ORGANIC CHEMICALS DIVISION RESEARCH Report

St. Louis Research Report No. 2536

FINAL REPORT
ON
HEAT TRANSFER STUDIES
IN A FIFTY GALLON GLASS-LINED
JACKETED REACTOR

Job No. 2979

Monsanto

ST. LOUIS, MO.

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Job No. 2979

June 21, 1960

Written by: W. L. Smull

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INTRODUCTION

The prediction of heat transfer rates in agitated, jacketed, glass-lined reactors is often of importance to Monsanto. Present literature (see References) covers only partially the prediction of process side heat transfer film coefficients in jacketed, agitated reactors and almost totally neglects the estimation of jacket side heat transfer film coefficients. This project was undertaken to obtain a general correlation for predicting jacket and process side heat transfer film coefficients of Newtonian liquids in a 50 gallon glass-lined reactor and to provide a base point for developing a correlation which would include reactor size and geometry.

SUMMARY

The initial phase of this project was carried out to (1) determine if jacket film coefficients could be effectively correlated on the basis of jacket flow rate and/or velocity energy dissipated, (2) measure the thermal resistance of the jacket scale, (3) remove the jacket scale so that the metal-glass wall thermal resistance could be evaluated, (4) determine the effectiveness of various jacket scale removal methods, (5) determine if the Sieder-Tate type correlation could be utilized to correlate the pot film coefficients. This phase was carried out with a series of operations which were as follows:

1. Steam on process side to water in jacket runs on uncleaned unit. (Runs 3 to 14)
2. Jacket cleaning with oxalic acid solution.
3. Repetition of runs made under item 1. (Runs 15 to 25)
4. Jacket cleaning with Drycid solution.
5. Repetition of runs made under item 1 (Runs 26 to 39).
6. Steam in jacket to water on process side runs. (Runs 43-52)

At the conclusion of this series of runs, an analysis of the data indicated that for a given fluid over a narrow temperature range, the jacket fluid film heat transfer coefficient could be effectively correlated by either the flow rate or velocity energy dissipated and the process side heat transfer film coefficient could be correlated by the Sieder-Tate type equation. The jacket scale was also found to be small compared to the overall resistance initially and negligible after the second cleaning treatment. This factor made it difficult to compare the two cleaning treatments as to effectiveness. It was also noted that the overall coefficients varied rather radically between each series of runs. The theory was proposed that the variation of steam consumption rate and excess steam vented caused a variation in the steam film (much greater than

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literature correlations indicated) due to the steam velocity varying the condensate film thickness. This theory was tested with the following runs.

1. Water on the process side to water in the jacket with the jacket flow varied. (Runs 56 to 63)

2. Water on the process side to water in the jacket with the agitator speed varied. (Runs 64 to 71)

3. Steam in the process side to water in the jacket using a high excess steam rate. (Runs 72-79)

The results of these series of runs confirmed the above theory since the film coefficient for the high excess steam run was nearly as large as the water film coefficient.

With the objectives of the initial phase realized the final phase of this project was begun. This consisted of formulating a Sieder-Tate type mathematical model of the heat transfer resistance and then obtaining data with which to evaluate the constants and coefficients and to demonstrate the applicability of the correlation. The following model was proposed.

$$\frac{1}{U_O} = S \left(\frac{G_J}{u_J}\right)^a (N_{Pr})_J^b \left(\frac{u_J}{u_W}\right)^{-0.14} + \frac{1}{h_B} + E \left(\frac{L_p^2 n \rho_p}{u_p}\right)^{-2/3} (N_{Pr})_p^{-1/3} \left(\frac{u_p}{u_F}\right)^{-0.14}$$

The following runs were carried out to evaluate this correlation.

1. Sodium chloride brine in the jacket to water on the process side with the jacket flow varied. (Runs 80 to 85)

2. Water in the jacket to water on the process side both jacket flow and agitator speed varied. (Runs 86 to 110)

3. Aroclor on the process side to water in the jacket with the agitator speed varied. (Runs 111-115)

4. Aroclor in the jacket to Aroclor on the process side with the jacket flow rate varied. (Runs 116-120)

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First, the water to water runs were correlated by using a modification of the IBM 704 general least squares program and the Box-Wilson method. This data gave a very high correlation coefficient squared of 0.991. The data obtained in the first run of sets 80-120 was used to obtain a correlation for the range of conditions covered by these runs. This correlation gave a 95% confidence limit of $\pm$ 40% (based on the smallest $1/U_o$ encountered) which is considerably higher than expected. It appears that the degree of correlation could be improved by employing all the data available and checking each fluid system employed separately.

CONCLUSIONS

A. The use of oxalic acid and Drycid as jacket cleaning agents under the conditions stated did not cause "fish scaling" of the glass coating.

B. The jacket heat transfer area of the 50 gallon "P" series Pfaudler glass-lined reactor employed in this investigation is 14.9 ft.^{2} and the jacket volume is 16.8 gallons.

C. The heat transfer coefficient for the metal-glass reactor wall is 100 Btu/hr.ft.^{2} °F.

D. Process side film coefficients of Newtonian liquids for a fifty gallon, series "P", glass-lined reactor and geometrically similar reactors of other sizes can be predicted by the following equation.

$$(j_H)_p = 0.3\ (N_{Re})_p^{2/3}$$

The 95% confidence limit for the value predicted by this equation is approximately $\pm$ 20% of this value.

E. The following equation,

$$h_J = 1.64 k_J \left(\frac{G_J}{u_J}\right)^{0.62} \cdot (N_{Pr})^{0.29} \left(\frac{u_J}{u_W}\right)^{0.14},$$

may be used to roughly estimate the jacket film heat transfer coefficient for Newtonian liquids. It provides estimates which have mean deviations from the measured values as follows:

Fluid	Average Deviation From Exp. Value, %
Water	~0
19% NaCl Brine	~10 above exp.
1248 Aroclor	~100 above exp.*

*This value is probably highly temperature sensitive.

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RECOMMENDATIONS FOR FUTURE WORK

Future work in this area should be directed towards extending the scope of this investigation. The major restrictions imposed on this work were: (1) it was basically concerned only with Newtonian liquids, (2) it did not cover scale-up, and (3) it investigated only the case for the full reactor.

The ability to predict scale-up factors is evidently the most important of these limitations. It appears that nozzle size, number, and arrangement, jacket flow rate, jacket pressure drop, jacket diameter, jacket flow area, and heat transfer area to total jacket area ratio are the factors which must be considered for scaling up jacket film coefficients. The most obvious route for obtaining this data is to perform measurements using water to water heat transfer coefficients similar to those of this investigation on a variety of reactors and then correlating the "S" factors in an emperical manner. However, a more fundamental approach to the problem seems advised because of the large number of variables which should be studied and the rather high cost of working with plant scale equipment. The use of scale models constructed of transparent plastic

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or glass would enable one to study flow patterns, using dye injection and similar techniques, and heat transfer rates for variations of all the above listed factors at a much lower expenditure of time and funds and yet provide a more fundamental correlation of these variables. The use of this method would then reduce the number of runs in plant scale equipment to those necessary to check the correlation.

The study of scale-up factors for process side coefficients has been rather well covered in the literature. Agitator and baffle efficiencies, however, have not been effectively covered. Anchor agitator systems, fortunately, have been well investigated, but many other systems used by Monsanto either have not been covered or received only a cursory study. Thus, a need for studies in this area is also indicated.

The accurate prediction of heat transfer rates for a partially filled reactor cannot be accomplished from the results of this work because of the variation in local coefficients and other effects.

The study using scale models, which was outlined above appears to be the most effective way of obtaining this information.

The prediction of condensing vapor and boiling liquid coefficients seems to be a rather straightforward problem and basically a matter of collecting the necessary data. The prediction of heat transfer coefficients for non-Newtonian fluids, however, pose a difficult problem because of the numerous and complex flow systems encountered which are poorly understood at best. The art of measuring the viscosity and the thermal conductivity of these fluids, for example, has not advanced to the point where reliable data can be obtained for many systems. It seems the work with systems of interest as they occur or are available is the most logical approach since a general correlation for non-Newtonian systems does not appear practical or possible when the present state of non-Newtonian fluid flow is considered.

EQUIPMENT LIST

A. Reactor

S-788, a fifty gallon, type "P", Pfaudler glass-lined, jacketed reactor. The top and bottom of the unit were replaced and the unit reglassed in 1951 at which time the jacket was probably well cleaned. At the time of the present work, the glass-lining was defective at the handhole and bottom outlet, however, no breaks in the glass covering the jacket heat transfer surface could be detected. The jacket inlet contained a 1 1/4" Pfaudler agitating nozzle which produced clockwise flow. The vessel was agitated in a counter-clockwise direction with a 3-finger, 20" diameter, agitator; the speed of which could be varied from 90-170 rpm. The unit contained a thermowell in the left front nozzle and a two finger baffle

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was located in the right rear nozzle. The baffle extended 26" below the face of the nozzle and was mounted ~15° from the radius of the pot in the direction of flow. The inside diameter of the reactor was 24".

B. Cleaning Solution Circulating System

A portable unit consisting of a 130 gallon, sheet steel, open top tank and a one inch, 316 stainless steel, Allis Chalmers pump with a head rating of 100 ft. of water at no flow. This unit was borrowed from the Queeny Plant.

C. Surge Tank

This unit was connected to the jacket water supply line and operated with approximately the upper half full of compressed air and the lower half filled with water. It served to reduce the fluctuations in the jacket water supply pressure. It consisted of an 82 gallon galvanized tank with a working pressure of 75 psig and was equipped with a safety valve.

D. Differential Temperature Recorder

A Brown Strip Chart Recorder with 0 to 1,5, 10, and 20 mv. scales. It was equipped with a 12 point switching box and was used with a 3 couple iron-constantan differential thermopile, which produced approximately 1 mv. per 11F°. temperature differential, to measure the jacket temperature differential and with a 2 couple iron-constantan differential thermopile, which produced approximately 1 mv. per 16F°. temperature differential, to measure the temperature difference of the process side inlet and outlet streams. This unit was calibrated with a Leeds and Northrup potentiometer before each series of runs.

E. Temperature Recorders

A Brown -20 to 200°C and a Brown 50 to 150°C. strip chart recorder were used to measure absolute temperatures. These units were equipped with iron-constantan thermocouples. The jacket wall surface temperature probes were held in place by Conax spring-loaded glands.

F. Jacket Flow Rotameter

A Schutte Koerting 9-R rotameter with a standard 9A rotor. The unit was capable of measuring flow rates from 4-40 gpm. of water.

G. Process Water Rotameter

A Fisher Porter B-6 tube with a BNSVT-63 float. The unit had a range of 0-12.3 gpm of water.

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H. Process Aroclor Rotameter

A Brooks R-11-M25 tube with a 11 LF-1 float. The unit had a range of 0-12.3 gpm of water.

I. Jacket Pressure Differential Manometer

A 36" Meriam U-tube mercury manometer equipped with dirt traps and bleed cocks.

J. Constant Head Tank

A thirty gallon open top iron drum mounted concentrically in a fifty-five gallon open top iron drum. The former served as an overflow constant head tank and the latter as the overflow drain. This unit was used to provide a constant liquid flow rate to the reactor.

K. Tachometer

A Hasler speed indicator with a range of 0-10,000 rpm. This was used to measure the agitator drive speed before it was reduced 7:1 to drive the agitator.

L. Temperature Surge Tank

This unit was installed between the hot water mixer and the constant head tank and served to reduce temperature fluctuations in the hot water. It consisted of an 82 gallon galvanized tank with a working pressure of 75 psig. The unit was equipped with a bleed line to prevent the buildup of non condensibles in the tank and a safety valve.

M. Hot Water Mixer

A 1" Penberthy steam-water mixing tee which provided hot water service.

N. Process Aroclor Cooler or Heater

A concentric pipe heat exchanger which was used to heat or cool the process side Aroclor. The unit was serviced with 110 lbs. steam and city water.

O. Process Aroclor Pump

A 3600 rpm 1 x 1 Worthington pump (Pump 1-CNB62F, Group CGH-6F, Serial 15-39979) which was used to circulate the process Aroclor.

P. Process Aroclor Surge Tank

A 55 gallon, 304 stainless steel, cone bottom tank. This unit was located between the reactor overflow loop and the pump.

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Q. Jacket Aroclor Unit

A mobile unit consisting of a pump, auxiliary heat exchanger, surge tank, and two vertical 440V. electrical heaters. This unit provided Aroclor service to the reactor jacket.

EXPERIMENTAL PROCEDURE

A. Heat Loss Runs

To determine the heat loss from the insulated top of the reactor, atmospheric steam was passed through both the jacket and the process side of the reactor. Two hours were allowed for the unit to reach steady state. The condensate from the pot was collected for two, 15 minute periods and the average weight of condensate was converted to Btu/hr./°F. above ambient temperature. This was then used to correct for heat loss from this source. The heat loss to the atmosphere from the jacket was determined in a similar manner.

B. Jacket Scale Removal and Prevention

To remove the jacket scale, three cleaning solutions, oxalic acid, inhibited hydrochloric acid, and Drycid (Oakite tradename for sulfamic acid), were selected. The first two were suggested by Pfaudler and the latter is widely employed by the Queeny Plant. Drycid and oxalic acid were used successfully, but the inhibited (with Metex Acid Additive, also known as Udylite inhibitor) hydrochloric acid (24) was found to be extremely corrosive in the JFQ TSD corrosion laboratory (16) and they recommended that this cleaning solution be rejected as unsuitable.

To prevent rescaling of the cleaned jacket, it was filled with sodium nitrite solution when not being used.

1. Oxalic Acid Cleaning (24)

One hundred gallons of ten weight per cent solution of oxalic acid was prepared, heated to 60°C., and circulated through the jacket for 24 hrs. at 60-65°C. at a flow rate of approximately 19 g.p.m. A small amount of steam was allowed to flow into the process side of the reactor to maintain the temperature. The solution was drained and the jacket flushed with water. A one per cent by weight solution of Versene Powder, Dow trade name for the tetrasodium salt of ethylene diaminetetracetic acid, was prepared and circulated through the jacket for one hour at room temperature (~30°C.) and flow rate of approximately 19 g.p.m. The jacket was again drained and flushed with water. This was followed by circulating a 2.5 wt. % sodium nitrite solution through the jacket for 10 min. The sodium nitrite solution was allowed to remain in the jacket until it was placed in service again.

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2. Drycid Solution (19)

Eighty gallons of eight ounces per gallon Drycid solution was prepared, heated to 60°C., and circulated at 60-65°C. and a flow rate of 19 g.p.m. for 14 1/2 hours through the jacket. The jacket was drained and flushed with water. A 1% (by weight) solution of lye was prepared and circulated through the jacket for 25 minutes at room temperature ($\sim$30°C.) and a flow rate of 19 g.p.m. The jacket was again drained and flushed with water. A 2.5 weight per cent solution of sodium nitrite was prepared and circulated through the jacket for 30 minutes at room temperature ($\sim$30°C.) and 19 g.p.m. This solution was allowed to remain in the jacket until the unit was placed in service.

3. Sodium Nitrite Treatment

After each operating period, the jacket was filled with water and four liters of saturated (at 30°C.) sodium nitrite solution was put in the jacket. A 4 liter vacuum flask equipped with a dip pipe and an air bulb was used to force the solution into the jacket through the bottom inlet nozzle.

C. Heat Transfer Runs With Water in the Jacket and Steam on the Process Side (Fig. I)

Heat transfer runs were made at jacket water flow rates of from 10 to 30 g.p.m., representing the minimum rate of interest and the maximum rate obtainable, respectively, at approximately 3 g.p.m. intervals. The desired jacket water flow rate was selected and the steam flow to the process side regulated to allow a small amount of uncondensed steam to pass through the pot and out the lower vent or the cloth handhole cover. The cloth handhole cover was used in place of the normal cover to prevent pressurization of the process side. The excess steam flow prevented a build-up of noncondensables in the process side, but was not great enough for the velocity to disturb the wall steam film. After these two flows were set, the unit was allowed to reach steady state as determined by a constant temperature rise of the water passing through the jacket. This normally required one-half hour.

Three sets of data were collected for each run at steady state condition. This procedure gave a measure of the variations present at "steady state" and also helped prevent the loss of the run if a particular set of readings was discarded. The following measurements were recorded for each set of data:

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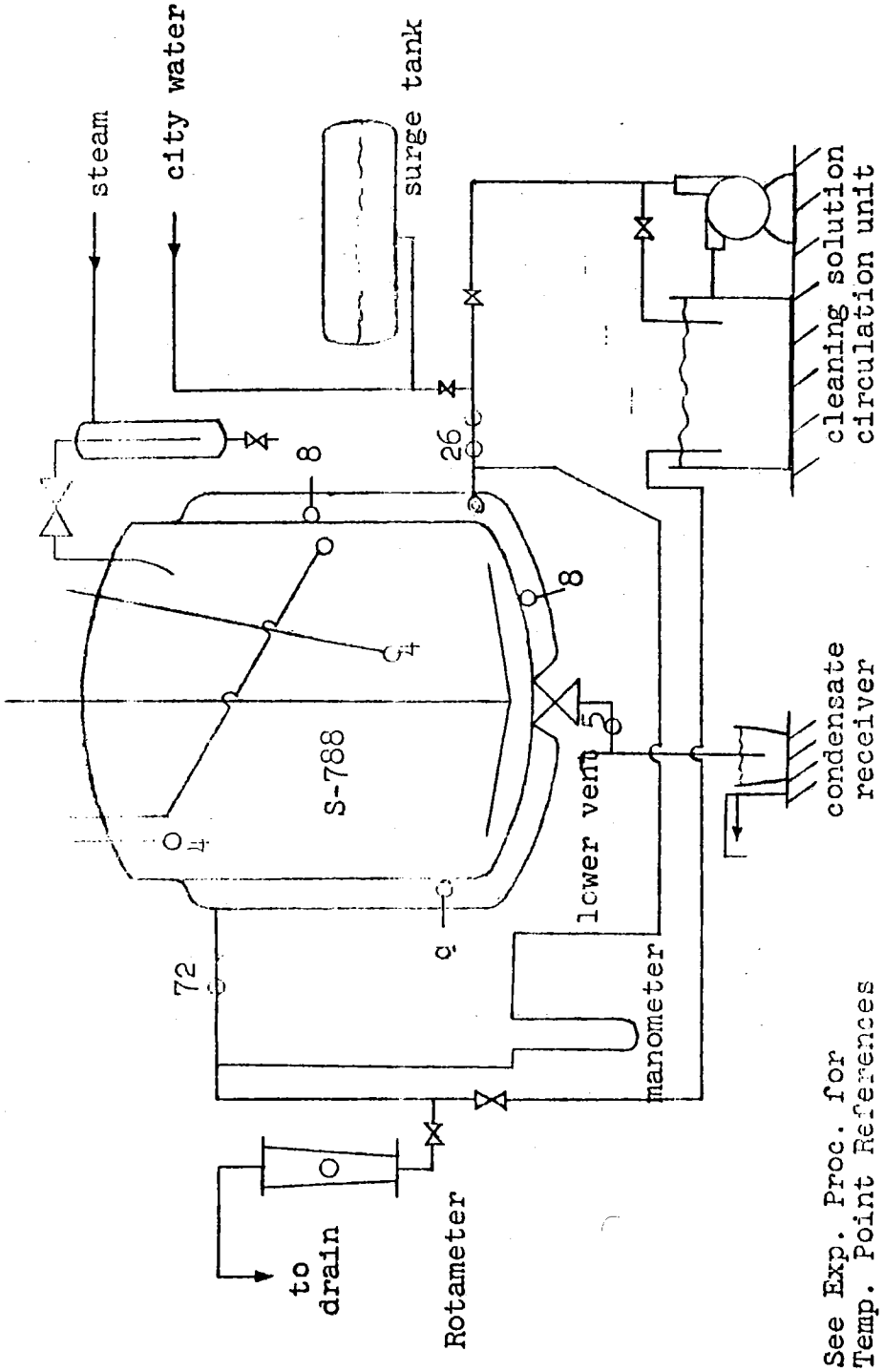


FIGURE I

Equipment Diagram
for
Water in the Jacket to Steam in the Process Side
Heat Transfer Studies

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Drawing Reference	Quality Measured
1	Jacket water flow rate
2	Jacket water temperature rise
3	Pressure drop across the jacket
4	Pot temperature at three locations
5	Condensate temperature
6	Jacket water inlet temperature
7	Jacket water outlet temperature
8	Surface temperature of the jacket wall at three locations.

After these measurements had been made, numbers 1, 2, and 3 were repeated.

While these measurements were being made and recorded, the condensate from the process side was collected in a bucket of cold water for a five minute period and weighed to the nearest ounce.

D. Heat Transfer Runs With Water on the Process Side and Steam in the Jacket (Fig. II)

Heat transfer runs were made at five different agitation rates and two bulk process side fluid temperatures. Water was supplied to the process side from a constant head tank at a rate of approximately 7 g.p.m. and overflowed via an adjustable leg. The adjustable leg was adjusted so the heat transfer surface was covered with water. Steam was fed to the jacket so that a small amount passed out a bleed valve near the top of the jacket. This prevented a build-up of noncondensables in the jacket. The desired water temperature and agitation rate were selected and the unit was allowed to reach steady state as indicated by a constant temperature rise of the water as it passed through the unit.

At each steady state condition three sets of data were collected. The measurements for each set were as follows:

Drawing Reference	Quantity Measured
1	Jacket temperature
2	Condensate temperature
3	Surface temperature of the jacket wall at three points
4	Process water temperature rise
5	Process water inlet temperature
6	Process water outlet temperature
7	Process water bulk temperature
	Agitator Speed
	Ambient Temperature

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During this time the condensate was collected in cold water for six minutes and weighed to the nearest ounce. After the three sets of readings were made the process water overflow was collected for 4 minutes and weighed.

E. Heat Transfer Runs with Liquid in the Jacket and Liquid on the Process Side (Fig. III)

Liquid-liquid heat transfer runs were made for the following systems.

Jacket Fluid	Process Fluid	Process Fluid Was:
Water	Water	Cooled
Brine	Water	Cooled
Water	Aroclor 1248	Cooled
Aroclor 1248	Aroclor 1248	Heated

The desired agitator speed and jacket flow rates were set and the process overflow leg was adjusted so that the process fluid covered the heat transfer surface. The process fluid rate was adjusted such that a temperature differential between the inlet and overflow of 10-15°C. was attained. The unit was allowed to reach steady state as indicated by constant temperature differentials of the two streams.

When the unit had attained steady state, three sets of data were collected. The measurements for each set were as follows:

Drawing Reference	Quantity Measured
1	Jacket fluid flow rate
1a	Process fluid flow rate
2	Jacket fluid temperature differential
3	Jacket pressure differential
4	Process fluid temperature differential
5	Process fluid inlet temperature
6	Process fluid outlet temperature
7	Process fluid temperature
8	Jacket fluid inlet temperature
9	Jacket fluid outlet temperature
10	Surface temperature of the jacket wall at three locations
	Ambient temperature

After these measurements had been completed numbers 1 through 4 were repeated and the next set of operating conditions selected.

Jacket wall surface temperatures were not recorded for runs 80-120 and jacket pressure differential was not recorded for runs 116-120.

