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THE EFFECT OF OCTADECYLAMINE
ACETATE ON OVERALL HEAT
TRANSFER COEFFICIENTS

Thesis for the Degree of M. S.
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Dana Duane Squire
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Dana Duane Squire

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Major professor

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THE EFFECT OF OCTADECYLAMINE ACETATE ON
OVERALL HEAT TRANSFER COEFFICIENTS

By

DANA DUANE SQUIRE

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
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1955

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ABSTRACT

Octadecylamine acetate is used for corrosion inhibition in many present day operations. Increase in heat transfer not due to the reduction of corrosion has been observed in plant equipment. It has been theorized that this amine, by forming a non-wettable surface, produces this increase in heat transfer by promoting dropwise condensation and/or by better run off of the condensate. The problem involved in this research is to study these effects of better heat transfer in the laboratory and in pilot plant operation.

A miniature laboratory model of a heat exchanger was made and increases of 10.8 percent in overall heat transfer coefficients was determined. This was a result of both better run off of condensate and promotion of dropwise condensation.

Filmwise condensation could not be obtained in the pilot plant heat exchanger because of contamination between the main line steam and the heat exchanger. Oil used in the threading and cutting of pipes was of sufficient quantity to promote dropwise condensation. Consequently, when octadecylamine was added a decrease in heat transfer resulted. This decrease is believed to be the result of a reaction between the octadecylamine acetate and the oil. This is also true in the case of corrosion inhibition. If there is oil in a system, the corrosion inhibition of octadecylamine acetate is greatly reduced.

Dana Duane Squire

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Figure 1. The effect of the concentration of the *Agrobacterium* suspension on the transformation efficiency of *Agrobacterium* strains.

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INTRODUCTION

INTRODUCTION

Octadecylamine acetate has, for the past eight years, been used for prevention of corrosion in steam and condensate return lines (26). Denman (3) first reported the use of this amine for treating boiler water. Octadecylamine acetate functions by the principle of forming a film of long chain polar amine molecules (11, 26) on the metal surface. This mono-molecular film is believed to maintain non-wettable characteristics (2, 24, 25, 26).

When a saturated vapor such as steam contacts a surface whose temperature is below the dew point of the saturated vapor, condensation results. Normal filmwise condensation does not occur on a non-wettable metallic surface (1, 9, 21, 26). There are two extreme types of condensation; these are dependent on the condition of the condensing surface (1). The normal type of condensation encountered on a wettable metallic surface is called "filmwise condensation." "Filmwise condensation" involves the formation of a continuous layer of liquid condensate on the metallic surface. This continuous layer introduces a resistance to heat transmission through the metallic wall as shown in Figure A of Diagram I.

The other extreme type of condensation, commonly known as "dropwise condensation", most generally occurs when the metallic surface is rendered non-wettable. The mechanism of dropwise condensation is exemplified by the following cycle. Vapor condenses on a non-wettable metallic surface in tiny, minute drops which gradually grow in size, until a critical size is reached. This

critical size is said to depend on the angle of inclination of the surface, the contact angle of drop, the surface tension of the liquid, and the density of the liquid (6). When the critical size is reached, the drop "sweeps" the surface collecting other droplets of condensed vapor and, moving downward, leaves behind it a bare strip of metallic surface exposed. This cycle thus eliminates resistance to heat transmission due to the liquid layer shown in Figure B of Diagram I.

The effectiveness of octadecylamine acetate and salts for corrosion inhibition in return condensate lines has been extensively investigated (11, 23, 26). Case histories (17, 18, 26) of operations using octadecylamine acetate for corrosion inhibition, show an increase in capacity or efficiency not due to elimination of the corrosion layer or fouling resistance. It has been theorized by investigators (2, 17, 24, 26) that dropwise condensation occurs and higher overall heat transfer coefficients results.

The purpose of this study was to investigate (1) the effectiveness of octadecylamine acetate as a promoter of dropwise condensation, (2) the conditions under which octadecylamine acetate acts as a promoter of dropwise condensation, (3) the effect of octadecylamine acetate on overall heat transfer coefficient.

HISTORY

Schmidt, Schurig, and Sellschopp (2), in 1930, initiated the study of the effect in induced dropwise condensation heat transfer coefficients. These investigators, using a steam chamber and metal disc cooled by a high velocity of jet water, found that values of steam side coefficients could be increased five to seven times the values predicted by the theoretical formula of Nusselt (16). This condensation was due to small amounts of oil in the steam.

Spoelstra, (22) in 1931, observed that fouled tubes from evaporators in Javanese sugar mills, even after cleaning, showed a marked decrease in heat transmission. Spoelstra discovered that the pores of the scale on these tubes contained thirty percent oil-like, organic substances. Subsequent investigations proved that tubes with a thin scale, if oily, had higher overall heat transfer coefficients than tubes which had no scale. Spoelstra's later apparatus was similar to that shown in Diagram II; he observed the type of condensation which resulted on different types of surfaces. No heat transfer coefficients were reported.

In 1932, Jakob (10) reported that direction and velocity of steam is a very important factor in determining the type of condensation. Jakob observed that at high steam velocities film condensation occurred while at low steam velocities mixed condensation resulted. The type of condensation appeared to be a function of cleanliness and other physical characteristics of the surface.

Nagle (15) in 1935, was issued a patent covering the use of certain reagents for inducing dropwise condensation, which usage was alleged to increase steam condensation efficiency. This patent was a result of studies Nagle and Drew (14) had previously completed; studies in which an attempt was made to explain the effects of surface conditions and types of various promoters, generally polar organic compounds, modes of condensation.

Nagle and co-workers, later in the same year, presented papers (4, 13) in which these conclusions were made:

- (1) clean steam, condenses in a filmwise manner on clean surfaces, rough or smooth.
- (2) steam condenses in a dropwise manner only if the cooling surface is contaminated.
- (3) dropwise condensation is more easily promoted on smooth surfaces.

In the late thirties, Emmons (5) found that the number of molecular layers of dropwise condensation promoter (stearic acid) had very little effect on the percent of dropwise condensation. Fitzpatrick, Baum, and McAdams (7) concluded that larger increases in capacity of a given apparatus would result if dropwise condensation occurred. The apparatus used was a condenser made of 5/8 inch No. 18 gauge metal tubing arranged vertically inside a copper plated steam jacket ten feet long. A fatty-acid promoter in the power plant steam caused immediate dropwise condensation and, consequently, filmwise condensation could not be obtained.

The subject under consideration was apparently dropped until 1949 when Fatica and Katz (6) published an article of a highly theoretical nature in which dropwise condensation was found to depend on the angle of inclination of the condensing surface, surface tension of the liquid condensing, density of the liquid condensing, and the contact angle of the condensed droplets with the metal surface. Two years later, Hampson (8) determined that the persistancy of dropwise condensation depended not only on these factors, but, also on the rate of condensation, method of application of promoter, and shape of condensing surface.

It should be noted that no references could be found where dropwise promoting additives were used in any type of heat transfer equipment other than laboratory size.

HEAT TRANSFER RELATIONSHIPS

The fundamental heat transfer relationship (19) used to evaluate heat transfer data in heat exchangers is:

$$Q = UA (\Delta t)_m$$

Where: Q = heat transfer rate, Btu./Hr.

U = overall heat transfer coefficient,
Btu./Hr./Ft.²/°F.

A = heat transfer area, ft.².

$(\Delta t)_m$ = logarithmic temperature difference or driving
force, °F.

The overall heat transfer coefficient, U, is the reciprocal of the sum of the resistances to heat transmission expressed as:

$$U = \frac{1}{R_s + R_f + R_w + R_m} \quad \text{or} \quad \frac{1}{\frac{1}{h_s} + \frac{1}{h_f} + \frac{1}{h_w} + \frac{x}{k}}$$

where: h_s = steam side film coefficient, Btu./Hr./Ft.²/°F.
 h_f = fouling factor due to dirt, scale, corrosion, etc., Btu./Hr./Ft.²/°F.
 x = thickness of metal wall through which heat is transferred, ft.
 k = thermal conductivity of metal, Btu./Hr./Ft.²/°F.

In a heat exchanger using steam as the heating media the mean temperature difference is calculated by:

$$(\Delta t)_m = \frac{(T - t_1) - (T - t_2)}{\ln \frac{(T - t_1)}{(T - t_2)}}$$

where: T = temperature of condensing steam.
 t_1 = temperature of water inlet.
 t_2 = temperature of water outlet.

