



An investigation of the condensation region of a system consisting of steam injected into a column of flowing water

by Roger Edward Democh

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree  
MASTER OF SCIENCE in Chemical Engineering

Montana State University

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**Abstract:**

The heat transfer and related parameters of a direct contact steam-water condenser were investigated in this study. In the steam-water system, steam was injected directly into flowing water, whereupon bubble collapse and heat transfer took place. Knowledge of the phenomena taking place in the condensation region and of the volume in which condensation and heat transfer took place were the investigation goals.

Three approaches were used to investigate these phenomena: volumetric heat transfer coefficient calculations and comparisons, variable volume region analyses (volume in which heat transfer took place), and three-dimensional temperature analyses of the system.

The heat transfer by condensation in the condenser was found to be only one of the essential system variables. The mixing upon steam injection, coalescence of bubbles upon injection, and the turbulence caused by steam and water-flow rate stream interactions, were also found to be variables of paramount importance to the heat transfer process. Predictive trends upon all of these variables and the interactions between them were advanced.

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CONSISTING OF STEAM INJECTED INTO A COLUMN OF FLOWING WATER

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## TABLE OF NOMENCLATURE

|          |   |                                                                         |                     |
|----------|---|-------------------------------------------------------------------------|---------------------|
| $D$      | = | bubble diameter                                                         | ft                  |
| $g$      | = | gravitational force 32.2                                                | ft/sec <sup>2</sup> |
| $m$      | = | mass of the bubble                                                      | #                   |
| $m_x$    | = | Levenspiel's constant                                                   | sec <sup>-1</sup>   |
| $t_x$    | = | temperature difference (T water - T saturated steam)                    | °F                  |
| $u$      | = | bubble rise velocity with respect to the liquid                         | ft/sec              |
| $V$      | = | steam velocity                                                          | ft/sec              |
| $v$      | = | downward fluid velocity (recycle velocity)                              | ft/sec              |
| $w$      | = | mass of displaced liquid                                                | #                   |
| $x$      | = | vertical distance moved by bubble in relation to the tube wall          | ft                  |
| $y$      | = | vertical distance moved by collapsing bubble with respect to the liquid | ft                  |
| $\theta$ | = | time                                                                    | sec                 |
| $\rho$   | = | density of liquid                                                       | #/ft <sup>3</sup>   |
| $\rho_s$ | = | density of bubble                                                       | #/ft <sup>3</sup>   |

## ABSTRACT

The heat transfer and related parameters of a direct contact steam-water condenser were investigated in this study. In the steam-water system, steam was injected directly into flowing water, whereupon bubble collapse and heat transfer took place. Knowledge of the phenomena taking place in the condensation region and of the volume in which condensation and heat transfer took place were the investigation goals.

Three approaches were used to investigate these phenomena: volumetric heat transfer coefficient calculations and comparisons, variable volume region analyses (volume in which heat transfer took place), and three-dimensional temperature analyses of the system.

The heat transfer by condensation in the condenser was found to be only one of the essential system variables. The mixing upon steam injection, coalescence of bubbles upon injection, and the turbulence caused by steam and water flow rate stream interactions, were also found to be variables of paramount importance to the heat transfer process. Predictive trends upon all of these variables and the interactions between them were advanced.

## INTRODUCTION

Steam-water systems are found in a variety of industrial operations today. The idea of injecting steam into water in a direct contact process has been in use for many years. An example of such a process is a sparged steam distillation column. In such processes, there has been little specific study on the mechanism of the intimate heat transfer, mixing, and fluid dynamics of such systems. Specifically, the region of condensation of such processes has received little consideration.

In this study, a steam-water condenser was chosen for investigation. The study of the heat transfer that took place at the point of injection of the steam into flowing water was of particular interest. Also, a better understanding of this region of the condenser and the volume in which the condensation took place was desired.

Although no specific work has been done on this exact system, certain aspects of the system have been treated by other experimenters.

Sidesman, et al., (7) was one of the most important contributors to the knowledge of direct contact heat transfer with change of phase. He is one of the few experimenters to make his studies using a volumetric heat transfer coefficient similarly defined to the one used in this study. Although his system involved the injection of liquid pentane into water (where the pentane was evaporated), he presented information indicating that sufficient coalescence in bubble injection can eliminate the effect of initial bubble diameter on the heat transfer coefficient. Since the

steam in this study was injected into the condenser at high flow rates, coalescence was obviously taking place. This factor must then be taken into account when evaluating the system parameters.

Levenspiel (6), in his work on the collapse of steam bubbles, has presented an empirical relationship for determining the bubble collapse in a steam-water system. Although his study was concerned with single bubbles, this expression was useful for determining bubble life in both the analog computer simulation and in describing the high density bubble region found in the system.

Florschuetz and Chao (2) have proposed a mechanism for vapor bubble collapse. They found that the mechanism of collapse could be divided into the following categories: 1) where the mechanism for collapse is controlled by liquid inertia; 2) where the controlling mechanism is heat transfer from the bubble to the liquid; and 3) an intermediate case where both effects are of comparable importance. Also, they discussed the effects of bouyant forces on bubbles in a normal gravitational field. They found that these forces gave rise to appreciable translational velocities. A consequence of these velocities was to enhance heat transfer and thus, collapse rate. Although their study was made under conditions of zero gravity upon single bubbles or chains of single bubbles, it presented a very thorough background in the steam-water area.

Krevelen and Hoftijzer (4) also have done related work on single bubbles and chains of single bubbles. The aspects of their experimental

correlation, which concerned Reynolds Number and critical flow rate in terms of a theoretical bubble diameter, were very helpful in this study. These correlations were used in calculation of heat transfer coefficients and in the analog computer simulation.

An annotated bibliography by Kepple and Tung (3) was used to obtain background material for this work. Although very extensive, little work was found related to this investigation.

Articles by Westwater (1) and Lackey (5) as well as a text by Tong (8) were also consulted for related ideas. Again, no specific information relating to this study was found.

The study of the various phenomena taking place in the intimate steam-water region was carried out by several methods. First, the volumetric heat transfer coefficient for the system was determined. Then these coefficients were compared to one another with functions such as steam and recycle flow rates. This was done to describe basically the system and determine its important variables.

In the second method of investigation, the volume in which the heat transfer took place was studied. This was necessary in order to obtain a more detailed view of the heat transfer taking place and to ascertain what parameters were most influential in this region. An analog computer simulation of the system was compared to the experimental volume regions to aid in the identification of these parameters.

The final method of investigation was to make an analysis of the system in terms of three-dimensional temperature profiles. Experimentally, this was accomplished by using a "point" thermocouple. This was done for all the steam addition methods. These profiles were analyzed in terms of observed regions in order to verify the important parameters of the system.

This study was accomplished by use of the equipment described in the Apparatus and Procedure section.

## APPARATUS AND PROCEDURE

A detailed drawing of the condenser, a flow diagram of the entire system, and sketches of the four steam additions used in this system, are found in Figures 1, 2, and 3, respectively.

A clear plastic 3-11/16-inch tube was used as the condenser for this experiment. Recycle water entered the top of the condenser from the constant head tank, flowed through the condenser vertically downward, and out the bottom of the condenser to the recycle pump. Thermocouple wells, consisting of 1/16-inch Swagelok fittings containing rubber septums, were installed on each side of the condenser 180° apart. They were staggered vertically above and below the steam inlet so that readings could be taken at one-half inch intervals. Figure 1 shows a detailed sketch of the location of these wells. Thermocouples used in these wells were Honeywell Thermocouples, Type 231M13P12-5. These thermocouples were 1/16-inch, stainless steel sheaved, iron-constantan type, giving average readings over approximately one inch of metal. In the latter part of the study these commercial thermocouples were replaced by "point" thermocouples. These "point" thermocouples gave more precise readings because they gave a reading from a small bead of metal. The "point" thermocouples were constructed by fusing the end of a piece of iron-constantan thermocouple wire and sealing the lead wire in a 1/16-inch tube.

Steam was injected into the condenser 24.5 inches from the bottom of the four-foot condenser through a 1/4-inch Swagelok fitting. Copper tubing (1/4-inch) connected the Swagelok to a 1/2-inch pipe line. There

were also a 30 psi Bourdon gage, a 3/16-inch orifice, and a 1/2-inch needle valve located on this steam line. Steam was added by four methods: steam initially injected directly into the stream perpendicular to the water flow ( $90^\circ$ ), steam directed upward into the flow ( $51^\circ$ ), steam directed downward into flow ( $129^\circ$ ), and steam directed countercurrently into water flow. (Angles stated are those subtended by initial steam direction from vertical wall.) Figure 3 shows sketches of the various steam addition methods used in this study.

A thirty-gallon mixing tank was located above the condenser in order to prevent channeling and changes in inlet temperature. A five-gallon constant head tank was attached to the top of the condenser to allow uniform flow into the condenser. Flow between the mixing tank and constant head tank was accomplished by gravitational flow through a submerged 1-1/4-inch pipe. A 1-1/4-inch pipe was attached to the lower part of the condenser to carry water to the pump. Approximately 3/4-foot of rubber tubing was used in this pipe section to isolate the condenser from pump vibrations. A specific diagram of the condenser and a flow diagram of the process appear in Figures 1 and 2, respectively.

After passing through the pump, water was recycled into the mixing tank. A 5/8-inch orifice was located in this line to measure flow rate. A fresh water line, beginning at a constant head tank and containing a 1/4-inch orifice, was joined into a tee connecting the fresh water line to the recycle line.

Overflow drains (3/4-inch) were provided on all tanks and pressure taps were installed on all major lines. The orifices on the steam, recycle, and fresh water lines were calibrated using a weigh tank and liquid in glass manometers.

An iron-constantan thermocouple system was employed in this study. Stationary thermocouples were placed at the inlet and exit of the condenser as well as in the steam line.

A Brown Potentiometer Pyrometer (Model No. 156Xk5-P), self-balancing type, was used to obtain temperature measurements. (Repeatability of readings was to within 0.1°F).

Epoxy resin was used to seal all metal to plastic surfaces of the construction.

In first preparing the system for operation, the mixing tank was filled with hot water at a temperature higher than the desired operating temperature. The valve on the line connecting the mixing and constant head tank was opened and the recycle pump was started. The system was allowed to run until flow rate control valves could be adjusted to cause steady state operation. During this operation the recycle rate desired must be set.

When steady state was reached the steam line valve and the fresh water valve were opened. At this time the mixer in the mixing tank had to be started to prevent channeling of recycle and fresh water back into

the system. Then the fresh water was adjusted so that the inlet temperature into the condenser remained constant. Once the steady state was reached, operating conditions were recorded and temperature readings at various wells were taken.

If other conditions were desired, steam and fresh water rates were changed and the same procedure was repeated.

## INVESTIGATION AND RESULTS

Since the data of this investigation is very helpful in understanding this discussion, a brief description of the tables in this study follows. Tables I-XXIV give the temperature readings in the condenser at their vertical location, fresh water rates, steam flow rates, inlet and exit temperatures, and estimated transfer region heights for each run. At the top of these tables steam addition method and recycle rate are given to categorize the runs for the reader. Tables XXV-XXVIII give volumetric heat transfer coefficients for the runs of the previous Tables I-XXIV. Steam addition method, temperature operating range, recycle rate, and steam flow rate are also given to acquaint the reader with location of original data. Tables XXIV-XXXIV indicate the height of the volumetric transfer region above and below the steam injection point. Height of overall transfer region, steam flow rate, and recycle rate also appear in these Tables XXIX-XXXIV. Steam injection method and operating temperature ranges are given at the top of these tables. Reynolds numbers for the recycle rate (liquid phase through condenser) ranged from 35 to 350.

The initial objective of the investigation was to determine the volumetric heat transfer coefficients of the system. The equipment was designed to study this parameter.

The volume in which the heat transfer took place was determined from temperature profiles. Thermocouple readings at the various "wells" were used to obtain these temperature profiles. The end limits of the volumes were chosen to be temperatures which were equal with little fluc-

tuation, to the inlet and exit temperatures of the condenser. Observations of the system (with respect to turbulence and bubble movement) were used to determine where the temperature changes ceased. Temperature readings were taken at the center of the condenser (assumed to be constant across the condenser) in this part of the investigation and in the following volume study.

The temperature driving force of the condenser ( $\Delta T$ ) was chosen as the arithmetic mean of the saturated steam temperature upon entry into the condenser at 204°F (which is the boiling point at this elevation) less the inlet and exit temperatures of the condenser.

$$\Delta T = \frac{(204 - T_{\text{exit}}) + (204 - T_{\text{inlet}})}{2}$$

The amount of heat added to the system ( $Q_S$ ) was the latent heat of vaporization (at 204°F) times the steam flow rate. Sensible heat effects, as reasoned by Levenspiel in a similar application, were ignored here because of their small effects (1%).

Using the above experimental values, the volumetric heat transfer coefficient was calculated with the following relationship:

$$h_v = \frac{Q_S}{\Delta T \cdot V} \quad (\text{BTU/ft}^3 \text{ sec } ^\circ\text{F})$$

The results of these calculations for the 90° steam addition are shown in Table XXV. The initial data and operation conditions for all these runs are found in Tables I-XII.

In Table XXV ( $1.965 \times 10^{-3}$  ft/sec recycle rate, operating temperature 165°-170°F) certain increases in magnitude of the volumetric heat transfer coefficient are found that could not be accounted for in terms of heat addition. In this case, values as large as 44 BTU/sec °F ft<sup>3</sup> were found where readings averaged between 7-12 BTU/sec °F ft<sup>3</sup>. These increases varied with steam rate and high values were found in mid-range steam flow rates. They did not correlate with steam rate increases. These volumetric heat transfer increases or variable volume decreases appeared at the above conditions in all runs performed in this study. It was these increases that prevented any predictive correlation between volumetric heat transfer coefficient and system parameters (such as system flow rates).

In Figure 9, a plot of the volumetric heat transfer coefficient ( $h_v$ ) versus recycle rate is given for the operating temperature range of 165°-170°F. Inconsistencies are illustrated in the volumetric heat transfer coefficients for increasing steam rates, as well as increasing magnitude for the recycle rate of  $1.965 \times 10^{-3}$  ft/sec.

It was then decided that parameters considered in the above approach were not the only major contributing factors to the system; therefore, a different approach was necessary. A study of the variable volume itself

was indicated. Since the heat added ( $Q_S$ ) and the driving force ( $\Delta T$ ) were values with little change in the previous calculations, there was reason to assume that the volume study would lead to a discovery of the additional parameters of the system. In an effort to differentiate between system characteristics and steam addition affects in the volume region, different steam addition methods were employed. These methods included steam injected upward at an angle of  $51^\circ$  into the stream, steam injected downward at an angle of  $129^\circ$  with the stream, and steam injected into the center of the condenser countercurrent to the stream. The results of these methods appear in Tables XIII-XXIV. Figure 3 shows these different steam addition methods. Tables XXVI-XXVIII give sample heat transfer coefficients of these runs. (Since it was seen that correlations were not possible in connection with volumetric heat transfer coefficients, the calculations on the later runs are given for every other data point.) Data from all the runs, analyzed in terms of volume regions with reference to steam injection point, appears in Tables XXIX-XXXIV.

In all the methods except the countercurrent addition method, the volume was found to decrease at the  $1.965 \times 10^{-3}$  ft/sec recycle rate. In the countercurrent addition method, the beginning of a region leading to volume decrease could be seen but at different operating conditions. The first two points of Table XXXIV show these points. This difference in conditions of volume decrease was due to a difference in steam flow rate. The countercurrent method had significantly less steam quantity than the others.

Tables XXIX-XXXIV also show that the entire volume region moved about the steam injection point, i.e.,  $1.965 \times 10^{-3}$  ft/sec recycle rate, Table XXX. At the conditions of most severe volume decrease, i.e.,  $1.965 \times 10^{-3}$  ft/sec recycle rate, Table XXIX, the volume region seemed to decrease convergently upon the injection point. In all systems it was found, as expected, that at low recycle rate and higher steam rates the volume region was somewhat above the injection point. At high recycle rates the volume region was lowered, except for the highest steam rate.

Since it was then established that other variables were affecting the system, an analog computer simulation was employed in order to better determine these variables.

It was thought that upon emergence into the stream, a bubble would begin collapsing. After a certain period of rising, the bubble would decrease to a point where the superimposed recycle velocity would sweep the bubble downward accounting for temperature changes below the steam inlet. Thus the bubble would rise initially when large, then would be forced downward after a certain amount of collapse. By predicting collapse rate and superimposing the recycle velocity upon bubble collapse mechanism, temperature profiles could be obtained to compare to experimental values.