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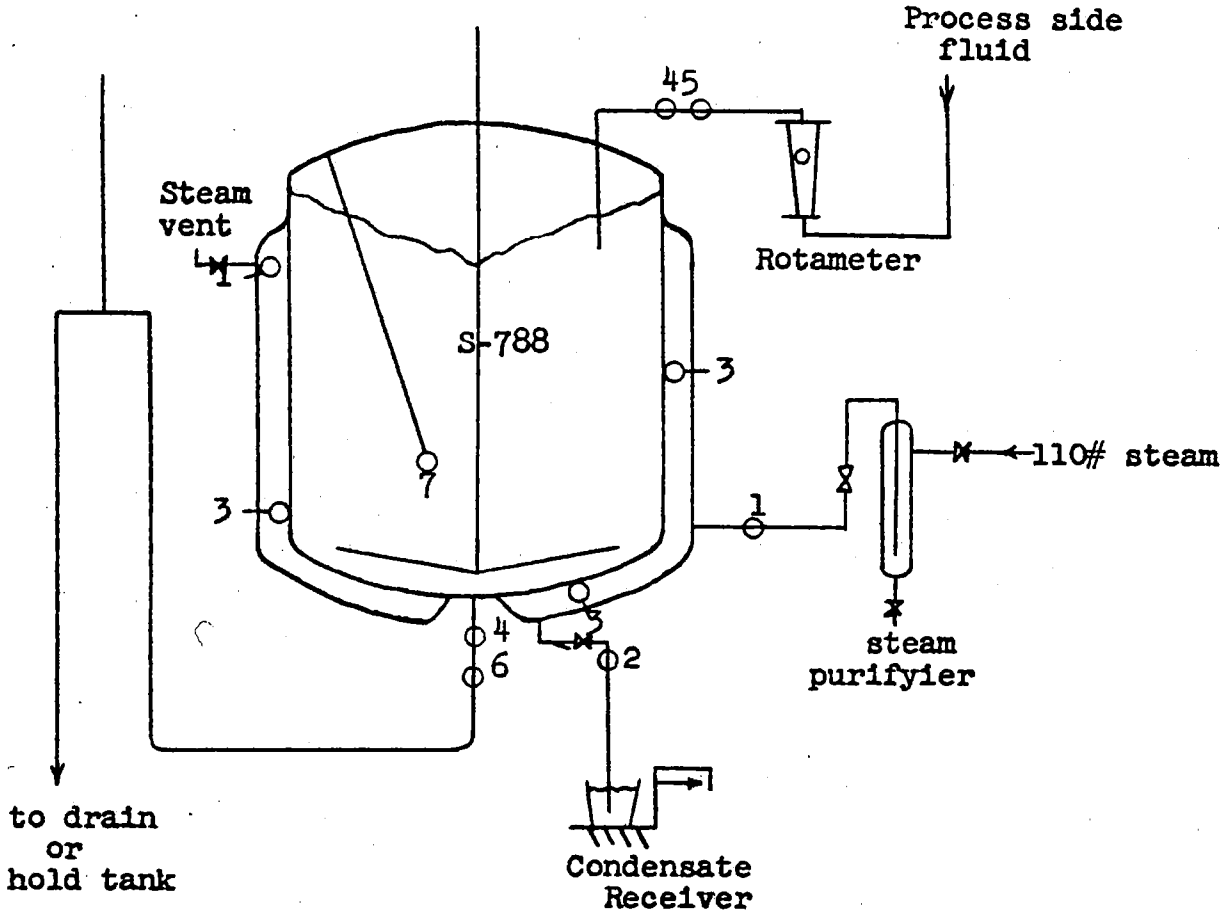


FIGURE II

Equipment Diagram For
Steam in the Jacket to Liquid in the Process Side
Heat Transfer Studies

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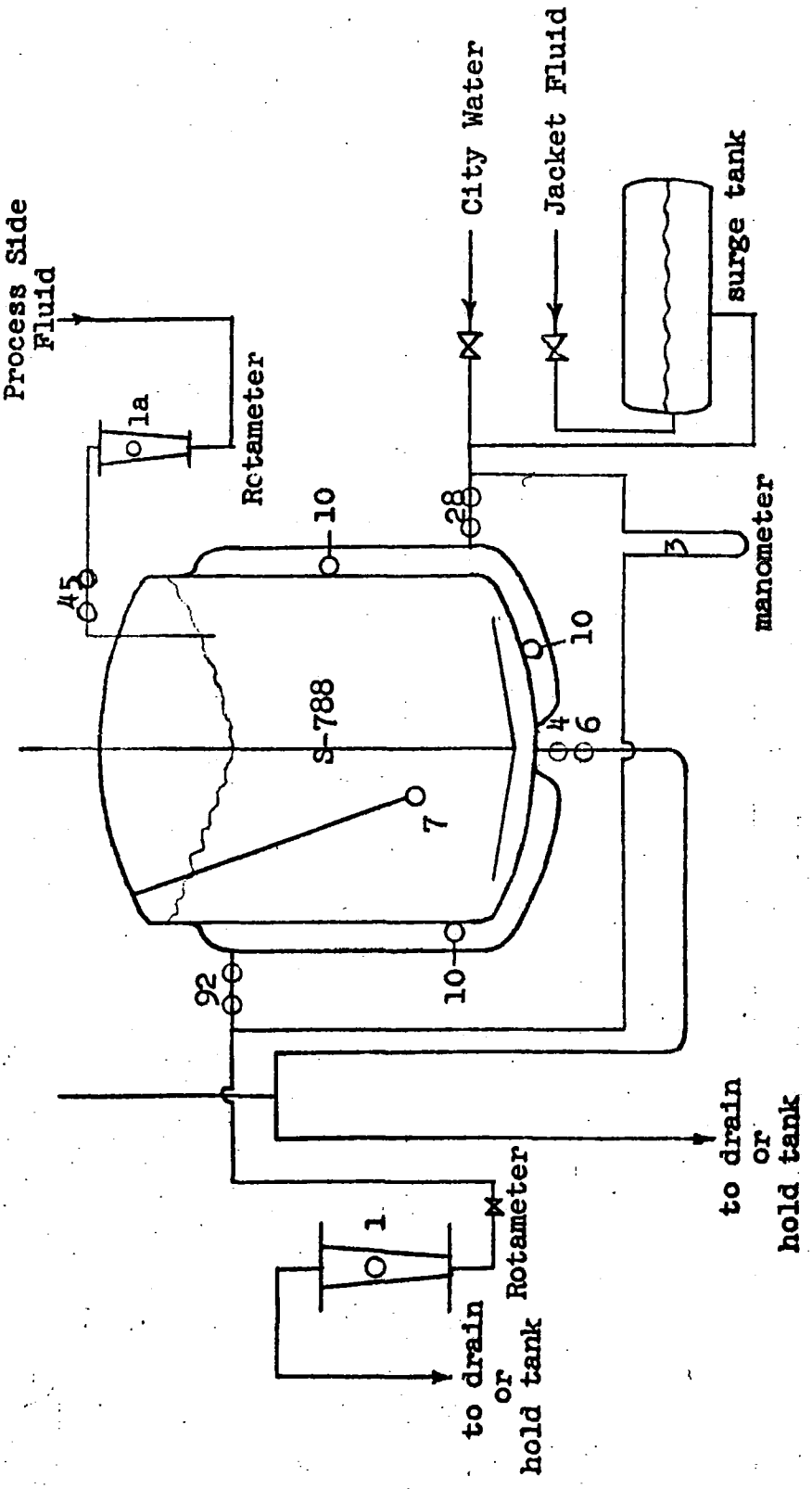


FIGURE III

Equipment Diagram For
Liquid-Liquid Heat Transfer Studies

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CALCULATIONS

A. Heat Transferred

The rate of heat transfer was determined from heat balances around the jacket and process side. The run was rejected if these two values differed by more than ± 5%. Sensible heat, latent heat, dissipated jacket fluid velocity energy, impeller energy dissipated, and losses or gains to the atmosphere were considered and calculated as follows:

$$q_S = (1.8\ ^\circ F/^\circ C)\ C\ G\ \Delta T$$

The specific heat was evaluated at the arithmetic average of the inlet and outlet temperatures.

$$q_L = W\ \lambda$$

$$q_V = \left(0.730\ \frac{\text{gpm-in. Hg}}{\text{Btu/hr.}}\right)\ Q_J\ \Delta_p$$

$$q_I = 1.32\ \left(\frac{n}{3600}\right)^{2.85}\ P_p^{0.85}\ \left(\frac{\rho}{3600}\right)^{0.15} \quad \text{(Ref. 4)}$$

Where 1.32 is an experimentally determined constants

$$q_{AJ} = 21.9\ (T_p - T_A)$$

$$q_{AP} = 52.8\ (T_J - T_A)$$

Where 21.9 and 52.8 are experimentally determined values.

B. Overall Heat Transfer Coefficient

$$U_o = \left(\frac{1^\circ C}{1.8^\circ F}\right) \frac{q}{A\ \Delta T_o}$$

C. Jacket Film Plus Scale Heat Transfer Coefficient

$$U_J = \left(\frac{1^\circ C}{1.8^\circ F}\right) \frac{q}{A\ \Delta T_W}$$

STLCOPCB4096335

CORRELATIONS

A. Correlation of Jacket Film Coefficients Using Flow Rate and Dissipated Velocity Energy

The resistance to heat transfer across the jacket wall is the sum of the film resistance on the process side, the metal-glass wall resistance, the jacket scale resistance, and the jacket water film resistance. Knowing the surface temperature of the wall (temperature of the metal-glass wall-jacket scale interface) made it possible to separate the jacket scale plus jacket water film resistance from the overall resistance. For the measurements made after the second cleaning, at which time the scale resistance was considered negligible, this quantity, U_J, was considered to be equal to the jacket water film resistance, h_J. The U_J data taken after the second jacket cleaning was then plotted on a log scale versus the log of the jacket flow rate and the jacket mixing power which gave equations of the following form.

$h_J = (Q_J)^c$ Fig. IV

$h_J = (P)^d$ Fig. VII

From these data, Wilson (7) type plots of $100/U_J$ versus $(100/Q_J)^c$ and $(1/P)^d$ were made for the data on the uncleaned jacket, the jacket after the first cleaning, and after the second cleaning (see Figs. III and IV). The heat transfer resistance, $100/U_J$, intercepts of these plots at infinite flow, $(1/P)^{0.585}$ or $(100/Q_J)^{0.986}$ equal to zero, are equal to the scale resistance for each of these jacket conditions, the intercept after the second cleaning being due to data uncertainty.

This same method was applied to the overall heat transfer coefficients for each of the three jacket conditions, Figs. V and VI, under the assumption that the condensing steam resistance remained constant for all runs. The intercepts of $(100/U_O)$ at infinite flow then represented the total heat transfer resistance for each jacket condition less the jacket water film resistance, and the difference between successive jacket condition intercepts were equal to the scale resistance removed by the jacket cleaning which was done between the runs. All slopes and intercepts were obtained by the least squares method. (13)

B. Correlation of Process Film Coefficients Using a Sieder-Tate Type Equation

These data were correlated by the following equation:

$$\frac{h_p D_p}{k_p} = E \left(\frac{L_p^2 \, n \, P_p}{\mu_p}\right)^{2/3} \left(\frac{C_p \mu_p}{k_p}\right)^{1/3} \left(\frac{\mu_p}{\mu_F}\right)^{0.14} \qquad (1)$$

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Since, if the areas of the various resistances are assumed equal and the jacket scale resistance is negligible,

$$\frac{100}{U_o} = \frac{100}{h_p} + \frac{100}{h_B} + \frac{100}{h_J}$$

Where h_B and h_J are assumed constant for the given case

$$\frac{100}{U_o} = \frac{100}{E} \quad \frac{D_p}{k_p} (N_{Re})_p^{-2/3} \quad (N_{Pr})_p^{-1/3} \left(\frac{\mu_p}{\mu_F}\right)^{-0.14} + \left(\frac{100}{h_B} + \frac{100}{h_J}\right)$$

or

$$\frac{100}{U_o} = \frac{100}{E} \quad \frac{(j_H)_p (N_{Re})_p^{-2/3}}{h_p} + \frac{100}{h_B} + \frac{100}{h_J}$$

A plot of $\frac{100}{U_o}$ vs. $\frac{(j_H)_p (N_{Re})_{10}^{-2/3}}{h_p}$ gives a straight line of slope $\frac{100}{E}$ and an intercept of $\left(\frac{100}{h_B} + \frac{100}{h_J}\right)$.

Because T_F was not measured μ_F was unknown and was determined by the relationship

$$\frac{\frac{100}{h_p}}{\Delta T_F} = \frac{\frac{100}{U_o}}{\Delta T_o}$$ which involved a trial and error process.

The correlation was further checked by subtracing the intercept of this plot from the values of $\frac{100}{U_o}$ and plotting this data in the form of Log j_H vs. Log N_{Re}. From this plot the least squares values of the intercept and slope were obtained which corresponded to the constant, E, and the exponent of (N_{Re}), respectively.

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C. Generalized Correlation for Liquid-liquid Heat Transfer in a Fifty Gallon Glass-lined Reactor

The overall heat transfer coefficient can be started as the sum of its parts as follows:

$$\frac{1}{U_o} = \frac{1}{h_J} + \frac{1}{h_D} + \frac{1}{h_B} + \frac{1}{h_p}$$

Assuming that the heat transfer area is constant.

The jacket film coefficient may be expressed by the following equation,

$$h_J = S' \frac{k_J}{D_J} \left(\frac{D_J G_J}{\mu_J}\right)^a \left(\frac{C_J \mu_J}{k_J}\right)^b \left(\frac{\mu_J}{\mu_W}\right)^{0.14},$$

of the Sieder-Tate form where the viscosity ratio, 0.14, is taken from the literature.

This equation may be modified to give

$$h_J = S\, k_J \left(\frac{G_J}{\mu_J}\right)^a (N_{Pr})_J^b \left(\frac{\mu_J}{\mu_W}\right)^{0.14} \quad \text{where } S = \left(\frac{S' D_J^{a-1}}{A_J^a}\right)$$

The scale film heat transfer resistance is a constant and was considered zero for the cleaned jacket. The wall heat transfer resistance

$\frac{1}{h_W} = \frac{L_M}{k_M} + \frac{L_G}{k_G}$ and was assumed to be constant over the temperature range employed.

The process film heat transfer coefficient may be expressed as in the preceding section.

$$h_p = E \frac{k_p}{D_p} \left(\frac{L_p^2\, n\, P_p}{\mu_p}\right)^{2/3} (N_{Pr})_p^{1/3} \left(\frac{\mu_p}{\mu_F}\right)^{0.14}$$

Substituting these results into the original equation the following equation is obtained.

$$\frac{1}{U_o} = \left(\frac{1}{S k_J}\right) \left(\frac{G_J}{\mu_J}\right)^{-a} (N_{Pr})_J^{-b} \left(\frac{\mu_J}{\mu_W}\right)^{-0.14} + \frac{L_M}{k_M} + \frac{L_a}{k_G}$$

$$+ \frac{D_p}{E k_p} \left(\frac{L_p^2\, n\, P_p}{\mu_p}\right)^{-2/3} (N_{Pr})_p^{-1/3} \left(\frac{\mu_p}{\mu_p}\right)^{-0.14}$$

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The constants in this equation were then evaulated by the method of least squares utilizing the I.B.M. 704 computer.

It should be noted that the viscosity ratios could not be evaluated directly because the film temperatures were not known. They were estimated using the trial and error method outlined in the previous section. Because of the small exponent of these groups even a relatively large error in the estimation of the film temperature should not affect the results to an appreciable extent.

SOURCES OF PHYSICAL AND THERMAL PROPERTIES EMPLOYED

	Water		NaCl Brine		Aroclor 1248	
	Ref.	Page	Ref.	Page	Ref.	Page
Viscosity	9	733	14	1696	18	26
Density	12	484	15	79, vol. 3	18	24
Thermal conductivity	9	733	9	730	18	26
Specific heat	10	2259-2262	15	328, vol. 2	18	24
Prandtl number	8	733	Calculated		18	26

k_Q = 0.5 Btu ft./hr.ft^2°F. (23) k_M = 30 Btu ft./hr.ft^2°F. (23)

ANALYTICAL DATA

Item	Value	JFQ Method No.
NaCl brine specific gravity	1.1419-1.1422 at 25°C.	116-A
$Na_2Cl_2O_7$ content of brine	2675 ppm	843-44
Aroclor 1248 viscosity		126-A
Process Mat'l., water-Aroclor runs	41.46 c.s. at 100°F.	
	3.21 c.s. at 210°F.	
Process mat'l., Aroclor-Aroclor runs	41.84 c.s. at 100°F.	
	3.19 c.s. at 210°F.	
Jacket mat'l., Aroclor-Aroclor runs	43.29 c.s. at 100°F.	
	319 c.s. at 210°F.	

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Item	Value	JFQ Method No.
Aroclor 1248 moisture content		78-B
Process mat'l., water-Aroclor runs	0.03%	
Process mat'l. Aroclor-Aroclor runs	0.09%	
Jacket mat'l., Aroclor-Aroclor runs	0.01%	

RAW MATERIALS

Drycid	Oakite Co.
Oxalic acid	JFQ No. 45650
Sodium Nitrite	JFQ No. 53050
Versene Powder	Dow Chemical Co.
Caustic Soda, liquid 50%	JFQ No. 18610
Aroclor 1248	JFQ No. 81102

Process Side
Lot B-524 PKG. 614
Non Electrical Grade

Jacket Side
Lot C-508 PKG. 614
Electrical Grade

EXPERIMENTAL AND CALCULATED DATA

A. Equations of Least Squares Fits to Data

1. Jacket Film Plus Scale Heat Transfer Coefficient

a. Plot to Determine Q_J Exponent

Log U_J = 1.5646 + 0.9856 Log Q_J (Fig. IV, Runs 26-39)

converting this to expotential form

$$\frac{100}{U_J} = 0.02911 \left(\frac{100}{Q_J}\right)^{0.986}$$

b. Correlation plots of $\frac{100}{U_J}$ vs. $Q_J^{0.986}$ (Fig. V)

before cleaning

$$\frac{100}{U_J} = 0.0881 + 0.0312 \left(\frac{100}{Q_J}\right)^{0.986} \quad \text{(Runs 3-14)}$$

DSW 622307

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after first cleaning

$$\frac{100}{U_J} = 0.0061 + 0.0308 \left(\frac{100}{Q_J}\right)^{0.986} \quad \text{(Runs 15-25)}$$

after second cleaning

$$\frac{100}{U_J} = 0.0039 + 0.0284 \left(\frac{100}{Q_J}\right)^{0.986} \quad \text{(Runs 26-39)}$$

Average slope of the 3 Eq. 0.0301

rerun after second cleaning using water to water heat transfer

$$\frac{100}{U_J} = -0.0105 + 0.0319 \left(\frac{100}{Q_J}\right)^{0.986} \quad \text{(Fig. VI, Runs 56-63)}$$

or by logarimic least squares analysis of the data

$$\frac{100}{U_J} = 0.0254 \left(\frac{100}{Q_J}\right)^{1.078}$$

c. Plot to determine P exponent Log U_J = 1.2527 + 0.3834 Log P (Fig. VII, Runs 26-39) or converting to expotential form

$$\frac{100}{U_J} = 0.0559 \left(\frac{1}{P}\right)^{0.383}$$

d. Correlation plots of $\frac{100}{U_J}$ vs. $\left(\frac{1}{P}\right)^{0.383}$ (Fig. VIII)

uncleaned jacket

$$\frac{100}{U_J} = 0.0972 + 0.0565 \left(\frac{1}{P}\right)^{0.383} \quad \text{(Runs 3-14)}$$

after first cleaning

$$\frac{100}{U_J} = 0.0015 + 0.545 \left(\frac{1}{P}\right)^{0.383} \quad \text{(Runs 15-25)}$$

after second cleaning

$$\frac{100}{U_J} = -0.0033 + 0.0572 \left(\frac{1}{P}\right) \quad \text{(Runs 26-39)}$$

Average slope of the 3 Eq. = 0.0561

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2. Overall Heat Transfer Coefficient with Jacket Varied

a. Correlation plots of $\frac{100}{U_o}$ vs. $(\frac{1}{P})^{0.383}$ (Fig. IX)

uncleaned jacket

$$\frac{100}{U_o} = 1.77 + 0.0630 \left(\frac{1}{P}\right)^{0.383} \quad \text{(Runs 3-14)}$$

after first cleaning

$$\frac{100}{U_o} = 1.68 + 0.0567 \left(\frac{1}{P}\right)^{0.383} \quad \text{(Runs 15-25)}$$

after second cleaning

$$\frac{100}{U_o} = 1.61 + 0.0897 \left(\frac{1}{P}\right)^{0.383} \quad \text{(Run 26-39)}$$

Average slope of the 3 Eq. 0.0698

b. Correlation plots of $\frac{100}{U_o}$ vs. $(\frac{100}{Q_J})^{0.986}$ (Fig. X)

before cleaning

$$\frac{100}{U_o} = 1.76 + 0.0346 \left(\frac{100}{Q_J}\right)^{0.986} \quad \text{(Runs 3-14)}$$

after first cleaning

$$\frac{100}{U_o} = 1.68 + 0.0318 \left(\frac{100}{Q_J}\right)^{0.986} \quad \text{(Runs 15-25)}$$

after second cleaning

$$\frac{100}{U_o} = 1.62 + 0.0446 \left(\frac{100}{Q_J}\right)^{0.986} \quad \text{(Runs 26-39)}$$

Average slope of the 3 Eq. = 0.0370

repeated after second cleaning using water to water heat transfer (Fig. XI)

Series I $\frac{100}{U_o} = 0.0661 \left(\frac{100}{Q_J}\right)^{0.986} + 1.150$ (Runs 56-63)

DSW 622309

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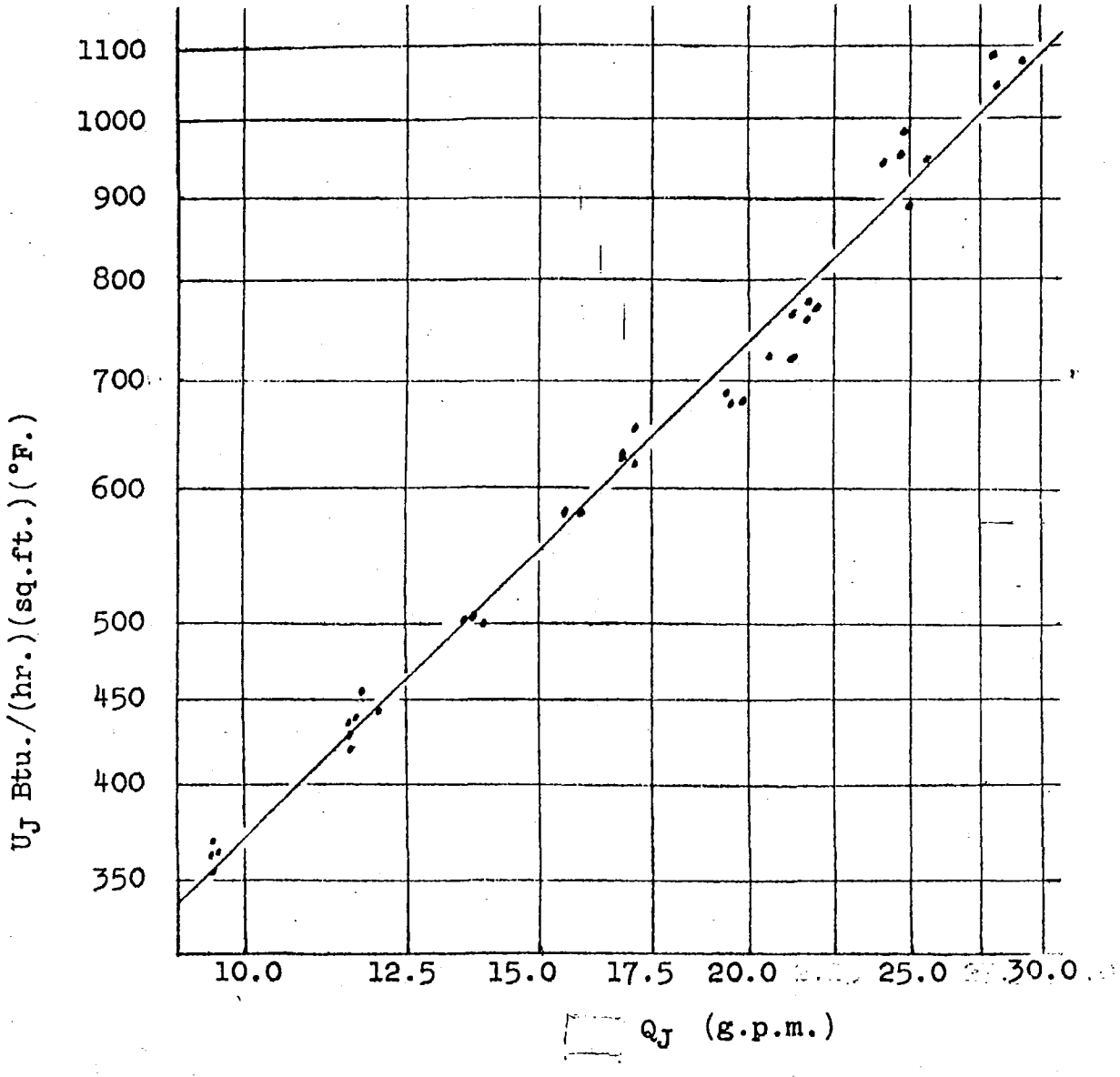


