OPTIMUM FEED PLATE LOCATION IN MULTICOMPONENT DISTILLATION

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Russell Howard Foy

1959

THESIS

OPTIMUM FEED PLATE LOCATION
IN MULTICOMPONENT DISTILLATION

by

RUSSELL HOWARD FOY

A THESIS

Submitted to the College of Engineering
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Chemical Engineering

1959

To my wi

their patienc

DEDICATION

To my wife, Janet, and daughter, Beth, for their patience and understanding.

OPTIMUM FEED PLATE LOCATION

IN MULTICOMPONENT DISTILLATION

by

RUSSELL HOWARD FOY

AN ABSTRACT

Submitted to the College of Engineering
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Chemical Engineering

1959

Approved [signature]

ABSTRACT

In a multiple component distillation design, it is evident that there exists an optimum feed plate location somewhere between the inoperative conditions of top or bottom plate, except in the case of an abbreviated column such as a stripper.

The two most commonly used methods for locating the optimum feed plate are those of Gilliland and Montrose-Scheibel.

Gilliland's method consists of choosing the feed plate so that the ratio of the key components on the feed plate is equal to the ratio of the key components in the feed. The method has been checked by far too few problems because of the long and tedious plate to plate calculations required. Several problems involving eleven plates have been checked by Gilliland's method and agree fairly well with the correlation developed in this investigation.

The method of Montrose and Scheibel is based on an empirical equation which involves the use of the ratio of the key components on the feed plate at total and minimum reflux. The equation appears to be based on only semi-rigorous calculations since the simplifying assumptions of constant relative volatility and latent heats were made to

reduce the labor of calculation. This empirical equation also makes use of the less than rigorous terms of minimum reflux and minimum number of plates. No attempt was made to check if the method agreed with the results of this investigation, as the Montrose and Scheibel assumptions are too general.

It was the purpose of this work to obtain an empirical multicomponent optimum feed plate location relation based upon a considerable number of truly rigorous plate to plate calculations. A rigorous plate to plate calculation is one which takes into consideration both the variation of equilibrium constant with temperature and an enthalpy or heat balance about each plate. To perform these rigorous calculations, a method of solution suited for a high speed computer was developed and programmed. The electronic digital computer used was the Michigan State University 40 cathode ray tube, single address machine.

The computer was used to solve several hundred problems rigorously. The results of these problems were then used to study the effect of certain variables such as reflux ratio, feed composition, and number of plates upon the relative optimum feed plate location. It was found that reflux ratio, number

little effect

A function of

various feed c

based on relat

function was m

Although

tion, no clain

feed compositi

relative volat

location as fo

commercial app

that when non-

feed plate loc

adjacent keys.

non-adjacent k

to use the cor

ratio, number of plates, and feed temperature had very little effect on the location of the optimum feed plate. A function of $\frac{X_{HK}X_{LK} + X_{LK}}{X_{HK} + X_{LK}}$ was found to fit the data of various feed compositions very well, and a correlation based on relative optimum feed plate location versus this function was made.

Although many problems were solved in this investigation, no claim is made that all possible combinations of feed composition, as well as types of components, i.e., relative volatilities, will have the optimum feed plate location as found using this correlation. However, most commercial applications will be covered. It is probable that when non-adjacent key components are used the optimum feed plate location is more sensitive than when employing adjacent keys. Since this investigation did not cover non-adjacent keys, care should be exercised when attempting to use the correlation for such systems.

TABLE OF CONTENTS

ACKNOWLEDGEMENT

The author wishes to take this opportunity to thank Professor J. W. Donnell for his helpful guidance and advice on the many problems which arose during this investigation.

Thanks are also extended to the Computer Laboratory staff of Michigan State University for their cooperation in making the MISTIC and the auxiliary equipment available for use in this investigation.

INTRODUCTION

INTRODUCTION

The unit operation of distillation is an old one, dating back to the early days of the alcohol stills. Through the years, the use of distillation as a means of separating a mixture of liquids into desired products has been growing steadily. The petroleum industry, perhaps, has been the largest contributor in the expansion of distillation techniques and applications. It has been estimated that two-thirds of the total investment in petroleum refineries is in distillation equipment.

The solution of binary distillation problems was first analyzed and organized into a systematic approach by Sorel (15) in 1893. His solution consisted of making energy and material balances around each plate and assuming that equilibrium is attained on each plate.

Practically all distillation calculations today use the theoretical plate concept; that is, the assumption that equilibrium is attained on each calculated plate. Then one applies the theoretical calculations to actual design by using an efficiency factor to obtain the number of physical plates to use. For example, if a plate of certain design is known to give fifty per cent efficiency on the liquid-vapor system in que

theoretical o

discussions i

tical plate ap

Sorel's

end of the di

(obtained by

to calculate

the other end

of the liquid

equilibrium d

the vapor ent

calculated by

tray in ques

assuming a c

latent and s

see if this

assumed to e

is seen to i

tedious proc

Ponchon

which can be

system in question, then two plates must be used for each theoretical one. Henceforth then, subsequent distillation discussions in this paper will be confined to the theoretical plate approach.

Sorel's rigorous method involves starting at either end of the distillation tower and using end products (obtained by a material balance and product specification) to calculate downward (or upward) plate by plate until the other end of the tower is reached. The composition of the liquid on a tray is obtained from vapor-liquid equilibrium data. Then the amount and composition of the vapor entering this tray from the tray below is calculated by a material and heat balance around the tray in question. This last calculation is made by assuming a certain vapor rate and checking from known latent and specific heat data for each component to see if this heat data will allow the amount of vapor assumed to enter the plate in question. This, then, is seen to involve a trial and error procedure - a tedious process.

Ponchon (14) however, developed a graphical method which can be used to execute the Sorel plate to plate calculation fo

in a relativel

ting an enthal

weight fractio

saturated vapo

equilibrium re

The method tak

vapor rates fr

method accompl

McCabe an

come the most

tures; in fact

as many others

simplifying as

The primary as

solution such

1. Neglig

and va

2. Laten

both

with

3. Neglig

4. No hea

calculation for binary systems in a rigorous fashion in a relatively short time. The method involves plotting an enthalpy versus composition (mole fraction or weight fraction) diagram for both saturated liquid and saturated vapor. This diagram is then used to satisfy equilibrium relationships and to make material balances. The method takes into account the change in liquid and vapor rates from plate to plate, which is what the Sorel method accomplishes.

McCabe and Thiele's (13) graphical method has become the most popular method of solution for binary mixtures; in fact, it has become a classic. This method, as many others before and after it, makes certain simplifying assumptions to handle problems more easily. The primary assumptions one must make when applying a solution such as this are:

1. Negligible sensible heat effects of liquids and vapors as compared to latent heats.
2. Latent heats of vaporization per mole of both components are equal and do not vary with temperature.
3. Negligible heat losses to surroundings.
4. No heats of mixing.

The latter two assumptions are two which are standard assumptions to nearly all methods of solution; and well they might be, for both effects are very small in comparison to the large amounts of heat being considered in a column. The first assumption is usually a good one to make. However, the second assumption is the one that could be greatly in error, and thus cause incorrect results. For most mixtures of two components which are members of the same homologous series, the assumption of equal molal heats of vaporization is a reasonable one, and the McCabe-Thiele method provides a very quick and accurate method of solution. The McCabe-Thiele method can also be modified to handle cases where the heats of vaporization are unequal. In this case, the method is slower but still gives good results.

The mechanics of the McCabe-Thiele method consist of plotting the equilibrium diagram for the components in question on a vapor-liquid composition graph. Plotted on the same graph are the operating lines, i.e., the upper operating line starts with the top product composition and has a slope equal to the ratio of liquid to vapor rates in the top of the tower, while the bottom operating line starts with the composition of the bottom product and has a slope equal to the ratio of liquid to vapor rates below the feed plate. The lines represent material balance equations and relate the composition of the vapor leaving a plate to the composition of the liquid leaving the plate above it. The number of plates required can be determined by alternately moving from the operating line horizontally to the equilibrium line, and from the equilibrium line vertically downward to the operating line, and so on until the bottom composition is reached. The procedure may be reversed and, starting with the bottom product, take vertical and horizontal steps until the top product composition is reached. Either way, each pair of horizontal and vertical steps represent a plate. If constant heats of vaporization are assumed, the operating lines referred to above are straight lines. If the heats of vaporization are not assumed to be equal, then the operating lines will not be straight, but curved. One method of plotting the curved operating lines would be to make use of a Ponchon diagram in conjunction with the McCabe-Thiele diagram. But rather than do that, one might just as well use a Ponchon diagram by itself, which accomplishes the same purpose in a simpler fashion.

The solution of multicomponent distillation problems is closely related to the solution of binary distillation problems, in that they are both based on theoretical plates, material balances, and heat balances. The procedure for the solution of a multicomponent problem is different, however, because the boiling points of the liquids are no longer a function of one component composition as was the case in binary mixtures. In multicomponent mixtures (three or more components) the liquid on a given plate may have an infinite number of boiling points corresponding to a certain composition for one component, depending upon the composition of the other components in the mixture.

In the previous discussion of binary distillation, the McCabe-Thiele graphical method was referred to as a classic because it gives rigorous (if curved operating lines are used) yet rapid and clear solutions to most

binary distillation problems. There is no similar method which is simple enough for multicomponent calculations. Plate to plate calculations are therefore widely recognized as the standard method for multicomponent systems. The other methods of solution may be roughly broken down into the categories of 1) graphical solutions, 2) overall equations, and 3) empirical solutions. Several examples of each category will now be outlined briefly.

The two most common plate to plate methods used are the Lewis-Matheson (12) which makes the major assumption of constant liquid and vapor rates, and the Thiele-Geddes (16) which uses heat balances as a major calculating tool.

The Lewis-Matheson method consists of starting with the desired end products and calculating the number of theoretical plates required. Plate to plate calculations from both extremes of the column to the feed plate are carried out by using material balances and equilibrium relationships and by making successive approximations as to the temperature on each plate. The reflux ratio must also be found by trial and error.

The calculations in detail are carried out as follows. The reflux ratio is first approximated and the composition of the vapor leaving the top tray is calculated. For a total condenser this step would not be necessary, since the composition of the vapor would be the same as that of the top product. By using some sort of equilibrium relationship such as Raoult's law, relative volatility, or K values (where $y = K x$ and equilibrium is attained when $\sum y = 1$, $K = f(T,P)$) the liquid composition and the temperature on the top plate are found by assuming values for the temperature until the sum of the mole fractions, as calculated from the equilibrium relationship, is unity. Similarly, the temperature of the still and the composition of the vapors rising from it are calculated. Reflux is assumed not to change from one end of the column to the other, except at the feed plate where the reflux is increased by the amount of liquid in the feed. By use of a material balance and the dew point equation, the temperatures and compositions on each plate are calculated plate by plate.

By studying the composition determined by working up from the bottom, a suitable feed plate is chosen.

The compositio

ponent which d

the feed plate

continued unti

which does not

head product)

compositions t

with those det

the problem is

feed plate mus

calculations r

The most

was to demonst

solved by usi

that used for

Because

bottoms compo

to mixtures t

in both produ

that there ar

the exact pro

plates. This

The composition of the light key (highest boiling component which does not come out in bottom product) on the feed plate is calculated. The computation is continued until the heavy key (lowest boiling component which does not appear in appreciable amounts in the overhead product) is of negligible concentration. If the compositions thus determined correspond substantially with those determined by calculating down the column, the problem is solved. If not, the composition on the feed plate must be re-estimated and the last series of calculations repeated.

The most important contribution of Lewis and Matheson was to demonstrate that multicomponent systems could be solved by using a plate to plate calculation similar to that used for binary mixtures.

Because the method starts with the distillate and bottoms composition, the method is not readily applicable to mixtures that have two or three components which appear in both product streams. It will be pointed out later that there are not enough degrees of freedom to specify the exact product composition together with the number of plates. This is the most serious disadvantage of the

method. The Lewis-Matheson method can be made more rigorous by taking into consideration the changing liquid and vapor rates by applying the principles used by Sorel, i.e., heat balances.

The method introduced by Thiele and Geddes in 1933 is a rigorous plate to plate calculation in which it is not necessary to know or assume the products. It is, however, necessary to start with the number of equilibrium plates and the reflux ratio. These constitute the primary assumptions. The secondary assumptions are the temperatures on each plate. The method makes use of mole fraction ratios; that is, the ratio of the mole fraction of a component in either the liquid or vapor phase to the mole fraction of the same component in the end product stream. Above the feed the ratios are with respect to the distillate, below the feed with respect to the bottom product.

Calculations are performed from both extremes of the tower toward the feed plate, making use of the previously mentioned mole fraction ratios. When the feed plate is reached, these ratios are meshed to find the composition of the products. After the feed plate mesh is accomplished, one must go back and calculate the compositions on each plate, which in turn are used to calculate the corresponding temperatures. If the calculated temperatures do not agree with those assumed, the process is repeated using the new assumptions, until the temperatures for all the plates agree on two successive trials. It should be stressed that all temperatures must agree, since an incorrect temperature at any point will invalidate all of the calculations.

The Thiele-Geddes method is a very good method for multicomponent systems. Its main advantage over the Lewis-Matheson method is the manner in which the unequal molal overflow is taken into account, as well as not having to start with the composition of the products.

In 1935, Gilliland (7) published a shortcut method for solution of multicomponent problems by using relative volatility, as well as a new function of relative operability. Equilibrium relationships are written for the two key components in terms of relative volatility. By writing component material balances around a plate for each key component, and by dividing one component balance by the other, Gilliland uses the resulting

equation to define relative operability. He then combines the relative operability with relative volatility to give the relative changes in composition for one complete equilibrium stage, i.e., from liquid on one plate to liquid on the next. By expanding the above relationship for total plates in each section, he obtains relative composition changes across both the enriching and stripping sections. The method is a rapid approximation that can be used with a fair degree of accuracy for sharp separations. However, using this method, it is necessary to know the composition on the feed plate.

The limitations of the method are that there are too many simplifying assumptions. For instance, if the relative volatility or operability varies from one end of the column to the other, an arithmetic average is used. It is, nevertheless, a good method for giving quick approximations, which could be used as a first estimate in a more rigorous method.

Some investigators, such as Lewis and Cope (11) and Jenny (10), developed graphical solutions comparable to the McCabe-Thiele method.

The Lewis and Cope method consists of constructing a separate plot of y vs. x for each component. Assuming an equilibrium relationship of $y = Kx$, with K dependent on temperature only, equilibrium lines are plotted for several temperatures, and the correct temperature determined by trial and error. This process is repeated for each plate. The method is very cumbersome and also requires a knowledge of the composition of the products.

Jenny proposed a graphical method utilizing a x vs. y diagram similar to the McCabe-Thiele diagram, which involves constructing a modified equilibrium line, which is supposed to allow for the non-volatile lighter than key and heavier than key components. The equilibrium line is plotted by making a few plate to plate calculations. Separate diagrams are used for both the stripping and enriching sections, using the light key for the enriching section and the heavy key for the stripping section. The operating lines are assumed to be straight. This method requires knowing the composition on the feed plate.

A method based on overall equations for both sections of the tower was proposed by Edmister (5). The equations are based on the use of absorption and stripping factors similar to those

lations. After

are washed at th

Many so-cal

posed, based on v

Several of these

In 1939, Bro

for obtaining the

for a given separ

The method is ba

the variables pl

minimum reflux v

minimum plates.

are used. The c

of rigorous calc

Most of the syst

systems.

About the s

their method, Gi

although develop

the actual minu

similar to those used by Kremser in absorption calculations. After evaluation of these equations, the results are meshed at the feed plate.

Many so-called empirical solutions have been proposed, based on various correlations of past calculations. Several of these correlations will now be discussed.

In 1939, Brown and Martin (1) proposed a method for obtaining the number of equilibrium plates required for a given separation at a specified reflux ratio. The method is based upon an empirical correlation and the variables plotted are actual reflux divided by minimum reflux versus the actual plates divided by the minimum plates. Key components and pinch-point concepts are used. The correlation was developed from the results of rigorous calculations for a number of separations. Most of the systems were binary, with some multicomponent systems.

About the same time that Brown and Martin published their method, Gilliland (8) proposed a method very similar, although developed independently. This correlation plotted the actual minus the minimum plates divided by one plus the actual pl

reflux divide

variables are

Gillilan

rigorous calc

The correlati

component sys

a little simp

In 1950,

lation which

plates to min

ratio of actu

tions of Fens

values for th

One of the mo

is that the

of minimum re

optimum condi

reflux. Thus

graph easily,

Several

similar to th

the actual plates versus the actual minus the minimum reflux divided by one plus the actual reflux. The variables are plotted on log-log scales.

Gilliland's correlation was also the result of rigorous calculations for a number of binary mixtures. The correlation was also checked for a few multi-component systems. The correlation of Gilliland is a little simpler to use than that of Brown and Martin.

In 1950, Donnell and Cooper (4) proposed a correlation which involved plotting the ratio of actual plates to minimum plates versus the logarithm of the ratio of actual boil up to minimum boil up. The equations of Fenske (6) and Underwood (17) are used to obtain values for the minimum plates and minimum vapor load. One of the most important advantages of this correlation is that the curve approaches a straight line in the region of minimum reflux. This is of importance since most optimum conditions lie in this range near the minimum reflux. Thus, it is desirable to be able to read the graph easily, or even interpolate if necessary.

Several other investigators made correlations similar to those already discussed. Included in the group re correlati...

Harbert (9).