The following theoretical treatment was used to simulate the system for the collapse of a bubble in a liquid:

1. For a steam bubble in a stagnant liquid, the following force balance was used:

$$m \frac{du}{d\theta} = (m-w) g - \text{drag force} \quad (1)$$

2. From the work of Krevelen and Hoftijzer, the drag force was determined as:

$$\frac{\text{drag force}}{m} = \frac{9 \rho u^2}{8 \rho_s D}$$

Substituting into equation (1) gives:

$$\frac{du}{d\theta} = -g(1 - \rho/\rho_s) - \frac{9 \rho u^2}{8 \rho_s D} \quad (2)$$

3. For a collapsing steam bubble, Levenspiel (6) indicated that:

$$\frac{d(\ln D)}{d\theta} = m_x^{-1} = 7.08 t_x (\text{sec}^{-1})$$

$$\frac{dD}{D} = 7.08 t_x d\theta$$

$$\int_{D_0}^D \frac{dD}{D} = 7.08 t_x \int_0^\theta d\theta$$

$$\ln \frac{D}{D_0} = 7.08 t_x \theta$$

$$D = D_0 e^{7.08 t_x \theta}$$

Substituting into equations (2) gives:

$$\frac{du}{d\theta} = -g(1 - \rho/\rho_s) - \frac{9}{8} \rho u^2 / \rho_s D_0 e^{7.08 t_x \theta} \quad (3)$$

Where  $D_o$  is given by Krevelen and Hoftijzer (4) as:

$$D_o = \left( \frac{72V^2 \rho}{\pi^2 g \Delta \rho} \right)^{1/5}$$

But  $u = dy/d\theta$

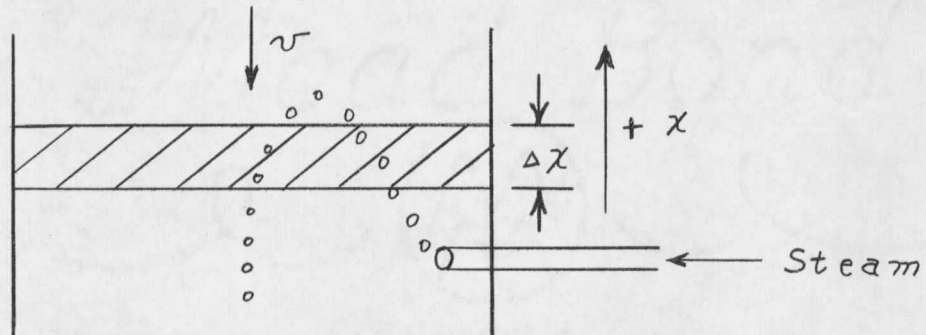
$$\therefore \frac{d^2 y}{d\theta^2} = g(\rho/\rho_s - 1) - \frac{9}{8} \frac{\rho (dy/d\theta)^2}{\rho_s D_o e^{7.08 t_x \theta}} \quad (4)$$

Initial conditions  $\theta = 0$

$y = 0$

$$\frac{dy}{d\theta} = v$$

4. However, the system studied in this investigation was a flowing medium; therefore, to translate bubble position:



$$x = y - v\theta \quad (5)$$

Using equations (4) and (5), bubble displacement can be calculated. In the development of these equations the value of the recycle flow rate has been superimposed upon the equations for a collapsing bubble. These collapsing bubble equations were developed in a stagnant liquid. This was done to simplify the development so it could be programmed.

Once the system was programmed on the analog computer and bubble displacement was calculated with respect to distance and time, it became obvious that the development was not adequately describing the system. The theory gave a calculated bubble displacement of only  $3/10$  of an inch at experimental conditions which gave maximum volume region; however, experimental data indicated temperature changes as far as eleven inches from the injection point.

From the results of the analog computer simulation, it was surmised that the heat transfer problem was only one of several contributing factors to the system. The effects of the coalescence and turbulence caused by the steam injection, and of the interaction of steam and recycled water streams at higher flow rates were now concluded to be of equal importance to the heat transfer problem.

Since it was now verified that these other factors were present, a more intricate analysis of the system was needed. A simple thermocouple, made of iron-constantan thermocouple wire fused at one end and sealed into a very small tubing, was used to obtain the temperature readings necessary for this probe. With this "point" thermocouple, a horizontal and vertical

three-dimensional probe of any steam addition method could be obtained.

The results of these probes, as well as dimensioned sketches of these systems made during operation, are found in Figures 4-7. Results of a probe on the  $1.965 \times 10^{-3}$  ft/sec recycle rate run (the condition at which volume decreased in earlier cases) are found in Figure 8. In Figures 4-8, data for each system is given in terms of distance across the condenser at the actual positions where readings were recorded.

In all of the above probes, the previous volume regions were shown to consist of several smaller regions. A high temperature high bubble population region was always found protruding into the stream at the steam injection point. This region was least affected by mixing and turbulence and seemed dependent only upon steam flow rate. Observations on this region during runs substantiated the above analysis. Surrounding this region an intermediate temperature and bubble population region was recorded. This region was distorted by the various mixing and turbulence situations and altered in magnitude and direction upon steam flow rate changes. This region was observed to contain an intermediate bubble population and was influenced by steam rate magnitude through bubble population. In the larger magnitude steam flow rate additions, turbulent mixing regions above and/or below the intermediate region were recorded. These disturbances diminished at lower steam rates or when optimum conditions were reached between steam and recycle streams. In these regions bubbles were generally absent. They were strictly caused by stream interactions.

In the countercurrent method, a small cone was found to exist. This was a very high temperature region and from observation it was found to be a high bubble population region. Above and surrounding this cone was a second region. Above this second region a turbulent mixing zone was found lying across the entire condenser. Below the steam injection point, little temperature change was found. Horizontally, two zones were noted approaching the center. Results and a sketch of this system are found in Figure 4.

In the probe of the system in which steam was injected at an angle of  $51^\circ$ , similar shapes and zones were found. A larger high temperature and bubble population region was found. It was directed upward into the flow. Surrounding this was the second region extending out and up into the tube. It was deformed slightly due to recycle flow rate. Around and above this second region, turbulent mixing existed. Again, below the injection point little temperature change was found. Two similar horizontal regions existed approaching the center. Results and a sketch of this system are found in Figure 5.

In the probe of the system in which steam was injected at an angle of  $129^\circ$ , similar shapes and zones were again observed. In this system, very little temperature change or turbulence was found above the steam injection point. However, below the injection point, a larger amount of turbulent mixing was recorded. These differences were probably due to cocurrent rather than countercurrent steam addition methods. This would tend to carry the condensation region and volume region downward. Also, a high tempera-

ture region, surrounded by a larger irregular shaped intermediate temperature region, was recorded. Turbulence and temperature fluctuations were recorded up to ten inches below the steam injection point. Two horizontal regions were found to exist approaching the center of the condenser. Results and a sketch of this system are found in Figure 6.

In the straight steam addition system (steam injected at an angle of  $90^\circ$ ) the greatest amount of turbulent mixing was observed. The high temperature high bubble population region also existed further across the condenser. The intermediate temperature and bubble region existed above, below, and around the high temperature core. Turbulent regions were found surrounding the intermediate region. They were much larger than previous regions of this type. Results and a sketch of this system appear in Figure 7.

In the probe of the  $1.965 \times 10^{-3}$  ft/sec recycle rate system (Table III), where volume decrease (or volumetric heat transfer increases) had previously appeared, significant differences were found. The turbulence, mixing, and temperature fluctuations were found to exist in a much smaller region than in previous studies. In fact, significantly smaller amount of turbulence and temperature fluctuations were found. From the data and observations found in Figure 8, it was concluded that the reasons for these irregularities must have been due to the relationship between steam and recycle flow rates. At the conditions of the run (Table III) these flow rates were the proper values to cause the least amount of interaction.

From the volumetric heat transfer coefficient study, it was apparent that the coefficient was not representative of the phenomena taking place. From the analog computer study, the heat transfer process approximation (based upon a bubble collapse mechanism) pointed out the fact that mixing, coalescence, and turbulence were essential factors to be considered. The variable volume and temperature probe studies showed the relationship of these mixing and turbulence parameters and their effect upon the system.

From this discussion and the data, it was apparent that the mixing process, which was involved in the condensation region, was a significant system parameter. Due to this mixing problem, the mechanism of heat transfer in the condensation region could not be analyzed completely.

## CONCLUSION

The volumetric heat transfer coefficient and analog computer studies indicated that the heat transfer process was not the only parameter of the system and that other variables were involved. Also, the analog study indicated that the simple bubble collapse mechanism used was not sufficient to take into account the factors caused by the coalescence of the steam jet.

From use of the different steam addition methods, it was learned that the mixing and turbulence of the system were affected by the steam introduction method. The relationship between steam and recycle flow rates was also found to affect mixing and turbulence in the variable volume analysis. An optimum relation between these flow rates was found to exist at the  $1.965 \times 10^{-3}$  ft/sec recycle rate (90° system, optimum temperature 165-175°F), where the volume of heat transfer was minimized with the same amount of heat addition as previously stated.

Probes of the systems indicated that the previous variable volume region, in which heat transfer took place, consisted of several smaller regions. A high temperature high bubble population region was the first of these. It was the region least affected by mixing and turbulence. Surrounding this, an intermediate bubble population region was recorded. It was this region that was most affected by the mixing and turbulence. The shape and size of this region indicated the prominence of these mixing and turbulence variables for a given case. Turbulent zones surrounding this intermediate region were found to indicate the amount of turbulence and mixing problems under specific operation conditions. No bubbles were found in this latter region.

## RECOMMENDATIONS

The construction of a more durable apparatus is one way in which this study could be advanced. This would permit higher temperatures in the recycle stream and use of hot water in place of steam when necessary. In this way the volumetric heat transfer coefficient would better represent the system and the effects of the mixing process could be separated. An example of a more durable apparatus could be a metal conduit with glass port holes at the condensation point.

Better temperature measurements through use of a better potentiometer could also aid in a probe of the system. Oscilloscope use on temperature fluctuations might be helpful in determining predictive equations for the system.

Photographs of the bubble regions would aid in determining a better mechanism for bubble collapse. This, in turn, would aid predictive efforts in describing the mixing and heat transfer processes.

Table I. Temperature Profiles and Operating Conditions at  $7.2 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ . (See Figure 1 for Nomenclature of this Table).

|                                                    |           |           |          |          |          |       |
|----------------------------------------------------|-----------|-----------|----------|----------|----------|-------|
| Fresh Water<br>Rate (#/hr.)                        |           | 14.4      | 43.1     | 86.4     | 115.1    | 144.0 |
| Steam Flow<br>Rate (#/hr.)                         |           | 52.5      | 62.5     | 77.5     | 92.5     | 115.0 |
| Inlet Temp.<br>(°F.)                               |           | 166.0     | 164.4    | 164.5    | 164.5    | 162.5 |
| Exit Temp.<br>(°F.)                                |           | 167.2     | 166.0    | 167.0    | 167.0    | 165.5 |
| Estimated<br>Height of<br>Transfer<br>Region (in.) |           | 9.5       | 8.5      | 11.5     | 11.5     | 11.5  |
| RU 13                                              |           |           |          |          |          |       |
| LU 12                                              |           |           |          |          |          |       |
| RU 11                                              |           |           |          |          |          |       |
| LU 10                                              |           |           |          |          |          |       |
| RU 9                                               |           |           |          |          |          |       |
| LU 8                                               |           |           |          |          |          |       |
| RU 7                                               | 166°F.    | 164.4°F.  | 164.5°F. | 164.5°F. | 162.5°F. |       |
| LU 6                                               |           |           |          |          |          |       |
| RU 5                                               |           |           |          |          |          |       |
| LU 4                                               | 166°F.    | 164.4°F.  | 164.5°F. | 164.5°F. | 162.5°F. |       |
| RU 3                                               | 166°F.    | 164.4°F.  | 164.5°F. | 164.6°F. | 162.5°F. |       |
| LU 2                                               | 166°F.    | 164.4°F.  | 164.5°F. | 164.5°F. | 162.5°F. |       |
| RU 1                                               | 166.1°F.  | 164.7°F.  | 165.0°F. | 165.0°F. | 163.0°F. |       |
| Zero                                               |           |           |          |          |          |       |
| RD 1                                               | 168.1°F.  | 166.7°F.  | 167.2°F. | 167.3°F. | 165.6°F. |       |
| LD 2                                               | 167.3°F.  | 166.3°F.  | 166.9°F. | 167.0°F. | 166.0°F. |       |
| RD 3                                               | 167.2°F.  | 166.2°F.  | 166.3°F. | 166.8°F. | 165.0°F. |       |
| LD 4                                               | 167.4°F.  | 166.15°F. | 166.5°F. | 166.8°F. | 165.1°F. |       |
| RD 5                                               | 167.1°F.  | 166.1°F.  | 166.5°F. | 166.6°F. | 165.2°F. |       |
| LD 6                                               | 167.3°F.  | 166.0°F.  | 166.5°F. | 166.8°F. | 165.3°F. |       |
| RD 7                                               | 167.1°F.  | 166.0°F.  | 166.6°F. | 166.8°F. | 165.0°F. |       |
| LD 8                                               | 167.2°F.  | 166.0°F.  | 166.9°F. | 166.9°F. | 165.4°F. |       |
| RD 9                                               | 167.25°F. | 166.0°F.  | 166.9°F. | 166.9°F. | 165.2°F. |       |
| LD 10                                              | 167.2°F.  | 166.0°F.  | 167.0°F. | 167.0°F. | 165.5°F. |       |
| RD 11                                              | 167.2°F.  | 166.0°F.  | 167.0°F. | 167.0°F. | 165.5°F. |       |

Table II. Temperature Profiles and Operating Conditions at  $4.59 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |          |         |         |         |         |
|----------------------------------------------------|----------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr.)                        | 28.8     | 57.6    | 86.5    | 115.1   | 158.2   |
| Steam Flow<br>Rate (#/hr.)                         | 52.5     | 62.5    | 77.5    | 91.8    | 115.0   |
| Inlet Temp.<br>(°F)                                | 164.0    | 165.5   | 164.0   | 164.0   | 163.9   |
| Exit Temp.<br>(°F)                                 | 165.45   | 168.0   | 167.0   | 167.0   | 167.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 9.5      | 11.5    | 11.5    | 4.0     | 5.5     |
| RU 13                                              |          |         |         |         |         |
| RU 12                                              |          |         |         |         |         |
| RU 11                                              |          |         |         |         |         |
| LU 10                                              |          |         |         |         |         |
| RU 9                                               |          |         |         |         |         |
| LU 8                                               |          |         |         |         |         |
| RU 7                                               | 164.0°F  | 165.5°F | 164.0°F | 164.0°F | 163.9°F |
| LU 6                                               |          |         |         |         |         |
| RU 5                                               |          |         |         |         |         |
| LU 4                                               | 164.0°F  | 165.5°F | 164.0°F | 164.0°F | 163.9°F |
| RU 3                                               | 164.0°F  | 165.5°F | 164.0°F | 164.0°F | 163.9°F |
| LU 2                                               | 164.0°F  | 165.5°F | 164.0°F | 164.0°F | 163.9°F |
| RU 1                                               | 164.1°F  | 166.0°F | 164.6°F | 164.8°F | 164.5°F |
| Zero                                               |          |         |         |         |         |
| RD 1                                               | 166.6°F  | 168.1°F | 167.0°F | 167.3°F | 168.2°F |
| LD 2                                               | 165.2°F  | 168.0°F | 166.8°F | 167.1°F | 167.5°F |
| RD 3                                               | 165.1°F  | 167.8°F | 166.9°F | 167.0°F | 166.9°F |
| LD 4                                               | 165.0°F  | 167.5°F | 166.7°F | 167.0°F | 167.0°F |
| RD 5                                               | 165.16°F | 167.8°F | 166.8°F | 167.0°F | 167.0°F |
| LD 6                                               | 165.15°F | 167.5°F | 166.7°F | 167.0°F | 167.0°F |
| RD 7                                               | 165.2°F  | 167.6°F | 166.9°F | 167.0°F | 167.0°F |
| LD 8                                               | 165.45°F | 167.7°F | 166.9°F | 167.0°F | 167.0°F |
| RD 9                                               | 165.45°F | 167.7°F | 166.9°F | 167.0°F | 167.0°F |
| LD 10                                              | 165.45°F | 168.0°F | 167.0°F | 167.0°F |         |
| RD 11                                              | 165.45°F | 168.0°F | 167.0°F | 167.0°F |         |

Table III. Temperature Profiles and Operating Conditions at  $1.965 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 28.8    | 57.6    | 86.4    | 72.0    | 115.0   |
| Steam Flow<br>Rate (#/hr)                          | 52.5    | 62.5    | 78.3    | 93.0    | 115.0   |
| Inlet Temp.<br>(°F)                                | 167.5   | 171.0   | 171.0   | 170.4   | 170.2   |
| Exit Temp.<br>(°F)                                 | 170.0   | 174.0   | 175.0   | 175.1   | 176.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 3.0     | 3.5     | 3.5     | 3.5     | 4.5     |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         |         |         |         |
| LU 8                                               |         |         |         |         |         |
| RU 7                                               |         |         |         |         |         |
| LU 6                                               |         |         |         |         |         |
| RU 5                                               | 167.5°F | 171.0°F | 171.0°F | 170.5°F | 170.2°F |
| LU 4                                               | 167.5°F | 171.0°F | 171.0°F | 170.5°F | 170.2°F |
| RU 3                                               | 167.5°F | 171.0°F | 171.0°F | 170.5°F | 170.8°F |
| LU 2                                               | 167.5°F | 171.0°F | 171.0°F | 170.6°F | 171.2°F |
| RU 1                                               | 167.5°F | 171.2°F | 171.1°F | 171.0°F | 173.0°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 170.1°F | 174.4°F | 175.1°F | 175.3°F | 176.0°F |
| LD 2                                               | 170.1°F | 174.0°F | 175.0°F | 175.1°F | 176.0°F |
| RD 3                                               | 170.0°F | 174.0°F | 175.0°F | 175.1°F | 176.0°F |
| LD 4                                               | 170.0°F | 174.0°F | 175.0°F | 175.1°F | 176.0°F |
| RD 5                                               | 170.0°F | 174.0°F | 175.0°F | 175.1°F | 176.0°F |
| LD 6                                               | 170.0°F |         |         |         |         |
| RD 7                                               | 170.0°F |         |         |         |         |
| LD 8                                               |         |         |         |         |         |
| RD 9                                               |         |         |         |         |         |
| LD 10                                              |         |         |         |         |         |
| RD 11                                              |         |         |         |         |         |