FIGURE IV

Log-Log Plot of Jacket Scale-Water Film Heat Transfer Coefficient versus of Jacket Flow Rate

Reactor: S-788, 50 gal. glass-lined, clean jacket Runs 26-39

WLS Job No. 7501-2479

DSW 622310

STLCOPCB4096343

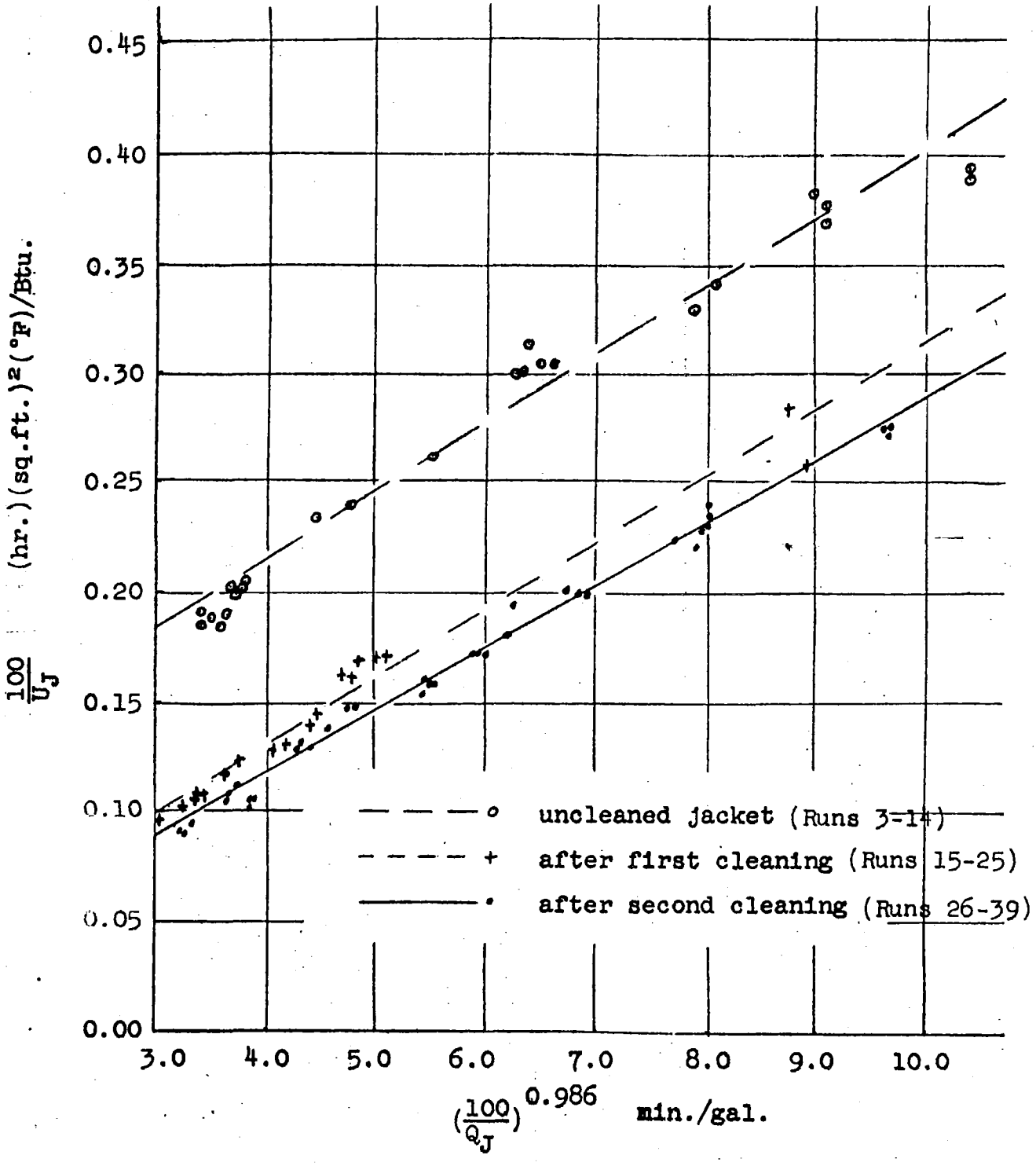


FIGURE V

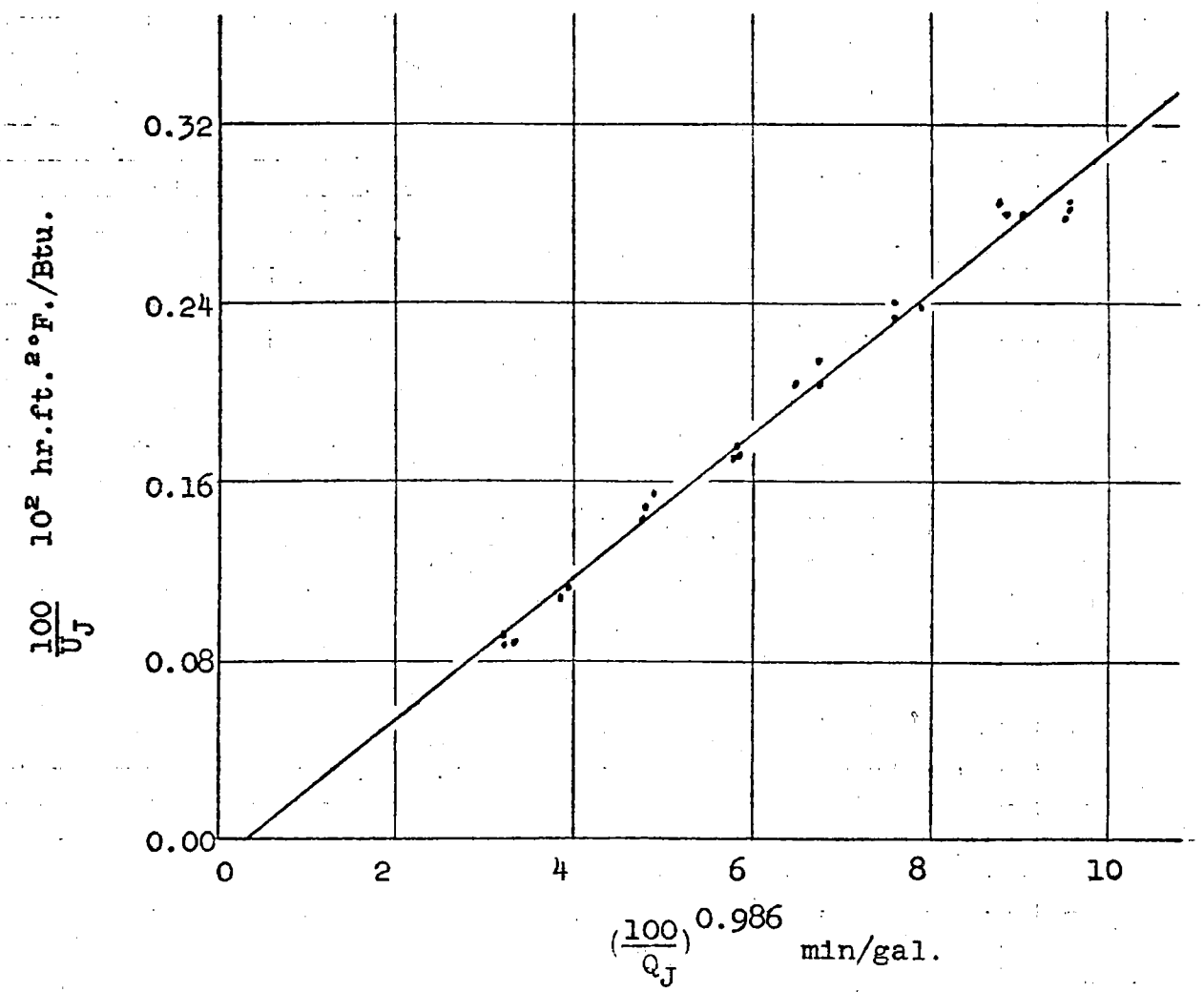
Modified Wilson Plot of Jacket Scale-Water Film Heat Transfer Coefficient versus Jacket Flow Rate

DSW 622311

Reactor: S-788, 50 gal. glass-lined

WLS Job No. 7501-2979

STLCOPCB4096344



DSW 622312

FIGURE VI

Modified Wilson Plot of Jacket Film Heat Transfer
Coefficients for Water-Water Heat Transfer

Reactor: S-788, 50 gal., glass-lined
Runs 56-63

WLS 11-2-59
Job No. 2979

STLCOPCB4096345

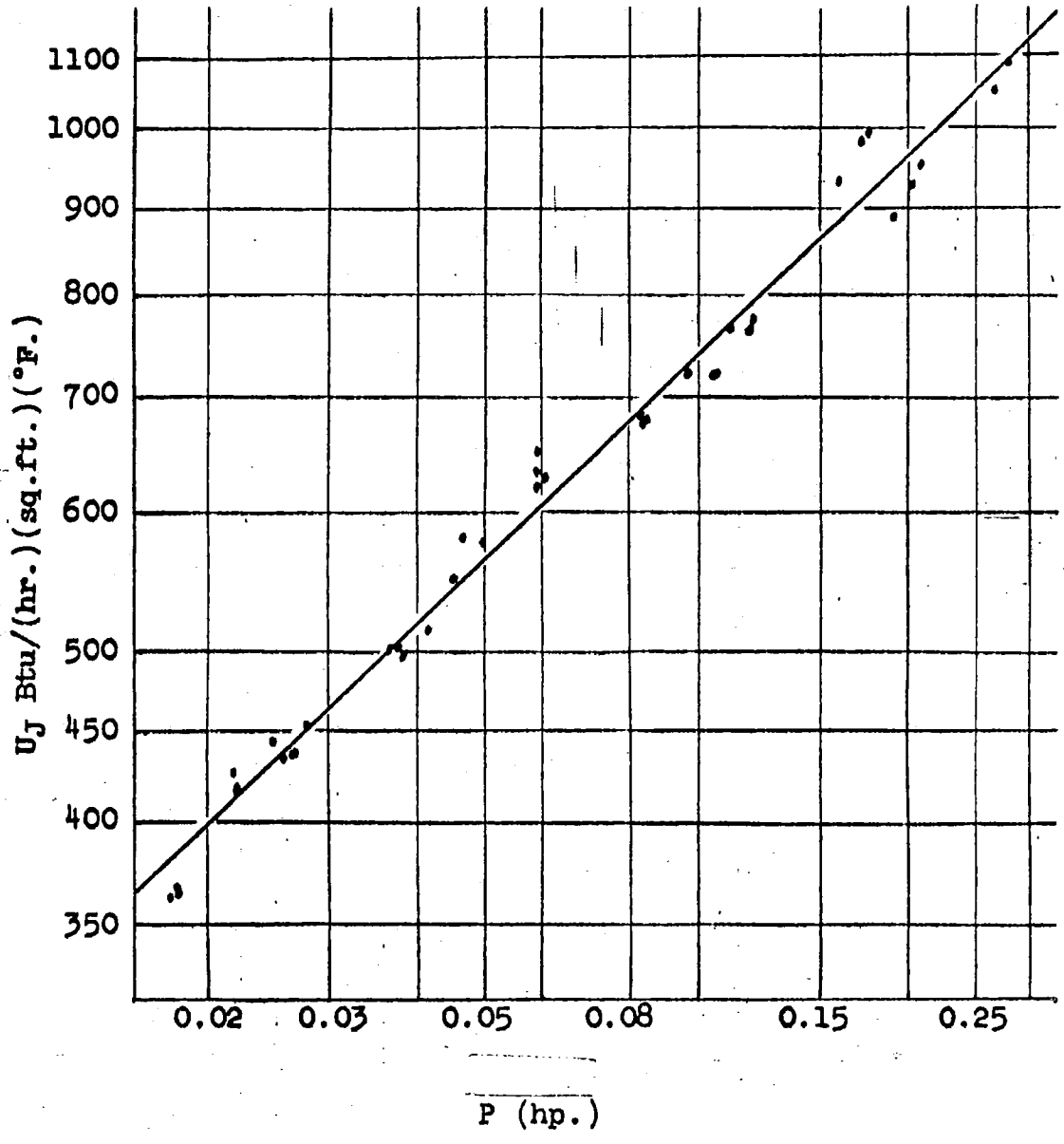


FIGURE VII

Log-Log Plot of Jacket Scale-Water Film Heat Transfer Coefficient versus Jacket Mixing Horsepower

Reactor: S-788, 50 gal. glass-lined, clean jacket Runs 26-39

WLS Job No. 7501-2979

DSW 622313

STLCOPCB4096346

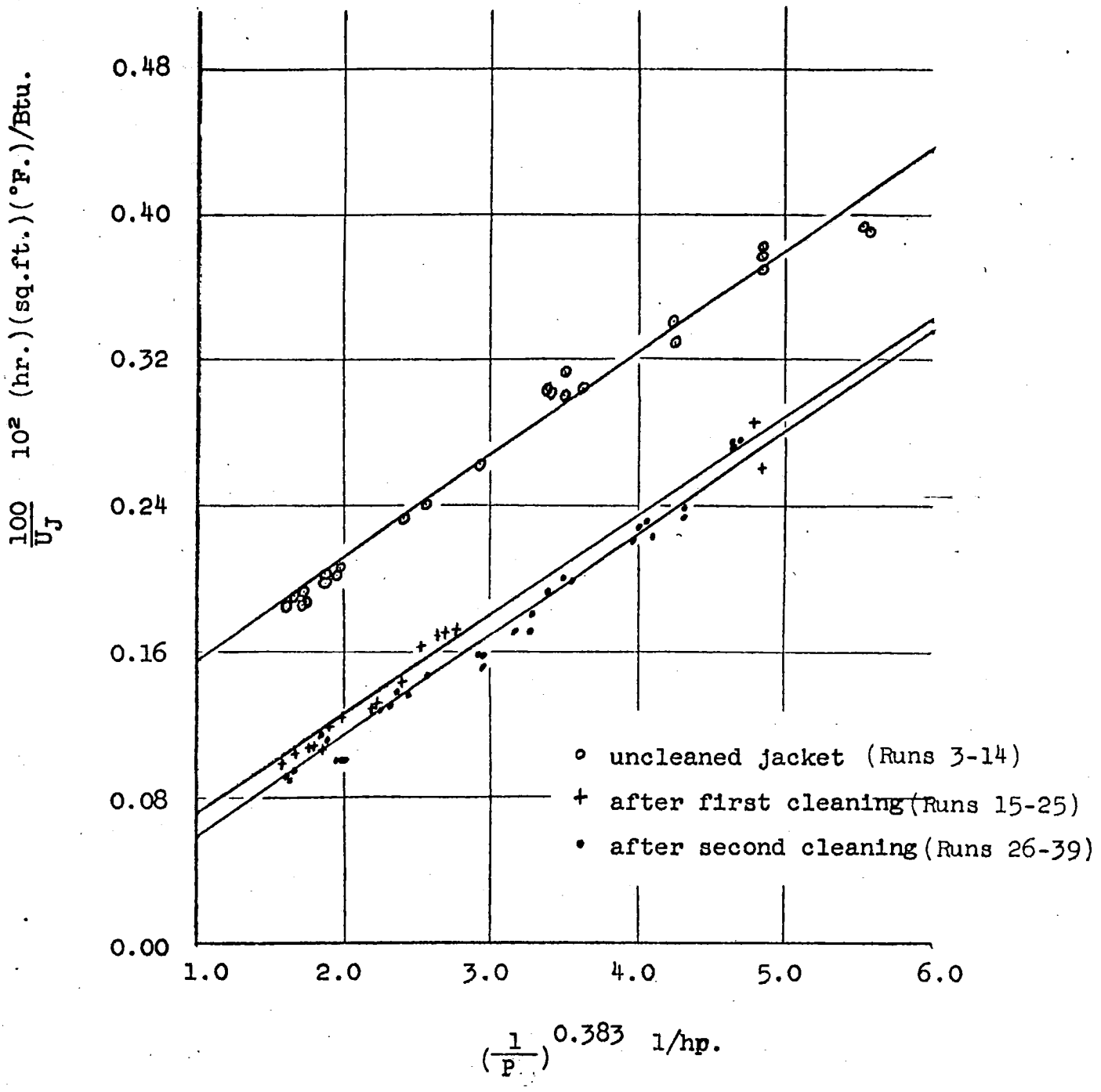


FIGURE VIII

Modified Wilson Plot of Jacket Film-Scale Heat Transfer Coefficient versus Jacket Mixing Horsepower

DSW 622314

Reactor: S-788, 50 gal. glass-lined

WLS Job No. 7501-2479

STLCOPCB4096347

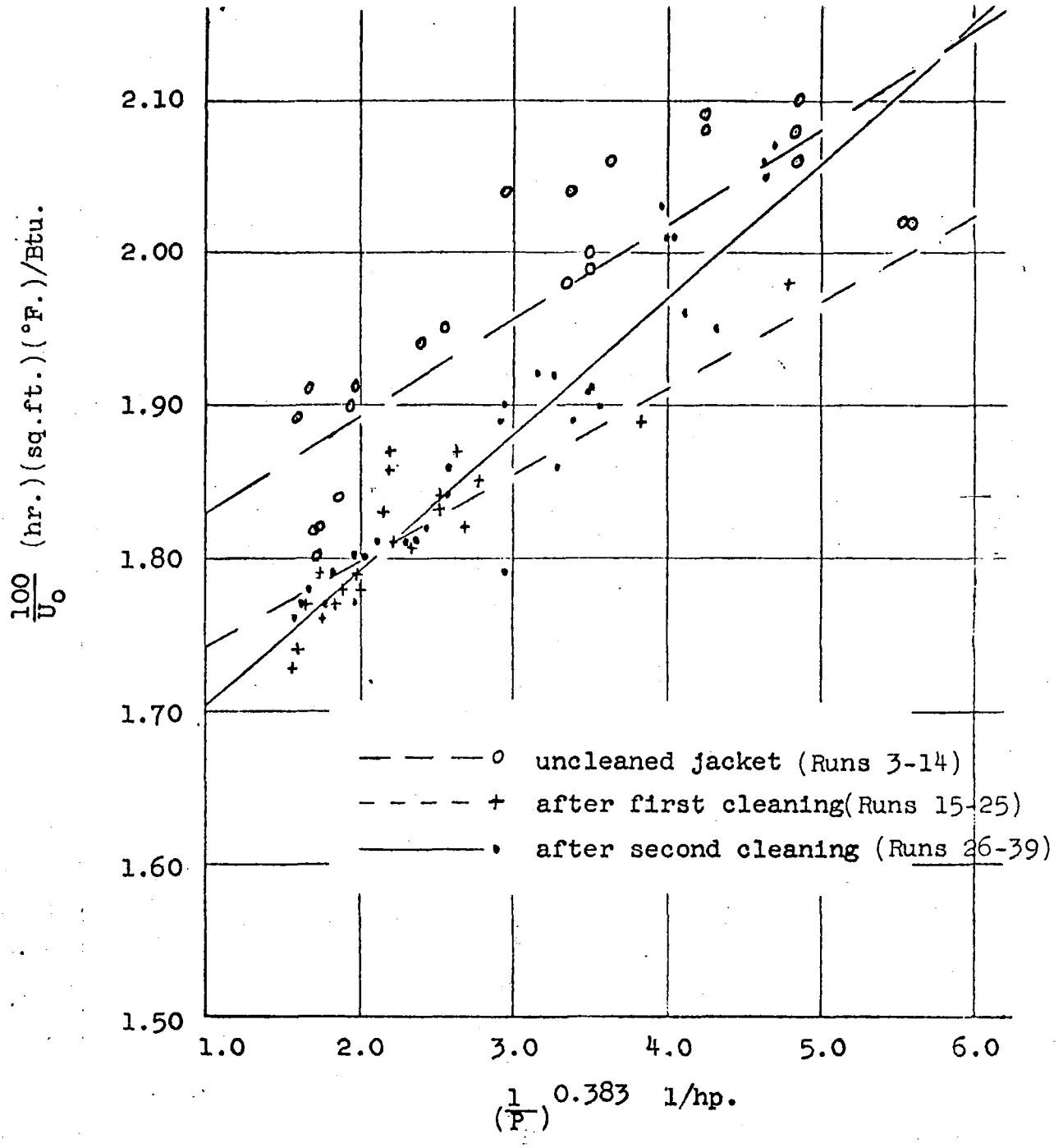


FIGURE IX

Modified Wilson Plot of
Overall Heat Transfer
Coefficient versus Jacket
Mixing Horsepower

