

1955

# Effect of hole size on plate efficiency in a perforated plate distillation column

Frank Leonard Kuchinski  
*Lehigh University*

Follow this and additional works at: <https://preserve.lehigh.edu/etd>



Part of the [Chemical Engineering Commons](#)

---

## Recommended Citation

Kuchinski, Frank Leonard, "Effect of hole size on plate efficiency in a perforated plate distillation column" (1955). *Theses and Dissertations*. 4999.  
<https://preserve.lehigh.edu/etd/4999>

This Thesis is brought to you for free and open access by Lehigh Preserve. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of Lehigh Preserve. For more information, please contact [preserve@lehigh.edu](mailto:preserve@lehigh.edu).

EFFECT OF HOLE SIZE  
ON PLATE EFFICIENCY  
IN A  
PERFORATED PLATE DISTILLATION COLUMN

by  
Frank Leonard Kuchinski

A THESIS

Presented to the Graduate Faculty  
of Lehigh University  
in Candidacy for the Degree of  
Master of Science

Lehigh University  
Bethlehem, Pennsylvania

1955

I

UNIVERSITY OF MICHIGAN  
COLLEGE OF ENGINEERING  
ANN ARBOR  
DEPARTMENT OF CHEMICAL ENGINEERING

and  
identified by name of thesis

written and submitted to the  
Department of Chemical Engineering  
in fulfillment of the requirements  
for the degree of Master of Science

by  
Name of Candidate

1955

I

CERTIFICATE OF APPROVAL

This thesis is accepted and approved in  
partial fulfillment of the requirements for the degree  
of Master of Science in Chemical Engineering.

Oct 11, 1955  
Date

L. L. Wenger  
Professor in Charge

Alan S. Faust  
Head of the Department

II

ACKNOWLEDGMENTS

ni havoraga hie hed pece ai nfaedd ahd  
envel sdt uol nmemedines sdt to dremittidit laidre  
enimeriana lromodit ad soneled to weter to

.....  
opradit of nomaodit

.....  
to nmdromit sdt to nmd

ACKNOWLEDGMENTS

This study was suggested and supervised by Dr. L. A. Wenzel to whom the author expresses his appreciation for the technical assistance rendered in the form of comments and criticisms.

The author also wishes to express his gratitude to Lehigh University, for undertaking the cost of equipment and the prompt and courteous services rendered by the library staff. The assistance of W. Szulborski in the machine and shop work required in the construction of the apparatus is also acknowledged.

PERFORATED PLATE COLUMN

This study was suggested and supervised by Dr. J. A. Howell to whom the author expresses his appreciation for the technical assistance rendered in the form of comments and criticisms.

The author also wishes to express his appreciation to the University of Kentucky for providing a stipend of \$1000.00 and the grant and courtesy furnished by the University of Kentucky for the use of the laboratory in the Department of Chemical Engineering in the completion of this investigation.

Gratitude is also expressed

TABLE OF CONTENTS

|  | Page No. |
|--|----------|
| Abstract.....  | 1        |
| Introduction.....  | 2        |
| Literature Review.....   | 4        |
| Experimental Procedure.....  | 10       |
| Apparatus and Materials.....   | 12       |
| Perforated Plate Column Design.....  | 14       |
| Figure I. Diagram of Equipment.....  | 15       |
| Figure II. Photograph of Equipment.....  | 16       |
| Figure III & Plate Holder Design.....  | 18       |
| Figure IV. Plate Holder Design.....  | 19       |
| Figure V. Perforated Plate Assembly-Front<br>View.....   | 21       |
| Figure VI. Photograph of Perforated Plate<br>Assembly, Front View.....   | 22       |
| Data and Results.....  | 26       |
| Table I. Summary of Dry Plate Pressure Drop<br>Data for 1/4, 3/16 Inch Hole<br>Diameter Plate Series.....  | 28       |
| Table II. Summary of Wet Plate Pressure Drop<br>Data for 1/4, 3/16, 1/8 Inch Hole<br>Diameter Plate Series.....                                    | 29       |
| Figure VII. Average Dry and Wet Plate Pressure<br>Drop for 1/4, 3/16, 1/8 Inch Hole<br>Diameter Plate Series Plotted<br>versus Mass Flow Rate..... | 30       |
| Table III. Murphree Plate Efficiency Summary<br>of Distillation Runs for 1/4, 3/16,<br>1/8 Inch Hole Diameter Plate<br>Series.....                 | 31       |
| Discussion of Results.....   | 32       |
| Limitations.....   | 36       |
| Recommendations.....   | 37       |
| Appendix:  |          |
| A. Nomenclature.....   | 38       |
| B. Summary of Design Information for the Per-<br>forated Plate Distillation Column.....  | 40       |

TABLE OF CONTENTS

Page No.

I ..... 1

2 ..... 2

3 ..... 3

4 ..... 4

5 ..... 5

6 ..... 6

7 ..... 7

8 ..... 8

9 ..... 9

10 ..... 10

11 ..... 11

12 ..... 12

13 ..... 13

14 ..... 14

15 ..... 15

16 ..... 16

17 ..... 17

18 ..... 18

19 ..... 19

20 ..... 20

21 ..... 21

22 ..... 22

23 ..... 23

24 ..... 24

25 ..... 25

26 ..... 26

27 ..... 27

28 ..... 28

29 ..... 29

30 ..... 30

31 ..... 31

32 ..... 32

33 ..... 33

34 ..... 34

35 ..... 35

36 ..... 36

37 ..... 37

38 ..... 38

39 ..... 39

40 ..... 40

TABLE OF CONTENTS (cont'd.)

Page No.

Appendix: (cont'd.)

C. Murphree Plate Efficiency Sample Calculation..... 41

D. Equilibrium Curve, MEOH-Water System..... 42

E. Figure VIII. Orifice Calibration Curve..... 43

F. Table IV. Experimental Study Run Data, IV to XI..... 44

G. Bibliography..... 60

.oW apaf

(.b'itnoo) :mibneqA

.....

IA .....noitAleo .0

SA ..... .0

EA ..... .0

..... .0

..... .0

..... .0

ABSTRACT

This report presents the results of distillation runs made in an effort to determine the effect of plate hole size, 1/4, 3/16, and 1/8 inch diameter on Murphree plate efficiency at variable mass flow rate. The system methyl alcohol-water was studied. In the distillation runs, all salient plate design variables and experimental operating conditions were maintained constant.

Mass flow rates ranged from 50-200 lb/hr-ft<sup>2</sup>, 100-170 lb/hr-ft<sup>2</sup>, and 130-150 lb/hr-ft<sup>2</sup> for plates having 1/4, 3/16, and 1/8 inch hole diameters, respectively.

Results show no observed effect of hole diameter or mass flow rate on Murphree plate efficiency for plates 1 and 2 within the range of data obtained in this study. However, for the bottom plate, 3, mass flow rate constant, Murphree plate efficiency increased from 44 percent for the 1/4 inch hole diameter plates to 96 percent for the 1/8 inch hole diameter plate indicating higher plate efficiency for smaller hole diameter perforations.

Correlation of average dry and wet pressure drop data indicate the equation  $P = R ( P + S )$  to be accurate within 5 percent for predicting total plate pressure drop.

INTRODUCTION

Recent research studies made on perforated plate-distillation columns have clearly indicated the numerous advantages this type of tray offers as compared to the conventional bubble-cap plate column. The misbelief of the overall inferiority of the perforated tray is partially attributed to conclusions based on meager design information previously contained in the literature. Chief among these misbeliefs were the limited range of vapor and liquid flows permissible, general lower plate efficiency, and difficulty of operating the column.

Results of Mayfield et al<sup>(8)</sup>, Marsh<sup>(7)</sup>, Ragatz<sup>(11)</sup> have shown perforated trays are more economical and more efficient for many applications as compared to bubble-cap plates. These studies have also resulted in data whereby the design of the perforated plate column can be made with more confidence.

The purpose of this investigation was the design and construction of a perforated plate distillation column with the object of studying the effect of changes in mechanical design features of a perforated plate on plate efficiency. Since the number of mechanical design features which could be studied are rather numerous it is the scope of this report to study the effect of perforation size, 1/4, 3/16, and 1/8 inch diameter, on plate efficiency while maintaining

INTRODUCTION

Recent research studies made on perforated plate-distillation columns have clearly indicated the numerous advantages this type of tray offers as compared to the conventional bubble-cap plate column. The misbelief of the overall inferiority of the perforated tray is partially attributed to conclusions based on meager design information previously contained in the literature. Chief among these misbeliefs were the limited range of vapor and liquid flows permissible, general lower plate efficiency, and difficulty of operating the column.

Results of Mayfield et al<sup>(8)</sup>, Marsh<sup>(7)</sup>, Ragatz<sup>(11)</sup> have shown perforated trays are more economical and more efficient for many applications as compared to bubble-cap plates. These studies have also resulted in data whereby the design of the perforated plate column can be made with more confidence.

The purpose of this investigation was the design and construction of a perforated plate distillation column with the object of studying the effect of changes in mechanical design features of a perforated plate on plate efficiency. Since the number of mechanical design features which could be studied are rather numerous it is the scope of this report to study the effect of perforation size, 1/4, 3/16, and 1/8 inch diameter, on plate efficiency while maintaining

Results of Mayfield et al<sup>(8)</sup>, Marsh<sup>(7)</sup>, Ragatz<sup>(11)</sup> have shown perforated trays are more economical and more efficient for many applications as compared to bubble-cap plates. These studies have also resulted in data whereby the design of the perforated plate column can be made with more confidence.

The purpose of this investigation was the design and construction of a perforated plate distillation column with the object of studying the effect of changes in mechanical design features of a perforated plate on plate efficiency. Since the number of mechanical design features which could be studied are rather numerous it is the scope of this report to study the effect of perforation size, 1/4, 3/16, and 1/8 inch diameter, on plate efficiency while maintaining



DISCUSSION

Recent research has indicated that the most effective method for the separation of the components of a mixture is the use of a gas-liquid chromatographic column. The most common type of column used is the packed column, in which the stationary phase is a solid material supported on an inert carrier. The mobile phase is a gas which flows through the column. The components of the mixture are separated on the basis of their different affinities for the stationary and mobile phases.

The most common type of stationary phase used in gas-liquid chromatography is a solid material supported on an inert carrier. The most common type of mobile phase used is a gas. The components of the mixture are separated on the basis of their different affinities for the stationary and mobile phases.

The most common type of stationary phase used in gas-liquid chromatography is a solid material supported on an inert carrier. The most common type of mobile phase used is a gas. The components of the mixture are separated on the basis of their different affinities for the stationary and mobile phases.

other plate variables constant. Methyl alcohol and water was the system selected to be studied.

metaw hms lodoole lymtem .jnetanoo neMseluv etalq nedto  
Seibude ad of hatoolea metaya erit saw

### LITERATURE REVIEW

Distillation is the separation of the more volatile component of a liquid mixture by a series of vaporizations and subsequent condensations of the more volatile component. Rectification of the more volatile component takes place in the following manner. Vapor in a column passes counter-currently to liquid reflux on a tray and condenses giving up its heat of condensation to the liquid on the tray, resulting in the vaporization of the lower boiling component in the liquid. These series of vaporizations and condensations take place on each tray of the distillation column until finally the vapors leaving the top tray are totally condensed in a condenser. Part of the distillate from the condenser is usually removed as product and the remainder returned to the top of the column as liquid reflux.

The process of distillation is usually performed in a bubble cap, perforated plate or packed type column. A perforated plate differs very little from a bubble cap plate in its operation. Both have the primary function of more efficiently effecting mass transfer of the lower boiling component from the liquid to the vapor and the higher boiling component from the rising vapor to the descending liquid. In a perforated plate vapor bubbles through a large number of small holes through a liquid whereas in a bubble-cap plate vapor bubbles through a series of caps containing slots

PERFORATED TRAY

submerged in the liquid. Vapor bubbling through the perforated tray must support the liquid above it; otherwise liquid will drain to the plate below. In the perforated plate the height of the liquid on the tray is governed by the weir height; in the bubble cap plate liquid height is maintained by the height of the downcomer pipe and does not drain the tray of liquid in the event vapor velocity is not great enough to support it. It is obvious that a minimum gas velocity (weep point) and pressure drop exists, depending on the perforated plate design and operating conditions, below which efficient operation of the perforated plate ceases. For perforated and bubble-cap plates an upper limiting vapor velocity (flood point) exists where the liquid seal in the downcomer is broken resulting in the flooding of the plate and column with liquid.

In the usual procedure for designing a distillation column for a desired rectification, the theoretical (or perfect) plates can be readily calculated by known methods (10,4). The design engineer is handicapped by the unknown relationship existing between the theoretical and actual plates, i.e., overall plate efficiency of the column.

Plate efficiency is usually expressed as overall column efficiency, and Murphree Plate efficiency. The overall column efficiency is defined as the ratio of the number of theoretical plates necessary to produce a given separation to the number of actual plates used to achieve the same separation

submerged in the liquid. Vapor bubbling through the perforated tray must support the liquid above it; otherwise liquid will drain to the plate below. In the perforated plate the height of the liquid on the tray is governed by the weir height; in the bubble cap plate liquid height is maintained by the height of the downcomer pipe and does not drain the tray of liquid in the event vapor velocity is not great enough to support it. It is obvious that a minimum gas velocity (weep point) and pressure drop exists, depending on the perforated plate design and operating conditions, below which efficient operation of the perforated plate ceases. For perforated and bubble-cap plates an upper limiting vapor velocity (flood point) exists where the liquid seal in the downcomer is broken resulting in the flooding of the plate and column with liquid.

In the usual procedure for designing a distillation column for a desired rectification, the theoretical (or perfect) plates can be readily calculated by known methods (10,4). The design engineer is handicapped by the unknown relationship existing between the theoretical and actual plates, i.e., overall plate efficiency of the column.

Plate efficiency is usually expressed as overall column efficiency, and Murphree Plate efficiency. The overall column efficiency is defined as the ratio of the number of theoretical plates necessary to produce a given separation to the number of actual plates used to achieve the same separation

under similar reflux conditions. The Murphree efficiency is defined by the ratio of the actual change in composition, which the vapor undergoes in passing through a plate to the change in composition which it would undergo if it left the plate in equilibrium with the liquid which leaves the plate. A method of relating Murphree plate efficiency to overall column efficiency is given by Perry<sup>(10)</sup>.

In equation form Murphree plate efficiency is expressed as follows:

$$E_m = \frac{y_n - y_{n-1}}{y_n^* - y_{n-1}} \quad (100)$$

where:  $E_m$  = Murphree plate efficiency (percent)  
 $y_n$  = mol fraction of vapor leaving plate n  
 $y_{n-1}$  = mol fraction of vapor leaving plate n-1  
 $y_n^*$  = mol fraction of vapor in equilibrium with liquid leaving plate n

Murphree plate efficiencies more than 100 percent can be obtained when the vapor leaving the plate is richer than the vapor in equilibrium with the liquid leaving the plate. This is possible, especially in large diameter columns, if the vapor leaving the plate is incompletely mixed and is in equilibrium with the liquid leaving the liquid on the inlet weir.

Two of the major factors affecting overall plate efficiency are the mechanical design features of the plate

under similar reflux conditions. The Murphree efficiency is defined by the ratio of the actual change in composition, which the vapor undergoes in passing through a plate to the change in composition which it would undergo if it left the plate in equilibrium with the liquid which leaves the plate. A method of relating Murphree plate efficiency to overall column efficiency is given by Perry<sup>(10)</sup>.