Table IV. Temperature Profiles and Operating Conditions at  $0.983 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 28.8    | 57.6    | 86.4    | 115.0   | 172.8   |
| Steam Flow<br>Rate (#/hr)                          | 52.2    | 62.5    | 78.3    | 93.2    | 115.0   |
| Inlet Temp.<br>(°F)                                | 165.5   | 164.5   | 165.0   | 165.0   | 165.0   |
| Exit Temp.<br>(°F)                                 | 169.5   | 169.9   | 171.0   | 171.0   | 172.2   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 9.5     | 9.5     | 11.5    | 9.5     | 14.0    |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               | 165.5°F | 164.5°F | 165.0°F | 165.0°F | 165.0°F |
| LU 8                                               | 165.5°F | 164.5°F | 165.0°F | 165.0°F | 165.0°F |
| RU 7                                               | 165.5°F | 164.5°F | 165.0°F | 165.0°F | 165.0°F |
| LU 6                                               | 165.5°F | 164.5°F | 165.5°F | 165.0°F | 165.9°F |
| RU 5                                               | 165.5°F | 165.0°F | 167.5°F | 167.3°F | 167.0°F |
| LU 4                                               | 165.5°F | 165.0°F | 167.0°F | 166.5°F | 167.2°F |
| RU 3                                               | 166.2°F | 165.5°F | 169.0°F | 168.2°F | 169.0°F |
| LU 2                                               | 165.9°F | 166.0°F | 166.8°F | 167.5°F | 168.2°F |
| RU 1                                               | 165.5°F | 166.0°F | 168.5°F | 169.0°F | 171.0°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 170.0°F | 170.0°F | 170.5°F | 170.8°F | 171.5°F |
| LD 2                                               | 169.0°F | 170.0°F | 170.2°F | 170.9°F | 172.0°F |
| RD 3                                               | 169.1°F | 169.9°F | 170.0°F | 171.0°F | 172.0°F |
| LD 4                                               | 169.0°F | 169.9°F | 171.0°F | 171.0°F | 172.0°F |
| RD 5                                               | 169.5°F | 169.9°F | 171.0°F | 171.0°F | 172.0°F |
| LD 6                                               | 169.5°F | 169.9°F | 171.0°F | 171.0°F | 172.0°F |
| RD 7                                               | 169.5°F |         |         |         | 172.2°F |
| LD 8                                               | 169.5°F |         |         |         | 172.2°F |
| RD 9                                               | 169.5°F |         |         |         | 172.2°F |
| LD 10                                              | 169.5°F |         |         |         | 172.2°F |
| RD 11                                              |         |         |         |         |         |

Table V. Temperature Profiles and Operating Conditions at  $7.2 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ . (See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 57.6    | 115.0   | 173.0   | 230.0   | 432.0   |
| Steam Flow<br>Rate (#/hr)                          | 51.0    | 52.5    | 77.5    | 92.5    | 115.0   |
| Inlet Temp.<br>(°F)                                | 145.0   | 145.0   | 144.5   | 145.0   | 145.0   |
| Exit Temp.<br>(°F)                                 | 146.8   | 146.9   | 146.6   | 147.1   | 148.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 5.0     | 4.5     | 5.0     | 2.5     | 8.0     |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         |         |         |         |
| LU 8                                               |         |         |         |         |         |
| RU 7                                               |         |         |         |         |         |
| LU 6                                               | 145.0°F | 145.0°F | 144.5°F | 145.0°F | 145.0°F |
| RU 5                                               | 145.0°F | 145.0°F | 144.5°F | 145.0°F | 145.0°F |
| LU 4                                               | 144.0°F | 145.0°F | 144.5°F | 145.0°F | 145.0°F |
| RU 3                                               | 145.0°F | 145.0°F | 144.5°F | 145.0°F | 145.0°F |
| LU 2                                               | 145.0°F | 145.0°F | 144.5°F | 145.0°F | 145.5°F |
| RU 1                                               | 145.0°F | 145.0°F | 144.5°F | 145.0°F | 146.0°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 147.0°F | 147.0°F | 147.0°F | 148.0°F | 148.0°F |
| LD 2                                               | 146.2°F | 146.2°F | 146.0°F | 147.1°F | 147.5°F |
| RD 3                                               | 146.3°F | 146.1°F | 146.2°F | 147.1°F | 147.2°F |
| LD 4                                               | 146.5°F | 146.9°F | 146.1°F | 147.1°F | 147.8°F |
| RD 5                                               | 146.8°F | 146.9°F | 146.6°F | 147.1°F | 148.0°F |
| LD 6                                               | 146.8°F | 146.9°F | 146.6°F | 147.1°F | 148.0°F |
| RD 7                                               | 146.8°F | 146.9°F | 146.6°F | 147.1°F | 148.0°F |
| LD 8                                               |         |         |         |         |         |
| RD 9                                               |         |         |         |         |         |
| LD 10                                              |         |         |         |         |         |
| RD 11                                              |         |         |         |         |         |

Table VI. Temperature Profiles and Operating Conditions at  $4.59 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |          |         |         |
|----------------------------------------------------|---------|---------|----------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 86.4    | 144.0   | 404.0    | 461.0   | 519.0   |
| Steam Flow<br>Rate (#/hr)                          | 52.5    | 61.3    | 78.2     | 92.5    | 115.0   |
| Inlet Temp.<br>(°F)                                | 138.0   | 139.0   | 138.0    | 138.0   | 137.5   |
| Exit Temp.<br>(°F)                                 | 139.5   | 140.0   | 141.0    | 141.0   | 141.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 5.5     | 5.5     | 10.0     | 6.0     | 7.0     |
| RU 13                                              |         |         |          |         |         |
| LU 12                                              |         |         |          |         |         |
| RU 11                                              |         |         |          |         |         |
| LU 10                                              |         |         |          |         |         |
| RU 9                                               |         |         |          |         |         |
| LU 8                                               |         |         |          |         |         |
| RU 7                                               |         |         |          |         |         |
| LU 6                                               | 138.0°F | 139.0°F | 138.0°F  | 138.0°F | 137.5°F |
| RU 5                                               | 138.0°F | 139.0°F | 138.0°F  | 138.0°F | 137.5°F |
| LU 4                                               | 138.0°F | 139.0°F | 138.0°F  | 138.0°F | 137.5°F |
| RU 3                                               | 138.0°F | 139.0°F | 138.0°F  | 138.0°F | 138.0°F |
| RU 1                                               | 137.5°F | 139.5°F | 138.5°F  | 138.5°F | 138.5°F |
| Zero                                               |         |         |          |         |         |
| RD 1                                               | 140.5°F | 142.0°F | 141.0°F  | 142.0°F | 141.5°F |
| LD 2                                               | 140.0°F | 140.0°F | 140.0°F  | 140.5°F | 141.0°F |
| RD 3                                               | 139.1°F | 140.5°F | 139.9°F  | 140.0°F | 141.0°F |
| LD 4                                               | 139.5°F | 141.0°F | 140.1°F  | 140.0°F | 141.0°F |
| RD 5                                               | 139.5°F | 141.0°F | 140.0°F  | 141.0°F | 141.0°F |
| LD 6                                               | 139.5°F | 141.0°F | 140.5°F  | 141.0°F | 141.0°F |
| RD 7                                               | 139.5°F | 141.0°F | 140.5°F  | 141.0°F | 141.0°F |
| LD 8                                               |         |         | 140.61°F |         |         |
| RD 9                                               |         |         | 141.0°F  |         |         |
| LD 10                                              |         |         | 141.0°F  |         |         |
| RD 11                                              |         |         | 141.0°F  |         |         |

Table VII. Temperature Profiles and Operating Conditions at  $1.965 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 115.0   | 144.0   | 288.0   | 346.0   | 461.0   |
| Steam Flow<br>Rate (#/hr)                          | 52.0    | 61.3    | 77.5    | 92.5    | 115.0   |
| Inlet Temp.<br>(°F)                                | 139.5   | 140.0   | 138.5   | 138.0   | 138.0   |
| Exit Temp.<br>(°F)                                 | 142.0   | 143.8   | 142.5   | 142.5   | 143.1   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 7.0     | 7.5     | 4.5     | 8.0     | 9.0     |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         |         |         |         |
| LU 8                                               | 139.5°F | 140.0°F |         |         |         |
| RU 7                                               | 139.5°F | 140.0°F |         |         | 138.0°F |
| LU 6                                               | 139.5°F | 140.0°F |         | 138.0°F | 138.0°F |
| RU 5                                               | 139.5°F | 140.0°F | 138.5°F | 138.0°F | 140.0°F |
| LU 4                                               | 139.5°F | 140.0°F | 138.5°F | 138.5°F | 140.0°F |
| RU 3                                               | 139.5°F | 141.0°F | 138.5°F | 139.0°F | 141.0°F |
| LU 2                                               | 139.5°F | 141.0°F | 138.5°F | 139.0°F | 141.0°F |
| RU 1                                               | 139.5°F | 142.0°F | 138.5°F | 140.0°F | 141.5°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 143.0°F | 144.0°F | 143.0°F | 143.0°F | 143.0°F |
| LD 2                                               | 141.0°F | 143.2°F | 142.0°F | 142.1°F | 143.1°F |
| RD 3                                               | 141.3°F | 143.8°F | 142.0°F | 142.5°F | 143.1°F |
| LD 4                                               | 141.5°F | 143.8°F | 142.5°F | 142.5°F | 143.1°F |
| RD 5                                               | 141.5°F | 143.8°F | 142.5°F | 142.5°F |         |
| LD 6                                               | 141.8°F |         | 142.5°F |         |         |
| RD 7                                               | 142.0°F |         |         |         |         |
| LD 8                                               | 142.0°F |         |         |         |         |
| RD 9                                               | 142.0°F |         |         |         |         |
| LD 10                                              |         |         |         |         |         |
| RD 11                                              |         |         |         |         |         |

Table VIII. Temperature Profiles and Operating Conditions at  $0.983 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 115.0   | 173.0   | 230.0   | 404.0   | 461.0   |
| Steam Flow<br>Rate (#/hr)                          | 52.5    | 61.1    | 77.5    | 92.5    | 115.0   |
| Inlet Temp.<br>(°F)                                | 141.0   | 140.0   | 141.5   | 138.0   | 138.0   |
| Exit Temp.<br>(°F)                                 | 145.5   | 145.5   | 149.0   | 146.0   | 147.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 9.0     | 7.5     | 9.0     | 7.0     | 6.5     |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               | 141.0°F | 140.0°F | 141.5°F |         |         |
| LU 8                                               | 141.0°F | 140.0°F | 141.5°F | 138.0°F | 138.0°F |
| RU 7                                               | 141.0°F | 140.0°F | 141.5°F | 138.0°F | 138.0°F |
| LU 6                                               | 141.0°F | 140.0°F | 141.5°F | 138.2°F | 138.0°F |
| RU 5                                               | 141.0°F | 140.0°F | 143.0°F | 138.7°F | 138.3°F |
| LU 4                                               | 141.0°F | 140.0°F | 143.5°F | 139.9°F | 139.2°F |
| RU 3                                               | 143.0°F | 142.0°F | 144.0°F | 140.5°F | 140.8°F |
| LU 2                                               | 143.0°F | 142.2°F | 144.8°F | 141.5°F | 141.8°F |
| RU 1                                               | 144.5°F | 144.0°F | 145.0°F | 142.0°F | 142.0°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 145.0°F | 146.0°F | 148.5°F | 146.0°F | 147.0°F |
| LD 2                                               | 145.0°F | 145.0°F | 149.0°F | 146.0°F | 147.0°F |
| RD 3                                               | 145.0°F | 145.5°F | 149.0°F | 146.0°F | 147.0°F |
| LD 4                                               | 145.5°F | 145.5°F | 149.0°F | 146.0°F | 147.0°F |
| RD 5                                               | 145.5°F | 145.5°F |         |         |         |
| LD 6                                               | 145.5°F |         |         |         |         |
| RD 7                                               |         |         |         |         |         |
| LD 8                                               |         |         |         |         |         |
| RD 9                                               |         |         |         |         |         |
| LD 10                                              |         |         |         |         |         |
| RD 11                                              |         |         |         |         |         |

Table IX. Temperature Profiles and Operating Conditions at  $7.2 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 144.0   | 230.0   | 403.5   | 575.5   | 634.0   |
| Steam Flow<br>Rate (#/hr)                          | 51.2    | 62.5    | 77.5    | 97.8    | 115.0   |
| Inlet Temp.<br>(°F)                                | 126.0   | 125.0   | 127.0   | 127.0   | 127.0   |
| Exit Temp.<br>(°F)                                 | 127.0   | 127.0   | 129.0   | 129.0   | 130.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 6.5     | 10.5    | 6.5     | 4.5     | 11.5    |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         |         |         |         |
| LU 8                                               |         |         |         |         |         |
| RU 7                                               |         |         |         |         |         |
| LU 6                                               |         |         |         |         |         |
| RU 5                                               | 126.0°F | 125.0°F | 127.0°F | 127.0°F | 127.0°F |
| LU 4                                               | 126.0°F | 125.0°F | 127.0°F | 127.0°F | 127.0°F |
| RU 3                                               | 126.0°F | 125.0°F | 127.0°F | 127.0°F | 127.8°F |
| LU 2                                               | 126.0°F | 125.0°F | 127.0°F | 127.0°F | 128.0°F |
| RU 1                                               | 126.0°F | 125.0°F | 127.0°F | 127.0°F | 127.5°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 129.5°F | 128.0°F | 129.9°F | 129.5°F | 130.1°F |
| LD 2                                               | 126.0°F | 126.2°F | 128.4°F | 128.5°F | 128.2°F |
| RD 3                                               | 126.5°F | 126.4°F | 128.4°F | 128.8°F | 128.7°F |
| LD 4                                               | 126.9°F | 126.2°F | 128.5°F | 129.0°F | 128.5°F |
| RD 5                                               | 126.9°F | 126.5°F | 128.5°F | 129.0°F | 129.9°F |
| LD 6                                               | 127.0°F | 126.2°F | 129.0°F | 129.0°F | 129.9°F |
| RD 7                                               | 127.0°F | 126.9°F | 129.0°F | 129.0°F | 130.0°F |
| LD 8                                               | 127.0°F | 126.5°F | 129.0°F |         | 130.0°F |
| RD 9                                               | 127.0°F | 126.9°F | 129.0°F |         | 130.0°F |
| LD 10                                              |         | 127.0°F |         |         | 130.0°F |
| RD 11                                              |         | 127.0°F |         |         |         |

Table X. Temperature Profiles and Operating Conditions at  $4.59 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 144.0   | 230.0   | 499.5   | 690.0   | 921.0   |
| Steam Flow<br>Rate (#/hr)                          | 51.2    | 62.5    | 76.8    | 93.3    | 115.0   |
| Inlet Temp.<br>(°F)                                | 124.0   | 124.0   | 123.5   | 124.0   | 124.0   |
| Exit Temp.<br>(°F)                                 | 125.3   | 126.4   | 126.4   | 127.1   | 128.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 5.0     | 11.5    | 9.5     | 7.5     | 11.5    |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         |         |         |         |
| LU 8                                               |         |         |         |         |         |
| RU 7                                               |         |         |         |         |         |
| LU 6                                               |         |         |         |         |         |
| RU 5                                               | 124.0°F | 124.0°F | 123.5°F | 124.0°F | 124.0°F |
| LU 4                                               | 124.0°F | 124.0°F | 123.5°F | 124.0°F | 124.0°F |
| RU 3                                               | 124.0°F | 124.0°F | 123.5°F | 124.0°F | 124.0°F |
| LU 2                                               | 124.0°F | 124.0°F | 123.5°F | 124.0°F | 124.0°F |
| RU 1                                               | 124.0°F | 124.2°F | 124.0°F | 125.0°F | 124.8°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 125.1°F | 126.9°F | 126.9°F | 128.0°F | 128.0°F |
| LD 2                                               | 125.0°F | 126.0°F | 126.0°F | 126.0°F | 127.0°F |
| RD 3                                               | 125.2°F | 126.1°F | 125.9°F | 126.9°F | 127.0°F |
| LD 4                                               | 125.2°F | 126.0°F | 126.2°F | 126.9°F | 127.4°F |
| RD 5                                               | 125.3°F | 126.0°F | 126.0°F | 127.0°F | 127.5°F |
| LD 6                                               | 125.3°F | 126.0°F | 126.2°F | 127.1°F | 127.7°F |
| RD 7                                               | 125.3°F | 126.0°F | 126.2°F | 127.1°F | 127.7°F |
| LD 8                                               | 125.3°F | 126.2°F | 126.4°F | 127.1°F | 127.9°F |
| RD 9                                               |         | 126.2°F | 126.4°F | 127.1°F | 127.9°F |
| LD 10                                              |         | 126.4°F | 126.4°F |         | 128.0°F |
| RD 11                                              |         | 126.4°F | 126.4°F |         | 128.0°F |