DSW 622315

Reactor: S-788, 50 gal. glass-lined

WLS

Job No. 7501-2979

STLCOPCB4096348

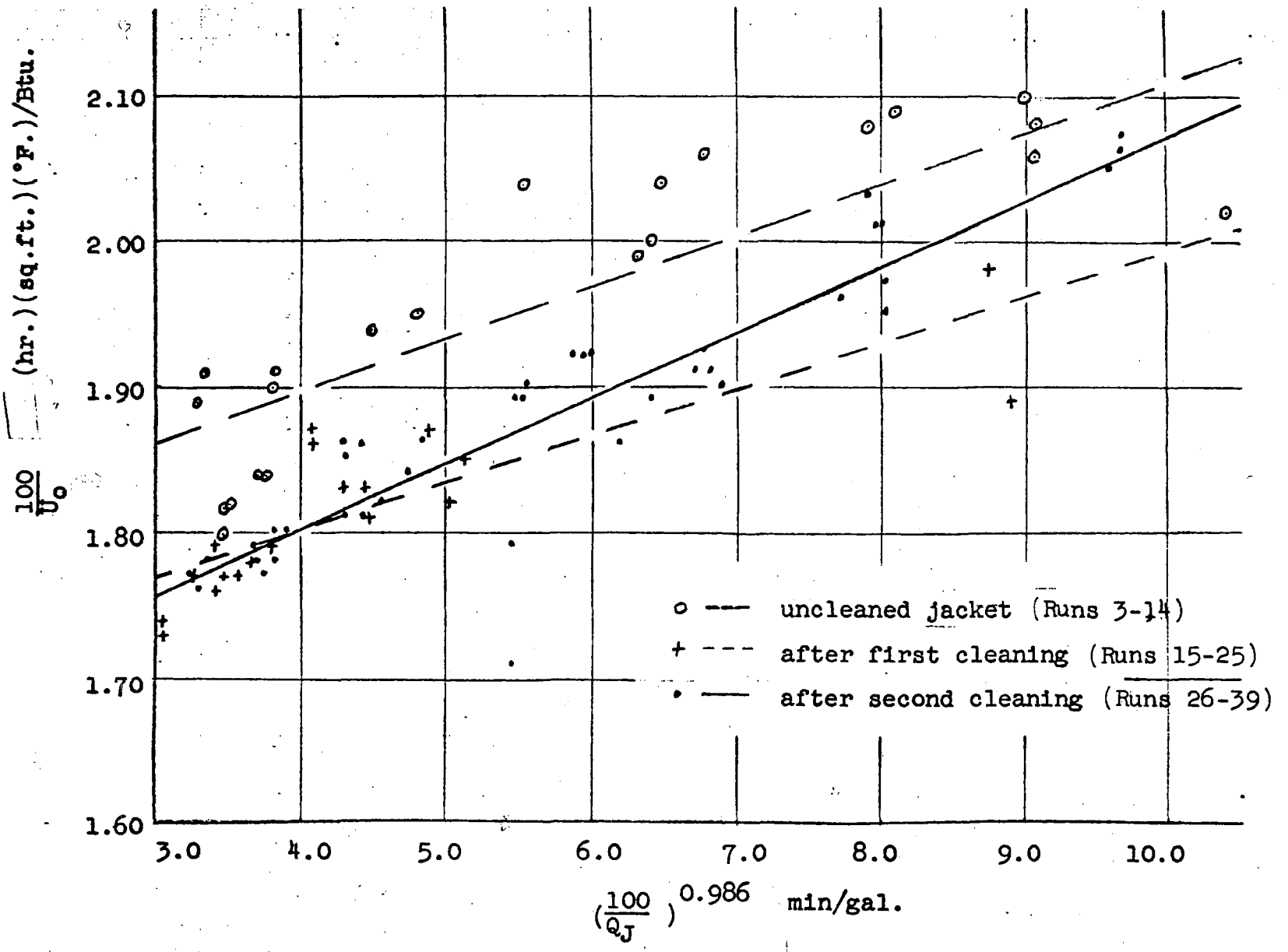


FIGURE X

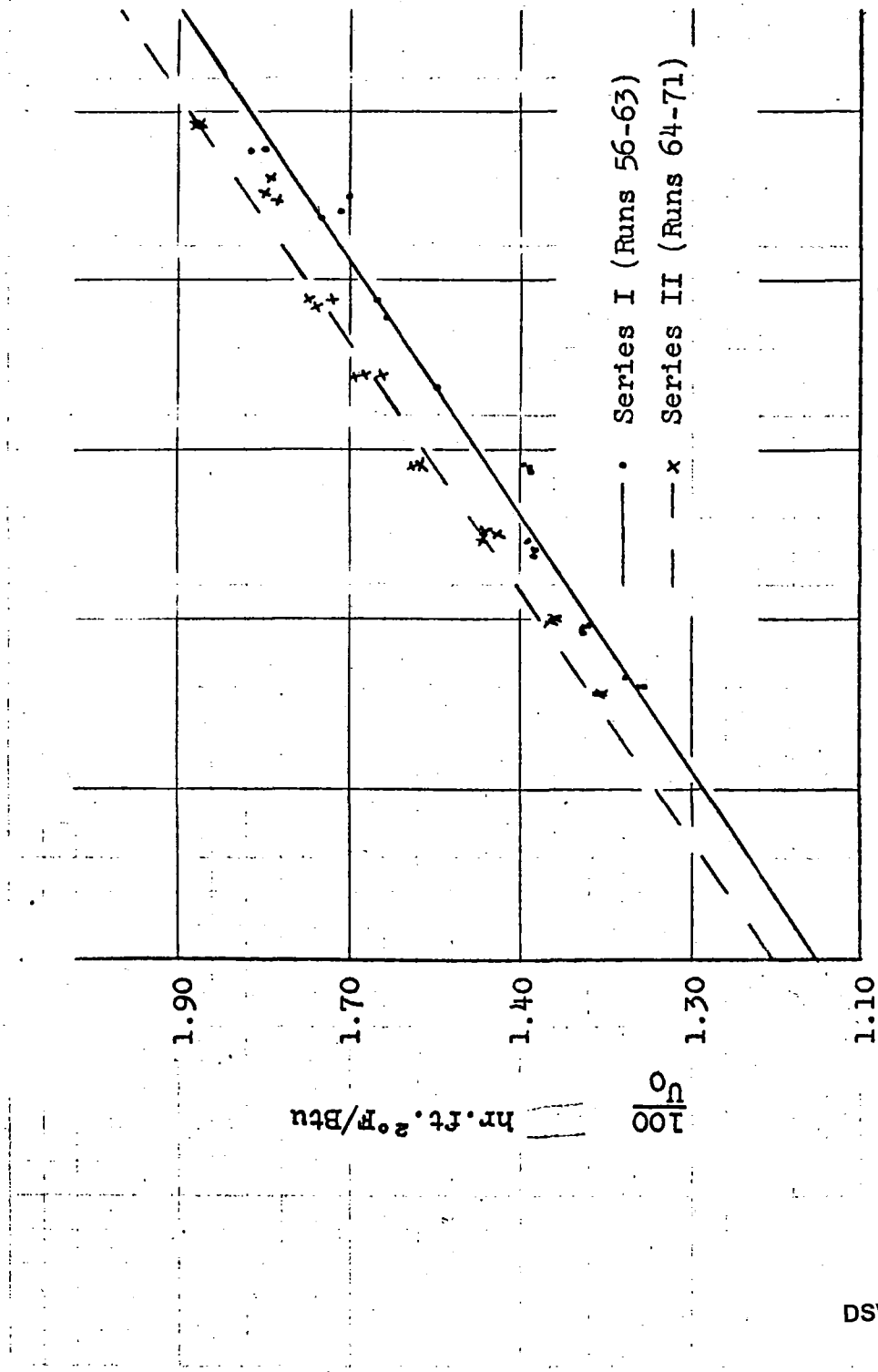
Modified Wilson Plot of Overall Heat Transfer Coefficient versus Jacket Flow Rate

Reactor: S-788, 50 gal. glass-lined

WLS Job No. 7501-2979

DSW 622316

STLCOPCB4096349



DSW 622317

FIGURE XI

Modified Wilson Plot of Overall Heat Transfer Coefficients for Water-Water Heat Transfer

Reactor: S-788

WLS 11-2-59
Nob No. 2979

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Series II

$$\frac{100}{U_o} = 0.0680 \left(\frac{100}{Q_J}\right)^{0.986} + 1.200 \text{ (Runs 64-71)}$$

Repeated after second cleaning using large steam excess on process side. (Fig. XII)

$$\frac{100}{U_o} = 0.0603 \left(\frac{100}{Q_J}\right)^{0.986} + 1.274 \text{ (Runs 72-97)}$$

3. Overall Heat Transfer Coefficient with Process Side Varied

a. Correlation plot of

$$\frac{100}{U_o} \text{ vs } \frac{D_p}{k_p (N_{Re})_p^{2/3} (N_{Pr})_p^{1/3} \left(\frac{\mu_p}{\mu_F}\right)^{0.14}}$$

Fig. III

$$\frac{100}{U_o} = 380.3 \frac{D_p}{k_p (N_{Re})_p^{2/3} (N_{Pr})_p^{1/3} \left(\frac{\mu_p}{\mu_F}\right)^{0.14}} + 1.1205 \text{ (Runs 43-52)}$$

The intercept of the above plot, 1.1205, was subtracted from the $\frac{100}{U_o}$ values and these values were considered to be h_p.

b. Correlation plot of Log $(j_H)_p$ vs. Log $(N_{Re})_p$ (Fig. XIV) if the exponent is assumed to be 2/3

$$(j_H)_p = 0.263 (N_{Re})_{10}^{2/3} - 0.4367$$

or by least squares

$$(j_H)_p = 0.0858 (N_{Re})_p^{0.748}$$

STLCOPCB4096351

B. Analysis of Least Squares Fits to Data

1. Jacket Film Heat Transfer Coefficients

a. Calculated From U_J Plot Slopes

Equation	Process Fluid	Fig. No.	Run Nos.
$h_J' = 35.4\ Q_J^{0.986}$	steam	V	(3-39)
$h_J' = 33.4\ Q_J^{0.986}$	water	VI	(56-63)
$h_J' = 1.78 \times 10^3\ P^{0.383}$	steam	VIII	(3-39)

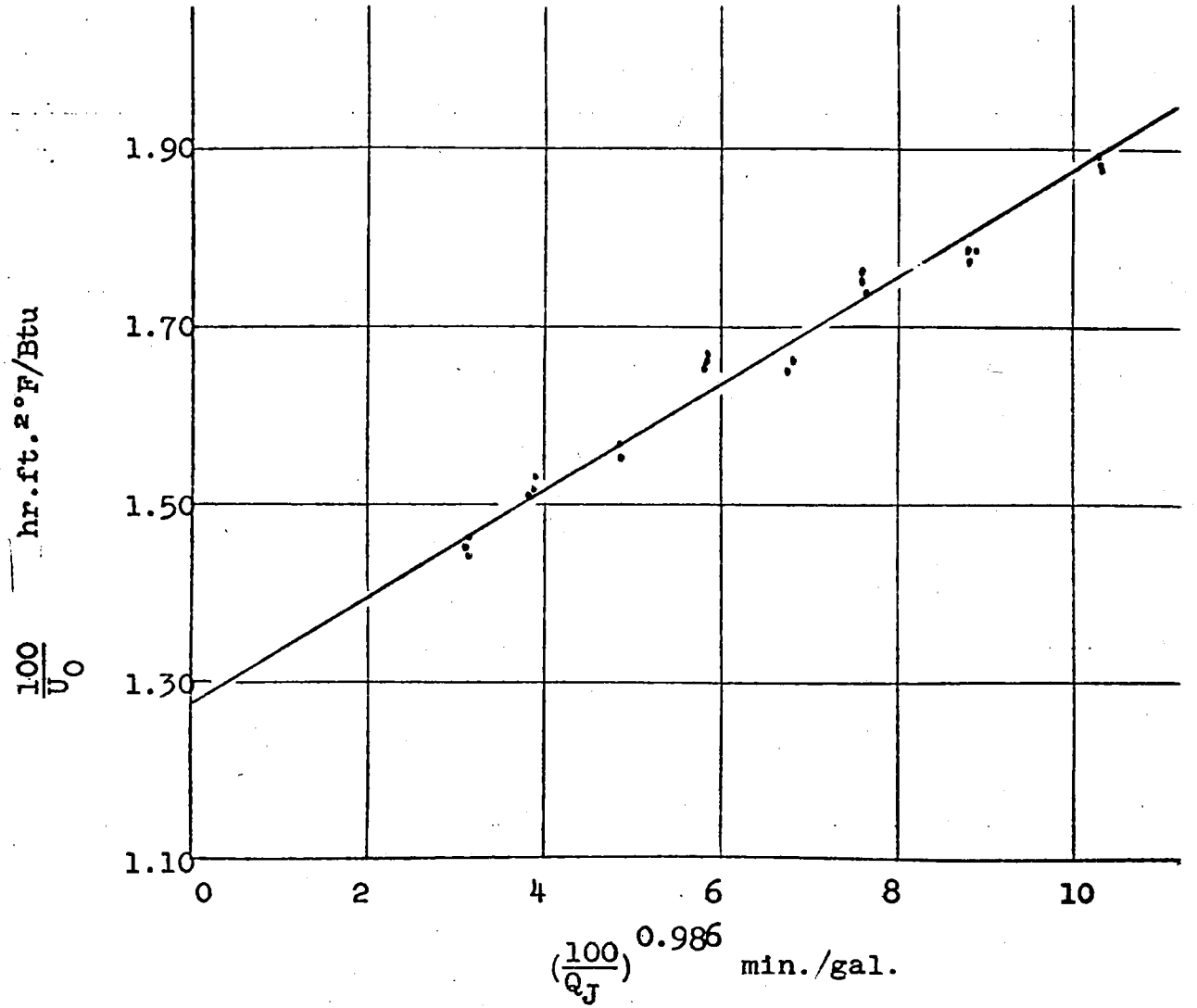
b. Calculated From U_o Plot Slopes

$h_J = 28.8\ (Q_J)^{0.986}$	steam	X	(3-39)
$h_J = 15.9\ (Q_J)^{0.986}$	water	XI	(56-71)
$h_J = 17.7\ (Q_J)^{0.986}$	steam, high excess	XII	(72-79)
$h_J = 1.43 \times 10^3\ P^{0.383}$	steam	IX	(3-39)

2. Jacket Scale Resistance Decrease

Based on Wilson Plot of	First Cleaning Btu/hr.ft.^{2}°F.	Second Cleaning Btu/hr.ft.^{2}°F.
U_J vs Q_J (Fig. V)	1.22×10^3	4.6×10^4
U_J vs P (Fig. VIII)	1.04×10^3	2.1×10^4
U_o vs Q_J (Fig. X)	1.2×10^3	1.7×10^3
U_o vs P (Fig. IX)	1.1×10^3	1.4×10^3

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DSW 622320

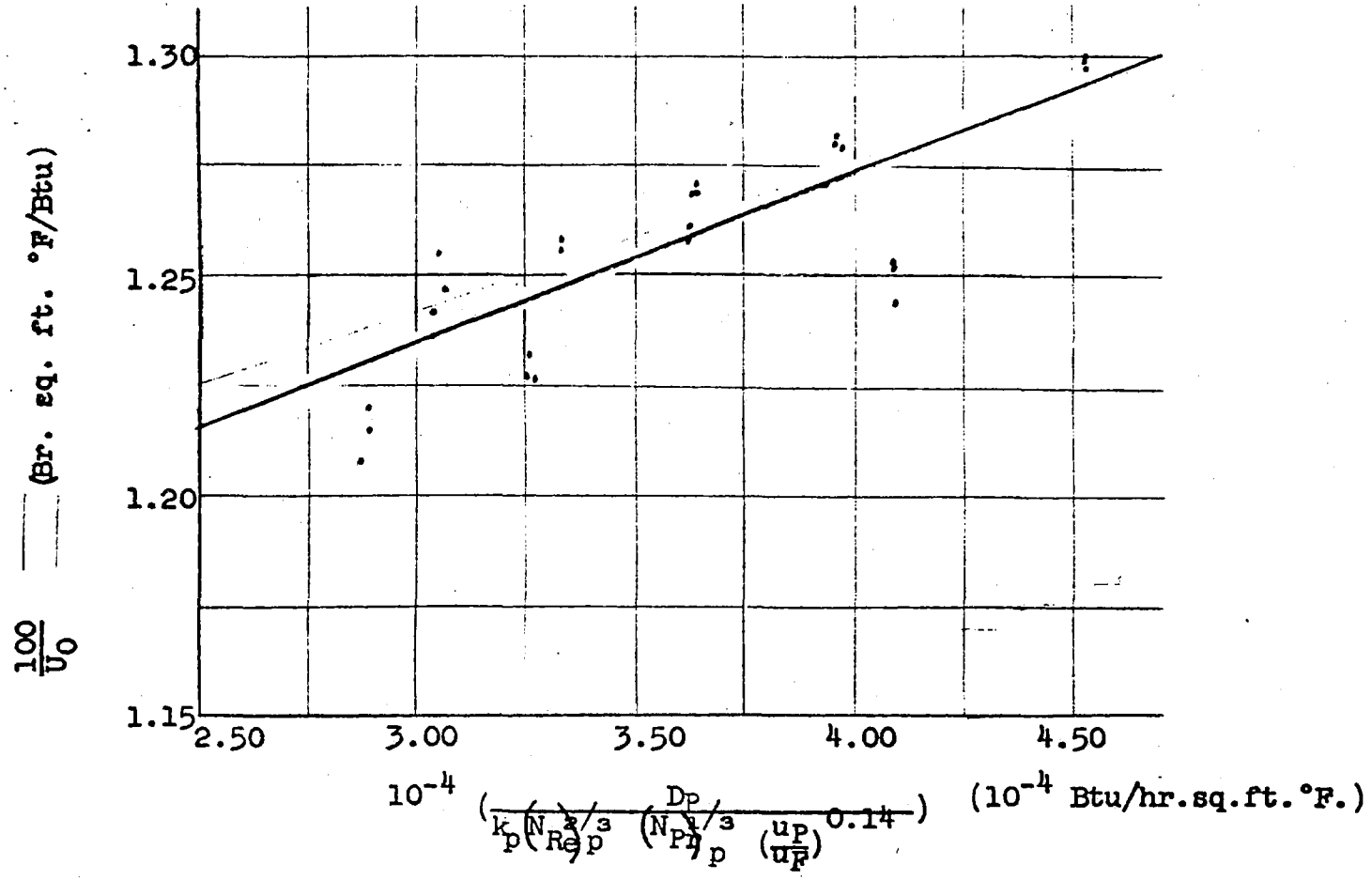
FIGURE XII

Modified Wilson Plot of Overall Heat Transfer Coefficients for Steam-Water Heat Transfer

Reactor: S-788, 50 gal., glass-lined
Runs 72-79

WLS 11-2-59
Job No. 2979

STLCOPCB4096353



DSW 622321

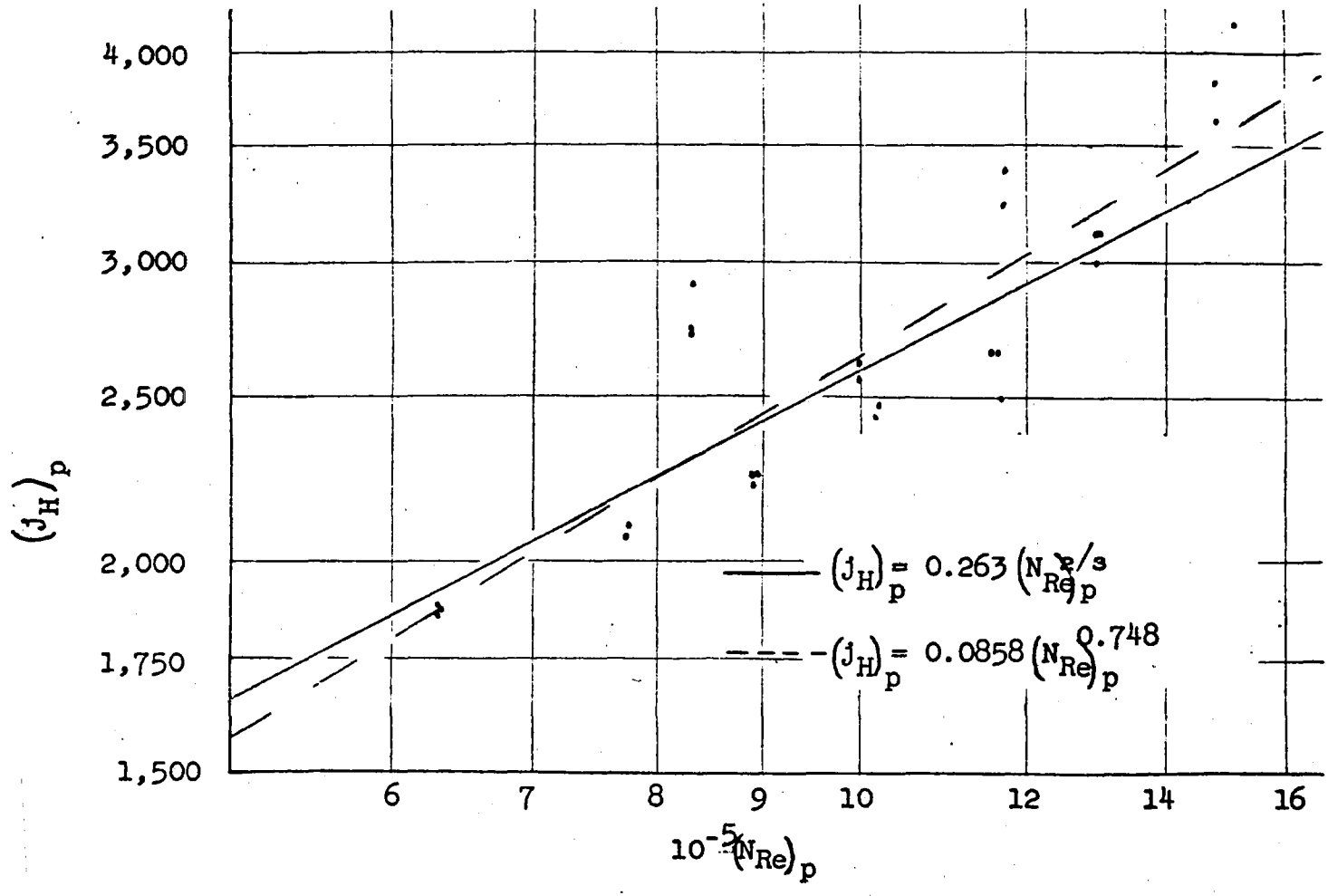
FIGURE XIII

Modified Wilson Plot of Film Heat Transfer Coefficients for Water Heated by Steam

Reactor: S-788, 50 gal. glass-lined
Runs 43-52

WLS 10-10-59
Job #2979

STLCOPCB4096354



DSW 622322

FIGURE XIV

Log-Log Plot of j_H Factor versus Reynolds Number

Reactor:S-788, 50 gal. glass-lined
Runs 43-52

WLS
10-10-59 Job #2979

STLCOPCB4096355

3. Per Cent of Jacket Scale Removed.

Based on U_J vs. Q_J least squares plots. (Fig. V)

	Per Cent Scale Removed	
	Based on Initial Scale	Based on Remaining Scale
First Cleaning (oxalic acid)	93.2%	93.2%
Second Cleaning (Drycid)	2.5%	36.1%
Total % scale removed	95.7%	

C. Cost of Jacket Cleaning Solutions

1. Oxalic Acid

Material	Cost (1) ¢/lb.	Solution Strength	Cost per 100 gal. Sol'n. $ (2)
Oxalic acid	25.0	10% by wt.	21.55
Versene	50.0	1.0% by wt.	4.31
		Total Cost	$25.86

2. Drycid

Drycid	50.0	8 oz. per gal.	25.00
Lye	3.5	1.0% by wt.	0.29
		Total Cost	$25.29

3. Sodium Nitrite

Sodium Nitrite	9.9	2.5% by wt.	2.11
		Total Cost	$2.11

(1) Price delivered to Queeny Plant as of 9-14-59
(2) Cost of water not included

DSW 622323

STLCOPCB4096356

TABLE I

Corrosion Test Data on Inhibited Hydrochloric Acid Cleaning Solution Recommended by Pfaudler (16)

Material	Environment	Exp. Period (Hrs.)	Corrosion Rate (mils/yr.)	Plastics Resistance (PWC Rating)
1. Mild steel	20% HCl inhibited with 0.5% (by vol.) of Metex acid additive	24	18,670	
316 S.S.	Moderately agitated 65-70°C.	24	188.3	(pitting)
2. 316 S.S.	Same as above except fresh solution and mild steel left out	24	8,408	
3. 316 S.S.	Ditto test 2 above with fresh solution again used and new 316 S.S. coupon	24	4,400	
4. Mild steel	20% HCl inhibited with 1.0% Metex acid additive - no agitation	24	854	
316 S.S.	Room temperature	24	31	(pitting)

DSW 622324

STLCOPCB4096357

D. Generalized Correlations for a Fifty Gallon Reactor

1. Using the data obtained in runs 90-1,2,3; 91-1,2,3; 93-1,2,3; 94-1,2,3; 99-1,2,3; 101-1,2,3; 102-1,2,3; 107-1,2,3; and 109-1,2,3 the following equation was obtained.

$$\frac{1}{U_o} = \frac{0.61}{k_J}\left(\frac{G_J}{u_J}\right)^{-0.62}(N_{P_r})_J^{-0.29}\left(\frac{u_J}{u_W}\right)^{-0.14} + 2.21\left(\frac{D_p}{k_p}\right)(N_{R_e})_p^{-2/3}$$

$$(N_{P_r})_p^{-1/3}\left(\frac{u_p}{u_F}\right)^{-0.14} + 0.008647$$

This may be separated into the following equations.

$$h_J = 1.64\, k_J \left(\frac{G_J}{u_J}\right)^{0.62}(N_{P_r})_J^{0.29}\left(\frac{u_J}{u_W}\right)^{0.14}$$

$$h_p = 0.453\left(\frac{k_p}{D_p}\right)(N_{R_e})_p^{2/3}(N_{P_r})_p^{1/3}\left(\frac{u_p}{u_F}\right)^{0.14}$$

$$h_B = 116 \text{ Btu/hr.ft.}^2\text{°F}$$

Standard deviations for the above are as follows:

Quantity	Std. Dev.
$\frac{1}{U_o}$	$\pm$ 0.00286 hr.ft.^{2}°F./Btu.
$\frac{1}{S}$	$\pm$ 0.66
a	$\pm$ 0.16
b	$\pm$ 0.13
$\frac{1}{E}$	$\pm$ 0.68
$\frac{1}{h_B}$	$\pm$ 0.0016 hr.ft^2°F./Btu

The correlation coefficient squared was 0.991

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2. Using the dat obtained in the first run of sets 80-120 the following equation was obtained:

$$\frac{1}{U_o} = \frac{1.34}{k_J} \left(\frac{G_J}{u_J}\right)^{-0.73} (N_{Pr})_J^{-0.54} \left(\frac{u_J}{u_W}\right)^{-0.14} + 3.38 \left(\frac{D_p}{k_p}\right) (N_{Re})_p^{-2/3}$$

$$(N_{Pr})_p^{-1/3} \left(\frac{u_p}{u_F}\right)^{-0.14} + 0.01235$$

This may be separated into the following equations:

$$h_J = 0.75\, k_J \left(\frac{G_J}{u_J}\right)^{0.73} (N_{Pr})_J^{0.54} \left(\frac{u_J}{u_W}\right)^{0.14}$$

$$h_P = 0.30 \left(\frac{k_p}{D_p}\right) (N_{Re})_p^{2/3} (N_{Pr})_p^{1/3} \left(\frac{u_p}{u_p}\right)^{0.14}$$

$$h_B = 81.0 \text{ Btu./hr.ft.}^2\text{°F.}$$

Standard deviations for the above are as follows:

Quantity	Std. Dev.
$\frac{1}{U_o}$	$\pm$ 0.00247 hr.ft.^{2}°F./Btu.
$\frac{1}{S}$	$\pm$ 1.13
a	$\pm$ 0.16
b	$\pm$ 0.36
$\frac{1}{E}$	$\pm$ 0.31
$\frac{1}{h_B}$	$\pm$ 0.0025

The correlation coefficient squared was 0.956

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DISCUSSION

A. Jacket Cleaning

The jacket scale heat transfer coefficient was 1100 Btu/hr.ft.^{2}°F. for the uncleaned unit. The oxalic acid-Versene treatment removed 93.2% of this resistance and the subsequent Drycid-lye treatment removed an additional 2.5% or 36.1% of the remaining scale as indicated by the U_J vs. Q_J correlations. The scale coefficient, 4.6 x 10^4 Btu/hr.ft.^{2}°F., remaining after these treatment was beyond the accuracy of the measurement and was assumed to be zero. Visual inspection of the jacket through holes cut to insert surface temperature probes also indicated that the jacket wall was clean and free of scale.

