FROTH FORMATION ABOVE DISTILLATION TRAYS

By

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PREFACE

In this thesis I have attempted to add to the understanding of the variables which affect the froth height in a distillation column. Air-water and air-oil systems were studied. The purpose was to determine the effect of gas velocity and clear liquid level on the froth height.

I appreciate the guidance and constructive criticism offered by Dr. Robert N. Maddox. I also wish to thank Mr. E. E. McCroskey for his aid in construction of the equipment and the use of his photographic equipment.

The generosity of Mr. E. K. Gaylord, through his support of my Honors Fellowship, helped make this work possible.

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CHAPTER I

THE PROBLEM

Statement of the Problem

The rapid growth in industry's demand for distillation towers has led to the adoption of design techniques which utilize many simplifying assumptions. The estimation of the froth height is one such example. In most cases a liberal estimate is made of the froth height and the design incorporates this estimation. It is obvious that such an estimation based on experience or a "rule of thumb" has certain inherent weaknesses.

Assuming that the design yielded an operable column, it could then cause money to be invested in oversized equipment which provides no additional return and hence, a net loss to the investor. The utilization of more expensive materials of construction, required by higher working pressures and corrosive systems, magnifies the costs connected with inferior design techniques.

In addition to its economic significance, the study of froth height is important from a technical point of view. In the design of distillation columns it is of paramount importance that the designer be aware of the factors which affect the operating efficiency of a distillation tray. In this respect the froth formation above the tray is quite important.

The purpose of this investigation was to collect and correlate data concerning the variables which affect the froth height. The hot-wire anemometer was used to locate the froth height. Preliminary investigation indicated that the use of the hot-wire anemometer would be a great improvement over existing techniques. The improved accuracy obtained by the use of this instrument made a real contribution to the value of the results.

Limitations of the Study

In this problem, only the air-water and the air-oil systems were investigated. The effects of the two major variables, gas velocity and clear liquid holdup, were studied. The studies were made using a non-flow pilot column containing one perforated tray.

Aside from the preliminary work, the constant temperature probe was employed in contrast to the variable resistance technique. This was done to improve the accuracy of the data collected. The electrical equipment provides measurements precise to three significant figures. The dynamic variability of the froth height makes this precision more than adequate.

The probe was centered in the froth bed. It covered a section approximately equal to one-third of the cross-sectional area of the column. This section was assumed to be representative of the froth-bed at any particular elevation above the plate.

Clarification of Terms

The word froth is used to denote the mixture of gas and liquid which is present above the distillation tray. It includes only the region where neither phase is readily distinguishable. Hence, the density of the froth will always be greater than the gas density and less than the liquid density.

Froth height denotes the distance that the interface between the froth and the gas phase is above the tray. The froth height data were recorded in centimeters, but have been converted to inches for ease in evaluation.

F factor or F value is a measure of the gas velocity with a density factor included. It has been accepted as a useful way to describe gas rates in a distillation tower. The F value, for any given velocity, is the product of the linear gas velocity multiplied by the square root of the density of the gas. The F factor, thus calculated, represents the square root of the pressure head equal to the superficial gas velocity. All quantities have units of feet, pounds or seconds.

CHAPTER II

REVIEW OF LITERATURE

Historical Background

In an effort to increase the available information concerning the design of distillation columns, the American Institute of Chemical Engineers initiated a research program on plate efficiencies. This program, started in 1952, is being conducted at the University of Delaware, the University of Michigan and North Carolina State College. The investigation of plate efficiencies has amplified the problem of determining the vapor residence time which in turn is dependent on the froth height.

Visual determination of froth heights has been tried by a number of investigators, but the results have been far from satisfactory. Gerster, et al, discuss the problems encountered when utilizing this technique.(2) It is logical that a better method could be devised for determining the froth level.

The hot-wire anemometer has properties which make it suitable for locating froth heights. Hot-wire anemometry was utilized as early as 1921, by Griffiths for determining the liquid level in a fuel tank.(5) From that time to the present the hot-wire anemometer, often called a resistance thermometer, has found many applications. A few such uses have been the measurement of temperature, flow-rate, and turbulence of gas streams.

Hot-Wire Anemometry

The salient feature on which anemometry is founded is the fact that the resistance of a wire changes with temperature. The factors that induce a change in temperature of a wire can, therefore, be studied and related to changes in the resistance of the wire. In the hot-wire anemometer, current is supplied to the wire for two reasons. First, it is necessary to heat the wire so that temperature changes are possible. Secondly, the current allows the resistance of the wire to be measured by means of a Wheatstone Bridge. There are two techniques used in the field of hot-wire anemometry. One is a constant temperature probe where the current is varied in order to maintain the reference temperature. The other is a variable resistance scheme where the current to the probe is esentially constant and the temperature allowed to vary in response to variations in the froth bed surrounding the probe.

Recently, work was completed by Albright at Oklahoma State University.(1) He evaluated the application of the hot-wire anemometer in the location of froth heights. He used a variable temperature probe, and found it to be quite satisfactory at low gas velocities.

The principle difference between the two possible type probes can be clarified by studying the factors which influence their operation. The basic law which enables one to predict the operation of the hot-wire anemometer is given by:

$$Q = U A_p \Delta t$$

where Q = Heat lost by probe, I^2R.

U = Heat transfer coefficient for the systems in which the probe is immersed.

A_p = Surface area of the probe.

Δt = Temperature of the probe minus the temperature of the cooling medium, $(T_p - T)$.

In going from one location to another in the froth, the value of U changes because of changes in the density and other properties of the system. For the sake of clarity let us assume that U changes by a factor of two, i.e., increases by 100% or decreases by 50%. Further more, let us assume that Δt is small compared with T_p. If the voltage is held constant, then Q will not change much as $Q = E\ I$. Δt will change by a factor of 2 which will cause only a slight percentage change in T_p. This is obviously semi-insensitive and is characteristic of the variable resistance probe.

In contrast let us see the effect of holding T_p constant and thereby R_p constant. Q must change by a factor of two when U decreases by a factor of two. Since A and Δt are held constant I^2 must be reduced by a factor of two. In other words $I_2 = I_1 / \sqrt{2}$ which means I will change by a factor of 1.4 when U changes by a factor of 2. This is a sensitive response and is characteristic of the constant temperature probe.

It may be argued that when the current is allowed to change the temperature of the fixed resistance of the Wheatstone Bridge will vary and introduce errors in the data taken. Theoretically this is a valid criticism; however, a check should be made on the magnitude of the possible temperature change. The heat lost by any resistance, if the voltage across it is changed by a factor of two, changes by a factor of 4. Since for a given resistance $Q = U\ A \Delta t$, where U and A will be constant and Δt will be small compared to T_r, Δt must change by a factor of 4 and it is believed that this change of Δt will produce a negligible change in T_r and consequently R_r.

Summary of the Literature

Previous published work on froth formation is almost non-existent. Information concerning the froth is commonly the by-product from a study of tray efficiencies. This is the case with regard to one of the more useful and recent reports concerning tray efficiencies. Data collected at the Universities of Delaware and Michigan and North Carolina State College include work on froth formation. These data were collected in connection with a program for the study of tray efficiencies in distillation columns sponsored by the American Institute of Chemical Engineers. Correlations based on the data are summarized in the progress report dated June 30, 1956.(3)

Figure 1 shows the relationship between clear liquid holdup and froth height for the air-water system at three different F values. Data necessary for the correlation presented in Figure 1 were extracted from work done at the University of Michigan and presented in the previously mentioned progress report.

In prior work concerning the location of froth height two techniques have been tried. Both methods have definite shortcomings and the data collected is of doubtful accuracy. The two methods employed to date are the visual and touch methods for determining froth height.

The visual method makes use of two glass windows in the column. A graduated device is mounted inside the column and the froth height can be visually recorded. The persons taking data must attempt to average the fluctuations in the froth height by sight and record this average as the best guess as to the actual froth height. The results from this technique have been far from satisfactory.

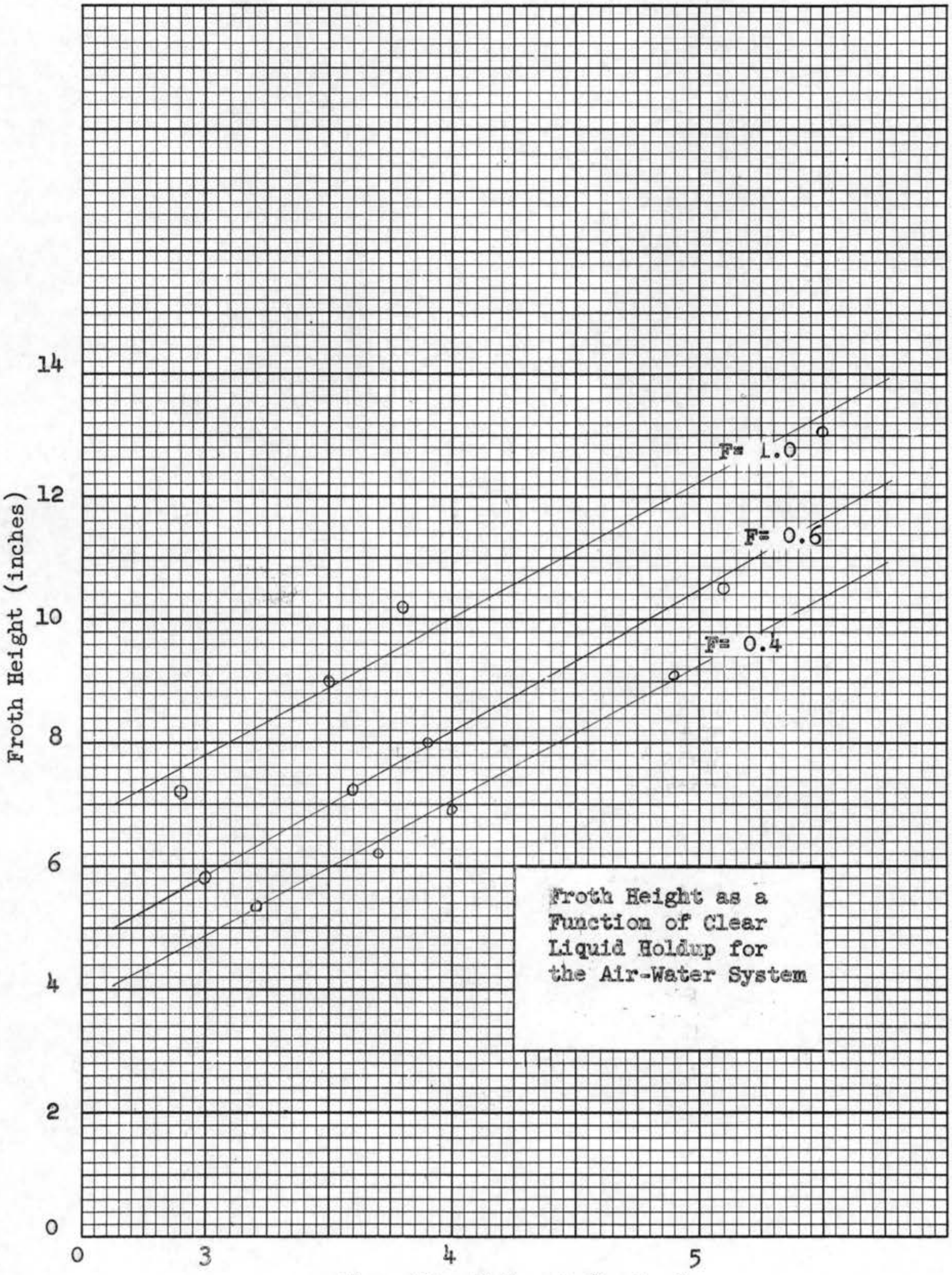


FIGURE 1

Correlation of Data Collected By Williams, et al.(3)

In the touch method the operator must insert his hand through the inspection port and locate the froth height by touch. Translating this point of contact into an accurate level of the froth is nearly impossible. In addition to the inherent difficulties of measuring the froth height accurately this method has another limitation. The column must be operated at atmospheric pressure or opening the inspection port will disturb the operation of the column.