Table XI. Temperature Profiles and Operating Conditions at  $1.965 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 115.0   | 230.0   | 404.0   | 635.0   | 750.0   |
| Steam Flow<br>Rate (#/hr)                          | 52.5    | 62.5    | 78.0    | 93.3    | 115.0   |
| Inlet Temp.<br>(°F)                                | 125.0   | 123.0   | 123.0   | 123.0   | 122.5   |
| Exit Temp.<br>(°F)                                 | 126.0   | 126.0   | 127.5   | 128.0   | 128.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 5.0     | 5.5     | 9.0     | 11.0    | 11.0    |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         |         |         |         |
| LU 8                                               |         |         |         |         |         |
| RU 7                                               |         |         |         |         | 122.5°F |
| LU 6                                               |         |         | 123.0°F | 123.0°F | 122.5°F |
| RU 5                                               |         |         | 123.0°F | 123.0°F | 123.0°F |
| LU 4                                               | 124.0°F | 123.0°F | 123.0°F | 123.0°F | 123.4°F |
| RU 3                                               | 124.0°F | 123.0°F | 124.0°F | 124.0°F | 125.0°F |
| LU 2                                               | 124.0°F | 123.0°F | 124.1°F | 124.0°F | 123.8°F |
| RU 1                                               | 124.0°F | 123.1°F | 124.2°F | 124.2°F | 125.0°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 126.5°F | 126.0°F | 128.0°F | 128.0°F | 127.0°F |
| LD 2                                               | 125.2°F | 125.2°F | 126.8°F | 127.0°F | 127.0°F |
| RD 3                                               | 125.2°F | 125.2°F | 127.0°F | 127.0°F | 127.5°F |
| LD 4                                               | 125.5°F | 126.0°F | 127.5°F | 127.5°F | 128.0°F |
| RD 5                                               | 126.0°F | 126.0°F | 127.5°F | 127.5°F | 128.0°F |
| LD 6                                               | 126.0°F | 126.0°F | 127.5°F | 128.0°F | 128.0°F |
| RD 7                                               | 126.0°F | 126.0°F | 127.5°F | 128.0°F | 128.0°F |
| LD 8                                               | 126.0°F |         |         | 128.0°F |         |
| RD 9                                               |         |         |         | 128.0°F |         |
| LD 10                                              |         |         |         |         |         |
| RD 11                                              |         |         |         |         |         |

Table XII. Temperature Profiles and Operating Conditions at  $0.983 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $90^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 115.0   | 202.0   | 432.5   | 576.0   | 750.0   |
| Steam Flow<br>Rate (#/hr)                          | 49.9    | 61.8    | 77.5    | 93.3    | 115.0   |
| Inlet Temp.<br>(°F)                                | 121.0   | 122.0   | 123.0   | 122.5   | 122.5   |
| Exit Temp.<br>(°F)                                 | 124.9   | 128.0   | 129.0   | 130.0   | 131.2   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 11.5    | 11.5    | 6.5     | 8.5     | 11.5    |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         |         | 122.5°F | 122.5°F |
| LU 8                                               |         |         |         | 122.5°F | 122.5°F |
| RU 7                                               |         | 122.0°F | 123.0°F | 123.0°F | 124.0°F |
| LU 6                                               | 121.0°F | 122.0°F | 123.0°F | 123.0°F | 123.0°F |
| RU 5                                               | 121.0°F | 123.0°F | 124.0°F | 124.0°F | 125.0°F |
| LU 4                                               | 121.0°F | 123.0°F | 124.0°F | 124.0°F | 125.0°F |
| RU 3                                               | 121.2°F | 123.5°F | 124.8°F | 125.0°F | 127.0°F |
| LU 2                                               | 121.3°F | 123.5°F | 124.5°F | 126.0°F | 127.5°F |
| RU 1                                               | 121.5°F | 124.0°F | 125.0°F | 126.0°F | 128.0°F |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 124.0°F | 128.0°F | 129.0°F | 130.0°F | 130.0°F |
| LD 2                                               | 123.0°F | 127.1°F | 129.0°F | 130.0°F | 131.0°F |
| RD 3                                               | 123.5°F | 127.5°F | 129.0°F | 130.0°F | 131.2°F |
| LD 4                                               | 124.0°F | 127.9°F | 129.0°F | 130.0°F | 131.2°F |
| RD 5                                               | 124.0°F | 128.0°F |         |         |         |
| LD 6                                               | 124.5°F | 128.0°F |         |         | 131.2°F |
| RD 7                                               | 124.9°F |         |         |         |         |
| LD 8                                               | 124.9°F |         |         |         |         |
| RD 9                                               |         |         |         |         |         |
| LD 10                                              |         |         |         |         |         |
| RD 11                                              |         |         |         |         |         |

Table XIII. Temperature Profiles and Operating Conditions at  $7.2 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $51^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|              |         |         |         |         |
|--------------|---------|---------|---------|---------|
| Fresh Water  |         |         |         |         |
| Rate (#/hr)  | 0.0     | 28.8    | 57.6    | 101.0   |
| Steam Flow   |         |         |         |         |
| Rate (#/hr)  | 42.5    | 53.75   | 56.25   | 62.5    |
| Inlet Temp.  |         |         |         |         |
| (°F)         | 162.0   | 164.0   | 163.0   | 162.6   |
| Exit Temp.   |         |         |         |         |
| (°F)         | 163.1   | 165.8   | 165.0   | 165.0   |
| Estimated    |         |         |         |         |
| Height of    |         |         |         |         |
| Transfer     |         |         |         |         |
| Region (in.) | 5.5     | 5.0     | 7.5     | 9.0     |
| RU 13        |         |         |         |         |
| LU 12        |         |         |         |         |
| RU 11        |         |         |         |         |
| LU 10        |         |         |         |         |
| RU 9         |         |         |         |         |
| LU 8         |         |         |         |         |
| RU 7         |         |         |         | 162.6°F |
| LU 6         |         |         | 163.0°F | 162.6°F |
| RU 5         |         |         | 163.0°F | 163.0°F |
| LU 4         | 162.0°F | 164.0°F | 163.2°F | 162.9°F |
| RU 3         | 162.0°F | 164.0°F | 163.5°F | 163.1°F |
| LU 2         | 162.0°F | 164.0°F | 163.4°F | 163.0°F |
| RU 1         | 164.0°F | 166.0°F | 164.0°F | 164.0°F |
| Zero         |         |         |         |         |
| RD 1         | 162.0°F | 165.2°F | 165.5°F | 164.0°F |
| LD 2         | 163.5°F | 165.8°F | 165.0°F | 165.0°F |
| RD 3         | 163.1°F | 165.8°F | 165.0°F | 165.0°F |
| LD 4         | 163.1°F | 165.8°F | 165.0°F | 165.0°F |
| RD 5         | 163.1°F |         |         |         |
| LD 6         |         |         |         |         |
| RD 7         |         |         |         |         |
| LD 8         |         |         |         |         |
| RD 9         |         |         |         |         |
| LD 10        |         |         |         |         |
| RD 11        |         |         |         |         |

Table XIV. Temperature Profiles and Operating Conditions at  $4.59 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $51^\circ$ . (See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 28.8    | 57.6    | 86.5    |
| Steam Flow<br>Rate (#/hr)                          | 46.25   | 52.1    | 56.25   | 62.5    |
| Inlet Temp.<br>(°F)                                | 167.0   | 166.8   | 167.5   | 166.5   |
| Exit Temp.<br>(°F)                                 | 168.1   | 168.8   | 169.2   | 169.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 7.0     | 9.5     | 9.0     | 13.0    |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         |         |         |
| LU 10                                              |         |         |         |         |
| RU 9                                               |         |         |         |         |
| LU 8                                               |         |         |         |         |
| RU 7                                               |         |         |         | 166.5°F |
| LU 6                                               |         | 166.8°F |         | 166.5°F |
| RU 5                                               |         | 166.8°F | 167.5°F | 167.0°F |
| LU 4                                               |         | 167.0°F | 167.5°F | 167.0°F |
| RU 3                                               | 167.0°F | 167.0°F | 168.0°F | 168.0°F |
| LU 2                                               | 167.0°F | 165.4°F | 168.0°F | 168.0°F |
| RU 1                                               | 168.0°F | 168.0°F | 168.5°F | 169.0°F |
| Zero                                               |         |         |         |         |
| RD 1                                               | 169.5°F | 169.5°F | 169.9°F | 170.0°F |
| LD 2                                               | 168.5°F | 169.0°F | 169.8°F | 168.9°F |
| RD 3                                               | 169.0°F | 169.0°F | 169.5°F | 168.8°F |
| LD 4                                               | 168.1°F | 168.8°F | 169.2°F | 168.8°F |
| RD 5                                               | 168.1°F | 168.8°F | 169.2°F | 168.9°F |
| LD 6                                               | 168.1°F | 168.8°F | 169.2°F | 169.0°F |
| RD 7                                               |         |         |         | 169.0°F |
| LD 8                                               |         |         |         | 169.0°F |
| RD 9                                               |         |         |         |         |
| LD 10                                              |         |         |         |         |
| RD 11                                              |         |         |         |         |

Table XV. Temperature Profiles and Operating Conditions at  $1.965 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $51^\circ$ .  
(See Figure 1 nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 28.8    | 86.5    | 115.0   |
| Steam Flow<br>Rate (#/hr)                          | 47.0    | 54.5    | 56.25   | 62.5    |
| Inlet Temp.<br>(°F)                                | 174.0   | 174.5   | 173.0   | 173.0   |
| Exit Temp.<br>(°F)                                 | 176.5   | 178.0   | 176.5   | 177.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 7.5     | 11.0    | 11.0    | 8.5     |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         |         |         |
| LU 10                                              |         |         |         |         |
| RU 9                                               |         | 174.5°F | 173.0°F | 173.0°F |
| LU 8                                               |         | 174.5°F | 173.0°F | 173.0°F |
| RU 7                                               |         | 174.9°F | 173.3°F | 173.5°F |
| LU 6                                               | 174.0°F | 175.0°F | 173.5°F | 173.8°F |
| RU 5                                               | 174.0°F | 175.5°F | 173.8°F | 174.0°F |
| LU 4                                               | 174.0°F | 175.8°F | 174.0°F | 174.5°F |
| RU 3                                               | 174.5°F | 176.0°F | 174.5°F | 174.5°F |
| LU 2                                               | 175.0°F | 176.6°F | 174.5°F | 175.3°F |
| RU 1                                               | 175.0°F | 177.2°F | 174.9°F | 176.0°F |
| Zero                                               |         |         |         |         |
| RD 1                                               | 177.0°F | 178.5°F | 175.0°F | 177.0°F |
| LD 2                                               | 177.0°F | 178.0°F | 176.5°F | 177.0°F |
| RD 3                                               | 176.5°F | 178.0°F | 176.5°F | 177.0°F |
| LD 4                                               | 176.5°F | 178.0°F | 176.5°F | 177.0°F |
| RD 5                                               |         |         |         |         |
| LD 6                                               |         |         |         |         |
| RD 7                                               |         |         |         |         |
| LD 8                                               |         |         |         |         |
| RD 9                                               |         |         |         |         |
| LD 10                                              |         |         |         |         |
| RD 11                                              |         |         |         |         |

Table XVI. Temperature Profiles and Operating Conditions at  $0.983 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $51^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 28.8    | 43.2    | 57.6    |
| Steam Flow<br>Rate (#/hr)                          | 37.5    | 50.0    | 56.25   | 62.5    |
| Inlet Temp.<br>(°F)                                | 162.5   | 164.1   | 164.0   | 160.0   |
| Exit Temp.<br>(°F)                                 | 165.5   | 168.0   | 169.0   | 166.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 6.5     | 8.5     | 10.5    | 10.5    |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         | 164.0°F | 160.0°F |
| LU 10                                              |         |         | 164.0°F | 160.0°F |
| RU 9                                               |         | 164.1°F | 164.8°F | 160.5°F |
| LU 8                                               | 162.5°F | 164.1°F | 164.8°F | 161.0°F |
| RU 7                                               | 162.5°F | 164.4°F | 165.0°F | 161.0°F |
| LU 6                                               | 162.5°F | 164.6°F | 165.3°F | 161.4°F |
| RU 5                                               | 163.0°F | 164.8°F | 165.8°F | 161.8°F |
| LU 4                                               | 163.3°F | 165.0°F | 166.0°F | 162.2°F |
| RU 3                                               | 163.8°F | 165.5°F | 166.4°F | 162.6°F |
| LU 2                                               | 164.0°F | 165.8°F | 167.4°F | 163.5°F |
| RU 1                                               | 164.2°F | 166.8°F | 168.0°F | 164.5°F |
| Zero                                               |         |         |         |         |
| RD 1                                               | 165.5°F | 168.0°F | 169.0°F | 166.0°F |
| LD 2                                               | 165.5°F | 168.0°F | 169.0°F | 166.0°F |
| RD 3                                               | 165.5°F | 168.0°F | 169.0°F | 166.0°F |
| LU 4                                               | 165.5°F | 168.0°F | 169.0°F | 166.0°F |
| RD 5                                               |         |         |         |         |
| LD 6                                               |         |         |         |         |
| RD 7                                               |         |         |         |         |
| LD 8                                               |         |         |         |         |
| RD 9                                               |         |         |         |         |
| LD 10                                              |         |         |         |         |
| RD 11                                              |         |         |         |         |

Table XVII. Temperature Profiles and Operating Conditions at  $7.2 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $129^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 28.8    | 57.6    | 72.0    |
| Steam Flow<br>Rate (#/hr)                          | 31.25   | 43.75   | 45.0    | 47.3    |
| Inlet Temp.<br>(°F)                                | 163.9   | 164.0   | 164.0   | 164.0   |
| Exit Temp.<br>(°F)                                 | 165.0   | 165.1   | 165.4   | 165.4   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 10.5    | 7.0     | 6.5     | 7.0     |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         |         |         |
| LU 10                                              |         |         |         |         |
| RU 9                                               |         |         |         |         |
| LU 8                                               |         |         |         |         |
| RU 7                                               |         |         |         |         |
| LU 6                                               |         |         |         |         |
| RU 5                                               |         |         |         |         |
| LU 4                                               |         |         |         |         |
| RU 3                                               |         |         |         |         |
| LU 2                                               | 163.9°F | 164.0°F | 164.0°F | 164.0°F |
| RU 1                                               | 163.9°F | 164.0°F | 164.0°F | 164.0°F |
| Zero                                               |         |         |         |         |
| RD 1                                               |         |         |         |         |
| LD 2                                               |         |         |         |         |
| RD 3                                               |         |         |         |         |
| LD 4                                               |         |         | 165.0°F | 164.6°F |
| RD 5                                               | 164.0°F | 164.9°F | 165.2°F | 165.0°F |
| LD 6                                               | 164.2°F | 165.0°F | 165.4°F | 165.0°F |
| RD 7                                               | 164.2°F | 165.1°F | 165.4°F | 165.4°F |
| LD 8                                               | 164.5°F | 165.1°F | 165.4°F | 165.4°F |
| RD 9                                               | 164.5°F | 165.1°F | 165.4°F | 165.4°F |
| LD 10                                              | 165.0°F | 165.1°F |         | 165.4°F |
| RD 11                                              | 165.0°F |         |         |         |

Table XVIII. Temperature Profiles and Operating Conditions at  $4.59 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $129^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |          |         |
|----------------------------------------------------|---------|---------|----------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 14.4    | 28.8     | 43.2    |
| Steam Flow<br>Rate (#/hr)                          | 31.25   | 35.0    | 42.5     | 47.3    |
| Inlet Temp.<br>(°F)                                | 160.0   | 160.0   | 161.5    | 161.0   |
| Exit Temp.<br>(°F)                                 | 161.3   | 162.0   | 163.6    | 163.6   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 9.0     | 7.0     | 7.0      | 8.5     |
| RU 13                                              |         |         |          |         |
| LU 12                                              |         |         |          |         |
| RU 11                                              |         |         |          |         |
| LU 10                                              |         |         |          |         |
| RU 9                                               |         |         |          |         |
| LU 8                                               |         |         |          |         |
| RU 7                                               |         |         |          |         |
| LU 6                                               |         |         |          |         |
| RU 5                                               |         |         |          |         |
| LU 4                                               |         |         |          |         |
| RU 3                                               |         |         |          |         |
| LU 2                                               | 160.0°F | 160.0°F | 161.5°F  | 161.0°F |
| RU 1                                               | 160.0°F | 160.0°F | 161.5°F  | 161.0°F |
| Zero                                               |         |         |          |         |
| RD 1                                               |         |         |          |         |
| LD 2                                               |         |         |          |         |
| RD 3                                               |         |         |          |         |
| LD 4                                               |         |         |          |         |
| RD 5                                               |         | 161.2°F | 162.85°F |         |
| LD 6                                               | 160.9°F | 161.2°F | 163.0°F  | 163.1°F |
| RD 7                                               | 161.0°F | 162.0°F | 163.6°F  | 163.1°F |
| LD 8                                               | 161.1°F | 162.0°F | 163.6°F  | 163.6°F |
| RD 9                                               | 161.3°F | 162.0°F | 163.6°F  | 163.6°F |
| LD 10                                              | 161.3°F | 162.0°F | 163.6°F  | 163.6°F |
| RD 11                                              | 161.3°F | 162.0°F | 163.6°F  | 163.6°F |