A comparison of the relative effectiveness of the two cleaning methods is difficult because of the relatively small initial scale coefficient and the fact that the scale remaining after the first cleaning may have been harder to remove. A check of the glass four months after cleaning shows no evidence of fish scaling, a major problem encountered in cleaning glass-lined equipment with highly acidic or basic cleaning agents. On a cost basis the oxalic acid-lye system would be the cheapest and the Drycid-Versene system the most expensive. (see Table) The final selection of the cleaning agent should be made on the basis of the type of scale to be removed and further corrosion laboratory data. It should be noted that the Drycid-Versene system appears to be the best system on the basis of inhibiting properties.

The inhibited hydrochloric acid cleaning solution suggested by Pfaudler performed poorly in corrosion laboratory tests. They state, "Contrary to the statement by the Pfaudler Company (24) Metex acid additive does not sufficiently inhibit 20% HCl to permit its use as a cleaning agent for steel jackets of glass-lined steel reactors. Neither does it inhibit the attack of 316 S.S." (16) The data they obtained are reported in the data section of this report.

Sodium nitrite solution was used in the jacket to prevent scale formation, but the time period involved was not sufficient to evaluate its effectiveness.

B. Jacket Heat Transfer Area and Volume

Pfaudler Bulletin No. 927(21) gives the heat transfer area as 14.9 ft.^{2} and the jacket volume as 15.7 gallons for a 50 gallon series "P" reactor. An earlier Pfaudler Bulletin, No. 881(22), gives values of 16.4 ft.^{2} and 22.5 gallons, respectively,

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values which have been widely used, but the local Pfaudler representative states that these values are a printing error. The surface area was calculated as 15.1 ft.^{2}, based on the outside area, by revolving a curve fit to the drawing of the jacket of a 50 gallon "P" series Pfaudler reactor, Monsanto order No. A-9533 dated 5-1-52. An attempt was made to measure the jacket area by cooling the jacket rapidly with brine and then measuring the frosted area. This attempt failed because the high thermal resistance of the glass caused indistinct frost lines. The jacket volume was measured by filling it with water and found to be 16.8 gallons. It should be noted that past pilot plant experience indicates that the volume of these jackets varies considerably from unit to unit. On the basis of these findings it was concluded that the correct value of the heat transfer area was 14.9 ft.^{2} and this value was employed in all calculations.

C. Jacket Flow Rate Variations

Variations in water main pressure caused jacket flow rate variations of up to ± 10%. The installation of the 82 gallon surge tank reduced the number of runs discarded because they did not give a heat balance within ± 5% from 43% to 11% of the total and throttling the flow at the jacket exit rather than entrance further reduced this to less than 3%.

D. Jacket Water Film Heat Transfer Coefficient Correlation

The correlations obtained from the water-water runs were as follows:

$$h_J = 15.9\ (Q_J)^{0.986}$$

$$h_J' = 33.4\ (Q_J)^{0.986}$$

Whereas the following relationships had been obtained from the steam-water runs

$$h_J = 28.8\ (Q_J)^{0.986}$$

$$h_J' = 35.4\ (Q_J)^{0.986}$$

It can be seen from these equations that while the average of three local coefficients, h_J, remained constant for these runs within the accuracy of the data, the average film coefficient, h_J, varied widely. Since the local coefficients

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are not dependent on a constant process side film coefficient, and the average coefficients are a dependent variation of the process side coefficient the runs appeared to be the likely source of trouble. Because it was possible to calculate the variation of h_p for the water-water runs, the steam film variation was then scrutinized. When it was originally decided to use steam to obtain a higher temperature differential, the value of the condensing steam film was calculated from a correlation given by McAdams (11) for cold finger condensing vapor coefficients. This correlation predicted values varying from 1400 to 1520 Btu/hr.ft^2°F. This gives an expected variation of 5.7×10^{-5} hr.ft.^{2}°F/Btu in the steam film resistance compared to an actual variation of 1.9×10^{-3} hr.ft^2°F/Btu as is indicated by the difference between the two sets of data.

To determine if the character of the condensing steam film was such that the calculation of the expected steam film coefficient from McAdams was in error, and if the film variation was causing the disagreement between the different sets of data, an additional series of runs was made. These runs were carried out in the same manner as the original steam-water runs except that approximately a two fold excess of steam was passed through the reactor. This excess steam flow was utilized to cause turbulence in the condensate film, thus decreasing the variation of the steam film coefficient with the condensation rate. This series of runs produced the following correlation:

$$h_J = 17.7 \ (Q_J)^{0.986}$$

From this it was concluded that if the steam film was agitated to the extent that the thickness of the condensate film had no effect on the condensing steam film coefficient, the correlation for the steam water runs would be equal to the correlation for the water-water runs. This also provided an explanation for the variation in the slope of plots of $\frac{100}{U_o}$ vs. $(\frac{100}{Q_J})^{0.986}$ for the steam-water runs.

It should also be noted that there is no reason for h_J to equal h_J' since the relationship between these is dependent upon the local points selected.

E. Process Side Film Heat Transfer Coefficient Correlations

These coefficients were correlated by the function $(j_H)_p = E \ (N_{Re})_p^{2/3}$, which is well established in the literature. The following values were obtained for E.

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E	Fluids Used	Runs
0.26	water	43 to 52
0.250	water & #5 process oil	(A-1) to (A-15)
0.30	water & 1248 Aroclor	same as second computer correlation
0.45	water	same as first computer correlation

The last value noted, 0.45, differs significantly from the other values, however, it was obtained using data which covered only a narrow range of this variable and its 95% confidence range includes the other values of E obtained.

The other values are in good agreement. The 0.26 and 0.30 values were obtained using the same reactor and different data and evaluation methods; and the 0.26 and 0.25 values were obtained using different reactors of the same model and the same evaluation method.

F. Heat Transfer Resistance of the Glass-Metal Reactor Wall

From the data of Runs (56-71) the wall heat transfer coefficient was found to be 98 Btu/hr.ft.^{2}°F and from the first computer correlation 116 Btu/hr.ft.^{2}°F. These values are in good agreement with Pfaudler's (23) estimate of 92-114 Btu/hr. ft.^{2}°F. A range is stated by Pfaudler because of variations in the average thickness of the glass coating.

G. Overall Heat Transfer Correlation Based on Water-Water Runs

The equation obtained using the 704 computer regression program with minor modifications was as follows:

$$\frac{1}{U_o} = \frac{0.61}{k_J}\left(\frac{G_J}{u_J}\right)^{-0.62}(N_{P_r})_J^{-0.29}\left(\frac{u_J}{u_W}\right)^{-0.14} +$$

$$\left(\frac{D_p}{0.45\,k_p}\right)(N_{R_e})_p^{-2/3}(N_{P_r})_p^{-1/3} + 0.008647$$

This equation was found to predict the overall heat transfer coefficients for all water-water runs (No. 86-110) within ± 3% and for the brine runs (No. 80-85) 3 to 8% higher than those measured. The Aroclor-Water runs (No. 111-115) indicated that the value of E, 0.45, used in the above equation was too high as was noted previously. However, even the large

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reduction of roughly 1/3 suggested would not appreciably affect the error limits stated above for runs 80-110 since this term contributes a maximum of only 7% of the total thermal resistance for these runs. The Aroclor-Aroclor data (Runs 116-120) did not fit the above correlation well. Utilizing an E value of $\sim$ 1/3, the actual jacket film resistance for Aroclor is roughly twice that predicted by the above equation.

H. Overall Heat Transfer Correlation Based on Water, Aroclor, and Brine Data

An attempt was made to correlate the data obtained in runs 80-120 with the following result.

$$\frac{1}{U_o} = \frac{1.34}{k_J} \left(\frac{G_J}{u_J}\right)^{-0.73} (N_{P_r})_J^{-0.54} \left(\frac{u_J}{u_W}\right)^{-0.14} +$$

$$3.38 \left(\frac{D_p}{k_p}\right) (N_{R_e})_p^{-2/3} (N_{P_r})_p^{-1/3} \left(\frac{u_p}{u_W}\right)^{-0.14} + 0.01235$$

The 95 per cent confidence limit for this equation (based on the lowest overall resistance encountered) is $\pm$ 40%.

This is considered to be a much poorer correlation of this data than is possible. The original plan for correlating this data was to employ all the available data and to correlate each fluid system separately and then on the basis of these results obtain the final correlation. Time limitations, unfortunately, dictated that the cruder and more expidious route employed be utilized.

Reasonable doubt exists in the minds of the department statistican and the author as to whether the values obtained for the constants actually provide the best fit to the data because of the questionable error distribution. This could be possible due to the multiplicity of problems encountered in adapting an existing program to the data. This doubt, however, is merely conjecture and has neither been substantiated nor widely explored.

The poor correlation obtained may also be caused by the assumption that the Reynolds number in the reactor jacket is directly proportional to the mass flow rate divided by the fluid viscosity for any Newtonian fluid and a given jacket size and geometry being in error. It appears that recorrelation of this data should be attempted before any extensive investigation of this possibility is undertaken.

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NOMENCLATURE

A	Heat transfer area, 14.9 ft.^{2}
A_J	Jacket flow area, ft.^{2}
a,b,c,d	Emperical constants
C	Specific heat of fluid, Btu/lb.°F
D_J	Hydraulic diameter of jacket, ft.
D_p	Reactor inside diameter, 2.00 ft.
E	Emperical constant
G	Mass flow rate, lbs./hr.
h	Heat transfer coefficient, Btu/hr.ft.^{2}°F.
h_J'	Average local heat transfer film coefficient at the three jacket thermocouple points, Btu/hr.ft.^{2}°F.
$(J_H)_p$	Heat transfer factor, $(\frac{hD}{k})_p (N_{Pr})_p^{-1/3} (\frac{u_p}{u_F})_p^{-0.14}$
k	Thermal conductivity, Btu.ft./hr.ft.^{2}°F.
L_p	Impeller diameter, 1.667 ft.
L_M	Metal wall thickness, ft.
L_G	Glass wall thickness, ft.
N_{Pr}	Prandlt number, $\frac{Cu}{k}$
$(N_{Re})_p$	Mixing Reynolds number, $\frac{L_p^2 \, n \, P_p}{u_p}$
n	Agitator speed, rev. per min.
P	Jacket mixing power (dissipated velocity energy), hp
Δp	Jacket pressure differential, in. Hg
Q	Flow rate, lbs./hr.
q	Heat transfer rate, Btu/hr.
q_L	Latent heat change Btu/hr.
q_V	Jacket velocity energy dissipated, Btu/hr.

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NOMENCLATURE (Cont'd.)

q_I	Impeller energy dissipated, Btu/hr.
q_A	Heat loss to atmosphere, Btu/hr.
S_J' S	Emperical constants
T	Bulk temperature, °C.
T_A	Ambient temperature, °C.
T_J	Arithmetic average of the inlet and outlet jacket temperatures.
T_W	Arithmetic average of the three jacket surface temperature thermocouple readings, °C.
ΔT	Fluid temperature differential, °C.
ΔT_F	$T_P - T_F$, °C.
ΔT_o	$T_J - T_P$, °C.
ΔT_W	$T_W - T_J$, °C.
U_J	Jacket film plus scale heat transfer coefficient, Btu/hr.ft.^{2}°F.
U_o	Overall heat transfer coefficient, Btu/hr.ft.^{2}°F.
W	Condensate rate, lbs./hr.
α & β	Emperical constants
λ	Latent heat, Btu/lb.
ρ	Density, lbs./ft.^{3}
u	Viscosity, lb/hr.ft.

Subscripts

B	refer to metal-glass wall
D	" " jacket scale or dirt film
F	" process side wall surface
G	" glass wall
J	" jacket
M	" metal wall
P	" process
W	" jacket side wall surface

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TABLE II

Jacket Heat Transfer Film Coefficient Runs
(Water in Jacket to Steam on Process Side)

Run No.	T_j °C.	T_p °C.	T_w °C.	Q_v g.p.m.	w_p lbs/hr.	ΔT_p C°	Δ_p cm. Hg	ΔT_j F°	λ_s Btu/lb.	q_{jp} 10^6 Btu/hr.	q_{sp} 10^6 Btu/hr.	q 10^6 Btu/hr.	q_{gj} 10^6 Btu/hr	q_w 10^6 Btu/hr	Heat Bal. Error %	ΔT_o C°	ΔT_w C°.	U_o Btu/hr.ft²F°	U_j Btu/hr.ft²F°	$\frac{100}{U_o}$ hr.ft²F°/Btu	$\frac{100}{U_j}$ hr.ft²F°/Btu	$\frac{100}{U_o} - \frac{100}{U_j}$ hr.ft²F°/Btu	P hp	$(\frac{1}{P})^{0.383}$	$(\frac{100}{Q_j})^{0.986}$
3-1	31.4	101.3	40.0	20.4	100.6	8.7	37.4	9.91	968.8	97.5	1.6	95.8	100.7	0.2	+4.9	69.9	8.6	51.2	416	1.95	0.240	1.71	0.0873	2.55	4.80
3-2	31.2	101.2	--	22.1	101.8	8.9	42.7	9.27	968.9	97.7	1.6	96.0	101.8	0.3	+5.7	--	--	--	--	--	--	--	--	--	--
3-3	31.4	101.4	--	22.0	100.3	8.9	41.8	9.33	968.7	98.1	1.6	96.4	102.3	0.3	+5.8	--	--	--	--	--	--	--	--	--	--
3-4	31.2	101.1	39.6	21.8	100.3	9.1	41.2	9.32	969.0	98.2	1.7	96.6	101.2	0.3	+4.4	69.9	8.4	51.6	429	1.94	0.233	1.71	0.103	2.39	4.48
4-1	30.6	100.2	38.1	25.6	102.7	8.9	58.8	8.05	970.0	99.5	1.6	97.8	102.7	0.4	+4.6	69.6	7.5	52.4	487	1.91	0.205	1.71	0.172	1.96	3.82
4-2	30.6	100.2	38.0	25.8	102.7	9.2	59.5	7.96	970.0	99.5	1.7	97.9	102.2	0.4	+4.0	69.6	7.4	52.5	494	1.90	0.202	1.70	0.176	1.94	3.81
4-3	30.4	99.9	--	25.8	101.3	8.8	59.6	7.93	970.4	98.3	1.6	96.6	101.9	0.4	+5.1	--	--	--	--	--	--	--	--	--	--
5-1	30.2	99.4	37.0	30.0	103.0	9.1	86.6	6.75	971.0	99.9	1.7	98.3	100.9	0.7	+1.9	69.2	6.8	53.0	540	1.89	0.185	1.71	0.298	1.59	3.28
5-2	30.2	99.6	--	29.7	103.1	9.4	79.3	7.08	970.8	100.1	1.7	98.5	104.7	0.7	+5.6	--	--	--	--	--	--	--	--	--	--
5-3	30.2	99.7	--	29.7	102.0	9.5	79.1	7.05	970.6	99.1	1.7	97.5	104.2	0.7	+6.1	--	--	--	--	--	--	--	--	--	--
5-4	30.2	99.9	37.1	29.4	102.0	9.6	79.7	6.95	970.4	99.1	1.8	97.6	101.7	0.7	+3.5	69.7	6.9	52.3	527	1.91	0.190	1.72	0.268	1.66	3.34
6-1	31.0	99.0	--	18.0	95.3	8.9	30.2	10.72	971.5	92.6	1.5	90.8	96.2	0.2	+6.4	--	--	--	--	--	--	--	--	--	--
6-2	31.1	99.0	--	17.8	94.6	9.1	33.4	10.84	971.5	91.8	1.6	90.1	96.2	0.2	+6.5	--	--	--	--	--	--	--	--	--	--
6-3	31.1	99.3	39.9	17.7	94.6	9.0	30.1	10.69	971.1	91.8	1.5	90.0	94.2	0.2	+4.4	68.2	8.8	49.2	382	2.04	0.262	1.78	0.0610	2.92	5.52
7-1	31.6	100.0	41.8	15.0	94.6	8.8	24.6	12.34	970.3	91.7	1.5	89.9	92.2	0.1	+2.4	68.4	10.2	49.1	329	2.04	0.304	1.74	0.0422	3.36	6.49
7-2	31.7	99.9	--	14.8	93.7	8.5	23.4	13.01	970.4	90.8	1.4	89.9	95.8	0.1	+7.6	--	--	--	--	--	--	--	--	--	--
7-3	31.8	100.1	42.0	14.4	93.7	9.0	21.3	12.68	970.2	90.8	1.5	89.0	90.9	0.1	+2.0	68.3	10.1	48.6	329	2.06	0.304	1.76	0.0351	3.61	6.77
8-1	32.3	101.0	43.1	12.3	93.0	8.7	16.3	14.70	969.1	90.1	1.5	88.3	90.1	0.1	+1.9	68.7	10.8	48.0	305	2.08	0.328	1.75	0.0229	4.24	7.90
8-2	32.4	101.5	43.7	12.0	93.7	8.8	16.9	14.91	968.6	90.6	1.5	88.8	89.1	0.1	+0.2	69.1	11.3	47.9	293	2.09	0.341	1.75	0.0232	4.23	8.09
8-3	32.6	101.7	--	11.9	93.7	8.5	15.0	15.81	968.4	90.6	1.4	88.7	93.7	0.1	+5.5	--	--	--	--	--	--	--	--	--	--
9-1	33.8	103.6	--	9.6	94.6	7.6	11.5	20.1	966.1	91.4	1.3	89.4	96.0	0.1	+6.8	--	--	--	--	--	--	--	--	--	--
9-2	33.7	103.5	46.8	9.3	93.4	7.7	10.9	20.0	966.2	91.4	1.3	89.4	92.4	0.1	+3.2	69.8	13.1	49.4	254	2.02	0.394	1.63	0.0116	5.52	10.4
9-3	33.8	103.6	46.8	9.3	94.6	7.7	10.6	20.1	966.1	91.4	1.3	89.4	93.0	0.1	+3.9	69.8	13.0	49.4	256	2.02	0.391	1.63	0.0113	5.57	10.4
10-1	29.6	100.2	36.9	28.0	108.7	9.2	73.6	7.55	970.1	105.3	1.8	103.8	105.2	0.6	+0.8	70.6	7.3	54.9	531	1.82	0.188	1.63	0.236	1.74	3.51
10-2	29.6	100.4	36.9	28.3	110.2	9.2	75.0	7.60	969.8	105.9	1.8	105.4	107.2	0.6	+1.1	70.8	7.3	55.6	539	1.80	0.186	1.61	0.243	1.72	3.46
10-3	29.5	100.4	37.0	28.5	109.4	9.1	75.3	7.57	969.8	106.2	1.8	104.7	107.3	0.6	+1.9	70.9	7.5	55.1	521	1.82	0.192	1.63	0.246	1.71	3.45
11-1	29.6	101.0	37.4	26.5	108.7	9.2	65.3	8.21	969.1	105.3	1.8	103.8	108.3	0.5	+3.8	71.4	7.8	54.2	496	1.84	0.202	1.64	0.198	1.86	3.70
11-2	29.6	100.8	37.4	26.2	108.7	9.0	65.4	8.18	969.4	105.3	1.8	103.8	106.8	0.5	+2.4	71.2	7.8	54.4	496	1.84	0.202	1.64	0.196	1.87	3.75
11-3	29.7	100.8	37.4	26.1	108.7	9.1	66.0	8.18	969.4	105.3	1.8	103.8	106.2	0.5	+1.8	71.1	7.7	54.4	503	1.84	0.198	1.64	0.197	1.86	3.76
12-1	31.0	100.8	41.5	15.4	99.0	7.9	21.9	12.28	969.4	95.9	1.4	94.0	94.2	0.1	+0.1	69.8	10.5	50.2	334	1.99	0.300	1.69	0.0386	3.48	6.32
12-2	31.0	100.8	41.9	15.2	98.2	7.9	21.9	12.28	969.4	95.2	1.4	93.3	92.9	0.1	-0.5	69.8	10.9	49.9	319	2.00	0.313	1.69	0.0381	3.49	6.40
12-3	30.9	100.7	41.6	15.6	99.7	7.6	23.4	12.48	969.5	96.7	1.4	94.8	96.9	0.1	+2.1	69.8	10.7	50.6	331	1.98	0.302	1.68	0.0418	3.38	6.27
13-1	30.6	100.3	--	17.3	100.6	8.9	28.6	10.45	970.0	97.5	1.6	95.8	90.1	0.1	-6.0	--	--	--	--	--	--	--	--	--	--
13-2	30.6	100.3	--	17.2	100.6	8.1	28.0	10.34	970.0	97.5	1.5	95.7	88.7	0.1	-7.2	--	--	--	--	--	--	--	--	--	--
13-3	30.6	100.3	--	17.1	100.6	7.8	27.8	10.34	970.0	97.5	1.4	95.6	88.2	0.1	-7.8	--	--	--	--	--	--	--	--	--	--