In, 1940,

determining the

method consists

ratio of the mo

the feed is bet

the plate above

Gilliland's met

feed is partial

Montrose a

for optimum fee

on an empirical

ratio of the lo

and minimum ref

only semi-rigor

assumptions of

heats were made

This empirical

rigorous terms

plates. No atte

agreed with the

Montrose and Sch

are correlations presented by Colburn (3) and by Harbert (9).

In, 1940, Gilliland (8) published a method for determining the optimum feed plate location. This method consists of placing the feed plate so that the ratio of the mole fractions of the key components in the feed is between the ratio of the key components on the plate above and below the feed plate. According to Gilliland's method, there is a slight variation if the feed is partially vaporized or all vapor.

Montrose and Scheibel in 1946 (8a) offer a method for optimum feed plate location. This method is based on an empirical equation which involves the use of the ratio of the key components on the feed plate at total and minimum reflux. The equation appears to be based on only semi-rigorous calculations since the simplifying assumptions of constant relative volatility and latent heats were made to reduce the labor of calculation. This empirical equation also makes use of the less than rigorous terms of minimum reflux and minimum number of plates. No attempt was made to check if the method agreed with the results of this investigation, as the Montrose and Scheibel assumptions are too general.

STATEMENT OF THE PROBLEM

STATEMENT OF THE PROBLEM

The need of a rigorous solution to multicomponent distillation problems is not a new idea. It was stated some years back by Colburn (2) that what the engineering profession needs in multicomponent calculations is "either an exact solution, even though it is difficult, or an approximate solution, if it is easy." With the advent of high speed computers, the challenge to see who could develop an exact solution first has grown considerably. This investigation was undertaken to: 1) develop an exact solution using a high speed computer as a tool to perform the calculations, and 2) use the exact solution to study the effect of feed tray location on the degree of separation in multicomponent mixtures.

When a distillation column is designed and built, it is desired that for a given number of plates, reflux ratio, and feed composition, the maximum separation be obtained. It is desirable, then, to locate the feed plate so that the optimum separation is obtained.

To illustrate the necessity for the optimum feed plate location, consider the following binary problem.

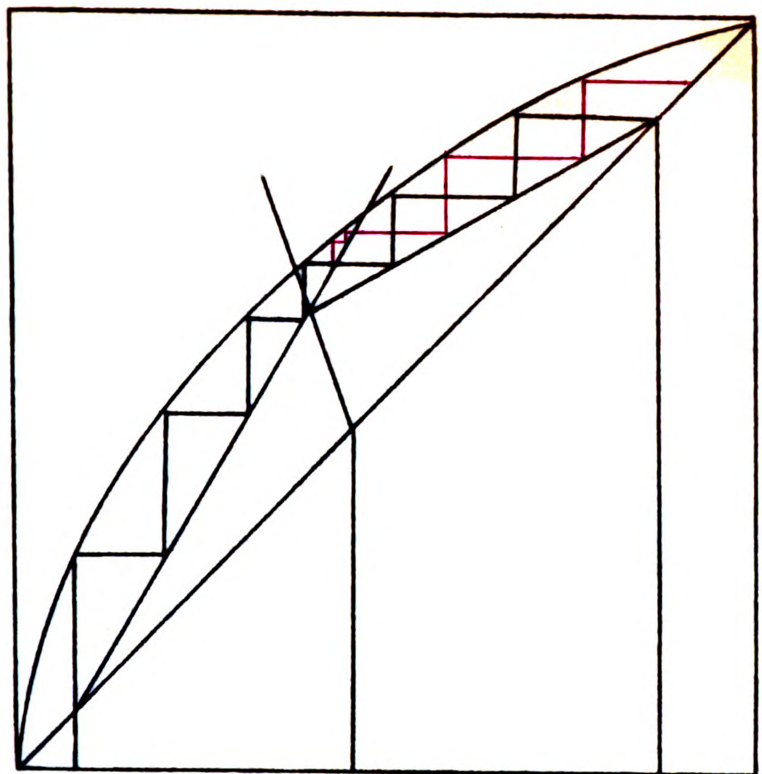

Figure 1

If the feed plate were not located on the fourth plate from the bottom, but higher up, it would require more plates to do the same job of separation, or a worse separation would be obtained, if the same number of plates were used.

The red line in Figure 1 illustrates the case where the feed plate is not the fourth but the sixth plate from the bottom. In this case, it would take two more plates to do the same job of separation. Similarily, if the feed plate were located lower than the fourth plate from the bottom, the same situation would arise.

Multicomponent systems are not so easy to illustrate as the foregoing binary one, but the same type of relationship exists. That is, there exists an optimum feed plate location, or series of locations, so that a maximum separation is obtainable.

In attempting to study the effect of feed tray location, it becomes necessary to work out many problems to see how the optimum varies with number of plates, reflux ratio, and feed composition. In a study such as this, a rigorous solution should be used in order to get a more accurate picture of the variables involved. Thus, this investigation utilized a high speed computer to solve many problems in a rigorous fashion (that is, taking into account changing vapor and liquid rates and perfect matching at the feed plate.)

NEED FOR HIGH SPEED COMPUTER

NEED FOR HIGH SPEED COMPUTER

The importance of greater and greater accuracy has been brought out as one reason why more rigorous methods of solution must be employed. The more rigorous a problem, the more trial and error calculations are required, until finally it is conceivable that an engineer working a rigorous multicomponent distillation problem might take weeks to solve the problem. Most of that time would be spent doing the rather routine trial and error calculations to make sure that all compositions, amounts, and temperatures were consistent with the material balances, heat balances, and equilibrium data. The answer to the engineer's dream is a high speed electronic computer. Of course, the engineer would still be required to set the problem up, but the computer would do all the calculations in a very short period of time.

The same problem that might take an engineer a week to solve could be solved using a computer in a few hours or less.

The great speed at which computers operate is also important from an economic standpoint. Once a program has been written for a problem, it can be used over and over for the solution of many similar problems. Although the cost of buying or renting a computer is quite high (rentals run on the order of $200 per hour) the cost is still substantially lower than paying the salary of an engineer for the time necessary to work out the problem by hand.

As was pointed out previously, the study of the effect of feed tray location on the separation obtained is one which requires many problems to be solved. This lends itself to computer application very nicely, since the computer can perform a rigorous solution in a short period of time.

Not only does the computer provide a means of studying the effect of feed tray location, but also it affords a detailed study of other variables which enter into the problem. One of the variables now being studied is the effect of condition of feed, i.e., pre-heated or cold, on the tower performance. Another important study is being made on the relationship between number of plates and reflux ratio to obtain a desired separation.

Another important advantage of the use of computers is their reliability. Although some might argue this to be a trivial point, it is nevertheless an important one. The reliability of computers is certainly better than an engineer running a slide rule or desk calculator. It must be admitted that computers do occasionally make a mistake. However, when a mistake is made, it is almost always so obvious that it is immediately noticed. On the other hand, an engineer could easily carry a mistake on and on without it being noticed.

In the discussion of previous methods used in solving multicomponent distillation problems, it was mentioned that some methods use the ratio of the so-called key components as a criterion for convergence of the feed plate mesh. This, of course, is only an approximation and serves to shorten the calculations. Once again, the computer can perform these calculations exactly and thus eliminate the need for the assumption. It may be argued that this advantage of the computer is merely due to the speed at which the machine operates. However, there is more to a computer than speed and accuracy. It enables one to solve lengthy and complex problems that could not be worked without the use of such a computer. Many of these seemingly impossible so

nicely by com

There are

blem of applyi

problems. The

one of the wel

presented by o

alternative wo

particularly s

latter alterna

none of the ex

to automatic c

itself or beca

which the meth

to make.

impossible solutions are now being handled very nicely by computers.

There are two alternative approaches to the problem of applying computers to solve distillation problems. The first alternative would be to adapt one of the well-known and accepted calculation methods presented by other authors to a computer. The second alternative would be to develop a calculation method particularly suited to automatic calculation. The latter alternative was chosen since it is felt that none of the existing calculation methods are suitable to automatic computation, either because of the method itself or because of certain simplifying assumptions which the method required, which were felt unnecessary to make.

DERIVATION OF EQUATIONS

The solutio

is one of trial

the simplifying

are not made. Th

obtain a solution

2) material balan

At this poin

given feed, the p

different in a mu

mixture. In a bi

fixed by specify

the composition

fixed. However,

cannot be specif

the composition

The situati

and the fact tha

simultaneous equ

trial and error

iterative proces

working through

positions until

DERIVATION OF EQUATIONS

The solution of a multicomponent distillation problem is one of trial and error. This is even more pronounced if the simplifying assumptions of constant liquid and vapor rates are not made. The three tools with which we are armed to obtain a solution are: 1) Vapor-liquid equilibrium conditions, 2) material balances, and 3) energy balances.

At this point, it is well to point out that from any given feed, the problem of product specification is quite different in a multicomponent mixture than it is in a binary mixture. In a binary mixture, the product desired may be fixed by specifying the composition of one component, since the composition of the other component will then also be fixed. However, in a multicomponent mixture the product cannot be specified for all the components. Instead, only the composition with respect to one component may be specified.

The situation of not being able to specify the products and the fact that computers are limited as to the number of simultaneous equations they can solve, leads directly to a trial and error solution. The solution becomes, then, an iterative process of assuming the composition of the products, working through the problem, and correcting the product compositions until the assumptions prove correct.

The primary variables which must be known before starting the solution of a problem are: 1) Feed composition and condition of the feed, 2) Reflux ratio, L/D, 3) number of plates above and below the feed plate, and 4) tower pressure. The latter is necessary for equilibrium and enthalpy data.

There are two types of problems which may arise. The first would be the problem of designing a new column with the proper number of plates to give a desired separation. The desired separation, of course, must be in accordance with the foregoing discussion on product specification.

The second type of problem would be the utilization of an existing column and the desire to determine the products obtainable with a given feed. Actually, both types of problems would be solved utilizing the same method of solution. The problem of determining the number of plates necessary to obtain a desired product requires an estimate of the number of plates, working through the problem, and checking the results with the desired products. If the results agree, then the number of plates assumed will be sufficient. If the results do not agree, then a new estimate of the number of plates must be made, and the problem reworked until the products obtained are acceptable. The problem with the number of plates already known and the products unknown is solved using the same method of solution as for the above type problem, except that the number of plates need not be assumed since it is already known. Therefore, the solution of both types of problems will be handled as one, and the number of plates in the column will be taken as a known variable.

The general solution of the problem will be to assume one of the product compositions and quantities (the top product in this solution) and calculate from both extremities of the tower toward the middle until the feed plate is reached from both directions. At this point a mesh, or comparison, of the compositions obtained from both directions is made. If the compositions are equal, to a specified degree of accuracy, then the products assumed are correct and the solution is complete. If the compositions do not mesh, then the assumed product is modified in proportion to the variation of the mesh, and the calculations are carried out again until the feed plate mesh is satisfactory.

In the development of the method, frequent reference to previous equations already developed will occur, and so are

numbered to help identify them. A diagram is provided to help picture the problem and also to refer to as to nomenclature.

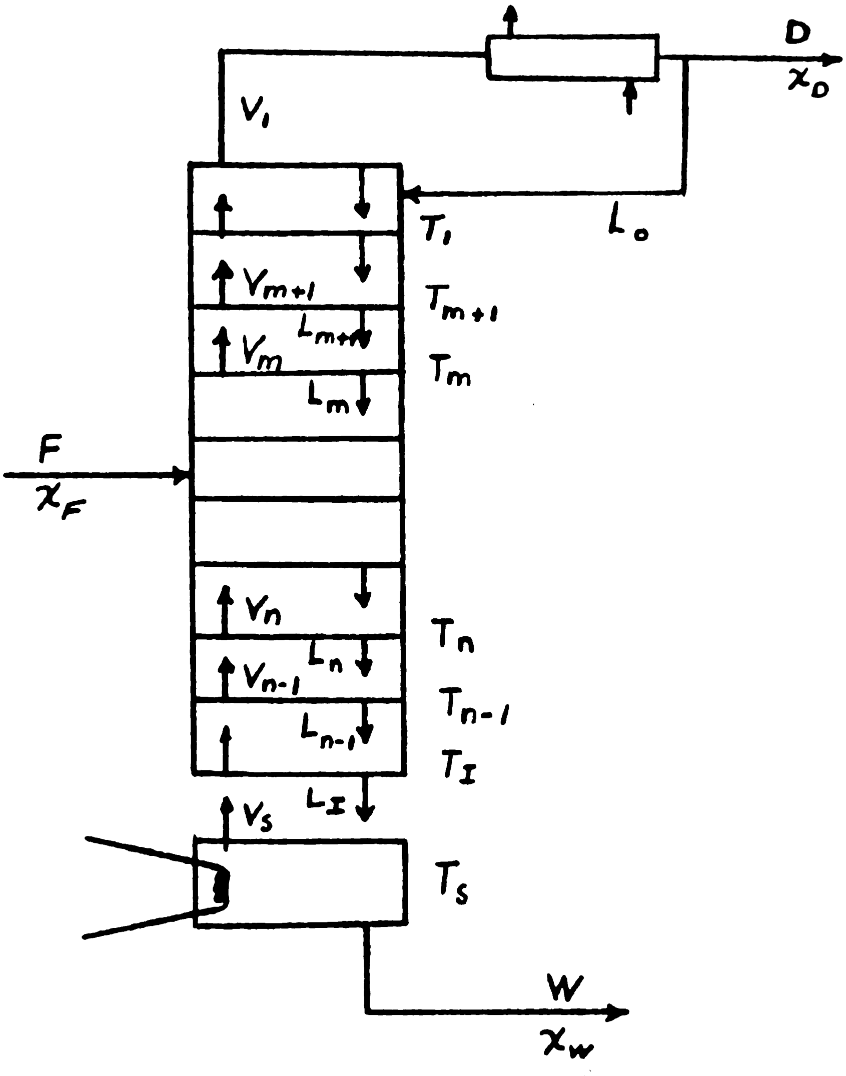

Figure 2

For simplification purposes, a basis of one mole of feed is chosen. This allows the composition of the feed, expressed in mole fractions, to be the moles of each component in the feed. It also provides an easy, quick estimate of the amount and composition of the top product by estimating the number of moles of each component which will be produced overhead. The first estimate of top product, as well as estimates of the top temperature, bottom temperature, and amount of vapor in the bottom section, are read into the computer as data. In the section on the actual computer programming, the entire list of data necessary to work a problem will be outlined.

The statement and derivation of the algebraic procedure used in the problem follows:

1) Calculate the amount of overhead product.

$$D = \sum_{i} D x_{Di}$$

For the first iteration this step is unnecessary, since the top product has been assumed. However, in later iterations the top product will be altered, making it necessary to perform this calculation.

2) Calculate the amount of bottom product.

$$W = F - D = 1 - D$$

3) Calculate the bottom composition.

$$X_{Wi} = \frac{FX_{Fi} - DX_{Di}}{W}$$

4) Using the assumed moles (DX_{Di}) of each component and the D from step 1, calculate the overhead composition. $X_{Di} = \frac{DX_{Di}}{D}$

5) Calculate V_1 and L_o from given reflux ratio and D calculated in 1.

$$V_1 = D(R+1)$$
$$L_o = R \cdot D$$

6) Determine the temperature on the top and bottom plate, using the bubble point and dew point calculations as shown below.

$$T_1 \text{ at top when } \sum_i \frac{x_{Di}}{K_i} = 1$$
$$T_s \text{ at bottom when } \sum_i K_i x_{wi} = 1$$

The values of K_i are obtained from a third degree polynomial in temperature. The K values are assumed to be dependent on temperature and pressure only. When the correct temperatures are found, then $K_i X_{wi} = Y_{wi}$ and each Y_{wi} is saved for later calculations.

7) Determine the dew point of the overhead product as follows:

$$T_D \text{ when } \sum_i K_i x_{Di} = 1$$

8) Calculate heat flux in top of column by subtracting enthalpy of reflux from enthalpy of top vapor, thusly:

$$h_o = L_o \sum_i \bar{h}_{oi} x_{Di} \quad \text{at} \quad T_D$$
$$H_1 = V_1 \sum_i \bar{H}_{1i} x_{Di} \quad \text{at} \quad T_1$$
$$Q_a = H_1 - h_o$$

Note that

It would have to

partial condense

9) Assumin

Q_r from

of the

the sam

enthal

produc

ponent

calcul

temper

Make a

A heat bal

separately give

Top se

Bottom se

Note that this solution is for a total condenser. It would have to be modified slightly for the use of a partial condenser.

9) Assuming no heat losses to surroundings, calculate Q_r from enthalpy of the feed and Q_a. The enthalpy of the feed is read in as data and is calculated in the same manner as all other enthalpies, i.e., the enthalpy of a mixture is the sum of the individual products of mole fraction and enthalpy of pure component. The enthalpy of each pure component is calculated from a third degree polynomial in temperature.

Make a heat balance around the entire column:

$$h_F + h_S = h_C + h_D + h_W$$

$$h_F = (h_W - H_S) + (h_C + h_D)$$

$$(h_S - h_W) = (h_C + h_D) - h_F$$

A heat balance around the top and bottom section separately gives:

Top section	$H = h_D + h_C + h$
or	$H - h = h_D + h_C = Q_A$
Bottom section	$H + h_W = h + h_S$
or	$H - h = h_S - h_W = Q_r$
Thus	$Q_r = Q_a - h_F$

Plate to

from the conde

The genera
looking at the
easy to see jus
same will apply
The compositio
y_{mi}, T_m, $L_{(m}$
V_{m-1}, T_{m-1}, an
consideration
ponents preser
The equations
material bala
2) i componen
tower, 3) he
the tower, 4
equations. I
simultaneous
would involve
number of pla

Plate to plate calculations are now ready to be made from the condenser down to the feed plate.

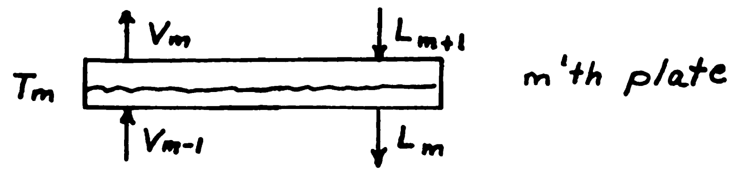

Figure 3

The general case of plate m will be illustrated. By looking at the second plate from the top in Figure 2, it is easy to see just what is known and what is unknown. The same will apply to the m'th plate as one works downward. The composition and temperature of L_{m+1} are known, while V_m y_{mi}, T_m, $L_{(m+1)}$, and x_{mi} are all unknown. Actually, V_{m-1}, T_{m-1}, and $y_{(m-1)i}$ are unknown also, but come into consideration on the next plate. If there are i components present, then there are $2i+3$ unknowns to solve for. The equations available for their solution are: 1) total material balance above m'th plate and around top of tower, 2) i component material balances around same portion of tower, 3) heat balance around above mentioned section of the tower, 4) dew point equation, and 5) i equilibrium equations. It is well to point out that if a set of simultaneous equations were set up for the whole tower, it would involve equations which would number $(2i+3)$ times the number of plates in the column. It is conceivable to have a column with fifty plates and ten components, which would require the solution of 1150 equations and 1150 unknowns. Very few, if any, computers even approach a capacity large enough to handle such a problem except by an iterative process. Even if a computer were large enough to handle the 1150 equations, it is doubtful if a solution could be obtained, since it is unlikely that all the equations would have constant coefficients.

The procedure used here to solve the $(2i+3)$ equations, one plate at a time, is a trial and error method based on assuming values for T_m and L_{m+1} and using Newton's method to arrive at better values for the assumed variables. This is done until the correction factor for T_m and L_{m+1} becomes arbitrarily close to zero.

10) Choose a temperature T_m and a liquid rate L_{m+1} .
    A good first estimate is to use the values obtained as answers to the previous plate. After the first iteration through the column this step will be altered by using the temperature and liquid rate for the previous iteration as the first guess, since they will be a better approximation than the temperature and liquid rate for the preceding plate.

11) Calculate V_m from D and the assumed L_{m+1} by an overall material balance around top of tower.

$$V_m = L_{m+1} + D$$

12) Calculate y_{mi} from a component material balance around top of tower.

$$y_{mi} = \frac{L_{m+1}\, x_{(m+1)i} + D\, x_{oi}}{V_m}$$

13) Calculate ϕ using assumed T_m. This also gives the values of x_{mi}.

$$\phi = 1 - \Sigma\, y_m / K_m$$

Note that ϕ will approach zero as the correct temperature is found.

14) Using assumed T_m, y_{mi}, and x_{mi} as calculated in 12 and 13, find H_m.

$$H_m = \Sigma\, \overline{H}_m\, y_m$$

15) Calculate h_{m+1} from temperature of plate above, T_{m+1}.

$$h_{m+1} = \Sigma\, \overline{h}_{m+1}\, x_{m+1}$$

16) Making a heat balance around top of column, find ϕ'.

$$\phi' = 1 - \frac{V_m H_m - L_{m+1}\, h_{m+1}}{Q_a}$$

ϕ' must also tend to zero as the proper T_m and L_{m+1} are obtained.

The Newton

iterations cons

derivatives of t

for the new vari

which must be su

estimates to imp

the derivatives

17) $\frac{\partial \phi}{\partial T}$

$\frac{\partial \phi}{\partial L}$

$\frac{\partial}{\partial}$

$\frac{\partial}{\partial}$

The Newton technique for quick convergence of iterations consists of substituting the slopes, or derivatives of the function at the point in question, for the new variables. A correction factor is calculated which must be subtracted from the previous T_m and L_{m+1} estimates to improve their accuracy. The equations for the derivatives are:

17) $$\frac{\partial \phi}{\partial T_m} = P_1 = \frac{\partial}{\partial T_m}\left(\Sigma\, y_m/K_m\right)$$

$$= \Sigma\, \frac{x_m}{K_m}\left(b_K + 2c_K T_m + 3d_K T_m^2\right)$$

$$\frac{\partial \phi}{\partial L_{m+1}} = P_2 = \frac{\partial}{\partial L_{m+1}}\left(\Sigma\, y_m/K_m\right)$$

$$= -\frac{1}{V_m}\Sigma\, \frac{x_{m+1} - y_m}{K_m}$$

$$\frac{\partial \phi'}{\partial T_m} = P_3 = \frac{\partial}{\partial T_m}\left(1 - \frac{V_m H_m - L_{m+1} h_{m+1}}{Q_a}\right)$$

$$= -\frac{V_m}{Q_a}\Sigma\left(b_h + 2c_h T_m + 3d_h T_m^2\right) y_m$$

$$\frac{\partial \phi'}{\partial L_{m+1}} = P_4 = \frac{\partial}{\partial L_{m+1}}\left(1 - \frac{V_m H_m - L_{m+1} h_{m+1}}{Q_a}\right)$$

$$= -\frac{1}{Q_a}\left[\Sigma\, \bar{H}_m x_{m+1} - \Sigma\, \bar{h}_{m+1} x_{m+1}\right]$$

18) The co

P_1

P_3

rewriti

ΔT

ΔL

19) The ne

by sub

previo

T

L

These new

steps 11 - 19 a

After step

n'th plate is c

through the col

until the feed

liquid leaving

saved for the fe

The calcula

tower in much th

18) The correction equations are:

$$p_1 \Delta T_m + p_2 \Delta L_{m+1} = \phi$$

$$p_3 \Delta T_m + p_4 \Delta L_{m+1} = \phi'$$

rewriting and solving for ΔT_m and ΔL_{m+1}:

$$\Delta T_m = \frac{\phi p_4 - p_2 \phi'}{p_4 p_1 - p_2 p_3}$$

$$\Delta L_{m+1} = \frac{\phi - p_3 \Delta T_m}{p_4}$$

19) The new estimates for T_m and L_{m+1} are obtained by subtracting the correction factor from the previous estimates:

$$T_m(\text{new}) = T_m(\text{old}) - \Delta T_m$$

$$L_{m+1}(\text{new}) = L_{m+1}(\text{old}) - \Delta L_{m+1}$$

These new values for T_m and L_{m+1} are used to go through steps 11 - 19 again until they satisfy all the equations.

After steps 11 - 19 are solved, the solution for the m'th plate is complete, at least for the first iteration through the column. Steps 10 - 19 are repeated M times until the feed plate is reached. The composition of the liquid leaving the feed plate as calculated above is then saved for the feed plate mesh later.

The calculations are now performed on the bottom of the tower in much the same manner as for the top of the tower.

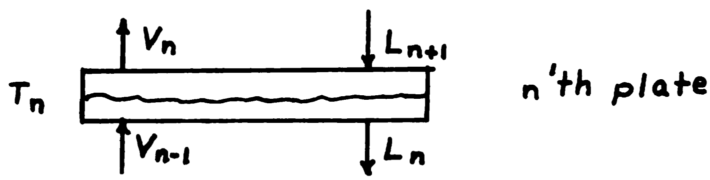

Figure 4

By looking at the reboiler of Figure 2 and considering it a theoretical plate, one can see that the known quantities for the solution of the n'th plate will be the composition and temperature of the vapor entering the plate from below, i.e., plate n-1. The unknown quantities are V_{n-1}, L_n, X_{ni}, T_n, and $Y_{(n-1)i}$. Once again, there are actually more unknowns in $L_{(n+1)}$, $T_{(n+1)}$, and $X_{(n+1)i}$ but they will be solved for on the (n+1)th plate. The same equations as used for the section above the feed plate are used in this section below the feed plate, except that the bubble point equation is substituted for the dew point equation. The Newton method is used here also, with the alteration that T_n and V_{n-1} are the two variables which are estimated.

20) Choose a first estimate of the temperature, T_n, and the vapor rate, V_{n-1}. Use as a first estimate the temperature and vapor rate from the solution of the previous plate. After the first iteration through the tower, this step will be altered the same as was step 10 in the other section of the column.

For the first plate above the reboiler, the original estimate cannot be obtained from the plate calculated below it, and so must be a good, qualified approximation. The vapor rate can be approximated quite well by considering the reflux ratio and the condition of the feed, i.e., liquid or vapor, superheated or supercooled.

21) Find K_{ni} using assumed T_n :

$$K_{ni} = a_{Ki} + b_{Ki} T_n + c_{Ki} T_n^2 + d_{Ki} T_n^3$$

22) Calculate the liquid rate from a material balance:

$$L_n = V_{n-1} + W$$

23) Calculate the composition of liquid on the n'th plate using a component material balance:

$$x_{ni} = \frac{W x_{wi} + V_{n-1} \, y_{(n-1)i}}{L_n}$$

For the first plate $y_{(n-1)i}$ was calculated in step 6 when $\Sigma K_n x_w = 1$. For succeeding plates $y_{(n-1)i}$ will be calculated in step 24 of the previous plate.

24) Calculate θ (bubble point equation.)

$$\theta = 1 - \Sigma K_n x_n$$

25) From the assumed T_n , and the temperature of the plate below, calculate H_{n-1} and h_n .

$$H_{n-1} = \Sigma \bar{H}_{n-1} \, y_{n-1}$$
$$h_n = \Sigma \bar{h}_n \, x_n$$

26) Calculate θ' (heat balance.)

$$\theta' = 1 + \frac{L_n h_n - V_{n-1} H_{n-1}}{Q_r}$$

27) The Newton method is used in the same manner here as for section above the feed plate and the equations for the slopes will not be derived.

Find $q_1 - q_4$

$$q_1 = -\Sigma y_n (b_K + 2 c_K T_n + 3 d_K T_n^2)$$
$$q_2 = -\frac{1}{L_n} \Sigma K_n (y_{n-1} - x_n)$$
$$q_3 = -L_n / Q_r \, \Sigma (b_h + 2 c_h T_n + 3 d_h T_n^2) x_n$$
$$q_4 = -\frac{1}{Q_r} \left[\Sigma \bar{H}_{n-1} \, y_{n-1} - \Sigma \bar{h}_n \, y_n \right]$$

28) Determine the correction factors ΔT_n and ΔV_{n-1}.

$$\Delta T_n = \frac{\theta q_4 - q_2 \theta'}{q_1 q_4 - q_2 q_3}$$

$$\Delta V_{n-1} = \frac{\theta' - q_3 \Delta T_n}{q_4}$$

29) Determine the new values of T_n and V_{n-1} to put back into step 21. Steps 21 - 29 are repeated until the correction factors become arbitrarily close to zero.

Steps 20 -

so must be repea

the compositions

as calculated fr

are compared to

The feed pl

composition of t

from the condens

the reboiler up.

This ratio

convenient prop

or not one has

the size and di

should be made.

of that compone

great. Convers

that component

$$T_n \text{ (new)} = T_n \text{ (old)} - \Delta T_n$$

$$V_{n-1}\text{(new)} = V_{n-1}\text{(old)} - \Delta V_{n-1}$$

Steps 20 - 29 represent the solution of one plate, and so must be repeated N times. When the feed plate is reached, the compositions of the liquid stream leaving the feed plate, as calculated from the condenser down and the reboiler up, are compared to see if convergence has been attained.

The feed plate mesh consists of taking the ratio of the composition of the liquid leaving the feed plate as calculated from the condenser down to the composition calculated from the reboiler up. This is done for all components.

$$r_i = \frac{X_{fi} \text{ (down)}}{X_{fi} \text{ (up)}}$$

This ratio r_i should, of course, approach unity. The convenient property of r is that it not only tells whether or not one has convergence but also gives an indication of the size and direction the correction on the assumed products should be made. If r is greater than unity, then the amount of that component coming out overhead has been assumed too great. Conversely, if r is less than one, the quantity of that component in the overhead has been assumed too small.

The magnitude of r also indicates the magnitude of the error in the assumed products.

The important thing is that the ratios be used to correct the products in such a manner so as to conform with the overall material balance. In order to be able to apply the ratios to all components, it is very important that some quantity of each component be assumed going out in each product. This can be illustrated by taking the case where one component was assumed to come out in only one product, i.e., top or bottom product. If this were so, then when the assumed product for that particular component was multiplied (or divided) by the feed mesh ratio, the amount of product would still be zero, and thus unchanged. It should be pointed out that the components will always be corrected in the product stream where their composition is the smaller. The product stream containing the larger composition of the component is then corrected using an overall material balance.

For the components which tend to leave in the overhead, the following equations are used for correcting the assumed products:

$$W x_{wi} \text{ (revised)} = r_i \cdot W x_{wi} \text{ (previous)}$$

$$D x_{Di} \text{ (revised)} = F x_{fi} - W x_{wi} \text{ (revised)}$$

For components which tend to leave in the bottom product the following correction equation is used:

$$Dx_{Di}(revised) = \frac{1}{r_i} Dx_{Di}\,(previous)$$

The fact that the revised Wx_{wi} is not calculated here for the components which tend to leave in the bottoms is explained by pointing out that when re-iterating through the entire problem, one must go all the way back to step 1. It can be seen that in steps 2 and 3 the new W and x_{wi} are calculated, and thus need not be calculated here.

If the feed plate mesh ratio is arbitrarily close to one for all components, the solution is complete, at least for the number of plates used. However, if the problem is of the type where one wants to determine the number of plates necessary to obtain a desired separation, then the solution may not be complete. That is if the products do not meet the desired specifications, then a new number of plates must be chosen, and the problem worked through again.

This is the advantage of using a computer, since it can calculate the new conditions very quickly, while without such a machine one must be satisfied with trying to set approximate specifications.

COMPUTER USED

Throughout
by Michigan Sta
computer is name
better known as
number system ar
IBM card input
used in this in
The storag
tubes and the
the capacity of
1024 storage l
to well over 1
memory is inst
MISTIC is
carries only o
symbols from t
and the letter
between 0 and
while the numb
one of the 102
the operation

COMPUTER USED

Throughout this investigation, the computer owned by Michigan State University was used exclusively. The computer is named "The Michigan State Integral Computer," better known as MISTIC. The computer operates in the binary number system and makes use of punch tape input and output. IBM card input and output are also available but were not used in this investigation.

The storage or memory consists of forty cathode ray tubes and the associated circuitry. At the present time, the capacity of the computer is rather limited, with only 1024 storage locations. However, this will soon be altered to well over 16,000 locations, when the new magnetic core memory is installed.

MISTIC is a single address machine, i.e., each instruction carries only one address. Orders for the MISTIC contain two symbols from the decimal digits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and the letters K, S, N, J, F, L, and one decimal number between 0 and 1023. The two symbols form the operation code, while the number is an identification number (address) for one of the 1024 electrostatic memory locations. In essence, the operation code tells the computer what to do and the

the address tell

For instance, th

of memory locati

Two orders

an order pair.

order in each wo

left to right.

Since the M

each order must

This would requi

grammer; and, fo

able to convert

automatically.

Input (DOI) and

When using

operation code,

uation symbol.

and L.

Because of

the distillatio

point subroutin

the computer to

the address tells it what to do it with or where to go. For instance, the order FS 135 says, "Bring in the contents of memory location 135 to the accumulator and add one to it."

Two orders constitute one word and are referred to as an order pair. There is a lefthand order and a righthand order in each word. The orders are obeyed in sequence left to right.

Since the MISTIC is a binary machine, the address in each order must be in binary form before entering the machine. This would require a tremendous amount of work by the programmer; and, fortunately, there is an input program available to convert the decimal addresses to sexadecimal automatically. This program is known as the Decimal Order Input (DOI) and is used in all problems.

When using the DOI, each order must contain a two digit operation code, an address between 0 and 1023, and a termination symbol. The termination symbols are K, S, N, J, F, and L.

Because of the complexity of the method of solution of the distillation problem, it was decided to use the floating point subroutine even though the subroutine actually causes the computer to perform the calculations at a much slower speed. However, by using the floating point routine, hereafter referred to as A_1, the tedious task of scaling the numbers was bypassed, since this subroutine keeps track of the decimal point automatically. To use ordinary MISTIC orders would require that all numbers be scaled so that they are between plus one and minus one. This scaling must also consider all numbers which will be calculated, making sure that they, too, would lie in the proper range.

Almost the entire distillation program is written in A_1, with a few orders being in ordinary MISTIC language. For any questions that arise concerning the few MISTIC orders, reference should be made to the MISTIC Programming Manual. In the appendix of this thesis is an outline of the orders encountered in using the A_1, subroutine. This may prove helpful as a reference when reading through the program.

DETAILED CODING PROCEDURE

DETAILED CODING PROCEDURE

This section will be devoted to outlining the problems of programming a problem for use on a high speed computer, as well as the detailed coding of the main program used. It is intended that such a detailed coding of the program might aid the reader in visualizing the method of calculation used.

Liquid vapor equilibrium data used throughout this investigation was of the type $y = Kx$. It was assumed that K depended only on temperature and pressure. In order to quickly calculate a desired K value at a given temperature, third degree polynomials of the form $K = a_k + b_kT + c_kT^2 + d_kT^3$ were used to describe the variation of K with temperature. The four constants were evaluated for various components, using the method of least squares on the data of Cooper and Donnell, and Maxwell. These polynomials were prepared at various pressures within the range of operation for a distillation column.

Enthalpy of liquids and vapors of each component were also represented by third order polynomials in temperature. The data used was from Maxwell. The enthalpy of a mixture was assumed to be the sum of the individual products of mole fraction and enthalpy of pure product.

Before one reads through the detailed coding of any program, it is well to point out that in many cases, calculations are set up in a far different manner and order for a computer than would be done if a person were to do the same calculations by hand or with a desk calculator. It should also be pointed out that in programming such a problem for a computer, there are quite often several choices of orders one could use. Thus, a person reading this program might well find places where orders could be changed or possibly even left out. This is especially tme in the program illustrated here. Due to the complexity of the problem, there were many changes to be made after the program was put together. In order to conserve time, the program was altered in sort of a piecemeal affair. However, this in no way affects the principles involved, nor the calculations which are being carried out.

Before getting into the main program, it should be pointed out that the enthalpy polynomial subroutine (HSR) and the equilibrium constant subroutine (KSR) will not be outlined. They simply involve the calculation of the K values and the enthalpy values for a given compound from a third degree polynomial. The factored form of the polynomial is used to decrease the number of orders required. For instance, $K = [(d_K T + c_K)T + b_K]T + a_K$. This way, the constants for the polynomials must be input in reverse order; that is, in the order d, c, b, and a for each component. The constants must be changed for each different tower pressure as well as for when different components are in the feed.

Whenever control is transferred to HSR or KSR from the main program, the K values or enthalpy values are calculated, then control is transferred automatically back to the next order in the main program. In other words, both HSR and KSR are closed subroutines.

The outline of the program shall be broken down into three sections: 1) Specification of Parameters, 2) Outline of Data, and 3) Main Program.

Specification of Parameters

This involves specifying various parameters before the problem can be worked. These parameters are essential to the solution of the problem. The parameters are used in conjunction with the S termination symbol to specify certain addresses within the program. The parameters which must be specified and stored in locations 3 - 11 are:

3) Specifies floating register for floating point subroutine
4) Number of components
5) Plates above feed plate
6) Plates below feed plate
7) Number of components x 4
8) Number of components x 8
9) Total number of plates less feed plate
10) Number of components expected in overhead product in appreciable amount
11) Number of components expected in bottom product in appreciable amount

For this program, location 3 is always the same and specifies location 28 as the floating register. All the other parameters may vary with the particular problem being worked. Perhaps the parameters specified in locations 10 and 11 should be made a little clearer. An example will be given to illustrate their use. In a given problem, there are eight components in the feed, and it is to be split in two products, the top product containing essentially the three most volatile components and the bottom product containing essentially the other five components. It is evident

that some of the light components will appear in the bottom product and some of the heavy components will appear in the top product, but in small amounts. In this case, location 10 will specify three components in overhead product and location 11 will specify five components in bottom product. The sum of locations 10 and 11 must always be equal to the total number of components in the feed. In the case of a component which will appear in both products in appreciable amounts, it won't matter where it is assumed to be in the greater amount.

The parameters are used primarily for the reading in of the program to the computer; and many of them are destroyed by storing other results in the same locations, once the program has been read in.

Outline of Data

There are certain bits of data that are necessary to work a problem, such as feed composition, feed condition, as well as initial estimates of certain variables which are to be determined by trial and error. Following is a list of essential data and the locations in which it is stored.

647-654	Assumed moles of each component leaving in overhead product
655	Initial estimate of still temperature
656	Integer one
657	Constant for bubble point and dew point convergence tests
658	Constant for temperature convergence
659	Reflux ratio ($^L/_D$)
660	Initial estimate of top temperature
661-663	Any other constants which are necessary when program alterntions are made
664	Initial estimate of vapor rate in stripping section
665-672	Mole fraction of each component in feed
673	Enthalpy of feed (BTU per mole)
674	Constant for ratio r convergence
675	Same as 661-663

The maximum number of components this program will handle is eight. If more memory space were available, the program could easily be altered to handle as many components as desired. The constants which must be specified for various convergence tests will depend on just how accurate an answer is desired. For example, in finding the temperature on a certain plate, the temperature is changed until the sum of the mole fractions is unity. However, to actually obtain unity might require very much time when a value of 1 ± .001 would serve just as well. In this case, then, the constant in location 657 would be .001.

When a feed is used which contains less than eight components, the remaining memory locations must be filled with some arbitrary constants. The reason being that the computer, in reading in the data, stores it consecutively. Thus, if the blank locations are not filled, the data following will be stored in a different location than specified. For the same reason, all data locations must be filled. It is also essential that in the feed composition, assumed Dx_D, and in the KSR and HSR the components are always in the same order.

Main Program

Outline of Storage Space

0, 1, 2	Temporary storage
3-11*	Parameter specification
10	Temperature storage for equilibrium and enthalpy subroutines

11-18	Storage of K and H values
20-27	Storage of h values
28-29	Floating accumulator (Specified by 3)
30-300	Program
300-356	Answer storage
357-398	Equilibrium constant subroutine
399-478	Enthalpy subroutine
479-646	Floating point subroutine
647-675	Data
676-686	Space for program alterations
687-706	Program
707-719	Space for program alterations
720-1023	Answer storage

*The parameters specified in locations 10 and 11 are destroyed after program is read in.

Outline of Answer Storage

300	D
301	W
302	$(\Sigma x_o/K)-1$, $(\Sigma K x_w)-1$
303	Qa
304	Qr
305	$-\phi$, ΔT_m, $-\theta$, ΔT_n
306	$\Sigma h_{m+1} L_{m+1}$, $-\phi'$, ΔL_{m+1}, $\Sigma V_{n-1} H_{n-1}$, θ', ΔV_{n-1}

307	Temperature storage in calculating $p_1 - p_4$, $q_1 - q_4$
308	$\Sigma H_m x_{m+1}$, $\Sigma H_{n-1} y_{n-1}$
309	$\Sigma h_{m+1} x_{m+1}$, $\Sigma h_n y_n$
310	p_1, $-q_1$
311	$-p_2$, $-q_2$
312	$-p_3$, $-q_3$
313	p_4, q_4
314	Constant for testing iterations through top of column
315	Used over and over for various sums
316	Constant for testing iterations through bottom of column
317-324	x_{oi}
325-332	x_{wi}
333-340	x_f as calculated from condenser downward
341-348	$y_{(n-1)i}$
349-356	x_{mi}
720-808	Temperature on various plates
813-905	Vapor rates from each plate
906-998	Liquid rates from each plate
999-1007	K values, r values
1008-1015	y_{mi}, y_{ni}
1016-1023	$x_{(m+1)i}$, x_{ni}

0030K

0)	41 314F	Put a zero in location 314
	50 L	Standard entry to subroutine
1)	26 479F	Enter floating point subroutine
	1K 29F	Set box 1 counter at 29
2)	88 F	Read in floating point fraction
	1S 647F	Store fraction in location 647
3)	13 2L	Loop to left side of location 2L
	85 660F	Bring in T_1
4)	8S 720F	Store T_1 in location 720
	85 655F	Bring in T_s
5)	8S 721S5	Store T_s in location 721S5
	85 664F	Bring in V_s
6)	8S 813S5	Store V_s in location 813S5
	5K F	Waste order (change for program alteration)
7)	8K F	Put zero in accumulator
	8S 316F	Store zero in location 316
8)	0K S5	Set box 0 for number of plates above feed
	1K S4	Set box 1 for number of components
9)	8K F	Put zero in accumulator
	14 647F	Add $D x_{0i}$ to accumulator
10)	12 9L	Loop to right side 9L
	8S 300F	Place $\Sigma D x_0$ in location 300

11)	87 659F	Multiply D by R
	8S 906F	Place DR = Lo in location 906
12)	84 300F	Add D to DR
	8S 813F	Place D(R + 1) = V_1 in location 813
13)	85 656F	Bring in integer 1
	80 300F	Subtract D
14)	8S 301F	Store 1-D = W in location 301
	1K S4	Set box 1 counter at S4
15)	15 665F	Bring in x_f
	10 647F	Subtract Dx_D
16)	86 301F	Divide by W
	1S 325F	Store $\frac{x_f - Dx_D}{W} = x_w$ in location 325
17)	13 15F	Loop to left side of location 15L
	1K S4	Set box 1 at S4
18)	15 647F	Bring in Dx_D
	86 300F	Divide by D
19)	1S 317F	Store $Dx_D/D = x_D$ in location 317
	13 18L	Loop to left side of location 18L
20)	85 720F	Bring in T_1
	8S 10F	Place T_1 in location 10 for KSR
21)	1K S4	Set box 1 at S4
	8J 22L	Leave A_1 go to left side of location 22L

22)	41 315F	Put zero in location 315
	50 22L	Standard entry to KSR
23)	26 357F	Transfer control to KSR
	15 317F	Bring in X_0 (equals y_1)
24)	16 11F	Divide by K
	1S 1016F	Store $y_1/K = X_1$ in location 1016
25)	84 315F	Add contents of location 315
	8S 315F	Store sum back in location 315
26)	12 23L	Loop to right side of location 23L
	80 656F	Subtract 1 from Σx_1
27)	8S 302F	Store $\Sigma x_1 - 1$ in location 302
	85 657F	Bring in convergence test constant
28)	8N 302F	Subtract absolute value of $(\Sigma x_1 - 1)$
	83 34L	If positive (convergence) go to left side of 34L; if minus, go on
29)	85 302F	Bring in $(\Sigma x_1 - 1)$
	83 32L	If positive (temperature too low) go to left side 32L
30)	85 720F	(Temperature too high) bring in T_1
	80 658F	Subtract temperature convergence constant
31)	8S 720F	Store new T_1 in location 720
	82 20L	T_1 always positive, so transfer to right side 20L

32)	85 720F	Bring in T_1 (temperature too low)
	84 658F	Add temperature convergence constant
33)	8S 720F	Store new T_1 in location 720
	82 20L	Transfer control to right side 20L
34)	85 721S5	Bring in T_s
	8S 10F	Place in location 10 for KSR
35)	1K S4	Set box 1 counter at S4
	8J 36L	Leave A_1, transfer to left side location 36L
36)	41 315F	Place zero in location 315
	50 36L	Standard entry to KSR
37)	26 357F	Transfer control to KSR
	15 325F	Bring in X_w
38)	17 11F	Multiply by K
	1S 341F	Place $X_w \cdot K = Y_s$ in location 341
39)	84 315F	Add contents of location 315
	8S 315F	Store sum in location 315
40)	12 37L	Loop to right side location 37L
	80 656F	Subtract 1 from Σy_s
41)	8S 302F	Store $-(1 - \Sigma y_s)$ in location 302
	85 657F	Bring in convergence test constant
42)	8N 302F	Subtract absolute of $-(1 - \Sigma y_s)$
	83 48L	If positive (convergence) go to left side 48L

43)	85 302F	Bring in $-(1 - \Sigma y_s)$
	83 46L	If plus (temperature too high) go to left side 48L
44)	85 721S5	Bring in T_s
	84 658F	Add temperature convergence constant
45)	8S 721S5	Store new T_s in location 721S5
	82 34L	Transfer to right side of 34L
46)	85 721S5	Bring in T_s
	80 658F	Subtract temperature convergence constant
47)	8S 721S5	Store new T_s in location 721S5
	82 34L	Transfer to right side 34L
48)	85 660F	Bring in initial estimate of T_1
	8S 10F	Place in location 10 for KSR
49)	1K S4	Set box 1 counter at S4
	8J 50L	Leave A_{1}, and go to left side of 50L
50)	41 315F	Store zero in location 315
	50 50L	Standard entry to KSR
51)	26 357F	Transfer control to KSR
	15 11F	Bring in K_i
52)	17 317F	Multiply by X_{oi}
	84 315F	Add contents of location 315
53)	8S 315F	Place sum in location 315
	12 51L	Loop to right side of 51L

54)	80 656F	Subtract 1 from Σ K X_D
	8S 302F	Store -(1 - Σ K x_D) in location 302
55)	85 657F	Bring in convergence test constant
	8N 302F	Subtract absolute of -(1 - Σ K x_D)
56)	82 61L	If plus (convergence) transfer to right side 61L
	85 302F	Bring in -(1 - Σ K x_D)
57)	82 59L	If plus (temperature too high) go to right side 59L
	85 660F	Bring in T_c
58)	84 658F	Add temperature convergence constant
	8S 660F	Store new T_c in location 660
59)	82 48L	Transfer to right side of 48L
	85 660F	Bring in T_c
60)	80 658F	Subtract temperature convergence constant
	8S 660F	Store new T_c in 660
61)	82 48L	Transfer to right side of 48L
	85 660F	Bring in T_c
62)	8S 10F	Store in location 10 for HSR
	8J 63L	Leave A_1, transfer to right side 63L
63)	41 315F	Place zero in location 315
	50 63L	Standard entry to HSR

64)	26 399F	Transfer control to HSR
	1K S4	Set box 1 at S4
65)	15 20F	Bring in $\bar{h}$
	17 317F	Multiply by X_0
66)	84 315F	Add contents of location 315
	8S 315F	Place sum in location 315
67)	13 65L	Loop to left side location 65L
	87 906F	Multiply h_c by L_o
68)	8S 315F	Store $h_c L_o$ in location 315
	8K 2F	Place interger 2 in accumulator
69)	83 687F	Transfer control to left side 687
	8K F	Waste order
70)	05 721F	Bring in T_m
	8S 10F	Place in location 10 for KSR
71)	1K S4	Set box 1 counter at S4
	8J 72L	Leave A_1, transfer to left side 72L
72)	41 315F	Place zero in location 315
	50 72L	Standard entry to KSR
73)	26 357F	Transfer control to KSR
	15 11F	Bring in K_i
74)	1S 999F	Store K_i in location 999
	12 73L	Loop to right side of location 73L

75) 05 907F Bring in L_{m+1}

84 300F Add D

76) 0S 814F Store $L_{m+1} + D = V_m$ in location 814

1K S4 Set box 1 counter at S4

77) 05 907F Bring in L_{m+1}

17 1016F Multiply by X_{m+1}

78) 14 647F Add X_0

06 814F Divide by V_m

79) 1S 1008F Store Y_m in location 1008

13 77L Loop to left side location 77L

80) 1K S4 Set box 1 counter at S4

15 1008F Bring in Y_m

81) 16 999F Divide by K

1S 349F Store $y_m / K_m = x_m$ in location 349

82) 84 315F Add contents of location 315

8S 315F Store sum in location 315

83) 12 80L Loop to right side of location 80L

80 656F Subtract 1 from Σx_m

84) 8S 305F Store $-1 + \Sigma x_m = -\phi$ in location 305

05 720F Bring in T_{m+1}

85) 8S 10F Place T_{m+1} in location 10 for HSR

8J 86L Leave A_1, transfer to left side of 86L

86)	41 309F	Place zero in location 309
	50 86L	Standard entry to HSR
87)	26 399F	Transfer control to HSR
	4K S4	Set box 4 counter at S4
88)	45 20F	Bring in $\bar{h}$
	47 1016F	Multiply by X_{m+1}
89)	84 309F	Add contents of location 309
	8S 309F	Store sum in location 309
90)	43 88L	Loop to left side of location 88L
	07 907F	Multiply by L_{m+1}
91)	8S 306F	Store $L_{m+1} \cdot h_{m+1}$ in location 306
	05 721F	Bring in T_m
92)	8S 10F	Place T_m in location 10 for HSR
	8J 93L	Leave $A_{I,J}$ transfer to left side of 93L
93)	41 315F	Place zero in location 315
	50 93L	Standard entry to HSR
94)	26 399F	Transfer control to HSR
	4K S4	Set box 4 counter at S4
95)	8K F	Bring in zero
	8S 308F	Store zero in location 308
96)	45 11F	Bring in $\bar{H}_m$
	47 1016F	Multiply by X_{m+1}

97)	84 308F	Add contents of location 308
	8S 308F	Place sum in location 308
98)	45 11F	Bring in $\bar{h}_m$
	47 1008F	Multiply by Y_m
99)	84 315F	Add contents of location 315
	8S 315F	Place sum in location 315
100)	43 96L	Loop to left side of location 96L
	07 814F	Multiply by V_m
101)	80 306F	Subtract L_{m+1} h_{m+1}
	86 303F	Divide by Q_a
102)	80 656F	Subtract integer 1
	8S 306F	Store $-\phi'$ in location 306
103)	1K 4F	Set box 1 counter at 4
	8K F	Place zero in accumulator
104)	1S 310F	Place zero in location 310
	13 104L	Loop to left side of 104L
105)	1K F	Set box 1 counter at zero
	2K S4	Set box 2 counter at S4
106)	8K 3F	Bring in integer 3
	17 367F	Multiply by d_K
107)	07 721F	Multiply by Tm
	8S 307F	Store 3dkTm in location 307

108)	8K 2F	Bring in integer 2
	17 368F	Multiply by c_K
109)	84 307F	Add $3d_K Tm$
	07 721F	Multiply by Tm
110)	14 369F	Add b_K
	27 349F	Multiply by X_m
111)	84 310F	Add contents of location 310
	8S 310F	Store sum in location 310
112)	1L 4F	Increase increment of box 1 by 4
	23 106L	Loop to left side of location 106L
113)	1K S4	Set box 1 counter at S4
	15 1016F	Bring in X_{m+1}
114)	10 1008F	Subtract Y_m
	16 999F	Divide by K_m
115)	84 311F	Add contents of location 311
	8S 311F	Store sum in location 311
116)	12 113L	Loop to right side of 113L
	06 814F	Divide by V_m
117)	8S 311F	Store $-\rho_2$ in location 311
	1K F	Set box 1 counter at zero
118)	2K S4	Set box 2 counter at S4
	8K 3F	Bring in integer 3

119)	17 416F	Multiply by d_h
	07 721F	Multiply by T_m
120)	8S 307F	Store in location 307
	8K 2F	Bring in integer 2
121)	17 417F	Multiply by c_h
	84 307F	Add $3d_h T_m$
122)	07 721F	Multiply by T_m
	14 418F	Add b_h
123)	27 1008F	Multiply by Y_m
	84 312F	Add contents of location 312
124)	8S 312F	Store sum in location 312
	1L 4F	Increase increment of box 1 by 4
125)	22 118L	Loop to right side of location 118L
	07 814F	Multiply by V_m
126)	86 303F	Divide by Q_a
	8S 312F	Store $-p_3$ in location 312
127)	85 309F	Bring in $\Sigma \bar{h}_{m+1} x_{m+1}$
	80 308F	Subtract $\Sigma \bar{H}_m x_{m+1}$
128)	86 303F	Divide by Q_a
	8S 313F	Store p_4 in location 313
129)	85 311F	Bring in $-p_2$
	87 312F	Multiply by $-p_3$

130)	8S 308F	Store $p_2\,p_3$ in location 308
	85 313F	Bring in p_4
131)	87 310F	Multiply by p_1
	80 308F	Subtract $p_2\,p_3$
132)	8S 308F	Store $p_4\,p_1 - p_2\,p_3$ in location 308
	85 311F	Bring in $-p_2$
133)	87 306F	Multiply by $-\phi'$
	8S 309F	Store $p_2\,\phi'$ in location 309
134)	81 305F	Bring in ϕ
	87 313F	Multiply by p_4
135)	80 309F	Subtract $p_2\phi'$
	86 308F	Divide by $p_4\,p_1 - p_2\,p_3$
136)	8S 305F	Store ΔT_m in location 305
	85 312F	Bring in $-p_3$
137)	87 305F	Multiply by ΔT_m
	80 306F	Subtract $-\phi'$
138)	86 313F	Divide by p_4
	8S 306F	Store ΔL_{m+1} in location 306
139)	05 721F	Bring in old T_m
	80 305F	Subtract ΔT_m
140)	0S 721F	Store new T_m in location 721
	05 907F	Bring on old L_{m+1}

141)	80 306F	Subtract ΔL_{m+1}
	0S 907F	Store new L_{m+1} in location 907
142)	85 305F	Bring in ΔT_m
	8N 658F	Subtract absolute of temperature convergence constant
143)	82 69L	If plus not convergence, transfer to right side 69L
	85 306F	Bring in ΔL_{m+1}
144)	8N 657F	Subtract absolute of temperature convergence constant
	82 69L	If plus not convergence, go to right side 69L
145)	1K S4	Set box 1 counter at S4
	15 349F	Bring in X_m
146)	1S 1016F	Store X_m in 1016 (now becomes X_{m+1})
	12 145L	Loop to right side 145L
147)	02 695F	Next plate, loop to right side 695
	1K S4	Set box 1 counter at S4
148)	15 349F	Bring in X_m (feed plate composition)
	1S 333F	Store in location 333
149)	13 148L	Loop to left side 148L
	8K 2F	Bring in integer 2
150)	83 181F	Transfer to left side location 181
	83 181F	Waste order

00181K

0)	0K S6	Set box 0 counter at S6
	8J 1L	Leave A_1, transfer to left side 1L
1)	L5 316F	Bring in loop counter constant
	L0 6F	Subtract number of plates below feed
2)	36 7L	If plus, go to left side 7L
	F5 316F	Bring in loop constant and add 1 to it
3)	40 316F	Store new loop constant at 316
	50 3L	Standard entry to A_1
4)	26 479F	Transfer control to A_1
	05 721S5	Bring in T_s
5)	0S 722S5	Store T_n in location 722S5
	05 813S5	Bring in V_{n-1}
6)	0S 814S5	Store V_{n-1} in 814S5
	82 7L	Transfer control to right side 7L
7)	22 704F	(MISTIC) transfer to right side 704
	05 814S4	Bring in V_{n-1}
8)	84 301F	Add W
	0S 907S5	Store $V_{n-1} + W = L$ in location 907S5
9)	1K S4	Set box 1 counter at S4
	15 341F	Bring in Y_{n-1}
10)	07 814S5	Multiply by V_{n-1}
	1S 1016F	Store in 1016

11)	85 301F	Bring in W
	17 325F	Multiply by X_w
12)	14 1016F	Add V_{n-1} y_{n-1}
	06 907S5	Divide by L_n
13)	1S 1016F	Store X_{ni} in location 1016
	12 9L	Loop to right side of 9L
14)	05 722S5	Bring in T_n
	8S 10F	Place T_n in location 10 for KSR
15)	1K S4	Set box 1 counter at S4
	8J 16L	Leave A_1, go to right side of 16L
16)	41 315F	Place zero in 315
	50 16L	Standard entry to KSR
17)	26 357F	Transfer control to KSR
	15 11F	Bring in K
18)	1S 999F	Store K at location 999
	17 1016F	Multiply by x_n
19)	1S 1008F	Store Y_n in location 1008
	84 315F	Add contents of location 315
20)	8S 315F	Place sum in location 315
	12 17L	Loop to right side of 17L
21)	80 656F	Subtract 1
	8S 305F	Store $(\Sigma y_n - 1) = -\theta$ in location 305

22)	05 721S5	Bring in T_{n-1}
	8S 10F	Store T_{n-1} in location 10 for HSR
23)	1K S4	Set box 1 counter at S4
	8J 24L	Leave A_1, go to left side 24L
24)	41 308F	Place zero in location 308
	50 24L	Standard entry to HSR
25)	26 399F	Transfer control to HSR
	15 11F	Bring in $\bar{H}$
26)	17 341F	Multiply by y_{n-1}
	84 308F	Add contents of location 308
27)	8S 308F	Store sum in location 308
	12 25L	Loop to right side of location 25L
28)	07 814S5	Multiply by V_{n-1}
	8S 306F	Store $H_{n-1} \cdot V_{n-1}$ in location 306
29)	05 722S5	Bring in T_n
	8S 10F	Store T_n in location 10 for HSR
30)	1K S4	Set box 1 counter at S4
	8J 31L	Leave A_1, transfer to left side 31L
31)	41 315F	Store zero in location 315
	50 31L	Standard entry to HSR
32)	26 399F	Transfer control to HSR
	8K F	Put zero in accumulator

33)	8S 309F	Store zero in location 309
	15 20F	Bring in $\bar{h}$
34)	17 1008F	Multiply by y_n
	84 309F	Add contents of location 309
35)	8S 309F	Store sum in location 309
	15 20F	Bring in $\bar{h}$
36)	17 1016F	Multiply by X_n
	84 315F	Add contents of location 315
37)	8S 315F	Store sum in location 315
	12 33L	Loop to right side of location 33L
38)	87 907S5	Multiply by L_n
	80 306F	Subtract V_{n-1} H_{n-1}
39)	86 304F	Divide by Q_{*}
	84 656F	Add integer 1
40)	8S 306F	Store θ' in location 306
	1K 4F	Set box 1 counter at 4
41)	8K F	Bring in zero
	1S 310F	Store zero in location 310
42)	12 41L	Loop to right side location 41L
	1K F	Set box 1 counter at zero
43)	2K S4	Set box 2 counter at S4
	8K 3F	Bring in integer 3

44)	17 367F	Multiply by d_K
	07 722S5	Multiply by T_n
45)	8S 307F	Store $3d_KT_n$ in location 307
	8K 2F	Bring in integer 2
46)	17 368F	Multiply by c_K
	84 307F	Add $3d_KT_n$
47)	07 722S5	Multiply by T_n
	14 369F	Add b_K
48)	27 1008F	Multiply by Y_n
	84 310F	Add contents of location 310
49)	8S 310F	Store sum in location 310 ($-q_1$)
	1L 4F	Increase box 1 counter by 4
50)	22 43L	Loop to right side of location 43L
	1K S4	Set box 1 counter at S4
51)	15 341F	Bring in Y_{n-1}
	10 1016F	Subtract X_n
52)	17 999F	Multiply by K_n
	84 311F	Add contents of location 311
53)	8S 311F	Store sum in location 311
	13 51L	Loop to left side of location 51L
54)	06 907S5	Divide by L_n
	8S 311F	Store $-q_2$ in location 311

55)	1K F	Set box 1 counter at zero
	2K S4	Set box 2 counter at S4
56)	8K 3F	Bring in integer 3
	17 416F	Multiply by d_h
57)	07 722S5	Multiply by T_n
	8S 307F	Store $3d_hT_n$ in location 307
58)	8K 2F	Bring in integer 2
	17 417F	Multiply by c_h
59)	84 307F	Add $3d_hT_n$
	07 722S5	Multiply by T_n
60)	14 418F	Add b_h
	27 1016F	Multiply by X_n
61)	84 312F	Add contents of location 312
	8S 312F	Store sum in location 312
62)	1L 4F	Increase box 1 counter by 4
	23 56L	Loop to left side of location 56L
63)	86 304F	Divide by Q_r
	07 907S5	Multiply by L_n
64)	8S 312F	Store $-q_3$ in location 312
	85 309F	Bring in $h_n Y_n$
65)	80 308F	Subtract $\bar{H}_{n-1}\ Y_{n-1}$
	86 304F	Divide by Q_r

66)	8S 313F	Store q_4 in location 313
	85 311F	Bring in - q_2
67)	87 312F	Multiply by - q_3
	8S 307F	Store q_2q_3 in location 307
68)	81 310F	Bring in q_1
	87 313F	Multiply by q_4
69)	80 307F	Subtract q_2q_3
	8S 307F	Store in location 307
70)	81 305F	Bring in θ
	87 313F	Multiply by q_4
71)	8S 305F	Store θq_4 in location 305
	85 311F	Bring in - q_2
72)	87 306F	Multiply by θ'
	84 305F	Add θq_4
73)	86 307F	Divide by $q_1q_4 - q_2q_3$
	8S 305F	Store ΔT_n in location 305
74)	85 312F	Bring in - q_3
	87 305F	Multiply by ΔT_n
75)	84 306F	Add θ'
	86 313F	Divide by q_4
76)	8S 306F	Store ΔV_{n-1} in location 306
	05 722S5	Bring in T_n (old)
77)	80 305F	Subtract ΔT_n
	0S 722S5	Store new T_n in location 722S5

78)	05 814S5	Bring in old V_{n-1}
	80 306F	Subtract ΔV_{n-1}
79)	0S 814S5	Store new V_{n-1} in location 814S5
	85 305F	Bring in ΔT_n
80)	8N 658F	Subtract temperature convergence constant
	82 7L	If plus (not convergence) loop to right side 7L
81)	85 306F	Bring in ΔV_{n-1}
	8N 657F	Subtract convergence test constant
82)	82 7L	If plus (not convergence) loop to right side 7L
	1K S4	Convergence, so set box 1 counter at S4
83)	15 1008F	Bring in yn
	1S 341F	Store yn in location 341 (now becomes Yn-1)
84)	13 83L	Loop to left side of location 83L
	02 181F	Next plate, loop to right side location 181
85)	1K SK	Set box 1 counter at SK
	15 333F	Bring in X_f as calculated from condenser downward
86)	16 1016F	Divide by X_f as calculated from reboiler upward
	1S 999F	Store r in location 999

87) 87 301F Multiply by W

17 325F Multiply by X_w

88) 8S 302F Store $r W x_w$ in location 302

81 302F Bring in $- r W x_w$

89) 14 665F Add x_f (also equals F x_f)

1S 647F Store revised D x_D in location 647

90) 12 85L Loop to right side of location 85L

1K SS Set box 1 counter at SS

91) 15 333SK Bring in X_f as calculated from top down

16 1016SK Divide by X_f as calculated from bottom up

92) 1S 999SK Store r in location 999SK

15 647SK Bring in previous D x_D

93) 16 999SK Divide by r

1S 647SK Store D x_D revised in location 647SK

94) 13 91L Loop to left side of location 91L

1K S4 Set box 1 counter at S4

95) 15 999F Bring in r

80 656F Subtract integer one

96) 8N 674F Subtract absolute of convergence constant

82 98L If plus must reiterate, transfer to right side 98L

97) 13 95L If above minus component converged, test next component

8K 2F Bring in integer 2 to make plus

98)	82 99L	Transfer control to right side location 99L
	8K 2F	Make plus for next order to be obeyed
99)	83 38F	Reiterate through entire tower
	8K F	Bring in zero
100)	8S 314F	Store zero in location 314 (for additional reflux ratios)
	8K F	Waste order
101)	1K 1S5	Set box 1 counter at 1S5
	15 720F	Bring in temperatures above feed plate
102)	8 96F	Output temperature
	12 101L	Loop to right side of location 101L
103)	1K S6	Set box 1 counter at S6
	15 720S9	Bring in temperatures below feed (in reverse order)
104)	89 6F	Output temperature
	1L 1022F	Used to output temperatures in forward order
105)	12 103L	Loop to right side of location 103L
	1K 1S5	Set box 1 counter at 1S5
106)	15 906F	Bring in liquid rates above feed plate
	89 6F	Output liquid rates
107)	13 106L	Loop to left side of location 106L
	1K S6	Set box 1 counter at S6

108)	15 906S9	Bring in liquid rates below feed (reverse order)
	89 6F	Output liquid rate
109)	1L 1022F	Used to output liquid rates in forward order
	13 108L	Loop to left side of location 108L
110)	1K 1S5	Set box 1 counter at 1S5
	15 813F	Bring in vapor rates above feed
111)	89 6F	Output vapor rate
	12 110L	Loop to right side of location 110L
112)	1K S6	Set box 1 counter at S6
	15 813S9	Bring in vapor rates below feed (reverse order)
113)	89 6F	Output vapor rates
	1L 1022F	Used to output vapor rates in forward order
114)	12 112L	Loop to right side of location 112L
	1K 16F	Set box 1 counter at 16
115)	15 317F	Bring in X_D and X_W
	89 6F	Output X_D and X_W
116)	13 115L	Loop to left side of location 115L
	85 300F	Bring in D

117) 89 6F		Output D
	8J 118L	Leave A_1 , transfer to location 118L
118) 0F F		Shuts machine off
	0F F	Waste order

00 687K

0)	85 720F	Bring in T_1
	8S 10F	Store T_1 in location 10 for HSR
1)	1K S4	Set box 1 counter at S4
	8J 2L	Leave A_1 , transfer to left side 2L
2)	41 303F	Store zero in location 303
	50 2L	Standard entry to HSR
3)	26 399	Transfer control to HSR
	15 11F	Bring in $\bar{H}_1$
4)	17 317F	Multiply by X_D
	84 303F	Add contents of location 303
5)	8S 303F	Store sum in location 303
	12 3L	Loop to right side of location 3L
6)	87 813F	Multiply by L_o
	80 315F	Subtract h_o
7)	8S 303F	Store Q_a in location 303
	80 673F	Subtract H_f
8)	8S 304F	Store Q_r in location 304
	8J 9L	Leave A_1 , transfer to 9L

9)	L5 314F	(MISTIC) Bring in loop counter
	L0 5F	Subtract contents of location 5
10)	32 15L	If plus go to right side of 15L
	F5 314F	Bring in contents of 314 and add one
11)	40 314F	Store in location 314
	50 11L	Standard entry to A_1
12)	26 479F	Enter A_1
	05 900F	Bring in V_n
13)	0S 907F	Store in location 907
	05 720F	Bring in T_n
14)	0S 721F	Store in location 721
	8K 2F	Bring in integer 2
15)	82 16L	Transfer to right side 16L
	50 15L	Standard entry to A_1
16)	26 479F	Transfer control to A_1
	8K 2F	Bring in integer 2 (makes plus)
17)	83 100F	Transfer to left side location 100
	50 17L	Standard entry to A_1
18)	26 479F	Enter A_1
	8K 2F	Bring in integer 2
19)	82 188F	Transfer to location 188
	82 188F	Waste order

There are many ways in which the foregoing program may be altered to perform a desired calculation. Several of the possible desirable alterations which have been made shall now be discussed.

In an investigation such as this where many problems must be solved, the program as it stands would only allow one problem to be worked, then the computer would shut off. If more problems were desired to be run, the new problem would then have to be read into the computer. It is desirable, then, to be able to put five, ten, or even twenty problems on one tape, and let the computer solve them all one after the other. The only major change which must be made is to remove the order which instructs the machine to shut off and to replace it by a transfer of control order to some location where the program alterations are to be stored.

If one desires a given problem to be worked for various values of reflux ratio, holding everything else constant, this may be accomplished very simply by changing the right hand order in location 36 to be SK(n)F, where (n) is the number of various reflux ratios to be run. Then it would only require a few new orders which would change the reflux ratio as desired and start the problem over using the new reflux ratio. This could be accomplished by either instructing the computer to read in more tape (on which the new reflux ratio would be) or by changing R in a stepwise manner, such as by increasing it by five each time.