In equation form Murphree plate efficiency is expressed as follows:

$$E_m = \frac{y_n - y_{n-1}}{y_n^* - y_{n-1}} \quad (100)$$

where:  $E_m$  = Murphree plate efficiency (percent)  
 $y_n$  = mol fraction of vapor leaving plate n  
 $y_{n-1}$  = mol fraction of vapor leaving plate n-1  
 $y_n^*$  = mol fraction of vapor in equilibrium with liquid leaving plate n

Murphree plate efficiencies more than 100 percent can be obtained when the vapor leaving the plate is richer than the vapor in equilibrium with the liquid leaving the plate. This is possible, especially in large diameter columns, if the vapor leaving the plate is incompletely mixed and is in equilibrium with the liquid leaving the liquid on the inlet weir.

Two of the major factors affecting overall plate efficiency are the mechanical design features of the plate

In equation form Murphree plate efficiency is expressed as follows:

$$E_m = \frac{y_n - y_{n-1}}{y_n^* - y_{n-1}} \quad (100)$$

- where:  $E_m$  = Murphree plate efficiency (percent)
- $y_n$  = mol fraction of vapor leaving plate n
- $y_{n-1}$  = mol fraction of vapor leaving plate n-1
- $y_n^*$  = mol fraction of vapor in equilibrium with liquid leaving plate n

Murphree plate efficiencies more than 100 percent can be obtained when the vapor leaving the plate is richer than the vapor in equilibrium with the liquid leaving the plate. This is possible, especially in large diameter columns, if the vapor leaving the plate is incompletely mixed and is in equilibrium with the liquid leaving the liquid on the inlet weir.

Two of the major factors affecting overall plate efficiency are the mechanical design features of the plate

under similar conditions. The surface efficiency  
 is defined as the ratio of the actual change in composition  
 which the vapor undergoes in passing through a plate to the  
 change in composition which it would undergo if it left the  
 plate in equilibrium with the liquid which leaves the plate.  
 A number of correlations have been proposed to predict the  
 overall plate efficiency. The following correlation is given  
 by O'Connell<sup>(4)</sup> and is based on the product of the liquid  
 viscosity and the relative volatility at the average column  
 temperature:

$$(O) \quad \frac{1 - \mu^{\frac{1}{2}}}{1 - \mu} = \frac{1 - \mu^{\frac{1}{2}}}{1 - \mu}$$

Drickamer and Bradford<sup>(4)</sup> correlation is based on the viscosity of the feed; Geddes<sup>(4)</sup> uses surface tension, density of liquid, density of vapor and diffusivities of the phases in the mixtures as well as the area of the bubble-cap slot. Gunnes<sup>(4)</sup> uses vapor pressure of feed stock, i.e., properties of the feed. The most recent of these correlations deserving further study is the method of Gerster et al<sup>(3)</sup> using separate gas and liquid film resistances to predict plate efficiency.

Considerable progress has been made recently in determining the effect of the various mechanical design features of a perforated plate. Umholtz<sup>(13)</sup> in his study of overall plate efficiency in a 1.83 and 3 inch diameter perforated plate distillation columns has studied the effect of free space area, percent downcomer area, pitch/diameter ratio of perforations, and perforation size. Nandi and Karim<sup>(9)</sup> using a 2-1/4 inch diameter column studied the effect of

and column, and the physical properties of the mixture being distilled.

Various methods of correlating the physical properties of the mixture with plate efficiency have been presented in the literature. The bases of these correlations are rather varied indicating the complexity of predicting overall plate efficiency. O'Connell's<sup>(4)</sup> correlation uses the product of the liquid viscosity and the relative volatility at the average column temperature; Drickamer and Bradford<sup>(4)</sup> correlation is based on the viscosity of the feed; Geddes<sup>(4)</sup> uses surface tension, density of liquid, density of vapor and diffusivities of the phases in the mixtures as well as the area of the bubble-cap slot. Gunnes<sup>(4)</sup> uses vapor pressure of feed stock, i.e., properties of the feed. The most recent of these correlations deserving further study is the method of Gerster et al<sup>(3)</sup> using separate gas and liquid film resistances to predict plate efficiency.

Considerable progress has been made recently in determining the effect of the various mechanical design features of a perforated plate. Umholtz<sup>(13)</sup> in his study of overall plate efficiency in a 1.83 and 3 inch diameter perforated plate distillation columns has studied the effect of free space area, percent downcomer area, pitch/diameter ratio of perforations, and perforation size. Nandi and Karim<sup>(9)</sup> using a 2-1/4 inch diameter column studied the effect of

and column, and the physical properties of the mixture being distilled.

Various methods of correlating the physical properties of the mixture with plate efficiency have been proposed. The literature in this field is extensive and it is not possible to review it here. However, the following methods are mentioned:

(1) The liquid viscosity and the liquid density are used to correlate the efficiency of the column. This method is based on the viscosity of the liquid and the density of the liquid.

(2) The surface tension of the liquid and the density of the liquid are used to correlate the efficiency of the column. This method is based on the surface tension of the liquid and the density of the liquid.

(3) The surface tension of the liquid, the density of the liquid, and the viscosity of the liquid are used to correlate the efficiency of the column. This method is based on the surface tension of the liquid, the density of the liquid, and the viscosity of the liquid.

(4) The surface tension of the liquid, the density of the liquid, and the viscosity of the liquid are used to correlate the efficiency of the column. This method is based on the surface tension of the liquid, the density of the liquid, and the viscosity of the liquid.

(5) The surface tension of the liquid, the density of the liquid, and the viscosity of the liquid are used to correlate the efficiency of the column. This method is based on the surface tension of the liquid, the density of the liquid, and the viscosity of the liquid.

(6) The surface tension of the liquid, the density of the liquid, and the viscosity of the liquid are used to correlate the efficiency of the column. This method is based on the surface tension of the liquid, the density of the liquid, and the viscosity of the liquid.

distillation rate, free space area, plate spacing, weir height, and perforation size on overall plate efficiency. Arnold et al<sup>(1)</sup> using a 15 inch diameter column studied pressure drop behavior of perforated trays (using air and water) by varying weir height, perforation size, free space area, and L/G ratios. Mayfield et al<sup>(8)</sup> using a 6 inch diameter column studied pressure drop behavior of perforated plates (using air) by varying the perforation size. In addition using a 6.5 foot diameter column data were obtained (using air-water) relating pressure drop, weir height, and L/G ratios.

In spite of these recent studies previously mentioned, attempts to correlate mechanical plate design features with the physical properties of the liquid in an effort to predict plate efficiency have as yet not been successful. The main reason being the complex nature of mass transfer between the vapor and liquid phases as a result of the changing physical phenomena of the vapor-liquid interaction as the mass flow rate is varied.

This vapor-liquid interaction can best be described as the foaming or frothing which a liquid undergoes on and above a plate as the mass flow rate is varied. Visual observation of a distillation tray in stable operation indicates three zones of different foam density. A highly agitated foam layer through which bubbles form and rise through the liquid, a zone of dense droplets, and finally a zone composed of a fine mist.

The mass transfer in these three zones is dependent upon the vapor and liquid film resistances, concentration gradient and surface area between the two phases. Gerster et al<sup>(3)</sup> has attempted to relate foam height with mass flow rate and the overall mass transfer coefficient in an effort to predict overall plate efficiency. West et al<sup>(14)</sup> elaborating on the equation proposed by Gerster et al<sup>(3)</sup> expressed the foam height in terms of fraction voids in the foam. In addition interfacial area was expressed as a function of volume of foam. It is believed that if plate efficiency data for a variety of liquids be obtained as a function of mass flow rate and utilizing the proposed methods of Gerster et al and West et al plate efficiency for any system could be calculated with relative ease and accuracy.

Mass transfer in these three zones is dependent upon the vapor and liquid film resistances, concentration gradient and surface area between the two phases. Gerster et al<sup>(3)</sup> has attempted to relate foam height with mass flow rate and the overall mass transfer coefficient in an effort to predict overall plate efficiency. West et al<sup>(14)</sup> elaborating on the equation proposed by Gerster et al<sup>(3)</sup> expressed the foam height in terms of fraction voids in the foam. In addition interfacial area was expressed as a function of volume of foam. It is believed that if plate efficiency data for a variety of liquids be obtained as a function of mass flow rate and utilizing the proposed methods of Gerster et al and West et al plate efficiency for any system could be calculated with relative ease and accuracy.

EXPERIMENTAL PROCEDURE

The object of this study was the design and construction of a perforated plate distillation column to determine the effect of plate hole size, 1/4, 3/16, and 1/8 inch diameter on Murphree plate efficiency. Methyl alcohol and water was the system selected to be studied in lieu of published equilibrium, density and refractive index data which was readily available.

Plans were to hold all salient plate design variables constant, except hole size, and perform distillation runs under constant operating conditions while varying the mass flow rate through the column. Plate design variables which efficiency is believed to be affected by and which were maintained constant are:

1. Weir height ----- 1/2 inch
2. Weir length ----- 5 inches
3. Column diameter, I.D. ----- 8.25 inches
4. Plate spacing ----- 9.5 inches
5. Perforated plate thickness --- .029 inches
6. Pitch/diameter of holes ----- 3.8
7. Percent downcomer area ----- 0.826
8. Baffle arrangement ----- 3/8 inch above perforated plate and 5/16 inches from weir. Height of baffle 5 inches.
9. Percent free space area ----- 1.17

Conditions at which the experiments were performed are: concentration of kettle charge 25 percent methanol-75 percent (weight % ~~water~~), atmospheric pressure, and constant L/G ratio, i.e., total reflux. The temperature of the reflux was maintained constant  $\pm 0.5^{\circ}\text{F}$  and 2-3 degrees below the boiling point of methanol.



EXPERIMENTAL PROCEDURE

The object of this study was to determine the effect of the number of plates on the efficiency of a distillation column.

The distillation column was constructed of glass sections, each section being 18 inches high and 2 inches in diameter. The sections were connected by means of ground glass joints. The column was supported by a metal stand.

The feed liquid was a mixture of methanol and water. The feed rate was controlled by a stopcock. The temperature of the feed was maintained at 25°C.

The vapor leaving the top of the column was condensed in a water-cooled condenser.

The liquid leaving the condenser was collected in a graduated cylinder. The volume of liquid collected was measured.

The composition of the liquid leaving the condenser was determined by means of a refractometer. The refractive index was measured at 25°C. The refractive index of pure methanol is 1.3262 and that of pure water is 1.3330.

The composition of the vapor leaving the top of the column was determined by means of a gas chromatograph.

|                                   |                               |
|-----------------------------------|-------------------------------|
| Feed composition                  | 0.50                          |
| Distillate composition            | 0.95                          |
| Bottoms composition               | 0.05                          |
| Feed rate (g/hr)                  | 100                           |
| Distillate rate (g/hr)            | 80                            |
| Bottoms rate (g/hr)               | 20                            |
| Number of plates                  | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 |
| Refractive index of distillate    | 1.3262                        |
| Refractive index of bottoms       | 1.3330                        |
| Refractive index of feed          | 1.3291                        |
| Refractive index of vapor         | 1.3262                        |
| Refractive index of liquid        | 1.3330                        |
| Refractive index of mixture       | 1.3291                        |
| Refractive index of pure methanol | 1.3262                        |
| Refractive index of pure water    | 1.3330                        |
| Refractive index of 50% mixture   | 1.3291                        |
| Refractive index of 10% mixture   | 1.3310                        |
| Refractive index of 90% mixture   | 1.3272                        |

The results of the experiment are shown in the following table.

The efficiency of the column was determined by means of the Murphree plate efficiency equation.

The efficiency of the column was found to be a function of the number of plates. The efficiency increased with the number of plates. The efficiency was 0.15 for one plate, 0.30 for two plates, 0.45 for three plates, 0.60 for four plates, 0.75 for five plates, 0.85 for six plates, 0.90 for seven plates, 0.92 for eight plates, 0.93 for nine plates, and 0.94 for ten plates.

The following table shows the efficiency of the column for different numbers of plates.

The glass portions of the distillation column were wrapped with two layers of glass wool asbestos, with the exception of approximately four square inches of the front of each glass section. This unwrapped section was covered with a piece of plexiglass through which plate distillation phenomena could be easily observed.

Samples of liquid and vapor leaving each plate were taken after steady state column operating conditions were reached. Using a refractometer all samples were analyzed for percent methanol, from these data Murphree plate efficiency could be readily calculated.

The apparatus employed in this investigation consists mainly of the perforated plate distillation column and steam boiler. Only essential information relative to the auxiliary apparatus will be listed below:

Pyrex Glass Cylinders. Four required, 8.25 inch inside diameter, 0.25 inches thick, 9.5 inches in height. Originally purchased from Hawshaw Scientific Glass Co. as battery jars. Battery jars were cut to size by Pittsburgh Plate & Glass Co., Allentown, Pa.

Brass Plate Holders. Five required, 12 x 12 x 3/8 inches. Brass sheet 0.029 inches thick, used for the distillation plate. Purchased from Whitehead Metals Co., Philadelphia, Pa.

Plate Gaskets. Teflon impregnated asbestos-3 ply, 9 inch outside diameter, 8 inch inside diameter. Manufactured by Johns-Manville Corp., Manville, N. J.

Distillation Kettle. Glass lined, 18 inch I.D., 25 inches in height, 75 psig jacket pressure, total heating surface 10 ft<sup>2</sup>. Manufactured by Pflauser & Co., Rochester, N.Y.

Refractometer. Abbe 56, Manufactured by Bausch & Lomb, Rochester, N. Y.

Steam Boiler. Gas fired, 5 H.P. Mfgs. Steam Rating. Used to supply steam to jacket of distillation kettle. Manufactured by Mears-Kane-Ofeldt, Inc., Philadelphia, Pa.

APPARATUS AND MATERIALS

The apparatus employed in this investigation consists mainly of the perforated plate distillation column and steam boiler. Only essential information relative to the auxiliary apparatus will be listed below:

Pyrex Glass Cylinders. Four required, 8.25 inch inside diameter, 0.25 inches thick, 9.5 inches in height. Originally purchased from Hawshaw Scientific Glass Co. as battery jars. Battery jars were cut to size by Pittsburgh Plate & Glass Co., Allentown, Pa.

Brass Plate Holders. Five required, 12 x 12 x 3/8 inches. Brass sheet 0.029 inches thick, used for the distillation plate. Purchased from Whitehead Metals Co., Philadelphia, Pa.

Plate Gaskets. Teflon impregnated asbestos-3 ply, 9 inch outside diameter, 8 inch inside diameter. Manufactured by Johns-Manville Corp., Manville, N. J.

Distillation Kettle. Glass lined, 18 inch I.D., 25 inches in height, 75 psig jacket pressure, total heating surface 10 ft<sup>2</sup>. Manufactured by Pflauser & Co., Rochester, N.Y.

Refractometer. Abbe 56, Manufactured by Bausch & Lomb, Rochester, N. Y.

Steam Boiler. Gas fired, 5 H.P. Mfgs. Steam Rating. Used to supply steam to jacket of distillation kettle. Manufactured by Mears-Kane-Ofeldt, Inc., Philadelphia, Pa.



Technical Report  
No. 100

### PERFORATED PLATE COLUMN DESIGN

The ideal column for this experimental study should be simple in construction to allow frequent changes in plate design, small enough to obtain reasonable boilup rates, permit close observation of the distillation process, and yet not be too costly. In Figure I, page 15, is shown a flow diagram and Figure II, page 16, a photograph of the perforated plate column and apparatus used in the experimental study.

#### SELECTION OF COLUMN SIZE

A four-plate column (2), 8-1/4 inch I.D. pyrex glass cylinders, 9-1/4 inches in height was selected and found to be commensurate with the boilup expected using a steam jacketed glass-lined kettle and heat available from the steam main.

#### CONDENSER SPECIFICATIONS

On the basis of the boilup of methanol expected from a 5 HP steam boiler and using a steam jacketed glass-lined kettle a condenser was designed. The specifications of this condenser are as follows: horizontal, single pass, counterflow, with vapor condensing in the shell and water flowing through the copper tubes. Tubes, eight 5/8 inch O.D., shell I.D. 2-3/4 inches, tube length 32 inches, total tube surface area 3.50 ft<sup>2</sup>.

#### REFLUX TEMPERATURE CONTROL SYSTEM

An automatic reflux temperature control system was

FIELD EXPERIMENTAL APPARATUS

Второй жидкий конденсатор имеет тот же диаметр, что и первый, но его высота составляет 100 см. В нем установлен рефлюксный ротатор, который позволяет регулировать скорость рефлюкса. В нижней части конденсатора установлен ротатор для дистиллята. Выходной поток дистиллята проходит через ротатор и попадает в приемный сосуд. Выходной поток конденсата проходит через ротатор и попадает в приемный сосуд. Выходной поток пара проходит через ротатор и попадает в приемный сосуд.

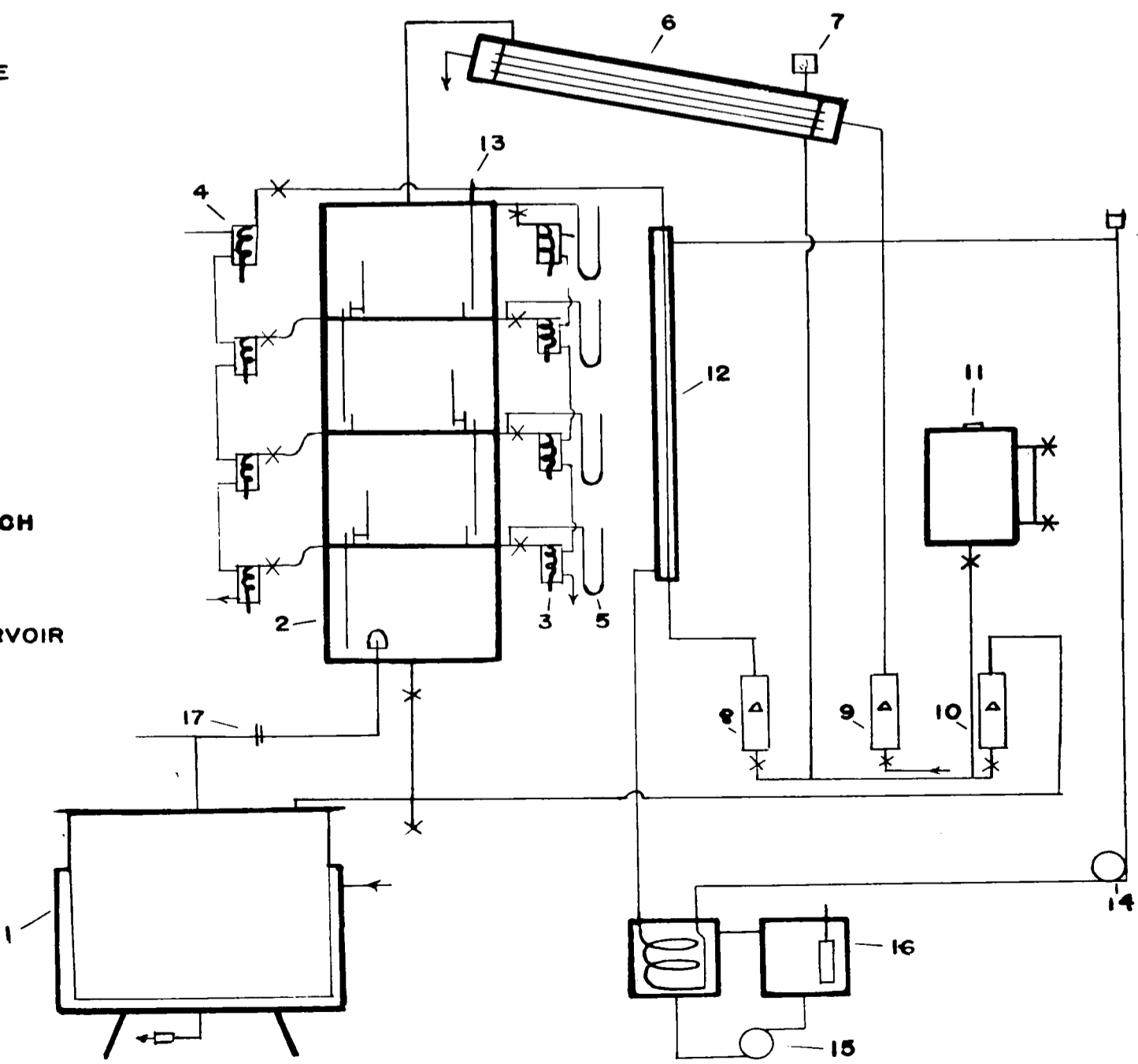
Второй жидкий конденсатор имеет тот же диаметр, что и первый, но его высота составляет 100 см. В нем установлен рефлюксный ротатор, который позволяет регулировать скорость рефлюкса. В нижней части конденсатора установлен ротатор для дистиллята. Выходной поток дистиллята проходит через ротатор и попадает в приемный сосуд. Выходной поток конденсата проходит через ротатор и попадает в приемный сосуд. Выходной поток пара проходит через ротатор и попадает в приемный сосуд.

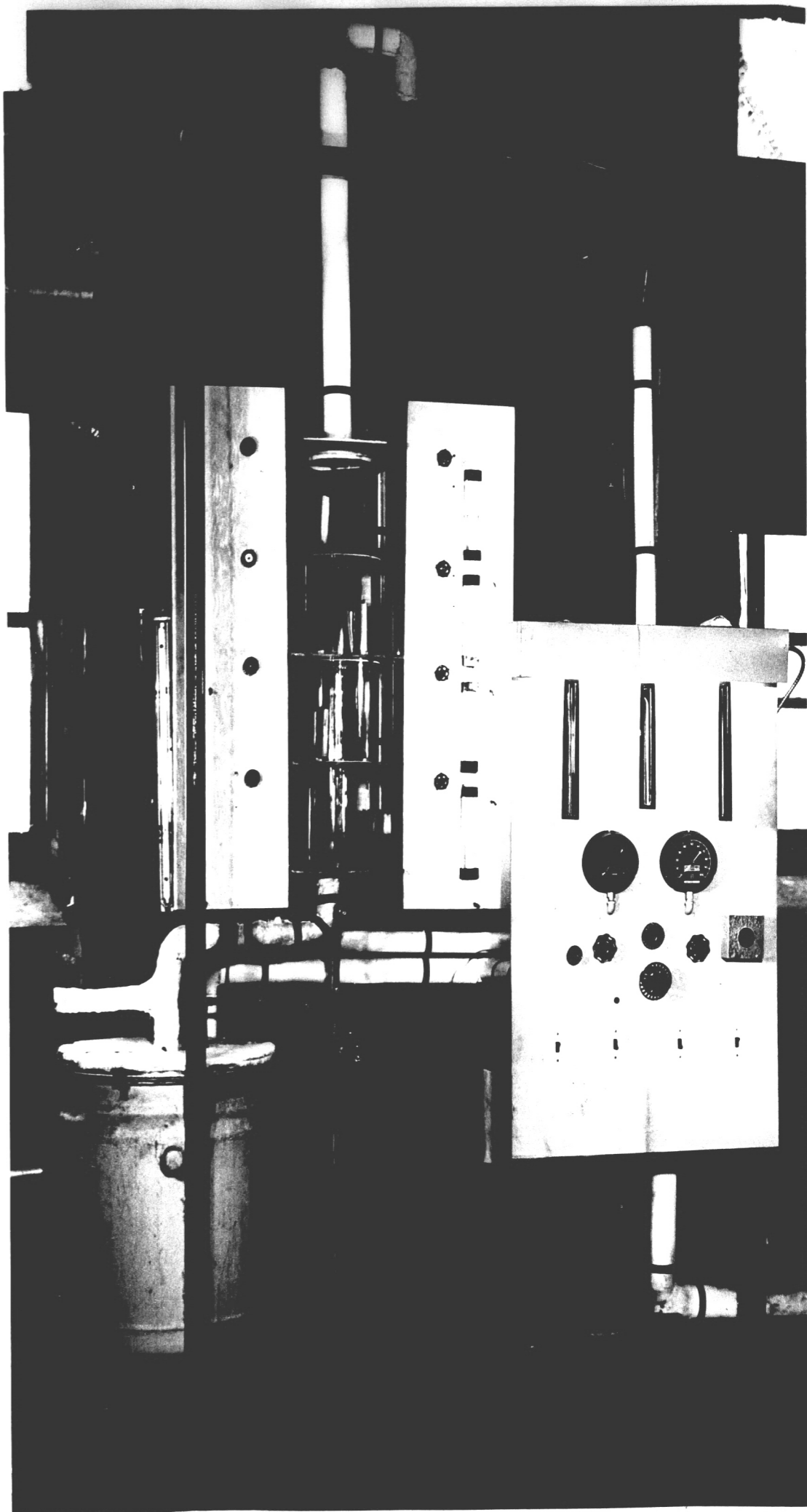
Второй жидкий конденсатор имеет тот же диаметр, что и первый, но его высота составляет 100 см. В нем установлен рефлюксный ротатор, который позволяет регулировать скорость рефлюкса. В нижней части конденсатора установлен ротатор для дистиллята. Выходной поток дистиллята проходит через ротатор и попадает в приемный сосуд. Выходной поток конденсата проходит через ротатор и попадает в приемный сосуд. Выходной поток пара проходит через ротатор и попадает в приемный сосуд.

Второй жидкий конденсатор имеет тот же диаметр, что и первый, но его высота составляет 100 см. В нем установлен рефлюксный ротатор, который позволяет регулировать скорость рефлюкса. В нижней части конденсатора установлен ротатор для дистиллята. Выходной поток дистиллята проходит через ротатор и попадает в приемный сосуд. Выходной поток конденсата проходит через ротатор и попадает в приемный сосуд. Выходной поток пара проходит через ротатор и попадает в приемный сосуд.

FIGURE I. DIAGRAM OF EQUIPMENT

- 1 STEAM JACKETED KETTLE
- 2 COLUMN
- 3 VAPOR CONDENSERS
- 4 LIQUID CONDENSERS
- 5 MANOMETERS
- 6 CONDENSER
- 7 VENT & BUBBLER
- 8 REFLUX ROTO
- 9 CONDENSER ROTO
- 10 DISTILLATE ROTO
- 11 CHARGE TANK
- 12 REFLUX HEATER
- 13 FENWALL THERMOSWITCH
- 14 RECYCLE PUMP
- 15 RESERVOIR PUMP
- 16 REFLUX HEATER RESERVOIR
- 17 ORIFICE





designed to maintain the reflux temperature  $\pm 0.5^{\circ}\text{F}$  and to within  $2-3^{\circ}\text{F}$  of the boiling point of methanol. Temperature of the reflux was controlled by a fenwall thermostat located at the top of the column. By means of the fenwall thermostat (13) and a relay, a pump and an immersion heater (1000 watts) were turned on. The reservoir pump (15) recycled hot water from the reflux heater reservoir to a constant temperature reservoir in which was located a heat exchanger. Another pump (14) recycled water through the heat exchanger located in the constant temperature reservoir to the heat exchanger through which the reflux flowed. When the temperature of the reflux was up to the desired temperature, the fenwall thermostat through the relay turned the reservoir pump (15) and immersion heater off, the recycle pump being in continual operation throughout the distillation run.

#### PLATE HOLDER DESIGN

Selection of the 12 x 12 x 3/8 inch brass plate was made on the basis of the ease at which brass could be machined. In the layout of the plate holders, calculations were based on obtaining maximum perforation area. With cross flow of liquid and using weirs, 58.2 percent perforation area was obtained. Figures III and IV, pages 18 and 19, show the details of construction of the five plate holders. Plate holder four is identical to plate holder two and is not shown in the drawings.





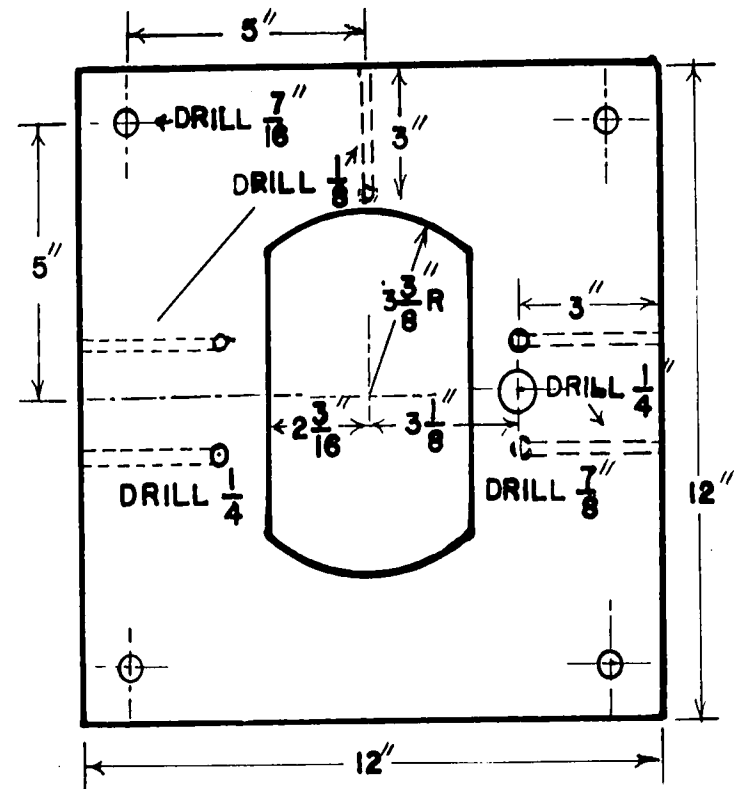


PLATE HOLDER-3

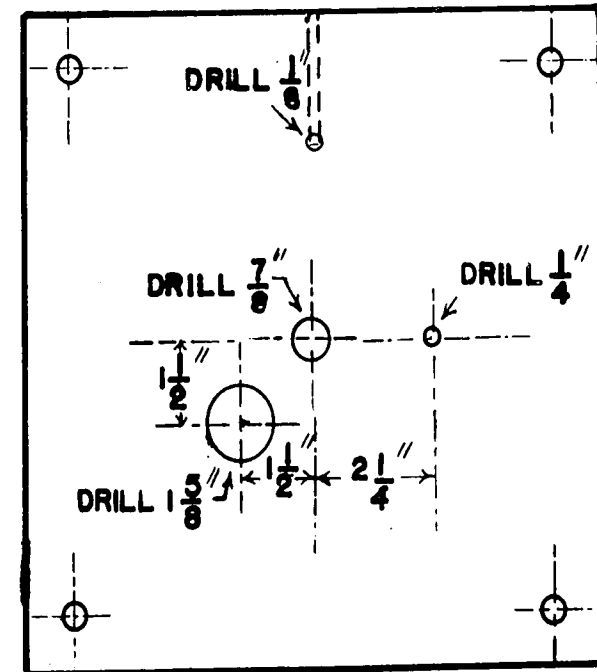


PLATE HOLDER-5

FIGURE IV.