CHAPTER III

METHOD AND PROCEDURE

Apparatus

Column

A four inch inside diameter transparent column was used in this investigation. The column was constructed from three glass sections and one lucite section. All sections were six inches long and were connected by the use of flanges and connecting rods. The plate to be used was mounted in the middle of the column thus providing a twelve inch section below the plate for flow distribution. The twelve inch section above the plate allowed the froth to be studied visually and allowed for the disentrainment of the liquid from the vapor.

The top of the column was open to the atmosphere as all data concerning the vapor rate were taken upstream from the plate. The bottom of the column was made from one-sixteenth inch galvanized sheet fitted with copper tubing connections for the air, manometer, and drain lines. The air line connection was one-half inch copper tubing which extended three inches above the bottom plate. The discharge end of this line was equipped with a small baffle plate to distribute the gas evenly across the cross-section of the column.

Trays

The trays used in this investigation were made of one-eighth inch stainless steel plate. The holes drilled were one-eighth inch in diameter. Preliminary work was done with a plate containing eight 1/8" holes on 2.3 centimeter triangular pitch. The pressure drop across this plate was found to be excessive and it was replaced with a plate having more flow area. The new plate contained thirty-seven 1/8" holes on 1.15 centimeter triangular pitch.

Probe

The probe was constructed from a piece of fine platinum wire, 0.005 inches in diameter and 10.75 inches long, stretched between two insulated copper leads. The sensitivity of the probe was directly proportional to the length of the platinum wire. This fact dictated that the maximum amount of wire be utilized. Two lucite spacing struts were employed to allow a greater length of platinum wire to be used. The probe was attached to one end of a lucite tube with the leads threaded inside the tube. The other end of the tube was held by an adjustable clamp which allowed the probe to be positioned at any desired elevation in the column. A scale placed on the upper portion of the probe allowed its position in the column to be easily determined. A photograph of the apparatus appears in Figure 2.

Auxiliaries

1. Preliminary studies were conducted using two Fischer-Porter model B4N-25-A rotameters in parallel to meter the air flowing to the column. These rotameters were installed on the inlet air line as the top of the column was open to the atmosphere.
2. One Fischer-Porter model B-5A-25-A rotameter was used for the final portion of the investigation. It was employed to enable a larger quantity of air to be metered. It was installed in the inlet air line for reasons stated above.

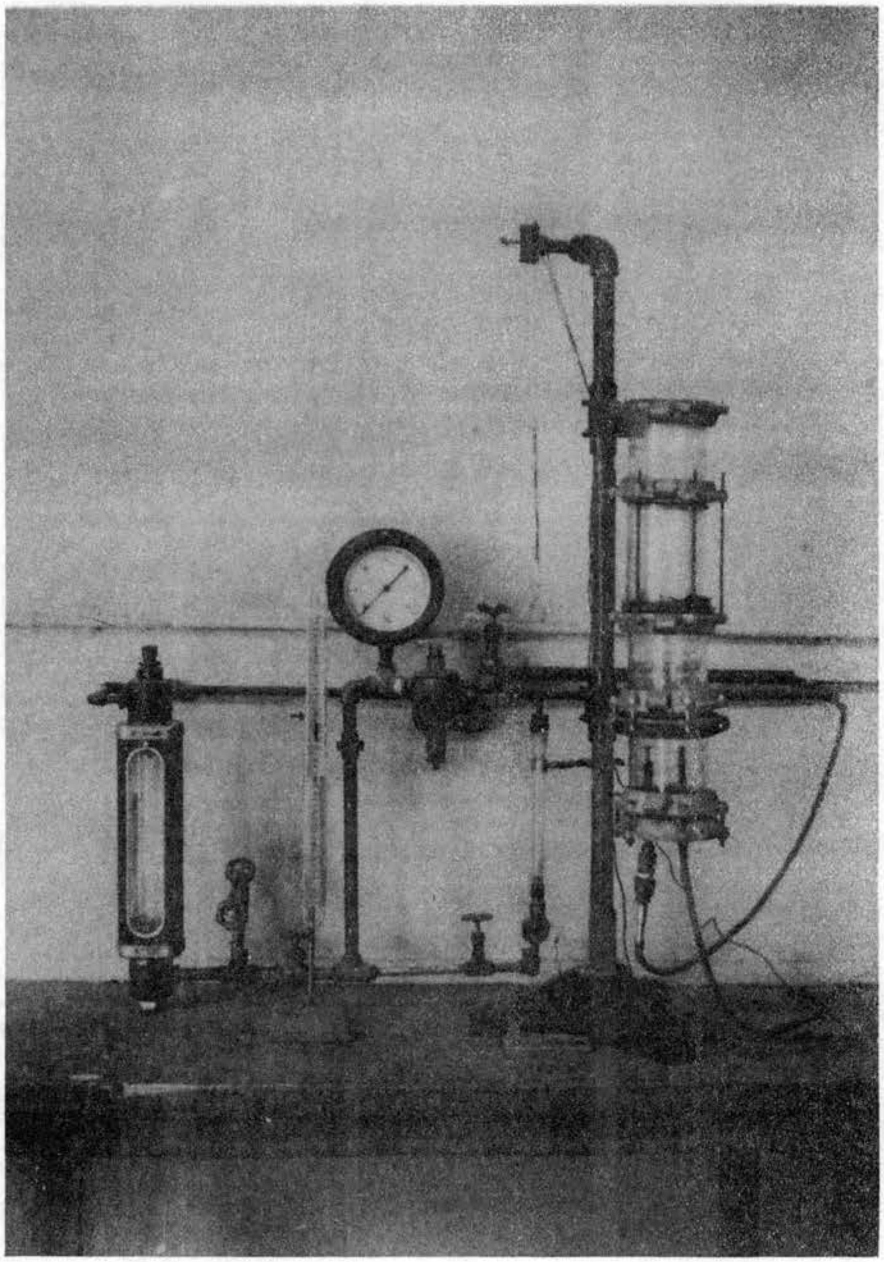


FIGURE 2

Experimental Apparatus

3. One U-tube manometer was constructed to determine the pressure drop across the plate. A metric scale divided into millimeters was used to measure the pressure differential. One leg of the manometer was connected to a tap located below the tray, and the other leg was open to the atmosphere. The manometer was filled with distilled water colored with a drop of fortisan solution.
4. One Leeds and Northrup Company Student Potentiometer No. 244726 was used to effect the necessary electrical measurements and adjustments. The fixed resistances were each 45 ohms. The slide wire contained 1000 divisions, each representing 0.01 ohm resistance or a total of 10 ohms. A drawing of the electrical circuit appears in Figure 3.
5. One Leeds and Northrup Company Model 2420-0 reflected beam galvanometer was used to indicate the balance of the Wheatstone Bridge.
6. One Leeds and Northrup Company Resistance Box No. 245486 was used to provide a variable resistance of desired magnitude. It provided resistance from 0 to 9,999 ohms in 1 ohm increments.
7. One Triplet Company model 0221-T ammeter was used to measure the current flowing through the probe. Its scale was calibrated from 0 to 500 D.C. milliamps.
8. The battery used was a 7.2 volt Nicad wet cell. A variable resistance was installed in series with the battery to provide a means of varying the potential across the probe.
9. A Curtin Company mecury therometer was used to measure the temperature of the froth. It was graduated from -30° to 120° F in 1° increments.

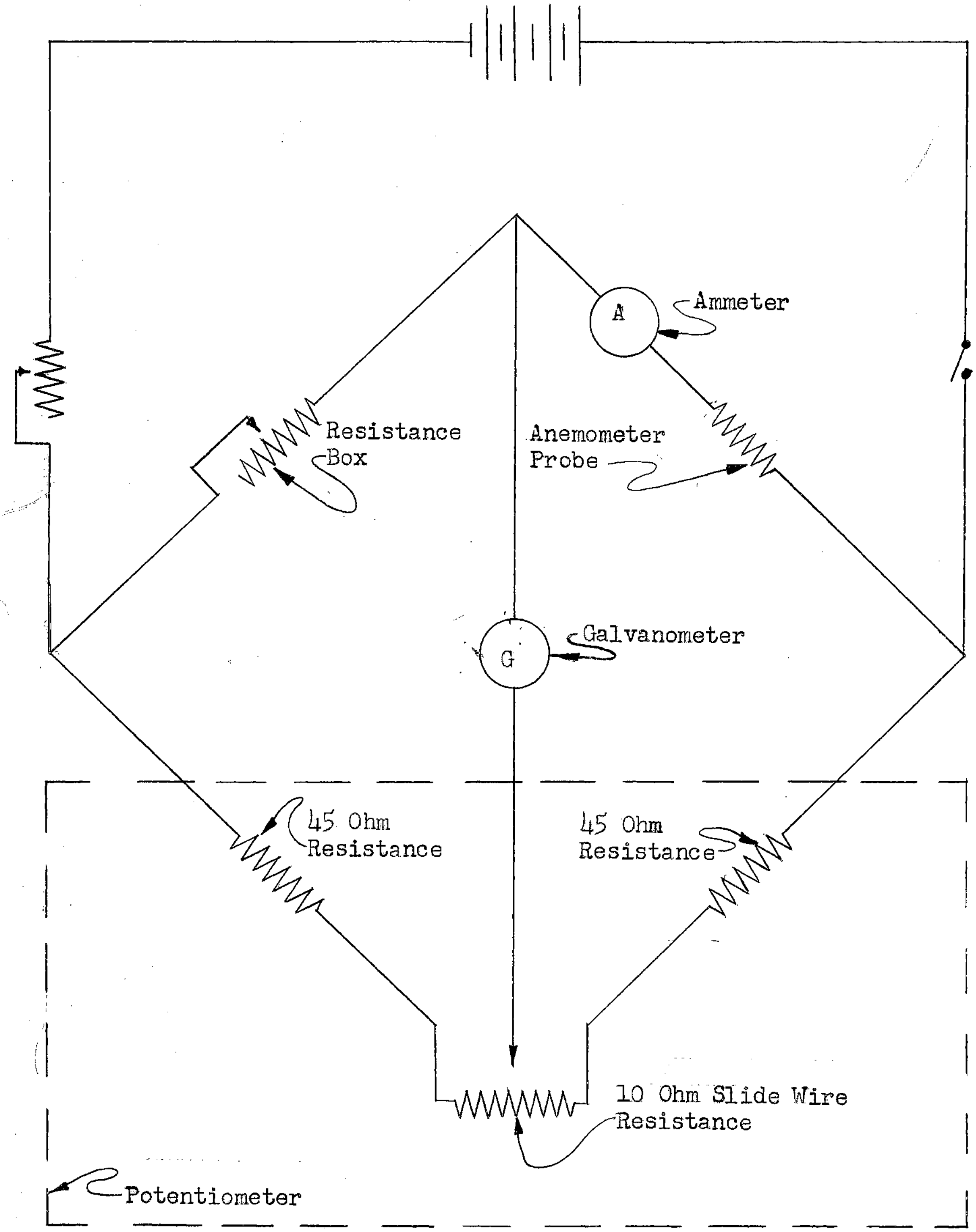


FIGURE 3

Electrical Circuit Diagram

10. Air for these studies were drawn from the laboratory compressed air tank. The tank was supplied by a single-stage compressor. An auxiliary compressor was available in the event the primary compressor could not furnish the quantity of air required. The pressure in the supply tank varied from 80 to 120 psig, depending on the rate of air withdrawal.
11. One Climax type 245 pressure regulator was installed in the inlet air line, upstream from the rotameter. It was used to reduce the air pressure from 100 psig to 25 psig. This installation served a two-fold purpose. First, it was a safety measure to protect the equipment from excessive pressures. Secondly, it served to eliminate the possibility of inaccuracies being introduced in the metering of the air due to pressure variations. The pressure in the supply tank was maintained above 25 psig.

Experimental Procedure

To start a run, the probe was positioned above the plate at the desired still liquid level. Water or oil, depending on the system being studied, was added until the probe was well covered. Air was introduced to the column and frothing commenced above the plate. There was a negligible amount of seepage. The froth temperature was recorded and checked at intervals to determine when the equilibrium temperature had been reached. While the froth was reaching equilibrium, current was supplied to the probe so that it could attain an equilibrium temperature. When it was determined that the froth had reached the equilibrium temperature, the air was turned off and the liquid allowed to drain slowly through the plate until the liquid surface was exactly even with the probe. The air was then adjusted to the desired rate. After the desired variables had been adjusted and recorded, the froth height was located.

The froth height was determined by making a vertical traverse with the hot-wire probe. The probe was lowered to a point just above the tray. The variable resistance in series with the battery was adjusted until the current flowing through the probe was between four hundred and five hundred milliamps. After the Wheatstone bridge was balanced, the variable resistance in the bridge and the current to the probe were recorded. The temperature of the froth was recorded. The probe was raised one centimeter and the current adjusted until the balance of the Wheatstone bridge was restored. The new current value and the position of the probe were recorded. The probe was then raised one centimeter and the process repeated. This technique was continued until the probe was obviously above the froth-gas interface. This visual observation was verified by the fact that current to the probe showed no change as the probe was raised farther above the tray. The temperature was taken to verify that no significant change had occurred. The air was turned off and the still liquid level was checked. This completed one experimental run.

CHAPTER IV

RESULTS

Preliminary Investigation of Anemometry Techniques

Before commencing the study of froth characteristics it was necessary that the alternate techniques of utilizing the hot-wire anemometer be studied and evaluated. The series of graphs which follow are representative of the data collected by the two different techniques. A total of four runs, two by each technique, are presented.