Table XIX. Temperature Profiles and Operating Conditions at  $1.965 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $129^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 14.4    | 28.8    | 43.2    |
| Steam Flow<br>Rate (#/hr)                          | 26.25   | 33.5    | 37.5    | 42.5    |
| Inlet Temp.<br>(°F)                                | 164.0   | 164.0   | 164.5   | 165.0   |
| Exit Temp.<br>(°F)                                 | 165.9   | 166.0   | 166.9   | 168.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 4.5     | 2.5     | 4.5     | 3.0     |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         |         |         |
| LU 10                                              |         |         |         |         |
| RU 9                                               |         |         |         |         |
| LU 8                                               |         |         |         |         |
| RU 7                                               |         |         |         |         |
| LU 6                                               |         |         |         |         |
| RU 5                                               |         |         |         |         |
| LU 4                                               |         |         |         |         |
| RU 3                                               |         |         |         |         |
| LU 2                                               | 164.0°F | 164.0°F | 164.5°F | 165.0°F |
| RU 1                                               | 164.0°F | 164.0°F | 164.5°F | 165.0°F |
| Zero                                               |         |         |         |         |
| RD 1                                               |         | 165.8°F |         | 167.8°F |
| LD 2                                               | 165.0°F | 166.0°F | 165.8°F | 167.9°F |
| RD 3                                               | 165.0°F | 166.0°F | 166.2°F | 168.0°F |
| LD 4                                               | 165.9°F | 166.0°F | 166.9°F | 168.0°F |
| RD 5                                               | 165.9°F | 166.0°F | 166.9°F | 168.0°F |
| LD 6                                               | 165.9°F |         | 166.9   | 168.0°F |
| RD 7                                               | 165.9°F |         | 166.9°F |         |
| LD 8                                               |         |         |         |         |
| RD 9                                               |         |         |         |         |
| LD 10                                              |         |         |         |         |
| RD 11                                              |         |         |         |         |

Table XX. Temperature Profiles and Operating Conditions at  $0.983 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected at an Angle of  $129^\circ$ .  
(See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 14.4    | 28.8    | 43.2    |
| Steam Flow<br>Rate (#/hr)                          | 18.75   | 25.0    | 31.5    | 37.5    |
| Inlet Temp.<br>(°F)                                | 163.0   | 162.9   | 162.0   | 160.5   |
| Exit Temp.<br>(°F)                                 | 166.0   | 166.0   | 166.0   | 165.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 7.0     | 2.5     | 3.0     | 5.5     |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         |         |         |
| LU 10                                              |         |         |         |         |
| RU 9                                               |         |         |         |         |
| LU 8                                               |         |         |         |         |
| RU 7                                               |         |         |         |         |
| LU 6                                               |         |         |         |         |
| RU 5                                               |         |         |         |         |
| LU 4                                               |         |         |         | 160.5°F |
| RU 3                                               |         |         |         | 160.5°F |
| LU 2                                               | 163.0°F | 162.9°F | 162.0°F | 161.0°F |
| RU 1                                               | 163.0°F | 162.9°F | 162.0°F | 161.0°F |
| Zero                                               |         |         |         |         |
| RD 1                                               |         | 165.8°F | 165.9°F | 164.0°F |
| LD 2                                               |         | 166.0°F | 165.8°F | 165.0°F |
| RD 3                                               |         | 166.0°F | 166.0°F | 165.0°F |
| LD 4                                               |         | 166.0°F | 166.0°F | 165.0°F |
| RD 5                                               | 165.4°F | 166.0°F | 166.0°F | 165.0°F |
| LD 6                                               | 165.4°F |         | 166.0°F |         |
| RD 7                                               | 166.0°F |         |         |         |
| LD 8                                               | 166.0°F |         |         |         |
| RD 9                                               | 166.0°F |         |         |         |
| LD 10                                              | 166.0°F |         |         |         |
| RD 11                                              |         |         |         |         |

Table XXI. Temperature Profiles and Operating Conditions at  $7.2 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected Countercurrent to the Recycle Flow. (Steam injected directly into stream flow.) In this method, the steam entered the center of the condenser 1.56 inches above the zero reference. (See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 14.4    | 28.8    | 43.2    | 57.6    |
| Steam Flow<br>Rate (#/hr)                          | 2.0     | 5.0     | 6.61    | 10.0    | 13.2    |
| Inlet Temp.<br>(°F)                                | 155.0   | 152.0   | 151.0   | 150.1   | 150.0   |
| Exit Temp.<br>(°F)                                 | 155.1   | 152.3   | 151.4   | 150.9   | 151.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 6.5     | 6.5     | 11.0    | 11.5    | 13.5    |
| RU 13                                              |         |         |         |         |         |
| LU 12                                              |         |         |         |         |         |
| RU 11                                              |         |         |         |         |         |
| LU 10                                              |         |         |         |         |         |
| RU 9                                               |         |         | 151.0°F | 150.1°F | 150.0°F |
| LU 8                                               |         | 152.0°F | 151.0°F | 150.1°F | 150.0°F |
| RU 7                                               | 155.0°F | 152.0°F | 151.1°F | 150.9°F | 150.1°F |
| LU 6                                               | 155.0°F | 152.0°F |         |         |         |
| RU 5                                               | 156.0°F | 152.6°F |         |         |         |
| LU 4                                               |         |         |         |         |         |
| RU 3                                               |         |         |         |         |         |
| LU 2                                               |         |         |         |         |         |
| RU 1                                               |         |         |         |         |         |
| Zero                                               |         |         |         |         |         |
| RD 1                                               | 155.1°F | 152.3°F | 151.8°F | 151.1°F | 150.8°F |
| LD 2                                               | 155.1°F | 152.3°F | 151.4°F | 151.0°F | 150.7°F |
| RD 3                                               | 155.1°F | 152.3°F | 151.4°F | 150.9°F | 150.9°F |
| LD 4                                               |         |         | 151.4°F | 150.9°F | 150.9°F |
| RD 5                                               |         |         | 151.4°F | 150.9°F | 151.0°F |
| LD 6                                               |         |         |         |         |         |
| RD 7                                               |         |         |         |         | 151.0°F |
| LD 8                                               |         |         |         |         | 151.0°F |
| RD 9                                               |         |         |         |         |         |
| LD 10                                              |         |         |         |         |         |
| RD 11                                              |         |         |         |         |         |

Table XXII. Temperature Profiles and Operating Conditions at  $4.59 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected Countercurrent to the Recycle Flow. (Steam injected directly into stream flow.) In this method, the steam entered the center of the condenser 1.56 inches above the zero reference. (See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 14.4    | 28.8    | 43.2    |
| Steam Flow<br>Rate (#/hr)                          | 4.0     | 6.2     | 10.0    | 12.0    |
| Inlet Temp.<br>(°F)                                | 145.5   | 145.0   | 145.0   | 145.9   |
| Exit Temp.<br>(°F)                                 | 146.0   | 145.9   | 146.1   | 147.0   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 10.0    | 11.5    | 13.0    | 15.0    |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         |         |         |
| LU 10                                              |         |         |         |         |
| RU 9                                               |         | 145.0°F | 145.0°F | 145.9°F |
| LU 8                                               | 145.5°F | 145.0°F | 145.0°F | 145.9°F |
| RU 7                                               | 145.5°F | 145.5°F | 145.7°F | 146.0°F |
| LU 6                                               | 146.0°F | 146.0°F | 145.9°F | 146.0°F |
| RU 5                                               |         |         |         |         |
| LU 4                                               |         |         |         |         |
| RU 3                                               |         |         |         |         |
| LU 2                                               |         |         |         |         |
| RU 1                                               |         |         |         |         |
| Zero                                               |         |         |         |         |
| RD 1                                               | 146.8°F | 146.0°F | 146.0°F |         |
| LD 2                                               | 146.5°F | 146.0°F | 146.0°F |         |
| RD 3                                               | 146.0°F | 145.9°F | 146.0°F |         |
| LD 4                                               | 146.0°F | 145.9°F | 146.1°F | 146.8°F |
| RD 5                                               | 146.0°F | 145.9°F | 146.1°F | 146.9°F |
| LD 6                                               |         |         | 146.1°F | 147.0°F |
| RD 7                                               |         |         |         | 147.0°F |
| LD 8                                               |         |         |         | 147.0°F |
| RD 9                                               |         |         |         |         |
| LD 10                                              |         |         |         |         |
| RD 11                                              |         |         |         |         |

Table XXIII. Temperature Profiles and Operating Conditions at  $1.965 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected Countercurrent to the Recycle Flow. (Steam injected directly into stream flow.) In this method, the steam entered the center of the condenser 1.56 inches above the zero reference. (See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 14.4    | 28.8    | 43.2    |
| Steam Flow<br>Rate (#/hr)                          | 2.1     | 5.8     | 9.6     | 12.0    |
| Inlet Temp.<br>(°F)                                | 144.1   | 143.0   | 143.0   | 144.0   |
| Exit Temp.<br>(°F)                                 | 144.9   | 144.0   | 144.6   | 145.7   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 10.0    | 13.0    | 13.0    | 13.0    |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         |         |
| RU 11                                              |         |         | 143.0°F | 144.0°F |
| LU 10                                              | 144.1°F | 143.0°F | 143.0°F | 144.0°F |
| RU 9                                               | 144.1°F | 143.0°F | 143.3°F | 143.9°F |
| LU 8                                               | 144.1°F | 143.0°F | 143.3°F |         |
| RU 7                                               | 144.1°F | 143.2°F |         |         |
| LU 6                                               | 144.3°F |         |         |         |
| RU 5                                               |         |         |         |         |
| LU 4                                               |         |         |         |         |
| RU 3                                               |         |         |         |         |
| LU 2                                               |         |         |         |         |
| RU 1                                               |         |         |         |         |
| Zero                                               |         |         |         |         |
| RD 1                                               | 144.5°F | 143.2°F | 154.0°F | 146.0°F |
| LD 2                                               | 144.3°F | 143.6°F | 144.6°F | 145.7°F |
| RD 3                                               | 144.9°F | 143.8°F | 144.6°F | 145.7°F |
| LD 4                                               | 144.9°F | 144.0°F | 144.6°F | 145.7°F |
| RD 5                                               | 144.9°F | 144.0°F |         |         |
| LD 6                                               |         | 144.0°F |         |         |
| RD 7                                               |         |         |         |         |
| LD 8                                               |         |         |         |         |
| RD 9                                               |         |         |         |         |
| LD 10                                              |         |         |         |         |
| Rd 11                                              |         |         |         |         |

Table XXIV. Temperature Profiles and Operating Conditions at  $0.983 \times 10^{-3}$  ft/sec Recycle Rate with Steam Injected Countercurrent to the Recycle Flow. (Steam injected directly into stream flow.) In this method, the steam entered the center of the condenser 1.56 inches above the zero reference. (See Figure 1 for nomenclature of this Table.)

|                                                    |         |         |         |         |
|----------------------------------------------------|---------|---------|---------|---------|
| Fresh Water<br>Rate (#/hr)                         | 0.0     | 14.4    | 28.8    | 43.2    |
| Steam Flow<br>Rate (#/hr)                          | 2.1     | 5.8     | 9.6     | 12.0    |
| Inlet Temp.<br>(°F)                                | 142.6   | 141.0   | 140.0   | 140.0   |
| Exit Temp.<br>(°F)                                 | 143.5   | 142.0   | 141.3   | 141.9   |
| Estimated<br>Height of<br>Transfer<br>Region (in.) | 11.0    | 11.5    | 13.0    | 15.5    |
| RU 13                                              |         |         |         |         |
| LU 12                                              |         |         |         | 140.0°F |
| RU 11                                              |         |         | 140.0°F | 140.0°F |
| LU 10                                              | 142.6°F | 141.0°F | 140.0°F | 140.2°F |
| RU 9                                               | 142.6°F | 141.0°F | 140.1°F | 140.2°F |
| LU 8                                               | 142.6°F | 141.3°F | 140.2°F |         |
| RU 7                                               |         | 141.2°F |         |         |
| LU 6                                               |         |         |         |         |
| RU 5                                               |         |         |         |         |
| LU 4                                               |         |         |         |         |
| RU 3                                               |         |         |         |         |
| LU 2                                               |         |         |         |         |
| RU 1                                               |         |         |         |         |
| Zero                                               |         |         |         |         |
| RD 1                                               | 143.7°F | 141.9°F | 141.2°F | 141.0°F |
| LD 2                                               | 143.5°F | 142.0°F | 141.3°F | 141.5°F |
| RD 3                                               | 143.5°F | 142.0°F | 141.3°F | 141.7°F |
| LD 4                                               | 143.5°F | 142.0°F | 141.3°F | 141.9°F |
| RD 5                                               |         |         |         | 141.9°F |
| LD 6                                               |         |         |         | 141.9°F |
| RD 7                                               |         |         |         |         |
| LD 8                                               |         |         |         |         |
| RD 9                                               |         |         |         |         |
| LD 10                                              |         |         |         |         |
| RD 11                                              |         |         |         |         |

Table XXV. Volumetric Heat Transfer Coefficients with Steam Injected at an Angle of 90°.

| Operating Temperature Range (°F) | Recycle Rate (ft/sec)  | Steam Flow Rate (#/hr) | Volumetric Heat Transfer Coefficient (BTU/sec °F ft <sup>3</sup> ) |
|----------------------------------|------------------------|------------------------|--------------------------------------------------------------------|
| 165-170                          | $7.2 \times 10^{-3}$   | 52.5                   | 7.65                                                               |
| "                                | "                      | 62.5                   | 11.50                                                              |
| "                                | "                      | 77.5                   | 9.09                                                               |
| "                                | "                      | 92.5                   | 10.90                                                              |
| "                                | "                      | 115.0                  | 12.90                                                              |
| "                                | $4.59 \times 10^{-3}$  | 52.5                   | 7.19                                                               |
| "                                | "                      | 62.5                   | 7.08                                                               |
| "                                | "                      | 77.5                   | 9.05                                                               |
| "                                | "                      | 91.8                   | 30.80                                                              |
| "                                | "                      | 115.0                  | 28.01                                                              |
| "                                | $1.965 \times 10^{-3}$ | 52.5                   | 25.60                                                              |
| "                                | "                      | 62.5                   | 29.30                                                              |
| "                                | "                      | 78.3                   | 37.40                                                              |
| "                                | "                      | 93.0                   | 44.00                                                              |
| "                                | "                      | 115.0                  | 42.80                                                              |
| "                                | $0.983 \times 10^{-3}$ | 52.5                   | 7.83                                                               |
| "                                | "                      | 62.5                   | 9.20                                                               |
| "                                | "                      | 78.3                   | 9.78                                                               |
| "                                | "                      | 93.2                   | 14.10                                                              |
| "                                | "                      | 115.0                  | 12.00                                                              |
| 138-145                          | $7.2 \times 10^{-3}$   | 51.0                   | 9.05                                                               |
| "                                | "                      | 62.5                   | 12.35                                                              |
| "                                | "                      | 77.5                   | 13.70                                                              |
| "                                | "                      | 92.5                   | 33.05                                                              |
| "                                | "                      | 115.0                  | 12.90                                                              |
| "                                | $4.59 \times 10^{-3}$  | 52.5                   | 5.99                                                               |
| "                                | "                      | 61.3                   | 8.93                                                               |
| "                                | "                      | 78.2                   | 8.92                                                               |
| "                                | "                      | 92.5                   | 12.40                                                              |
| "                                | "                      | 115.0                  | 13.10                                                              |

Table XXV. (continued)

| Operating<br>Temperature<br>Range (°F) | Recycle Rate<br>(ft/sec) | Steam Flow<br>Rate (#/hr) | Volumetric<br>Heat Transfer<br>Coefficient<br>(BTU/sec °F ft <sup>3</sup> ) |
|----------------------------------------|--------------------------|---------------------------|-----------------------------------------------------------------------------|
| 138-145                                | 1.965 x 10 <sup>-3</sup> | 52.0                      | 6.06                                                                        |
| "                                      | "                        | 61.3                      | 6.73                                                                        |
| "                                      | "                        | 77.5                      | 14.00                                                                       |
| "                                      | "                        | 92.5                      | 9.39                                                                        |
| "                                      | "                        | 115.0                     | 10.40                                                                       |
| "                                      | 0.983 x 10 <sup>-3</sup> | 52.5                      | 4.96                                                                        |
| "                                      | "                        | 61.1                      | 6.99                                                                        |
| "                                      | "                        | 77.5                      | 7.59                                                                        |
| "                                      | "                        | 92.5                      | 11.00                                                                       |
| "                                      | "                        | 115.0                     | 14.85                                                                       |
| 120-131                                | 7.2 x 10 <sup>-3</sup>   | 51.2                      | 5.25                                                                        |
| "                                      | "                        | 62.5                      | 3.95                                                                        |
| "                                      | "                        | 77.5                      | 8.10                                                                        |
| "                                      | "                        | 97.8                      | 14.80                                                                       |
| "                                      | "                        | 115.0                     | 6.80                                                                        |
| "                                      | 4.59 x 10 <sup>-3</sup>  | 51.2                      | 6.71                                                                        |
| "                                      | "                        | 62.5                      | 3.71                                                                        |
| "                                      | "                        | 76.8                      | 5.29                                                                        |
| "                                      | "                        | 93.3                      | 8.21                                                                        |
| "                                      | "                        | 115.0                     | 6.64                                                                        |
| "                                      | 1.965 x 10 <sup>-3</sup> | 52.5                      | 6.86                                                                        |
| "                                      | "                        | 62.5                      | 7.38                                                                        |
| "                                      | "                        | 78.0                      | 5.69                                                                        |
| "                                      | "                        | 93.3                      | 5.59                                                                        |
| "                                      | "                        | 115.0                     | 6.85                                                                        |
| "                                      | 0.983 x 10 <sup>-3</sup> | 49.9                      | 2.76                                                                        |
| "                                      | "                        | 61.8                      | 3.52                                                                        |
| "                                      | "                        | 77.5                      | 7.90                                                                        |
| "                                      | "                        | 93.3                      | 7.30                                                                        |
| "                                      | "                        | 115.0                     | 6.69                                                                        |

Table XXVI. Volumetric Heat Transfer Coefficients with Steam Injected at an Angle of 51°.

| Operating<br>Temperature<br>Range (°F) | Recycle Rate<br>(ft/sec) | Steam Flow<br>Rate (#/hr) | Volumetric<br>Heat Transfer<br>Coefficient<br>(BTU/sec °F ft <sup>3</sup> ) |
|----------------------------------------|--------------------------|---------------------------|-----------------------------------------------------------------------------|
| 160-170                                | 7.2 x 10 <sup>-3</sup>   | 53.75                     | 14.2                                                                        |
| "                                      | "                        | 62.50                     | 8.92                                                                        |
| "                                      | 4.59 x 10 <sup>-3</sup>  | 52.1                      | 7.85                                                                        |
| "                                      | "                        | 62.5                      | 6.85                                                                        |
| "                                      | 1.965 x 10 <sup>-3</sup> | 54.5                      | 9.25                                                                        |
| "                                      | "                        | 62.5                      | 13.15                                                                       |
| "                                      | 0.983 x 10 <sup>-3</sup> | 50.0                      | 8.0                                                                         |
| "                                      | "                        | 62.5                      | 7.5                                                                         |

Table XXVII. Volumetric Heat Transfer Coefficients with Steam Injected at an Angle of  $129^\circ$ .

| Operating<br>Temperature<br>Range ( $^\circ\text{F}$ ) | Recycle Rate<br>(ft/sec) | Steam Flow<br>Rate (#/hr) | Volumetric<br>Heat Transfer<br>Coefficient<br>(BTU/sec $^\circ\text{F ft}^3$ ) |
|--------------------------------------------------------|--------------------------|---------------------------|--------------------------------------------------------------------------------|
| 160-170                                                | $7.2 \times 10^{-3}$     | 43.75                     | 8.16                                                                           |
| "                                                      | "                        | 47.30                     | 8.89                                                                           |
| "                                                      | $4.59 \times 10^{-3}$    | 35.00                     | 6.00                                                                           |
| "                                                      | "                        | 47.30                     | 6.80                                                                           |
| "                                                      | $1.965 \times 10^{-3}$   | 33.50                     | 17.80                                                                          |
| "                                                      | "                        | 42.50                     | 19.50                                                                          |
| "                                                      | $0.983 \times 10^{-3}$   | 25.00                     | 13.00                                                                          |
| "                                                      | "                        | 37.50                     | 8.50                                                                           |

Table XXVIII. Volumetric Heat Transfer Coefficients with Steam Injected in the Countercurrent Addition Method.

| Operating<br>Temperature<br>Range (°F) | Recycle Rate<br>(ft/sec) | Steam Flow<br>Rate (#/hr) | Volumetric<br>Heat Transfer<br>Coefficient<br>(BTU/sec · °F ft <sup>3</sup> ) |
|----------------------------------------|--------------------------|---------------------------|-------------------------------------------------------------------------------|
| 140-155                                | $7.2 \times 10^{-3}$     | 5.00                      | 0.58                                                                          |
| "                                      | "                        | 10.00                     | 0.825                                                                         |
| "                                      | $4.59 \times 10^{-3}$    | 6.20                      | 0.469                                                                         |
| "                                      | "                        | 12.00                     | 0.715                                                                         |
| "                                      | $1.965 \times 10^{-3}$   | 5.80                      | 0.382                                                                         |
| "                                      | "                        | 12.00                     | 0.805                                                                         |
| "                                      | $0.983 \times 10^{-3}$   | 5.80                      | 0.411                                                                         |
| "                                      | "                        | 12.00                     | 0.615                                                                         |

Table XXIX. Volume Movement with Respect to Steam Injection Point. (Steam injected at 90° angle in operating range 165-170°F).

| Height of Transfer Region (in.) | Steam Flow Rate (#/hr) | Recycle Rate (ft/sec)  | Height of Transfer Region Above Injection Point (in.) | Height of Transfer Region Below Injection Point (in.) |
|---------------------------------|------------------------|------------------------|-------------------------------------------------------|-------------------------------------------------------|
| 9.5                             | 52.5                   | $7.2 \times 10^{-3}$   | 1.0                                                   | 8.5                                                   |
| 7.5                             | 62.5                   | "                      | 1.0                                                   | 6.5                                                   |
| 11.5                            | 77.5                   | "                      | 1.0                                                   | 10.5                                                  |
| 11.5                            | 92.5                   | "                      | 1.0                                                   | 10.5                                                  |
| 11.5                            | 115.0                  | "                      | 1.0                                                   | 10.5                                                  |
| 9.5                             | 52.5                   | $4.59 \times 10^{-3}$  | 1.0                                                   | 8.5                                                   |
| 11.5                            | 62.5                   | "                      | 1.0                                                   | 10.5                                                  |
| 11.5                            | 77.5                   | "                      | 1.0                                                   | 10.5                                                  |
| 4.0                             | 91.8                   | "                      | 1.0                                                   | 3.0                                                   |
| 5.5                             | 115.0                  | "                      | 1.0                                                   | 4.5                                                   |
| 3.0                             | 52.5                   | $1.965 \times 10^{-3}$ | 0.0                                                   | 3.0                                                   |
| 3.5                             | 62.5                   | "                      | 1.0                                                   | 2.5                                                   |
| 3.5                             | 78.3                   | "                      | 1.0                                                   | 2.5                                                   |
| 3.5                             | 93.0                   | "                      | 1.0                                                   | 2.5                                                   |
| 4.5                             | 115.0                  | "                      | 4.5                                                   | 0.0                                                   |
| 9.5                             | 52.5                   | $0.983 \times 10^{-3}$ | 4.5                                                   | 5.0                                                   |
| 9.5                             | 62.5                   | "                      | 6.5                                                   | 3.0                                                   |
| 11.5                            | 78.3                   | "                      | 7.0                                                   | 4.5                                                   |
| 9.5                             | 93.2                   | "                      | 6.5                                                   | 3.0                                                   |
| 14.0                            | 115.0                  | "                      | 7.0                                                   | 7.0                                                   |

Table XXX. Volume Movement with Respect to Steam Injection Point. (Steam injected at 90° angle in operating range 138-145°F).

| Height of Transfer Region (in.) | Steam Flow Rate (#/hr) | Recycle Rate (ft/sec)  | Height of Transfer Region Above Injection Point (in.) | Height of Transfer Region Below Injection Point (in.) |
|---------------------------------|------------------------|------------------------|-------------------------------------------------------|-------------------------------------------------------|
| 5.0                             | 51.0                   | $7.2 \times 10^{-3}$   | 0.0                                                   | 5.0                                                   |
| 4.5                             | 62.5                   | "                      | 0.0                                                   | 4.5                                                   |
| 5.0                             | 77.5                   | "                      | 0.0                                                   | 5.0                                                   |
| 2.5                             | 92.5                   | "                      | 0.0                                                   | 2.5                                                   |
| 8.0                             | 115.0                  | "                      | 3.0                                                   | 5.0                                                   |
| 5.5                             | 52.5                   | $4.59 \times 10^{-3}$  | 1.0                                                   | 4.5                                                   |
| 5.5                             | 61.3                   | "                      | 1.0                                                   | 4.5                                                   |
| 10.0                            | 78.2                   | "                      | 1.0                                                   | 9.0                                                   |
| 6.0                             | 92.5                   | "                      | 1.0                                                   | 5.0                                                   |
| 7.0                             | 115.0                  | "                      | 4.5                                                   | 2.5                                                   |
| 7.0                             | 52.0                   | $1.965 \times 10^{-3}$ | 0.0                                                   | 7.0                                                   |
| 7.5                             | 61.3                   | "                      | 4.5                                                   | 3.0                                                   |
| 4.5                             | 77.5                   | "                      | 0.0                                                   | 4.5                                                   |
| 8.0                             | 92.5                   | "                      | 5.0                                                   | 3.0                                                   |
| 9.0                             | 115.0                  | "                      | 6.5                                                   | 2.5                                                   |
| 9.0                             | 52.5                   | $0.983 \times 10^{-3}$ | 4.5                                                   | 4.5                                                   |
| 7.5                             | 61.1                   | "                      | 4.5                                                   | 3.0                                                   |
| 9.0                             | 77.5                   | "                      | 6.5                                                   | 2.5                                                   |
| 7.0                             | 92.5                   | "                      | 7.0                                                   | 0.0                                                   |
| 6.5                             | 115.0                  | "                      | 6.5                                                   | 0.0                                                   |

Table XXXI. Volume Movement with Respect to Steam Injection Point. (Steam injected at 90° angle in operating range 120-131°F).

| Height of Transfer Region (in.) | Steam Flow Rate (#/hr) | Recycle Rate (ft/sec)  | Height of Transfer Region Above Injection Point (in.) | Height of Transfer Region Below Injection Point (in.) |
|---------------------------------|------------------------|------------------------|-------------------------------------------------------|-------------------------------------------------------|
| 6.5                             | 51.2                   | $7.2 \times 10^{-3}$   | 0.0                                                   | 6.5                                                   |
| 10.5                            | 62.5                   | "                      | 0.0                                                   | 10.5                                                  |
| 6.5                             | 77.5                   | "                      | 0.0                                                   | 6.5                                                   |
| 4.5                             | 97.8                   | "                      | 0.0                                                   | 3.0                                                   |
| 11.5                            | 115.0                  | "                      | 4.5                                                   | 7.0                                                   |
| 5.0                             | 51.2                   | $4.59 \times 10^{-3}$  | 0.0                                                   | 5.0                                                   |
| 11.5                            | 62.5                   | "                      | 1.0                                                   | 10.5                                                  |
| 9.5                             | 76.8                   | "                      | 1.0                                                   | 8.5                                                   |
| 7.5                             | 93.3                   | "                      | 1.0                                                   | 6.5                                                   |
| 11.5                            | 115.0                  | "                      | 1.0                                                   | 10.5                                                  |
| 5.0                             | 52.5                   | $1.965 \times 10^{-3}$ | 0.0                                                   | 5.0                                                   |
| 5.5                             | 62.5                   | "                      | 1.0                                                   | 4.5                                                   |
| 9.0                             | 78.0                   | "                      | 4.5                                                   | 4.5                                                   |
| 11.0                            | 93.3                   | "                      | 4.5                                                   | 6.5                                                   |
| 11.0                            | 115.0                  | "                      | 6.5                                                   | 4.5                                                   |
| 11.5                            | 49.9                   | $0.983 \times 10^{-3}$ | 4.5                                                   | 7.0                                                   |
| 11.5                            | 61.8                   | "                      | 6.5                                                   | 5.0                                                   |
| 6.5                             | 77.5                   | "                      | 6.5                                                   | 0.0                                                   |
| 8.5                             | 93.3                   | "                      | 8.5                                                   | 0.0                                                   |
| 11.5                            | 115.0                  | "                      | 8.5                                                   | 3.0                                                   |

Table XXXIII. Volume Movement with Respect to Steam Injection Point. (Steam injected at 51° angle in operating range 160-170°F).

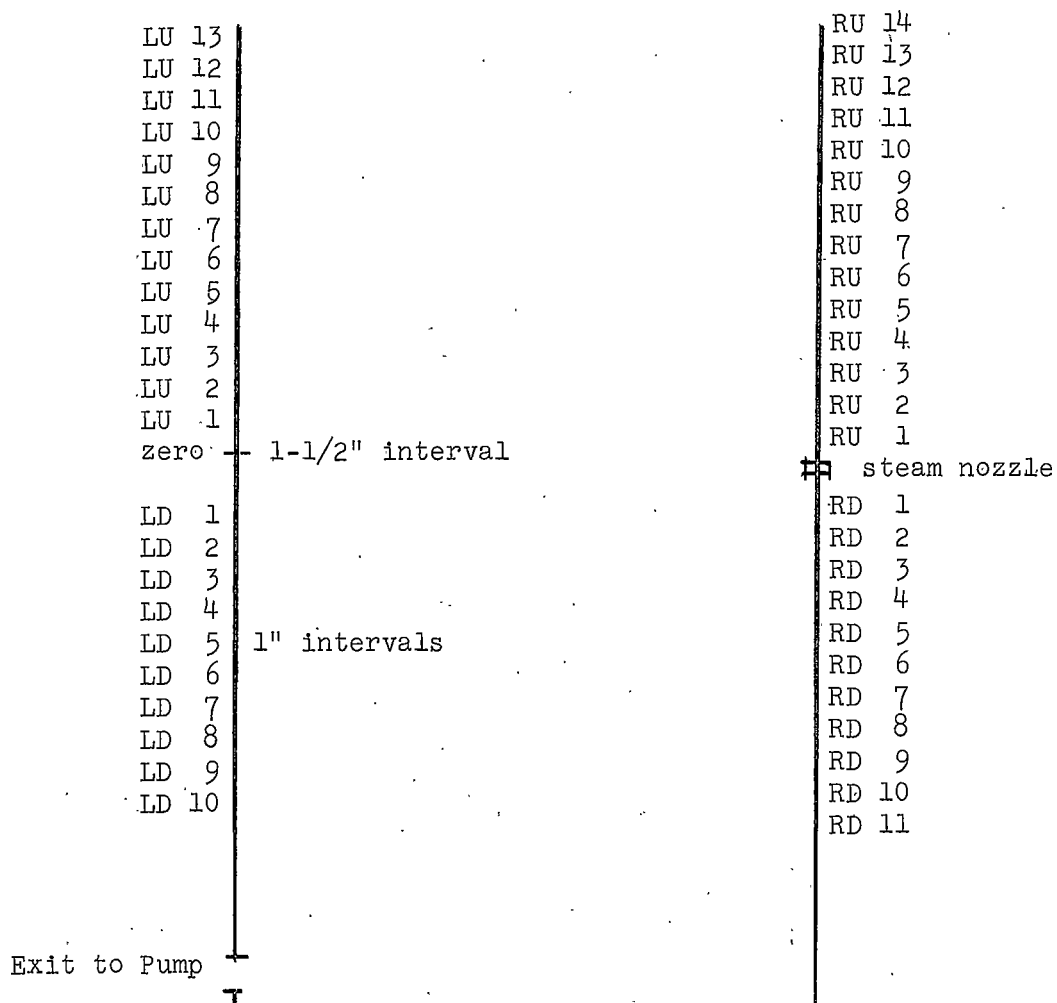
| Height of Transfer Region (in.) | Steam Flow Rate (#/hr) | Recycle Rate (ft/sec)  | Height of Transfer Region Above Injection Point (in.) | Height of Transfer Region Below Injection Point (in.) |
|---------------------------------|------------------------|------------------------|-------------------------------------------------------|-------------------------------------------------------|
| 5.5                             | 42.5                   | $7.2 \times 10^{-3}$   | 2.5                                                   | 3.0                                                   |
| 5.0                             | 53.75                  | "                      | 2.5                                                   | 2.5                                                   |
| 7.5                             | 56.25                  | "                      | 5.0                                                   | 2.5                                                   |
| 9.0                             | 62.5                   | "                      | 6.5                                                   | 2.5                                                   |
| 7.0                             | 46.25                  | $4.59 \times 10^{-3}$  | 2.5                                                   | 4.5                                                   |
| 9.5                             | 52.10                  | "                      | 5.0                                                   | 4.5                                                   |
| 9.0                             | 56.25                  | "                      | 4.5                                                   | 4.5                                                   |
| 13.0                            | 62.50                  | "                      | 6.5                                                   | 6.5                                                   |
| 7.5                             | 47.0                   | $1.965 \times 10^{-3}$ | 4.5                                                   | 3.0                                                   |
| 11.0                            | 28.8                   | "                      | 8.5                                                   | 2.5                                                   |
| 11.0                            | 86.5                   | "                      | 8.5                                                   | 2.5                                                   |
| 8.5                             | 115.0                  | "                      | 8.5                                                   | 0.0                                                   |
| 6.5                             | 37.5                   | $0.983 \times 10^{-3}$ | 6.5                                                   | 0.0                                                   |
| 8.5                             | 50.0                   | "                      | 8.5                                                   | 0.0                                                   |
| 10.5                            | 56.25                  | "                      | 10.5                                                  | 0.0                                                   |
| 10.5                            | 62.5                   | "                      | 10.5                                                  | 0.0                                                   |

Table XXXIII. Volume Movement with Respect to Steam Injection Point. (Steam injected at 129° angle in operating range 160-170°F).

| Height of Transfer Region (in.) | Steam Flow Rate (#/hr) | Recycle Rate (ft/sec)  | Height of Transfer Region Above Injection Point (in.) | Height of Transfer Region Below Injection Point (in.) |
|---------------------------------|------------------------|------------------------|-------------------------------------------------------|-------------------------------------------------------|
| 10.5                            | 31.25                  | $7.2 \times 10^{-3}$   | 0.0                                                   | 10.5                                                  |
| 7.0                             | 43.75                  | "                      | 0.0                                                   | 7.0                                                   |
| 6.5                             | 45.0                   | "                      | 0.0                                                   | 6.5                                                   |
| 7.0                             | 47.3                   | "                      | 0.0                                                   | 7.0                                                   |
| 9.0                             | 31.25                  | $4.59 \times 10^{-3}$  | 0.0                                                   | 9.0                                                   |
| 7.0                             | 35.0                   | "                      | 0.0                                                   | 7.0                                                   |
| 7.0                             | 42.5                   | "                      | 0.0                                                   | 7.0                                                   |
| 8.5                             | 47.3                   | "                      | 0.0                                                   | 8.5                                                   |
| 4.5                             | 26.25                  | $1.965 \times 10^{-3}$ | 0.0                                                   | 4.5                                                   |
| 2.5                             | 33.5                   | "                      | 0.0                                                   | 2.5                                                   |
| 4.5                             | 37.5                   | "                      | 0.0                                                   | 4.5                                                   |
| 3.0                             | 42.5                   | "                      | 0.0                                                   | 3.0                                                   |
| 7.0                             | 18.75                  | $0.983 \times 10^{-3}$ | 0.0                                                   | 7.0                                                   |
| 2.5                             | 25.0                   | "                      | 0.0                                                   | 2.5                                                   |
| 3.0                             | 31.5                   | "                      | 0.0                                                   | 3.0                                                   |
| 5.5                             | 37.5                   | "                      | 3.0                                                   | 2.5                                                   |

Table XXXIV. Volume Movement with Respect to Steam Injection Point. (Steam injected directly into stream flow in operating range 140-155°F.) Countercurrent addition method.

| Height of Transfer Region (in.) | Steam Flow Rate (#/hr) | Recycle Rate (ft/sec)  | Height of Transfer Region Above Injection Point (in.) | Height of Transfer Region Below Injection Point (in.) |
|---------------------------------|------------------------|------------------------|-------------------------------------------------------|-------------------------------------------------------|
| 6.5                             | 2.0                    | $7.2 \times 10^{-3}$   | 6.5                                                   | 0.0                                                   |
| 6.5                             | 5.0                    | "                      | 6.5                                                   | 0.0                                                   |
| 11.0                            | 6.61                   | "                      | 8.5                                                   | 2.5                                                   |
| 11.5                            | 10.0                   | "                      | 8.5                                                   | 3.0                                                   |
| 13.5                            | 13.2                   | "                      | 8.5                                                   | 5.0                                                   |
| 10.0                            | 4.0                    | $4.59 \times 10^{-3}$  | 7.0                                                   | 3.0                                                   |
| 11.5                            | 6.2                    | "                      | 8.5                                                   | 3.0                                                   |
| 13.0                            | 10.0                   | "                      | 8.5                                                   | 4.5                                                   |
| 15.0                            | 12.0                   | "                      | 8.5                                                   | 6.5                                                   |
| 10.0                            | 2.1                    | $1.965 \times 10^{-3}$ | 7.0                                                   | 3.0                                                   |
| 13.0                            | 5.8                    | "                      | 8.5                                                   | 4.5                                                   |
| 13.0                            | 9.6                    | "                      | 10.5                                                  | 2.5                                                   |
| 13.0                            | 12.0                   | "                      | 10.5                                                  | 2.5                                                   |
| 11.0                            | 2.1                    | $0.983 \times 10^{-3}$ | 8.5                                                   | 2.5                                                   |
| 11.5                            | 5.8                    | "                      | 9.0                                                   | 2.5                                                   |
| 13.0                            | 9.6                    | "                      | 10.5                                                  | 2.5                                                   |
| 15.5                            | 12.0                   | "                      | 11.0                                                  | 4.5                                                   |



Three digit code: First, side of condenser (L = left, R = right); Second, position with respect to steam nozzle (0 reference) (D = below, U = above); Last value, number of well on that side and position of condenser. Wells were spaced so that reading could be taken at 1/2-inch intervals.

Figure 1. Condenser Sketch with Thermocouple Well Code.

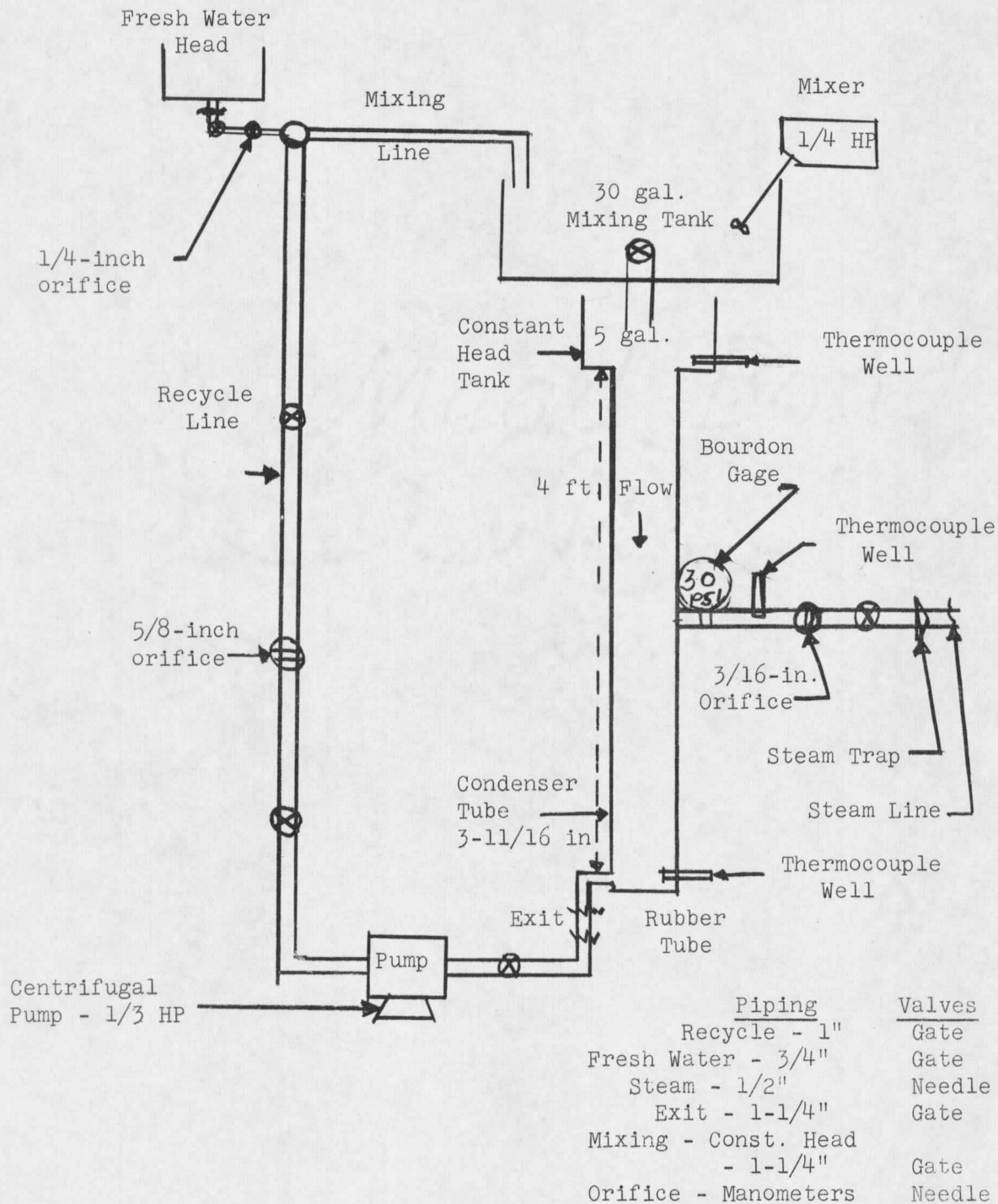


Figure 2. Flow Diagram of Apparatus Used.

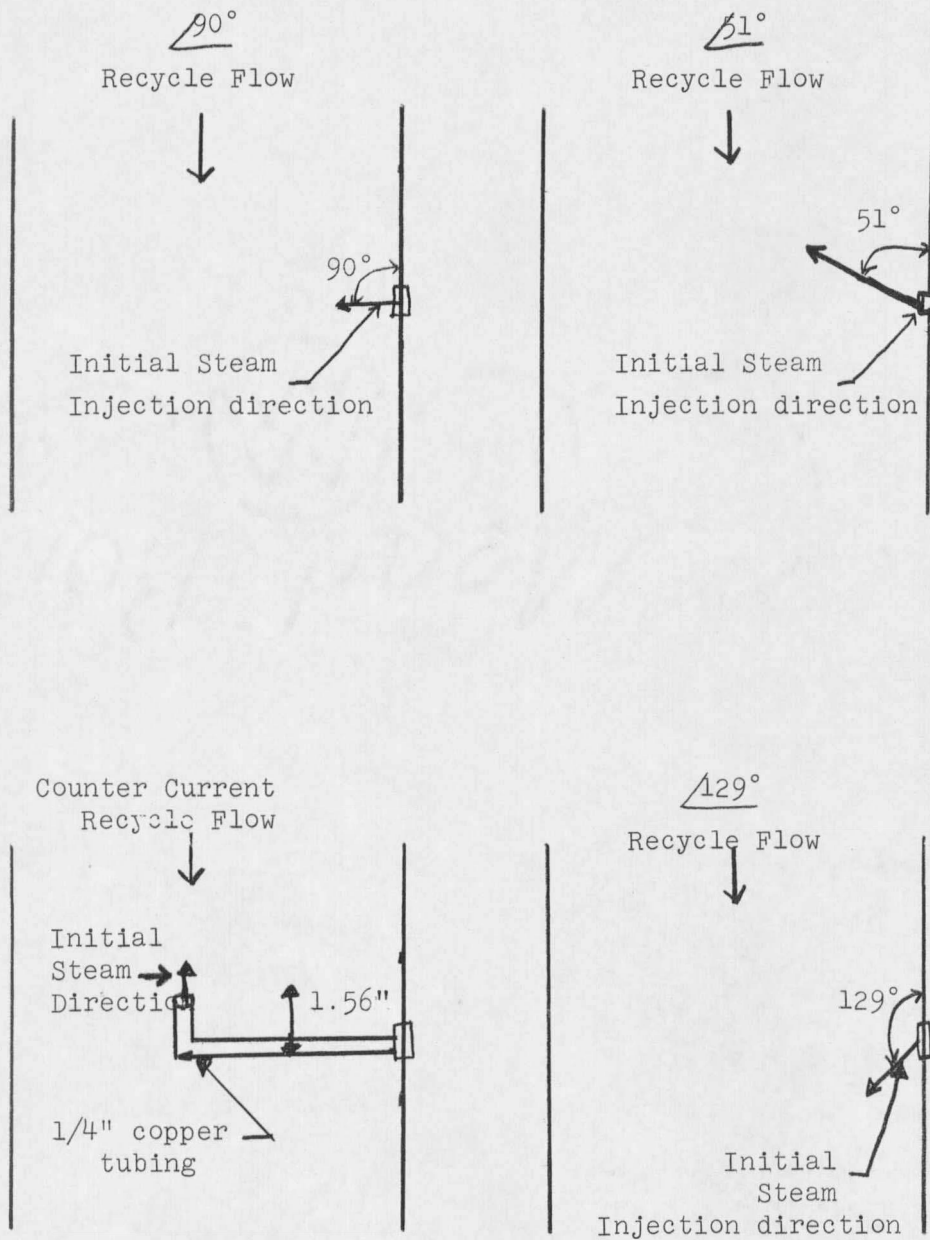
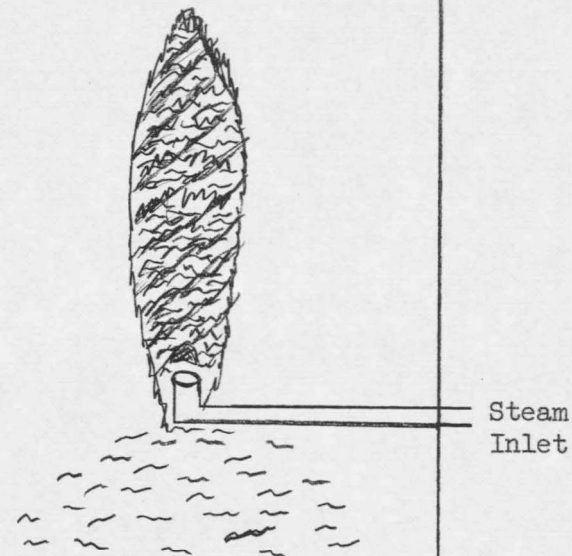


Figure 3. Sketch of Steam Addition Methods.

# Temperature Profiles

|                                                            |                               |      |
|------------------------------------------------------------|-------------------------------|------|
| LU 6                                                       | 143.0 143.2 144.0 143.5 143.0 | RU 7 |
|                                                            |                               | RU 6 |
| LU 5                                                       | 143.3 143.1 144.5 143.1 143.0 | RU 5 |
| LU 4                                                       | 143.0 143.3 145.4 143.8 143.0 | RU 4 |
| LU 3                                                       | 144.0 144.5 147.0 144.4 143.9 | RU 3 |
| LU 2                                                       | 143.3 144.0 147.0 143.5 143.1 | RU 2 |
| LU 1                                                       | 145.0 145.6 148.0 145.5 145.0 | RU 1 |
|                                                            | 143.9 144.2 160.0 144.0 143.7 |      |
| Zero                                                       | 145.1 146.0 150.0 145.9 145.0 | RD 1 |
| LD 1                                                       |                               | RD 2 |
| LD 2                                                       | 145.1 145.1 145.2 145.2 145.1 | RD 3 |
| Exact Distance across condenser in sixths of the diameter. |                               |      |

# Observations



Inner Core Height 3/8 - inch

Figure 4. Temperature Probe of Counter Current Steam Addition Method. Recycle Rate =  $0.983 \times 10^{-3}$  ft/sec. Steam Rate of Flow 12#/hr. Inlet Temperature = 143°F. Exit Temperature = 145.1°F.

(See Figure 1 for nomenclature of this figure.)

| Temperature Profiles |       |       |       |       |       |       |
|----------------------|-------|-------|-------|-------|-------|-------|
|                      | 160.1 | 160.8 | 160.0 | 160.0 | 160.0 | RU 11 |
| LU 10                |       |       |       |       |       | RU 10 |
| LU 9                 |       |       |       |       |       | RU 9  |
| LU 8                 | 163.0 | 162.5 | 162.0 | 161.0 | 160.8 | RU 8  |
| LU 7                 |       |       |       |       |       | RU 7  |
| LU 6                 | 164.5 | 163.5 | 163.0 | 162.5 | 162.0 | RU 6  |
| LU 5                 |       |       |       |       |       | RU 5  |
| LU 4                 | 165.1 | 164.0 | 163.0 | 163.7 | 163.9 | RU 4  |
| LU 3                 | 164.8 | 164.0 | 163.8 | 163.5 | 164.0 | RU 3  |
| LU 2                 | 164.5 | 163.6 | 163.5 | 163.2 | 163.3 | RU 2  |
| LU 1                 | 165.9 | 164.0 | 163.9 | 164.0 | 164.5 | RU 1  |
| Zero                 | 165.7 | 164.5 | 164.3 | 164.3 | 164.5 |       |
|                      | 164.6 | 164.6 | 164.5 | 166.0 | 165.0 |       |
|                      | 166.0 | 166.5 | 167.0 | 167.0 | 167.0 |       |
|                      | 166.0 | 166.5 | 168.0 | 170.0 | 166.0 |       |
|                      | 166.0 | 165.8 | 165.9 | 165.5 | 194.0 |       |

----- indicates temperature fluctuation.

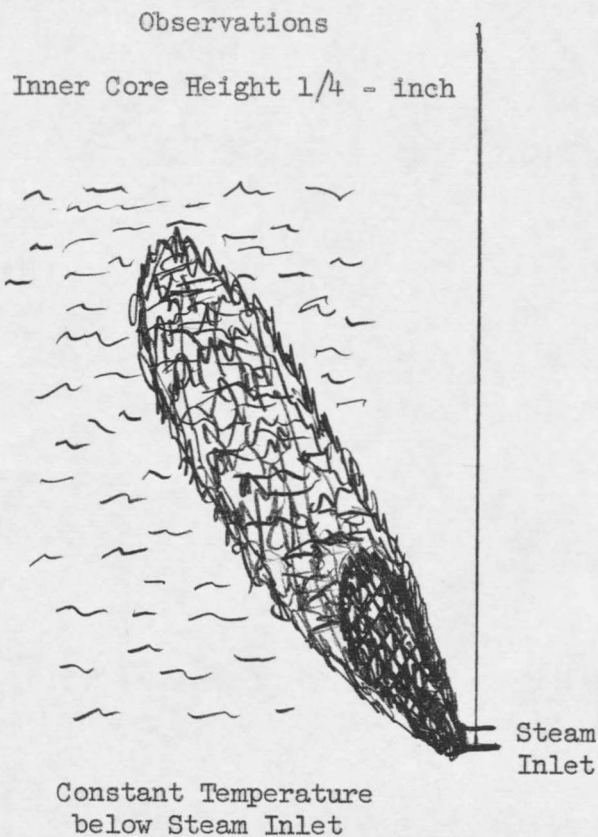


Figure 5. Temperature Probe of Steam Addition Method where the Steam is injected at  $51^\circ$  angle. Recycle Rate =  $0.983 \times 10^{-3}$  ft/sec. Steam Rate of Flow = 62.5 #/hr. Inlet Temperature =  $160^\circ\text{F}$ . Exit Temperature =  $166^\circ\text{F}$ .

(See Figure 1 for nomenclature of this figure.)

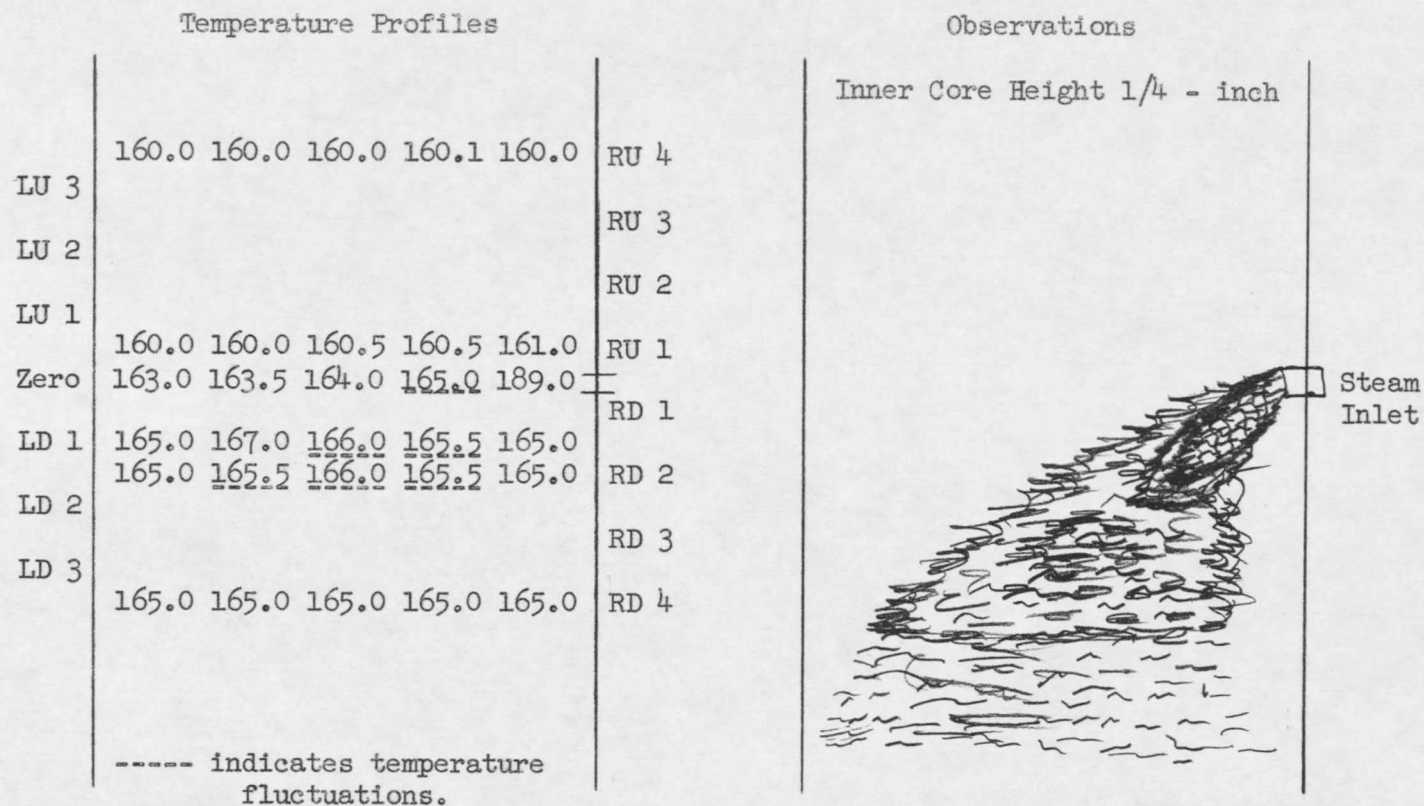


Figure 6. Temperature Probe of Steam Addition Method where the Steam was injected at 129° angle. Recycle Rate =  $0.983 \times 10^{-3}$  ft/sec. Steam Rate of Flow = 37.5 #/hr. Inlet Temperature = 160° F. Exit Temperature = 165° F.

(See Figure 1 for nomenclature of this figure.)

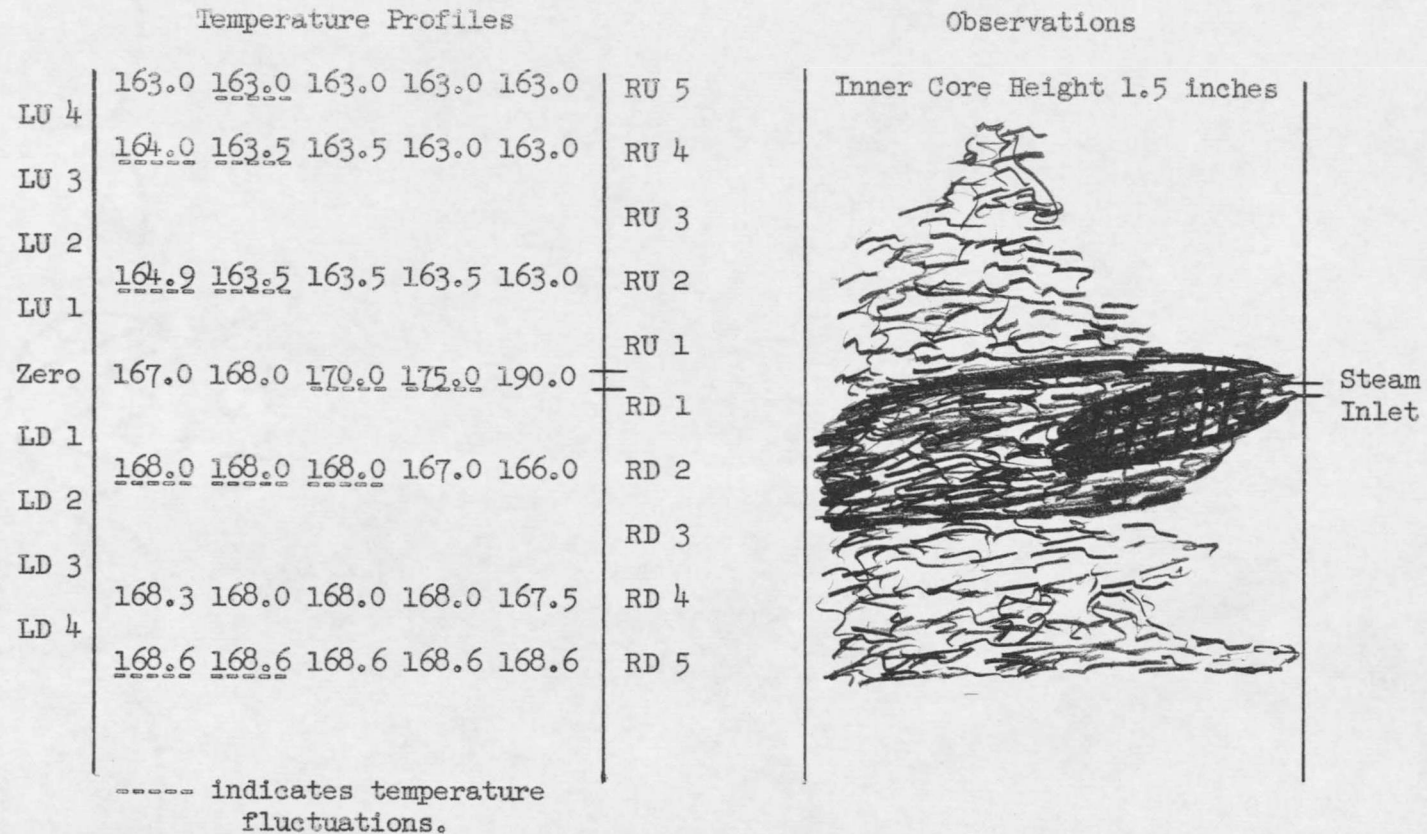


Figure 7. Temperature Profiles of Steam Addition Method where the Steam was injected at an angle of  $90^\circ$ . Recycle Rate =  $0.983 \times 10^{-3}$  ft/sec. Steam Rate of Flow = 115 #/hr. Inlet Temperature =  $163^\circ\text{F}$ . Exit Temperature =  $168.6^\circ\text{F}$ .

(See Figure 1 for nomenclature of this figure.)

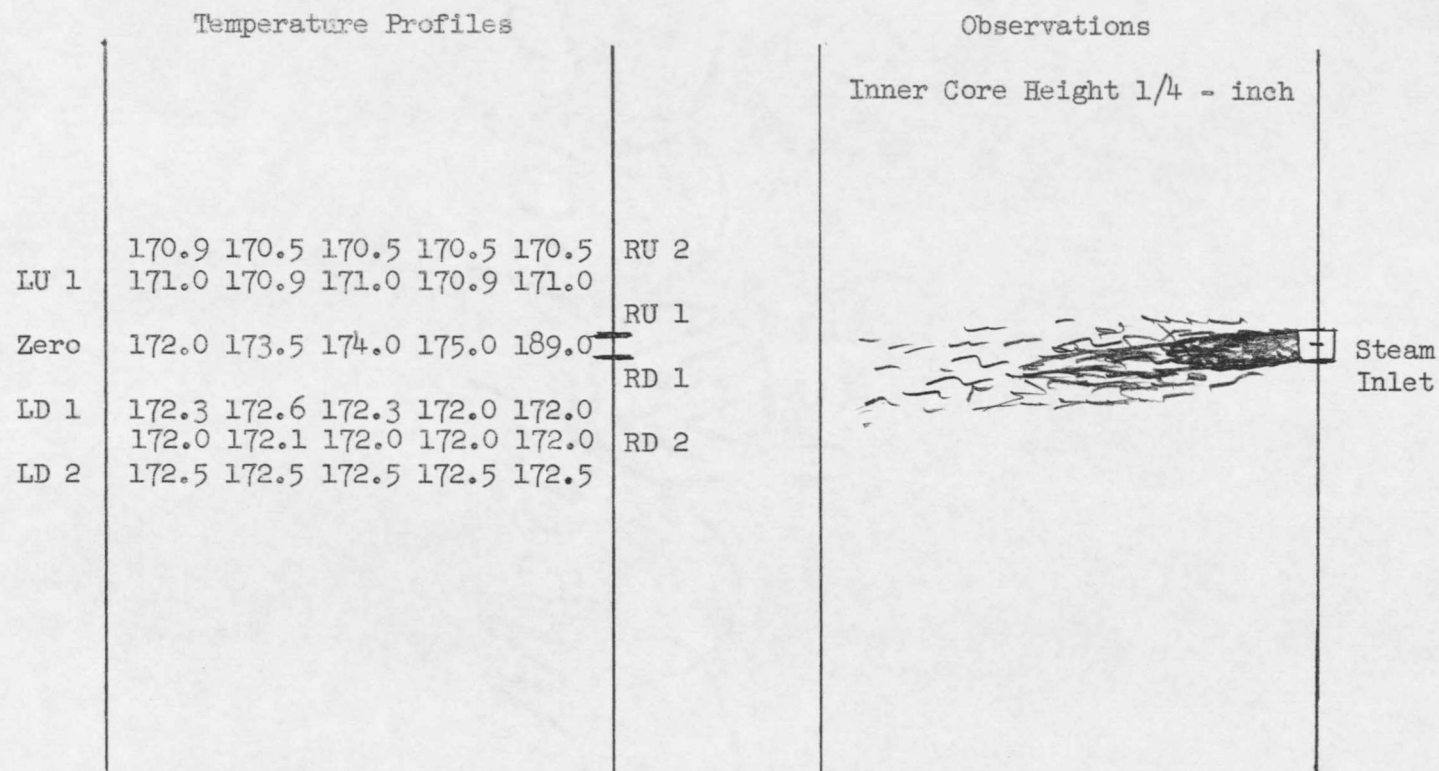


Figure 8. Temperature Profiles of Steam Addition Method where the steam was injected at an angle of  $90^{\circ}$ . Recycle Rate =  $1.965 \times 10^{-3}$  ft/sec. Steam Rate of Flow = 52.5 #/hr. Inlet Temperature =  $170.5^{\circ}\text{F}$ . Exit Temperature =  $172.5^{\circ}\text{F}$ .

(See Figure 1 for nomenclature of this figure.)

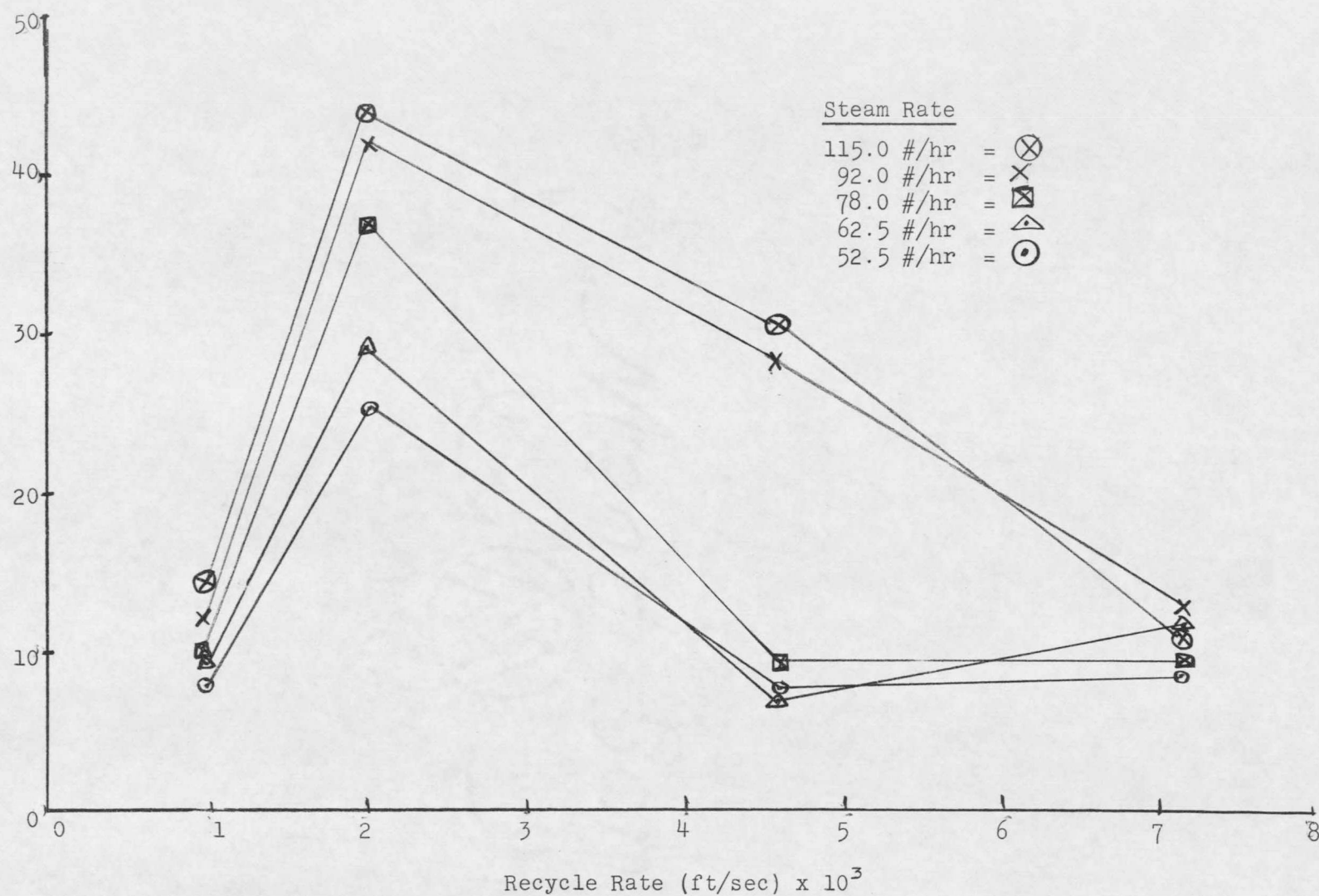


Figure 9. Graph of Volumetric Heat Transfer Coefficient versus Recycle Rate using Steam Rate as a Parameter (for Operating Temperature Range of 165-170°F).

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