SCALE 1 = 4

### PLATE DESIGN

Selection of the percent free space area (1.17) was made by calculating the maximum mass flow rate,  $G$ , and computing the pressure drop across each tray by fixing the weir height, weir length, percent downcomer area, and baffle arrangement.

The pressure drop calculation consists of two (main) components, namely, the pressure drop as a result of vapor flowing through the perforations and the height of the liquid on the tray. To the liquid depth above the tray, the height of calculated weir head is added a correction called an "aeration factor"<sup>(2)</sup>. The aeration factor being defined as the ratio of the observed pressure drop through the liquid on the tray to the calculated clear liquid on the tray. For purposes of design of this plate an aeration factor of 1.0 was used. Essentially this aeration factor takes into consideration the foaming characteristics of the liquid. To calculate aeration factors, the observed pressure drop through the liquid is obtained as the difference between the total observed pressure drop and the observed dry-tray pressure drop at the same air rate.

The computed pressure drop calculated in the above manner would have to be sufficiently large to overcome the resistance the vapors would be subjected to in passing through the perforations in addition to supporting the liquid above

PERFORATED PLATE

(VI.I) same design with diameter of 20 centimeters

... design of vapor flow ...

... distance between plates ...

... design of ...

... design of ...

... design of ...

... design of ...

... design of ...

... design of ...

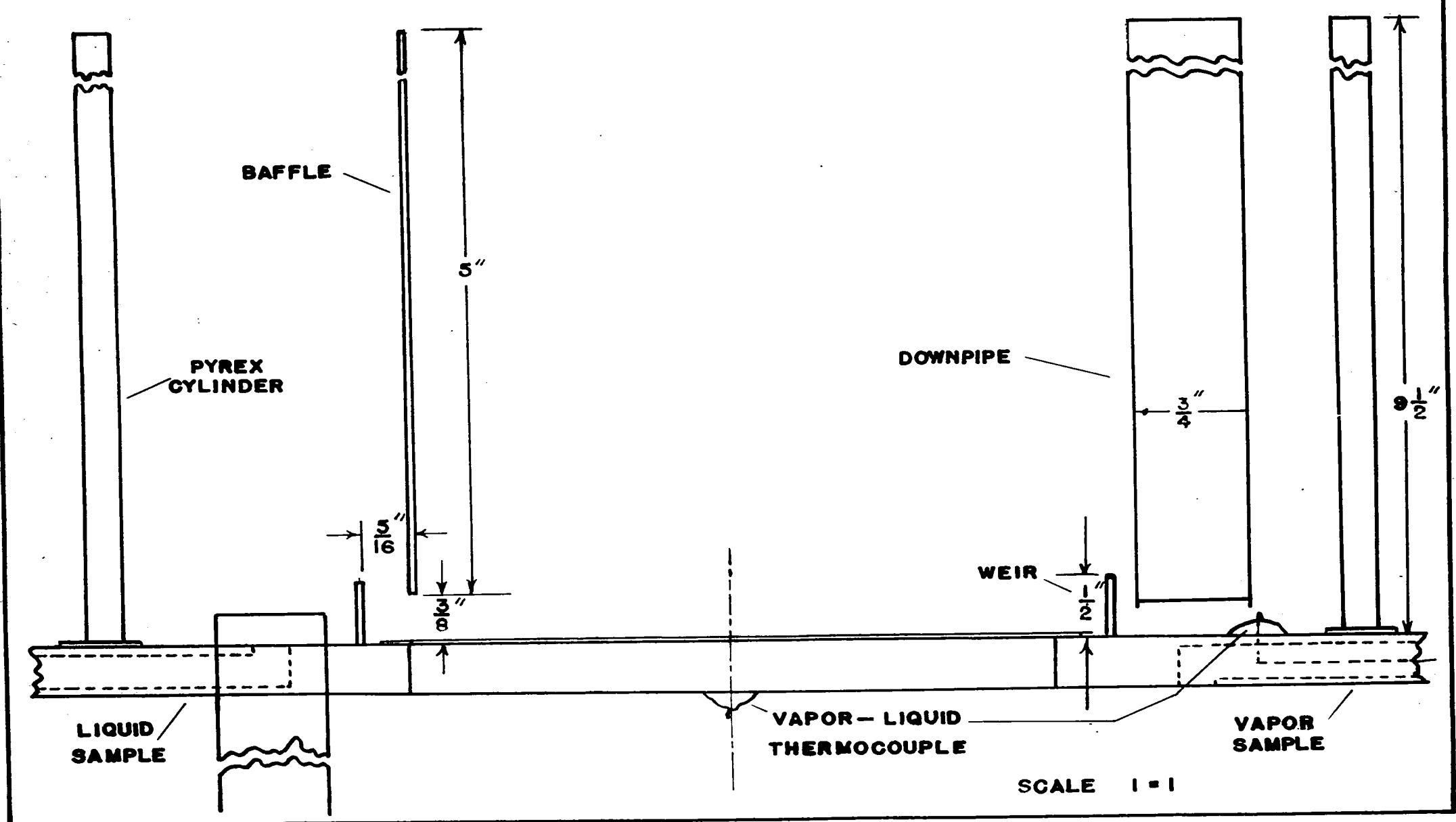
... design of ...

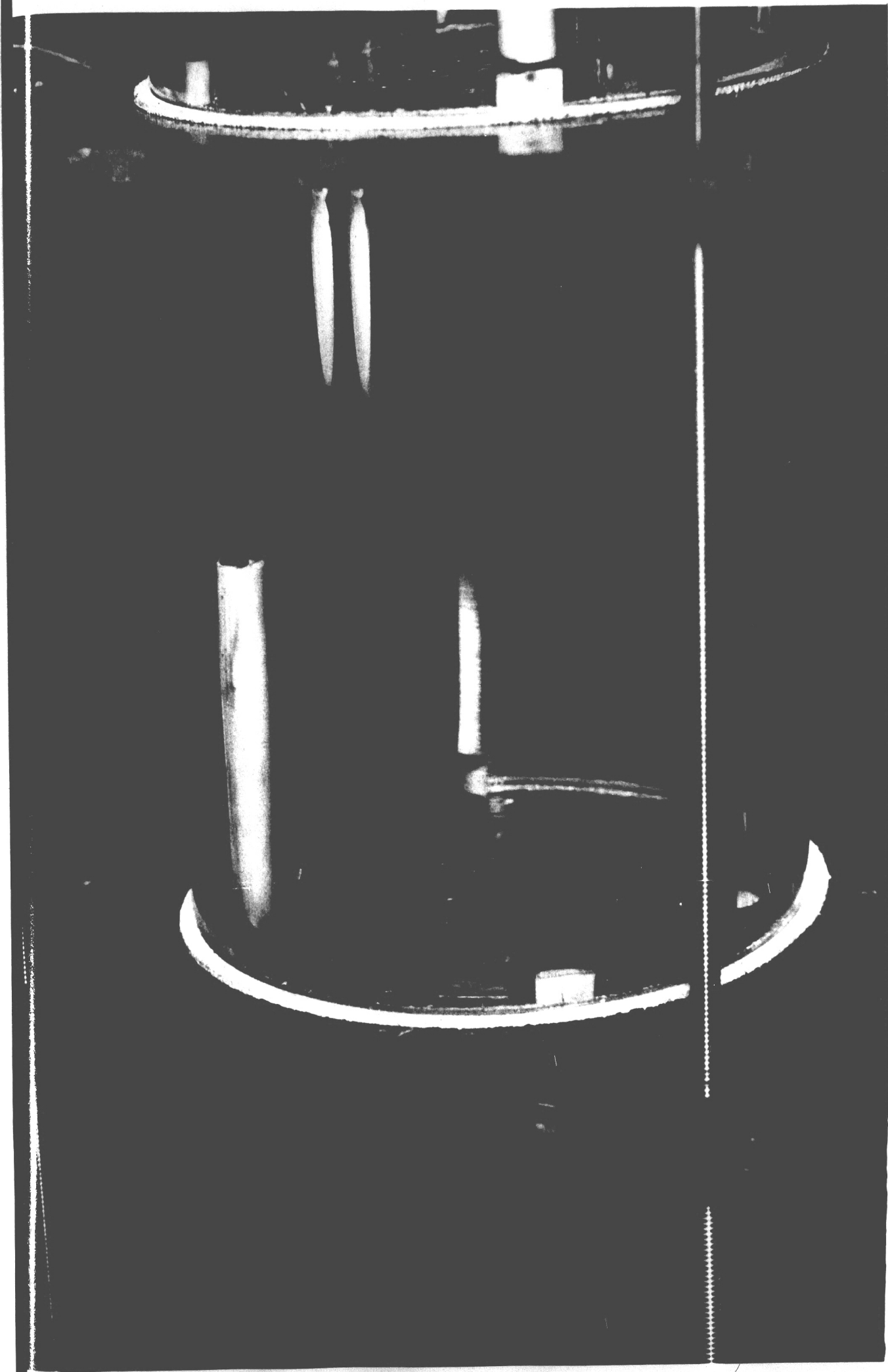
... design of ...

... design of ...

... design of ...

FIGURE V. PERFORATED PLATE FRONT VIEW





each perforation. In addition, the upper limit of the pressure drop should be sufficiently low enough that the downcomer backup is not excessive and the column as a result, flooded. Consideration of the hole size was also made as the operating range of the column, i.e., range between the weep and flood point, is considerably reduced with an increase in hole size. In the design of any column it is desirable that the pressure drop be a minimum and yet the range between the weep and flood point be a maximum.

#### PLATE LAYOUT

The perforated plate was punched with the desired hole diameter punch on equilateral triangular centers with a pitch/diameter hole ratio of 3.8. Calculations for the plate layout are included in the Appendix C, page 41. The perforated plates were soldered to the plate holder. Figure VI, page 22, shows a 3/16 inch hole diameter perforated plate assembly.

#### VAPOR AND LIQUID SAMPLING SYSTEM

Referring to Figure IV, page 19, showing the details for the perforated plate holders, holes 1/4 inch diameter, were drilled through each side of the 3/8 inch brass plate holders. One hole was drilled through the bottom of the plate for the vapor sample and the other through the top to obtain a liquid sample; refer Figure V. Small condensers



For cooling the liquid and condensing the vapor...

...were located at such a distance...

EXPERIMENTAL PROCEDURE

The purpose of this experiment was to determine...

In the column were obtained near constant values... of the vapor and...

The liquid level in the column was maintained at a constant height... by means of a float valve...

...

RESULTS AND DISCUSSION

The results of the experiment are shown in Figure 1...

It is seen that the vapor rate is independent of the liquid level...

...

CONCLUSIONS

It is concluded that the vapor rate is independent of the liquid level...

and that the liquid level in the column is maintained at a constant height...

...

REFERENCES

1. ...

2. ...

3. ...

...

4. ...

5. ...

VAPOR RATE MEASUREMENT

A sharp edge orifice, flange type, 0.75 inch hole diameter was designed and calibrated. The calibration curve for this orifice is included in Appendix E, Figure VIII.

WET AND DRY PLATE PRESSURE DROP

elod dant 27.0 ,oyt anna12 ,eolico epeo qeada  
coltasdlao 1/4 .hooofflao 5m hooahob new rotomib  
oxtat ,E rihnerd of hoba1ont of eolico ead6 wof avuo  
.EEN

DATA AND RESULTS

The distillation runs and sample data obtained in this study are listed in Table IV of the Appendix F.

WET AND DRY PLATE PRESSURE DROP

Prior to starting the distillation runs using the binary, methyl alcohol and water, data were taken to obtain the resistance (pressure drop in inches of water), the 1/4 and 3/16 inch holes offered to the flow of gas. This was accomplished by recording the pressure below and above each plate when air at varying rates was pumped through the column. The difference in pressure was recorded as the pressure drop across the plate. A summary of these data recorded as dry plate pressure drop is shown in Table I, page 28.

Pressure drop data were also obtained during the distillation runs that were made in the course of the experimental study. These data for 1/8, 3/16, and 1/4 inch holes are recorded as wet plate pressure drop and are listed in Table II, page 29. Wet pressure drop data includes the resistance the gas, methanol vapor, encounters in passing through the holes in addition to supporting the liquid above it.

A graph showing the relationship between dry and wet pressure drop data for the 1/4 and 3/16 inch diameter holes is shown in Figure VII, page 30.





The experimental results are shown in Appendix C, page 11. In  
 the manner in which the results were calculated  
 with the corresponding mass flow rate. A sample calculation  
 is given in Appendix D, page 12. It is a sample of the  
 results given in Appendix C.

TABLE I

Summary of Dry Plate Pressure Drop Data for 1/4, 3/16 Inch Diameter Holes Plate Series

| No. of Reading | Orifice Reading In.-H <sub>2</sub> O | P <sub>1</sub> | P <sub>2</sub> In. | P <sub>3</sub> Red Oil | P <sub>4</sub> | P <sub>1</sub> -P <sub>2</sub> | P <sub>2</sub> -P <sub>3</sub> In. H <sub>2</sub> O | P <sub>3</sub> -P <sub>4</sub> | Avg. P In.-H <sub>2</sub> O | G Lb. Hr-Ft <sup>2</sup> | Hole Diameter Inches |
|----------------|--------------------------------------|----------------|--------------------|------------------------|----------------|--------------------------------|---|--------------------------------|-----------------------------|--------------------------|----------------------|
| 1              | 2.50                                 | 2.90           | 3.35               | 4.0                    | 4.18           | 1.33                           | 1.03  | 1.40                           | 1.25                        | 168                      | 1/4                  |
| 2              | 1.95                                 | 2.25           | 2.50               | 2.90                   | 3.20           | 0.738                          | 1.18  | 0.885                          | 0.93                        | 148                      | 1/4                  |
| 3              | 1.00                                 | 1.20           | 1.35               | 1.55                   | 1.70           | 0.442                          | 0.59  | 0.442                          | 0.49                        | 107                      | 1/4                  |
| 4              | 0.41                                 | 0.60           | 0.61               | 0.75                   | 0.83           | -                              | 0.44  | 0.222                          | 0.22                        | 68                       | 1/4                  |
| 5              | 1.85                                 | 2.10           | 2.40               | 2.75                   | 3.00           | 0.885                          | 1.03  | 0.736                          | 0.88                        | 145                      | 1/4                  |
| 6              | 3.80                                 | 4.25           | 4.85               | 5.53                   | 6.15           | 1.77                           | 2.01  | 1.83                           | 1.87                        | 209                      | 1/4                  |
| 7              | 0.20                                 | 0.30           | 0.31               | 0.40                   | 0.44           | 0.030                          | 0.265   | 0.127                          | 0.14                        | 48                       | 1/4                  |
| 8              | 3.80                                 | 4.35           | 4.90               | 5.55                   | 6.25           | 1.62                           | 1.92  | 2.07                           | 1.87                        | 209                      | 1/4                  |
|                |                                      |                |                    |                        |                |                                |   |                                |                             |                          |                      |
| 1              | 2.60                                 | 3.45           | 3.90               | 4.33                   | 4.73           | 1.33                           | 1.27  | 1.18                           | 1.26                        | 171                      | 3/16                 |
| 2              | 0.58                                 | 0.80           | 0.90               | 1.00                   | 1.12           | 0.295                          | 0.295   | 0.354                          | 0.32                        | 80                       | 3/16                 |
| 3              | 0.20                                 | 0.33           | 0.35               | 0.43                   | 0.45           | 0.074                          | 0.22  | 0.074                          | 0.56                        | 48                       | 3/16                 |
| 4              | 0.20                                 | 0.30           | 0.35               | 0.43                   | 0.45           | 0.148                          | 0.22  | 0.074                          | 0.15                        | 48                       | 3/16                 |
| 5              | 0.78                                 | 1.10           | 1.20               | 1.35                   | 1.50           | 0.295                          | 0.443   | 0.443                          | 0.39                        | 94                       | 3/16                 |
| 6              | 1.65                                 | 2.30           | 2.60               | 2.95                   | 3.28           | 0.885                          | 1.03  | 0.974                          | 0.96                        | 137                      | 3/16                 |
| 7              | 2.80                                 | 3.85           | 4.38               | 4.90                   | 5.47           | 1.565                          | 1.535   | 1.68                           | 1.62                        | 179                      | 3/16                 |
| 8              | 3.25                                 | 4.45           | 5.10               | 5.70                   | 6.30           | 1.92                           | 1.77  | 1.77                           | 1.82                        | 193                      | 3/16                 |
| 9              | 0.20                                 | 0.30           | 0.35               | 0.40                   | 0.45           | 0.147                          | 0.147   | 0.147                          | 0.15                        | 48                       | 3/16                 |

|   |      |      |      |      |      |       |       |       |      |    |      |
|---|------|------|------|------|------|-------|-------|-------|------|----|------|
| 8 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 4 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |

|   |      |      |      |      |      |       |       |       |      |    |      |
|---|------|------|------|------|------|-------|-------|-------|------|----|------|
| 8 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 4 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 4 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |
| 2 | 0.30 | 0.30 | 0.30 | 0.40 | 0.40 | 0.15A | 0.15A | 0.15A | 0.12 | 48 | 2/16 |