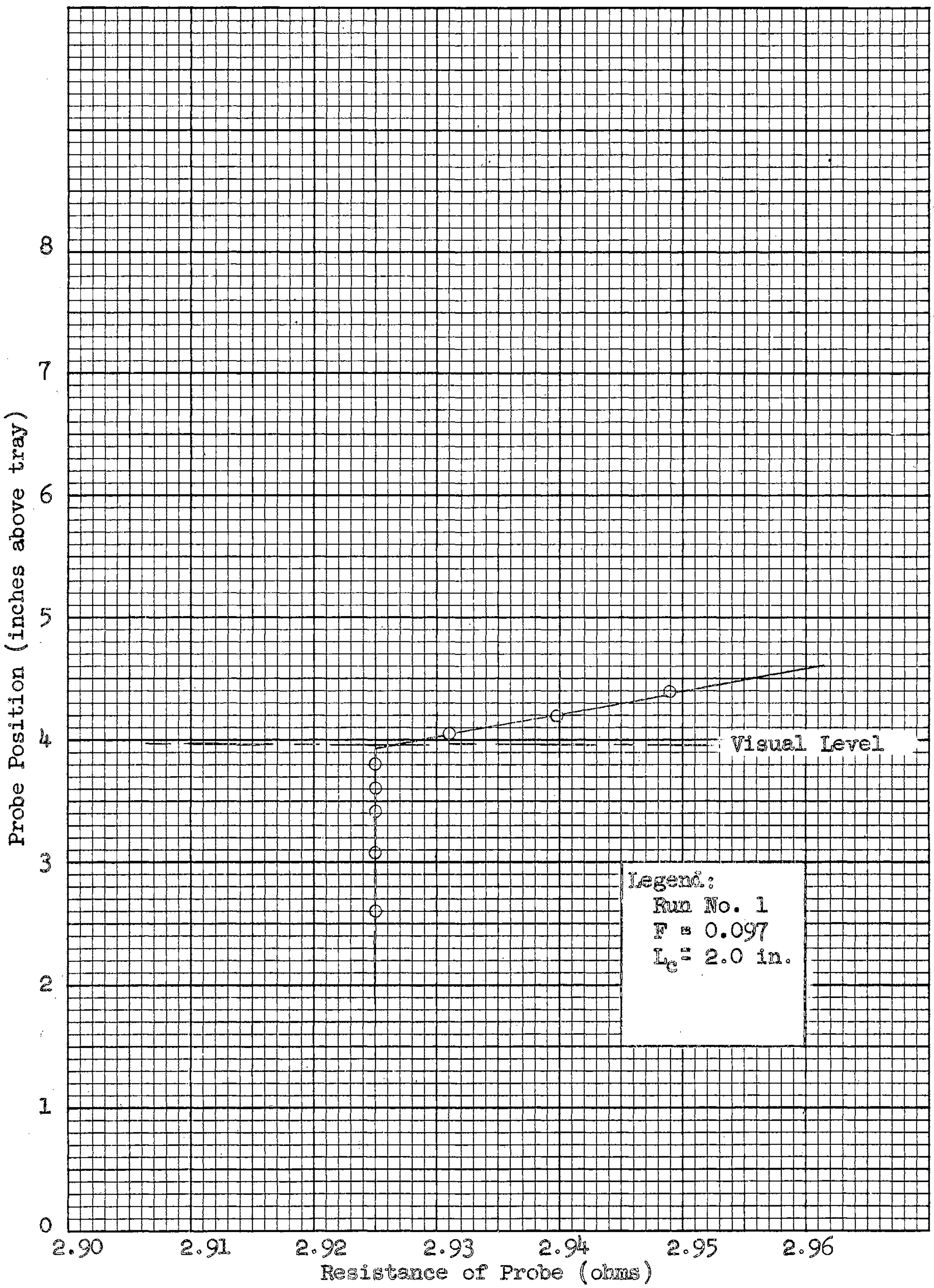


FIGURE 4

Typical Vertical Traverse using Variable Resistance Probe

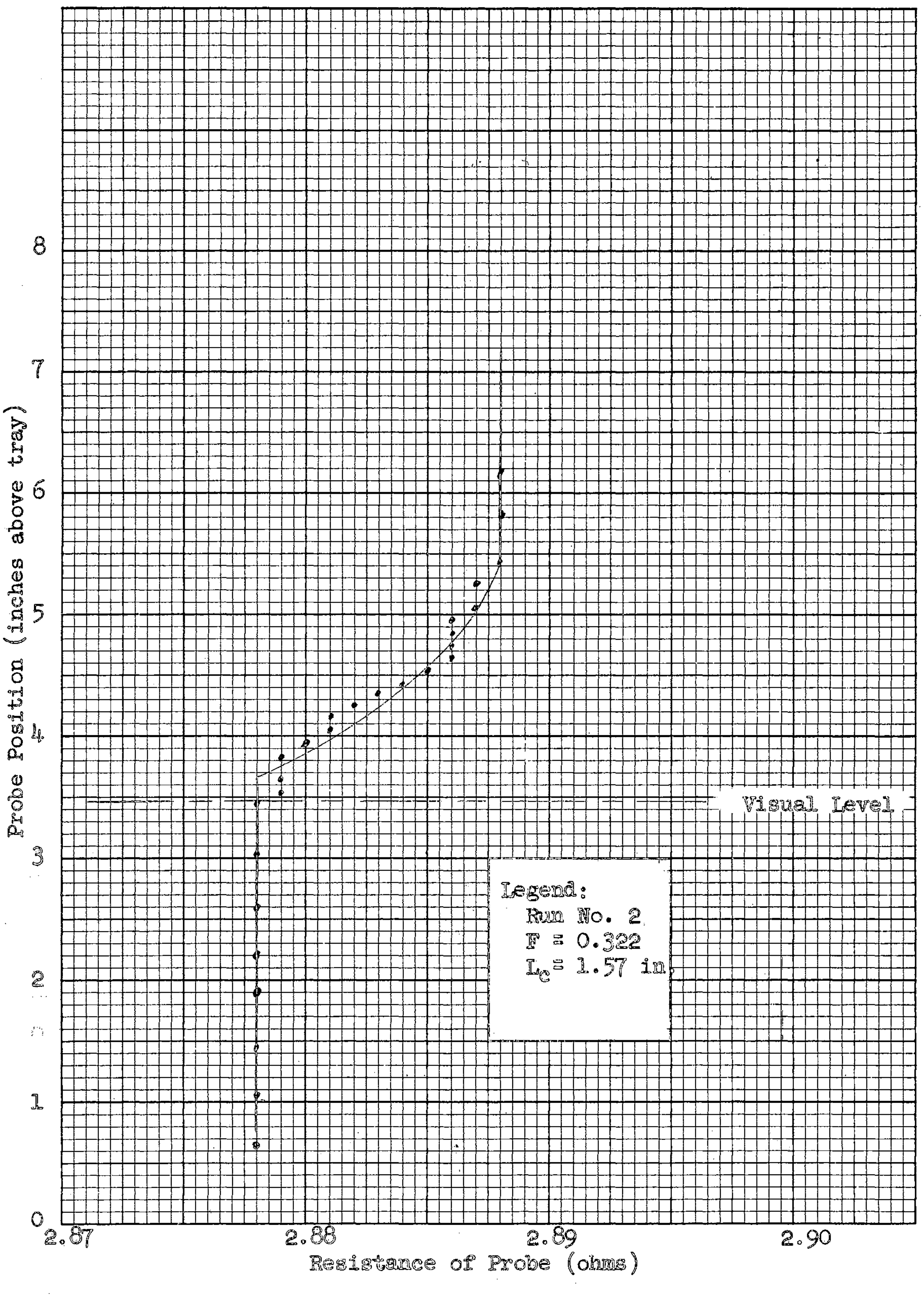


FIGURE 5

Typical Vertical Traverse using Variable Resistance Probe

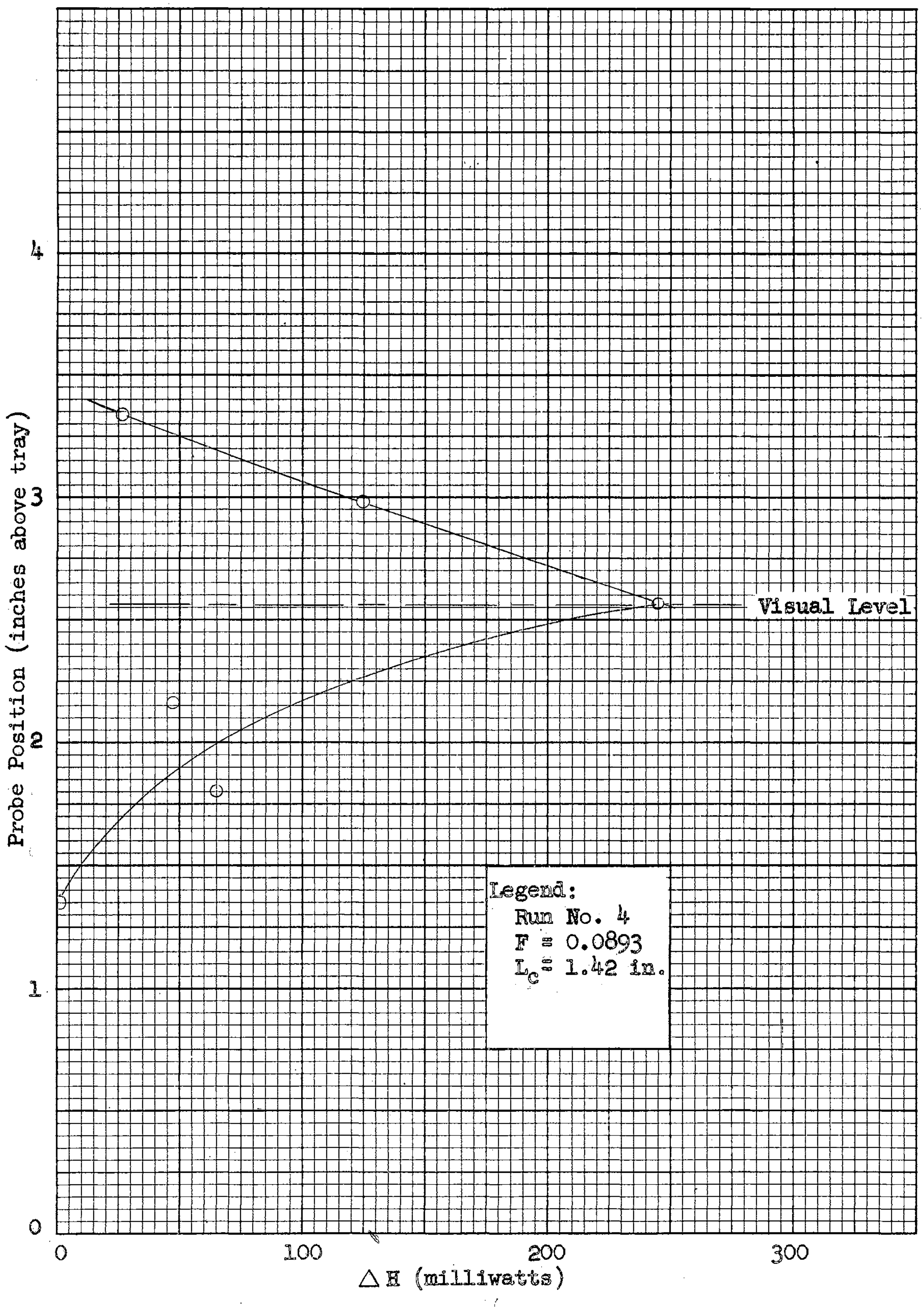
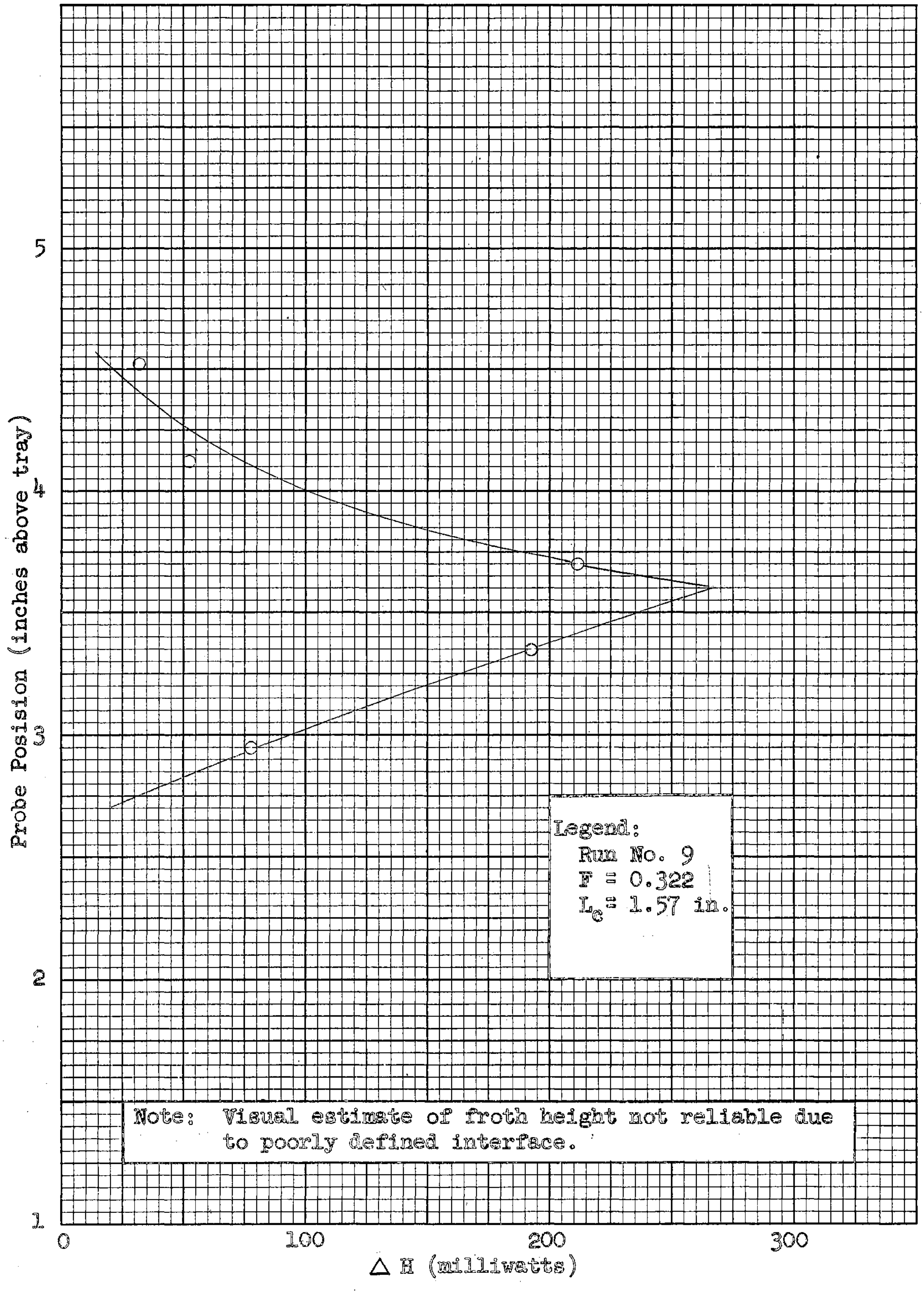


FIGURE 6

Typical Vertical Traverse with Constant Temperature Probe



Note: Visual estimate of froth height not reliable due to poorly defined interface.

FIGURE 7

Typical Vertical Traverse with Constant Temperature Probe

Factors Which Influence Froth Height

The data collected in this investigation provide two correlations. These correlations are presented graphically on the following pages. The first series of graphs depict the relationship between the froth height and the gas velocity as expressed as F values. The other independent variable, liquid level, is held constant for any one correlation. The second series of graphs show the correlation between the froth height and the clear liquid holdup while the F value is held constant.

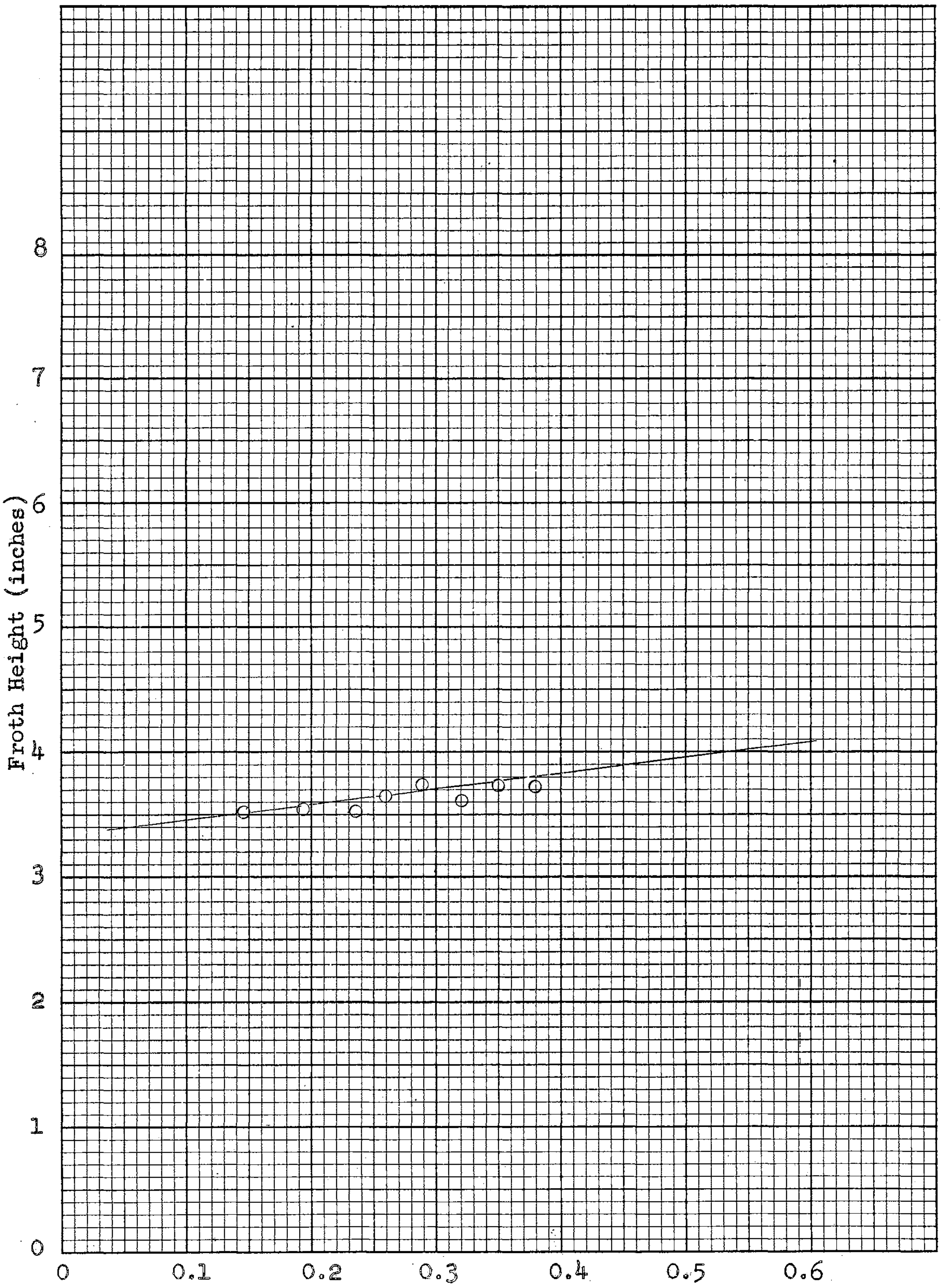


FIGURE 8

Froth Height vs F Factor for Air-Water System, $L_c = 1.57$ in.

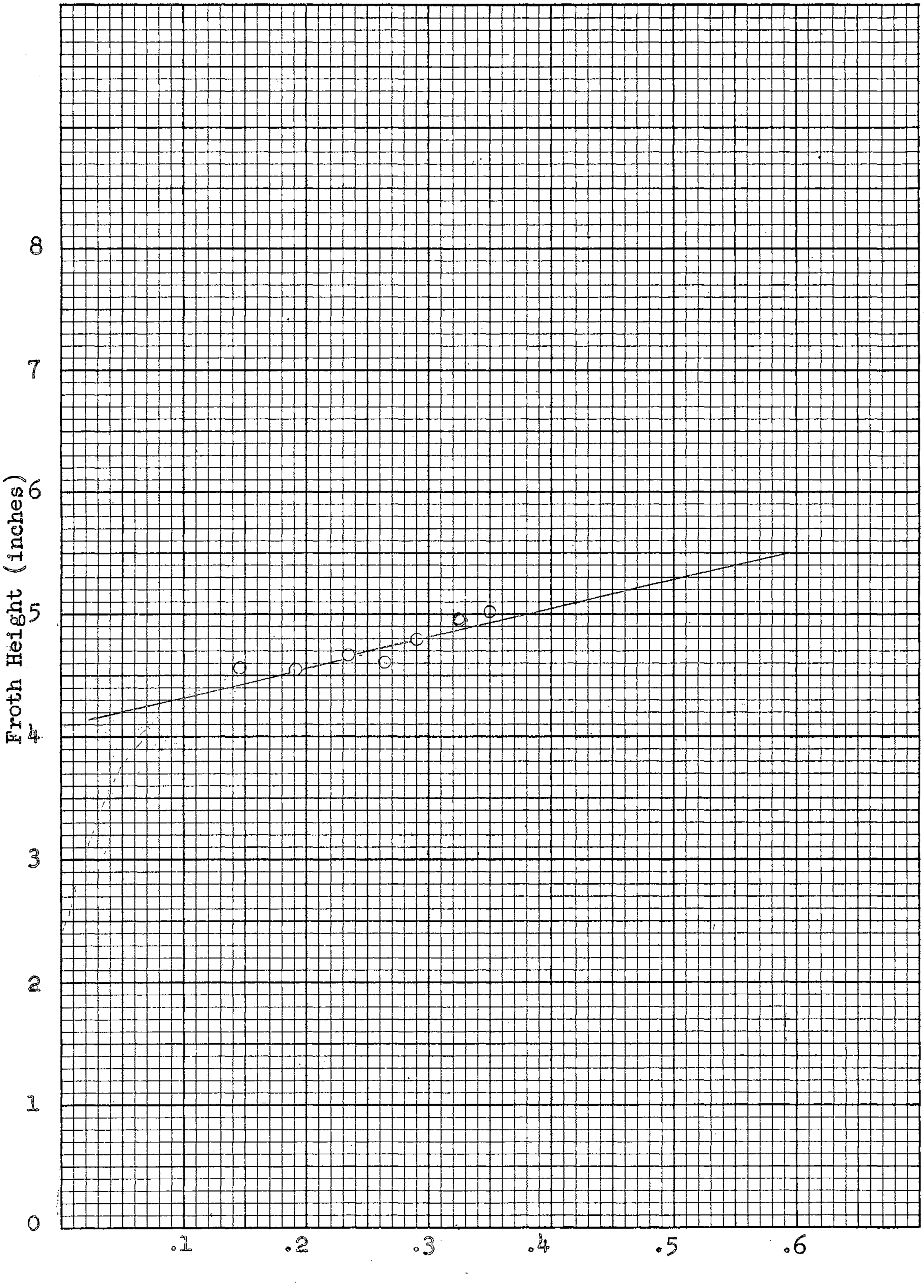


FIGURE 9

Froth Height vs F Factor for Air-Water System, L_c= 2.36 in.

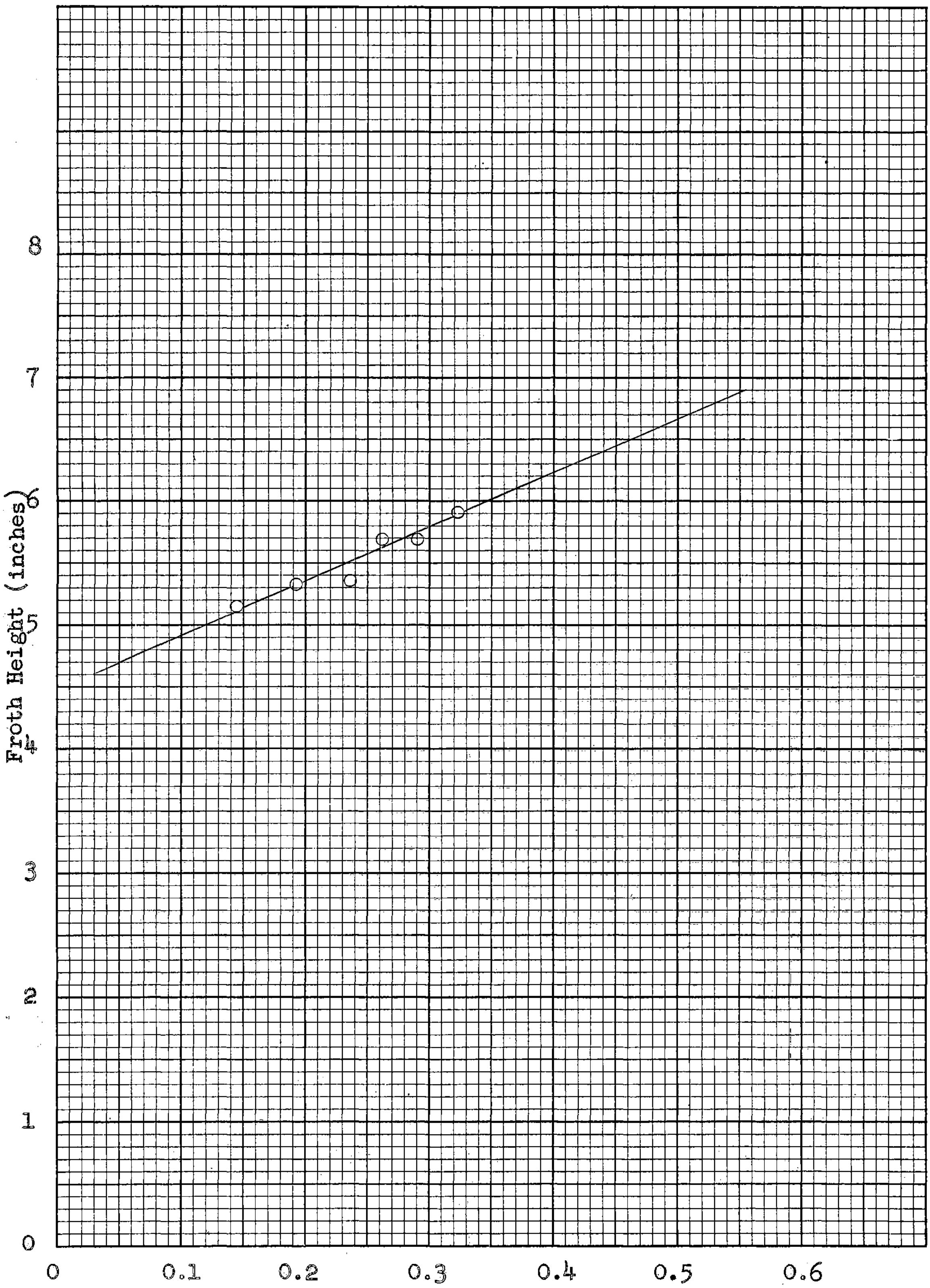


FIGURE 10

Froth Height vs F Factor for Air-Water System, $L_c = 3.15$ in.

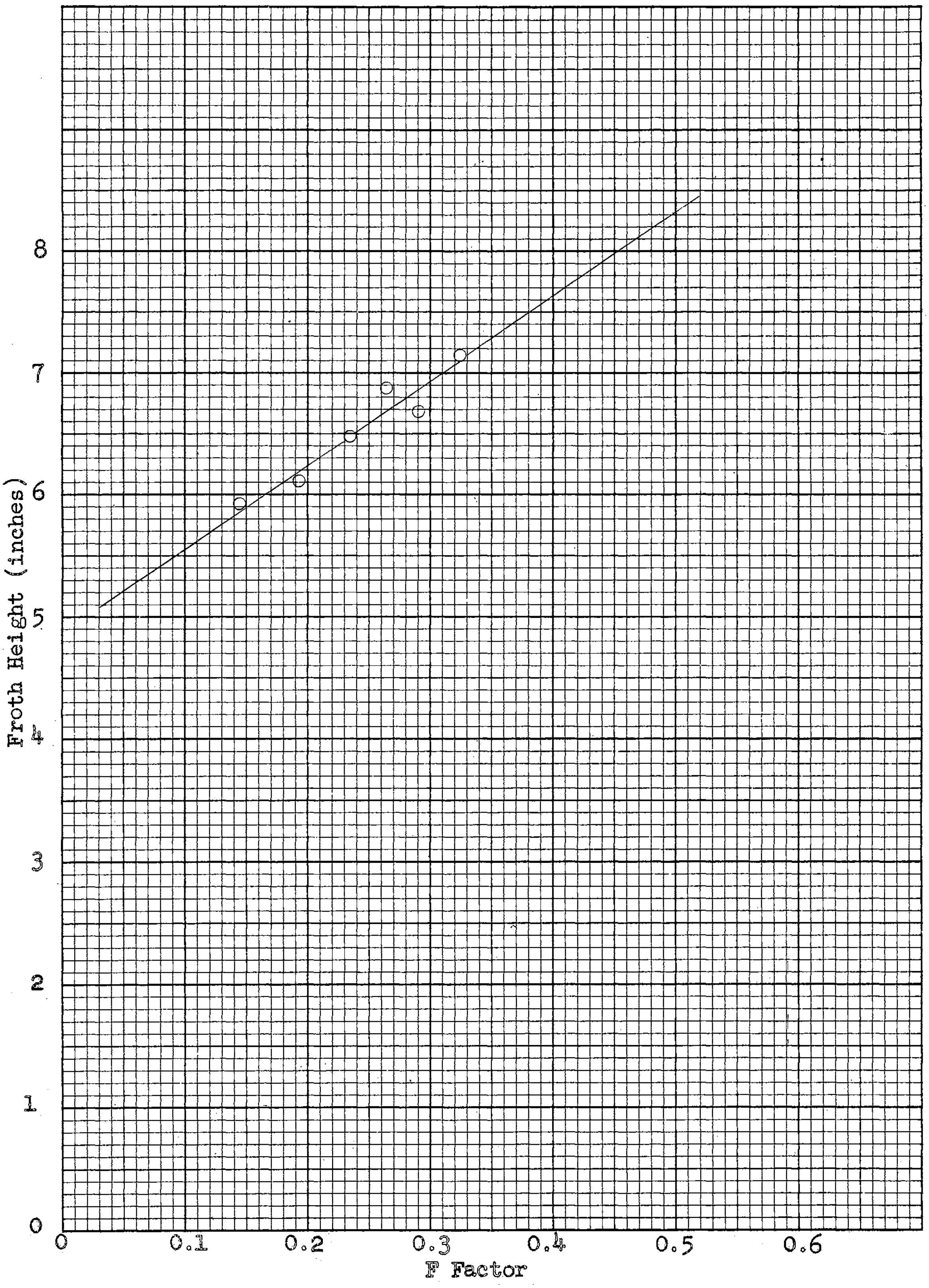


FIGURE 11

Froth Height vs F Factor for Air-Water System, $L_c = 3.98$ in.

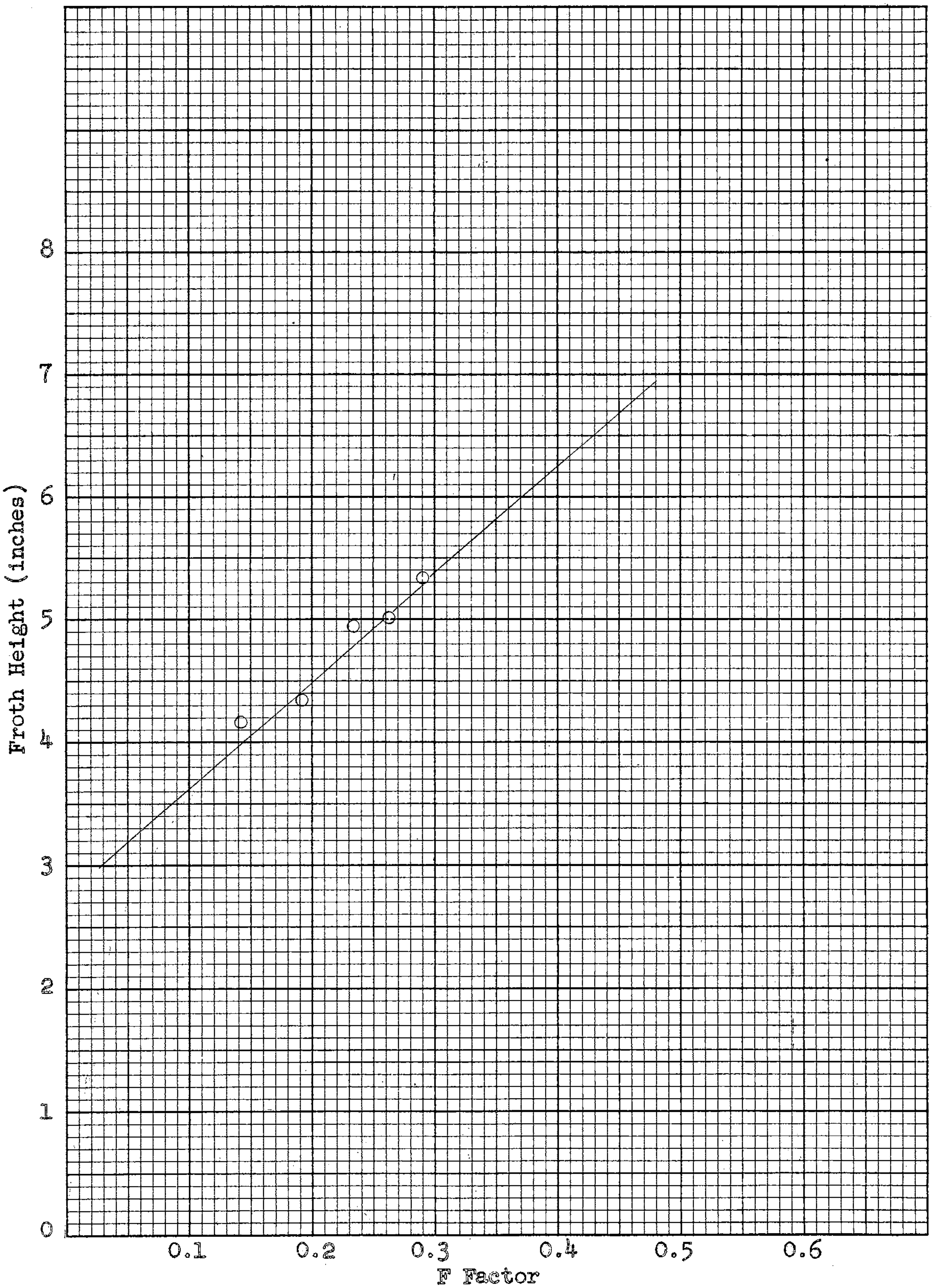


FIGURE 12

Froth Height vs F Factor for Air-Oil System, $L_c = 3.15$ in.

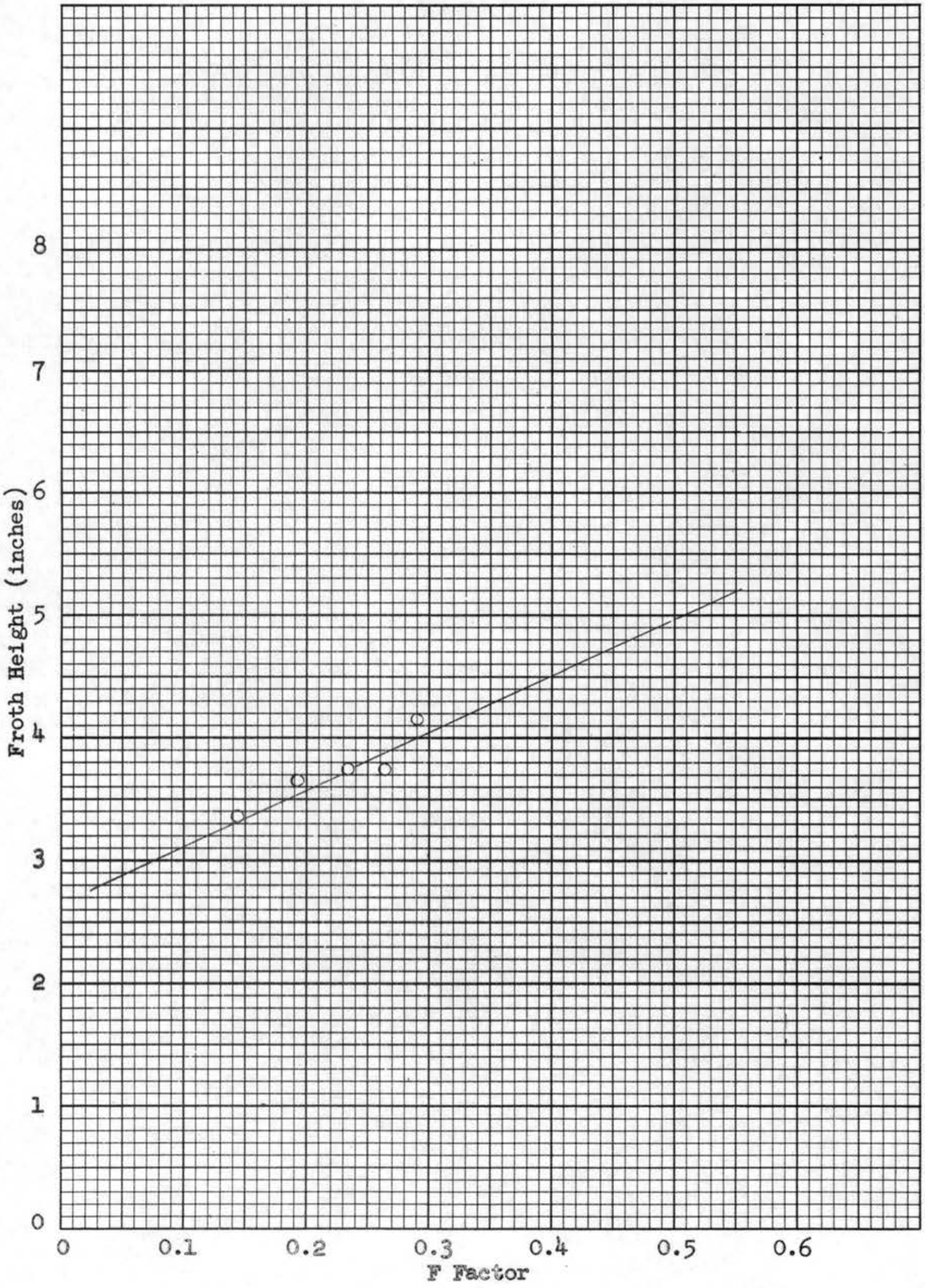


FIGURE 13

Froth Height vs F Factor for Air-Oil System, L_c= 2.36 in.

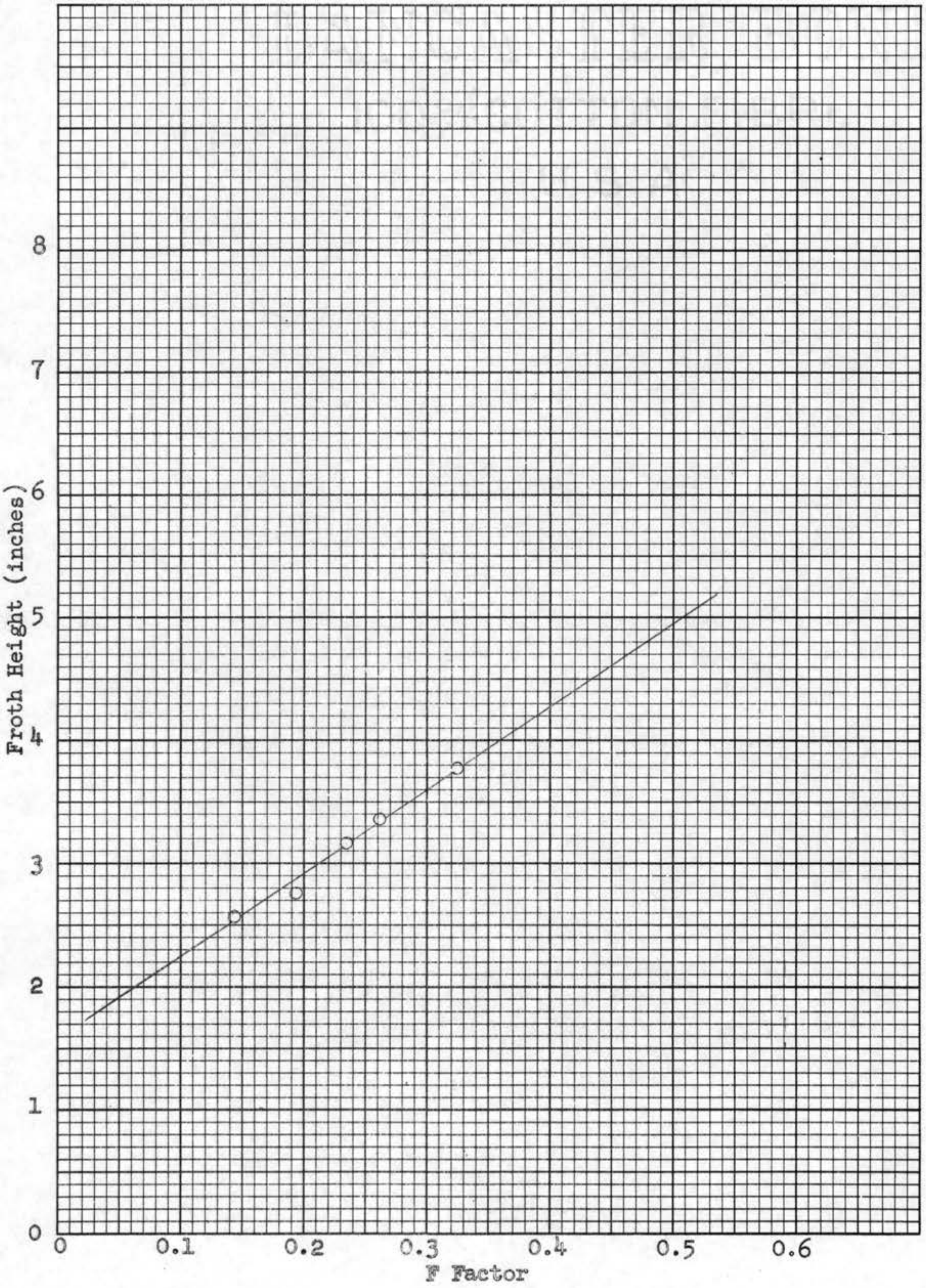


FIGURE 14

Froth Height vs F Factor for Air-Oil System, L_c= 1.57 in.

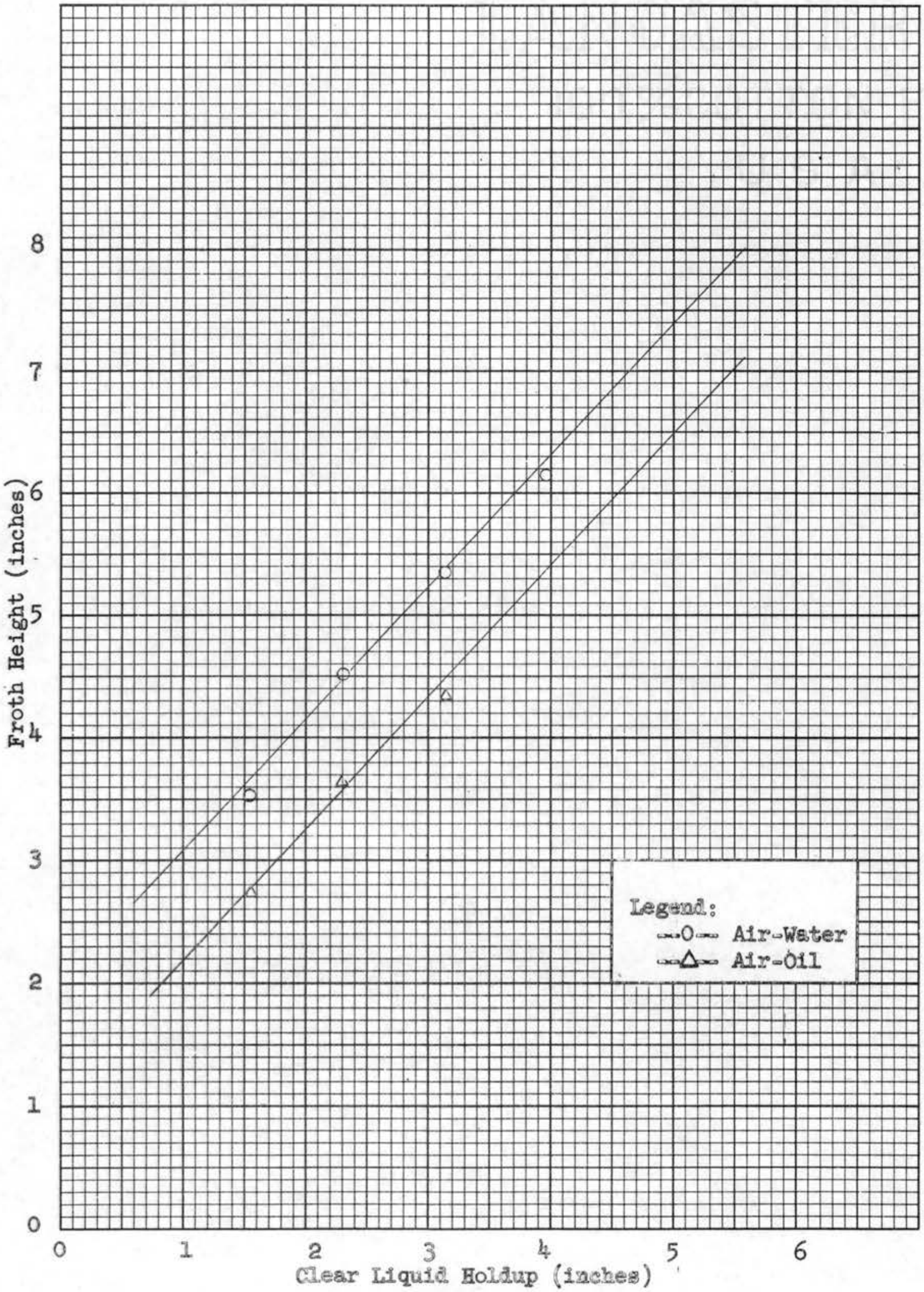


FIGURE 15

Froth Height vs Clear Liquid Holdup, F = 0.191

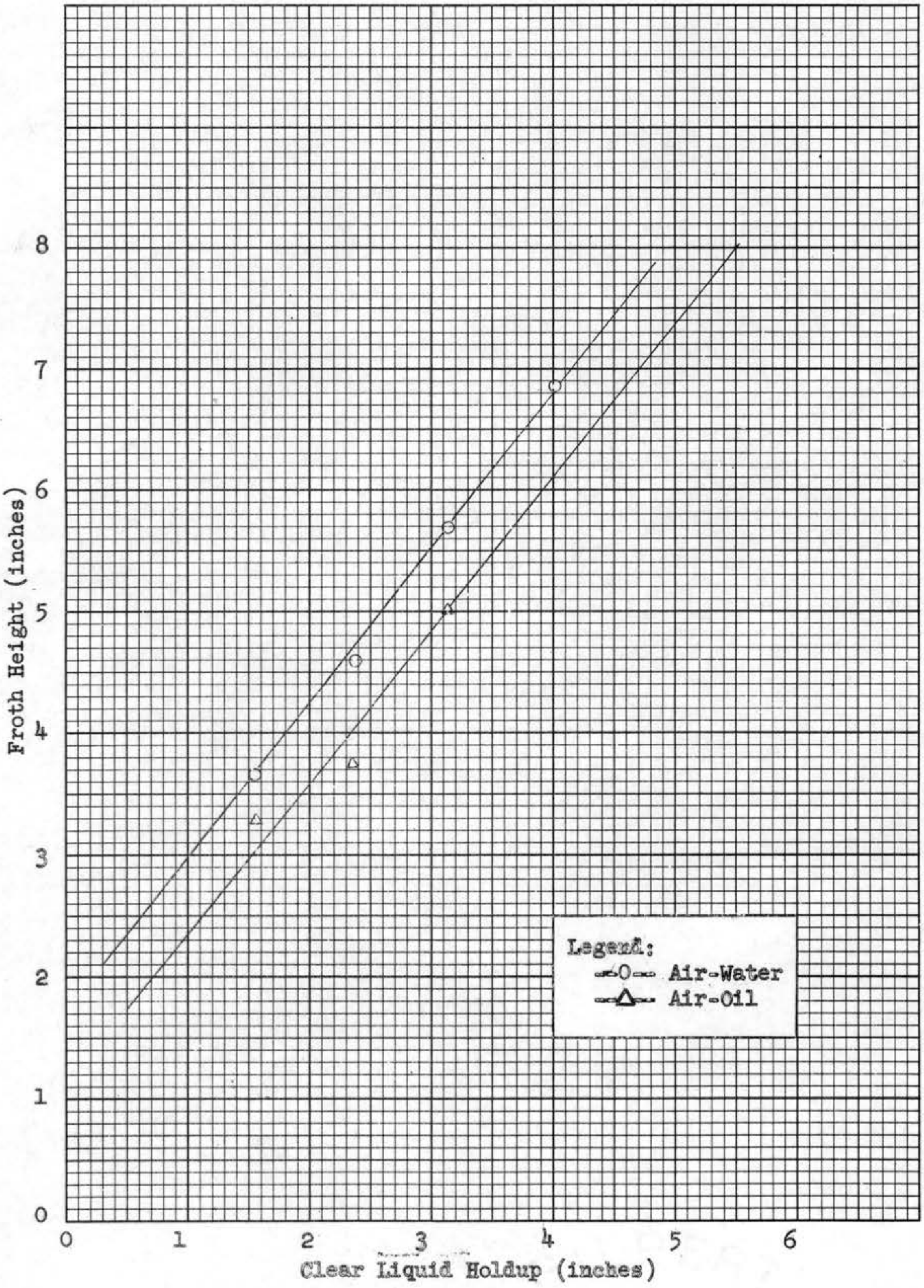


FIGURE 16

Froth Height vs Clear Liquid Holdup, F = 0.261

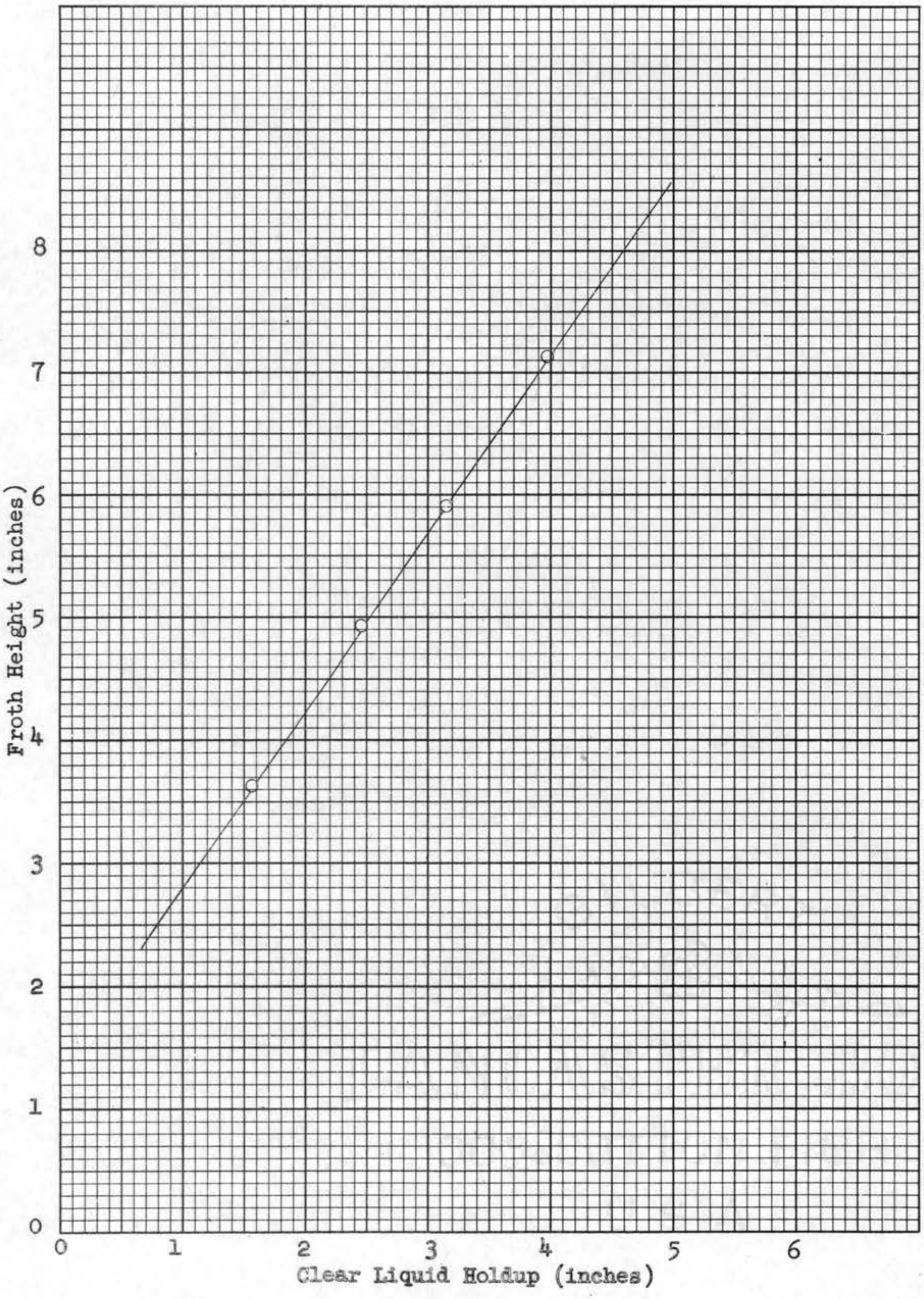


FIGURE 17

Froth Height vs Clear Liquid Holdup for Air-Water System, F= 0.322

CHAPTER V

INTERPRETATION OF RESULTS

Summary and Conclusions

The graphs representing typical data for each of the anemometry techniques illustrate the difference in sensitivity and usefulness of the two schemes. The theoretical considerations which cause the constant temperature probe to be more sensitive were discussed in Chapter II. The curves clearly verify this analysis.

The variable resistance probe, being the less sensitive, is useful for locating the froth-gas interface only when it is fairly well defined. A typical vertical traverse at such conditions appears in Figure 4. As the probe emerges from the froth the heat transfer characteristics of the system change immensely and induce a significant change in the temperature of the probe. The sharp change in slope of the curve depicts this change in the temperature and hence the resistance of the probe.

As the velocity of the gas is increased the interface becomes irregular and poorly defined. This is result of a surging action and the jetting of small pencils of froth into the vapor space. This instability causes the temperature change of the probe to vary gradually as it approaches and is raised above the froth-gas interface. The lack of sensitivity to small changes in the heat transfer characteristics of the system cause the data to be of doubtful accuracy. The changes in the resistance of the probe are so small that errors due to the precision of the electrical measurements could seriously distort the data.

Figure 5 presents data collected by the use of the variable resistance probe when the interface is not well defined. Even though the resistance scale is expanded beyond the precision limits of the data, the location of the froth-gas interface is not clearly discernable.

In contrast, the data taken with the constant temperature probe are quite useful. The location of the interface is based on the premise that this is the point at which the maximum change in the heat loss from the probe will occur. In mathematical terms this means that at the interface dW/dx is a maximum, where W refers to the heat loss from the probe in watts and x is the distance of the probe above the tray. Comparing the curves of Figures 6 and 7, it is apparent that this maximum point is not as sharp at the higher gas velocity. This is not considered a serious weakness, but is merely a reflection of differences in the structure of the interface at the two conditions.

The data indicate that a linear correlation exists between froth height, H_f, and F factor. In addition, the y-axis intercept and the slope of the regression line were found to vary linearly with the clear liquid holdup, L_c. This information suggests that it is feasible to derive an empirical formula relating froth height, F factor and clear liquid holdup. This equation would have the form:

$$H_f = f(L_c) + f(L_c,F)$$

All correlations were made statistically using a least squares fit and assuming linear relationships. The final form of the equations for both the air-water and the air-oil systems are as follows:

Air-Water:

$$H_f = 2.36 + 0.66L_c + 2.43L_cF - 3.09F \qquad (1)$$

Air-Oil:

$$H_f = 0.48 + 0.79L_c + 1.18L_cF + 3.92F \qquad (2)$$

These expressions allow the determination of the froth height by knowing the values of L_c and F, both of which are readily available. It is recognized that these equations are known to be accurate only within the limits of the experimental data; however, the writer believes they can be safely extrapolated well beyond the limiting F value of 0.38.

Suggestions for Future Study

Although this problem is concerned only with the factors influencing the location of the froth-gas interface, the data indicate that the hot-wire anemometer can be utilized in studying the characteristics of the froth at any point above the distillation tray. As was pointed out earlier, the study of froth formation is an intergral part in the evaluation of plate efficiencies. The work that has been done at the University of Delaware on plate efficiencies has shown that the effective froth height does not always coincide with the actual froth-gas interface. The data collected in this work indicate that the hot-wire anemometer can be utilized to determine the density of the froth bed at any point above the tray. A typical vertical traverse, starting at a point just above the plate, shows that the heat given up by the probe as it is raised has three distinct characteristics at different segments of the traverse. In the first portion, the heat loss decreases at a constant rate. In the second stage, there is no noticeable change in heat loss from one step to the next. The third segment represents the interface and here the heat loss drops off very rapidly. These characteristics indicate that the body of the froth contains two regions, one of varying density and a second of constant density. By properly calibrating the probe it appears feasible to use it to study the density at any point in the froth bed. It is felt that such a study of the variables affecting the density of the froth bed should aid in evaluating the mass transfer characteristics of a distillation tray.

The similarity between the correlation relating froth height, clear liquid holdup, and F factor for both the air-water and air-oil data suggests that it may be possible to determine an expression which would apply to any vapor-liquid system. By studying the effects of such variables as viscosity, surface tension, liquid density, etc. such an expression could be obtained. The effect of the plate design should be evaluated and incorporated into the relationship. The goal of such work would be a relationship which would allow a designer to accurately estimate the froth height for any system and tray design. Such information would be quite useful in determining the plate spacing in the distillation column.

TABLE I

TEST OF EQUATION 1 WITH DATA COLLECTED BY WILLIAMS, et al.(4)

Clear Liquid Holdup in.	F Factor	H_f experimental in.	H_f calculated in.
3	0.4	4.9	6.01
4	0.6	8.2	9.01
5	1.0	12.3	14.62

The empirical equation for the air-water system was tested by using data collected at the University of Michigan. The data were collected using a bubble cap tray operating at atmospheric temperature and pressure. In view of the fact that the equation was derived from data concerning a perforated tray, the agreement between the predicted and experimental values is very good. The results of the calculations are presented in Table I. This agreement illustrates the value of this work, and emphasizes the potential of additional research in the field of froth formation.

NOMENCLATURE

A = Surface area.

E = Voltage.

F = F Factor, $v\sqrt{\rho}$

H = Height above tray, inches.

I = Current, amps.

L = Depth of liquid on tray, inches.

R = Resistance, ohms.

T = Temperature.

U = Overall heat transfer coefficient, Btu/hrft^2 $^{\circ}$F.

Q = Heat flow, Btu/hr.

v = Superficial gas velocity based on the cross-sectional area of the column, ft/sec.

ρ = Density, lb/ft^3.

Δt = Temperature difference for heat transfer, $^{\circ}$F.

Subscripts

c = Clear liquid holdup.

f = Froth.

p = Probe.

r = Resistance.

BIBLIOGRAPHY

1. Albright, M. A. "Use of the Hot Wire Anemometer to Locate Froth Levels." (unpublished M. S. Thesis, School of Chemical Engineering, Oklahoma State University, 1956.)

2. American Institute of Chemical Engineers Research Committee. "Tray Efficiencies in Distillation Columns." Third Annual Progress Report. American Institute of Chemical Engineers. New York City, New York, 1955.

3. American Institute of Chemical Engineers Research Committee. "Tray Efficiencies in Distillation Columns." Fourth Annual Progress Report. American Institute of Chemical Engineers. New York City, New York, 1956.

4. Crozier, Ronald D. "Froth Stratification and Liquid Mixing in a Bubble Tray Column.", