                0
     FRACTION        FRACTION         FRACTION         FRACTION         FRACTION
 0.10000E+01     0.00000E+00      0.00000E+00      0.00000E+00      0.00000E+00
        NPTS
          17
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        0.9     4540.7     5093.5
           2        1.5     9275.4     6368.2
           3        2.3    16462.0     7070.0
           4        3.6    25402.6     7130.7
           5        4.5    35912.7     8007.6
           6        6.0    48052.8     7948.9
           7        7.3    62477.3     8601.3
           8        9.3    98704.4    10617.8
           9       11.2   141637.0    12641.5
          10       11.8   165438.9    14016.2
          11       13.1   210542.0    16047.0
          12       13.9   249332.7    17893.9
          13       14.9   296137.3    19890.6
          14       16.3   351423.5    21520.0
          15       17.0   389181.6    22958.8
          16       17.5   430493.4    24534.8
          17       17.9   465981.5    26019.1
```

```
      IDNUM          DATE        SURFACE
         98        120886              3
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3             6              0              0              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+00   0.90000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         16
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        0.9     4226.0    4477.6
          2        1.6     8969.5    5663.4
          3        2.5    15401.1    6257.3
          4        4.0    24782.8    6247.2
          5        5.5    36443.4    6619.0
          6        9.9    64230.4    6471.1
          7       12.5    97579.3    7819.2
          8       15.4   140025.3    9068.4
          9       16.5   165583.3   10033.9
         10       18.0   204880.7   11358.8
         11       19.2   247385.6   12885.8
         12       20.7   297127.9   14367.2
         13       21.8   345712.2   15842.2
         14       22.9   388821.5   17013.3
         15       23.8   429097.4   18005.5
         16       25.1   473430.7   18896.3
```

```
      IDNUM          DATE        SURFACE
         99        120986              3
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3             6              0              0              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.50000E-01   0.95000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         17
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.0     4670.2    4488.4
          2        1.9     9434.1    5084.8
          3        3.0    16199.7    5481.4
          4        4.6    25021.2    5421.4
          5        6.3    36258.3    5771.5
          6        7.7    48912.0    6340.8
          7       10.3    64997.0    6298.1
          8       13.9    99374.9    7128.1
          9       16.1   142627.4    8860.6
         10       16.9   166433.1    9821.4
         11       18.3   204078.8   11171.3
         12       19.6   247828.2   12663.7
         13       21.1   298605.7   14155.2
         14       22.3   349428.4   15655.5
         15       23.1   390123.3   16892.6
         16       23.7   430464.2   18165.8
         17       24.7   474040.8   19211.6
```

```
          IDNUM           DATE        SURFACE
            100         121086              3
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              3              6              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.20000E+00    0.80000E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
             16
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        1.2     4731.7    4061.3
              2        1.9     9110.9    4839.2
              3        3.3    16501.9    4958.3
              4        4.8    25246.9    5244.9
              5        6.9    36554.5    5274.8
              6        9.3    48384.0    5192.7
              7       12.1    64466.8    5339.3
              8       15.3    98621.5    6447.2
              9       17.5   141840.9    8115.6
             10       19.9   202318.2   10150.9
             11       21.4   247982.5   11591.3
             12       22.7   293364.0   12947.0
             13       23.8   349660.0   14665.0
             14       24.6   387327.9   15719.5
             15       25.7   427326.1   16631.0
             16       26.7   473858.4   17730.2
```

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          IDNUM           DATE        SURFACE
            101         121186              3
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              3              6              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.30000E+00    0.70000E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
             15
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        1.2     4916.0    3968.7
              2        2.0     9366.3    4612.0
              3        3.6    16501.9    4644.3
              4        5.6    26121.5    4679.5
              5        7.6    36207.6    4759.4
              6       10.6    48257.0    4533.9
              7       13.6    62720.3    4624.8
              8       17.1    98732.0    5758.3
              9       19.6   141941.3    7250.4
             10       21.8   201222.6    9213.8
             11       23.0   249352.9   10849.1
             12       24.5   295990.1   12061.8
             13       26.1   348928.0   13344.1
             14       27.0   387352.5   14365.1
             15       28.0   427580.8   15274.7
```

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      IDNUM          DATE        SURFACE
        102        121286              3
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3             6              0              0              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.50000E+00   0.50000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         15
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        1.4     4916.0     3604.9
          2        2.4     9665.6     4021.2
          3        4.2    16234.9     3907.2
          4        6.2    25786.1     4186.3
          5        8.9    35525.5     4008.4
          6       11.6    47993.8     4147.9
          7       15.3    62342.8     4077.5
          8       19.4    98452.3     5081.9
          9       21.3   138005.4     6469.7
         10       24.2   201118.7     8322.8
         11       25.5   245921.3     9640.5
         12       26.4   294160.9    11162.4
         13       28.3   349316.0    12356.1
         14       29.2   386413.7    13234.8
         15       29.7   425030.2    14305.2
```

```
      IDNUM          DATE        SURFACE
        103        121586              3
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3             0              0              0              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         13
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        1.7     5022.1     3020.1
          2        3.2    10026.5     3157.0
          3        5.1    16302.2     3225.2
          4        7.2    25586.6     3560.6
          5        8.3    36595.5     4419.9
          6        8.9    48179.0     5386.6
          7        9.5    63166.8     6625.7
          8       10.8    97785.7     9051.8
          9       12.8   142707.3    11130.5
         10       15.4   205885.1    13408.6
         11       16.9   249177.8    14713.7
         12       18.4   295485.0    16021.4
         13       20.2   350186.6    17302.4
```

```
       IDNUM          DATE       SURFACE
         104        121886             3
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           3             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.60000E+00   0.40000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          15
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        1.6     4999.8    3148.3
           2        2.7     9366.3    3461.5
           3        4.6    16689.1    3666.5
           4        6.6    25346.1    3818.4
           5        9.7    36436.0    3744.3
           6       12.8    49661.0    3869.7
           7       16.5    63099.0    3833.7
           8       21.8    98829.2    4529.2
           9       25.1   138912.3    5529.0
          10       26.1   200457.1    7681.9
          11       27.0   243816.0    9038.7
          12       28.2   294386.9   10438.8
          13       28.9   345574.2   11937.6
          14       30.1   386413.7   12849.7
          15       31.7   432122.5   13649.2
```

```
       IDNUM          DATE       SURFACE
         105        121986             3
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           3             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.70000E+00   0.30000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          14
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        1.9     5393.3    2823.4
           2        3.0     9482.0    3181.9
           3        5.1    16070.7    3131.9
           4        7.8    25869.4    3312.8
           5       11.0    37355.3    3380.8
           6       14.8    48657.4    3289.7
           7       17.8    61725.6    3459.1
           8       22.3    98355.3    4400.9
           9       22.2   139244.6    6280.3
          10       24.1   202213.0    8405.6
          11       25.1   251036.3    9992.9
          12       25.9   294536.8   11372.0
          13       27.9   348059.5   12473.1
          14       29.1   386221.3   13284.5
```

```
     IDNUM          DATE       SURFACE
       106        121986             3
 COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
         3             6             0             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.85000E+00   0.15000E+00   0.00000E+00   0.00000E+00   0.00000E+00
      NPTS
        14
        NO  SUPERHEAT  HEAT FLUX      ALPHA
         1        1.7     4894.0     2855.5
         2        2.9     9136.5     3197.3
         3        5.0    16736.4     3380.1
         4        7.2    24346.3     3372.0
         5       10.2    35912.7     3517.5
         6       12.0    47654.9     3980.2
         7       14.4    97592.3     6798.8
         8       16.1   139924.1     8708.9
         9       18.6   203696.0    10968.6
        10       20.1   247250.6    12286.2
        11       22.1   300131.0    13559.8
        12       23.5   344324.5    14663.0
        13       25.3   394538.8    15587.2
        14       26.2   429151.5    16360.4
```

```
     IDNUM          DATE       SURFACE
       107         10687             3
 COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
         1             6             0             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.15000E+00   0.85000E+00   0.00000E+00   0.00000E+00   0.00000E+00
      NPTS
        12
        NO  SUPERHEAT  HEAT FLUX      ALPHA
         1        1.3     4977.5     3719.4
         2        2.4     9305.7     3949.3
         3        4.0    16527.0     4128.7
         4        6.0    25757.2     4268.1
         5        8.7    36476.0     4214.1
         6       11.4    49847.5     4389.2
         7       13.8    61339.8     4445.9
         8       22.2    97108.6     4377.6
         9       28.4   141389.9     4973.1
        10       33.6   201118.7     5978.6
        11       35.7   247130.4     6932.1
        12       37.1   291434.0     7845.2
```

```
      IDNUM          DATE       SURFACE
        108         12087             3
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
          1             6             0             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.25000E+00   0.75000E+00   0.00000E+00   0.00000E+00   0.00000E+00
       NPTS
          9
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.4     4556.7    3334.9
          2        2.6     9305.7    3570.5
          3        6.4    25147.7    3905.3
          4       10.8    47731.2    4400.2
          5       21.1    96566.4    4574.0
          6       30.0   140283.8    4673.9
          7       34.8   202629.6    5826.2
          8       36.1   245020.2    6784.3
          9       34.7   294235.9    8472.7
```

```
      IDNUM          DATE       SURFACE
        109         12087             3
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
          1             6             0             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.40000E+00   0.60000E+00   0.00000E+00   0.00000E+00   0.00000E+00
       NPTS
          9
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.3     4418.9    3354.3
          2        2.6     9690.9    3795.2
          3        6.1    24972.4    4066.8
          4       11.1    48990.8    4418.3
          5       19.8    96097.6    4861.9
          6       24.5   137572.3    5613.1
          7       28.5   198707.8    6976.4
          8       29.0   246241.5    8489.1
          9       30.1   290469.0    9664.5
```

```
      IDNUM           DATE        SURFACE
        110          13087              3
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.60000E+00    0.40000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         10
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.2     4159.9    3483.1
          2        2.9     9989.6    3473.2
          3        6.8    26020.6    3836.2
          4       12.4    49522.6    3982.7
          5       21.7    97410.7    4482.6
          6       22.5   139142.7    6184.8
          7       24.9   200457.1    8044.1
          8       25.4   244273.2    9609.0
          9       26.7   293233.9   10999.1
         10       28.5   340088.6   11916.7
```

```
      IDNUM           DATE        SURFACE
        111          13087              3
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         11
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.7     4561.9    2658.0
          2        3.3     9512.6    2856.9
          3        7.9    25778.1    3279.8
          4        9.3    46872.9    5038.0
          5       10.9    79588.5    7276.8
          6       11.7    96758.1    8244.9
          7       13.8   136454.0    9911.4
          8       17.1   201687.2   11770.0
          9       18.9   243845.3   12919.3
         10       20.8   294517.8   14142.3
         11       22.5   347007.9   15413.9
```

```
      IDNUM         DATE      SURFACE
        112        13087            3
  COMPONENT    COMPONENT    COMPONENT    COMPONENT    COMPONENT
          1            3            6            0            0
   FRACTION     FRACTION     FRACTION     FRACTION     FRACTION
0.10000E+00  0.10000E+00  0.80000E+00  0.00000E+00  0.00000E+00
       NPTS
         11
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.2     4621.2    3963.7
          2        2.1     8992.9    4214.9
          3        3.7    16229.4    4380.2
          4        5.6    24533.4    4405.5
          5       10.6    47587.1    4489.9
          6       16.5    77700.4    4701.6
          7       20.8    99291.4    4764.0
          8       28.2   138651.1    4912.1
          9       34.2   200442.2    5866.0
         10       37.4   244562.2    6544.5
         11       38.3   293885.1    7677.3
```

```
      IDNUM         DATE      SURFACE
        115        31087            5
  COMPONENT    COMPONENT    COMPONENT    COMPONENT    COMPONENT
          4            0            0            0            0
   FRACTION     FRACTION     FRACTION     FRACTION     FRACTION
0.10000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
       NPTS
         19
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        2.6     1665.9     631.4
          2        5.6     4072.6     721.3
          3        8.1     9420.7    1158.2
          4       10.3    16145.8    1565.8
          5       12.1    23771.3    1967.3
          6       13.5    33197.9    2460.5
          7       14.2    41343.2    2909.4
          8       14.7    49229.9    3359.3
          9       15.7    63604.8    4056.6
         10       16.6    79524.7    4785.5
         11       17.5    99573.5    5689.2
         12       18.2   118865.5    6516.0
         13       19.0   141547.0    7456.5
         14       19.4   159571.0    8233.1
         15       19.8   178781.9    9042.1
         16       20.7   225167.6   10866.1
         17       22.3   273856.6   12304.9
         18       22.8   292597.5   12833.5
         19       24.3   326407.8   13411.7
```

```
       IDNUM          DATE       SURFACE
         120         32087             7
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           6             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          20
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        0.4     2647.8     6937.1
           2        1.1     5503.6     4840.8
           3        2.1     9897.7     4643.5
           4        3.2    15048.1     4745.6
           5        4.3    21375.6     4939.9
           6        5.4    25924.0     4760.4
           7        5.6    29413.3     5209.0
           8        7.2    38330.5     5334.9
           9        8.4    48575.1     5773.1
          10        9.9    60186.4     6104.9
          11       11.1    73565.7     6647.8
          12       12.0    88614.2     7377.1
          13       12.7   103332.3     8113.8
          14       13.2   118407.2     9000.2
          15       13.4   137479.3    10222.1
          16       13.9   155111.4    11197.6
          17       14.2   179495.3    12677.5
          18       14.4   197076.3    13650.8
          19       14.7   221484.2    15073.9
          20       15.4   245980.9    15922.4

       IDNUM          DATE       SURFACE
         121         32387             7
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           4             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          19
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        2.2     2328.6     1066.3
           2        4.4     4479.9     1013.8
           3        7.9     8387.3     1062.8
           4       11.0    12985.0     1182.0
           5       12.8    18973.1     1480.1
           6       13.6    23261.6     1711.8
           7       14.3    26551.2     1854.6
           8       15.7    35861.8     2291.2
           9       16.2    46550.5     2877.4
          10       16.6    57733.1     3477.7
          11       17.1    69632.8     4079.6
          12       17.4    83580.0     4804.3
          13       17.7    98138.0     5553.5
          14       18.0   116111.7     6433.9
          15       18.6   131874.2     7085.1
          16       19.3   152041.7     7888.7
          17       20.0   170666.8     8514.3
          18       20.4   181196.4     8894.5
          19       21.0   198170.6     9446.0
```

```
      IDNUM          DATE         SURFACE
        122         32487               7
  COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
         13             0               0               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.10000E+01   0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
       NPTS
         16
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.9     2136.1    1133.1
          2        4.2     4624.8    1109.6
          3        7.5     8415.1    1127.0
          4        9.9    10950.6    1100.6
          5       11.2    12893.0    1155.2
          6       12.7    15625.4    1228.7
          7       14.0    18702.2    1336.3
          8       16.6    26031.1    1566.3
          9       18.2    34908.2    1922.4
         10       19.2    45661.8    2383.3
         11       19.8    55401.3    2799.2
         12       21.0    82889.5    3956.2
         13       21.9   114005.6    5203.0
         14       22.7   131654.2    5789.7
         15       24.2   150095.5    6199.2
         16       25.0   160471.5    6415.0
```

```
      IDNUM          DATE         SURFACE
        123         32587               7
  COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
         13             4               6               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.50000E-02   0.89000E-01     0.90600E+00     0.00000E+00     0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.0     2384.0    2424.0
          2        2.4     5314.2    2225.1
          3        4.1     9011.9    2218.2
          4        6.7    14512.2    2174.2
          5        8.6    19793.7    2311.5
          6       12.3    27083.3    2195.2
          7       14.3    30367.6    2121.4
          8       17.2    35593.1    2068.9
          9       20.0    44742.7    2241.0
         10       22.0    56006.3    2544.3
         11       24.4    68083.5    2792.7
         12       25.5    82186.2    3219.0
         13       31.4   111679.1    3559.2
         14       33.4   128541.8    3847.3
         15       34.0   148952.7    4375.2
         16       34.9   166759.3    4771.8
         17       15.4    35979.0    2332.3
         18       12.7    26878.3    2118.2
```

```
       IDNUM          DATE        SURFACE
         124         32687              7
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          13             4              6              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.36000E-01   0.19000E+00    0.77400E+00    0.00000E+00    0.00000E+00
        NPTS
          12
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        4.1     5180.8     1259.3
           2       10.4    12713.8     1224.0
           3       15.2    18540.7     1222.1
           4       20.6    24564.5     1190.7
           5       26.6    32657.7     1226.6
           6       22.4    43028.7     1918.6
           7       27.0    55191.9     2040.9
           8       32.5    79081.6     2436.8
           9       33.3    96524.9     2900.2
          10       32.2   111684.0     3473.6
          11       33.6   129344.9     3854.7
          12       33.2   147383.9     4435.2
```

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       IDNUM          DATE        SURFACE
         125         32687              7
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          13             4              6              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.14300E+00   0.32800E+00    0.52900E+00    0.00000E+00    0.00000E+00
        NPTS
          17
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        3.8     5000.2     1302.0
           2        9.8    12883.6     1316.5
           3       13.9    19117.3     1371.1
           4       18.6    25396.1     1367.3
           5       19.5    34578.0     1774.5
           6       20.6    45056.7     2183.1
           7       23.1    55186.8     2389.7
           8       25.9    81649.6     3154.3
           9       26.5    96461.6     3642.4
          10       26.5   112746.5     4259.4
          11       26.5   130659.6     4921.9
          12       26.9   148281.8     5507.3
          13       27.8   169338.4     6090.5
          14       19.0    55881.8     2942.9
          15       16.3    35928.7     2210.8
          16       12.1    19808.2     1642.1
          17        9.5    13259.8     1401.9
```

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        IDNUM          DATE        SURFACE
          126         32787              7
    COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           13             4              6              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
  0.92000E-01   0.82900E+00    0.79000E-01    0.00000E+00    0.00000E+00
         NPTS
           16
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        4.4     4790.1    1090.7
            2       10.8    13101.8    1214.9
            3       13.4    19628.7    1460.6
            4       15.3    26570.7    1732.0
            5       16.9    35543.5    2102.6
            6       17.9    45078.6    2523.5
            7       18.6    56065.8    3020.4
            8       19.7    83645.6    4236.0
            9       20.2    99940.9    4945.4
           10       20.4   115263.8    5642.5
           11       20.8   131236.5    6311.8
           12       20.9   149394.2    7142.3
           13       21.8   179230.0    8227.1
           14       18.7    57058.8    3046.3
           15       15.5    27507.8    1779.3
           16       13.0    18775.6    1447.6



        IDNUM          DATE        SURFACE
          128         33087              7
    COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
            4             6              0              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
  0.12380E+00   0.87620E+00    0.00000E+00    0.00000E+00    0.00000E+00
         NPTS
           12
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        1.9     5151.0    2762.9
            2        5.6    14557.9    2576.9
            3        7.6    20536.6    2690.5
            4       10.5    27486.0    2615.2
            5       13.4    36083.9    2697.8
            6       17.6    45142.9    2566.7
            7       20.5    56064.8    2739.9
            8       26.3    81496.4    3094.4
            9       29.3   114659.6    3912.4
           10       31.0   131176.3    4225.7
           11       29.5   149464.5    5063.8
           12       31.3   180124.1    5749.4
```

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      IDNUM          DATE       SURFACE
        130         33087             7
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
          4             6             0             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.26080E+00   0.73920E+00   0.00000E+00   0.00000E+00   0.00000E+00
       NPTS
         10
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        2.9     5017.2    1721.0
          2        7.6    13720.4    1810.1
          3       13.7    26472.3    1929.9
          4       17.1    34854.7    2034.2
          5       20.2    43970.9    2174.5
          6       22.0    55813.4    2532.5
          7       25.3    81831.0    3230.1
          8       27.1   113666.8    4199.9
          9       27.7   149898.8    5418.7
         10       28.5   178074.9    6244.2
```

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      IDNUM          DATE       SURFACE
        131         33187             7
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
         13             4             6             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.57000E-01   0.46900E+00   0.47400E+00   0.00000E+00   0.00000E+00
       NPTS
         11
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        4.1     4822.8    1178.7
          2       11.0    13199.1    1199.0
          3       16.7    26222.0    1570.8
          4       18.4    35239.8    1919.8
          5       20.6    45588.8    2217.4
          6       21.9    56665.4    2592.4
          7       23.8    82124.6    3456.9
          8       24.7   112847.2    4560.5
          9       25.4   130364.0    5137.8
         10       25.9   148741.9    5743.8
         11       27.0   179450.4    6644.1
```

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       IDNUM            DATE         SURFACE
         132           33187               7
   COMPONENT       COMPONENT       COMPONENT       COMPONENT       COMPONENT
          13               4               6               0               0
    FRACTION        FRACTION        FRACTION        FRACTION        FRACTION
 0.48000E-01     0.70400E+00     0.24800E+00     0.00000E+00     0.00000E+00
        NPTS
          12
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        4.2     4829.6     1159.1
           2       10.8    13419.2     1241.7
           3       14.2    19589.4     1383.0
           4       16.0    26978.0     1690.0
           5       17.9    35256.1     1974.4
           6       19.4    45404.4     2342.1
           7       19.8    56828.9     2869.1
           8       20.2    82824.5     4104.9
           9       20.9   116829.3     5592.1
          10       21.4   132108.2     6177.2
          11       21.9   150623.2     6875.2
          12       22.9   179432.7     7849.5
```