As mentioned in the section on the MISTIC computer itself, it is necessary to use DOI when reading in more tape. Because of the limited storage space in the computer, the DOI has been overwritten and thus destroyed. Before anything can be read in again, DOI must be read once again and stored in its proper locations. Thus, whenever the main program is altered to read in more data instead of shutting off, the DOI must be the first thing on the tape. The computer may be instructed to read the DOI by writing a bootstrap start in the program alteration. Even though the DOI, when read in again, will destroy some of the stored answers, nothing is hurt since the solution was already completed and the new problem will simply store its answers overtop the new DOI just read in.

Other variables which can be changed by slight program alterations are: 1) number of plates in the column, or simply the location of the feed plate, and 2) the feed composition. If any changes are desired in the data to the program, such as feed composition or reflux ratio, the entire set of data must be made up, even though many of the things remain the same.

If it is desired to change the number of plates or the feed plate location, then only the orders which use the S termination symbol followed by a 5, 6, or 9 must be repeated. This is because they are the only orders which will be changed in this case. Because this change in number of plates was a common occurrence in this investigation, a special tape containing only the orders which would change (S5, S6, and S9 orders) was made up and used frequently.

Another program alteration which was used mainly at first to see if the program was working was to instruct the computer to punch out the composition of liquid on each plate for each iteration. By doing this, one can see how fast the problem is converging and also see how many iterations are required.

Through the cooperation of the computer laboratory staff, problems for this investigation were many times run off at night. In these instances, the foregoing program alterations were made use of to prepare problems which would run all night and require no watching. Many times, tapes were prepared which contained several combinations of feed composition, reflux ratio, number of plates, and feed plate location.

One improvement which could be made in this program, if more storage space were available, would be to include various tests and checks to make sure certain physical laws are not broken, such as negative equilibrium constants. The computer could be instructed to shut off if such a thing occurred, or could go on to the next problem, if a program alteration were used to run a series of problems.

DATA AND DISCUSSION OF RESULTS

At first glance at the data, the reaction one might have is that it does not matter much where the feed plate is located. This, in a majority of cases, results in overdesign if the optimum feed location is not used and the column still carries out the desired separation. Of course, only in special cases such as stripping columns, will the optimum location be near either extreme of the column.

The variables which were studied to see if optimum location changed were: 1) feed composition, 2) reflux ratio, 3) number of plates, 4) condition of feed, and 5) tower pressure.

It was generally found that for most feed compositions, the optimum location for the feed plate varied from 55-75% of the way from the bottom of the column upward. If either extreme of mostly all light key or heavy key in the feed were approached, the optimum would be near the top of the column for high heavy key concentrations and near the bottom for high light key concentrations.

The method of determining the degree of separation in a multicomponent problem may take on different forms depending upon what is being attempted in the column. The criterion for separation used in this investigation was concerned with: 1) the highest purity of light key in the overhead product (with particular attention paid to the amount of heavy key there also) and 2) the maximum recovery of light key in the overhead and the heavy key in the residue. The maximum recovery was taken as the maximum of the sums of the recovery of light key out the overhead and the recovery of heavy key out in the residue. This criterion was found to agree very well with the criterion of purity of products. The various variables involved will now be discussed individually.

Composition of Feed

This was without a doubt the most studied variable of those involved. Many different feed compositions were tested to see how the optimum feed plate location might change with composition.

Key components are those components between which the actual separation is made, and not the components which may be specified in attempting to obtain a desired product. The key components depend upon pressure, condenser duty, and top and bottom temperatures. Upon fixing these variables, the key components are fixed and one has no choice but to take what separation is obtained for a given number of plates. The key components in all the calculations made were butane and isopentane.

Table I

	Temp ^{o}F	Feed Composition					$\frac{X_{HK}X_{LK} + X_{LK}}{X_{LK} + X_{HK}}$
		i-But.	n-But.	i-Pent.	n-Pent.	Hex.	
Feed A	126	.20	.25	.15	.20	.20	.72
Feed B	128	.10	.30	.30	.20	.10	.65
Feed C	125	.10	.50	.20	.10	.10	.86
Feed D	117	.10	.60	.10	.10	.10	.94
Feed E	109	.05	.70	.10	.10	.05	.96
Feed F	137	.30	.30	.15	.15	.10	.77
Feed G	113	.10	.20	.40	.20	.10	.47
Feed H	123	.10	.15	.50	.15	.10	.35
Feed I	100	.30	.30	.15	.15	.10	.77
Feed J*	137	.30	.30	.15	.15	.10	.77

*Feed J at 150 psi, all others at 100 psi.

It has been previously mentioned that for the extreme cases of nearly all light key or heavy key in the feed, the optimum location of feed plate would approach the bottom or the top of the column. To take advantage of this, the function $\frac{X_{HK}X_{LK} + X_{LK}}{X_{HK} + X_{LK}}$ was used as the means of defining the composition of the feed in terms of the key

DATA AND DISCUSSION OF RESULTS

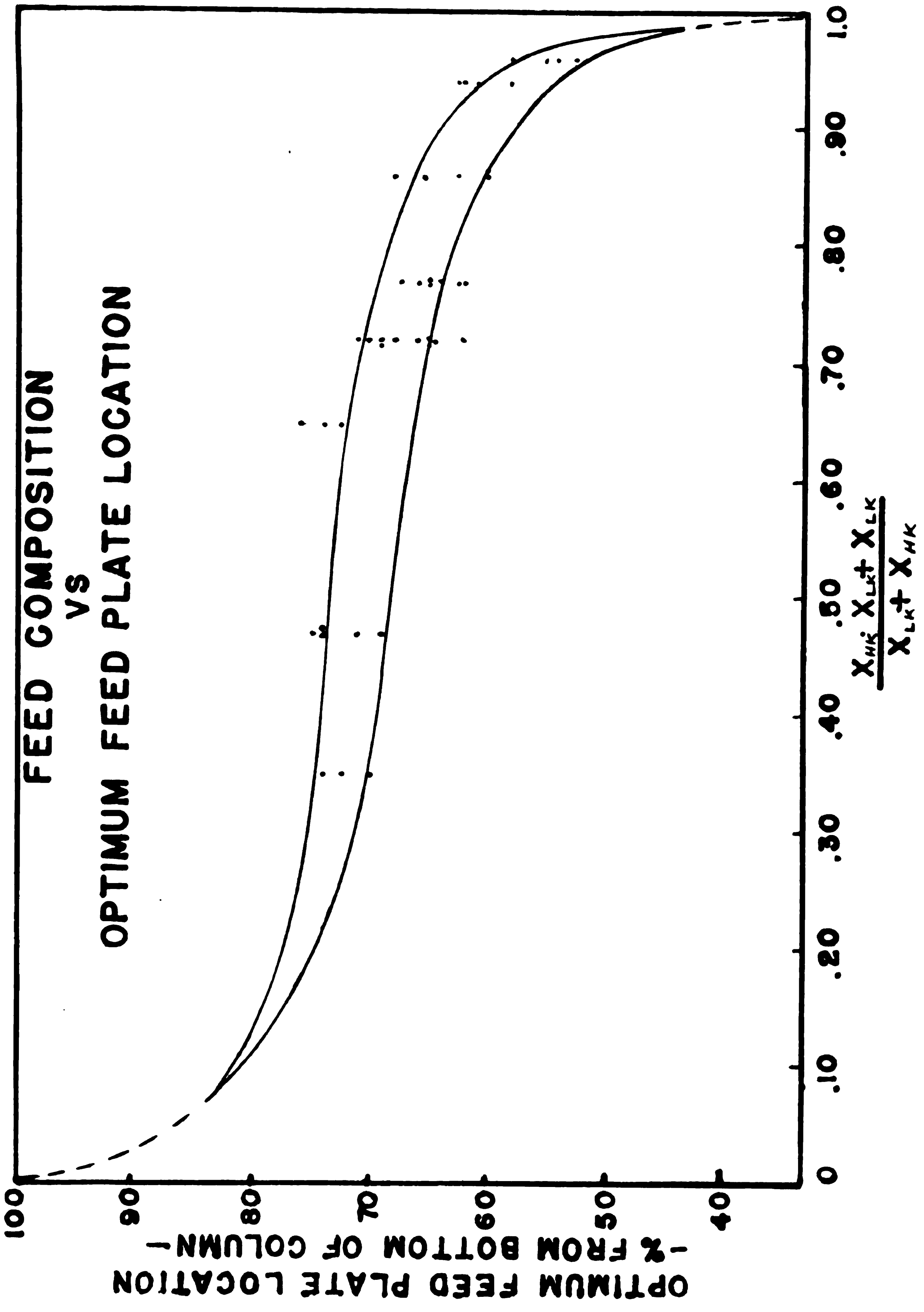
FEED COMPOSITION
VS
OPTIMUM FEED PLATE LOCATION
OPTIMUM FEED PLATE LOCATION
-% FROM BOTTOM OF COLUMN-
100
90
80
70
60
50
40
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
X_HK · X_LK + X_LK
X_LK + X_HK

Figure 5

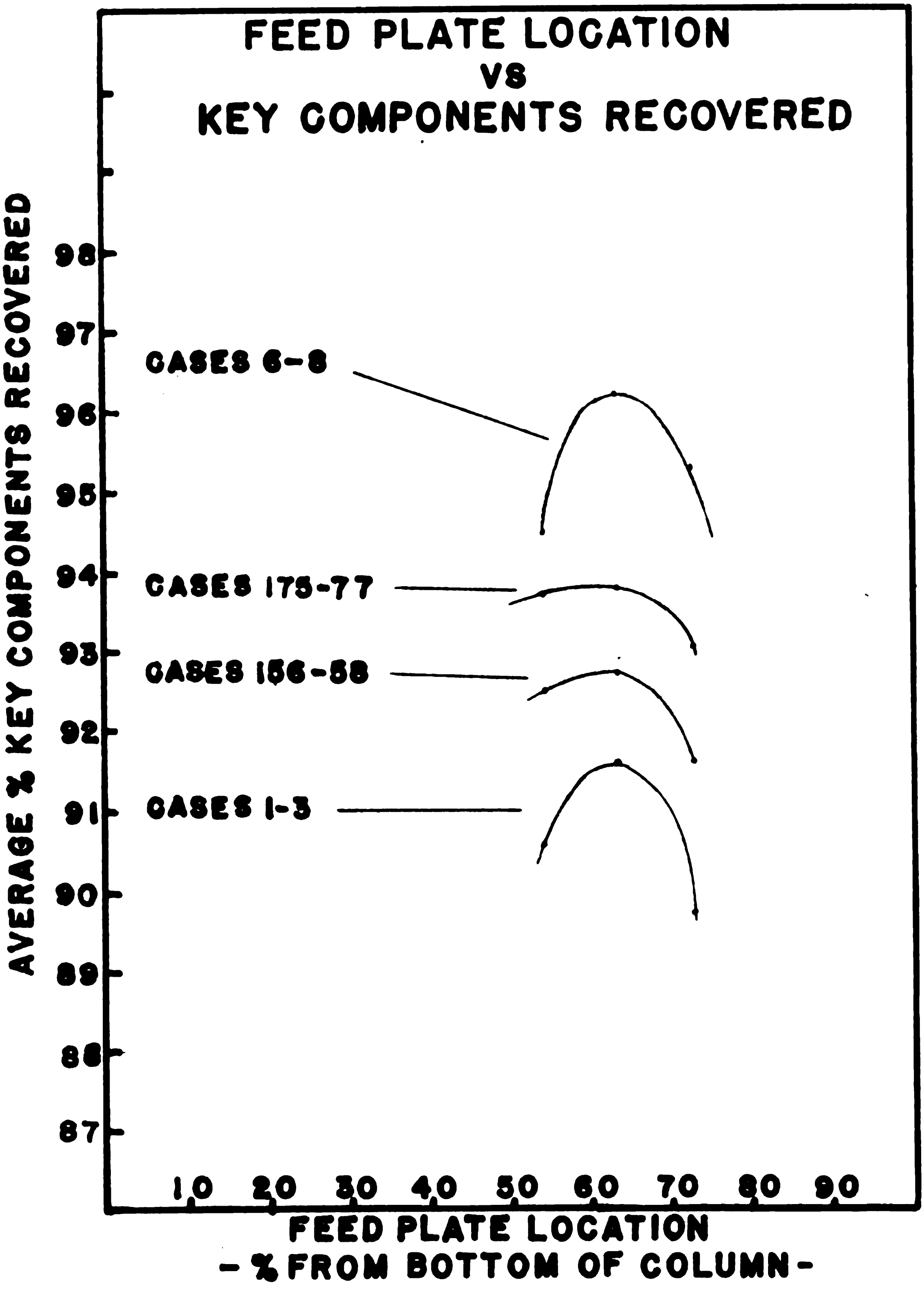
FEED PLATE LOCATION
VS
KEY COMPONENTS RECOVERED
AVERAGE % KEY COMPONENTS RECOVERED
98
97
96
95
94
93
92
91
90
89
88
87
CASES 6-8
CASES 175-77
CASES 156-58
CASES 1-3
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
FEED PLATE LOCATION
- % FROM BOTTOM OF COLUMN -

Figure 6

components. Figure 5 shows the results of plotting this function versus optimum feed plate location expressed in percentages from the bottom of the column. The data does not cover the entire range of feed composition; but does, however, cover most cases which will normally be met (see Table I). The ends of the curve are dotted since they are strictly empirical. By examining the abscissa of Figure 5, it can be seen that when the feed is all light key ($X_{HK} = 0$) then the function goes to 1 and the optimum location of feed plate should approach the bottom of the column. When the feed is all heavy key ($X_{LK} = 0$) then the function goes to zero and the optimum feed plate location approaches the top of the column.

Figure 5 was determined using the data of Table II (see Appendix). The maximum separation, and thus the optimum location of feed plate, was determined by plotting the average of the per cent light key recovered out the overhead and the per cent heavy key recovered out the bottom, versus feed plate location. Typical plots are shown in Figure 6. The optimum feed plate location was then plotted versus the function describing the feed composition in Figure 5. The band was drawn in to include the points scattered, due to changes in reflux ratio, feed condition, and column pressure, as well as to include the "band" of optimum locations observed for several columns.

It is felt that the most important variable not investigated was that of variation of relative volatility between the key components. Although some problems were solved using a six-component feed, nearly all the problems solved in this investigation had a feed composed of the same five hydrocarbons. Any future work in this field should include this variable, as well as including components other than aliphatic hydrocarbons.

Reflux Ratio

By examining Table II for cases 1-81 and cases 82-155, which illustrate variation of reflux ratio, it can be seen that the degree of separation increases with reflux ratio. This is true up to a high value of reflux ratio, and then the products obtained remain the same with increasing reflux ratio. From plots of the type shown in Figure 6, it was found that the optimum feed plate location remained nearly the same for various reflux ratios. There is only a slight shift of the optimum feed plate location upward in the column with increased reflux ratio.

<u>Number of Plates</u>

Once again, the number of plates in a column has very little effect on the relative optimum feed plate location, that is, the feed plate location expressed as a percentage, such as used in Figure 5. In towers with a small number of plates (11) the optimum location sometimes resulted in a specific location, rather than a band of feed plate locations, which occurred in many columns with more plates. This band occurred due to the flat shape of the separation versus feed plate location curve (Figure 6.)

The columns with 21 and 31 plates which were calculated often had pinch points where the composition and temperatures did not change from one plate to the next. One set of problems was solved using 41 plates and the same relative optimum feed plate location was obtained as for columns with 21 and 31 plates. However, because of the increased number of plates in the pinch region, the optimum location band was slightly widened.

<u>Condition of Feed</u>

To determine if the optimum feed plate location changed with the condition of feed, that is, hot or cold feed, the same feed composition was used at two different temperatures. Feed F was at 137°F and Feed I at 100°F. Cases 211-222 and 254-268 are the solutions applicable here. In this case, the optimum location was not affected by the change of feed condition. It seems safe to generalize that, at least for all liquid feed, the condition of the feed will not affect the relative optimum feed plate location. However, caution should be used in extending this generalization to include vapor feeds.

Tower Pressure

Since the tower pressure is not an independent variable in commercial design but must be compatible with condenser temperature and product specifications, it is difficult to determine the effect of pressure on the optimum feed plate location.

The only check was the comparison of Feed F with Feed J (cases 211-222 and 269-282.) Feed J was used in a column at 150 psi pressure while the column for Feed F and all other cases were at 100 psi.

Although slightly different products were obtained, no appreciable change in optimum feed plate location was found.

CONCLUSIONS

CONCLUSIONS

1. A rigorous method for the solution of multicomponent distillation problems has been developed and programmed for a high speed digital computer.
2. Several hundred problems have been solved rigorously to use in making a correlation of optimum feed plate location.
3. From these numerous solutions, a correlation between the optimum feed plate location and the feed composition has been made. The function $\frac{X_{HK}X_{LK} + X_{LK}}{X_{HK} + X_{LK}}$ was found to give a good correlation of feed composition.
4. The effects of other variables such as reflux ratio, tower pressure, feed condition, and number of plates, upon relative optimum feed plate location, have also been studied and found to be very small.

APPENDIX

Table II

CASE	FEED	REFLUX RATIO	PLATES ABOVE FEED PLATE	PLATES BELOW FEED PLATE	Mole Fraction of Distillate					
					iC_4	C_4	iC_5	C_5	C_6	D
1	A	2	3	7	.4525	.5095	.0263	.0111	.0007	.4261
2	A	2	4	6	.4397	.5194	.0307	.0099	.0003	.4441
3	A	2	5	5	.4257	.5130	.0476	.0136	.0002	.4604
4	A	2	6	4	.4065	.4935	.0763	.0236	.0002	.4812
5	A	2	7	3	.3813	.4639	.1106	.0440	.0002	.5100
6	A	6	3	7	.4532	.5345	.0095	.0027	.0001	.4359
7	A	6	4	6	.4418	.5394	.0157	.0031	.0000	.4499
8	A	6	5	5	.4297	.5327	.0319	.0056	.0000	.4642
9	A	6	6	4	.4094	.5075	.0680	.0151	.0000	.4861
10	A	6	7	3	.3805	.4719	.1130	.0345	.0001	.5220
11	A	10	3	7	.4534	.5385	.0065	.0016	.0001	.4370
12	A	10	4	6	.4422	.5424	.0131	.0023	.0000	.4504
13	A	10	5	5	.4297	.5327	.0319	.0056	.0000	.4642
14	A	10	6	4	.4098	.5095	.0067	.0140	.0000	.4867
15	A	10	7	3	.3803	.4731	.1137	.0328	.0001	.5239
16	A	14	3	7	.4534	.5401	.0053	.0011	.0000	.4374
17	A	14	4	6	.4424	.5437	.0120	.0019	.0000	.4506
18	A	14	5	5	.4299	.5336	.0312	.0053	.0000	.4643
19	A	14	6	4	.4100	.5103	.0662	.0136	.0000	.4869

20	A	14	7	3	.3801	.4735	.1141	.0323	.0000	.5247
21	A	18	3	7	.4535	.5409	.0047	.0009	.0000	.4376
22	A	18	4	6	.4425	.5443	.0115	.0017	.0000	.4506
23	A	18	5	5	.4300	.5341	.0309	.0051	.0000	.4644
24	A	18	6	4	.4100	.5106	.0660	.0134	.0000	.4871
25	A	18	7	3	.3800	.4736	.1143	.0321	.0000	.5253
26	A	2	4	16	.5337	.4592	.0054	.0017	.0001	.3672
27	A	2	6	14	.4438	.5464	.0082	.0015	.0000	.4501
28	A	2	8	12	.4375	.5453	.0156	.0016	.0000	.4569
29	A	2	10	10	.4178	.5209	.0156	.0057	.0000	.4785
30	A	2	12	8	.3842	.4790	.1158	.0210	.0000	.5201
31	A	2	14	6	.3661	.4554	.1403	.0383	.0000	.5450
32	A	6	4	16	.5230	.4750	.0016	.0004	.0000	.3790
33	A	6	6	14	.4450	.5541	.0009	.0001	.0000	.4494
34	A	6	8	12	.4421	.5525	.0051	.0003	.0000	.4524
35	A	6	10	10	.4267	.5332	.0383	.0019	.0000	.4687
36	A	6	12	8	.3829	.4784	.1279	.0108	.0000	.5223
37	A	10	4	16	.5225	.4763	.0009	.0002	.0000	.3801
38	A	10	6	14	.4450	.5545	.0004	.0000	.0000	.4494
39	A	10	8	12	.4425	.5531	.0043	.0002	.0000	.4520
40	A	10	10	10	.4274	.5342	.0369	.0015	.0000	.4679
41	A	10	12	8	.3821	.4775	.1308	.0097	.0000	.5235

42	A	14	4	16	.5227	.4764	.0007	.0002	.0000	.3802
43	A	14	6	14	.4451	.5546	.0003	.0000	.0000	.4493
44	A	14	8	12	.4426	.5532	.0040	.0001	.0000	.4519
45	A	14	10	10	.4275	.5343	.0369	.0014	.0000	.4679
46	A	14	12	8	.3814	.4767	.1326	.0093	.0000	.5243
47	A	18	4	16	.5228	.4766	.0005	.0001	.0000	.3804
48	A	18	6	14	.4451	.5547	.0002	.0000	.0000	.4493
49	A	18	8	12	.4427	.5533	.0039	.0001	.0000	.4518
50	A	18	10	10	.4274	.5342	.0371	.0013	.0000	.4680
51	A	18	12	8	.3808	.4760	.1343	.0090	.0000	.5252
52	A	2	5	25	.4644	.5225	.0104	.0026	.0000	.4300
53	A	2	6	24	.4501	.5412	.0074	.0014	.0000	.4442
54	A	2	7	23	.4448	.5493	.0051	.0007	.0000	.4496
55	A	2	9	21	.4435	.5537	.0026	.0002	.0000	.4510
56	A	2	12	18	.4403	.5503	.0091	.0003	.0000	.4542
57	A	2	15	15	.4161	.5200	.0614	.0025	.0000	.4807
58	A	2	18	12	.3753	.4690	.1367	.0190	.0000	.5329
59	A	6	5	25	.4548	.5437	.0013	.0003	.0000	.4397
60	A	6	6	24	.4469	.5524	.0007	.0001	.0000	.4475
61	A	6	9	21	.4444	.5555	.0001	.0000	.0000	.4500
62	A	6	12	18	.4435	.5544	.0020	.0000	.0000	.4509
63	A	6	15	15	.4272	.5339	.0384	.0005	.0000	.4682

64	A	10	5	25	.4541	.5451	.0006	.0001	.0000	.4404
65	A	10	6	24	.4467	.5529	.0003	.0000	.0000	.4477
66	A	10	9	21	.4444	.5555	.0000	.0000	.0000	.4500
67	A	10	12	18	.4437	.5546	.0017	.0000	.0000	.4508
68	A	10	15	15	.4282	.5352	.0362	.0004	.0000	.4671
69	A	14	5	25	.4539	.5456	.0004	.0001	.0000	.4405
70	A	14	6	24	.4467	.5531	.0002	.0000	.0000	.4477
71	A	14	9	21	.4445	.5555	.0000	.0000	.0000	.4500
72	A	14	12	18	.4437	.5546	.0017	.0000	.0000	.4508
73	A	14	15	15	.4282	.5353	.0362	.0003	.0000	.4671
74	A	18	5	25	.4538	.5458	.0003	.0001	.0000	.4406
75	A	18	6	24	.4467	.5532	.0001	.0000	.0000	.4477
76	A	18	9	21	.4445	.5555	.0000	.0000	.0000	.4500
77	A	18	12	18	.4437	.5546	.0017	.0000	.0000	.4508
78	A	18	15	15	.4281	.5351	.0365	.0003	.0000	.4672
79	A	2	8	32	.4451	.5510	.0035	.0004	.0000	.4493
80	A	2	12	28	.4441	.5551	.0007	.0000	.0000	.4503
81	A	2	16	24	.4421	.5526	.0052	.0001	.0000	.4524
82	B	2	2	8	.2202	.6386	.1092	.0302	.0018	.4498
83	B	2	3	7	.2204	.6406	.1125	.0259	.0008	.4486
84	B	2	4	6	.2137	.6245	.1340	.0273	.0004	.4624
85	B	2	5	5	.2030	.5951	.1682	.0335	.0003	.4861

86	B	2	6	4	.883	.5532	.2122	.0460	.0002	.5225
87	B	6	2	8	.2353	.6917	.0608	.0117	.0005	.4231
88	B	6	3	7	.2318	.6859	.0716	.0105	.0002	.4298
89	B	6	4	6	.2230	.6626	.1014	.0130	.0001	.4471
90	B	6	5	5	.2095	.6237	.1479	.0189	.0001	.4757
91	B	6	6	4	.1915	.5706	.2073	.0305	.0001	.5200
92	B	6	7	3	.1723	.5135	.2628	.0514	.0001	.5770
93	B	10	3	7	.2345	.6960	.0619	.0075	.0001	.4255
94	B	10	4	6	.2248	.6700	.0947	.0105	.0001	.4440
95	B	10	5	5	.2108	.6294	.1433	.0164	.0000	.4734
96	B	10	6	4	.1921	.5740	.2060	.0278	.0000	.5192
97	B	10	7	3	.1721	.5142	.2658	.0479	.0000	.5792
98	B	14	3	7	.2356	.7004	.0577	.0062	.0001	.4236
99	B	14	4	6	.2255	.6729	.0922	.0094	.0000	.4428
100	B	14	5	5	.2113	.6314	.1419	.0154	.0000	.4726
101	B	14	7	3	.1924	.5752	.2058	.0266	.0000	.5190
102	B	14	7	3	.1718	.5139	.2680	.0462	.0000	.5807
103	B	18	3	7	.2363	.7029	.0552	.0055	.0001	.4225
104	B	18	4	6	.2259	.6743	.0910	.0088	.0000	.4422
105	B	18	5	5	.2115	.6323	.1414	.0148	.0000	.4724
106	B	18	6	4	.1924	.5758	.2057	.0261	.0000	.5190
107	B	18	7	3	.1717	.5140	.2687	.0455	.0000	.5812
108	B	2	4	16	.2382	.7028	.0497	.0091	.0002	.4193

109	B	2	6	14	.2356	.7031	.0550	.0064	.0000	.4243
110	B	2	8	12	.2224	.6653	.1024	.0098	.0000	.4494
111	B	2	10	10	.2023	.6054	.1740	.0182	.0000	.4949
112	B	2	12	8	.1791	.5359	.2492	.0358	.0000	.5580
113	B	2	14	6	.1634	.4884	.2867	.0615	.0000	.6112
114	B	6	4	16	.2484	.7420	.0084	.0011	.0000	.4024
115	B	6	6	14	.2468	.7399	.0126	.0007	.0000	.4052
116	B	6	8	12	.2362	.7084	.0532	.0021	.0000	.4233
117	B	6	10	10	.2111	.6330	.1500	.0060	.0000	.4738
118	B	6	12	8	.1761	.5280	.2788	.0172	.0000	.5679
119	B	10	4	16	.2495	.7459	.0041	.0005	.0000	.4007
120	B	10	6	14	.2480	.7437	.0081	.0003	.0000	.4033
121	B	10	8	12	.2379	.7135	.0472	.0015	.0000	.4204
122	B	10	10	10	.2122	.6365	.1468	.0045	.0000	.4713
123	B	10	12	8	.1750	.5249	.2858	.0143	.0000	.5714
124	B	14	4	16	.2499	.7471	.0027	.0003	.0000	.4002
125	B	14	6	14	.2484	.7449	.0065	.0002	.0000	.4026
126	B	14	8	12	.2383	.7148	.0458	.0012	.0000	.4197
127	B	14	10	10	.2124	.6371	.1466	.0039	.0000	.4708
128	B	14	12	8	.1742	.5224	.2903	.0013	.0000	.5741
129	B	18	4	16	.2500	.7477	.0020	.0002	.0000	.3999
130	B	18	6	14	.2486	.7455	.0057	.0002	.0000	.4023

131	B	18	8	12	.2384	.7151	.0454	.0011	.0000	.4195
132	B	18	10	10	.2123	.6370	.1471	.0036	.0000	.4709
133	B	18	12	8	.1737	.5210	.2928	.0125	.0000	.5757
134	B	2	6	24	.2425	.7226	.0314	.0035	.0000	.4124
135	B	2	9	21	.2421	.7259	.0304	.0016	.0000	.4130
136	B	2	12	18	.2292	.6875	.0799	.0034	.0000	.4362
137	B	2	15	15	.2067	.6120	.1641	.0095	.0000	.4839
138	B	2	18	12	.1774	.5320	.2614	.0292	.0000	.5637
139	B	6	6	24	.2496	.7481	.0022	.0002	.0000	.4007
140	B	6	9	21	.2494	.7482	.0024	.0001	.0000	.4010
141	B	6	12	18	.2435	.7306	.0255	.0044	.0000	.4106
142	B	6	15	15	.2170	.6510	.1303	.0017	.0000	.4608
143	B	6	18	12	.1665	.4994	.3253	.0088	.0000	.6007
144	B	10	6	24	.2499	.7491	.0009	.0001	.0000	.4002
145	B	10	9	21	.2497	.7491	.0012	.0000	.0000	.4005
146	B	10	12	18	.2448	.7344	.0206	.0002	.0000	.4085
147	B	10	15	15	.2189	.6568	.1232	.0011	.0000	.4568
148	B	14	6	24	.2499	.7494	.0006	.0000	.0000	.4000
149	B	14	9	21	.2498	.7493	.0009	.0000	.0000	.4003
150	B	14	12	18	.2450	.7351	.0197	.0002	.0000	.4081
151	B	14	15	15	.2192	.6576	.1223	.0009	.0000	.4562
152	B	18	6	24	.2500	.7496	.0004	.0000	.0000	.4000
153	B	18	9	21	.2498	.7495	.0007	.0000	.0000	.4003

154	B	18	12	18	.2451	.7353	.0194	.0001	.0000	.4080
155	B	18	15	15	.2192	.6575	.1225	.0008	.0000	.4563
156	C	2	3	7	.1689	.7972	.0293	.0043	.0003	.5822
157	C	2	4	6	.1681	.8010	.0278	.0031	.0001	.5846
158	C	2	5	5	.1656	.7974	.0340	.0030	.0000	.5932
159	C	2	6	4	.1611	.7823	.0525	.0041	.0000	.6092
160	C	2	7	3	.1540	.7512	.0871	.0077	.0000	.6346
161	C	6	3	7	.1703	.8176	.0110	.0011	.0001	.5826
162	C	6	4	6	.1686	.8192	.0114	.0008	.0000	.5890
163	C	6	5	5	.1661	.8159	.0171	.0009	.0000	.5987
164	C	6	6	4	.1622	.8021	.0339	.0018	.0000	.6134
165	C	6	7	3	.1555	.7711	.0690	.0044	.0000	.6388
166	C	6	5	15	.1689	.8293	.0017	.0001	.0000	.5917
167	C	6	6	14	.1673	.8317	.0010	.0001	.0000	.5977
168	C	6	8	12	.1664	.8315	.0021	.0000	.0000	.6011
169	C	6	10	10	.1631	.8153	.0213	.0003	.0000	.6131
170	C	6	8	22	.1588	.7940	.0465	.0007	.0000	.6297
171	C	6	10	20	.1667	.8332	.0001	.0000	.0000	.6001
172	C	6	11	19	.1666	.8332	.0002	.0000	.0000	.6001
173	C	6	13	17	.1664	.8318	.0019	.0000	.0000	.6011
174	C	6	15	15	.1669	.8331	.0000	.0000	.0000	.5991
175	D	6	3	7	.1474	.8381	.0111	.0032	.0002	.6690
176	D	6	4	6	.1467	.8413	.0101	.0020	.0001	.6731

177	D	6	5	5	.1447	.8414	.0121	.0018	.0000	.6821
178	D	6	6	4	.1422	.8446	.0121	.0011	.0000	.7006
179	D	6	7	3	.1388	.8277	.0300	.0035	.0000	.7174
180	D	6	5	15	.1456	.8536	.0007	.0001	.0000	.6865
181	D	6	6	14	.1438	.8557	.0004	.0000	.0000	.6951
182	D	6	8	12	.1429	.8567	.0004	.0000	.0000	.6998
183	D	6	10	10	.1422	.8533	.0044	.0001	.0000	.7031
184	D	6	12	8	.1375	.8251	.0366	.0008	.0000	.7271
185	D	6	10	20	.1429	.8571	.0000	.0000	.0000	.7000
186	D	6	11	19	.1429	.8571	.0000	.0000	.0000	.7000
187	D	6	13	17	.1428	.8571	.0001	.0000	.0000	.7000
188	D	6	15	15	.1425	.8548	.0027	.0000	.0000	.7019
189	E	2	3	7	.0708	.9166	.0097	.0028	.0001	.6915
190	E	2	4	6	.0704	.9201	.0079	.0017	.0000	.6952
191	E	2	5	5	.0698	.9217	.0074	.0011	.0000	.7003
192	E	2	6	4	.0690	.9214	.0086	.0010	.0000	.7066
193	E	2	7	3	.0681	.9176	.0130	.0013	.0000	.7141
194	E	6	3	7	.0708	.9252	.0032	.0007	.0000	.6977
195	E	6	4	6	.0700	.9271	.0025	.0004	.0000	.7059
196	E	6	5	5	.0692	.9281	.0025	.0002	.0000	.7151
197	E	6	6	4	.0682	.9281	.0034	.0003	.0000	.7258
198	E	6	7	3	.0673	.9258	.0064	.0005	.0000	.7368

199	E	6	5	15	.0739	.9252	.0007	.0001	.0000	.6743
200	E	6	6	14	.0705	.9290	.0004	.0000	.0000	.7074
201	E	6	8	12	.0673	.9326	.0001	.0000	.0000	.7431
202	E	6	10	10	.0667	.9330	0002	.0000	.0000	.7495
203	E	6	12	8	.0664	.9294	.0042	.0000	.0000	.7530
204	E	6	14	6	.0639	.8942	.0410	.0008	.0000	.7823
205	E	6	10	20	.0669	.9331	.0000	.0000	.0000	.7474
206	E	6	11	19	.0667	.9333	.0000	.0000	.0000	.7493
207	E	6	13	17	.0667	.9333	.0000	.0000	.0000	.7499
208	E	6	15	15	.0667	.9333	.0001	.0000	.0000	.7500
209	E	6	17	13	.0666	.9322	.0012	.0000	.0000	.7509
210	E	6	19	11	.0656	.9184	.0160	.0000	.0000	.7622
211	F	6	3	7	.5022	.4732	.0190	.0054	.0002	.5875
212	F	6	4	6	.4934	.4876	.0169	.0022	.0000	.6063
213	F	6	6	14	.5008	.4986	.0005	.0001	.0000	.5989
214	F	6	8	12	.4990	.4989	.0020	.0001	.0000	.6011
215	F	6	10	10	.4889	.4888	.0218	.0005	.0000	.6136
216	F	6	12	8	.4489	.4488	.0980	.4043	.0000	.6682
217	F	6	7	23	.5092	.4905	.0002	.0000	.0000	.5890
218	F	6	9	21	.5039	.4961	.0001	.0000	.0000	.5953
219	F	6	11	19	.5000	.5000	.0001	.0000	.0000	.6000
220	F	6	13	17	.4994	.4994	.0011	.0000	.0000	.6007