PROCEDURE

PROCEDURE

A. Finger Type Condenser

The finger type condenser (see Diagram II) similar to that used by Spoelstra (22), Emmons (5), and Nagle and Drew (14) was made from two pieces of copper tubing. The smaller copper tube ($d_o = 0.250$ in., $d_i = 0.190$ in.) was inserted in the larger copper tube ($D_o = 0.500$ in., $D_i = 0.435$ in.) and soldered into place in an annular mechanism assimilating the water side of a miniature condenser. Water was introduced into the inside tube from the top and traveled down the tube within 0.125 in. $\pm$ $.0625$ in. of the end. At this point, the water entered the larger tube, reversed its direction, and traveled the entire length (6.5 in.) of the outside tube into a half gallon jar where it was weighed in one minute increments.

This condenser was held by a cork which also supported a thermometer for steam temperature measurement and a laboratory type reflux condenser. The cork was covered with tinfoil to prevent any impurities from the cork to enter the system and placed in a two liter Erlenmeyer flask containing one liter of distilled water. The distilled water generated a constant source of atmospheric steam upon heating with a Bunsen burner.

The advantages of this system are:

- (1) a "closed" system was provided by the use of the reflux condenser by which clean atmospheric pressure could be generated for long periods of time.
- (2) clear, accurate visual observation could be maintained at all times.

- (3) apparatus could be dismantled, cleaned thoroughly, and put together with a minimum amount of time and effort.

Extreme cleanliness of apparatus being a necessity, the following system of cleaning was adopted. The finger type condenser was ground with four successively finer grades of emery cloth and, finally, rubbed and polished thoroughly with crocus cloth. Condenser, Erlemeyer flask, tinfoil, reflux condenser, and contact parts were scrubbed with "Ajax", a commercial scouring agent, and rinsed thoroughly with tap water and then with distilled water. The scrubbing and rinsing procedure was repeated until distilled water formed a liquid layer on all parts of the system. Hereafter, when any reference to cleaning of apparatus is made, the procedure outlined in this paragraph was followed.

The system was allowed to reflux for one hour at an estimated ninety percent filmwise condensation surface. Data was obtained in the following manner:

- (1) water rate was adjusted by use of valve from main water line.
- (2) system was allowed to reach equilibrium (outlet temperature constant).
- (3) inlet temperature was measured with a calorimetric thermometer ($\pm 0.05^{\circ}\text{F.}$).
- (4) outlet temperature was measured at the beginning of a one-minute time interval and at the end of the time interval. If any deviation in temperatures occurred, an arithmetic average was taken.

- (5) outlet water was collected in a half gallon jar over such time interval and weighed.

The finger type condenser was again cleaned thoroughly and stearic acid powdered, sprinkled on a clean cheesecloth, was rubbed on the outer surface of the larger copper tube. Stearic acid powder was used because references (1, 5, 8) indicated that stearic acid gave the non-wettable surface necessary for the promotion of excellent dropwise condensation. Thus, run thirty-nine through sixty-nine were made; good dropwise condensation was observed.

The apparatus was again cleaned and the system allowed to reflux for approximately five to six hours at which time one-hundred percent filmwise condensation was observed. The system was cleaned with "Filmeen", a commercial grade of octadecylamine acetate, rubbed on the surface of the condenser. After ten minutes of operation, approximately forty-five percent dropwise condensation was observed and "better run-off" ^{*} occurred. Runs seventy through one-hundred and two were made.

B. Laboratory Heat Exchanger

The heat exchanger used in the laboratory was a two-pass, sixteen tube per pass, shell and tube heat exchanger. The tubes were 18 BWG, 5/8 inch outside diameter, which gave a surface area of 10.4 square feet. The tube bundles were removed from the shell and soaked for five days in a six percent solution of Dearborn

* Steam condensate dropped at a much faster rate from the bottom of finger type condenser

Company's Formula 134, inhibited hydrochloric acid. Subsequent examination of these tubes showed that most of the scale accumulated in more than four years of operation had been removed.

A four point recorder was used to take continuous temperature readings at the (1) inlet cooling water, (2) outlet cooling water, (3) steam temperature in shell, and (4) temperature of condensate. It was observed that the condensate temperature was lower than the steam temperature, so a larger steam trap was substituted. However, the water flow rates varied so widely that continuous data from the four point recorder could not be used. Finally, calibration thermometers ($\pm 0.09^{\circ}\text{C.}$) were used to obtain desired temperatures readings. The steam pressure was regulated by a "dead weight" pressure valve. The steam was from the University Power Plant line.

A Milton-Roy "Mini-pump" was first used to pump small amounts of concentrated octadecylamine acetate solution into the steam line between the "dead weight" pressure valve and the heat exchanger, but due to the character of the octadecylamine acetate solution the "balls and checks" were soon plugged. Finally, a 1/6 horsepower, single phase, Milton-Roy pump was obtained which successfully pumped desired concentrations in properly regulated amounts.

The feed solution of octadecylamine acetate was dissolved in a 150 pound calibrated feed tank in 170°F. condensate water. The rate of feed, based on steam condensation rate, was controlled by adjusting the strokes of the pump.

Runs one through ten were made after two days of continuous operation without introducing any promoter. Data was taken in the same manner described for the finger type apparatus. Runs eleven through nineteen were made on the fourth day and runs twenty through twenty-eight were made on the seventh day of continuous operation.

Octadecylamine acetate was then introduced into the steam system at two to four parts per million. The finger type condenser was placed in position B (see Diagram III); steam slowly injected into this apparatus allowed observations of the type of condensation. The condensate formed in droplets previously described and runs twenty-nine through thirty-four were made after ten hours of operation.

Feeding octadecylamine acetate at one hundred parts per million runs thirty-five through forty-three were made; partial dropwise condensation and a white scum-like material was observed in miniature condenser apparatus.

The finger type condenser was then placed in position A (see Diagram III), where almost one hundred percent dropwise condensation was observed. The finger type condenser was cleaned and main line steam from the power plant injected into apparatus; only filmwise condensation was observed over a three day period.

DATA AND RESULTS

DATA AND RESULTS

A. Finger Type Condenser

Surface highly polished, no promoter, 90% filmwise condensation observed.

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Temp. °F.	Water Velocity Ft./Sec.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F
1	1.484	54.4	64.8	208.5	0.574	162.9
2	1.484	54.0	64.5	208.0	0.574	164.6
3	1.484	53.9	64.4	207.5	0.574	165.1
4	1.484	54.0	64.4	208.0	0.574	163.0
5	2.063	54.2	61.7	208.0	0.798	162.2
6	2.078	54.1	61.5	207.5	0.804	161.5
7	2.156	53.7	61.0	208.0	0.834	164.3
8	2.157	54.8	62.3	208.5	0.834	169.7
9	2.172	53.8	60.9	207.5	0.840	161.2
10	2.359	53.7	60.5	208.0	0.913	167.1
11	2.359	54.3	60.8	208.0	0.913	160.3
12	2.375	54.1	60.7	208.0	0.919	163.6
13	2.391	54.2	60.5	208.0	0.925	157.2
14	2.453	54.2	60.4	207.5	0.949	159.2
15	3.469	53.4	58.0	206.5	1.342	165.9
16	3.484	53.5	58.0	207.5	1.348	162.8
17	3.531	53.9	58.5	207.5	1.366	168.8
18	3.844	52.7	56.9	207.0	1.487	166.8
19	3.906	52.8	57.0	207.5	1.511	168.9

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Temp. °F.	Water Velocity Ft./Sec.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F
20	3.922	53.1	57.1	208.0	1.517	161.3
21	3.953	53.3	57.3	207.0	1.529	163.9
22	4.156	54.4	58.3	208.3	1.608	167.8
23	4.203	52.8	56.6	207.6	1.626	164.2
24	4.219	52.8	56.6	207.8	1.632	164.6
25	4.250	52.8	56.5	207.9	1.644	161.4
26	4.266	52.8	56.4	207.5	1.650	157.9
27	4.656	52.9	56.3	207.8	1.801	162.4
28	4.672	52.9	56.3	207.4	1.807	163.4
29	4.906	52.8	56.1	207.6	1.898	166.1
30	6.844	53.7	56.0	208.2	2.647	161.3
31	7.126	54.1	56.4	208.2	2.756	167.9
32	7.219	52.8	55.0	207.8	2.792	162.2
33	7.406	53.0	55.1	207.6	2.864	159.3
34	7.406	52.9	55.0	208.0	2.864	158.8
35	7.500	52.9	55.0	207.6	2.901	161.2
36	9.406	53.0	54.7	207.3	3.638	163.8
37	10.875	54.1	55.5	208.5	4.206	156.7
38	11.000	54.3	55.7	208.2	4.255	158.5

Average Mean Heat Transfer Coefficient

163.1 Btu./Hr./Ft.²/°F.

Surface highly polished. Stearic acid powder rubbed on surface.