Summary of Wet Plate Pressure Drop Data for 1/4, 3/16, 1/8 Inch Hole Diameter Plate Series

Summary of Wet Plate Pressure Drop Data for 1/4, 3/16, 1/8 Inch Hole Diameter Plate Series

PART I

- 88 -

- 29 -

TABLE II

Summary of Wet Plate Pressure Drop Data for 1/4, 3/16, 1/8 Inch Hole Diameter Plate Series

| Run No. | Time | Plate In. Red Oil |      |      |      | P <sub>2</sub> -P <sub>1</sub> | Pressure In. H <sub>2</sub> O P <sub>3</sub> -P <sub>2</sub> | Drop Avg. P <sub>4</sub> -P <sub>3</sub> | G Calc lb/hr-ft <sup>2</sup> | Hole Diameter |      |
|---------|------|-------------------|------|------|------|--------------------------------|--|--|------------------------------|---------------|------|
|         |      | 1                 | 2    | 3    | 4    |                                |  |  |                              |               |      |
| 6       | 1400 | 0.3               | 0.8  | 1.4  | 1.8  | 1.48                           | 1.77   | 1.18                                     | 1.47                         | 149           | 1/8  |
| 6       | 1530 | 0.3               | 0.8  | 1.35 | 1.7  | 1.48                           | 1.62   | 1.03                                     | 1.35                         | 137           | 1/8  |
| 6       | 1730 | 0.3               | 0.8  | -    | 1.7  | 1.48                           | 1.62   | 1.03                                     | 1.37                         | 137           | 1/8  |
| 7       | 1545 | 0.2               | 0.75 | 1.35 | 1.85 | 1.62                           | 1.77   | 1.48                                     | 1.62                         | 137           | 1/4  |
| 7       | 1745 | 0.2               | 0.75 | 1.35 | 1.85 | 1.62                           | 1.77   | 1.48                                     | 1.62                         | 137           | 1/4  |
| 7       | 1815 | 0.3               | 1.20 | 1.85 | 2.35 | 2.66                           | 1.92   | 1.48                                     | 2.02                         | 165           | 1/4  |
| 7       | 1940 | 0.85              | 1.70 | 2.70 | 3.70 | 2.51                           | 2.95   | 2.95                                     | 2.80                         | 194           | 1/4  |
| 8       | 1700 | 0.35              | 1.30 | 2.4  | 3.3  | 2.80                           | 3.24   | 2.67                                     | 2.90                         | 185           | 1/4  |
| 8       | 1810 | 0.35              | 1.25 | 2.1  | 3.1  | 2.51                           | 2.51   | 2.95                                     | 2.66                         | 175           | 1/4  |
| 9       | 1840 | 0.35              | 1.00 | 1.75 | 2.2  | 1.92                           | 2.21   | 1.33                                     | 1.82                         | 157           | 1/4  |
| 9       | 1930 | 0.28              | 0.90 | 1.60 | 2.0  | 1.77                           | 2.07   | 1.18                                     | 1.67                         | 150           | 1/4  |
| 10      | 1445 | 0.10              | 0.40 | 0.70 | 1.0  | 0.89                           | 0.89   | 0.89                                     | 0.89                         | 108           | 3/16 |
| 10      | 1840 | 0.20              | 0.95 | 1.6  | 2.2  | 2.21                           | 1.92   | 1.77                                     | 1.97                         | 166           | 3/16 |
| 10      | 2000 | 0.95              | 1.90 | 2.8  | 3.65 | 2.80                           | 2.66   | 2.51                                     | 2.70                         | 192           | 3/16 |
| 11      | 1946 | 0.10              | 0.4  | 0.7  | 1.0  | 0.89                           | 0.89   | 0.89                                     | 0.89                         | 108           | 3/16 |
| 11      | 1700 | 0.2               | 0.9  | 1.6  | 2.2  | 2.06                           | 2.06   | 1.77                                     | 1.96                         | 166           | 3/16 |



TABLE III

Murphree Plate Efficiency - Summary of Distillations Runs for  
1/8, 3/16, 1/4 Hole Diameter Plate Series

| Run<br>No. | Time | G<br>lbs<br>hr-ft <sup>2</sup> | Hole<br>Diameter | Murphree Plate Efficiency<br>Percent |            |            |
|------------|------|--------------------------------|------------------|--------------------------------------|------------|------------|
|            |      |                                |                  | Plate<br>1                           | Plate<br>2 | Plate<br>3 |
| 6          | 1400 | 149                            | 1/8              | 126.0                                | 89.6       | 99.0       |
| 6          | 1530 | 137                            | 1/8              | 108.5                                | 88.0       | 94.6       |
| 6          | 1730 | 137                            | 1/8              | 155.0                                | 81.6       | 94.3       |
| 7          | 1545 | 137                            | 1/4              | 168.0                                | 82.9       | 70.9       |
| 7          | 1715 | 137                            | 1/4              | 156.0                                | 94.3       | 86.2       |
| 7          | 1950 | 165                            | 1/4              | 125.0                                | 89.4       | 41.4       |
| 7          | 2015 | 188                            | 1/4              | 184.0                                | 100.0      | 42.5       |
| 8          | 1700 | 185                            | 1/4              | 117.0                                | 89.7       | 55.3       |
| 8          | 1810 | 175                            | 1/4              | 117.0                                | 93.6       | 54.9       |
| 9          | 1230 | ca. 50                         | 1/4              | 131.0                                | 79.4       | 79.1       |
| 9          | 1330 | ca. 50                         | 1/4              | 139.0                                | 122.0      | 95.5       |
| 9          | 1820 | 157                            | 1/4              |                                      |            | 49.8       |
| 9          | 1930 | 150                            | 1/4              | 97.2                                 | 95.7       | 40.1       |
| 10         | 1630 | 99                             | 3/16             | 105.5                                | 92.4       | 86.6       |
| 10         | 1945 | 166                            | 3/16             | 129.0                                | 97.3       | 78.5       |
| 11         | 1730 | 166                            | 3/16             | 118.0                                | 92.5       | 40.5       |
| 11         | 1945 | 99                             | 3/16             | 89.6                                 | 97.5       | 78.0       |



DISCUSSION OF RESULTS

The calculated results of this investigation are presented in Table I to Table III. A comparison of the experimental results with the theoretical results is shown in Figure 1. The experimental results are shown in Figure 2. The theoretical results are shown in Figure 3.

The experimental results show that the Murphree plate efficiency increases with increasing gas flow rate and decreasing liquid flow rate. The theoretical results show that the Murphree plate efficiency increases with increasing gas flow rate and decreasing liquid flow rate. The experimental results are shown in Figure 1. The theoretical results are shown in Figure 2.

$$E = \frac{1}{1 + \frac{G}{L}}$$

The experimental results show that the Murphree plate efficiency increases with increasing gas flow rate and decreasing liquid flow rate. The theoretical results show that the Murphree plate efficiency increases with increasing gas flow rate and decreasing liquid flow rate. The experimental results are shown in Figure 1. The theoretical results are shown in Figure 2.

obtained in this study. However, for the bottom plate, 3, mass flow rate constant, Murphree plate efficiency increased from 44 percent for the 1/4 inch hole diameter plate to 96 percent for the 1/8 inch hole diameter plate indicating higher plate efficiency for smaller hole diameter plate perforations. In addition, Murphree plate efficiency for all distillation runs increased from the bottom plate to the top plate of the column.

The data obtained in this study on the methanol-water distillation run can be explained using the gas film and liquid film plate efficiency concept of mass transfer as outlined by Gerster et al<sup>(3)</sup>.

According to the data of Gerster et al<sup>(3)</sup> the gas vapor rate had very little effect on the  $N_G$ , the number of gas transfer units as a result of the other counteracting variables involved, namely the degree of "aeration" of the liquid. The effect of vapor rate,  $N_G$ , is readily explained as follows: an increase of gas flow increases the degree of "aeration" and as a result increases the contact time between the gas and liquid, in addition to increasing the interfacial area available for mass transfer. These phenomena are counteracted by the decreased time available for mass transfer as a result of decreased contact time between gas and liquid.

Gerster et al has also pointed out the increase in

the gas film resistance with increasing methanol concentration. At a liquid plate concentration of 90 mole percent methanol, 90 percent of the resistance to mass transfer is in the gas film, and at 10 mole percent methanol only 55 percent of the resistance is in the gas film. This increasing effect of liquid film resistance with decreasing plate concentration indicates the importance of considering plate design variables affecting liquid film resistance in distillation runs where low plate concentrations are involved. Data as obtained by Cerster et al also shows a decrease in Murphree plate efficiency with increase in plate concentration.

A plate design variable which does show effect on Murphree efficiency as indicated by results obtained in this study is plate hole size. A decrease in hole size, 1/4" to 1/8" diameter gave higher Murphree plate efficiencies for the bottom plate which is what would be expected as a result of the increase in the degree of "aeration". This same increase in plate efficiency was not readily observed in the top plate as a result of the higher gas film resistance due to the higher concentration of methanol on the plate. In other words, the increase in the degree of aeration as a result of the smaller hole size was counteracted by the higher gas film resistance, hence no observed increase in Murphree plate efficiency was obtained.

In the lower perforated plate, 3, the decrease in plate concentration did lower the Murphree plate efficiency

obtained in this study. However, for the bottom plate, 3, the efficiency increased as flow rate constant, liquid concentration, and plate concentration increased. From the percent for the 1/8 inch hole diameter plate to 90 percent for the 1/4 inch hole diameter plate indicating higher efficiency for smaller hole diameter plate perforations. In addition, efficiency for smaller hole diameter plate perforations was higher for the 1/8 inch hole diameter plate than for the 1/4 inch hole diameter plate. This indicates that the bottom plate is more efficient than the top plate.

The data obtained in this study on the methanol-water distillation run can be explained using the data obtained in this study on the effect of plate concentration on Murphree efficiency. It is noted that the efficiency of the bottom plate is higher than that of the top plate. This is due to the higher concentration of methanol on the bottom plate.

The effect of plate concentration on Murphree efficiency is shown in Figure 1. It is noted that the efficiency of the bottom plate is higher than that of the top plate. This is due to the higher concentration of methanol on the bottom plate. The efficiency of the bottom plate is higher than that of the top plate. This is due to the higher concentration of methanol on the bottom plate.

The effect of plate concentration on Murphree efficiency is shown in Figure 1. It is noted that the efficiency of the bottom plate is higher than that of the top plate. This is due to the higher concentration of methanol on the bottom plate. The efficiency of the bottom plate is higher than that of the top plate. This is due to the higher concentration of methanol on the bottom plate.

Cerster et al has also indicated that the increase in





as is indicated by data in all distribution runs. However, the effect of the increased hole size as a result of changing the flow velocity above the plate was the controlling factor and resulted in decrease in plate efficiency. Some error was observed at constant hole diameter.

### LIMITATIONS

The limitations of this experimental study are summarized as follows:

1. Accuracy of pressure drop data  $\pm$  0.5 inches of water.
2. Comparison of percent methanol obtained from refractive index data (using the refractometer) with density measurement (Westphal balance) showed a deviation of 0.91%.
3. Refractometer readings differed in the majority of readings in the fourth decimal place  $\pm$  1. This could result in an error of 0.5 percent methanol by weight.

RECOMMENDATIONS

one year's introduction and to avoid initial cost

to avoid the expense of

to avoid 2.0  $\frac{1}{2}$  inch diameter to avoid .1

to avoid

to avoid the expense of avoiding .3

(to avoid the expense of avoiding)

(to avoid the expense of avoiding)

to avoid the expense of avoiding

to avoid the expense of avoiding .5

to avoid the expense of avoiding

to avoid the expense of avoiding

to avoid the expense of avoiding

RECOMMENDATIONS

Insofar as the range of study was limited by the steam supply available, it is suggested that additional data be obtained at higher mass flow rates.

Calculation of the heat transfer coefficient for the distillation kettle used in this study indicate that a mass flow rate of 700 lb/hr-ft<sup>2</sup> is capable of being obtained, (U<sub>calc</sub> = 147). To efficiently handle this vapor rate a new condenser would need to be designed as the present condenser was designed to handle a vapor rate of ca. 300 lb/hr-ft<sup>2</sup>.

Construction of a new thermocouple housing on the plate holders is suggested as the sauerisen used was easily chipped when the distillation column was dismantled.

EXPERIMENTAL

of limited accuracy in the range of operation  
 the steam supply available. It is suggested that additional  
 data be obtained at higher mass flow rates.  
 Calculation of the heat transfer coefficient for  
 the distillation kettle used in this study indicates that  
 heat loss from the kettle is negligible. The rate of heat  
 loss from the kettle is estimated to be about 100 Btu/hr-ft<sup>2</sup>.  
 The heat loss from the kettle is negligible. The rate of heat  
 loss from the kettle is estimated to be about 100 Btu/hr-ft<sup>2</sup>.  
 The heat loss from the kettle is negligible. The rate of heat  
 loss from the kettle is estimated to be about 100 Btu/hr-ft<sup>2</sup>.  
 The heat loss from the kettle is negligible. The rate of heat  
 loss from the kettle is estimated to be about 100 Btu/hr-ft<sup>2</sup>.  
 The heat loss from the kettle is negligible. The rate of heat  
 loss from the kettle is estimated to be about 100 Btu/hr-ft<sup>2</sup>.  
 The heat loss from the kettle is negligible. The rate of heat  
 loss from the kettle is estimated to be about 100 Btu/hr-ft<sup>2</sup>.