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       IDNUM            DATE         SURFACE
         133           40187               7
   COMPONENT       COMPONENT       COMPONENT       COMPONENT       COMPONENT
           4               6               0               0               0
    FRACTION        FRACTION        FRACTION        FRACTION        FRACTION
 0.57320E+00     0.42680E+00     0.00000E+00     0.00000E+00     0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        3.9     4898.1     1266.9
           2       10.0    12875.4     1286.1
           3       12.9    19087.7     1474.8
           4       15.5    26155.7     1685.4
           5       17.5    35012.7     1997.0
           6       19.7    46130.7     2343.9
           7       21.1    56442.5     2673.8
           8       22.6    81828.2     3619.3
           9       23.3    97708.2     4189.1
          10       23.5   114803.1     4878.8
          11       23.9   132727.0     5557.6
          12       24.3   151138.2     6224.9
          13       25.2   179257.5     7110.5
```

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      IDNUM          DATE        SURFACE
        134         40687              7
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3             0              0              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         16
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        3.6     4897.8    1345.1
          2        9.8    13361.7    1365.9
          3       13.4    19902.2    1486.6
          4       14.9    25385.6    1698.1
          5       16.8    34441.0    2048.6
          6       18.3    45393.4    2485.8
          7       18.9    56746.9    2997.3
          8       19.2    69061.5    3592.8
          9       19.5    85116.7    4373.6
         10       19.6    99591.6    5078.3
         11       19.7   114995.9    5836.0
         12       19.8   132502.6    6680.7
         13       20.1   151128.0    7517.0
         14       20.8   182005.5    8743.4
         15       21.7   216677.9    9984.5
         16       22.4   240174.3   10739.4
```

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      IDNUM          DATE        SURFACE
        135         40787              7
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3             4              6              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.93000E-01   0.98000E-01    0.80900E+00    0.00000E+00    0.00000E+00
       NPTS
         15
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        2.0     5182.6    2605.4
          2        5.5    13858.6    2517.8
          3        8.1    20052.5    2464.6
          4       11.2    27601.4    2456.9
          5       14.1    35410.2    2510.5
          6       17.0    45495.4    2678.5
          7       20.4    55840.9    2738.8
          8       22.4    67717.8    3018.9
          9       24.1    83020.4    3451.9
         10       26.4    97665.1    3696.0
         11       29.2   114997.4    3937.6
         12       30.8   129793.8    4210.3
         13       31.4   150419.3    4796.6
         14       32.1   180349.4    5626.7
         15       31.9   214968.8    6730.8
```

```
        IDNUM           DATE        SURFACE
          136          40887              7
    COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
            3              4              6              0              0
      FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
  0.53000E-01    0.14500E+00    0.80200E+00    0.00000E+00    0.00000E+00
         NPTS
           13
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        2.8     5119.0     1802.7
            2        7.1    13977.3     1967.7
            3       10.0    20375.1     2030.6
            4       12.6    27477.4     2174.7
            5       15.2    35283.9     2328.0
            6       17.6    45093.2     2563.8
            7       21.2    57010.4     2694.8
            8       27.0    82414.0     3049.0
            9       27.2    96716.7     3561.5
           10       28.7   112678.7     3919.8
           11       29.2   132154.2     4520.3
           12       29.6   149401.0     5048.7
           13       30.3   179425.1     5929.6
```

```
        IDNUM           DATE        SURFACE
          137          40887              7
    COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
            3              4              6              0              0
      FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
  0.24000E+00    0.60000E-01    0.70000E+00    0.00000E+00    0.00000E+00
         NPTS
           14
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        2.8     5718.0     2071.4
            2        6.3    13695.8     2180.8
            3        9.1    19979.6     2186.7
            4       12.2    27015.0     2207.4
            5       15.1    35418.5     2348.7
            6       18.3    45381.9     2481.8
            7       20.9    57771.3     2770.7
            8       25.1    81108.7     3236.1
            9       28.2   112779.9     3996.5
           10       28.7   130992.7     4557.2
           11       29.2   151656.6     5198.0
           12       29.2   179255.4     6136.7
           13       29.4   214071.7     7282.7
           14       30.3   236548.9     7809.7
```

```
     IDNUM          DATE       SURFACE
       138         40987             7
 COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
         3             4             6             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.61000E-01   0.33000E-01   0.90600E+00   0.00000E+00   0.00000E+00
      NPTS
        18
        NO  SUPERHEAT  HEAT FLUX     ALPHA
         1        1.7     5516.1    3175.9
         2        4.8    14824.3    3090.0
         3        6.2    21784.2    3485.9
         4        9.0    27881.4    3095.5
         5       11.5    37158.6    3226.1
         6       14.4    46109.7    3211.9
         7       16.4    57306.2    3488.2
         8       21.4    82826.7    3865.5
         9       24.7    98452.1    3982.8
        10       26.0   114787.7    4413.9
        11       27.4   132416.8    4826.7
        12       28.4   150476.6    5292.1
        13       30.5   180654.3    5927.8
        14       31.8   214207.4    6742.8
        15       19.8    83270.0    4211.1
        16       15.8    57393.4    3643.3
        17       10.9    36492.3    3333.4
        18        9.1    28445.3    3133.3


     IDNUM          DATE       SURFACE
       139         40987             7
 COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
         3             4             6             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.28400E+00   0.29600E+00   0.42000E+00   0.00000E+00   0.00000E+00
      NPTS
        13
        NO  SUPERHEAT  HEAT FLUX     ALPHA
         1        3.7     5273.6    1420.1
         2        9.2    13083.6    1428.4
         3       13.3    18926.0    1418.3
         4       16.9    26559.1    1572.4
         5       18.9    34492.9    1828.8
         6       20.6    45280.8    2202.2
         7       22.3    56985.7    2560.5
         8       24.1    82180.9    3416.1
         9       24.6    96671.6    3924.7
        10       24.9   112197.1    4510.6
        11       24.7   130814.4    5286.4
        12       25.1   148838.3    5930.8
        13       26.3   178246.1    6785.9
```

```
          IDNUM           DATE        SURFACE
            140          41487              7
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              3              4              6              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.26000E+00    0.52000E+00    0.22000E+00    0.00000E+00    0.00000E+00
           NPTS
             12
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        4.0     5306.2    1314.0
              2        9.9    13169.7    1335.8
              3       12.3    18988.3    1547.7
              4       14.5    27270.8    1879.3
              5       16.4    35455.3    2158.0
              6       18.9    56792.9    3003.8
              7       19.5    83302.5    4277.7
              8       19.8    97292.8    4907.1
              9       20.2   114839.3    5690.5
             10       20.6   130929.7    6365.2
             11       21.1   150682.1    7130.2
             12       22.1   180084.3    8146.9
```

```
          IDNUM           DATE        SURFACE
            141          41587              7
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              3              4              6              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.53000E+00    0.23000E+00    0.24000E+00    0.00000E+00    0.00000E+00
           NPTS
             11
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        3.9     5203.7    1329.5
              2       10.3    13094.0    1276.3
              3       13.2    18758.4    1418.9
              4       16.4    27806.4    1699.9
              5       17.9    35047.1    1962.6
              6       20.9    56578.1    2712.4
              7       22.3    81484.0    3652.1
              8       22.5   115239.5    5115.4
              9       23.0   130743.4    5691.7
             10       23.6   150598.2    6385.8
             11       24.6   179185.6    7288.2
```

```
     IDNUM           DATE         SURFACE
       142          42187               7
 COMPONENT      COMPONENT       COMPONENT       COMPONENT       COMPONENT
         3              4               0               0               0
   FRACTION       FRACTION        FRACTION        FRACTION        FRACTION
0.54200E+00    0.45800E+00     0.00000E+00     0.00000E+00     0.00000E+00
      NPTS
        10
        NO  SUPERHEAT  HEAT FLUX     ALPHA
         1        4.3     4077.9     943.6
         2       12.2    12380.2    1017.7
         3       14.7    19248.8    1305.7
         4       16.1    26650.0    1653.7
         5       17.0    34714.7    2040.8
         6       18.0    46356.9    2578.3
         7       18.4    57085.5    3101.6
         8       19.2    84110.1    4388.0
         9       20.3   113369.1    5587.2
        10       20.8   131441.8    6322.1
```

```
     IDNUM           DATE         SURFACE
       143          42287               7
 COMPONENT      COMPONENT       COMPONENT       COMPONENT       COMPONENT
         3              0               0               0               0
   FRACTION       FRACTION        FRACTION        FRACTION        FRACTION
0.10000E+01    0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
      NPTS
        13
        NO  SUPERHEAT  HEAT FLUX     ALPHA
         1        4.4     4491.9    1016.5
         2        8.1     8289.9    1027.5
         3       12.2    12794.0    1049.9
         4       17.3    26257.7    1516.2
         5       18.7    34487.7    1840.7
         6       19.7    57270.3    2906.5
         7       19.8    69355.0    3494.8
         8       19.9    82858.9    4163.4
         9       20.2   113272.1    5596.0
        10       20.4   131436.0    6437.9
        11       20.8   149306.0    7189.4
        12       21.7   170030.5    7844.9
        13       22.2   179185.7    8067.5
```

```
       IDNUM          DATE         SURFACE
         144         42387               7
   COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
           3             0               0               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.10000E+01   0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        3.5    56214.5   16124.8
           2       10.3    13283.6    1285.5
           3       13.9    19591.3    1405.5
           4       16.1    24765.3    1537.9
           5       17.8    34155.1    1920.0
           6       19.0    44974.2    2368.4
           7       19.5    57156.4    2937.9
           8       19.7    69793.4    3544.2
           9       20.0    84911.3    4248.2
          10       20.2   114896.2    5693.5
          11       20.5   132540.9    6470.7
          12       20.8   150439.4    7246.8
          13       21.4   182215.8    8528.8
```

```
       IDNUM          DATE         SURFACE
         145         42487               7
   COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
           6             0               0               0               0
    FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.10000E+01   0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
        NPTS
          12
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        1.1    11211.4    9770.5
           2        3.4    14988.8    4413.2
           3        4.8    21220.6    4441.1
           4        6.0    29325.4    4849.4
           5        7.4    37702.9    5119.7
           6        8.7    48246.0    5551.1
           7       10.3    59850.7    5818.6
           8       12.2    87612.7    7199.6
           9       13.6   119570.0    8809.4
          10       14.7   155263.0   10579.2
          11       16.0   197481.0   12335.5
          12       17.0   245679.3   14472.3
```

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      IDNUM           DATE        SURFACE
        150         120386              3
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          6              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        0.8     4007.8    5038.6
          2        1.4     9106.7    6469.0
          3        2.3    16116.7    7065.6
          4        3.4    24728.5    7183.5
          5        4.8    36317.5    7594.9
          6        6.1    48636.4    8018.0
          7        7.0    61946.0    8890.6
          8        8.2    80494.0    9869.7
          9        9.1    98036.2   10742.4
         10       10.8   141023.1   13077.4
         11       11.4   165059.4   14439.4
         12       12.5   203237.2   16195.1
         13       13.8   249311.0   18054.1
         14       14.7   297105.0   20271.7
         15       15.6   342305.5   21946.3
         16       16.5   396606.1   24005.5
         17       17.1   431862.7   25312.7
         18        8.8    97953.8   11160.7
         19        5.6    48843.1    8699.7
         20        4.5    36307.9    8056.1

      IDNUM           DATE        SURFACE
        151          20387              3
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              3              6              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.20000E+00    0.20000E+00    0.60000E+00    0.00000E+00    0.00000E+00
       NPTS
         14
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.4     4519.5    3247.6
          2        2.7     9451.5    3461.8
          3        4.4    16334.1    3687.7
          4        6.6    25667.6    3897.6
          5       12.6    48761.8    3857.8
          6       19.1    78865.4    4125.3
          7       23.6    96818.5    4109.4
          8       32.0   139013.7    4341.0
          9       36.9   202335.9    5486.2
         10       32.6   245783.5    7542.8
         11       33.7   293567.9    8715.8
         12       34.5   345574.2   10024.4
         13       34.4   386774.6   11253.6
         14       35.6   434517.1   12208.4
```

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        IDNUM          DATE        SURFACE
          155         51587              7
    COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
            3             0              0              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
  0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
         NPTS
           17
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        3.7     4921.0    1315.4
            2        9.5    12875.7    1353.8
            3       12.4    19854.3    1602.7
            4       14.5    26691.4    1838.8
            5       16.4    34833.8    2126.1
            6       17.8    43906.4    2470.6
            7       19.0    55787.1    2934.0
            8       19.6    69288.1    3540.4
            9       20.0    83890.7    4200.9
           10       20.3    99253.2    4886.1
           11       20.4   116121.9    5679.2
           12       20.7   130868.7    6308.5
           13       21.0   149989.1    7138.0
           14       21.6   170348.9    7887.7
           15       22.4   193694.5    8652.7
           16       22.9   211898.5    9239.3
           17       24.0   238135.8    9910.8


        IDNUM          DATE        SURFACE
          156         51887              7
    COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
            1             0              0              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
  0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
         NPTS
           14
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        4.1     4767.6    1158.0
            2       10.8    12879.8    1188.6
            3       13.4    18901.7    1405.9
            4       16.0    25915.4    1617.6
            5       17.9    34521.8    1924.7
            6       19.6    44581.3    2269.7
            7       20.7    55584.6    2680.0
            8       21.5    68678.0    3201.8
            9       21.9    82427.9    3758.7
           10       22.5    96998.5    4315.0
           11       23.0   114895.6    4994.3
           12       23.6   131517.0    5575.0
           13       24.4   149501.8    6116.8
           14       25.9   171362.2    6625.3
```

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                    IDNUM           DATE        SURFACE
                      157          51987              7
                COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
                        6              0              0              0              0
                  FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
              0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
                     NPTS
                       17
                       NO  SUPERHEAT  HEAT FLUX     ALPHA
                        1        2.1     9804.7    4653.0
                        2        3.5    15421.5    4414.5
                        3        4.8    21529.3    4461.0
                        4        6.7    29698.1    4436.1
                        5        7.7    38465.7    4989.7
                        6        9.6    48823.4    5079.2
                        7       10.4    60670.6    5816.7
                        8       11.1    72795.8    6560.2
                        9       12.4    87450.2    7069.4
                       10       13.4   100667.1    7524.4
                       11       14.1   119153.2    8465.0
                       12       14.6   136312.1    9363.9
                       13       15.4   155452.0   10061.7
                       14       15.8   175526.5   11119.1
                       15       16.4   197488.4   12053.6
                       16       17.0   220467.3   13006.8
                       17       17.6   243936.9   13869.6
```

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                    IDNUM           DATE        SURFACE
                      160         101387              8
                COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
                        6              0              0              0              0
                  FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
              0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
                     NPTS
                       20
                       NO  SUPERHEAT  HEAT FLUX     ALPHA
                        1        1.1     5773.0    5320.4
                        2        2.1     9841.6    4671.0
                        3        3.3    15751.8    4750.1
                        4        4.5    21318.3    4787.9
                        5        6.0    30200.5    5019.9
                        6        7.5    37720.2    5036.7
                        7        9.2    47877.8    5193.5
                        8       10.6    59536.3    5636.2
                        9       12.2    72862.8    5962.1
                       10       13.4    86573.3    6448.1
                       11       14.1   101731.9    7191.4
                       12       14.4   120034.9    8324.3
                       13       15.2   138218.2    9111.8
                       14       15.7   154888.6    9863.1
                       15       16.2   175756.9   10826.2
                       16       17.1   197805.2   11579.8
                       17       17.5   222318.2   12694.9
                       18       17.8   244333.5   13738.1
                       19       18.5   268318.2   14527.8
                       20       19.3   295332.8   15336.0
```

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     IDNUM          DATE       SURFACE
       161        101687             8
 COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
         8             0             0             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
      NPTS
        18
        NO   SUPERHEAT   HEAT FLUX       ALPHA
         1         2.3      2198.2       941.5
         2         5.1      4524.7       883.9
         3         8.7      8422.1       966.2
         4        10.7     12786.9      1196.5
         5        12.5     19831.6      1588.1
         6        13.3     27622.0      2079.4
         7        13.8     35749.2      2585.3
         8        14.2     45426.3      3191.0
         9        14.6     56959.0      3893.0
        10        15.0     69668.6      4646.7
        11        15.3     83834.6      5481.1
        12        15.4     97957.1      6341.3
        13        15.8    115132.9      7285.2
        14        16.1    131655.9      8170.1
        15        16.4    148565.6      9060.3
        16        16.9    169534.5     10045.0
        17        17.2    189481.8     11007.1
        18        18.1    183638.6     10171.1


     IDNUM          DATE       SURFACE
       162        101987             8
 COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
         1             0             0             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
      NPTS
        17
        NO   SUPERHEAT   HEAT FLUX       ALPHA
         1         1.8      2073.1      1161.0
         2         4.0      4802.1      1188.1
         3         7.0      8266.5      1186.4
         4        11.0     13250.5      1203.7
         5        13.7     18672.6      1365.9
         6        15.2     26877.8      1772.5
         7        16.6     36034.6      2177.2
         8        17.1     45393.7      2656.8
         9        17.6     57171.0      3256.8
        10        17.9     68664.3      3846.7
        11        18.2     83482.1      4581.2
        12        18.5     99551.6      5385.1
        13        18.7    114573.0      6116.2
        14        19.1    131541.9      6872.5
        15        19.6    149659.0      7629.8
        16        20.1    169855.9      8439.9
        17        20.9    190820.7      9149.8
```

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      IDNUM          DATE        SURFACE
        163        102087              8
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1             8              6              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.50000E-01   0.40000E-01    0.91000E+00    0.00000E+00    0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        0.9     2324.1    2557.0
          2        2.3     5625.2    2460.6
          3        3.6     9135.1    2529.2
          4        6.0    14310.6    2404.7
          5        8.7    20905.1    2394.5
          6       11.6    27613.1    2373.5
          7       14.5    35731.3    2459.5
          8       18.2    46174.2    2536.3
          9       21.6    56012.6    2594.7
         10       25.3    66927.6    2644.1
         11       29.3    80124.0    2732.7
         12       31.1    95806.4    3081.8
         13       34.5   110651.0    3211.0
         14       36.7   128827.6    3514.2
         15       35.6   148146.2    4161.4
         16       37.9   166426.5    4388.4
         17       37.3   190257.4    5096.1
         18       37.9   211421.8    5572.9


      IDNUM          DATE        SURFACE
        164        102187              8
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1             8              6              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.11000E-01   0.74000E-01    0.91500E+00    0.00000E+00    0.00000E+00
       NPTS
         14
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        3.7     4680.3    1250.5
          2        8.1     8758.0    1079.3
          3       13.5    13028.8     966.2
          4       18.2    17576.7     966.9
          5       23.6    24725.1    1048.6
          6       28.0    32099.6    1145.3
          7       31.9    42270.0    1324.8
          8       34.3    52296.8    1524.1
          9       33.9    77930.1    2301.5
         10       34.9   109838.2    3150.4
         11       35.7   127986.1    3586.1
         12       35.1   148907.4    4239.9
         13       35.8   167624.7    4683.5
         14       37.3   190518.4    5113.6
```

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      IDNUM           DATE        SURFACE
        165         102287              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              8              6              0              0
      FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.90000E-02    0.24300E+00    0.74800E+00    0.00000E+00    0.00000E+00
       NPTS
         16
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        3.0     4688.3     1540.9
          2        8.2    13204.4     1613.5
          3       11.6    19617.9     1696.4
          4       14.4    27734.4     1931.6
          5       17.0    34994.5     2054.5
          6       18.9    45359.3     2395.4
          7       21.0    55382.7     2632.0
          8       21.9    67652.3     3084.6
          9       22.4    82564.9     3689.4
         10       22.4    97029.7     4330.9
         11       22.6   112693.6     4987.4
         12       23.0   129566.9     5638.5
         13       23.5   149088.7     6332.4
         14       24.5   168252.8     6878.3
         15       25.1   188732.6     7528.3
         16       25.1   204074.2     8118.0
```

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      IDNUM           DATE        SURFACE
        166         102687              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          8              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.60000E-01    0.94000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         16
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        1.6     5500.8     3412.5
          2        3.0     9232.5     3040.9
          3        4.8    14768.1     3046.3
          4        7.0    20647.7     2957.2
          5        9.7    27465.9     2835.9
          6       12.6    37254.8     2964.4
          7       15.3    45902.3     2993.8
          8       19.4    58070.1     2997.4
          9       22.6    68924.1     3050.0
         10       26.5    82288.2     3107.5
         11       28.8    99381.8     3449.2
         12       29.1   111914.3     3849.0
         13       30.5   130319.5     4269.5
         14       30.2   147652.9     4896.7
         15       31.5   167926.5     5328.7
         16       32.3   189911.2     5882.1
```

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      IDNUM           DATE        SURFACE
        167         102787              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          8              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.15000E+00    0.85000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        2.5     5542.0     2251.3
          2        4.0     8792.0     2176.7
          3        6.3    13802.2     2206.7
          4        8.4    19951.8     2364.8
          5       10.7    27212.2     2540.4
          6       13.7    35894.1     2624.5
          7       16.9    45086.5     2665.8
          8       21.7    56468.0     2598.1
          9       22.6    68208.3     3021.0
         10       23.8    82280.8     3459.9
         11       25.0   112981.3     4524.9
         12       25.2   130599.2     5178.0
         13       25.4   147579.3     5803.5
         14       25.8   166917.8     6464.5
         15       26.3   189488.9     7200.9
         16       26.0   211394.1     8142.1
         17       26.5   236208.1     8924.8
         18       26.4   257359.4     9731.8


      IDNUM           DATE        SURFACE
        168         111287              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1              8              6              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.17500E-01    0.17500E+00    0.80750E+00    0.00000E+00    0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        2.7     4842.1     1799.0
          2        4.9    19481.6     4004.2
          3        7.4    13391.4     1807.8
          4       10.5    20040.5     1915.7
          5       14.5    28276.2     1956.2
          6       17.0    35795.1     2102.2
          7       18.5    44975.8     2429.3
          8       20.7    55386.9     2680.0
          9       23.5    68211.4     2905.3
         10       25.2    83788.4     3322.2
         11       25.2    97056.6     3847.1
         12       25.5   114315.1     4476.9
         13       25.6   129440.4     5050.4
         14       25.7   148396.7     5763.3
         15       26.1   166381.5     6362.8
         16       26.6   188247.9     7084.2
         17       27.2   212454.4     7816.4
         18       27.4   236875.5     8641.4
```

```
      IDNUM           DATE        SURFACE
        169         111387              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          6              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         19
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.0     5438.2    5650.7
          2        2.0     9269.8    4667.8
          3        3.4    15448.9    4519.7
          4        4.6    20921.1    4542.8
          5        6.7    32371.3    4812.8
          6        9.2    48340.8    5231.3
          7        9.6    59197.7    6140.5
          8       11.2    72560.5    6450.9
          9       12.1    86838.6    7177.1
         10       13.2   100796.0    7634.4
         11       14.3   117659.4    8207.1
         12       14.8   136724.1    9219.8
         13       15.5   155010.6   10031.2
         14       16.0   175766.6   10961.9
         15       16.4   195989.6   11918.2
         16       17.0   217938.0   12825.4
         17       17.1   245419.3   14349.8
         18       18.4   293594.7   15982.8
         19       18.6   326780.6   17531.2

      IDNUM           DATE        SURFACE
        170         111687              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          3              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         19
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        3.5     4692.7    1353.3
          2        6.1     7822.7    1283.3
          3        9.6    13004.9    1353.3
          4       12.2    19655.9    1615.9
          5       14.4    26034.2    1802.3
          6       16.4    34430.2    2101.1
          7       17.6    44671.1    2543.0
          8       18.1    56848.0    3135.3
          9       18.5    69980.9    3774.4
         10       18.9    83848.6    4437.6
         11       19.0    99021.0    5200.6
         12       19.3   115730.7    5981.0
         13       19.3   132386.5    6865.0
         14       19.3   150084.4    7771.6
         15       19.7   172823.2    8793.0
         16       20.1   193733.8    9657.7
         17       20.2   214151.4   10604.8
         18       20.8   238340.8   11471.6
         19       21.2   261762.5   12367.9
```

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        IDNUM           DATE         SURFACE
          171         111787               8
    COMPONENT      COMPONENT       COMPONENT       COMPONENT       COMPONENT
            8              0               0               0               0
     FRACTION       FRACTION        FRACTION        FRACTION        FRACTION
 0.10000E+01    0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
         NPTS
           18
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        4.8     4631.8      956.4
            2        8.8     8294.2      946.0
            3       11.3    13092.7     1157.7
            4       13.4    18985.2     1412.2
            5       14.7    26956.6     1832.1
            6       15.4    36574.9     2371.6
            7       16.0    45269.6     2827.2
            8       16.5    56716.5     3435.8
            9       17.1    70997.4     4161.9
           10       17.5    84584.6     4843.1
           11       17.7    97407.7     5510.6
           12       18.1   113513.6     6266.3
           13       18.5   131822.9     7120.4
           14       18.5   149561.8     8066.7
           15       18.9   171244.8     9053.1
           16       19.5   193878.4     9937.8
           17       20.3   220034.0    10864.1
           18       21.2   239018.1    11249.5


        IDNUM           DATE         SURFACE
          172         111987               8
    COMPONENT      COMPONENT       COMPONENT       COMPONENT       COMPONENT
            3              8               6               0               0
     FRACTION       FRACTION        FRACTION        FRACTION        FRACTION
 0.12200E+00    0.39000E-01     0.83900E+00     0.00000E+00     0.00000E+00
         NPTS
           15
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        2.1     5436.8     2604.6
            2        3.7     9727.6     2659.5
            3        5.8    15253.9     2643.9
            4       10.2    27495.1     2686.4
            5       12.9    36632.0     2829.5
            6       19.9    55919.5     2815.2
            7       22.9    69695.2     3037.8
            8       28.0    83552.7     2981.7
            9       29.0    94391.6     3249.6
           10       29.6   112831.5     3812.6
           11       29.4   131752.7     4475.5
           12       31.2   168372.9     5399.1
           13       32.1   211634.3     6595.8
           14       31.4   235336.9     7495.4
           15       32.3   259486.2     8026.1
```

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        IDNUM          DATE       SURFACE
          173        112087             8
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            3             8             6             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.24600E+00   0.13100E+00   0.62300E+00   0.00000E+00   0.00000E+00
         NPTS
           15
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        2.9     4956.8    1685.6
            2        5.7     9436.8    1645.5
            3        8.2    13724.8    1677.8
            4       12.1    21296.7    1756.0
            5       15.5    29820.2    1921.6
            6       21.0    44098.3    2097.9
            7       22.5    54469.4    2421.0
            8       24.4    66739.3    2739.3
            9       24.7    80138.4    3248.3
           10       25.1   112279.0    4464.6
           11       25.4   146949.3    5777.7
           12       26.3   186675.6    7088.8
           13       26.8   209212.8    7820.1
           14       26.8   234587.3    8760.6
           15       27.4   260077.0    9500.1
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        IDNUM          DATE       SURFACE
          174        112387             8
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            3             8             6             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.22500E+00   0.25100E+00   0.52400E+00   0.00000E+00   0.00000E+00
         NPTS
           16
           NO  SUPERHEAT  HEAT FLUX     ALPHA
            1        4.0     5227.5    1318.8
            2        6.6     8844.5    1337.3
            3       10.2    13725.0    1344.9
            4       14.0    19328.1    1379.0
            5       18.2    29855.0    1638.7
            6       20.9    44161.8    2108.5
            7       22.4    56461.0    2516.7
            8       23.4    67599.1    2894.1
            9       23.1    81625.3    3539.6
           10       23.4    96469.9    4130.1
           11       23.6   117871.4    4987.2
           12       24.0   130116.0    5421.5
           13       24.4   146540.5    5996.8
           14       25.1   168655.3    6730.4
           15       25.7   187119.8    7279.3
           16       26.4   209697.6    7950.7
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       IDNUM           DATE        SURFACE
         175         112487              8
   COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
           3              8              6              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
 0.40900E+00    0.91000E-01    0.50000E+00    0.00000E+00    0.00000E+00
        NPTS
          15
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        3.2     4839.8     1504.7
           2        5.8     8754.4     1512.1
           3        8.9    13782.1     1543.4
           4       12.3    19347.8     1577.3
           5       16.5    26396.5     1598.1
           6       20.3    32929.4     1618.4
           7       23.8    44977.4     1888.7
           8       24.6    54875.9     2231.1
           9       25.7    66285.8     2582.6
          10       25.7    80045.0     3118.1
          11       25.9   110862.4     4283.2
          12       26.5   147202.1     5563.8
          13       27.1   164754.1     6088.4
          14       27.7   187721.2     6770.4
          15       28.2   210425.7     7463.3
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       IDNUM           DATE        SURFACE
         176         113087              8
   COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
           3              8              6              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
 0.30300E+00    0.31000E-01    0.66600E+00    0.00000E+00    0.00000E+00
        NPTS
          16
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        1.3     2594.1     1947.5
           2        2.9     5362.8     1841.0
           3        5.2     8958.5     1726.8
           4        7.9    13616.9     1722.4
           5       11.3    19708.2     1745.8
           6       16.9    30389.8     1799.3
           7       21.2    43170.1     2033.8
           8       23.1    54873.3     2373.4
           9       25.9    68982.1     2666.2
          10       26.8    80577.7     3001.8
          11       27.5    95692.1     3481.2
          12       29.1   111400.9     3834.2
          13       28.6   128556.2     4497.2
          14       29.2   150465.2     5160.1
          15       29.8   168498.1     5657.2
          16       30.5   190229.1     6235.1
```

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       IDNUM          DATE        SURFACE
         178        122187              8
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           2             0              0              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
 0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        1.7     2175.0     1310.3
           2        7.0     9292.6     1330.2
           3       14.9    18983.3     1270.3
           4       17.7    29877.6     1686.3
           5       19.3    44738.8     2316.2
           6       20.0    54811.2     2744.6
           7       20.7    67224.1     3246.0
           8       21.1    81994.2     3889.1
           9       21.7    97568.3     4501.4
          10       22.9   120700.5     5267.3
          11       24.2   147266.0     6096.3
          12       25.1   165800.3     6598.2
          13       26.2   186669.5     7129.1
```

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       IDNUM          DATE        SURFACE
         179        122187              8
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           1             0              0              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
 0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
          15
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        1.7     2028.9     1168.7
           2        3.7     4476.8     1203.8
           3        7.4     8616.4     1165.9
           4       14.7    18436.6     1254.4
           5       18.9    29178.9     1542.0
           6       21.3    43859.1     2057.0
           7       22.1    53086.9     2404.0
           8       22.5    67180.6     2991.1
           9       22.7    82275.9     3627.5
          10       23.0    95818.0     4168.3
          11       23.0   122334.7     5312.2
          12       23.0   149049.3     6482.1
          13       23.4   167802.6     7174.3
          14       23.8   188163.9     7906.5
          15       24.7   210350.7     8517.9
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   IDNUM           DATE        SURFACE
     180         122387              8
COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
        1             2              6              0              0
  FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.55000E-01   0.39000E-01    0.90600E+00    0.00000E+00    0.00000E+00
     NPTS
       20
       NO  SUPERHEAT  HEAT FLUX      ALPHA
        1        1.0     2307.2     2344.6
        2        3.6     8721.9     2412.9
        3        8.3    19858.0     2388.9
        4       13.2    31079.7     2361.7
        5       17.1    43932.8     2566.0
        6       18.9    55135.1     2914.3
        7       20.7    67284.8     3245.0
        8       22.3    81760.3     3668.9
        9       23.9    96648.5     4038.5
       10       25.8   120524.7     4677.6
       11       27.7   149310.5     5396.6
       12       29.1   167134.0     5744.6
       13       30.8   187532.0     6093.1
       14       32.3   211352.7     6545.8
       15       27.3   149179.4     5460.8
       16       22.7    96586.8     4258.3
       17       19.7    68667.7     3490.1
       18       18.0    56269.1     3124.2
       19       15.9    44913.0     2831.1
       20       11.8    30847.4     2611.6

   IDNUM           DATE        SURFACE
     181          10488              8
COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
        1             2              6              0              0
  FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.16300E+00   0.50000E-01    0.78700E+00    0.00000E+00    0.00000E+00
     NPTS
       20
       NO  SUPERHEAT  HEAT FLUX      ALPHA
        1        5.0     8270.8     1648.3
        2       11.4    18871.2     1652.5
        3       16.7    29481.6     1760.5
        4       19.7    43446.7     2202.7
        5       21.8    54454.9     2495.3
        6       23.7    68092.0     2875.6
        7       26.2    82082.4     3132.0
        8       28.2    94572.4     3357.1
        9       30.2   120387.3     3984.0
       10       31.9   146137.8     4579.1
       11       31.5   166196.5     5280.2
       12       31.0   186961.3     6024.8
       13       32.1   207483.2     6455.6
       14       26.7   148689.2     5564.4
       15       21.9    96109.6     4386.5
       16       20.0    81310.5     4057.9
       17       18.8    68132.9     3623.4
       18       17.9    56779.6     3179.6
       19       16.7    45410.8     2721.5
       20       14.2    30326.3     2129.6
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      IDNUM          DATE       SURFACE
        182         10588             8
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
          1             2             6             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.82000E-01   0.13900E+00   0.77900E+00   0.00000E+00   0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        1.3     2918.2     2194.4
          2        5.0     8520.9     1690.3
          3       10.4    19394.2     1871.0
          4       12.8    30852.7     2412.9
          5       14.9    45425.1     3051.6
          6       16.3    56337.6     3454.1
          7       17.8    67843.8     3820.9
          8       18.2    81616.2     4475.7
          9       20.0    97211.7     4859.9
         10       21.2   122070.7     5756.5
         11       22.4   149496.4     6669.2
         12       23.1   166594.9     7204.8
         13       23.7   189704.6     8000.0
         14       20.7   150085.3     7246.3
         15       17.5    97979.6     5591.7
         16       16.2    83047.2     5118.3
         17       14.8    69211.8     4661.9
         18       14.0    57248.9     4088.0
         19       13.3    46007.2     3463.9
         20       11.7    31563.5     2707.8

      IDNUM          DATE       SURFACE
        183         10588             8
  COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
          1             2             6             0             0
   FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
0.22000E-01   0.80000E-01   0.89800E+00   0.00000E+00   0.00000E+00
       NPTS
          9
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        1.1     2475.3     2234.3
          2        4.7     9220.9     1978.2
          3       10.2    32586.3     3187.0
          4       12.0    46341.0     3860.3
          5       13.2    58464.2     4439.0
          6       14.4    70986.9     4918.0
          7       16.1    98093.9     6103.6
          8       18.6   149713.1     8053.6
          9       19.2   169972.2     8864.5
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      IDNUM          DATE        SURFACE
        184         10688              8
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          1             2              6              0              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.37600E+00   0.86000E-01    0.53800E+00    0.00000E+00    0.00000E+00
       NPTS
         19
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        2.0     2158.2     1087.2
          2        4.2     4790.8     1142.9
          3        7.3     8222.0     1123.5
          4       12.7    18386.1     1448.0
          5       14.7    29884.5     2027.0
          6       15.9    44454.4     2797.2
          7       15.2    55876.2     3678.8
          8       16.1    69426.1     4313.6
          9       16.3    81329.4     4985.7
         10       17.2    97188.8     5649.6
         11       18.7   121621.5     6509.4
         12       19.8   148540.9     7493.5
         13       20.9   167270.5     8006.0
         14       19.9   147748.8     7423.4
         15       16.6    97027.9     5861.3
         16       14.8    68984.9     4653.9
         17       13.4    46028.9     3433.3
         18       11.9    31353.3     2632.9
         19       10.7    18859.7     1759.4

      IDNUM          DATE        SURFACE
        185         11188              8
  COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
          2             5             10              8              0
   FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.74000E-01   0.50000E-02    0.40000E-02    0.91700E+00    0.00000E+00
       NPTS
         20
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1        7.4     8309.9     1124.1
          2       11.6    18888.8     1629.1
          3       14.0    30432.2     2167.6
          4       16.0    44841.7     2808.8
          5       17.1    55337.3     3232.8
          6       18.2    68093.8     3745.7
          7       19.0    81487.9     4280.6
          8       20.0    98305.8     4904.2
          9       21.3   120356.5     5659.1
         10       22.2   148843.2     6713.5
         11       22.9   167476.1     7316.0
         12       23.9   187127.6     7844.1
         13       22.4   148149.6     6606.3
         14       20.1    96632.0     4817.9
         15       19.0    81419.3     4288.2
         16       18.0    68945.4     3820.1
         17       16.6    55189.5     3321.0
         18       15.4    45246.1     2940.5
         19       12.9    30948.7     2397.1
         20       10.6    20145.4     1894.1
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          IDNUM           DATE        SURFACE
            186          11388              8
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              2              5             10              8              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.30000E+00    0.50000E+00    0.10400E+00    0.96000E-01    0.00000E+00
           NPTS
             16
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        5.1     4683.6     915.2
              2       13.3    18852.8    1412.8
              3       16.9    30567.9    1812.7
              4       18.6    45094.2    2422.7
              5       19.1    54930.6    2876.7
              6       19.9    68941.1    3469.1
              7       20.8    80430.8    3863.4
              8       21.7    95859.4    4425.2
              9       23.5   119524.8    5086.5
             10       25.6   147326.8    5764.8
             11       26.9   165666.8    6169.1
             12       25.3   145960.3    5771.3
             13       21.5    97796.3    4538.4
             14       19.1    68498.7    3586.1
             15       16.3    44804.5    2742.0
             16       14.1    30471.6    2158.9
```

```
          IDNUM           DATE        SURFACE
            187          11488              8
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              2              5             10              8              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.11900E+00    0.80200E+00    0.41000E-01    0.38000E-01    0.00000E+00
           NPTS
             19
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        4.5     4826.4    1062.7
              2        7.7     8705.4    1124.8
              3       12.2    18651.9    1532.5
              4       15.8    29967.1    1900.5
              5       18.3    44193.7    2415.7
              6       19.1    55260.9    2898.1
              7       20.1    67981.7    3377.2
              8       21.1    80874.4    3825.5
              9       22.0    95299.5    4328.7
             10       23.8   119394.1    5022.0
             11       25.5   147628.9    5794.1
             12       23.6   119730.1    5063.2
             13       21.9    96064.8    4389.4
             14       20.7    81647.2    3947.1
             15       19.3    67913.9    3522.5
             16       18.0    55799.1    3097.5
             17       16.6    44638.7    2682.4
             18       14.3    31337.1    2186.3
             19       11.2    19927.7    1773.4
```

```
      IDNUM           DATE        SURFACE
        188          11588              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
         12              3             13              4              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.20000E+00    0.20000E+00    0.20000E+00    0.40000E+00    0.00000E+00
       NPTS
         18
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        4.2     4853.9    1165.0
          2        7.4     8785.9    1185.0
          3       10.9    19094.0    1752.9
          4       14.0    31403.1    2249.9
          5       16.1    44880.3    2785.1
          6       17.0    55796.4    3289.1
          7       17.9    68345.4    3823.0
          8       18.7    81091.3    4344.8
          9       19.6    95934.4    4891.7
         10       20.9   118993.9    5686.1
         11       22.7   148975.5    6564.3
         12       23.6   165337.7    7003.9
         13       25.0   187918.2    7516.6
         14       22.6   147419.7    6535.9
         15       19.7    97333.6    4946.6
         16       17.7    70490.2    3985.3
         17       14.7    44541.9    3036.9
         18       12.4    30622.8    2476.9
```

```
      IDNUM           DATE        SURFACE
        189          20988              8
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          6              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         17
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        1.4     5474.7    3946.7
          2        3.3    11924.0    3621.5
          3        5.4    21143.7    3912.8
          4        6.7    32835.9    4866.1
          5        8.1    48185.7    5936.6
          6        8.9    58890.3    6622.3
          7        9.6    71610.9    7494.8
          8       10.5    86526.0    8239.3
          9       10.8   100677.5    9362.1
         10       11.2   118004.1   10504.3
         11       11.7   135465.9   11614.9
         12       11.9   153453.1   12853.4
         13       12.5   183516.4   14674.5
         14       12.9   217521.2   16867.9
         15       13.2   242259.4   18319.0
         16       13.7   266267.6   19459.1
         17       14.0   294862.0   21008.0
```

```
       IDNUM          DATE       SURFACE
         190         20988             3
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           6             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          12
          NO SUPERHEAT HEAT FLUX     ALPHA
           1       7.9   16365.0    2083.6
           2       9.6   36283.6    3776.8
           3      11.2   64296.8    5727.9
           4      12.2   98508.8    8092.7
           5      13.6  142157.9   10433.4
           6      14.6  188414.0   12875.3
           7      16.3  244714.9   14996.6
           8      18.6  307508.3   16506.7
           9      20.6  383243.0   18608.4
          10      21.6  424398.6   19656.1
          11      22.7  466460.4   20543.8
          12      23.3  512992.4   22005.5
```

```
       IDNUM          DATE       SURFACE
         191         21288             3
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           4             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
           8
          NO SUPERHEAT HEAT FLUX     ALPHA
           1      10.8   65155.8    6022.4
           2      11.8   83544.5    7105.3
           3      12.3   96334.9    7807.6
           4      15.2  139808.4    9217.5
           5      17.9  189726.8   10570.3
           6      20.0  246058.0   12328.7
           7      21.8  313570.3   14361.2
           8      24.0  380422.4   15873.5
```

```
          IDNUM           DATE        SURFACE
            192          21688              3
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              4              0              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
             17
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        9.6    36021.3    3758.5
              2       11.1    62399.6    5601.8
              3       15.3   135113.7    8844.1
              4       18.2   187089.7   10283.3
              5       19.7   216929.8   10984.8
              6       20.8   248342.4   11930.2
              7       21.9   277704.2   12666.4
              8       22.9   310246.2   13557.3
              9       23.8   346184.0   14534.1
             10       24.6   386052.1   15661.7
             11       25.7   431511.6   16765.1
             12       26.8   468255.7   17444.6
             13       25.0   386606.0   15451.7
             14       23.3   313743.4   13489.5
             15       21.1   241913.5   11471.2
             16       18.1   186467.2   10303.1
             17       15.7   139257.8    8857.7
```

```
          IDNUM           DATE        SURFACE
            193          21788              3
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              4              6              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.12380E+00    0.87620E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
             16
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        6.3    36824.3    5889.0
              2       11.1    64203.4    5796.7
              3       15.7    98245.6    6247.9
              4       19.5   139660.2    7173.6
              5       24.8   187743.0    7573.7
              6       26.1   216669.2    8309.4
              7       27.9   245003.7    8768.6
              8       30.5   317309.1   10409.7
              9       32.8   385690.0   11776.1
             10       34.6   440121.5   12729.4
             11       35.2   475753.7   13530.3
             12       32.8   399558.5   12163.3
             13       29.8   312416.8   10468.6
             14       26.8   248480.7    9257.8
             15       23.4   189876.7    8115.1
             16       19.0   138465.1    7305.9
```

```
          IDNUM           DATE        SURFACE
            194          21888              3
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              4              6              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.26080E+00    0.73920E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
             17
             NO  SUPERHEAT  HEAT FLUX      ALPHA
              1        7.8    35040.6     4468.7
              2       13.4    63456.1     4724.4
              3       17.2    98900.1     5743.4
              4       21.2   139909.3     6609.8
              5       24.6   190131.0     7722.3
              6       27.2   246769.5     9079.8
              7       29.4   312744.2    10631.9
              8       31.2   380422.4    12177.0
              9       32.7   423013.1    12935.6
             10       34.2   471813.4    13799.3
             11       31.1   390755.9    12548.5
             12       28.4   310713.3    10957.7
             13       25.7   244273.2     9515.4
             14       22.8   189473.3     8319.0
             15       19.0   135998.8     7140.6
             16       15.8    97036.2     6148.0
             17       12.6    62642.9     4966.8
```

```
          IDNUM           DATE        SURFACE
            195          21988              3
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              4              6              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.57320E+00    0.42680E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
             17
             NO  SUPERHEAT  HEAT FLUX      ALPHA
              1       10.0    35351.1     3539.0
              2       13.2    61216.9     4638.4
              3       15.2    94854.6     6250.9
              4       17.6   141185.4     8007.1
              5       19.7   194525.4     9867.6
              6       21.6   247130.4    11454.4
              7       23.6   308517.6    13060.7
              8       26.1   388485.3    14866.6
              9       27.6   427378.5    15502.0
             10       29.4   485224.7    16480.7
             11       26.0   380511.7    14612.4
             12       23.8   314936.3    13246.8
             13       21.1   246227.2    11665.7
             14       18.9   190414.6    10091.4
             15       16.4   139373.0     8500.5
             16       14.3    97420.9     6833.8
             17       11.8    62943.5     5352.2
```

```
       IDNUM            DATE          SURFACE
         196           30188                3
   COMPONENT       COMPONENT        COMPONENT        COMPONENT        COMPONENT
           6               0                0                0                0
     FRACTION         FRACTION         FRACTION         FRACTION         FRACTION
 0.10000E+01     0.00000E+00      0.00000E+00      0.00000E+00      0.00000E+00
        NPTS
          19
          NO   SUPERHEAT  HEAT FLUX     ALPHA
           1        21.4    63634.7    2979.8
           2        24.5    77291.4    3157.4
           3        25.6    94147.5    3684.1
           4        27.3   117031.7    4281.3
           5        28.1   137457.9    4890.0
           6        31.0   173239.4    5589.1
           7        33.1   213568.3    6457.5
           8        34.5   244207.6    7074.0
           9        35.2   294386.9    8374.9
          10        36.5   344505.8    9449.9
          11        37.5   380653.9   10140.2
          12        38.5   424196.9   11005.9
          13        37.8   386244.2   10218.7
          14        37.5   347007.9    9256.6
          15        37.3   310215.3    8320.3
          16        35.8   275305.4    7691.8
          17        33.1   212870.5    6425.7
          18        29.3   135260.0    4612.3
          19        26.9    94524.5    3510.4

       IDNUM            DATE          SURFACE
         197           30188                3
   COMPONENT       COMPONENT        COMPONENT        COMPONENT        COMPONENT
           6               0                0                0                0
     FRACTION         FRACTION         FRACTION         FRACTION         FRACTION
 0.10000E+01     0.00000E+00      0.00000E+00      0.00000E+00      0.00000E+00
        NPTS
          18
          NO   SUPERHEAT  HEAT FLUX     ALPHA
           1        15.9    48843.1    3064.3
           2        17.9    63703.0    3552.9
           3        19.1    78046.5    4091.8
           4        20.5    99669.2    4852.7
           5        21.8   139114.0    6367.4
           6        23.5   172770.9    7360.0
           7        24.9   218640.8    8768.2
           8        26.4   263814.8    9982.8
           9        27.2   295542.0   10858.4
          10        28.4   342735.6   12049.4
          11        28.9   384347.5   13316.7
          12        30.2   430953.0   14249.8
          13        30.2   383603.8   12705.3
          14        29.4   345956.4   11779.1
          15        27.6   291766.8   10573.0
          16        25.2   217921.6    8633.7
          17        22.4   138809.8    6210.7
          18        20.3    96392.8    4739.5
```

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       IDNUM          DATE        SURFACE
         198         30288              3
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           6             0              0              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
          18
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        4.8    36834.7     7669.1
           2        6.2    49868.5     8067.0
           3        7.9    62273.9     7867.7
           4        9.9    96431.6     9777.2
           5       12.1   139692.7    11551.0
           6       13.5   176008.8    13085.8
           7       14.9   213296.3    14363.4
           8       16.1   257455.7    15942.6
           9       17.0   288868.5    17000.3
          10       18.9   352364.8    18645.5
          11       19.6   387952.4    19808.3
          12       20.6   425854.1    20717.3
          13       19.2   382071.6    19921.6
          14       18.6   349173.0    18801.3
          15       18.8   318936.9    16969.3
          16       14.8   215510.4    14528.5
          17       12.0   140155.6    11689.3
          18        9.9    97613.2     9830.9


       IDNUM          DATE        SURFACE
         199         30288              3
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           6             0              0              0              0
    FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.10000E+01   0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
           8
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1       38.4   117349.1     3055.3
           2       42.5   140618.6     3309.7
           3       45.6   164637.5     3611.7
           4       47.4   190818.0     4028.6
           5       49.0   214552.0     4375.0
           6       50.3   245797.0     4888.1
           7       51.8   277880.8     5362.1
           8       52.6   307587.6     5844.5
```

```
       IDNUM          DATE       SURFACE
         200         30388             3
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           6             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          15
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1       30.9    98829.2    3193.7
           2       34.5   120364.9    3487.7
           3       36.5   137743.6    3773.0
           4       38.1   164150.1    4312.6
           5       39.7   189253.9    4769.8
           6       41.2   215811.0    5243.7
           7       42.5   246406.5    5800.5
           8       44.0   281551.0    6403.1
           9       45.0   306729.8    6818.5
          10       45.8   343780.6    7508.3
          11       43.8   287205.8    6556.6
          12       42.6   245187.5    5760.4
          13       41.1   219823.5    5351.5
          14       36.9   140976.5    3819.6
          15       31.6    98375.1    3108.4
```

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       IDNUM          DATE       SURFACE
         201         30488             3
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           4             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
           8
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1       20.4    26384.6    1294.6
           2       22.9    34905.8    1524.8
           3       25.4    47146.8    1859.7
           4       26.8    59949.9    2238.4
           5       29.0    78237.2    2698.1
           6       31.0   100572.4    3243.5
           7       32.1   118007.2    3673.0
           8       32.8   139729.1    4257.7
```

```
      IDNUM           DATE        SURFACE
        202          30488              3
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          4              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
          8
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        7.5    25643.7    3414.3
          2        8.4    37081.6    4440.3
          3        9.0    47731.2    5290.2
          4        9.9    61064.2    6168.7
          5       11.2    80277.1    7147.0
          6       12.0    94995.7    7900.8
          7       13.2   114082.1    8670.4
          8       14.5   139499.2    9624.0
```

```
      IDNUM           DATE        SURFACE
        203          31088              3
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          4              6              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.12380E+00    0.87620E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         13
         NO  SUPERHEAT  HEAT FLUX     ALPHA
          1        6.9    34224.6    4944.1
          2       12.4    64310.9    5175.9
          3       17.2    96662.3    5632.6
          4       21.9   135896.6    6206.3
          5       27.0   184405.1    6820.1
          6       30.6   243402.7    7953.6
          7       33.4   309048.3    9241.1
          8       36.9   383795.2   10389.4
          9       34.0   315300.8    9260.8
         10       30.4   246699.5    8127.6
         11       25.7   189890.2    7396.5
         12       20.6   137250.7    6675.1
         13       16.6    97517.0    5872.8
```

```
        IDNUM          DATE       SURFACE
          204         31088             3
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            4             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
  0.12380E+00   0.87620E+00   0.00000E+00   0.00000E+00   0.00000E+00
         NPTS
           11
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1       24.1    60176.4     2493.8
            2       32.3    96949.9     3003.0
            3       37.9   136795.4     3610.3
            4       43.3   189902.0     4386.0
            5       48.1   243693.4     5066.3
            6       48.8   276746.6     5670.3
            7       50.3   309031.8     6147.7
            8       46.4   244439.9     5271.5
            9       41.0   189634.2     4622.4
           10       35.9   137468.9     3828.2
           11       30.1    95991.0     3184.7
```

```
        IDNUM          DATE       SURFACE
          205         31088             3
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            4             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
  0.12380E+00   0.87620E+00   0.00000E+00   0.00000E+00   0.00000E+00
         NPTS
            8
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1       26.5    60478.4     2284.1
            2       35.9    95077.2     2644.9
            3       44.9   137240.7     3054.1
            4       51.3   185827.6     3622.2
            5       57.2   242657.5     4243.5
            6       50.9   185695.0     3651.5
            7       44.5   138144.0     3105.8
            8       36.6    94524.5     2586.0
```

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       IDNUM          DATE        SURFACE
         206         31188              3
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           4             6              0              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.26080E+00   0.73920E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
          11
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        7.6    35351.1     4658.2
           2       12.0    61514.5     5117.3
           3       17.5    96854.0     5547.2
           4       21.4   137801.0     6444.6
           5       23.9   185695.0     7760.3
           6       26.5   243111.4     9181.0
           7       28.6   312604.8    10943.0
           8       31.5   378562.4    12035.2
           9       28.0   308363.9    10994.1
          10       24.8   246380.1     9932.4
          11       21.7   187907.5     8654.4
```

```
       IDNUM          DATE        SURFACE
         207         31188              3
   COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
           4             6              0              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
0.26080E+00   0.73920E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
          11
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1       18.4    35118.5     1907.0
           2       27.3    61293.2     2245.4
           3       33.8    94800.8     2804.8
           4       36.0   137697.1     3826.7
           5       37.5   186092.7     4959.0
           6       39.5   242052.4     6122.1
           7       41.3   308038.2     7463.0
           8       38.0   246227.2     6482.8
           9       35.4   186600.3     5275.3
          10       30.9   136237.1     4406.3
          11       27.2    95448.7     3509.8
```

```
        IDNUM          DATE       SURFACE
          208         31188             3
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            4             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
  0.26080E+00   0.73920E+00   0.00000E+00   0.00000E+00   0.00000E+00
         NPTS
           10
           NO SUPERHEAT  HEAT FLUX     ALPHA
            1      22.4    40666.7    1811.5
            2      27.1    61224.0    2257.3
            3      38.2    94982.4    2483.3
            4      45.7   135801.8    2971.8
            5      48.4   187531.9    3871.4
            6      50.2   241611.5    4811.5
            7      46.3   239087.4    5165.6
            8      42.8   186234.9    4353.8
            9      39.5   138372.8    3502.8
           10      36.0    97525.3    2710.6
```

```
        IDNUM          DATE       SURFACE
          209         31488             3
    COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
            4             6             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
  0.57320E+00   0.42680E+00   0.00000E+00   0.00000E+00   0.00000E+00
         NPTS
           12
           NO SUPERHEAT  HEAT FLUX     ALPHA
            1      10.0    35693.9    3583.2
            2      12.4    61735.8    4961.0
            3      14.5    96774.1    6680.8
            4      17.3   139154.5    8044.8
            5      19.5   188453.7    9672.5
            6      21.9   243845.3   11147.5
            7      23.4   276160.5   11821.5
            8      24.6   311588.8   12653.7
            9      21.8   245644.6   11262.3
           10      19.0   188442.1    9926.6
           11      16.8   140179.3    8324.2
           12      14.5   101729.3    7028.5
```

```
         IDNUM          DATE       SURFACE
           210         31488             3
     COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
             4             6             0             0             0
       FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
   0.57320E+00   0.42680E+00   0.00000E+00   0.00000E+00   0.00000E+00
          NPTS
            11
            NO SUPERHEAT HEAT FLUX    ALPHA
             1      20.1   34670.5   1723.3
             2      22.6   62565.5   2763.7
             3      25.9   97989.3   3783.2
             4      28.1  137468.9   4894.8
             5      30.0  187520.1   6257.9
             6      31.9  242948.0   7626.4
             7      32.6  273576.6   8397.1
             8      31.5  245200.4   7774.4
             9      30.1  188987.2   6282.9
            10      28.3  137265.5   4857.0
            11      24.5   97717.1   3983.8
```

```
         IDNUM          DATE       SURFACE
           211         31688             3
     COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
             4             0             0             0             0
       FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
   0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
          NPTS
            12
            NO SUPERHEAT HEAT FLUX    ALPHA
             1       8.1   34778.5   4270.9
             2      10.3   61361.3   5973.7
             3      12.4   94989.9   7676.8
             4      14.6  135801.8   9287.3
             5      17.3  186367.1  10757.8
             6      19.8  244300.7  12340.9
             7      21.2  278853.0  13128.1
             8      22.8  313966.8  13796.7
             9      16.9  242366.5  14332.4
            10      17.3  187398.8  10822.1
            11      14.6  135906.5   9295.0
            12      11.9   92566.3   7767.9
```

```
     IDNUM        DATE     SURFACE
       212       31688           3
 COMPONENT   COMPONENT   COMPONENT   COMPONENT   COMPONENT
         4           0           0           0           0
   FRACTION    FRACTION    FRACTION    FRACTION    FRACTION
0.10000E+01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
      NPTS
        10
        NO  SUPERHEAT  HEAT FLUX     ALPHA
         1       17.2    34791.2    2020.6
         2       19.8    62805.8    3178.2
         3       21.4    95725.3    4479.8
         4       24.5   137811.2    5617.5
         5       26.7   187920.2    7028.4
         6       28.5   242366.5    8508.5
         7       29.1   279476.3    9600.3
         8       26.1   189768.1    7271.2
         9       24.4   136237.2    5590.6
        10       21.5    95543.7    4445.0
```

```
     IDNUM        DATE     SURFACE
       213       32188           8
 COMPONENT   COMPONENT   COMPONENT   COMPONENT   COMPONENT
         6           0           0           0           0
   FRACTION    FRACTION    FRACTION    FRACTION    FRACTION
0.10000E+01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
      NPTS
        14
        NO  SUPERHEAT  HEAT FLUX     ALPHA
         1        2.2     9397.6    4204.7
         2        5.1    20842.4    4082.1
         3        8.1    37039.2    4590.4
         4       10.0    60397.9    6035.4
         5       11.5    85750.6    7452.1
         6       12.9   117763.2    9156.9
         7       13.9   153085.8   10980.8
         8       15.4   193745.4   12572.7
         9       16.2   239629.6   14798.6
        10       15.1   194882.3   12882.9
        11       14.2   155231.9   10969.4
        12       12.7   118352.9    9332.7
        13       11.5    87683.5    7628.9
        14        9.9    58736.8    5921.8
```

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       IDNUM           DATE          SURFACE
         214          32188                8
   COMPONENT      COMPONENT        COMPONENT       COMPONENT       COMPONENT
           6              0                0               0               0
    FRACTION       FRACTION         FRACTION        FRACTION        FRACTION
 0.10000E+01    0.00000E+00      0.00000E+00     0.00000E+00     0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1       13.5    18838.2     1393.4
           2       18.5    34225.5     1853.7
           3       21.0    54497.8     2595.4
           4       23.0    82400.6     3585.7
           5       23.8   109442.9     4590.1
           6       25.6   146526.3     5715.5
           7       26.9   184582.2     6855.8
           8       26.7   231082.3     8654.2
           9       25.9   188994.0     7306.1
          10       26.0   146683.8     5650.3
          11       24.5   112115.6     4580.9
          12       23.0    80365.8     3495.0
          13       21.1    56081.7     2662.7
```

```
       IDNUM           DATE          SURFACE
         215          32188                8
   COMPONENT      COMPONENT        COMPONENT       COMPONENT       COMPONENT
           6              0                0               0               0
    FRACTION       FRACTION         FRACTION        FRACTION        FRACTION
 0.10000E+01    0.00000E+00      0.00000E+00     0.00000E+00     0.00000E+00
        NPTS
           7
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1       24.6    31843.7     1295.5
           2       30.7    52300.1     1704.2
           3       32.9    76809.9     2336.9
           4       34.8   107064.6     3077.9
           5       35.3   145537.6     4123.6
           6       35.8   182062.0     5079.7
           7       35.6   227840.5     6395.7
```

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       IDNUM          DATE       SURFACE
         216         32288             8
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           4             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          12
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1        7.6     8347.8     1095.9
           2       12.1    18582.0     1536.1
           3       16.0    35798.3     2240.6
           4       18.0    55700.7     3087.7
           5       19.3    82338.1     4265.0
           6       20.7   111915.3     5412.8
           7       21.5   146630.6     6808.7
           8       22.4   189354.5     8466.4
           9       21.9   148652.5     6773.3
          10       21.0   113089.3     5380.6
          11       19.7    81184.1     4128.7
          12       18.0    55573.0     3089.0
```

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       IDNUM          DATE       SURFACE
         217         32288             8
   COMPONENT     COMPONENT     COMPONENT     COMPONENT     COMPONENT
           4             0             0             0             0
     FRACTION      FRACTION      FRACTION      FRACTION      FRACTION
 0.10000E+01   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00
        NPTS
          10
          NO  SUPERHEAT  HEAT FLUX      ALPHA
           1       18.7     7264.2      387.4
           2       27.0    17955.3      665.0
           3       24.8    35037.4     1410.9
           4       27.0    54938.9     2031.4
           5       28.7    78965.6     2755.8
           6       29.6   110403.0     3731.5
           7       29.9   144859.6     4849.2
           8       29.1   109802.7     3777.8
           9       29.0    78757.4     2717.6
          10       27.5    53685.3     1951.9
```

```
       IDNUM           DATE        SURFACE
         218          32288              8
   COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
           4              6              0              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.12380E+00    0.87620E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
          14
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1        3.7     8782.0    2348.6
           2        7.9    19732.8    2501.5
           3       13.3    34810.6    2625.4
           4       17.3    56788.4    3285.9
           5       20.1    81884.8    4077.2
           6       22.1    96666.0    4372.8
           7       23.3   112827.9    4838.3
           8       24.6   130190.1    5292.4
           9       25.7   149561.1    5827.3
          10       27.2   187527.7    6906.3
          11       24.5   148063.8    6043.2
          12       22.4   113239.8    5062.8
          13       19.6    81822.5    4172.7
          14       16.6    56064.2    3380.0
```

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       IDNUM           DATE        SURFACE
         219          32288              8
   COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
           4              6              0              0              0
     FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.12380E+00    0.87620E+00    0.00000E+00    0.00000E+00    0.00000E+00
        NPTS
          13
          NO  SUPERHEAT  HEAT FLUX     ALPHA
           1       19.8    17837.1     901.9
           2       27.9    32191.6    1154.8
           3       32.9    52505.1    1595.3
           4       35.9    77171.8    2148.7
           5       37.0    90918.1    2454.2
           6       37.7   106451.1    2826.4
           7       38.2   123295.1    3227.8
           8       38.0   143366.1    3772.0
           9       38.3   177087.0    4626.7
          10       36.4   141991.9    3901.6
          11       34.4   108417.0    3149.4
          12       31.3    77788.1    2484.3
          13       28.6    52762.1    1844.2
```

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        IDNUM          DATE        SURFACE
          220         32288              8
    COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
            4             6              0              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.12380E+00   0.87620E+00    0.00000E+00    0.00000E+00    0.00000E+00
         NPTS
            7
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1       20.4    17697.2      866.3
            2       32.6    31070.6      952.1
            3       42.0    50627.7     1205.4
            4       45.9    74418.2     1620.1
            5       47.4    89280.2     1885.2
            6       48.6   106856.7     2199.3
            7       48.7   122018.4     2503.9
```

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        IDNUM          DATE        SURFACE
          221         32388              8
    COMPONENT     COMPONENT      COMPONENT      COMPONENT      COMPONENT
            4             6              0              0              0
     FRACTION      FRACTION       FRACTION       FRACTION       FRACTION
 0.26080E+00   0.73920E+00    0.00000E+00    0.00000E+00    0.00000E+00
         NPTS
           12
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        5.5     8988.0     1637.8
            2       11.2    19554.6     1747.5
            3       17.3    33833.4     1959.5
            4       20.3    56261.7     2773.4
            5       23.5    80852.6     3438.2
            6       24.5    95733.5     3909.4
            7       24.9   109605.3     4403.2
            8       25.1   127178.0     5062.7
            9       25.4   145842.7     5738.1
           10       22.4   111401.0     4966.7
           11       20.2    81352.9     4019.9
           12       17.6    57878.7     3284.0
```

```
          IDNUM           DATE        SURFACE
            222          32388              8
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              4              6              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.26080E+00    0.73920E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
             10
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1       23.4    17375.5     741.6
              2       33.1    31646.3     955.2
              3       32.8    52145.6    1590.3
              4       32.1    78117.4    2434.7
              5       33.6   107470.1    3200.3
              6       33.9   124916.2    3683.6
              7       33.5   144797.4    4325.7
              8       32.7   108944.7    3329.5
              9       29.9    79628.6    2665.5
             10       28.6    52735.6    1846.5
```

```
          IDNUM           DATE        SURFACE
            223          32488              8
      COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
              4              6              0              0              0
        FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
    0.57320E+00    0.42680E+00    0.00000E+00    0.00000E+00    0.00000E+00
           NPTS
              7
             NO  SUPERHEAT  HEAT FLUX     ALPHA
              1        7.5     7978.1    1057.4
              2       14.1    18428.5    1304.9
              3       17.8    33528.2    1879.1
              4       22.9    54523.3    2378.6
              5       27.5    79329.7    2884.6
              6       29.1    92498.7    3183.0
              7       27.6    97688.3    3542.7
```

```
        IDNUM          DATE         SURFACE
          224         32488               8
    COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
            4             6               0               0               0
     FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.57320E+00   0.42680E+00     0.00000E+00     0.00000E+00     0.00000E+00
         NPTS
            9
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1       16.2     8080.8      499.0
            2       30.4    16488.2      542.6
            3       34.6    31737.9      917.1
            4       36.8    52185.8     1418.5
            5       38.0    77600.6     2041.4
            6       38.2    91150.1     2383.3
            7       37.9   109020.1     2878.7
            8       37.1   123445.4     3327.7
            9       36.0   144251.5     4009.5
```

```
        IDNUM          DATE         SURFACE
          225         31688               3
    COMPONENT     COMPONENT       COMPONENT       COMPONENT       COMPONENT
            6             0               0               0               0
     FRACTION      FRACTION        FRACTION        FRACTION        FRACTION
 0.10000E+01   0.00000E+00     0.00000E+00     0.00000E+00     0.00000E+00
         NPTS
           13
           NO  SUPERHEAT  HEAT FLUX      ALPHA
            1        5.3    33931.4     6372.8
            2        8.5    63409.8     7432.2
            3       10.4    96949.9     9291.6
            4       12.3   138235.3    11280.6
            5       14.3   186999.5    13036.6
            6       16.3   243693.4    14996.0
            7       17.4   274045.0    15793.8
            8       18.4   312260.8    16976.0
            9       19.3   349173.0    18095.0
           10       16.5   247743.3    14973.3
           11       14.6   187386.7    12820.4
           12       12.6   136795.4    10887.1
           13       10.4    96854.0     9304.1
```

```
      IDNUM           DATE        SURFACE
        226          31688              3
  COMPONENT      COMPONENT      COMPONENT      COMPONENT      COMPONENT
          6              0              0              0              0
    FRACTION       FRACTION       FRACTION       FRACTION       FRACTION
0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
       NPTS
         11
         NO  SUPERHEAT  HEAT FLUX      ALPHA
          1       12.4    35299.3     2854.9
          2       16.9    61674.9     3656.0
          3       19.0    96384.5     5076.0
          4       21.3   138029.7     6470.9
          5       23.3   184394.9     7900.9
          6       25.6   247004.8     9667.1
          7       26.5   275482.3    10399.2
          8       25.4   242203.7     9531.2
          9       24.1   186225.2     7719.2
         10       21.9   137592.1     6294.5
         11       19.6    97901.7     4988.1
```

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