Good dropwise condensation observed.

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Temp. °F.	Water Velocity Ft./Sec.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F
39	1.469	54.0	65.8	209.0	0.568	182.8
40	1.500	53.9	66.0	209.0	0.580	191.4
41	1.516	54.0	65.4	208.8	0.586	182.2
42	1.531	53.9	65.5	207.8	0.592	188.5
43	2.656	53.8	60.0	208.4	1.027	170.8
44	2.734	53.9	60.2	208.5	1.058	178.8
45	2.750	53.7	60.0	208.8	1.064	179.2
46	2.750	53.6	60.3	208.6	1.064	191.0
47	3.625	53.6	58.6	208.0	1.402	187.6
48	3.656	53.5	58.6	208.0	1.414	192.9
49	3.656	53.9	58.8	208.2	1.414	185.5
50	3.734	53.9	58.4	208.0	1.444	173.9
51	4.406	53.6	57.4	208.2	1.704	171.8
52	4.406	53.0	57.2	207.8	1.704	190.5
53	4.406	53.3	57.6	208.0	1.704	195.0
54	4.500	53.4	57.5	208.6	1.741	188.9
55	5.133	52.8	56.2	208.4	1.985	178.2
56	5.156	52.7	56.2	208.8	1.994	183.8
57	5.156	52.9	56.3	208.8	1.994	178.7
58	5.188	52.8	56.1	208.6	2.007	147.7
59	5.906	53.4	56.3	208.5	2.284	175.3

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Temp. °F.	Water Velocity Ft./Sec.	Heat Transfer Coefficient Btu./Hr./Sq. ft./°F
60	5.968	53.5	56.3	207.0	2.308	172.7
61	5.968	53.4	56.2	208.5	2.308	170.9
62	6.032	53.5	56.3	208.5	2.333	172.9
63	6.626	53.5	56.1	208.5	2.563	176.2
64	6.656	53.2	55.8	208.5	2.575	176.6
65	6.656	53.2	55.8	208.5	2.575	176.6
66	8.616	53.1	55.2	208.5	3.333	184.3
67	8.688	53.0	55.0	208.5	3.361	176.9
68	8.718	53.2	55.2	208.5	3.372	177.6
69	8.782	53.0	55.0	209.5	3.397	177.5

AVERAGE MEAN HEAT TRANSFER COEFFICIENT

180.8 Btu./Hr./Ft.²/°F.

Surface highly polished. Octadecylamine acetate rubbed on surface.
45% dropwise condensation and "better run-off" observed after 10 minutes of operation.

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Temp. °F.	Water Velocity Ft./Sec.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F
70	2.202	54.2	62.2	208.5	0.852	184.2
71	2.203	54.0	61.9	208.0	0.852	182.4
72	2.219	54.1	61.9	208.0	0.858	181.4
73	2.219	59.0	61.8	208.5	0.858	180.7

Run No.	Water Temp. °F.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Temp. °F.	Water Velocity Ft./Sec.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F
74	2.891	54.2	60.3	208.0	1.118	184.0
75	2.906	54.1	60.1	208.0	1.124	181.6
76	2.922	54.0	60.1	208.5	1.130	185.1
77	2.938	54.2	60.3	208.0	1.136	186.9
78	3.656	54.0	58.7	208.0	1.414	178.2
79	3.672	54.0	58.8	208.5	1.420	182.2
80	3.688	54.0	58.7	208.0	1.427	179.7
81	3.688	54.0	58.7	208.5	1.427	179.1
82	3.689	54.0	58.6	208.0	1.427	175.8
83	3.689	53.8	58.7	208.5	1.427	186.7
84	3.703	53.9	58.6	208.0	1.432	180.3
85	3.703	53.9	58.7	208.5	1.432	183.6
86	4.078	54.3	58.5	208.5	1.577	177.0
87	4.094	54.3	58.4	208.0	1.584	174.1
88	4.375	54.0	57.9	208.0	1.692	176.5
89	4.375	54.0	58.0	208.5	1.692	180.4
90	4.406	53.9	57.8	208.0	1.704	177.6
91	4.812	54.3	57.9	208.0	1.861	179.2
92	4.846	54.3	57.9	208.5	1.875	179.9
93	4.846	54.3	57.9	208.0	1.874	180.5
94	4.938	54.3	58.0	208.5	1.910	188.6
95	5.938	54.4	57.3	208.0	2.297	178.0
96	5.986	54.4	57.4	208.0	2.308	185.0
97	6.000	54.4	57.3	208.5	2.321	179.3
98	6.032	54.3	57.3	208.5	2.333	186.3

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Temp. °F.	Water Velocity Ft./Sec.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F
99	7.750	54.5	56.7	208.0	2.998	175.9
100	7.812	54.4	56.6	208.0	3.022	177.2
101	7.812	54.4	56.6	207.5	3.022	177.7
102	7.846	54.5	56.7	208.5	3.035	177.5

AVERAGE MEAN HEAT TRANSFER COEFFICIENT

180.68 Btu./Hr./Ft.²/°F.

DATA

B. Laboratory Heat Exchanger

No promoter, third day of continuous operation. Atmospheric pressure 28.9 inches of mercury.

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Press. P.S.I.G.	Steam Press. P.S.I.A.
1	37.93	54.0	197.2	34.0	48.2
2	39.52	54.0	197.2	34.5	48.7
3	41.21	54.0	193.1	33.5	47.7
4	46.88	54.0	183.9	33.5	47.7
5	55.48	53.9	168.4	33.0	47.2
6	59.35	53.8	161.9	32.0	46.2
7	74.78	53.6	151.2	32.0	46.2
8	89.35	53.5	140.0	31.0	45.2
9	101.38	53.4	130.8	31.0	45.2
10	139.09	53.1	111.2	31.0	45.2

No promoter, fourth day of continuous operation. Atmospheric pressure 29.15 inches of mercury.

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Press. P.S.I.G.	Steam Press. P.S.I.A.
11	33.38	56.2	207.1	34.5	48.8
12	37.93	56.1	194.0	34.0	48.3
13	43.02	56.1	186.9	33.5	47.8

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Press. P.S.I.G.	Steam Press. P.S.I.A.
14	48.58	55.9	179.4	33.0	47.3
15	61.54	55.4	159.1	32.5	46.8
16	69.77	55.4	151.2	32.0	46.3
17	88.40	55.1	140.4	32.0	46.3
18	98.64	54.9	133.2	31.0	45.3
19	111.32	54.8	124.2	31.0	45.3

No promoter, seventh day of continuous operation. Atmospheric pressure 28.91 inches of mercury.

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Press. P.S.I.G.	Steam Press. P.S.I.A.
20	30.77	55.3	207.7	36.0	50.2
21	38.81	55.1	190.4	34.0	48.2
22	42.62	54.9	184.8	34.5	48.7
23	49.23	54.8	175.3	34.0	48.2
24	60.33	54.6	158.0	33.0	47.2
25	77.84	54.4	146.8	32.5	46.7
26	94.19	54.3	133.9	31.5	45.7
27	96.65	54.2	130.6	32.0	46.2
28	114.94	54.1	122.4	31.5	45.7

Octadecylamine acetate as promoter. Two to four parts per million.

Atmospheric pressure 28.59 inches of mercury.

Run No.	Water Rate #/Min.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Press. P.S.I.G.	Steam Press. P.S.I.A.
29	50.73	55.4	171.3	36.5	50.5
30	57.79	55.2	162.3	36.0	50.0
31	70.52	55.0	149.8	36.0	50.0
32	86.03	54.7	137.5	35.0	49.0
33	107.40	54.6	124.9	34.0	48.0
34	119.79	54.5	119.5	32.5	46.5

Octadecylamine acetate as promoter. One hundred parts per million.

Atmospheric pressure 28.8 inches of mercury.

Run No.	Water Temp. °F.	Inlet Temp. °F.	Outlet Temp. °F.	Steam Press. P.S.I.G.	Steam Press. P.S.I.A.
35	27.27	55.7	179.5	38.5	52.6
36	31.20	55.4	176.0	36.5	50.6
37	37.29	55.0	167.9	35.0	49.1
38	46.82	54.9	162.0	35.0	49.1
39	54.33	54.5	149.4	34.0	48.1
40	81.34	54.3	131.4	33.5	47.6
41	91.10	54.3	128.5	33.0	47.1
42	100.10	54.3	122.0	33.0	47.1
43	104.30	54.1	116.2	32.5	46.6

RESULTS

B. Laboratory Heat Exchanger (Con'd)

No promoter, third day of continuous operation. Atmospheric pressure 28.9 inches of mercury.

Run No.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F	$\frac{1}{U_o} \times 10^{-3}$	Water Velocity Ft./Sec.	$v^{.8}$	$\frac{1}{v^{.8}}$
1	222.0	4.505	0.421	0.501	1.996
2	230.2	4.344	0.439	0.518	1.930
3	230.5	4.338	0.457	0.535	1.869
4	234.5	4.264	0.520	0.594	1.684
5	230.1	4.346	0.616	0.678	1.475
6	228.3	4.380	0.659	0.717	1.395
7	249.0	4.016	0.830	0.8615	1.161
8	255.6	3.912	0.992	0.9936	1.006
9	251.6	3.975	1.125	1.0987	0.910
10	243.8	4.102	1.540	1.413	0.708

No promoter, fourth day of continuous operation. Atmospheric pressure 29.15 inches of mercury.

Run No.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F	$\frac{1}{U_o} \times 10^{-3}$	Water Velocity Ft./Sec.	$v^{.8}$	$\frac{1}{v^{.8}}$
11	216.9	4.610	0.371	0.453	2.208
12	211.2	4.735	0.421	0.501	1.996
13	220.9	4.527	0.478	0.554	1.805

Run No.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F	$\frac{1}{U_o} \times 10^{-3}$	Water Velocity Ft./Sec.	$V^{.8}$	$\frac{1}{V^{.8}}$
14	227.8	4.389	0.539	0.609	1.642
15	224.1	4.462	0.683	0.737	1.357
16	228.9	4.369	0.774	0.815	1.227
17	248.5	4.024	0.981	0.9851	1.015
18	250.2	3.997	1.095	1.0753	0.930
19	249.6	4.006	1.269	1.210	0.826

No promoter, seventh day of continuous operation. Atmospheric pressure 28.91 inches of mercury.

Run No.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F	$\frac{1}{U_o} \times 10^{-3}$	Water Velocity Ft./Sec.	$V^{.8}$	$\frac{1}{V^{.8}}$
20	199.6	5.010	0.338	0.421	2.375
21	208.2	4.803	0.427	0.507	1.972
22	213.1	4.693	0.469	0.545	1.835
23	219.6	4.554	0.542	0.612	1.634
24	217.2	4.604	0.664	0.721	1.387
25	240.9	4.151	0.856	0.883	1.133
26	243.1	4.114	1.036	1.0287	0.972
27	235.3	4.250	1.063	1.0502	0.952
28	245.5	4.073	1.264	1.206	0.829

Octadecylamine acetate as promoter. Two to four parts per million.

Atmospheric pressure 28.59 inches of mercury.

Run No.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F.	$\frac{1}{U_o} \times 10^{-3}$	Water Velocity Ft./Sec.	$v^{.8}$	$\frac{1}{v^{.8}}$
29	210.1	4.760	0.563	0.632	1.582
30	214.7	4.658	0.641	0.701	1.427
31	221.3	4.519	0.783	0.822	1.217
32	227.7	4.392	0.955	0.9638	1.038
33	233.6	4.281	1.192	1.1502	0.8694
34	240.0	4.167	1.330	1.256	0.796

Octadecylamine abetate at promoter. One hundred parts per million.

Atmospheric pressure 28.8 inches of mercury.

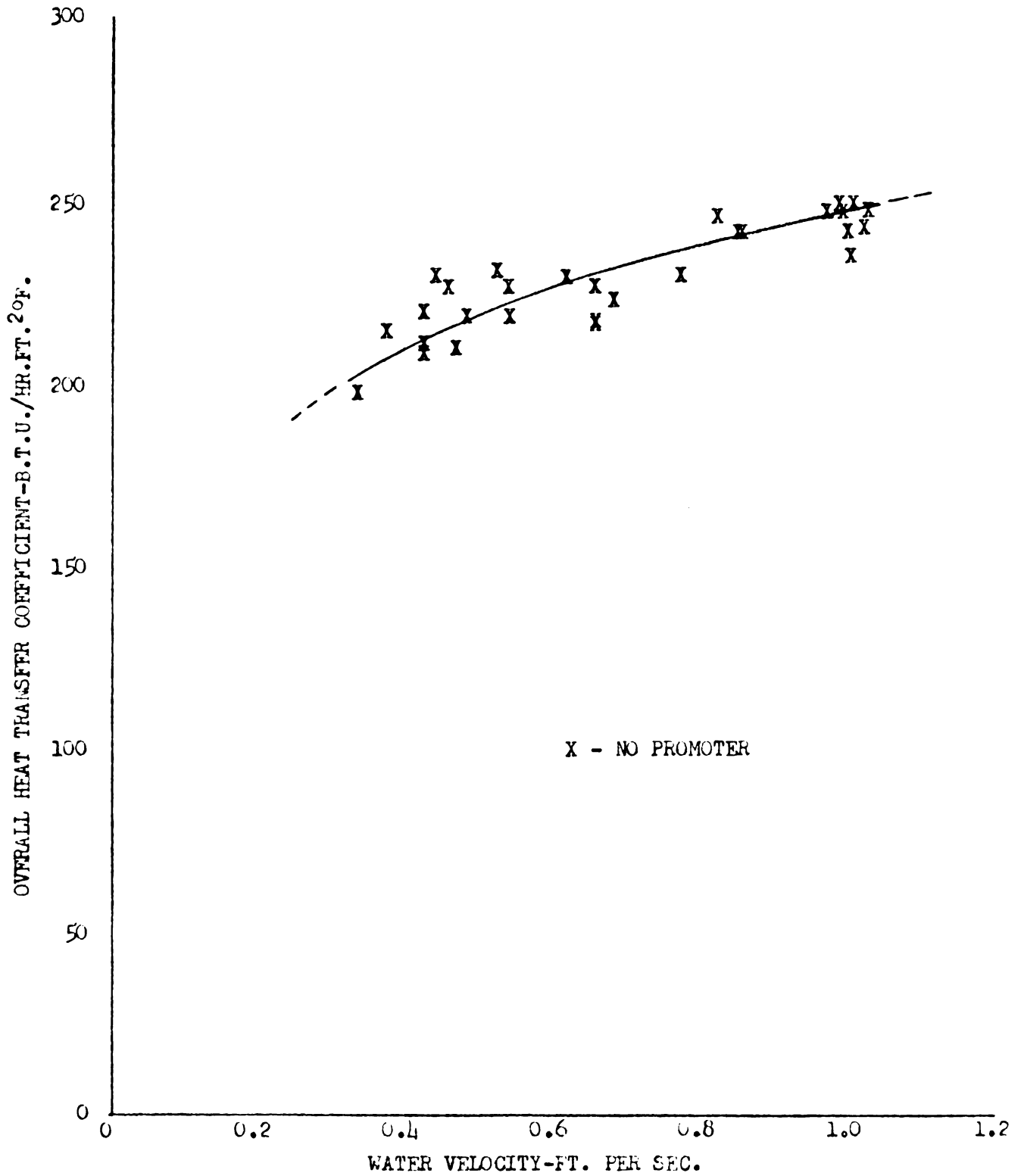
Run No.	Heat Transfer Coefficient Btu./Hr./Ft. ² /°F.	$\frac{1}{U_o} \times 10^{-3}$	Water Velocity Ft./Sec.	$v^{.8}$	$\frac{1}{v^{.8}}$
35	122.9	8.137	0.300	0.382	2.618
36	136.9	7.305	0.343	0.425	2.353
37	150.3	6.653	0.410	0.480	2.083
38	174.6	5.727	0.515	0.588	1.701
39	172.7	5.790	0.598	0.663	1.508
40	198.6	5.035	0.895	0.9148	1.093
41	212.9	4.697	1.002	1.000	1.000
42	209.0	4.785	1.101	1.073	0.932
43	197.4	5.066	1.147	1.122	0.891

TABLE OF RESULTS
Finger Type Condenser

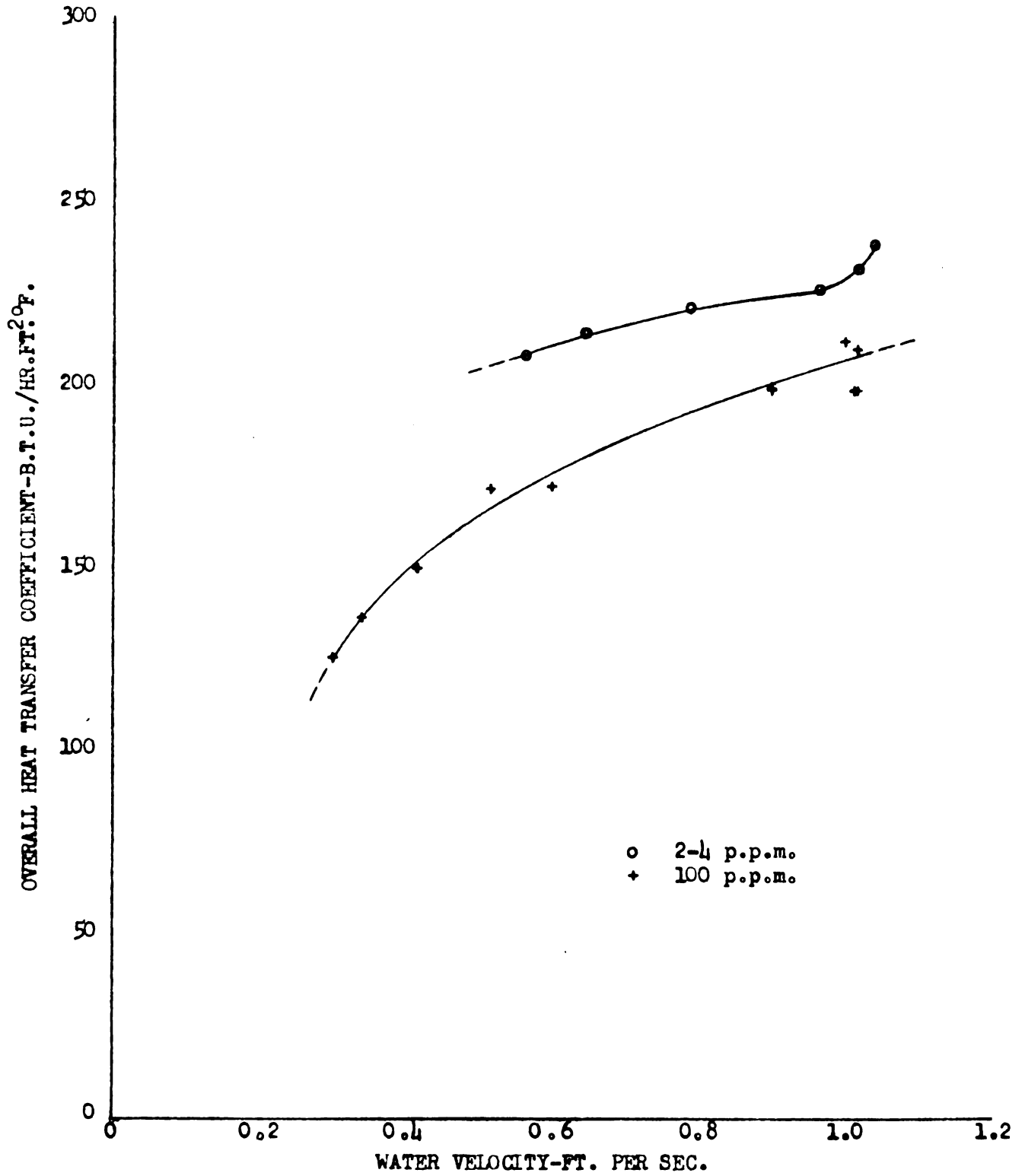
Condition	Average Mean Heat Transfer Coefficient Btu./Hr./Ft. ² /°F	Increase (Percent)
No Promoter	163.1	---
Stearic Acid	180.8	10.85
Octadecylamine Acetate	180.68	10.80

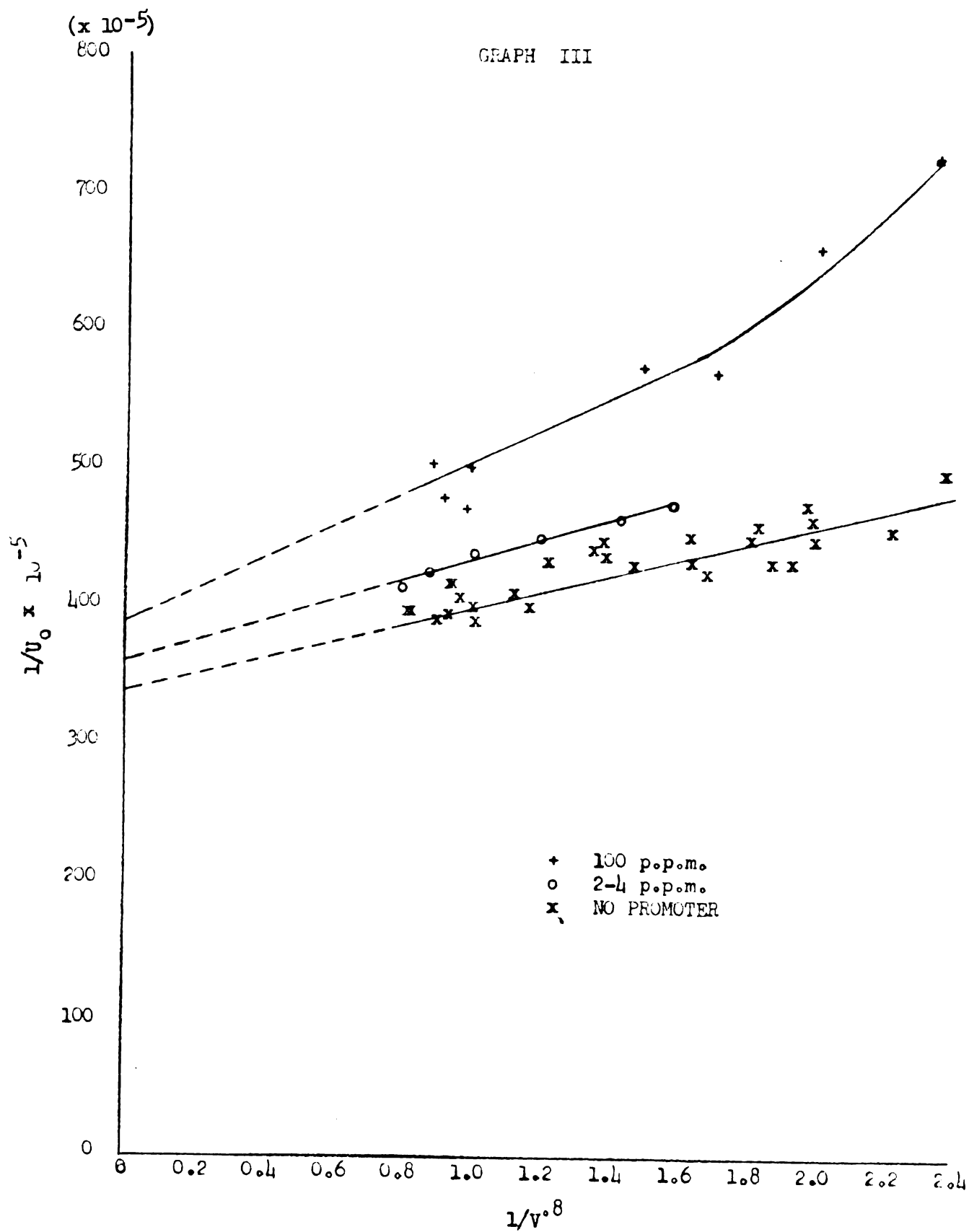
GRAPHS AND DIAGRAMS

GRAPH I



GRAPH II





GRAPH IV

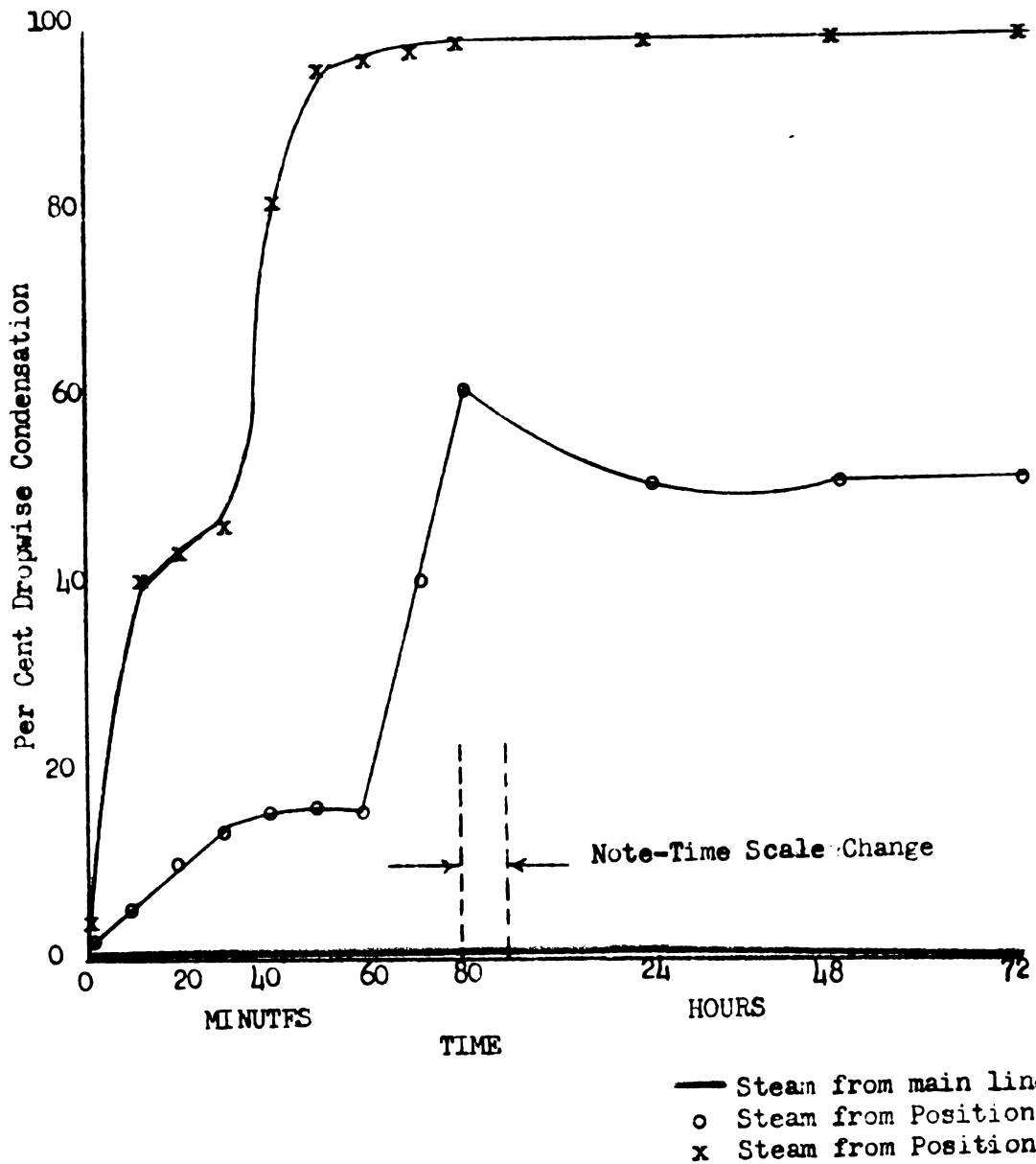


DIAGRAM I

Effect of Filming Corrosion Inhibitor on Heat Transfer

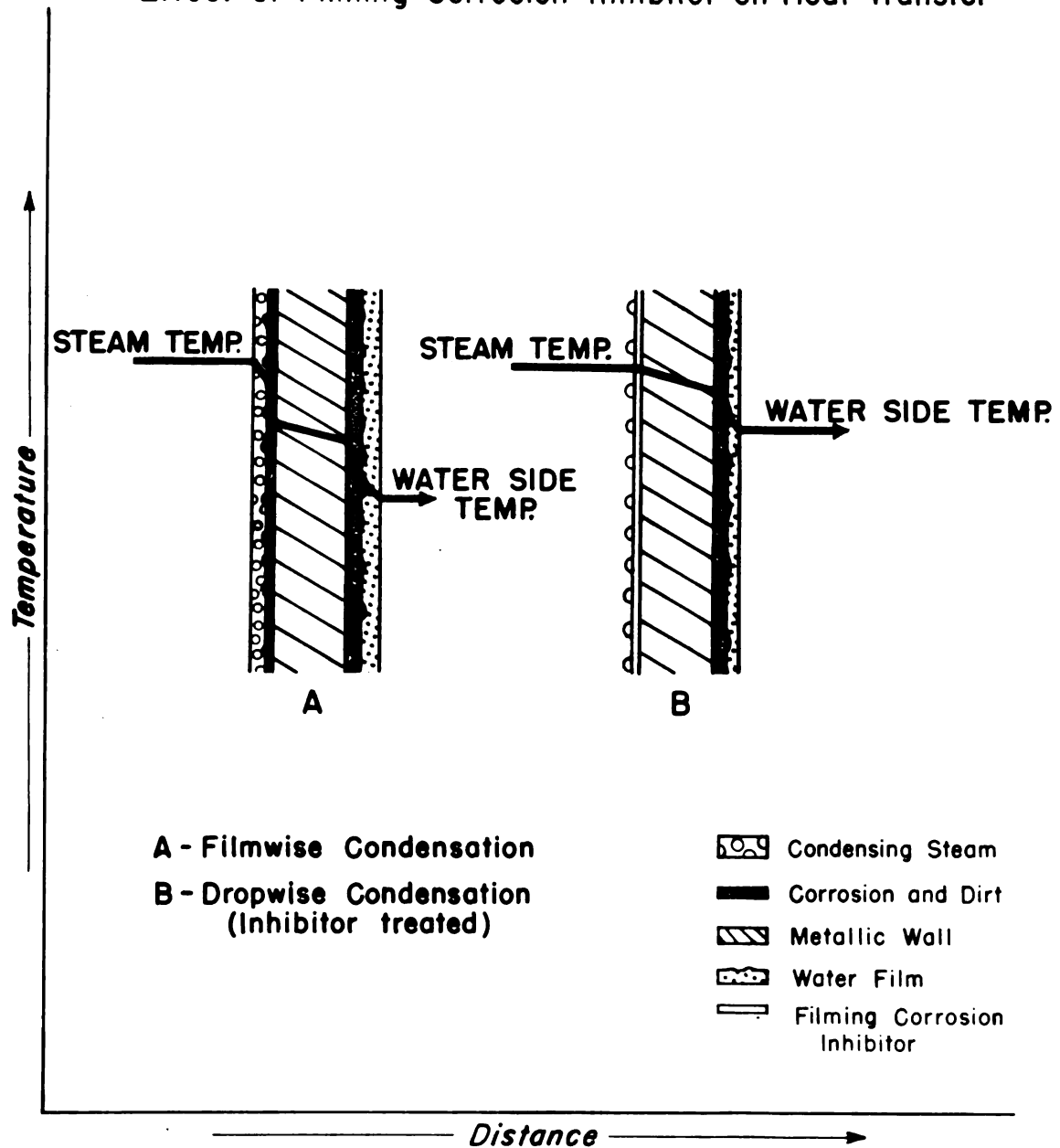


DIAGRAM II

Finger Type Condenser

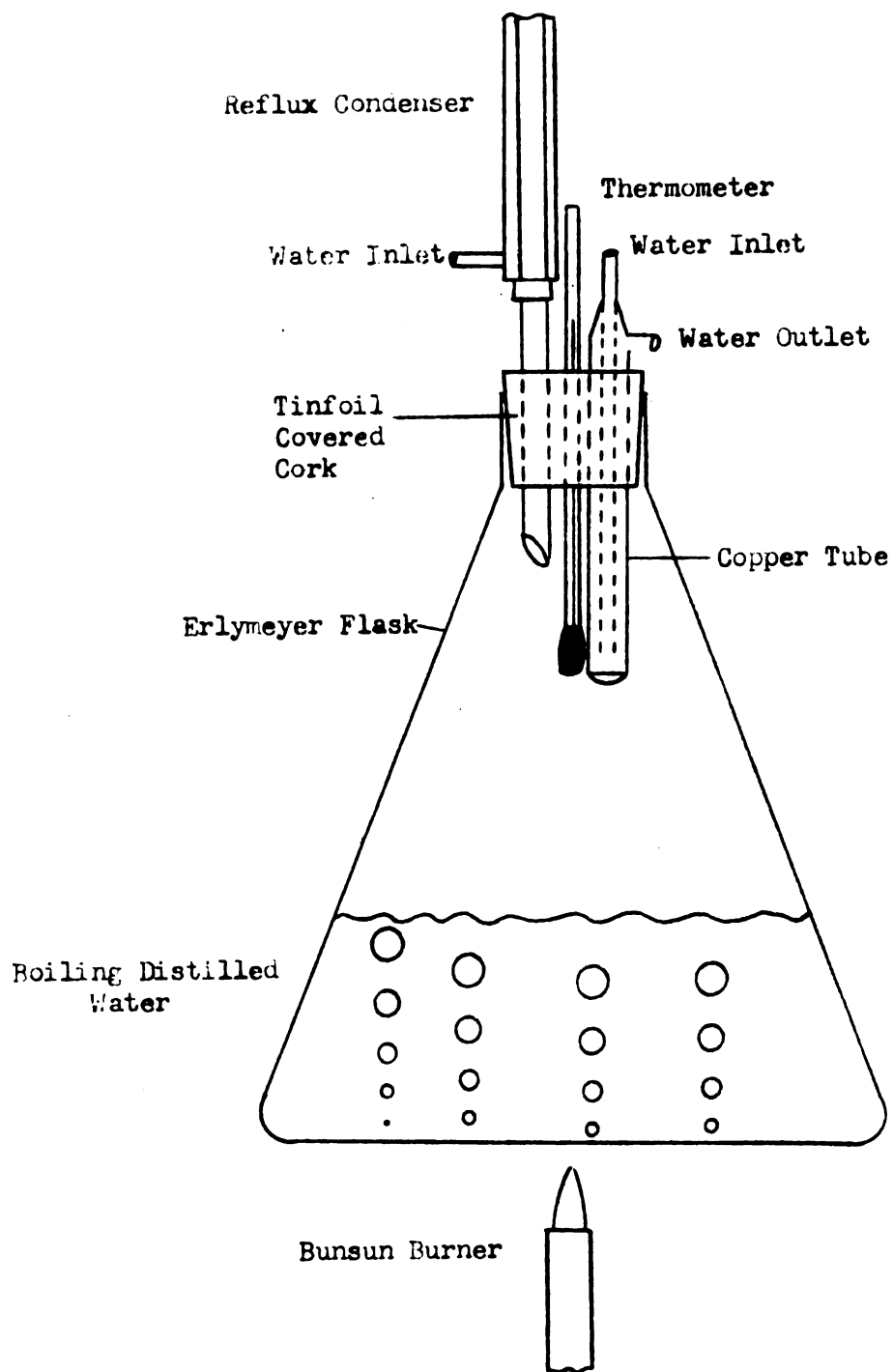
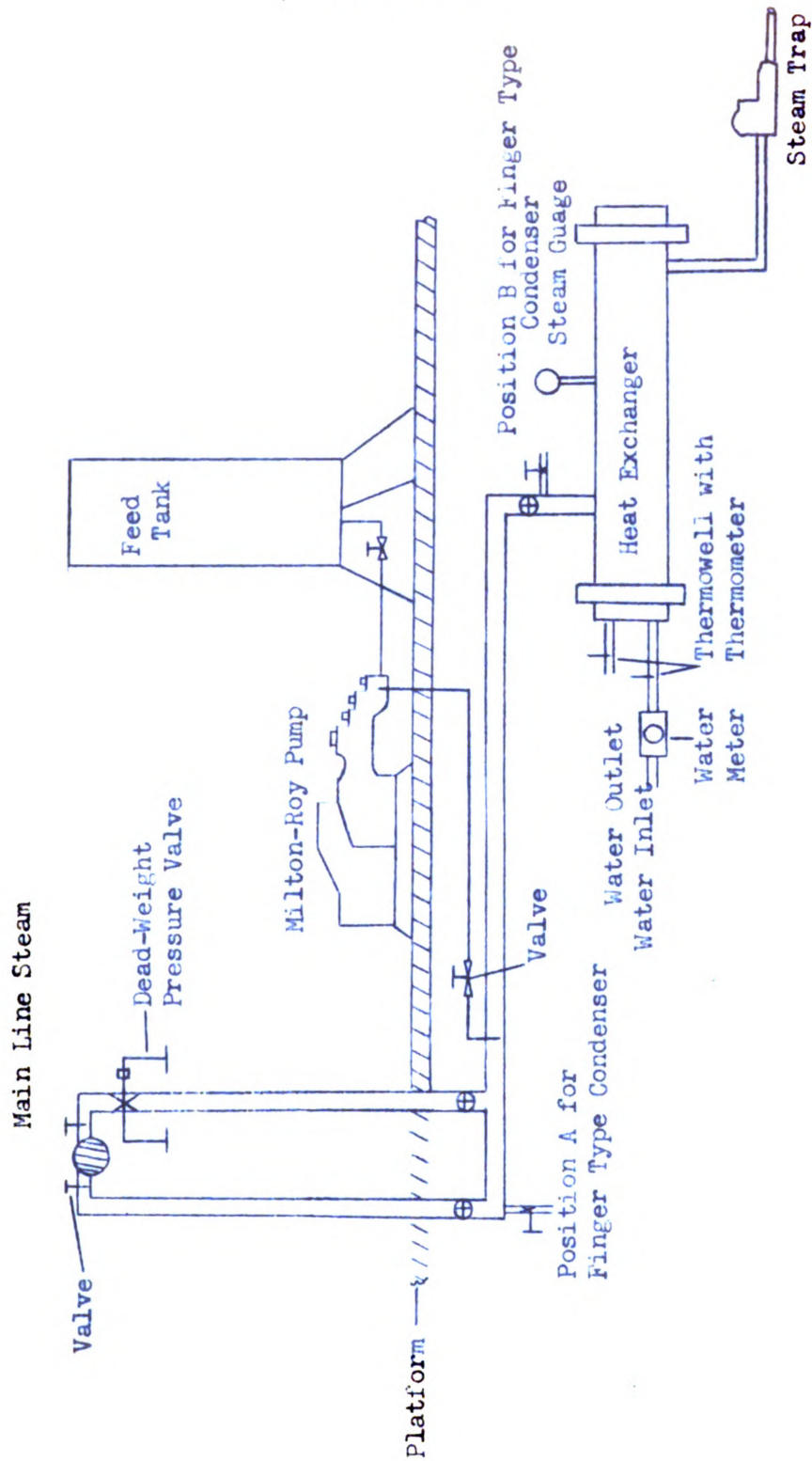


DIAGRAM III



SCHEMATIC DIAGRAM FOR LABORATORY HEAT EXCHANGER

DISCUSSION

DISCUSSION

A. Finger Type Condenser

The amount of heat transferred was determined from weight flow rate of cooling water and temperature rise in the cooling water. The magnitude of the calculated overall heat transfer coefficients could not be compared with previous studies (5, 14, 22) on this type of apparatus; no data of this nature was reported.

The magnitude of the overall coefficients seem to be a little conservative. This was also true for values reported by Wilson (27) on small straight pipes. Wilson concluded that "quantities of air collecting on the water side greatly increased the resistance to heat flow" (27). This is believed to be the case perhaps, to a greater extent in the finger type apparatus because as the water reversed its direction at the end of the miniature condenser pockets of air could possibly be built up and gradually creep along the inside of the larger copper tube, thus increasing the resistance to heat transfer. Very large resistances are reported by Perry (19) for air or gas films.

Another reason for the comparatively low heat transfer coefficients be the thickness of the condensate film. Although no accurate measurements of this thickness could be made an abnormally thick condensate layer was observed.

A plot of overall heat transfer coefficients against velocity gave a straight line relationship with a slope of zero. Due to this fact, the overall heat transfer coefficients could be averaged

directly for the magnitudes of velocities used. Nagle and Drew (14) who used a small visual condenser, reported that, less than fifteen percent variation in overall heat transfer coefficients was observed when the water rate was varied between 4.17 and 12.17 lbs./min.

In the case of the finger type condenser, the largest deviation was 8.36 percent variation from the mean when the water rate was varied between 1.484 and 11.000 lbs./min. This, along with the abnormally thick condensate layer observed, might lead to the conclusion that the condensate layer or air film was a controlling resistance.

A relative comparison between the mean average heat transfer coefficients of the film condensate and the type of condensation promoted by octadecylamine acetate show an increase of 10.8 percent. Although only approximately 45 percent of the condensate seemed to be forming in drops in the case of the octadecylamine acetate a much greater run off was observed. Because of the fact that only 45 percent of the surface area was covered with drops and that the mean overall heat transfer coefficients almost equaled those determined using stearic acid where 100 percent dropwise condensation was observed, the increased heat transmission was concluded to be also due to the greater condensate run off rate.

B. Laboratory Heat Exchanger

The heat transfer coefficients, calculated from the data for the octadecylamine acetate promoter are plotted on Graph II, while those obtained in the absence of the promoter are plotted on Graph I. The promoted induced coefficients were lower than those determined

without the promoter. A Wilson (27) plot was made (Graph III) by plotting the reciprocal of overall heat transfer coefficients against water velocity. The quality of the power plant steam was then questioned. Tests were made employing the finger type apparatus at positions A and B as shown in Diagram III. Results of the type of condensation observed are plotted in Graph IV. Inspection of this graph shows that while the main line steam gave pure filmwise condensation, the test apparatus system gave varying degrees of dropwise condensation. It appears that oil used in the threading and cutting of pipes and/or contaminants in new pressure regulating valve and/or pipe compound were of sufficient quantity to promote dropwise condensation even after a six month period of irregular operation.

Thus, dropwise condensation was present before the promoter was introduced and, therefore, hindered the correct application of the amine. In the case of the one hundred parts per million application of amine, the slope of the curve is much steeper at the low water velocity ranges than the slope of the curves at two to four parts per million and no promoter. This would indicate a "washing" action which removed a possible emulsion of amine and water from the surface of the tubes (13).

One would suspect from observation made on the finger type apparatus that there is a hindering or an undesirable reaction between the contaminants and the promoter. The net result is

probably a decrease in non-wettability of the amine; since it has been reported (26) that the corrosion inhibition of the filming amines are reduced in plants having excessive quantities of oil in steam.

CONCLUSIONS

CONCLUSIONS

The following conclusions were made from the data and results reported:

A. Finger Type Condenser

- (1) octadecylamine acetate rubbed on the surface of a highly clean and polished copper surface promotes forty-five percent dropwise condensation.
- (2) the direct effect of octadecylamine acetate on overall heat transfer coefficients show an increase of 10.8 percent.
- (3) the increase of these overall heat transfer coefficients is due to better condensate run off and promotion of dropwise condensation.
- (4) higher overall heat transfer coefficients obtained by stearic acid were almost equaled by the use of octadecylamine acetate.

B. Laboratory Heat Exchanger

- (1) oil used in cutting and threading of pipes is of sufficient quantity to promote dropwise condensation over the period of time considered in this research.
- (2) if further work is to be done with steam condensation, a continuous, contaminant free source of steam is required, and a new, clean heat exchanger with a pyrex plate glass window to observe type of condensation.

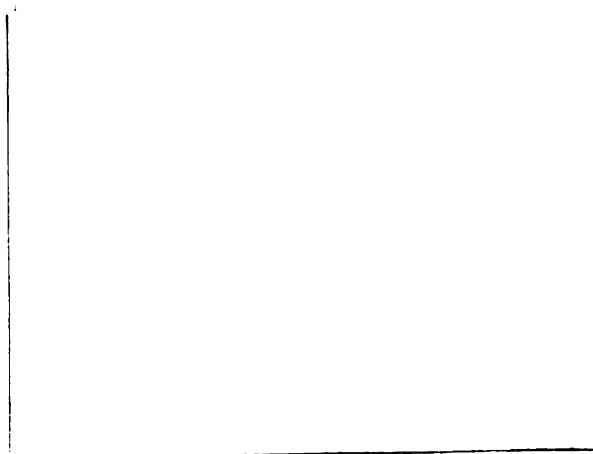
BIBLIOGRAPHY

1. Brown, G. G. and Associates, "Unit Operations," John Wiley & Sons, Inc., New York, pp. 448-453, 1950.
2. Denman, W. L., "Improvement of Heat Transfer by the Use of Filmeen," Dearborn Chemical Co., Chicago, Ill., Bulletin No. 941, (August 3, 1954).
3. Denman, W. L., "Method of Treating Water Including Boiler Waters and Composition Therefore," U. S. Patent No. 2,400,543.
4. Drew, T. B., W. M. Nagle, and W. Q. Smith, "The Conditions for Dropwise Condensation of Steam," A.I.Ch.E. Trans., Vol. 31, pp. 605-21, 1935.
5. Emmons, H., "The Mechanism of Drop Condensation," A.I.Ch.E. Trans. Vol. 35, pp. 109-122, 1939.
6. Fatica, N., and D. L. Katz, "Dropwise Condensation," Chemical Engineering Progress, Vol. 45, November, 1949, pp. 661-674.
7. Fitzpatrick, J. P., S. Baum, and W. H. McAdams, "Dropwise Condensation of Steam on Vertical Tubed," A.I.Ch.E. Trans. Vol. 35, pp. 97-107, 1939.
8. Hampson, H., "Proceedings of the General Discussion on Heat Transfer," Inst. of Mech. Engrs. London, & American Soc. of Mech. Engrs., New York, pp. 58-61, 1951.
9. Jakob, M., "Heat Transfer," John Wiley & Sons, Inc., New York, pp. 693-696, 1949.
10. Jakob, M., "Zeit. Ver deut. Ing." Vol. 76, pp. 1161, 1932.
11. Kahler, H. L., and J. K. Brown, "Experiences with Filming Amines in Control of Condensate Line Corrosion," Combustion, January, 1954, (Reprint).
12. McAdams, W. H., "Heat Transmission," 3rd Ed., McGraw-Hill Book Co., New York, pp. 347-351, 1954.
13. Nagle, W. M., G. S. Bays, L. M. Blenderman, and T. B. Drew, "Heat Transfer Coefficients During Dropwise Condensation of Steam," A.I.Ch.E. Trans. Vol. 31, pp. 593-604, 1935.
14. Nagle, W. M., and T. B. Drew, "The Dropwise Condensation of Steam," A.I.Ch.E. Trans. Vol. 30, pp. 217-255, 1933.

15. Nagle, W. M., U. S. Patent 1,995,361 March 26, 1935.
16. Nusselt, W., "Zeit. Ver. deut. Ing." Vol. 60, pp. 541-509, 1916.
17. Obrecht, M. F., "Filming Inhibitors for Corrosion Control and Increased Heat Transfer in Steam Condensing Systems," Not Published. To be presented at 46th Annual National District Heating Association, Chicago, May 24, 1955.
18. Obrecht, M. F., et al., "How Filming Amines Control Corrosion in Piping," Heating, Piping and Air Conditioning, May 1955, pp. 129-132.
19. Perry, J. H., "Chemical Engineer's Handbook," 3rd Ed., McGraw-Hill Book Co., 1950, pp. 456-498.
20. Schmidt, E., W. Schuring, and W. Sellschopp, "Technische Mechanik und Thermodynamik", Edition 1, pp. 53, 1930.
21. Shea, F. L., and N. W. Krase, "Dropwise on Film Condensation of Steam," A.I.Ch.E. Trans. Vol. 36, pp. 463-490, 1940.
22. Spoelstra, H. J., "Arch. Suikerind," Vol. 39, pp. 905-56, 1931.
23. Staff Reporter, "More Heat, Less Corrosion," Chemical Eng., pp. 140, April, 1955.
24. Tanzola, W. A., and J. G. Weidman, "Film Forming Corrosion Inhibitors also Aid Heat Transfer," The Paper Industry, April, 1954, pp. 48.
25. Weidman, J. C., "Experiences with Filming Amines for Improving Heat Transfer," Presented at American Power Conference, April 1, 1955. In press.
26. Wilkes, J. W., W. L. Derman, and M. F. Obrecht, "Filming Amines - Use and Misuse in Power Plant Water - Steam Cycles," Proc. 17 Ann. Amer. Power Conf., April 1, 1955.
27. Wilson, E. E., "A Basis for Rational Design of Heat Transfer Apparatus," Amer. Soc. Mech. Engrs. Trans., Vol. 37, pp. 47-82, 1915.

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