221	F	6	15	15	.4937	.4937	.0125	.0001	.0000	.6077
222	F	6	17	13	.4608	.4608	.0078	.0006	.0000	.6510
223	G	6	2	8	.3044	.5876	.0925	.0148	.0007	.3258
224	G	6	3	7	.3022	.5881	.0974	.0122	.0003	.3258
225	G	6	4	6	.2983	.5828	.1077	.0111	.0001	.3325
226	G	6	5	5	.2936	.5738	.1218	.0107	.0001	.3370
227	G	6	6	4	.2890	.5632	.1367	.0110	.0000	.3405
228	G	6	4	16	.3275	.6520	.0186	.0018	.0000	.3053
229	G	6	6	14	.3269	.6528	.0193	.0010	.0000	.3058
230	G	6	8	12	.3240	.6470	.0281	.0009	.0000	.3086
231	G	6	10	10	.3199	.6380	.0412	.0009	.0000	.3125
232	G	6	12	8	.3143	.6254	.0593	.0010	.0000	.3177
233	G	6	6	24	.3318	.6634	.0045	.0003	.0000	.3014
234	G	6	8	22	.3323	.6644	.0032	.0001	.0000	.3010
235	G	6	9	21	.3322	.6643	.0035	.0001	.0000	.3011
236	G	6	10	20	.3320	.6639	.0041	.0001	.0000	.3012
237	G	6	11	19	.2962	.5923	.1091	.0025	.0000	.3377
238	H	6	2	8	.3681	.5103	.1094	.0115	.0008	.2663
239	H	6	3	7	.3643	.5173	.1092	.0088	.0003	.2702
240	H	6	4	6	.3591	.5153	.1178	.0077	.0001	.2741
241	H	6	5	5	.3531	.5086	.1310	.0072	.0001	.2777
242	H	6	6	4	.3470	.4989	.1469	.0071	.0000	.2803

243	H	6	4	16	.3895	.5781	.0304	.0019	.0000	.2566
244	H	6	6	14	.3876	.5793	.0319	.0011	.0000	.2579
245	H	6	8	12	.3825	.5718	.0447	.0010	.0000	.2613
246	H	6	10	10	.3754	.5601	.0634	.0010	.0000	.2661
247	H	6	12	8	.3662	.5443	.0884	.0010	.0000	.2723
248	H	6	6	24	.3957	.5933	.0107	.0004	.0000	.2527
249	H	6	7	23	.3959	.5938	.0100	.0003	.0000	.2526
250	H	6	8	22	.3956	.5933	.0109	.0002	.0000	.2528
251	H	6	9	21	.3942	.5911	.0145	.0002	.0000	.2537
252	H	6	10	20	.3942	.5911	.0145	.0002	.0000	.2537
253	H	6	11	19	.3426	.5138	.1413	.0023	.0000	.2919
254	I	6	3	7	.5056	.4860	.0068	.0013	.0000	.5885
255	I	6	4	6	.5041	.4883	.0067	.0009	.0000	.5909
256	I	6	5	5	.5024	.4893	.0075	.0008	.0000	.5928
257	I	6	6	4	.5010	.4894	.0088	.0008	.0000	.5937
258	I	6	7	3	.5001	.4887	.0104	.0009	.0000	.5926
259	I	6	5	15	.5044	.4946	.0008	.0001	.0000	.5944
260	I	6	6	14	.5009	.4986	.0005	.0000	.0000	.5988
261	I	6	8	12	.4992	.4990	.0018	.0000	.0000	.6010
262	I	6	10	10	.4897	.4896	.0203	.0005	.0000	.6127
263	I	6	7	23	.5012	.4986	.0002	.0000	.0000	.5986
264	I	6	11	19	.5000	.5000	.0001	.0000	.0000	.6000

265	I	6	13	17	.4999	.4999	.0001	.0000	.0000	.6001
266	I	6	15	15	.4999	.4999	.0002	.0000	.0000	.6001
267	I	6	17	13	.4999	.4999	.0003	.0000	.0000	.6002
268	I	6	19	11	.4998	.4998	.0004	.0000	.0000	.6002
269	J	6	3	7	.4920	.4872	.0154	.0053	.0001	.6079
270	J	6	4	6	.4907	.4864	.0174	.0055	.0000	.6094
271	J	6	5	5	.4893	.4851	.0196	.0059	.0000	.6107
272	J	6	6	4	.4878	.4834	.0223	.0066	.0000	.6115
273	J	6	7	3	.4863	.4811	.0253	.0073	.0000	.6109
274	J	6	6	14	.5012	.4984	.0003	.0001	.0000	.5984
275	J	6	8	12	.4996	.4994	.0009	.0001	.0000	.6004
276	J	6	10	10	.4950	.4949	.0089	.0011	.0000	.6060
277	J	6	12	8	.4981	.4977	.0038	.0004	.0000	.6022
278	J	6	11	19	.5001	.4999	.0000	.0000	.0000	.5998
279	J	6	13	17	.5001	.4999	.0000	.0000	.0000	.5999
280	J	6	15	15	.5000	.5000	.0000	.0000	.0000	.6000
281	J	6	17	13	.5000	.5000	.0000	.0000	.0000	.6000
282	J	6	19	11	.5000	.5000	.0000	.0000	.0000	.5999

COMPUTER LABORATORY

LIBRARY ROUTINE A 1 - 63

TITLE	Floating Decimal Arithmetic Routine
TYPE	Interpretive routine with 18 interpretive orders, entered as a closed routine, left by an 8J interpretive order.
NUMBER OF WORDS	168

PURPOSE This routine manipulates numbers in the floating decimal form, that is, numbers which are represented as $A \times 10^P$. It is of the interpretive type. This means that it selects parameters called interpretive orders which are written by the user one at a time and performs a calculation corresponding to each interpretive order. Interpretive orders carry out normal arithmetic operations such as addition and multiplication and some red tape operations such as counting and address changing.

In general, one will use this routine to do computations which do not require the full speed of the computer but which are too time-consuming to be done by hand. It is especially effective for problems with scaling difficulties. In a sense, one may think of the floating decimal routine as converting the MISTIC to a medium speed floating decimal computer having a very convenient order code.

ACCURACY About 9 decimals

TEMPORARY STORAGE 0, 1, 2

PRESET PARAMETERS S3 is used to specify two locations of non-temporary storage, S3 and 1S3, which are used for the floating decimal accumulator.

METHOD OF USE The floating decimal routine is entered as a standard subroutine. Following the entry, i.e., after the transfer of control to the subroutine, one begins writing interpretive orders. These orders each occupy one-half word and consist of a pair of function digits followed by a single address. They, therefore, have the same form as standard machine orders and may be read by the Decimal Order Input with full use of the conventional terminating symbols.

The first of the two function digits of an interpretive order describes the group characteristics of the order and may take values 0, 1, ..., 8. Normal arithmetic interpretive orders have this digit equal to 8. The second of the two function digits describes the type of interpretive order.

INTERPRETIVE ORDER LIST WITH FIRST FUNCTION DIGIT b = 8

Let F be the floating decimal number in the floating accumulator and let F(n) be the floating decimal number in location n.

80 N Replace F by F - F(n).

81 n Replace F by -F(n).

82 n Transfer control to the right hand interpretive order in n if F $\geqslant$ 0.

83 n Transfer control to the left hand interpretive order in n if F $\geqslant$ 0.

84 n Replace F by F + F(n).

85 n Replace F by F(n).

86 n Replace F by F/F(n).

87 n Replace F by F x F(n).

88 0 Replace F by one number read from the input tape punched as sign, any number of decimal digits, sign, and two decimal digits to represent the exponent. For example, $.8971 \times 10^{10}$ would be punched as + 8971 + 10.

89 n Punch or print F as a sign, n decimal digits, sign, two decimal digits to represent the exponent and two spaces. This print out may be reread by this routine. After F has been punched or printed, it may not remain in the floating accumulator unmodified. n can take values 2 to 9.

8K n Replace F by n if 0 $\leqslant$ n < 200.

8S n Replace $F(n)$ by F.

8N n Replace F by $|F| - |F(n)|$.

8J n Transfer control to the ordinary Illiac order on the left hand side of n. This used to escape from the floating decimal subroutine.

8F n Give a carriage return and line feed and start a new block of printing having n columns. This order is only obeyed once for a particular block of printing. At this time, a counter is set up which will cause a carriage return and line feed to occur automatically from then on after every set of numbers that is printed.

INTERPRETIVE ORDERS WITH $b \neq 8$.

If the first function digit of an interpretive order is 0, 1, ..., 7, it will refer to one of a set of control registers or b- registers in the floating decimal routine which are similarly numbered. These registers are used for counting the number of passages through loops or cycles and for advancing addresses on successive passages. For this purpose, a particular b- register which may be used in a particular cycle contains two counting indices g_b and c_b. These are both intergers in the range 0 to 1023. The index

c_b is used for counting purposes to determine the number of passages through a loop. The index g_b is used for advancing the addresses of interpretive arithmetic orders. Although the interpretive order with first function digit b is not actually altered in the memory, it is obeyed as if g_b is increased by one upon each passage through the cycle. The multiplicity of b- registers allows one to program many loops within loops.

ORDER LIST WITH n ≠ 8

b0 n Replace F by F - F(n+g_b).

b1 n Replace F by -F(n+g_b).

b2 n Replace g_b, c_b by g_b + 1, c_b + 1.
Then transfer control to the right hand (if b2 n) or left hand interpretive (if b3 n) order in n if c_b + 1

b3 n is negative. This transfer is used at the end of a loop.

b4 n Replace F by F + F(n + g_b).

b5 n Replace F by F(n + g_b).

b6 n Replace F by F/F(n+g_b).

b7 n Replace F by F x F(n + g_b).

bK n Replace g_b, c_b by 0, -n. This interpretive order is used for preparing to cycle around a loop n times.

bS n Replace F(n + g_b) by F.

bN n   Replace F by $|F| - |F(n+g_b)|$.

bL n   Replace g_b, c_b by $g_b + n$, c_b. This interpretive order is used when one wishes to step addresses by some increment other than +1 in a loop. If one places bL 1022 in a loop, the effect will be to decrease addresses by one on each passage. bL 1 will increase them by 2, etc.

8L n   Replace g_b c_b by n, c_b, where b is the last b-register referred to by some previous interpretive order.

DURATION OF INDIVIDUAL INTERPRETIVE ORDERS

8N 80 84	5 milliseconds + m x (3/2). Where m is the number of shifts required to convert A, p back to standard form.
81 85	2 milliseconds
82 83	3 milliseconds
87	5 milliseconds
86	6 milliseconds
8K	3 milliseconds
8S	3 milliseconds
8F	3 milliseconds
8L	2 milliseconds
8J	3 milliseconds

When an interpretive order is preceded by b $\neq$ 8, add one millisecond to the above times.

When one wishes to repeat a cycle of interpretive orders n times, the interpretive order bK n may be written before entering the loop to set the counter c_b to -n. The interpretive orders in the loop will be obeyed n times if the loop is terminated by b2 or b3 interpretive order to transfer control to the beginning of the loop. This transfer of control interpretive order will be obeyed n-1 times and disobeyed the nth time.

Use of Auxiliary Routines. It is often convenient to be able to leave the floating decimal routine so as to modify interpretive orders or to perform calculations which may be done more effectively outside of floating point. To leave the floating decimal routine one uses an 8J n order. (All standard floating decimal auxiliaries are entered in this way.) To return to floating decimal, one should transfer control to the left hand side of word 29 of the floating decimal routine. The interpretive order following the 8J n order which was last obeyed will then be obeyed and so on. In this way, it is not necessary to plant a link in auxiliary subroutines. One may, in fact, think of the 8J n order as a subroutine order. In case any changes are made in the floating decimal accumulator while outside the floating decimal routine, control should be returned to the left hand side of word 19 rather than 29 so that this number may be standardized before re-entry.

Handling of Numbers. Each number is represented in the form $A \times 10^p$ where $1 > |A| \geqslant 1/10$, and $64 > p \geqslant -64$. In a single register of the memory, the number A is placed in the 33 most significant binary digits ($a_0, a_1, \ldots, a_{32}$) in the same way as an ordinary fraction is placed in the entire register. An accuracy of between 8 and 9 decimal digits is therefore achieved. The exponent p is stored as the interger $p + 64$ in the 7 least significant digits of the same register. For convenience, the floating decimal accumulator uses two registers S3 and 1S3 for holding the number $A \times 10^p$. The fraction $a/2$ is in S3 and the interger $p + 64$ is in 1S3.

The only exception to the above rules is the number zero which cannot, of course, be represented as $A \times 10^p$ with $|A| \geqslant 10$. For this reason, zero is handled in a special way. It is represented as a number with $A = 0$ and $p = -64$. This representation happens to correspond exactly with the ordinary machine representation of zero.

After each arithmetic interpretive order is obeyed, the number in the floating decimal accumulator is standardized, i.e., the number in S3 representing A/2 is adjusted so 1 $|A| \geq 1/10$ and p is changed accordingly. To accomplish this, control is transferred to word 19 in the floating decimal routine after each arithmetic order.

If an interpretive store order is attempted when F has an exponent greater than 63, the machine will stop on the order 34 p at location p, where p is word 72 of the routine.

<u>Important Words in the Routine</u>. Word 2 in the floating decimal routine determines the location of the current interpretive order. When obeying the left hand interpretive order in location n, this word is 50 nF S5 20F and when obeying the right hand interpretive order in location n, it is L5 nF 00 20F. Other words of interest are the b-registers which start at word 158 (for g_0 and c_0) and go to 165 (g_7 and c_7.) These registers hold g_b and c_b in the form 80 g_bF 00 (2048 + c_b) F.

<u>Warning</u>. When the same number is continually added to a sum, such as when an argument is being increased, the error can be quite large, because it is additive over a decade. For example, if we increase 10 to 100 by units, we can get a maximum error of 90 x 2^{-33} because the errors all have the

same sign. If we increase 10^3 to 10^4, we can have a maximum error of 9000×2^{-33}. This can easily be prevented by writing an auxiliary subroutine to stabilize the fractional part of F, i.e., to replace it by the nearest multiple of say 10^{-7}.

NOMENCLATURE

D	Moles of overhead product
F	Moles of feed
H	Enthalpy of vapor stream
$\bar{H}$ or $\bar{h}$	Enthalpy of pure component as vapor or liquid
K	Equilibrium constant (y/x)
L	Moles of liquid
M	Plates above feed
N	Plates below feed
Q	Heat flux, enthalpy of vapor minus enthalpy of liquid in passing streams
R	Reflux ratio ($^L/_D$)
T	Temperature °F
V	Moles of vapor
W	Moles of bottom product
a,b,c,d	Constants
h	Enthalpy of liquid stream
p	Partial derivatives used in rectifying section
q	Partial derivatives used in stripping section
r	Ratio of composition of particular component on feed plate as calculated from opposite directions
x	Mole fraction in liquid
y	Mole fraction in vapor

SUBSCRIPTS

a	Rectifying section
c	Condenser
D	Distillate
f	Feed or feed plate
h	Constant of enthalpy polynomial
i	Particular component
k	Constant of equilibrium constant polynomial
m	Plate number in rectifying section, numbered in Arabic numerals from condenser to feed plate
n	Plate number in stripping section, numbered in Roman numerals from reboiler to feed plate
s	Reboiler
r	Stripping section

BIBLIOGRAPHY

1) Brown, G. G., and Martin, H. A., Transactions of American Institute of Chemical Engineers, 35, 679, (1939).

2) Colburn, A. P., Transactions of American Institute of Chemical Engineers, 37, 355, (1941).

3) Colburn, A. P., Transactions of American Institute of Chemical Engineers, 37, 805, (1941).

4) Donnell, J. W., and Cooper, C. M., Chemical Engineering, 57, 121, (1950).

5) Edmister, W. C., Transactions of American Institute of Chemical Engineers, 42, 15, (1946).

6) Fenske, M. R., Industrial Engineering Chemistry, 24, 482, (1932).

7) Gilliland, E. R., Industrial and Engineering Chemistry, 27, 260, (1935).

8) Gilliland, E. R., Industrial and Engineering Chemistry, 32, 918, 1101, and 1220, (1940).

9) Harbert, W. D., Industrial Engineering Chemistry, 24, 482, (1932).

10) Jenny, F. J., Transactions of American Institute of Chemical Engineers, 35, 635, (1939).

11) Lewis, W. K., and Cope, J. Q., Industrial and Engineering Chemistry, 24, 498, (1932).

12) Lewis, W. K., and Matheson, G. L., Industrial and Engineering Chemistry, 24, 494, (1932).

13) McCabe, W. L., and Thiele, E. W., Industrial and Engineering Chemistry, 17, 605, (1925).

14) Ponchon, Tech. Moderne, 13, 20, (1921).

15) Sorel, E., "La Rectification de l'Achol," Paris, 1893.

16) Thiele, E. W., and Geddes, R. L., Industrial and Engineering Chemistry, 25, 289, (1933).

17) Underwood, A. J. U., Journal of Institute of Petroleum (London) 32, 614, (1946).

8a) Montrose, C.F., and Scheibel, E.G., Industrial and Engineering Chemistry, 38, 268, (1946).