APPENDIX A. Nomenclature

- G = Mass flow rate: lbs/hr-ft<sup>2</sup>
- E<sub>m</sub> = Murphree plate efficiency
- y<sub>1</sub> = Mol fraction vapor leaving plate 1
- y<sub>2</sub> = Mol fraction vapor leaving plate 2
- y<sub>3</sub> = Mol fraction vapor leaving plate 3
- y<sub>4</sub> = Mol fraction vapor leaving plate 4
- x<sub>1</sub> = Mol fraction liquid leaving plate 1
- x<sub>2</sub> = Mol fraction liquid leaving plate 2
- x<sub>3</sub> = Mol fraction liquid leaving plate 3
- y<sub>n</sub>\* = Mol fraction of vapor in equilibrium with liquid  
 leaving plate n, where n is the plate number starting  
 from the top of the column.
- P/D = Pitch/diameter ratio. Ratio of the length of one  
 side of an equilateral triangle to the hole diameter.
- P = Pressure drop, inches, H<sub>2</sub>O
- Percent Free Space Area =  $\frac{\text{Perforation area (100)}}{\text{Column cross section area}}$
- Thermocouple designations:
- 1. = water exit overhead condenser
- 2. = reflux entering top of column
- 3. = reference thermocouple maintained at 0°C
- 4. = vapor -- plate 1
- 5. = liquid -- plate 2
- 6. = vapor -- plate 2
- 7. = liquid -- plate 2

APPENDIX A. NOMENCLATURE

- $W$  = Mass flow rate: lbs/hr-ft<sup>2</sup>
- $\eta$  = Murphree plate efficiency
- $Y_1$  = Mol fraction vapor leaving plate 1
- $Y_2$  = Mol fraction vapor leaving plate 2
- $Y_3$  = Mol fraction vapor leaving plate 3
- $Y_4$  = Mol fraction vapor leaving plate 4
- $X_1$  = Mol fraction liquid leaving plate 1
- $X_2$  = Mol fraction liquid leaving plate 2
- $X_3$  = Mol fraction liquid leaving plate 3
- $Y_n^*$  = Mol fraction of vapor in equilibrium with liquid leaving plate  $n$ , where  $n$  is the plate number starting from the top of the column.
- $H/D$  = Height/diameter ratio. Ratio of the length of one side of an equilateral triangle to the side diameter.
- $\rho$  = Pressure drop, inches H<sub>2</sub>O
- Percent free space =  $\frac{\text{fractional area (GGI)}}{\text{column cross section area}}$
- Thermocouple designations:
  - 1. = water exit overhead condenser
  - 2. = water entering top of column
  - 3. = reference thermocouple maintained at 0°C
  - 4. = vapor -- plate 1
  - 5. = liquid -- plate 2
  - 6. = vapor -- plate 3
  - 7. = liquid -- plate 3

- 8. = vapor -- plate 3
- 9. = liquid -- plate 3
- 10. = vapor -- plate 4
- 11. = distillate exit overhead condenser

8 edaig -- uocsv = .8  
 3 edaig -- blupif = .8  
 2 edaig -- uocsv = .01  
 mtebucp baedrevo jtr edallitab = .11



APPENDIX B. Summary of Design Information for the  
Perforated Distillation Column

Column diameter, I.D., inches ----- 8.25  
 Distance between perforated plates, inches ----- 9.50  
 Number of perforated plates ----- 3  
 Column cross section area, ft<sup>2</sup> ----- 0.3718  
 Maximum perforated plate area/plate, ft<sup>2</sup> ----- 0.216

1/8 inch hole diameter series:

Number of holes/plate ----- 51  
 Distance between hole centers, inches ----- 0.475  
 Hole arrangement ----- 6,7,8,9,8,7,6

3/16 inch hole diameter series:

Number of holes/plate ----- 24  
 Distance between hole centers, inches ----- 0.712  
 Hole arrangement ----- 4,5,6,5,4

1/4 inch hole diameter series:

Number of holes/plate ----- 13  
 Distance between hole centers, inches ----- 0.950  
 Hole arrangement ----- 4,5,4

APPENDIX B. Summary of Design Information for the  
Perforated Plate Fraction Column

Column diameter, inches, 1.00

Distance between perforated plates, inches, 0.50

Number of perforated plates, 10

Column cross section area, ft<sup>2</sup>, 0.785

Maximum allowable plate area, ft<sup>2</sup>, 0.785

1/8 inch hole diameter, inches, 0.125

Number of holes, 64

Distance between hole centers, inches, 0.50

Plate thickness, inches, 0.015

1/8 inch hole diameter, inches, 0.125

Number of holes, 64

Distance between hole centers, inches, 0.50

Plate thickness, inches, 0.015

1/8 inch hole diameter, inches, 0.125

Number of holes, 64

Distance between hole centers, inches, 0.50

Plate thickness, inches, 0.015

APPENDIX C. Murphree Plate Efficiency Sample Calculation

Run VIII, Plate 2, time 1730:

$$E_m = \frac{y_2 - y_3}{y_2^* - y_3} (100) = \frac{0.846 - 0.640}{0.870 - 0.640} (100) = 89.7\%$$

$$y_2 = \frac{90.7}{\frac{90.7}{32} + \frac{9.3}{18}} = 0.846$$

$$y_3 = \frac{76.0}{\frac{76.0}{32} + \frac{24.0}{18}} = 0.640$$

$$y_2^* = \frac{80.6}{\frac{80.6}{32} + \frac{13.35}{18}} = 0.700$$

From equilibrium curve pg  
a value of 0.870 is obtained

APPENDIX C. Murphree Plate Efficiency Sample Calculation

from VLE, Plate 2, time 1.80:

$$87.88 = (100) \frac{0.840 - 0.848}{0.840 - 0.848} = (100) \frac{y^* - y}{y^* - y} = \eta$$

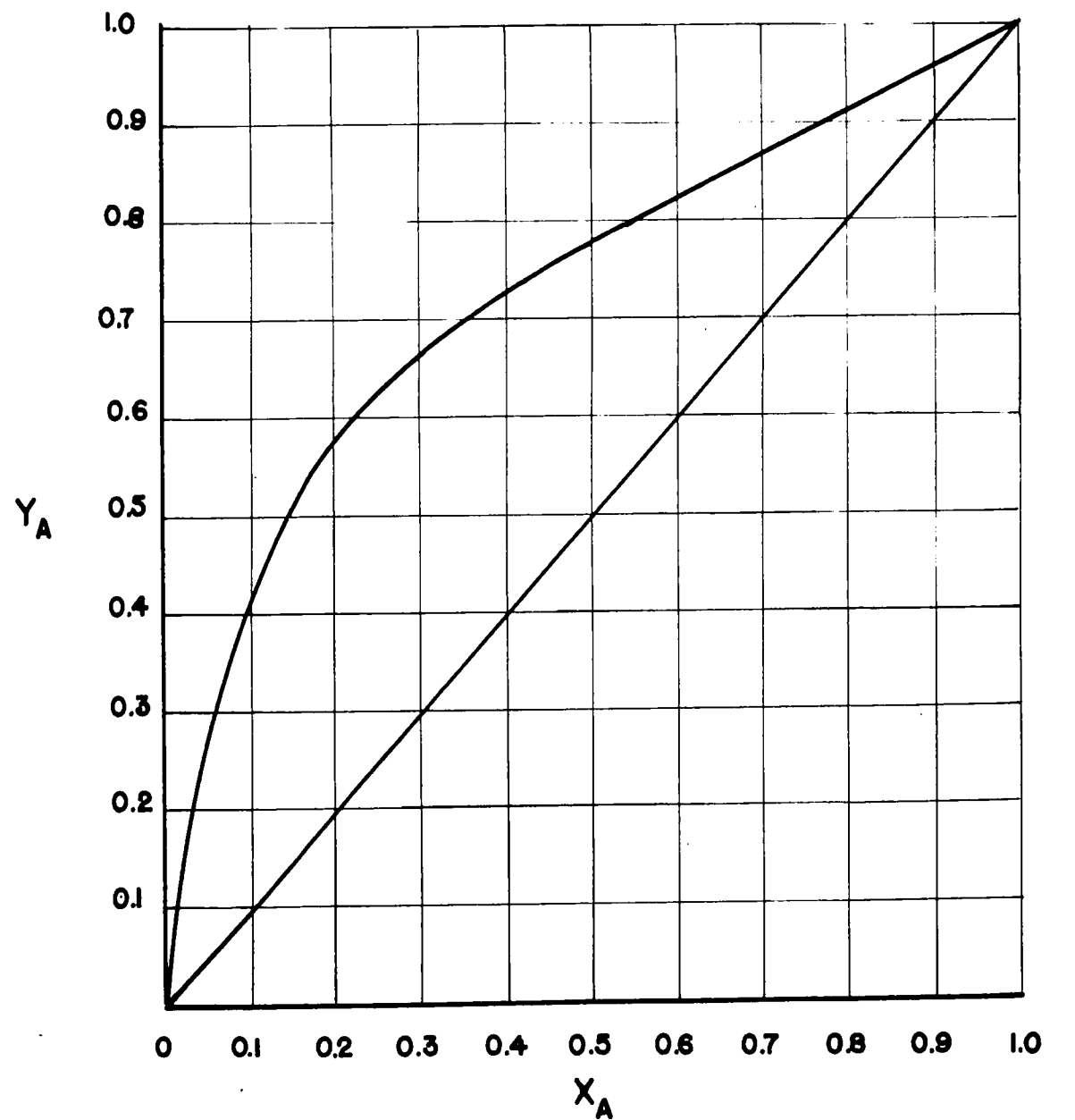
$$0.848 = \frac{\frac{V \cdot C_B}{S}}{\frac{V \cdot C_B}{S} + \frac{V \cdot C_A}{S}} = \frac{V \cdot C_B}{V \cdot C_B + V \cdot C_A} = \frac{C_B}{C_B + C_A}$$

$$0.840 = \frac{\frac{0.1V}{S}}{\frac{0.1V}{S} + \frac{0.1V}{S}} = \frac{0.1V}{0.1V + 0.1V} = \frac{0.1V}{0.2V} = \frac{C_B}{C_B + C_A}$$

$$0.840 = \frac{\frac{1.0C_A}{S}}{\frac{1.0C_A}{S} + \frac{0.1C_B}{S}} = \frac{1.0C_A}{1.0C_A + 0.1C_B} = \frac{C_A}{C_A + 0.1C_B}$$

EQUILIBRIUM CURVE†

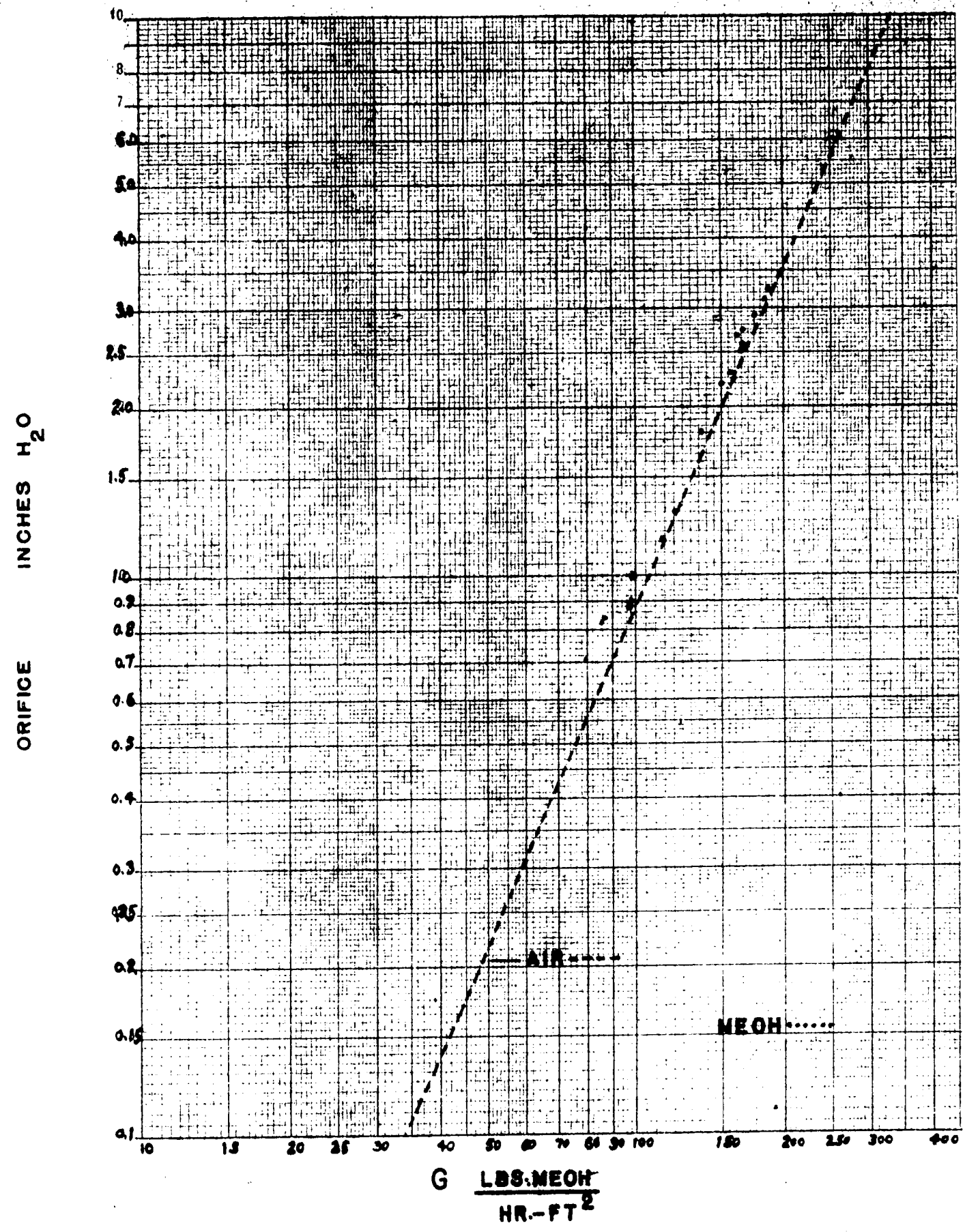
MEOH - H<sub>2</sub>O



† JU CHIN CHU  
DATA  
1 ATM.



FIGURE VIII.  
F. ORIFICE CURVE



APPENDIX F. TABLE IV

RUN IV DATA

| Time | Temperature °F           |       |       |       |       |       |       |       |       |       |     | Pressure             |      |     |      | Orifice In.<br>Red Oil | Kettle Jacket<br>(steam) psig | Reflux | Roto<br>Rdg. |
|------|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|----------------------|------|-----|------|------------------------|-------------------------------|--------|--------------|
|      | Thermocouple Designation |       |       |       |       |       |       |       |       |       |     | Plate In.<br>Red Oil |      |     |      |                        |                               |        |              |
|      | 1                        | 2     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 1   | 2                    | 3    | 4   |      |                        |                               |        |              |
| 1500 | Steam to kettle          |       |       |       |       |       |       |       |       |       |     |                      |      |     |      |                        |                               |        |              |
| 1545 | 117.0                    | 113.8 | 155.4 | 171.1 | 135.5 | 171.9 | 177.5 | 177.5 | 177.5 | 122.3 | 0.1 | 0.45                 | 0.9  | 1.3 | 0.25 | 10                     | -                             | 79.5   |              |
| 1645 | 118.4                    | 145.9 | 149.8 | 149.6 | 151.8 | 151.8 | -     | 173.4 | 154.4 | 95.2  | 0.1 | 0.35                 | 0.7  | 1.0 | 0.28 | 5                      | 2.8                           | 54.0   |              |
| 1730 | 120.0                    | 145.9 | 148.8 | 148.8 | 151.8 | 151.8 | -     | 173.8 | 157.2 | 101.3 | 0.1 | 0.30                 | 0.65 | 1.0 | 0.25 | 5                      | 2.85                          | 51.0   |              |
| 1815 | 111.8                    | 135.5 | 145.5 | 145.5 | 150.6 | 150.3 | -     | 173.8 | 156.4 | 90.0  | 0.1 | 0.30                 | 0.65 | 1.0 | 0.24 | 5                      | 2.50                          | 52.0   |              |



|      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1373 | 1374 | 1375 | 1376 | 1377 | 1378 | 1379 | 1380 | 1381 | 1382 | 1383 | 1384 | 1385 | 1386 | 1387 | 1388 | 1389 | 1390 | 1391 | 1392 | 1393 | 1394 | 1395 | 1396 | 1397 | 1398 | 1399 | 1400 | 1401 | 1402 | 1403 | 1404 | 1405 | 1406 | 1407 | 1408 | 1409 | 1410 | 1411 | 1412 | 1413 | 1414 | 1415 | 1416 | 1417 | 1418 | 1419 | 1420 | 1421 | 1422 | 1423 | 1424 | 1425 | 1426 | 1427 | 1428 | 1429 | 1430 | 1431 | 1432 | 1433 | 1434 | 1435 | 1436 | 1437 | 1438 | 1439 | 1440 | 1441 | 1442 | 1443 | 1444 | 1445 | 1446 | 1447 | 1448 | 1449 | 1450 | 1451 | 1452 | 1453 | 1454 | 1455 | 1456 | 1457 | 1458 | 1459 | 1460 | 1461 | 1462 | 1463 | 1464 | 1465 | 1466 | 1467 | 1468 | 1469 | 1470 | 1471 | 1472 | 1473 | 1474 | 1475 | 1476 | 1477 | 1478 | 1479 | 1480 | 1481 | 1482 | 1483 | 1484 | 1485 | 1486 | 1487 | 1488 | 1489 | 1490 | 1491 | 1492 | 1493 | 1494 | 1495 | 1496 | 1497 | 1498 | 1499 | 1500 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|

RUN IV. SAMPLE DATA

RUN V. DATA

Kettle Charge  
Hole Diameter  
1.17% Free Space Area

| Time | Temperature °F  |       |       |       |       |       |   |       |       |       |     | Pressure Plate In. Red Oil |      |      | Orifice In. H <sub>2</sub> O | Kettle Jacket (steam) psig | Reflux | Photo Redg. Condenser |
|------|-----------------|-------|-------|-------|-------|-------|---|-------|-------|-------|-----|----------------------------|------|------|------------------------------|----------------------------|--------|-----------------------|
|      | 1               | 2     | 4     | 5     | 6     | 7     | 8 | 9     | 10    | 11    | 1   | 2                          | 3    | 4    |                              |                            |        |                       |
| 1235 | Steam to kettle |       |       |       |       |       |   |       |       |       |     |                            |      |      |                              |                            |        |                       |
| 1400 | 118.4           | 136.4 | 144.2 | 144.2 | 144.2 | 147.6 | - | 172.6 | 153.5 | 84.5  | 0.1 | 0.30                       | 0.60 | 1.0  | -                            | 10                         | 2.5    | 54                    |
| 1545 | 93.3            | 135.5 | 148.0 | 148.0 | 151.0 | 149.9 | - | 181.5 | 153.9 | 118.9 | 0.3 | 1.0                        | 1.40 | 1.8  | -                            | 30                         | 7.7    |                       |
| 1600 | 84.9            | 132.1 | 147.2 | 153.4 | 152.5 | 151.4 | - | 181.8 | 156.0 | 98.2  | 0.3 | 0.8                        | 1.4  | 1.85 | -                            | 30                         | 7.6    |                       |
| 1715 | 86.7            | 126.9 | 149.2 | 146.4 | 152.2 | 151.0 | - | 184.8 | 156.8 | 96.5  | 0.3 | 0.8                        | 1.4  | 1.85 | -                            | 30                         | 7.0    |                       |
| 1805 | Steam off       |       |       |       |       |       |   |       |       |       |     |                            |      |      |                              |                            |        |                       |





1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050 2100 2150 2200 2250 2300 2350 2400 2450 2500 2550 2600 2650 2700 2750 2800 2850 2900 2950 3000 3050 3100 3150 3200 3250 3300 3350 3400 3450 3500 3550 3600 3650 3700 3750 3800 3850 3900 3950 4000 4050 4100 4150 4200 4250 4300 4350 4400 4450 4500 4550 4600 4650 4700 4750 4800 4850 4900 4950 5000 5050 5100 5150 5200 5250 5300 5350 5400 5450 5500 5550 5600 5650 5700 5750 5800 5850 5900 5950 6000 6050 6100 6150 6200 6250 6300 6350 6400 6450 6500 6550 6600 6650 6700 6750 6800 6850 6900 6950 7000 7050 7100 7150 7200 7250 7300 7350 7400 7450 7500 7550 7600 7650 7700 7750 7800 7850 7900 7950 8000 8050 8100 8150 8200 8250 8300 8350 8400 8450 8500 8550 8600 8650 8700 8750 8800 8850 8900 8950 9000 9050 9100 9150 9200 9250 9300 9350 9400 9450 9500 9550 9600 9650 9700 9750 9800 9850 9900 9950 10000

CONSEC-  
 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

people change - 101 Reception

RUN VI. SAMPLE DATA

| TIME | SAMPLE DESIG. | N <sub>D</sub> 25°C | % MEOH | MOL FRACT. MEOH |
|------|---------------|---------------------|--------|-----------------|
| 1445 | x-4           | 1.3402              | 66.5   | 0.528           |
|      | x-3           | 1.3397              | 68.6   | 0.553           |
|      | x-2           | 1.3338              | 89.0   | 0.822           |
| 1455 | x-1           | 1.3309              | 94.25  | 0.903           |
| 1500 | Dist.         | 1.3285              | 98.6   |                 |
| 1507 | y-4           | 1.3345              | 87.5   | 0.797           |
|      | y-3           | 1.3340              | 88.8   | 0.814           |
| 1515 | y-2           | 1.3306              | 94.7   | 0.910           |
|      | y-1           | 1.3283              | 98.5   | 0.973           |
| 1610 | x-4           | 1.3406              | 64.5   |                 |
|      | x-3           | 1.3400              | 67.5   |                 |
|      | x-2           | 1.3333              | 89.9   |                 |
| 1625 | x-1           | 1.3306              | 94.8   |                 |
| 1628 | Dist.         | 1.3290              | 97.2   |                 |
|      | y-4           | 1.3401              | 67.0   |                 |
|      | y-3           | 1.3350              | 86.4   |                 |
| 1640 | y-2           | 1.3310              | 94.1   |                 |
| 1643 | y-1           | 1.3289              | 98.0   |                 |
| 1655 | x-4           | 1.3407              | 64.0   | 0.50            |
| 1658 | x-3           | 1.3401              | 67.0   | 0.533           |
|      | x-2           | 1.3339              | 88.8   | 0.818           |
|      | x-1           | 1.3307              | 94.6   | 0.9085          |
| 1710 | Dist.         | 1.3288              | 98.1   |                 |
| 1713 | y-4           | 1.3402              | 66.7   | 0.533           |
| 1716 | y-3           | 1.3350              | 86.4   | 0.778           |
|      | y-2           | 1.3310              | 94.1   | 0.902           |
| 1725 | y-1           | 1.3279              | 99.6   | 0.992           |
| 1727 | x-2           | 1.3339              | 89.0   |                 |
| 1730 | Dist.         | 1.3286              | 98.4   |                 |







|      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |    |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----|
| 3048 | 3049 | 3050 | 3051 | 3052 | 3053 | 3054 | 3055 | 3056 | 3057 | 3058 | 3059 | 3060 | 3061 | 3062 | 3063 | 3064 | 3065 | 3066 | 3067 | 3068 | 3069 | 3070 | 3071 | 3072 | 3073 | 3074 | 3075 | 3076 | 3077 | 3078 | 3079 | 3080 | 3081 | 3082 | 3083 | 3084 | 3085 | 3086 | 3087 | 3088 | 3089 | 3090 | 3091 | 3092 | 3093 | 3094 | 3095 | 3096 | 3097 | 3098 | 3099 | 3100 | 3101 | 3102 | 3103 | 3104 | 3105 | 3106 | 3107 | 3108 | 3109 | 3110 | 3111 | 3112 | 3113 | 3114 | 3115 | 3116 | 3117 | 3118 | 3119 | 3120 | 3121 | 3122 | 3123 | 3124 | 3125 | 3126 | 3127 | 3128 | 3129 | 3130 | 3131 | 3132 | 3133 | 3134 | 3135 | 3136 | 3137 | 3138 | 3139 | 3140 | 3141 | 3142 | 3143 | 3144 | 3145 | 3146 | 3147 | 3148 | 3149 | 3150 | 3151 | 3152 | 3153 | 3154 | 3155 | 3156 | 3157 | 3158 | 3159 | 3160 | 3161 | 3162 | 3163 | 3164 | 3165 | 3166 | 3167 | 3168 | 3169 | 3170 | 3171 | 3172 | 3173 | 3174 | 3175 | 3176 | 3177 | 3178 | 3179 | 3180 | 3181 | 3182 | 3183 | 3184 | 3185 | 3186 | 3187 | 3188 | 3189 | 3190 | 3191 | 3192 | 3193 | 3194 | 3195 | 3196 | 3197 | 3198 | 3199 | 3200 | 3201 | 3202 | 3203 | 3204 | 3205 | 3206 | 3207 | 3208 | 3209 | 3210 | 3211 | 3212 | 3213 | 3214 | 3215 | 3216 | 3217 | 3218 | 3219 | 3220 | 3221 | 3222 | 3223 | 3224 | 3225 | 3226 | 3227 | 3228 | 3229 | 3230 | 3231 | 3232 | 3233 | 3234 | 3235 | 3236 | 3237 | 3238 | 3239 | 3240 | 3241 | 3242 | 3243 | 3244 | 3245 | 3246 | 3247 | 3248 | 3249 | 3250 | 3251 | 3252 | 3253 | 3254 | 3255 | 3256 | 3257 | 3258 | 3259 | 3260 | 3261 | 3262 | 3263 | 3264 | 3265 | 3266 | 3267 | 3268 | 3269 | 3270 | 3271 | 3272 | 3273 | 3274 | 3275 | 3276 | 3277 | 3278 | 3279 | 3280 | 3281 | 3282 | 3283 | 3284 | 3285 | 3286 | 3287 | 3288 | 3289 | 3290 | 3291 | 3292 | 3293 | 3294 | 3295 | 3296 | 3297 | 3298 | 3299 | 3300 | 3301 | 3302 | 3303 | 3304 | 3305 | 3306 | 3307 | 3308 | 3309 | 3310 | 3311 | 3312 | 3313 | 3314 | 3315 | 3316 | 3317 | 3318 | 3319 | 3320 | 3321 | 3322 | 3323 | 3324 | 3325 | 3326 | 3327 | 3328 | 3329 | 3330 | 3331 | 3332 | 3333 | 3334 | 3335 | 3336 | 3337 | 3338 | 3339 | 3340 | 3341 | 3342 | 3343 | 3344 | 3345 | 3346 | 3347 | 3348 | 3349 | 3350 | 3351 | 3352 | 3353 | 3354 | 3355 | 3356 | 3357 | 3358 | 3359 | 3360 | 3361 | 3362 | 3363 | 3364 | 3365 | 3366 | 3367 | 3368 | 3369 | 3370 | 3371 | 3372 | 3373 | 3374 | 3375 | 3376 | 3377 | 3378 | 3379 | 3380 | 3381 | 3382 | 3383 | 3384 | 3385 | 3386 | 3387 | 3388 | 3389 | 3390 | 3391 | 3392 | 3393 | 3394 | 3395 | 3396 | 3397 | 3398 | 3399 | 3400 | 3401 | 3402 | 3403 | 3404 | 3405 | 3406 | 3407 | 3408 | 3409 | 3410 | 3411 | 3412 | 3413 | 3414 | 3415 | 3416 | 3417 | 3418 | 3419 | 3420 | 3421 | 3422 | 3423 | 3424 | 3425 | 3426 | 3427 | 3428 | 3429 | 3430 | 3431 | 3432 | 3433 | 3434 | 3435 | 3436 | 3437 | 3438 | 3439 | 3440 | 3441 | 3442 | 3443 | 3444 | 3445 | 3446 | 3447 | 3448 | 3449 | 3450 | 3451 | 3452 | 3453 | 3454 | 3455 | 3456 | 3457 | 3458 | 3459 | 3460 | 3461 | 3462 | 3463 | 3464 | 3465 | 3466 | 3467 | 3468 | 3469 | 3470 | 3471 | 3472 | 3473 | 3474 | 3475 | 3476 | 3477 | 3478 | 3479 | 3480 | 3481 | 3482 | 3483 | 3484 | 3485 | 3486 | 3487 | 3488 | 3489 | 3490 | 3491 | 3492 | 3493 | 3494 | 3495 | 3496 | 3497 | 3498 | 3499 | 3500 | 3501 | 3502 | 3503 | 3504 | 3505 | 3506 | 3507 | 3508 | 3509 | 3510 | 3511 | 3512 | 3513 | 3514 | 3515 | 3516 | 3517 | 3518 | 3519 | 3520 | 3521 | 3522 | 3523 | 3524 | 3525 | 3526 | 3527 | 3528 | 3529 | 3530 | 3531 | 3532 | 3533 | 3534 | 3535 | 3536 | 3537 | 3538 | 3539 | 3540 | 3541 | 3542 | 3543 | 3544 | 3545 | 3546 | 3547 | 3548 | 3549 | 3550 | 3551 | 3552 | 3553 | 3554 | 3555 | 3556 | 3557 | 3558 | 3559 | 3560 | 3561 | 3562 | 3563 | 3564 | 3565 | 3566 | 3567 | 3568 | 3569 | 3570 | 3571 | 3572 | 3573 | 3574 | 3575 | 3576 | 3577 | 3578 | 3579 | 3580 | 3581 | 3582 | 3583 | 3584 | 3585 | 3586 | 3587 | 3588 | 3589 | 3590 | 3591 | 3592 | 3593 | 3594 | 3595 | 3596 | 3597 | 3598 | 3599 | 3600 | 3601 | 3602 | 3603 | 3604 | 3605 | 3606 | 3607 | 3608 | 3609 | 3610 | 3611 | 3612 | 3613 | 3614 | 3615 | 3616 | 3617 | 3618 | 3619 | 3620 | 3621 | 3622 | 3623 | 3624 | 3625 | 3626 | 3627 | 3628 | 3629 | 3630 | 3631 | 3632 | 3633 | 3634 | 3635 | 3636 | 3637 | 3638 | 3639 | 3640 | 3641 | 3642 | 3643 | 3644 | 3645 | 3646 | 3647 | 3648 | 3649 | 3650 | 3651 | 3652 | 3653 | 3654 | 3655 | 3656 | 3657 | 3658 | 3659 | 3660 | 3661 | 3662 | 3663 | 3664 | 3665 | 3666 | 3667 | 3668 | 3669 | 3670 | 3671 | 3672 | 3673 | 3674 | 3675 | 3676 | 3677 | 3678 | 3679 | 3680 | 3681 | 3682 | 3683 | 3684 | 3685 | 3686 | 3687 | 3688 | 3689 | 3690 | 3691 | 3692 | 3693 | 3694 | 3695 | 3696 | 3697 | 3698 | 3699 | 3700 | 3701 | 3702 | 3703 | 3704 | 3705 | 3706 | 3707 | 3708 | 3709 | 3710 | 3711 | 3712 | 3713 | 3714 | 3715 | 3716 | 3717 | 3718 | 3719 | 3720 | 3721 | 3722 | 3723 | 3724 | 3725 | 3726 | 3727 | 3728 | 3729 | 3730 | 3731 | 3732 | 3733 | 3734 | 3735 | 3736 | 3737 | 3738 | 3739 | 3740 | 3741 | 3742 | 3743 | 3744 | 3745 | 3746 | 3747 | 3748 | 3749 | 3750 | 3751 | 3752 | 3753 | 3754 | 3755 | 3756 | 3757 | 3758 | 3759 | 3760 | 3761 | 3762 | 3763 | 3764 | 3765 | 3766 | 3767 | 3768 | 3769 | 3770 | 3771 | 3772 | 3773 | 3774 | 3775 | 3776 | 3777 | 3778 | 3779 | 3780 | 3781 | 3782 | 3783 | 3784 | 3785 | 3786 | 3787 | 3788 | 3789 | 3790 | 3791 | 3792 | 3793 | 3794 | 3795 | 3796 | 3797 | 3798 | 3799 | 3800 | 3801 | 3802 | 3803 | 3804 | 3805 | 3806 | 3807 | 3808 | 3809 | 3810 | 3811 | 3812 | 3813 | 3814 | 3815 | 3816 | 3817 | 3818 | 3819 | 3820 | 3821 | 3822 | 3823 | 3824 | 3825 | 3826 | 3827 | 3828 | 3829 | 3830 | 3831 | 3832 | 3833 | 3834 | 3835 | 3836 | 3837 | 3838 | 3839 | 3840 | 3841 | 3842 | 3843 | 3844 | 3845 | 3846 | 3847 | 3848 | 3849 | 3850 | 3851 | 3852 | 3853 | 3854 | 3855 | 3856 | 3857 | 3858 | 3859 | 3860 | 3861 | 3862 | 3863 | 3864 | 3865 | 3866 | 3867 | 3868 | 3869 | 3870 | 3871 | 3872 | 3873 | 3874 | 3875 | 3876 | 3877 | 3878 | 3879 | 3880 | 3881 | 3882 | 3883 | 3884 | 3885 | 3886 | 3887 | 3888 | 3889 | 3890 | 3891 | 3892 | 3893 | 3894 | 3895 | 3896 | 3897 | 3898 | 3899 | 3900 | 3901 | 3902 | 3903 | 3904 | 3905 | 3906 | 3907 | 3908 | 3909 | 3910 | 3911 | 3912 | 3913 | 3914 | 3915 | 3916 | 3917 | 3918 | 3919 | 3920 | 3921 | 3922 | 3923 | 3924 | 3925 | 3926 | 3927 | 3928 | 3929 | 3930 | 3931 | 3932 | 3933 | 3934 | 3935 | 3936 | 3937 | 3938 | 3939 | 3940 | 3941 | 3942 | 3943 | 3944 | 3945 | 3946 | 3947 | 3948 | 3949 | 3950 | 3951 | 3952 | 3953 | 3954 | 3955 | 3956 | 3957 | 3958 | 3959 | 3960 | 3961 | 3962 | 3963 | 3964 | 3965 | 3966 | 3967 | 3968 | 3969 | 3970 | 3971 | 3972 | 3973 | 3974 | 3975 | 3976 | 3977 | 3978 | 3979 | 3980 | 3981 | 3982 | 3983 | 3984 | 3985 | 3986 | 3987 | 3988 | 3989 | 3990 | 3991 | 3992 | 3993 | 3994 | 3995 | 3996 | 3997 | 3998 | 3999 | 4000 | 4001 | 4002 | 4003 | 4004 | 4005 | 4006 | 4007 | 4008 | 4009 | 4010 | 4011 | 4012 | 4013 | 4014 | 4015 | 4016 | 4017 | 4018 | 4019 | 4020 | 4021 | 4022 | 4023 | 4024 | 4025 | 4026 | 4027 | 4028 | 4029 | 4030 | 4031 | 4032 | 4033 | 4034 | 4035 | 4036 | 4037 | 4038 | 4039 | 4040 | 4041 | 4042 | 4043 | 4044 | 4045 | 4046 | 4047 | 4048 | 4049 | 4050 | 4051 | 4052 | 4053 | 4054 | 4055 | 4056 | 4057 | 4058 | 4059 | 4060 | 4061 | 4062 | 4063 | 4064 | 4065 | 4066 | 4067 | 4068 | 4069 | 4070 | 4071 | 4072 | 4073 | 4074 | 4075 | 4076 | 4077 | 4078 | 4079 | 4080 | 4081 | 4082 | 4083 | 4084 | 4085 | 4086 | 4087 | 4088 | 4089 | 4090 | 4091 | 4092 | 4093 | 4094 | 4095 | 4096 | 4097 | 4098 | 4099 | 4100 | 4101 | 4102 | 4103 | 4104 | 4105 | 4106 | 4107 | 4108 | 4109 | 4110 | 4111 | 4112 | 4113 | 4114 | 4115 | 4116 | 4117 | 4118 | 4119 | 4120 | 4121 | 4122 | 4123 | 4124 | 4125 | 4126 | 4127 | 4128 | 4129 | 4130 | 4131 | 4132 | 4133 | 4134 | 4135 | 4136 | 4137 | 4138 | 4139 | 4140 | 4141 | 4142 | 4143 | 4144 | 4145 | 4146 | 4147 | 4148 | 4149 | 4150 | 4151 | 4152 | 4153 | 4154 | 4155 | 4156 | 4157 | 4158 | 4159 | 4160 | 4161 | 4162 | 4163 | 4164 | 4165 | 4166 | 4167 | 4168 | 4169 | 4170 | 4171 | 4172 | 4173 | 4174 | 4175 | 4176 | 4177 | 4178 | 4179 | 4180 | 4181 | 4182 | 4183 | 4184 | 4185 | 4186 | 4187 | 4188 | 4189 | 4190 | 4191 | 4192 | 4193 | 4194 | 4195 | 4196 | 4197 | 4198 | 4199 | 4200 | 4201 | 4202 | 4203 | 4204 | 4205 | 4206 | 4207 | 4208 | 4209 | 4210 | 4211 | 4212 | 4213 | 4214 | 4215 | 4216 | 4217 | 4218 | 4219 | 4220 | 4221 | 4222 | 4223 | 4224 | 4225 | 4226 | 4227 | 4228 | 4229 | 4230 | 4231 | 4232 | 4233 | 4234 | 4235 | 4236 | 4237 | 4238 | 4239 | 4240 | 4241 | 4242 | 4243 | 4244 | 4245 | 4246 | 4247 | 4248 | 4249 | 4250 | 4251 | 4252 | 4253 | 4254 | 4255 | 4256 | 4257 | 4258 | 4259 | 4260 | 4261 | 4262 | 4263 | 4264 | 4265 | 4266 | 4267 | 4268 | 4269 | 4270 | 4271 | 4272 | 4273 | 4274 | 4275 | 4276 | 4277 | 4278 | 4279 | 4280 | 4281 | 42 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----|











| Time   | Temp. °F | Thermocouple Designation | Pressure | Plate In. | Orifice In. H <sub>2</sub> O | Kettle Jacket (steam) psig | Reflux | Condenser | Roto Rdg |
|--------|----------|--------------------------|----------|-----------|------------------------------|----------------------------|--------|-----------|----------|
| 80:00  | 96.52    | I-1000                   |          |           |                              |                            |        |           |          |
| 84:00  | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 88:00  | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 92:00  | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 96:00  | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 100:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 104:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 108:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 112:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 116:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 120:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 124:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 128:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 132:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 136:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 140:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 144:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 148:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 152:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 156:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 160:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 164:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 168:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 172:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 176:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 180:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 184:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 188:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 192:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 196:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 200:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 204:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 208:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 212:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 216:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 220:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 224:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 228:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 232:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 236:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 240:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 244:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 248:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 252:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 256:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 260:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 264:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 268:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 272:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 276:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 280:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 284:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 288:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 292:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 296:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |
| 300:00 | 98.00    | I-1000                   |          |           |                              |                            |        |           |          |

RUN XI.

Kettle Charge  
 3/16" Hole Diameter  
 1.17% Free Space Area

| Time | Temperature °F |       |       |       |       |       |   |       |    |    |      | Pressure |     |     |        | Orifice In. H <sub>2</sub> O | Kettle Jacket (steam) psig | Roto Rdg  |  |  |
|------|----------------|-------|-------|-------|-------|-------|---|-------|----|----|------|----------|-----|-----|--------|------------------------------|----------------------------|-----------|--|--|
|      | 1              | 2     | 4     | 5     | 6     | 7     | 8 | 9     | 10 | 11 | 1    | 2        | 3   | 4   | Reflux |                              |                            | Condenser |  |  |
| 1500 | Steam to pot   |       |       |       |       |       |   |       |    |    |      |          |     |     |        |                              |                            |           |  |  |
| 1645 | 93             | 147.8 | 152.2 | 149.9 | 132.8 | 154.8 | - | 190.0 | -  | -  | 0.2  | 0.9      | 1.6 | 2.2 | 2.5    | 38                           | 8.0                        |           |  |  |
| 1730 |                |       |       |       |       |       |   |       |    |    | 0.2  | 0.95     | 1.6 | 2.2 | 2.5    | 39                           | 8.0                        |           |  |  |
| 1900 | 96.5           | 140.0 | 152.6 | 150.6 | 133.7 | 154.8 | - | 195.9 | -  | -  | 0.19 | 0.9      | 1.6 | 2.2 | 2.4    | 43                           | 7.5                        |           |  |  |
| 1917 |                |       |       |       |       |       |   |       |    |    |      |          |     |     |        |                              |                            |           |  |  |
| 1945 | 118.4          | 147.0 | 153.4 | 151.8 | 135.0 | 156.8 | - | 195.9 | -  | -  |      | 0.1      | 0.4 | 0.7 | 1.0    | 24                           | 4.0                        |           |  |  |
| 2130 | Steam off      |       |       |       |       |       |   |       |    |    |      |          |     |     |        |                              |                            |           |  |  |



1700 1730 1735 1745 1753 1758 1805 1807 1809 1815 1821 1824 1827 1830 1837 1847 1900 1852 1915 1946 1940 1944 1955 2014 2025 2040 2045 2047 2055 2057 2100 2105 2112

Dist. x-4 x-3 x-2-L x-1 x-2-R y-4 y-3 y-2 Dist. y-1 Dist. Dist. x-3 x-2-L x-1 y-4 y-3 y-2 Dist. y-1

1.3299 1.3405 1.3406 1.3407 1.3408 1.3409 1.3361 1.3361 1.3361 1.3332 1.3332 1.3382 1.3382 1.3409 1.3409 1.3385 1.3386 1.3340 1.3340 1.3304 1.3305 1.3292 1.3294 1.3305 1.3305 1.3305 1.3405 1.3405 1.3381 1.3380 1.3396 1.3396 1.3381 1.3345 1.3399 1.3399 1.3396 1.3396 1.3346 1.3346 1.3310 1.3310

96.1 64.7 63.3 82.5 90.2 74.4 62.75 73.0 88.6 95.1 97.1 95.0 95.0 65.0 74.75 69.00 74.75 87.60 68.00 69.00 69.00 87.30 94.10 94.1

0.508 0.492 0.837 0.621 0.487 0.603 0.815 0.95 0.512 0.554 0.798 0.553 0.554 0.795 0.899 0.899

RUN XI. SAMPLE DATA

| TIME | SAMPLE DESIG. | $n_D$ 25°C | WEIGHT % MECH | MOL FRACT. MECH |
|------|---------------|------------|---------------|-----------------|
| 1700 | Dist.         | 1.3299     | 96.1          |                 |
| 1730 | x-4           | 1.3405     |               | 0.508           |
|      |               | 1.3406     | 64.7          |                 |
|      |               | 1.3407     |               | 0.492           |
| 1735 | x-3           | 1.3408     | 63.3          |                 |
| 1745 |               | 1.3409     |               | 0.492           |
| 1753 | x-2-L         | 1.3361     |               |                 |
| 1758 |               | 1.3361     | 82.5          |                 |
|      |               | 1.3361     |               |                 |
| 1805 | x-1           | 1.3332     | 90.2          | 0.837           |
| 1807 |               | 1.3332     |               |                 |
| 1809 | x-2-R         | 1.3382     | 74.4          | 0.621           |
| 1815 |               | 1.3382     |               |                 |
| 1821 | y-4           | 1.3409     | 62.75         | 0.487           |
| 1824 |               | 1.3409     |               |                 |
| 1827 | y-3           | 1.3385     | 73.0          | 0.603           |
| 1830 |               | 1.3386     |               |                 |
| 1837 | y-2           | 1.3340     | 88.6          | 0.815           |
|      |               | 1.3340     |               |                 |
| 1847 | Dist.         | 1.3304     | 95.1          |                 |
| 1900 |               | 1.3305     |               |                 |
| 1852 | y-1           | 1.3292     | 97.1          | 0.95            |
| 1915 |               | 1.3294     |               |                 |
| 1946 | Dist.         | 1.3305     | 95.0          |                 |
| 1940 |               |            |               |                 |
| 1944 |               |            |               |                 |
| 1955 | Dist.         | 1.3305     | 95.0          |                 |
| 2014 |               | 1.3305     |               |                 |
|      | x-3           | 1.3405     | 65.0          | 0.512           |
|      |               | 1.3405     |               |                 |
| 2025 | x-2-L         | 1.3381     | 74.75         |                 |
|      |               | 1.3380     |               |                 |
| 2040 | x-2-R         | 1.3396     | 69.00         | 0.554           |
| 2045 |               | 1.3396     |               |                 |
| 2047 | x-2-L         | 1.3381     | 74.75         |                 |
|      | x-1           | 1.3345     | 87.60         | 0.798           |
| 2055 | y-4           | 1.3399     | 68.00         | 0.553           |
| 2057 |               | 1.3399     |               |                 |
| 2100 | y-3           | 1.3396     | 69.00         | 0.554           |
| 2105 |               | 1.3396     |               |                 |
|      | y-2           | 1.3346     | 87.30         | 0.795           |
|      |               | 1.3346     |               |                 |
| 2112 | Dist.         | 1.3310     | 94.10         | 0.899           |
|      |               | 1.3310     |               |                 |
|      | y-1           |            | 94.1          | 0.899           |