DSW 622334

STLCOPCB4096367

Run No.	T_J °C.	T_P °C.	T_W °C.	Q_J g.p.m.	w_p lbs./hr.	ΔT_{P_o} °C.	Δp cm.Hg	ΔT_{W_o} °F	h_P Btu/lb.	q_{HP} 10^6Btu/hr.	q_{HF} 10^6Btu/hr.	q_J 10^6Btu/hr.	q_{HJ} 10^6Btu/hr.	q_W 10^6Btu/hr.	Heat Bal. Error %	ΔT_{lo} C°	ΔT_W C°	U_o Btu/hr.ft²F°	U_J Btu/hr.ft²F°	$\frac{100}{U_o}$ hr.ft²F°/Btu	$\frac{100}{U_J}$ hr.ft²F°/Btu	$\frac{100}{U_o} - \frac{100}{U_J}$ hr.ft²F°/Btu	$\frac{F}{hp}$	$\frac{1}{F}^{0.383}$	$\left(\frac{100}{q_J}\right)^{0.986}$
14-1	32.3	104.6	45.2	10.7	99.0	8.5	13.4	17.85	965.0	95.5	1.5	93.7	95.1	0.0	+1.5	72.3	12.9	48.4	271	2.06	0.369	1.69	0.0164	4.83	9.07
14-2	32.2	104.5	45.4	10.8	97.4	8.4	13.2	17.85	965.1	93.9	1.5	92.1	93.6	0.0	+1.2	72.2	13.1	47.6	262	2.10	0.382	1.72	0.0163	4.84	8.98
14-3	32.3	104.4	45.3	10.7	98.2	8.2	13.4	17.63	965.2	94.8	1.4	92.9	93.9	0.0	+1.1	72.1	13.0	48.1	266	2.08	0.376	1.70	0.0164	4.83	9.07
After run #14 the jacket was cleaned for the first time. The oxalic acid treatment was used																									
15-1	30.6	98.8	35.3	24.1	102.7	8.7	47.6	8.36	971.7	99.7	1.6	98.0	100.3	0.3	+2.0	68.2	4.7	53.6	778	1.87	0.128	1.74	0.131	2.18	4.07
15-2	30.6	98.8	35.3	24.0	102.7	8.6	47.8	8.31	971.7	99.7	1.6	98.0	99.4	0.3	+1.1	68.2	4.7	53.6	778	1.87	0.128	1.74	0.131	2.18	4.07
15-3	30.6	98.7	35.3	24.1	102.7	8.7	47.8	8.31	971.8	99.7	1.6	98.0	99.8	0.3	+1.5	68.1	4.7	53.7	778	1.86	0.128	1.73	0.132	2.17	4.07
16-1	34.1	105.0	44.2	11.1	101.3	8.3	13.2	17.12	964.5	99.7	1.5	95.4	94.6	0.0	-1.4	70.9	10.1	50.4	353	1.98	0.284	1.70	0.0168	4.78	8.73
16-2	34.4	105.1	--	11.2	--	8.5	13.5	17.28	964.4	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	--
16-3	34.4	105.0	44.1	10.9	105.7	8.2	13.1	17.66	965.5	102.0	1.6	100.3	95.8	0.0	-4.5	70.6	9.7	53.0	386	1.89	0.259	1.63	0.0163	4.83	8.89
17-1	29.4	98.2	35.3	32.2	111.0	8.1	84.0	6.68	972.4	107.9	1.6	106.2	107.2	0.8	+0.2	68.8	3.9	57.6	1017	1.74	0.098	1.64	0.309	1.57	3.05
17-2	29.4	98.5	33.3	32.1	111.7	8.2	85.7	6.97	972.0	108.5	1.7	106.4	111.4	0.8	+3.5	69.1	3.9	57.7	1023	1.73	0.098	1.63	0.314	1.56	3.06
17-3	29.4	98.5	33.3	32.0	111.0	8.4	86.0	6.79	972.2	107.9	1.7	106.3	108.2	0.8	+1.0	68.9	3.9	57.5	1016	1.74	0.099	1.64	0.314	1.56	3.07
18-1	29.6	100.3	34.3	26.8	111.8	9.1	61.8	8.11	970.0	108.3	1.8	105.8	108.4	0.5	+1.0	70.9	4.7	56.2	848	1.78	0.118	1.66	0.190	1.89	3.66
18-2	29.4	99.3	33.7	28.3	110.3	8.6	68.3	7.78	971.1	107.1	1.7	105.5	109.8	0.6	+3.5	69.9	4.3	56.3	916	1.77	0.109	1.66	0.221	1.78	3.47
18-3	29.4	99.3	33.8	27.5	110.3	8.3	64.9	7.85	971.1	107.1	1.7	105.5	107.6	0.5	+1.5	69.9	4.2	56.3	937	1.77	0.107	1.66	0.204	1.84	3.56
19-1	30.1	101.5	35.8	21.9	111.0	9.3	41.7	9.85	968.5	107.4	1.9	106.0	107.4	0.3	+1.0	71.4	5.7	55.4	694	1.81	0.144	1.67	0.104	2.38	4.47
19-2	30.1	101.6	35.6	22.1	109.4	9.0	42.5	9.80	969.6	106.1	1.8	104.6	107.9	0.3	+2.9	71.5	5.5	54.6	709	1.83	0.141	1.69	0.107	2.15	4.43
19-3	29.9	101.6	35.1	23.4	111.6	9.1	46.9	9.40	969.6	108.1	1.8	106.6	109.8	0.3	+2.7	71.7	5.2	55.4	765	1.81	0.131	1.68	0.126	2.21	4.18
20-1	30.3	102.6	37.0	19.5	111.7	8.8	34.1	10.92	967.2	108.1	1.8	106.6	106.2	0.2	-0.6	72.3	6.7	55.0	594	1.82	0.171	1.65	0.0761	2.68	5.02
20-2	30.2	102.4	36.6	20.8	110.3	9.1	38.0	10.64	967.5	106.7	1.8	105.2	110.3	0.2	+4.7	72.2	6.4	54.4	614	1.84	0.163	1.68	0.0903	2.51	4.71
20-3	30.2	102.2	36.6	20.4	110.3	9.1	38.7	10.53	967.7	106.7	1.8	105.2	107.2	0.2	+1.7	72.0	6.4	54.5	614	1.83	0.163	1.67	0.0902	2.51	4.79
21-1	30.0	90.0	--	15.8	81.0	5.4	23.5	10.06	982.1	79.4	0.8	76.9	79.2	0.1	+2.9	--	--	--	--	--	--	--	--	--	--
21-2	30.0	90.0	--	15.7	81.7	5.5	23.4	10.05	982.1	80.3	0.8	77.8	78.6	0.1	+0.7	--	--	--	--	--	--	--	--	--	--
21-3	30.0	90.1	--	15.6	80.3	5.7	23.4	10.08	981.9	78.8	0.8	76.3	78.2	0.1	+2.3	--	--	--	--	--	--	--	--	--	--
22-1	30.2	100.8	36.8	19.1	106.6	8.6	32.0	10.96	969.4	103.3	1.6	102.6	104.2	0.2	+1.4	70.6	6.6	54.2	580	1.85	0.172	1.68	0.0698	2.77	5.11
22-2	30.0	100.4	36.4	20.1	105.7	8.6	34.7	10.43	969.8	102.6	1.6	100.9	104.5	0.2	+3.4	70.4	6.4	53.5	588	1.87	0.170	1.70	0.0798	2.63	4.86
22-3	30.0	100.5	--	20.1	105.0	8.6	35.2	10.68	969.7	101.9	1.6	100.2	107.0	0.2	+6.6	--	--	--	--	--	--	--	--	--	--
23-1	31.5	102.1	--	13.7	105.0	6.6	18.4	17.08	967.8	101.8	1.2	99.7	116.7	0.1	+17.0	--	--	--	--	--	--	--	--	--	--
23-2	31.4	102.1	--	13.4	105.7	6.6	17.8	16.65	967.8	102.2	1.3	100.2	110.3	0.1	+10.0	--	--	--	--	--	--	--	--	--	--
23-3	31.4	102.1	--	13.4	105.0	6.6	17.8	16.83	967.8	101.8	1.3	99.8	112.3	0.1	+12.6	--	--	--	--	--	--	--	--	--	--
24-1	29.2	99.0	33.5	28.8	111.0	8.5	70.8	7.50	971.4	107.8	1.7	106.2	107.8	0.1	+1.4	69.8	4.3	56.7	922	1.76	0.108	1.65	0.233	1.75	3.41
24-2	29.2	99.1	33.5	28.9	109.4	8.6	70.8	7.50	971.4	106.3	1.7	104.7	108.0	0.1	+3.0	69.9	4.3	55.9	909	1.79	0.110	1.68	0.234	1.74	3.40
24-3	29.0	98.8	33.1	30.1	110.3	8.8	76.5	7.08	971.7	107.2	1.7	105.6	106.1	0.1	+0.4	69.8	4.1	56.5	961	1.77	0.104	1.67	0.264	1.66	3.26
25-1	29.4	100.0	--	26.5	110.3	8.7	59.2	8.36	970.3	107.0	1.7	105.4	111.3	0.0	+5.6	--	--	--	--	--	--	--	--	--	--
25-2	29.4	99.9	34.3	25.9	110.3	8.5	57.0	8.25	970.4	107.0	1.7	105.4	106.5	0.0	+1.0	70.5	4.9	55.9	803	1.79	0.124	1.67	0.169	1.98	3.78
25-3	29.4	100.0	34.3	25.6	111.0	8.9	56.0	8.46	970.3	107.8	1.8	106.3	107.9	0.0	+1.5	70.6	4.9	56.2	808	1.78	0.124	1.66	0.164	2.00	3.82
After run #25 the jacket was cleaned for the second time. The Drycid treatment was used.																									
26-1	30.4	100.0	34.3	25.8	108.0	9.4	58.6	8.15	970.3	105.0	1.8	103.5	104.7	0.4	+0.8	69.6	3.9	55.5	986	1.80	0.102	1.70	0.173	1.96	3.81
26-2	30.4	100.2	34.5	25.1	108.5	9.7	55.5	8.50	970.1	105.2	1.9	103.8	106.2	0.4	+1.9	69.8	4.1	55.5	944	1.80	0.106	1.69	0.169	2.02	3.90
26-3	30.4	100.3	34.5	25.7	109.4	9.6	56.4	8.38	970.0	106.1	1.9	104.7	107.2	0.4	+0.4	69.9	4.1	56.5	952	1.77	0.105	1.66	0.165	1.99	3.82

DSW 622335

STLCOPCB4096368

Run No.	t_{wi} °F	t_{wi} °C	t_{wo} °F	Q_w g.p.m.	W_a lbs/hr.	ΔT_{wi} °C	ΔP cm.Hg	ΔT_{wo} °F	Q_{wi} Btu/hr.	Q_{wo} 10^6 Btu/hr.	Q_{wv} 10^6 Btu/hr.	Q_a 10^6 Btu/hr	Q_{wo} 10^6 Btu/hr.	Heat Bal. Error	ΔT_o °C	ΔT_W °C	U_o Btu/hr.ft²F°	U_j Btu/hr.ft²F°	$\frac{100}{U_o}$ hr.ft²F°/Btu	$\frac{100}{U_j}$ hr.ft²F°/Btu	$\frac{100}{U_c}$ $\frac{100}{U_j}$ hr.ft²F°/Btu	P hp	$(\frac{1}{F})^{0.385}(\frac{100}{Q_j})^{0.986}$	
27-1	30.6	99.2	35.4	22.8	105.4	9.3	46.2	9.04	971.2	100.3	1.7	98.7	102.7	0.3	+3.8	68.6	4.8	53.7	767	1.86	0.130	1.73	0.120	2.25	4.29
27-2	30.6	99.2	35.4	22.2	103.4	9.0	44.5	8.88	971.2	100.3	1.7	98.7	98.2	0.3	-0.8	68.6	4.8	53.7	767	1.86	0.130	1.73	0.113	2.31	4.41
27-3	30.6	99.6	35.4	22.7	104.3	9.1	46.2	9.12	970.8	101.4	1.7	99.8	103.1	0.3	+3.0	69.0	4.8	54.0	776	1.85	0.129	1.72	0.120	2.25	4.31
28-1	33.4	103.2	41.4	12.6	100.6	8.5	17.1	15.45	966.6	97.2	1.5	95.4	96.8	0.1	+1.4	69.8	8.0	51.0	445	1.96	0.224	1.72	0.025	4.11	7.68
28-2	33.5	103.3	41.9	12.1	101.3	8.1	16.0	15.83	966.4	97.8	1.5	96.0	95.4	0.1	-0.7	69.8	8.4	51.3	427	1.95	0.234	1.72	0.022	4.32	8.07
28-3	33.5	103.6	42.0	12.1	100.6	8.4	16.0	16.23	966.1	97.2	1.5	95.4	97.8	0.1	+2.4	70.1	8.5	50.8	419	1.97	0.239	1.73	0.022	4.32	8.01
29-1	32.2	100.2	38.3	16.3	99.7	8.3	24.7	11.90	970.1	96.7	1.5	94.9	96.6	0.1	+1.7	68.0	6.1	52.1	581	1.92	0.172	1.75	0.046	3.26	6.00
29-2	32.0	100.2	38.1	16.6	99.7	8.4	25.6	11.72	970.1	96.7	1.5	94.9	96.9	0.1	+2.0	68.2	6.1	52.0	581	1.92	0.172	1.75	0.049	3.17	5.87
29-3	32.2	100.3	38.3	16.4	99.7	8.3	24.5	11.78	970.0	96.7	1.5	94.9	96.2	0.1	+1.3	68.1	6.1	52.0	581	1.92	0.172	1.75	0.046	3.26	5.95
30-1	32.1	102.2	38.4	17.9	110.2	7.4	28.6	12.09	967.8	105.7	1.5	104.9	107.8	0.1	+2.7	70.1	6.3	55.9	622	1.79	0.161	1.63	0.059	2.95	5.46
30-2	32.0	102.2	38.3	17.9	115.4	7.5	28.6	12.17	967.8	111.7	1.6	110.0	108.4	0.1	-1.5	70.2	6.3	58.4	652	1.71	0.153	1.56	0.059	2.95	5.45
30-3	32.0	102.1	38.3	18.3	108.7	7.4	29.5	12.11	967.9	105.3	1.4	103.4	110.3	0.2	+6.5	70.1	6.3	--	--	--	--	--	--	--	--
31-1	31.4	102.3	36.8	21.5	109.4	9.5	39.6	10.08	967.6	105.8	1.9	104.4	107.9	0.2	+3.2	70.9	5.4	55.0	722	1.82	0.138	1.68	0.097	2.44	4.55
31-2	31.4	101.9	36.5	22.7	109.4	9.3	43.6	9.60	968.1	105.9	1.8	104.4	108.6	0.3	+3.7	70.5	5.1	55.2	764	1.81	0.131	1.68	0.113	2.31	4.31
31-3	31.4	102.0	36.8	22.2	109.4	9.3	41.6	9.65	968.0	105.9	1.8	104.4	105.8	0.3	+2.0	70.6	5.4	55.2	722	1.81	0.138	1.67	0.106	2.36	4.42
32-1	30.8	100.1	34.4	29.9	110.2	9.4	80.6	7.34	970.2	105.9	1.9	105.5	109.3	0.7	+2.9	69.3	3.6	56.8	1093	1.76	0.091	1.67	0.280	1.63	3.28
32-2	30.6	99.9	34.2	30.5	109.4	9.7	84.1	7.00	970.4	106.2	1.9	104.8	106.3	0.7	+0.8	69.3	3.6	56.4	1088	1.77	0.092	1.68	0.290	1.61	3.23
32-3	30.7	100.0	34.4	29.4	108.7	9.4	79.0	7.33	970.3	105.7	1.9	104.3	107.5	0.7	+2.4	69.3	3.7	56.2	1053	1.78	0.095	1.68	0.268	1.66	3.34
33-1	30.9	100.3	35.1	26.6	109.4	9.2	67.1	8.14	970.0	106.1	1.8	104.6	107.9	0.5	+2.7	69.4	4.2	56.2	928	1.78	0.108	1.67	0.204	1.84	3.69
33-2	31.0	100.6	35.4	26.2	110.0	9.2	65.6	8.33	969.6	106.6	1.8	105.1	108.8	0.5	+3.0	69.6	4.4	56.4	890	1.77	0.112	1.66	0.191	1.89	3.75
33-3	30.9	100.7	35.0	26.8	109.4	9.3	67.8	7.96	969.5	106.0	1.8	104.5	106.1	0.5	+1.1	69.8	4.1	56.8	952	1.79	0.115	1.68	0.208	1.83	3.66
34-1	34.4	100.3	43.2	10.0	90.0	7.0	15.6	17.3	970.0	87.5	1.1	85.3	86.3	0.0	+1.2	65.9	8.8	48.3	362	2.07	0.276	1.69	0.0178	4.68	9.67
34-2	34.4	100.1	43.2	10.1	90.7	6.8	15.7	17.0	970.2	88.1	1.1	85.9	83.9	0.0	-2.3	65.7	8.8	48.7	364	2.05	0.275	1.67	0.0181	4.64	9.60
34-3	34.3	100.3	43.0	10.0	90.7	7.0	15.9	17.3	970.0	88.1	1.1	85.9	86.0	0.0	+0.1	66.0	8.7	48.5	368	2.06	0.272	1.69	0.0181	4.64	9.67
35-1	33.2	97.9	40.2	12.3	90.0	7.1	19.6	13.8	972.7	87.5	1.2	85.4	84.5	0.1	-1.2	64.7	7.0	49.2	455	2.03	0.220	1.81	0.0276	3.96	7.90
35-2	33.4	97.9	40.8	12.1	90.7	6.7	18.7	14.6	972.7	88.3	1.1	86.1	87.9	0.1	+2.0	64.5	7.4	49.8	435	2.01	0.230	1.78	0.0259	4.05	8.00
35-3	33.4	98.3	40.8	12.2	91.4	7.0	19.1	14.7	972.3	88.9	1.2	86.8	86.8	0.1	-0.1	64.9	7.4	49.8	438	2.01	0.228	1.78	0.0267	4.00	7.96
36-1	33.2	102.3	40.4	14.3	108.0	8.3	22.8	14.3	967.6	98.6	1.5	96.8	101.7	0.1	+4.9	69.1	7.2	52.3	502	1.91	0.199	1.71	0.0373	3.52	6.81
36-2	33.2	102.1	40.4	14.1	102.9	8.4	22.6	14.0	967.8	98.6	1.5	96.8	98.3	0.1	+1.4	68.9	7.2	52.5	502	1.90	0.199	1.70	0.0365	3.55	6.90
36-3	33.2	101.8	40.4	14.5	101.8	7.9	23.0	13.9	968.2	97.9	1.4	96.0	100.3	0.1	+4.4	68.6	7.2	52.3	498	1.91	0.201	1.71	0.0381	3.49	6.71
37-1	33.0	101.7	39.7	15.7	104.8	8.0	25.1	13.0	968.3	100.8	1.5	99.0	101.7	0.1	+2.6	68.7	6.7	53.8	552	1.86	0.181	1.68	0.0450	3.28	6.19
37-2	33.0	101.8	40.7	15.2	102.9	7.8	23.9	13.5	968.2	99.4	1.4	97.5	102.3	0.1	+4.8	68.8	7.7	52.8	515	1.89	0.194	1.69	0.0416	3.38	6.40
37-3	33.0	102.0	--	15.1	101.8	8.1	24.2	13.8	968.0	98.0	1.5	96.2	103.7	0.1	+7.7	69.0	--	--	--	--	--	--	--	--	--
38-1	32.6	99.1	38.2	17.7	99.4	7.7	30.1	11.1	971.4	96.2	1.4	94.3	97.8	0.2	+3.5	66.5	5.6	52.9	628	1.89	0.159	1.73	0.0508	2.92	5.52
38-2	32.6	99.0	38.2	17.8	99.4	7.8	29.8	11.1	971.5	96.2	1.4	94.3	98.4	0.1	+4.2	66.4	5.6	53.0	628	1.89	0.159	1.73	0.0508	2.92	5.48
38-3	32.6	99.0	38.1	17.6	98.3	7.8	29.6	10.9	971.5	95.6	1.4	93.7	95.5	0.2	+1.7	66.4	5.5	52.6	635	1.90	0.158	1.74	0.0595	2.95	5.54
39-1	32.2	102.0	37.8	20.7	106.6	9.4	35.9	10.4	968.0	103.3	1.8	101.8	107.1	0.2	+5.0	69.8	5.6	54.3	677	1.84	0.148	1.69	0.0848	2.57	4.73
39-2	32.3	102.0	37.8	20.3	105.4	9.5	35.8	10.3	968.0	102.5	1.8	100.7	104.0	0.2	+2.1	69.7	5.5	53.9	682	1.86	0.147	1.71	0.0832	2.57	4.82
39-3	32.2	101.7	37.8	20.4	105.7	9.0	35.7	10.3	968.3	102.5	1.7	101.0	104.7	0.2	+3.5	69.5	5.6	54.3	674	1.84	0.148	1.69	0.0832	2.57	4.79

DSW 622336

STLCOPCB4096369

TABLE III

Program Film Heat Transfer Film Coefficient Runs
(Steam in Annulus to Water in Pressure Tube)

| Run No. | | |

TABLE IV

Annular Side Heat Transfer Film Coefficient Runs
(Water in Process Side in Annular Region)

Run No.	T_{wi} °F	T_{wo} °F	T_b °F	ΔT_{wi} °F	ΔT_{wo} °F	ΔT_{lm} °F	Q_{wi} 10^6 Btu/hr	Q_{wo} 10^6 Btu/hr	Q_{ave} 10^6 Btu/hr	Q_{ht} 10^6 Btu/hr	Q_{ht} 10^6 Btu/hr	Q_{ht} 10^6 Btu/hr	Heat Bal. Error %	Q_{ave} 10^6 Btu/hr	Q_{ht} 10^6 Btu/hr	$\frac{Q_{ht}}{A_{ht}\Delta T_{lm}}$ 10^6 Btu/hr-ft²-°F	$\left(\frac{Q}{A}\right)_{ht}$ 10^6 Btu/hr-ft²	$\left(\frac{Q}{A}\right)_{ht}$ 10^6 Btu/hr-ft²	$\left(\frac{Q}{A}\right)_{ht}^{0.14}$	$\frac{Q_{ht}}{A_{ht}\Delta T_{lm}}$ 10^6 Btu/hr-ft²-°F
56-1	55.5	21.0	26.5	8.88	5.06	11.9	58.1	53.1	0.3	0.0	1.5	0.1	50.9	+1.1	55.0	358	1.817	9.57	5.18	10.11	1.477	5.33	1.425	0.995	0.108
2	55.4	21.0	27	8.84	5.08	11.9	58.0	52.5	0.3	0.0	1.5	0.1	50.8	+1.1	55.1	351	1.811	9.57	5.18	10.08	1.476	5.33	1.419	0.995	0.108
3	55.2	21.0	26.3	8.84	5.08	11.9	58.1	52.5	0.3	0.0	1.5	0.1	50.9	+0.9	55.5	358	1.861	9.57	5.18	10.08	1.476	5.33	1.415	0.995	0.108
57-1	55.0	20.6	25.5	8.86	5.08	11.1	56.4	56.7	0.3	0.1	1.4	0.2	55.3	+2.0	60.0	391	1.667	0.258	7.80	4.38	10.11	1.481	5.33	1.412	0.108
2	55.2	20.6	25.5	8.84	5.11	11.1	57.3	58.8	0.3	0.1	1.5	0.1	56.1	+3.4	60.5	397	1.658	0.254	7.99	4.33	10.11	1.480	5.33	1.418	0.108
3	55.2	20.6	25.8	8.84	5.11	11.1	57.3	58.8	0.3	0.1	1.5	0.1	55.9	+4.8	60.3	397	1.658	0.240	7.99	4.33	10.11	1.480	5.33	1.418	0.108
58-1	55.0	20.1	26	10.14	4.19	16.7	63.8	62.3	0.3	0.1	1.5	0.1	62.7	+0.6	67.1	505	1.500	0.171	5.80	2.72	10.11	1.481	5.33	1.412	0.108
2	55.0	20.2	25.5	10.14	4.19	16.7	63.7	62.5	0.3	0.1	1.6	0.1	62.4	-0.3	67.1	505	1.495	0.172	5.80	2.77	10.11	1.481	5.33	1.412	0.108
3	55.0	20.2	25.5	10.14	4.19	16.7	63.7	62.9	0.3	0.1	1.6	0.1	62.4	+0.5	66.9	503	1.495	0.176	5.80	2.77	10.11	1.481	5.33	1.412	0.108
59-1	54.9	19.6	25.5	10.08	5.18	15.0	67.9	69.3	0.3	0.4	1.6	0.1	66.6	+2.2	70.4	887	1.420	0.113	3.86	2.65	10.10	1.485	5.33	1.409	0.108
2	54.9	19.6	25.5	10.14	5.14	15.0	67.7	71.0	0.3	0.4	1.5	0.1	66.2	+3.4	70.0	882	1.406	0.113	3.86	2.65	10.11	1.485	5.33	1.414	0.108
3	55.0	19.6	25.2	10.14	5.14	15.0	67.7	70.8	0.3	0.4	1.5	0.1	66.5	+5.4	70.1	882	1.406	0.113	3.86	2.65	10.11	1.485	5.33	1.412	0.108
60-1	56.9	21.0	26.9	9.87	5.05	13.3	57.8	56.3	0.3	0.0	1.6	0.1	56.2	-0.5	58.8	357	1.711	0.260	9.08	4.80	10.11	1.466	5.38	1.408	0.107
2	57.1	21.0	26.9	9.87	5.05	13.3	57.7	57.5	0.3	0.0	1.6	0.1	56.4	+1.8	59.4	357	1.733	0.260	9.08	4.80	10.11	1.466	5.38	1.408	0.107
3	57.1	21.0	26.9	9.87	5.05	13.3	57.7	57.7	0.3	0.0	1.6	0.1	55.8	+3.8	57.7	353	1.733	0.264	8.79	4.76	10.11	1.465	5.38	1.405	0.107
61-1	56.3	20.4	25.9	9.78	4.65	20.4	61.5	59.8	0.3	0.1	1.6	0.1	60.2	-1.0	64.6	488	1.597	0.205	6.74	3.68	10.10	1.470	5.38	1.441	0.108
2	56.4	20.4	25.9	9.78	4.78	21.0	62.0	62.4	0.3	0.1	1.6	0.1	60.2	+1.8	64.7	488	1.595	0.204	6.74	3.68	10.11	1.469	5.33	1.440	0.108
3	56.5	20.4	25.9	9.78	4.78	21.0	62.0	63.6	0.3	0.1	1.6	0.1	60.7	+4.4	64.7	488	1.595	0.204	6.74	3.68	10.11	1.469	5.33	1.440	0.108
62-1	55.6	20.0	27	10.32	3.77	14.6	59.2	66.4	0.3	0.2	1.5	0.2	64.9	+3.1	67.1	645	1.488	0.155	4.82	2.63	10.11	1.477	5.33	1.428	0.108
2	55.7	19.8	27	10.32	3.80	14.6	59.8	67.1	0.3	0.2	1.5	0.2	64.6	+4.0	67.3	670	1.486	0.154	4.82	2.64	10.10	1.475	5.38	1.429	0.108
3	55.8	19.8	27	10.32	3.80	14.6	59.8	68.1	0.3	0.2	1.5	0.2	64.9	+4.8	67.3	694	1.486	0.154	4.78	2.45	10.10	1.475	5.38	1.429	0.108
63-1	55.2	19.4	27.5	11.39	2.76	17.8	71.0	73.5	0.3	0.7	1.5	0.2	69.8	+4.6	73.8	1133	1.374	0.088	3.33	1.67	10.11	1.480	5.33	1.419	0.108
2	55.3	19.4	27.5	11.39	2.76	17.8	72.2	73.5	0.3	0.7	1.5	0.2	71.0	+2.8	73.8	1152	1.365	0.091	3.23	1.68	10.11	1.478	5.33	1.418	0.108
3	55.4	19.4	27.5	11.47	2.68	18.2	72.1	73.5	0.3	0.7	1.5	0.2	70.9	+4.7	73.5	1165	1.368	0.091	3.23	1.68	10.10	1.478	5.33	1.418	0.108

Hot overflow, Q_{ht} for runs 56-65 was 396 #/hr.

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STLCOPCB4096371

TABLE V

Process Side Heat Transfer Film Coefficients Runs
(Water in Process Side to Water in Jacket)

Run No.	T_{wi} °F	T_{wo} °F	T_b °F	q_j gpm	ΔP_j psi	ΔT_j °C	Δp psi/hr.	10^3 Btu/hr.	10^3 Btu/hr.	10^3 Btu/hr.	10^3 Btu/hr.	10^3 Btu/hr.	10^3 lbs/hr.	Heat Bal. Error %	ΔT_{lm} °C	h_o Btu/hr. ft² °F	$\frac{100}{h_o}$ 10^{-2} hr. ft² °F/Btu	$(\frac{100}{h_o})^{0.986}$	$(\frac{1}{\mu})^{0.383}$	10^4 cst/hr.	$(N_{Pr})^{1/3}$	$\frac{D_p}{k}$ hr. ft² °F/Btu	$10^{-3}(N_{Re})^{0.1}$	$(\frac{\mu}{\mu_p})^{0.14}$	$\frac{100}{h_p}$ 10^2 hr. ft² °F/Btu
64-1	60.1	80.4	24.5	9.8	9.77	6.70	11.4	58.3	58.8	0.3	0.0	0.1	1.9	58.7	+3.5	39.7	53.3	1.876	9.88	5.35	1.011	1.939	5.29	1.531	0.995	0.105
2	60.0	80.4	25.0	9.8	9.73	6.70	11.4	58.0	58.8	0.3	0.0	0.1	1.8	58.5	+3.9	39.6	53.2	1.880	9.88	5.35	1.011	1.939	5.29	1.530	0.995	0.105
5	60.0	80.4	25.2	9.9	9.64	6.70	11.5	57.5	59.5	0.3	0.0	0.1	1.8	56.8	+4.1	--	--	--	--	--	--	--	--	--	--	--
65-1	59.5	19.8	24.1	18.2	10.49	5.99	16.6	62.5	62.7	0.3	0.1	0.1	1.9	60.9	+2.6	39.7	57.2	1.748	7.78	4.21	1.011	1.444	5.29	1.517	0.994	0.105
2	59.5	19.8	24.0	18.4	10.55	5.62	16.5	62.9	63.2	0.3	0.1	0.1	1.9	61.2	+2.9	39.7	57.5	1.739	7.72	4.20	1.010	1.444	5.29	1.518	0.994	0.105
5	59.4	19.8	24.3	18.5	10.50	5.65	16.2	62.7	63.8	0.3	0.1	0.1	1.9	61.6	+3.2	39.6	58.0	1.724	7.78	4.25	1.011	1.445	5.29	1.515	0.994	0.105
66-1	58.5	19.8	24.8	16.6	11.15	4.51	26.3	66.6	67.2	0.3	0.1	0.1	1.8	65.1	+2.9	39.3	61.8	1.618	5.87	3.16	1.011	1.454	5.30	1.492	0.994	0.106
2	58.5	19.8	25.3	16.7	11.11	4.51	26.3	66.2	67.2	0.3	0.1	0.1	1.8	64.8	+3.9	39.3	61.5	1.626	5.84	3.16	1.014	1.454	5.30	1.500	0.994	0.105
5	58.5	19.8	25.2	16.8	11.15	4.49	26.5	66.8	67.8	0.3	0.1	0.1	1.8	65.1	+3.5	39.3	61.8	1.618	5.81	3.14	1.015	1.454	5.30	1.499	0.994	0.105
67-1	59.6	19.8	27.7	24.3	12.77	3.45	54.8	75.9	75.8	0.3	0.4	0.2	1.7	74.5	+4.5	40.6	68.5	1.460	4.03	2.07	1.015	1.442	5.29	1.528	0.994	0.105
2	59.8	19.8	28.0	24.3	12.79	3.46	54.0	76.0	78.0	0.3	0.4	0.2	1.7	74.6	+4.7	40.8	68.2	1.466	4.00	2.08	1.014	1.441	5.29	1.530	0.994	0.105
5	59.8	19.9	28.0	24.5	12.85	3.45	53.4	76.5	75.8	0.3	0.4	0.2	1.7	74.9	+4.0	40.8	68.5	1.460	4.00	2.08	1.014	1.441	5.29	1.530	0.994	0.105
68-1	59.7	20.2	27.5	10.7	10.15	6.38	13.0	60.3	60.7	0.3	0.0	0.2	1.7	58.9	+3.4	39.5	55.6	1.798	9.07	4.90	1.015	1.442	5.29	1.530	0.995	0.105
2	59.6	20.2	28.0	10.7	10.13	6.35	13.0	60.3	60.8	0.3	0.0	0.2	1.7	58.9	+3.8	39.4	55.7	1.795	9.04	4.95	1.017	1.442	5.29	1.530	0.995	0.105
5	59.8	20.2	27.8	10.8	10.18	6.37	12.6	60.5	60.6	0.3	0.0	0.2	1.7	59.1	+2.9	39.4	56.0	1.788	8.99	4.95	1.015	1.442	5.29	1.528	0.995	0.105
69-1	59.8	19.6	26.0	14.1	11.13	5.14	20.6	66.2	64.9	0.3	0.1	0.2	1.7	64.8	+2.6	40.2	60.1	1.664	6.91	3.70	1.014	1.441	5.29	1.530	0.995	0.105
2	59.9	19.6	26.0	14.1	11.06	5.17	20.3	65.7	65.2	0.3	0.1	0.2	1.7	64.2	+1.9	40.3	59.5	1.681	6.93	3.73	1.015	1.441	5.29	1.532	0.994	0.105
5	59.9	19.6	27.0	14.2	10.98	5.21	20.2	65.1	66.3	0.3	0.1	0.2	1.7	63.7	+4.5	40.3	59.8	1.695	6.88	3.73	1.014	1.441	5.29	1.531	0.994	0.105
70-1	59.2	19.1	27.3	19.8	11.96	3.98	35.2	71.1	70.6	0.3	0.2	0.2	1.7	69.7	+1.9	40.1	64.9	1.541	4.94	2.64	1.015	1.447	5.29	1.517	0.994	0.105
2	59.4	19.0	27.0	19.5	11.98	3.97	35.2	71.5	69.4	0.3	0.2	0.2	1.7	69.0	+0.1	40.2	64.9	1.541	5.02	2.66	1.015	1.445	5.29	1.522	0.994	0.105
5	59.5	19.0	27.0	19.5	12.13	4.07	35.4	72.2	71.0	0.3	0.2	0.2	1.7	70.8	+0.8	40.3	65.5	1.527	5.02	2.65	1.014	1.444	5.29	1.525	0.994	0.105
71-1	59.1	18.6	27.6	30.9	13.22	2.88	83.1	78.6	79.7	0.3	0.7	0.2	1.7	77.8	+4.4	40.5	71.1	1.406	3.18	1.60	1.015	1.447	5.29	1.515	0.993	0.105
2	59.1	18.5	27.8	31.2	13.24	2.86	84.6	78.7	80.0	0.3	0.7	0.2	1.7	77.5	+4.7	40.6	71.0	1.408	3.14	1.59	1.011	1.447	5.29	1.506	0.993	0.105
5	59.2	18.6	27.7	31.3	13.24	2.87	85.5	78.7	80.2	0.3	0.7	0.2	1.7	77.5	+4.8	40.6	71.0	1.408	3.14	1.58	1.016	1.447	5.29	1.516	0.993	0.105

For overflow, q_j for runs 64-71 was 3303 lbs/hr.

DSW 622339

STLCOPCB4096372

TABLE VI

Jacket Heat Transfer Film Coefficient Runs
(Steam, High Excess, in Process Side to Water in Jacket)

Run No.	T_E °C	T_I °C	T_A °C	Q_J gpm	W_P #/hr.	ΔT_J °C	ΔT_P °C	Δp cm Hg	λ_P Btu/lb.	q_{1P} 10^3 Btu/hr	q_{3P} 10^3 Btu/hr.	q_{4A} 10^3 Btu/hr.	q_{5A} 10^3 Btu/hr.	q_V 10^3 Btu/hr.	q_{A1} 10^3 Btu hr	q 10^3 Btu hr	Heat Bal. Error %	ΔT_{lo} °F	U_o Btu/hr. ft² °F	$\frac{100}{U_o}$ 10^2 hr. ft² °F/Btu	$(\frac{100}{q_J})^{0.986}$	$(\frac{1}{p})^{0.383}$
72-1	117.2	24.7	26.0	9.6	149.4	16.55	0.2	7.0	950.2	142.0	0.0	4.8	131.5	0.0	0.0	137.2	-4.2	92.5	53.0	1.887	10.30	6.50
2	117.1	24.8	26.0	9.6	149.4	16.51	0.1	7.0	950.3	142.0	0.0	4.8	131.2	0.0	0.0	137.2	-4.4	92.3	53.1	1.883	10.30	6.50
3	117.4	24.7	26.0	9.6	150.1	16.50	0.2	7.1	950.0	142.6	0.0	4.8	131.1	0.0	0.0	137.8	-4.8	92.7	52.8	1.894	10.30	6.45
73-1	116.6	23.1	26.1	12.8	160.6	13.51	0.2	13.2	950.9	152.7	0.0	4.8	143.3	0.0	0.1	147.9	-3.2	93.5	57.1	1.751	7.59	4.54
2	116.8	23.1	26.3	12.7	160.0	13.59	0.1	13.2	950.7	152.1	0.0	4.8	144.7	0.0	0.1	147.3	-1.8	93.7	57.5	1.739	7.63	4.56
3	117.2	23.1	26.2	12.8	160.6	13.64	0.1	13.3	950.2	152.6	0.0	4.8	143.0	0.0	0.1	147.8	-3.3	94.1	56.7	1.764	7.59	4.53
74-1	116.1	21.8	26.2	16.7	167.5	10.99	0.1	23.8	951.6	159.4	0.0	4.8	152.2	0.1	0.1	154.6	-4.7	94.3	60.1	1.664	5.84	3.28
2	115.8	21.8	26.3	16.7	170.6	10.99	0.2	23.4	951.9	162.3	0.0	4.7	152.2	0.1	0.1	157.6	-3.5	94.0	60.3	1.658	5.84	3.30
3	116.3	21.8	26.1	16.7	171.2	10.99	0.2	23.6	951.3	162.9	0.0	4.8	152.2	0.1	0.1	158.1	-3.8	94.5	60.0	1.667	5.84	3.29
75-1	115.4	20.2	26.0	25.1	184.4	8.01	0.1	55.7	952.4	175.6	0.0	4.7	167.0	0.4	0.1	170.9	-2.6	95.2	65.3	1.531	3.90	2.02
2	115.1	20.2	26.3	25.4	186.2	7.95	0.2	58.1	952.7	177.4	0.0	4.7	167.7	0.4	0.1	172.7	-3.2	94.9	65.8	1.520	3.87	2.00
3	114.7	20.2	26.5	25.6	186.9	7.90	0.4	58.0	953.2	178.2	0.1	4.7	168.0	0.4	0.1	173.6	-3.5	94.5	66.1	1.513	3.82	1.98
76-1	117.3	23.9	23.4	11.0	161.2	15.49	0.3	14.6	950.1	153.2	0.0	5.0	141.1	0.0	0.0	148.2	-4.8	93.4	56.3	1.776	8.80	4.65
2	117.4	23.8	23.5	11.0	160.6	15.43	0.1	13.6	950.0	152.6	0.0	5.0	140.6	0.0	0.0	147.6	-4.7	93.6	56.0	1.786	8.80	4.77
3	117.4	23.8	23.6	10.9	159.4	15.55	0.1	13.4	950.0	151.4	0.0	5.0	140.4	0.0	0.0	146.4	-4.1	93.6	56.0	1.786	8.88	4.80
77-1	116.9	22.5	24.5	14.3	166.9	12.86	0.2	22.2	950.5	158.6	0.0	4.9	152.5	0.1	0.0	153.7	-0.8	94.4	60.2	1.661	6.80	3.58
2	116.8	22.4	24.7	14.5	170.0	12.78	0.2	22.6	950.7	161.6	0.0	4.9	153.6	0.1	0.1	156.7	-2.1	94.4	60.6	1.650	6.71	3.53
3	116.7	22.4	24.5	14.5	168.8	12.76	0.1	22.4	950.8	160.5	0.0	4.9	153.4	0.1	0.0	155.6	-1.5	94.3	60.6	1.650	6.71	3.56
78-1	115.3	21.0	24.5	20.3	191.2	9.80	0.0	37.7	952.5	182.1	0.0	4.8	165.1	0.2	0.1	177.3	-7.1	94.3	--	--	--	2.56
2	115.1	21.0	24.0	20.0	178.8	9.72	0.3	37.8	952.7	170.3	0.1	4.8	162.9	0.2	0.1	165.6	-1.8	94.1	64.4	1.553	4.88	2.56
3	115.4	21.0	24.6	20.2	178.1	9.72	0.2	37.5	952.4	169.6	0.0	4.8	161.3	0.2	0.1	164.8	-2.3	94.4	63.7	1.570	4.84	2.56
79-1	114.6	19.4	25.0	31.5	197.5	6.72	0.2	87.0	953.3	188.3	0.0	4.7	175.9	0.8	0.1	183.6	-4.7	95.2	68.5	1.460	3.13	1.57
2	114.6	19.4	25.0	31.3	195.6	6.80	0.4	87.2	953.3	186.5	0.1	4.7	176.8	0.8	0.1	181.9	-3.3	95.2	68.9	1.451	3.11	1.57
3	114.4	19.4	25.4	31.5	198.1	6.77	0.4	86.9	953.5	188.9	0.1	4.7	177.2	0.8	0.1	184.3	-4.3	95.0	69.2	1.445	3.13	1.57

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TABLE VII

(Liquid-Liquid Heat Transfer Runs)

Run Number	Jacket Fluid	Process Fluid	T_J °C.	T_P °C.	Q_1 B.T.U.	n lbs./hr.	$\frac{D}{D_J}$ ft.	$(N_{Pr})_J$	k_J Btu/hr.ft.°F	$(\frac{\mu_J}{\mu_W})^{0.14}$	$\frac{12n}{D_J \cdot 10^{-3}}$	$(N_{Pr})_P$	k_P Btu/hr.ft.°F	$(\frac{\mu_P}{\mu_P})^{0.14}$	ΔT_o °C.	Btu/hr.	Heat Bal. Error %	Exp. Btu/hr.ft²°F	$(\frac{1}{U_o})$ Exp. Hr.ft²°F/Btu	$(\frac{1}{U_o})$ Calc. Hr.ft²°F/Btu.	Cal. U_o Error %	F hp
80-1	NaCl brine	water	1.8	29.1	11.1	10.16	1.08	14.82	0.3223	1.058	8.91	5.53	0.3546	0.997	27.3	[illegible]	+2.6	48.2	0.02074	0.01923	+7.8	
-2	"	"	1.6	29.1	11.1	10.16	1.08	14.93	0.3220	1.059	8.95	5.53	0.3546	0.997	27.5	35.4	+2.0	48.0	0.02083			
-3	"	"	1.6	29.1	11.1	10.16	1.08	14.93	0.3220	1.059	8.95	5.53	0.3546	0.997	27.5	35.3	+2.8	47.9	0.02089			
81-1	"	"	2.4	30.3	4.32	10.16	0.431	14.50	0.3231	1.072	9.14	5.37	0.3560	0.984	27.9	24.8	+0.8	33.1	0.03017	0.02467	+22.2	
-2	"	"	2.6	30.3	4.11	10.15	0.412	14.41	0.3234	1.074	9.14	5.37	0.3560	0.984	27.7	24.4	+0.8	32.8	0.03045			
-3	"	"	2.8	30.3	4.02	10.16	0.407	14.30	0.3236	1.071	9.14	5.37	0.3560	0.985	27.5	23.9	+2.0	32.4	0.03086			
82-1	"	"	1.2	30.0	6.66	10.15	0.640	15.14	0.3215	1.069	9.09	5.42	0.3557	0.986	28.8	30.4	+3.0	39.4	0.02541	0.02175	+16.8	
-2	"	"	1.2	30.0	6.65	10.16	0.639	15.14	0.3215	1.069	9.09	5.42	0.3557	0.986	28.8	30.1	+4.0	39.0	0.02566			
-3	"	"	1.1	29.9	6.61	10.15	0.635	15.20	0.3214	1.069	9.09	5.43	0.3556	0.986	28.8	30.1	+6.6	39.0	0.02566			
83-1	"	"	0.6	29.3	8.50	10.15	0.799	15.49	0.3207	1.077	9.00	5.50	0.3549	0.985	28.7	32.9	+1.5	42.7	0.02340	0.02042	+14.5	
-2	"	"	0.6	29.3	8.50	10.16	0.799	15.49	0.3207	1.066	9.00	5.50	0.3549	0.985	28.7	32.	+0.3	42.0	0.02373			
-3	"	"	0.6	29.3	8.46	10.17	0.795	15.49	0.3207	1.066	9.00	5.50	0.3549	0.985	28.7	32.7	+2.8	42.5	0.02354			
84-1	"	"	1.7	29.9	5.28	10.16	0.515	14.87	0.3222	1.070	9.09	5.43	0.3556	0.985	28.2	27.1	+0.4	35.8	0.02791	0.02322	+20.1	
-2	"	"	2.0	29.9	5.28	10.16	0.521	14.70	0.3226	1.070	9.09	5.43	0.3556	0.985	27.9	27.1	+0.7	36.2	0.02761			
-3	"	"	2.1	29.9	5.24	10.16	0.518	14.67	0.3228	1.069	9.09	5.43	0.3556	0.985	27.8	26.7	+0.4	35.8	0.02793			
85-1	"	"	3.1	30.2	4.28	10.15	0.437	14.18	0.3240	1.069	9.14	5.39	0.3559	0.986	27.1	24.3	+4.1	33.4	0.02991	0.02469	+21.2	
-2	"	"	3.1	30.2	4.25	10.16	0.433	14.18	0.3240	1.069	9.14	5.39	0.3559	0.986	27.1	24.0	+3.8	33.0	0.03028			
-3	"	"	3.2	30.1	4.23	10.16	0.432	14.15	0.3241	1.068	9.14	5.40	0.3558	0.986	26.9	23.4	+6.4	32.4	0.03083			
86-1	water	"	12.7	50.8	29.6	10.17	5.07	8.73	0.3362	1.022	13.3	3.51	0.3724	0.993	38.1	71.8	+4.2	70.3	0.01422	0.01587	-10.0	0.244
-2	"	"	12.7	50.8	29.8	10.17	5.10	8.73	0.3362	1.024	13.5	3.51	0.3724	0.993	38.1	70.7	+6.1	69.3	0.01443			0.249
-3	"	"	12.7	50.8	29.9	10.17	5.12	8.73	0.3362	1.024	13.5	3.51	0.3724	0.993	38.1	70.7	+6.5	69.3	0.01443			0.251
87-1	"	"	13.2	50.9	19.8	10.17	3.44	8.59	0.3368	1.030	13.3	3.50	0.3724	0.993	37.7	65.9	+2.1	65.2	0.01534	0.01661	-7.6	0.080
-2	"	"	13.2	51.1	19.7	10.17	3.42	8.59	0.3368	1.031	13.3	3.49	0.3726	0.993	37.9	65.9	+1.8	65.0	0.01538			0.079
-3	"	"	13.2	51.2	19.6	10.17	3.40	8.59	0.3368	1.031	13.4	3.48	0.3726	0.993	38.0	65.9	+2.0	64.7	0.01546			0.078
88-1	"	"	13.8	52.6	14.3	10.17	2.52	8.44	0.3376	1.036	13.7	3.40	0.3736	0.994	38.8	63.6	-1.3	61.2	0.01634	0.01742	-6.2	0.033
-2	"	"	13.8	52.6	14.3	10.17	2.52	8.44	0.3376	1.036	13.7	3.40	0.3736	0.994	38.8	63.6	-0.6	61.2	0.01634			0.033
-3	"	"	13.8	52.6	14.5	10.17	2.56	8.44	0.3376	1.038	13.7	3.40	0.3736	0.994	38.8	62.4	+1.1	60.0	0.01667			0.034
89-1	"	"	14.5	52.7	10.9	10.13	1.96	8.26	0.3384	1.045	13.7	3.39	0.3737	0.994	38.2	57.5	-0.4	56.2	0.01779	0.01825	-2.5	0.016
-2	"	"	14.5	52.7	10.8	10.12	1.94	8.26	0.3384	1.044	13.7	3.39	0.3737	0.994	38.2	57.6	-2.1	56.3	0.01776			0.016
-3	"	"	14.5	52.8	10.7	10.12	1.93	8.26	0.3384	1.044	13.7	3.38	0.3737	0.994	38.3	57.8	-2.2	56.5	0.01776			0.016
90-1	"	"	13.0	51.8	25.4	10.11	4.38	8.65	0.3366	1.023	13.4	3.44	0.3731	0.993	38.8	72.9	-0.6	70.0	0.01428	0.01610	-11.2	0.164
-2	"	"	13.0	51.9	25.4	10.12	4.38	8.65	0.3366	1.024	13.5	3.44	0.3731	0.993	38.9	72.3	+0.6	69.4	0.01441			0.165
-3	"	"	13.0	51.9	25.8	10.12	4.44	8.65	0.3366	1.024	13.5	3.44	0.3731	0.993	38.9	72.3	+2.8	69.4	0.01441			0.172

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TABLE VII (cont'd.)

Run Number	Jacket Fluid	Process Fluid	T_J °C.	T_p °C.	Q_i R.P.M.	n Rev./hr.	$\frac{Q}{W_J}$ ft.	$(N_{Pr})_J$	k_J Btu/hr.ft.°F	$(\frac{\mu_J}{\mu_W})^{0.14}$	$\frac{\cdot 10^{-}}{\mu_p}$	$N_{Pr})_p$	k_p Btu/hr.ft.°F	$(\frac{\mu}{\mu_p})^{0.14}$	ΔT_e °C.	ϵ Btu/hr.	Heat Bal. Error %	Exp. Btu/hr.ft²°F	$(\frac{1}{U_{ox}})$ Exp. Hr.ft²°F/Btu	$\frac{1}{(U_o)}$ Calc. Hr.ft²°F/Btu	Cal. U_o Error %	P hp
91-1	water	water	13.7	51.4	16.9	10.12	2.98	8.47	0.3374	1.031	13.4	3.47	0.3728	0.994	37.7	64.7	+3.2	64.0	0.01562	0.01698	-8.0	0.052
-2	"	"	13.7	51.7	17.0	10.12	2.99	8.47	0.3374	1.032	13.5	3.45	0.3730	0.993	38.0	64.6	+3.2	63.4	0.01577			0.052
-3	"	"	13.6	51.8	16.9	10.12	2.98	8.49	0.3373	1.033	13.5	3.44	0.3730	0.993	38.2	64.6	+2.5	63.1	0.01585			0.052
92-1	"	"	14.3	52.5	12.5	10.12	2.23	8.32	0.3381	1.040	13.6	3.40	0.3735	0.994	38.2	60.4	-0.2	59.0	0.01695	0.01782	-4.9	0.023
-2	"	"	14.4	52.5	12.5	10.11	2.24	8.29	0.3382	1.039	13.6	3.40	0.3735	0.994	38.1	60.4	-0.2	59.2	0.01689			0.023
-3	"	"	14.4	52.5	12.5	10.11	2.24	8.29	0.3382	1.039	13.6	3.40	0.3735	0.994	38.1	60.4	+0.3	59.2	0.01689			0.024
93-1	"	"	15.0	52.8	10.2	10.12	1.86	8.14	0.3390	1.044	13.7	3.38	0.3737	0.995	37.8	55.7	+1.8	55.0	0.01818	0.01848	-1.6	0.014
-2	"	"	15.0	52.7	10.2	10.17	1.86	8.14	0.3390	1.044	13.7	3.39	0.3737	0.994	37.7	56.1	+0.9	55.6	0.01798			0.014
-3	"	"	14.9	52.7	10.3	10.17	1.84	8.16	0.3389	1.044	13.7	3.39	0.3737	0.994	37.8	56.5	+1.2	55.8	0.01792			0.014
94-1	"	"	11.0	50.2	29.2	5.60	4.77	9.19	0.3341	1.021	7.24	3.55	0.3731	0.989	39.2	71.8	-1.1	68.3	0.01464	0.01636	-10.5	0.251
-2	"	"	11.0	50.1	28.9	5.60	4.72	9.19	0.3341	1.021	7.23	3.55	0.3730	0.989	39.1	71.9	-0.1	68.5	0.01460			0.246
-3	"	"	11.0	50.1	29.0	5.61	4.74	9.19	0.3341	1.020	7.24	3.55	0.3730	0.989	39.1	72.2	+1.2	68.9	0.01451			0.245
95-1	"	"	11.4	51.2	19.9	5.60	3.28	9.07	0.3346	1.028	7.37	3.48	0.3743	0.990	39.8	69.0	-3.3	64.7	0.01546	0.01713	-9.7	0.084
-2	"	"	11.4	51.4	19.6	5.60	3.24	9.07	0.3346	1.028	7.40	3.47	0.3746	0.990	40.0	69.7	-5.0	65.0	0.01538			0.083
-3	"	"	11.4	51.6	19.8	5.60	3.27	9.07	0.3346	1.028	7.41	3.46	0.3748	0.990	40.2	70.0	-4.0	65.0	0.01538			0.084
96-1	"	"	12.2	53.6	14.6	5.57	2.47	8.87	0.3356	1.035	7.63	3.34	0.3773	0.990	41.4	67.5	-1.6	60.9	0.01642	0.01787	-8.1	0.035
-2	"	"	12.2	53.8	14.6	5.60	2.47	8.87	0.3356	1.036	7.68	3.32	0.3775	0.990	41.6	67.6	-1.9	60.6	0.01650			0.035
-3	"	"	12.2	53.8	14.4	5.60	2.44	8.87	0.3356	1.036	7.68	3.32	0.3775	0.990	41.6	67.6	-2.7	60.6	0.01650			0.034
97-1	"	"	12.4	51.6	10.8	5.60	1.84	8.81	0.3358	1.047	7.42	3.46	0.3748	0.992	39.2	55.9	+3.6	53.2	0.01880	0.01882	-0.1	0.016
-2	"	"	12.4	51.6	10.7	5.61	1.82	8.81	0.3358	1.047	7.43	3.46	0.3748	0.992	39.2	55.9	+1.1	53.2	0.01880			0.016
-3	"	"	12.3	51.6	10.8	5.60	1.85	8.83	0.3357	1.046	7.42	3.46	0.3748	0.992	39.3	56.3	+2.0	53.4	0.01873			0.016
98-1	"	"	10.7	49.1	25.0	5.60	4.05	9.28	0.3337	1.024	7.10	3.62	0.3718	0.990	38.4	69.0	+0.4	67.0	0.01492	0.01667	-10.5	0.158
-2	"	"	10.6	49.0	24.5	5.59	3.95	9.31	0.3336	1.024	7.08	3.63	0.3717	0.990	38.4	68.9	-1.3	66.9	0.01495			0.150
-3	"	"	10.6	49.0	25.1	5.60	4.05	9.31	0.3336	1.024	7.09	3.63	0.3717	0.990	38.4	68.9	+1.3	66.9	0.01495			0.160
99-1	"	"	11.2	50.0	16.7	5.60	2.74	9.14	0.3343	1.035	7.22	3.56	0.3729	0.990	38.8	63.1	+1.7	60.7	0.01647	0.01757	-6.3	0.050
-2	"	"	11.2	50.0	16.8	5.60	2.76	9.14	0.3343	1.035	7.22	3.56	0.3729	0.990	38.8	63.1	+2.5	60.7	0.01647			0.050
-3	"	"	11.2	50.0	16.8	5.60	2.76	9.14	0.3343	1.035	7.22	3.56	0.3729	0.990	38.8	63.1	+2.5	60.7	0.01647			0.050
100-1	"	"	11.6	51.0	12.6	5.60	2.09	9.02	0.3348	1.040	7.34	3.50	0.3741	0.991	39.4	60.5	0.0	57.3	0.01745	0.01837	-5.0	0.023
-2	"	"	11.7	51.0	12.5	5.60	2.08	8.99	0.3350	1.040	7.34	3.50	0.3741	0.991	39.3	60.5	-0.5	57.5	0.01739			0.023
-3	"	"	11.6	51.0	12.6	5.60	2.09	9.02	0.3348	1.040	7.34	3.50	0.3741	0.991	39.4	60.5	+0.5	57.3	0.01745			0.023
101-1	"	"	12.2	52.1	10.2	5.60	1.73	8.87	0.3356	1.046	7.48	3.43	0.3754	0.991	39.9	58.3	0.0	54.5	0.01835	0.01903	-3.6	0.014
-2	"	"	12.2	52.1	10.3	5.60	1.74	8.87	0.3356	1.045	7.48	3.43	0.3754	0.991	39.9	58.5	+0.7	54.7	0.01828			0.014
-3	"	"	12.2	52.2	10.3	5.60	1.74	8.87	0.3356	1.044	7.49	3.42	0.3756	0.991	40.0	58.3	-0.7	55.3	0.01808			0.014
102-1	"	"	9.6	47.9	28.8	7.87	4.50	9.62	0.3324	1.018	9.79	3.71	0.3703	0.991	38.3	71.9	+1.5	70.0	0.01428	0.01614	-11.6	0.238
-2	"	"	9.6	47.9	28.9	7.87	4.52	9.62	0.3324	1.018	9.79	3.71	0.3703	0.991	38.3	71.9	+1.5	70.0	0.01428			0.241
-3	"	"	9.6	48.0	28.9	7.88	4.52	9.62	0.3324	1.019	9.83	3.70	0.3704	0.991	38.4	71.9	+1.5	69.9	0.01431			0.241

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TABLE VII (cont'd.)

Run Number	Jacket Fluid	Process Fluid	T_J °C.	T_P °C.	Q_1 g.p.m.	n Rev./hr.	$\frac{Q}{a_J}$ ft.	$(N_{Pr})_J$	k_J Btu/hr.ft²°F	$(\frac{\mu_J}{\mu_W})^{0.14}$	$\frac{D}{D_p}$	$(N_{Pr})_P$	k_p Btu/hr.ft²°F	$(\frac{\mu_P}{\mu_P})^{0.14}$	ΔT_o °C.	Btu/hr.	Heat Bal. Error %	Exp. Btu/hr.ft²°F	$\frac{1}{U_o}$ Exp. hr.ft²°F/Btu	$(\frac{1}{U_o})$ Calc. hr.ft²°F/Btu	Cal. U_o Error %	P hp.
103-1	water	water	10.1	49.0	19.9	7.88	3.16	9.47	0.3330	1.031	9.98	3.63	0.3717	0.992	38.9	68.1	+1.0	65.3	0.01531	0.01687	-9.3	0.082
-2	"	"	10.2	49.0	20.0	7.87	3.18	9.43	0.3331	1.031	9.97	3.63	0.3717	0.992	38.8	68.1	+1.3	65.4	0.01529			0.081
-3	"	"	10.2	49.0	19.8	7.87	3.15	9.43	0.3331	1.031	9.97	3.63	0.3717	0.992	38.8	67.6	-0.5	65.8	0.01520			0.081
104-1	"	"	10.8	50.3	14.2	7.87	2.30	9.25	0.3339	1.041	10.21	3.54	0.3733	0.992	39.5	62.2	+0.5	58.7	0.01704	0.01772	-3.8	0.032
-2	"	"	10.8	50.3	14.3	7.87	2.32	9.25	0.3339	1.041	10.21	3.54	0.3733	0.992	39.5	62.2	+2.7	58.7	0.01704			0.033
-3	"	"	10.8	50.3	14.4	7.86	2.34	9.25	0.3339	1.041	10.22	3.54	0.3733	0.992	39.5	62.2	+1.9	58.7	0.01704			0.033
105-1	"	"	11.4	50.8	11.0	7.86	1.82	9.07	0.3346	1.046	10.29	3.51	0.3739	0.993	39.4	58.5	+0.5	55.4	0.01805	0.01851	-2.5	0.016
-2	"	"	11.4	50.8	10.9	7.87	1.80	9.07	0.3346	1.046	10.28	3.51	0.3739	0.993	39.4	58.5	-0.3	55.4	0.01805			0.016
-3	"	"	11.4	50.8	10.9	7.87	1.80	9.07	0.3346	1.046	10.28	3.51	0.3739	0.993	39.4	58.5	+0.3	55.4	0.01805			0.016
106-1	"	"	9.8	48.9	24.9	7.87	3.93	9.57	0.3327	1.027	9.95	3.63	0.3716	0.992	39.1	70.5	+0.6	67.3	0.01486	0.01638	-9.3	0.153
-2	"	"	9.8	48.9	24.8	7.87	3.92	9.57	0.3327	1.027	9.95	3.63	0.3716	0.992	39.1	70.5	+0.3	67.3	0.01486			0.153
-3	"	"	9.8	48.9	24.8	7.87	3.92	9.57	0.3327	1.026	9.95	3.63	0.3716	0.992	39.1	71.0	0.0	67.8	0.01475			0.151
107-1	"	"	10.3	49.8	16.9	7.87	2.70	9.41	0.3333	1.037	10.12	3.58	0.3727	0.992	39.5	65.5	+1.1	61.8	0.01618	0.01725	-6.2	0.051
-2	"	"	10.4	49.8	16.8	7.87	2.69	9.37	0.3334	1.037	10.12	3.58	0.3727	0.992	39.4	65.5	+0.7	62.0	0.01613			0.050
-3	"	"	10.4	49.8	16.8	7.87	2.69	9.37	0.3334	1.036	10.12	3.58	0.3727	0.992	39.4	65.4	+0.9	62.0	0.01613			0.050
108-1	"	"	11.0	50.5	12.8	7.87	2.09	9.19	0.3341	1.044	10.24	3.53	0.3735	0.993	39.5	60.3	+2.1	57.0	0.01754	0.01802	-2.7	0.024
-2	"	"	11.0	50.5	12.8	7.87	2.09	9.19	0.3341	1.044	10.24	3.53	0.3735	0.993	39.5	60.3	+2.0	57.0	0.01754			0.024
-3	"	"	11.0	50.5	12.8	7.86	2.09	9.19	0.3341	1.044	10.25	3.53	0.3735	0.993	39.5	60.3	+2.8	57.0	0.01754			0.024
109-1	"	"	11.4	51.7	10.3	7.86	1.70	9.08	0.3346	1.050	10.47	3.45	0.3750	0.993	40.3	58.1	+1.4	53.9	0.01855	0.01873	-1.0	0.014
-2	"	"	11.3	51.6	10.3	7.86	1.69	9.10	0.3345	1.050	10.43	3.46	0.3749	0.993	40.3	58.1	+1.4	53.9	0.01855			0.014
-3	"	"	11.4	51.5	10.2	7.87	1.68	9.08	0.3346	1.050	10.41	3.46	0.3747	0.993	40.1	57.7	+1.2	53.7	0.01862			0.014
110-1	"	"	12.8	53.0	6.2	7.88	1.07	8.71	0.3363	1.062	10.69	3.37	0.3766	0.994	40.2	49.1	+4.3	45.6	0.02193	0.02085	+5.2	0.004
-2	"	"	12.8	53.0	6.2	7.87	1.07	8.71	0.3363	1.062	10.68	3.37	0.3766	0.994	40.2	49.1	+4.3	45.6	0.02193			0.004
-3	"	"	12.8	53.0	6.2	7.87	1.07	8.71	0.3363	1.065	10.68	3.37	0.3766	0.994	40.2	48.6	+5.5	45.2	0.02212			0.004
111-1	"	Aroclor 1248	3.2	73.5	22.9	5.59	2.94	12.03	0.3244	1.052	0.554	125	0.0574	0.722	70.3	50.1	-3.8	26.6	0.03764	0.03779	-0.4	0.120
-2	"	"	3.2	73.5	22.3	5.59	2.87	12.03	0.3244	1.052	0.554	125	0.0574	0.716	70.3	48.9	-1.8	25.9	0.03856			0.113
-3	"	"	3.2	73.5	22.6	5.59	2.91	12.03	0.3244	1.052	0.554	125	0.0574	0.720	70.3	49.5	-3.0	26.2	0.03810			0.116
112-1	"	"	3.2	69.4	23.6	7.88	3.04	12.03	0.3244	1.056	0.671	147	0.0575	0.767	67.2	54.6	-4.0	30.3	0.03301	0.03296	+0.2	0.123
-2	"	"	3.2	69.3	23.3	7.88	3.00	12.03	0.3244	1.056	0.669	147	0.0575	0.762	67.1	53.9	-3.7	29.9	0.03339			0.126
-3	"	"	3.2	69.3	23.4	7.88	3.01	12.03	0.3244	1.056	0.669	147	0.0575	0.762	67.1	53.7	-4.1	29.8	0.03351			0.127
113-1	"	"	3.0	66.5	23.1	9.63	2.96	12.12	0.3241	1.056	0.723	166	0.0576	0.781	63.5	55.1	-2.5	32.3	0.03091	0.03111	-0.6	0.123
-2	"	"	3.0	66.5	23.1	9.63	2.96	12.12	0.3241	1.056	0.723	166	0.0576	0.780	63.5	54.9	-2.9	32.2	0.03103			0.124
-3	"	"	3.0	66.4	23.4	9.63	3.00	12.12	0.3241	1.056	0.719	167	0.0576	0.781	63.4	54.8	-2.6	32.2	0.03104			0.127
114-1	"	"	3.0	67.3	23.1	8.64	2.96	12.12	0.3241	1.056	0.669	160	0.0576	0.769	64.3	53.7	-3.2	31.1	0.03212	0.03244	-1.0	0.124
-2	"	"	3.0	67.2	23.4	8.64	3.00	12.12	0.3241	1.056	0.667	161	0.0576	0.772	64.2	54.4	-4.4	31.6	0.03166			0.127
-3	"	"	3.0	67.2	23.5	8.64	3.01	12.12	0.3241	1.056	0.667	161	0.0576	0.772	64.2	54.0	-3.7	31.4	0.03189			0.128

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TABLE VII (cont'd.)

Run Number	Jacket Fluid	Process Fluid	T_J °C.	T_P °C.	Q_t K.P.H.	n Rev./hr.	$\frac{Q}{u_J}$ ft.	$(N_{Pr})_J$	k_J Btu/hr.ft.°F	$(\frac{\mu_J}{\mu_W})^{0.14}$	$\frac{k}{u} \times 10^{-6}$	$(N_{Pr})_P$	k_P Btu/hr.ft.°F	$(\frac{\mu_P}{\mu_W})^{0.14}$	ΔT_o °C.	Q Btu/hr.	Heat Bal. Error %	Exp. Btu/hr.ft²°F	$\frac{1}{(U_o)}$ Exp. Hr.ft²°F/Btu	$\frac{1}{(U_o)}$ Calc. Hr.ft²°F/Btu	Cal. U_o Error %	F hp
115-1	water	Aroclor 1248	3.0	70.3	23.4	6.84	3.00	12.12	0.3241	1.054	0.603	141	0.0575	0.745	67.3	52.0	-3.8	28.8	0.03472	0.03059	-1.0	0.127
-2	"	"	3.0	70.2	23.4	6.84	3.00	12.12	0.3241	1.054	0.601	142	0.0575	0.746	67.2	51.8	-3.9	28.7	0.03479			0.127
-3	"	"	3.0	70.2	23.4	6.84	3.00	12.12	0.3241	1.054	0.601	142	0.0575	0.743	67.2	51.6	-4.1	28.6	0.03494			0.127
116-1	Aroclor 1248	"	124.8	78.7	8.22	8.99	1.54	33.2	0.0549	0.916	1.059	106.8	0.0560	1.042	46.1	26.8	-1.8	21.7	0.0461	0.04274	+7.9	
-2	"	"	124.8	78.6	8.22	8.99	1.54	33.2	0.0549	0.917	1.054	107.2	0.0560	1.047	46.2	27.5	+1.1	22.2	0.0451			
-3	"	"	124.8	78.1	8.14	8.99	1.52	33.2	0.0549	0.914	1.058	109.0	0.0560	1.047	46.7	27.1	-1.8	21.6	0.0462			
117-1	"	"	129.6	76.4	5.39	8.99	1.13	29.8	0.0548	0.885	0.978	115.5	0.0560	1.044	53.2	24.3	+3.7	17.0	0.0587	0.05032	+16.6	
-2	"	"	129.7	76.6	5.41	8.99	1.14	29.7	0.0548	0.885	0.983	114.8	0.0560	1.043	53.1	23.8	+6.7	16.7	0.0598			
-3	"	"	129.8	76.8	5.39	8.99	1.13	29.7	0.0548	0.886	0.992	114.0	0.0560	1.043	53.0	23.9	+7.9	16.8	0.0595			
118-1	"	"	138.8	74.3	2.55	8.99	0.597	26.6	0.0547	0.860	0.907	124.2	0.0561	1.043	54.5	22.8	+0.9	15.6	0.0641	0.07054	-9.1	
-2	"	"	139.2	74.4	2.55	8.99	0.600	26.6	0.0547	0.858	0.911	123.7	0.0561	1.042	54.8	21.9	+7.3	14.9	0.0671			
-3	"	"	139.3	74.7	2.55	8.99	0.600	26.6	0.0547	0.854	0.921	122.5	0.0561	1.038	54.6	20.3	+17.8	13.9	0.0722			
119-1	"	"	136.6	75.9	3.83	8.99	0.883	27.0	0.0547	0.876	0.957	117.6	0.0560	1.048	50.7	25.8	+5.0	19.0	0.0527	0.05780	-8.8	
-2	"	"	136.6	75.9	3.84	8.99	0.885	27.0	0.0547	0.876	0.957	117.6	0.0560	1.047	50.7	25.7	+4.7	18.9	0.0529			
-3	"	"	136.4	75.9	3.84	8.99	0.888	27.0	0.0547	0.876	0.957	117.6	0.0560	1.047	50.5	25.6	+3.5	18.9	0.0529			
120-1	"	"	129.4	78.6	6.74	8.99	1.40	30.0	0.0548	0.906	1.054	107.2	0.0560	1.050	50.8	28.7	+1.0	21.1	0.0475	0.04546	+4.5	
-2	"	"	129.2	78.5	6.74	8.99	1.40	30.1	0.0548	0.906	1.054	107.5	0.0560	1.049	50.7	28.8	+1.9	21.2	0.0472			
-3	"	"	128.8	78.4	6.74	8.99	1.39	30.3	0.0549	0.906	1.048	107.9	0.0560	1.048	50.4	28.3	-4.6	20.9	0.0478			

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TABLE VIII

Process Side Film Heat Transfer Coefficient Runs

Run No.	Process Fluid	Jacket Fluid	U_o Btu/hr.ft²°F	$\frac{1}{U_o}$	T_p °F	n Rev./min.	$(N_{Re})_p^{0.8}$	$(N_{Pr})_p$	$(\frac{u_p}{u_F})^{0.14}$	$\frac{D_p}{k_p}(N_{Re})_p^{-2/3}(N_{Pr})_p^{-1/3}(\frac{u_p}{u_F})^{-0.14}$ hr.ft²°F/Btu
A-1	water	water	67.5	0.0148	95	131.0	77.5	4.92	1.021	0.824
A-2	"	"	66.9	0.0149	95	105.0	62.1	4.92	1.022	0.962
A-3	"	"	65.0	0.0154	113	63.0	45.0	3.97	1.019	1.244
A-4	"	"	64.7	0.0154	114	64.8	46.2	3.94	1.020	1.228
A-5	"	"	70.7	0.0141	126	146.4	117.0	3.49	1.009	0.696
A-6	"	"	69.0	0.0145	127	107.1	86.0	3.45	1.009	0.846
A-7	"	"	66.1	0.0151	126	64.3	51.4	3.49	1.012	1.182
A-8	Process oil #5	steam	36.1	0.0277	165	65.7	4.42	82.5	1.043	9.52
A-9	"	"	40.0	0.0250	168	85.0	6.01	78.8	1.033	7.80
A-10	"	"	46.3	0.0216	171	107.1	7.82	75.6	1.028	6.80
A-11	"	"	50.1	0.0200	172	145.0	10.75	74.4	1.023	5.54
A-12	"	"	47.5	0.0210	170	107.1	7.68	77.5	1.028	6.84
A-13	"	"	41.3	0.0242	167	84.3	5.86	80.0	1.034	8.04
A-14	"	"	35.6	0.0281	163	65.7	4.35	83.8	1.043	9.54
A-15	"	"	50.3	0.0199	172	145.0	10.75	74.4	1.023	5.54

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The data tabulated in Table VIII were obtained using procedures similar to those outlined in the Experimental Procedure section of this report using S-1164, a fifty gallon series "P" glass-lined Pfaudler reactor equipped with a three blade impeller, thermowell, and a two finger baffle inserted to maximum depth. The calculations were carried out in the manner outlined in this report except that the heat transfer area was considered to be 16.4 ft^2. The following least squares correlations were obtained for this data:

Runs A-1 to A-7

$$\frac{1}{U_o} = 1.286 + 0.203 \frac{D_p}{k_p} (N_{Re})_p^{-2/3} (N_{Pr})^{-1/3} (\frac{u_p}{u_F})^{-0.14}$$

Runs A-7 to A-15

$$\frac{1}{U_o} = 0.804 + 0.206 \frac{D_p}{k_p} (N_{Re})_p^{-2/3} (N_{Pr})_p^{-1/3} (\frac{u_p}{u_F})^{-0.14}$$

After subtracting the intercepts from the $\frac{1}{U_o}$ values the following plot was made.

$$(J_H)_p = 0.227 (N_{Re})_p^{2/3}$$

If this equation is corrected to the value of the heat transfer area used elsewhere in this report, the following results:

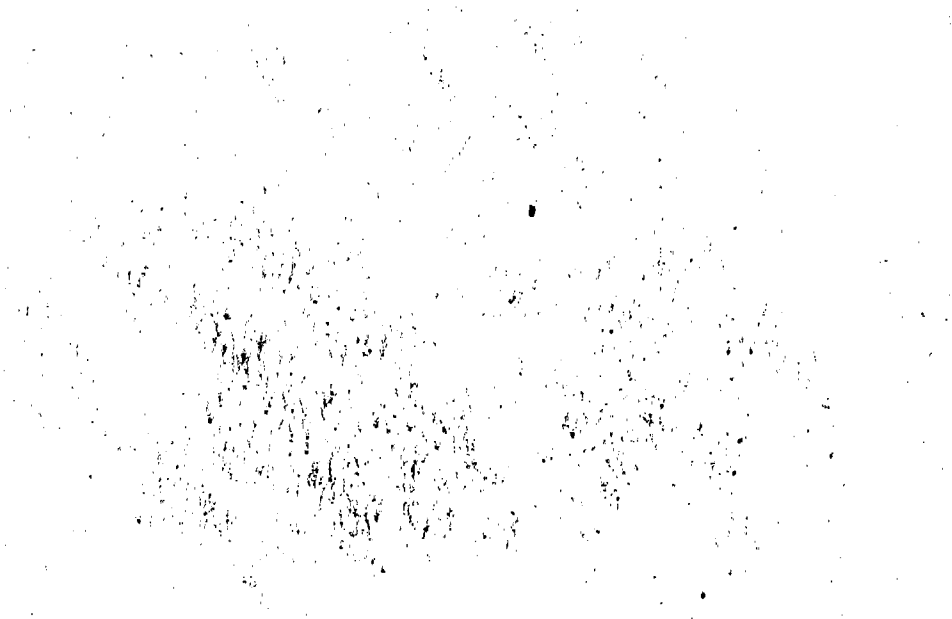
$$(J_H)_p = 0.250 (N_{Re})_p^{2/3}$$

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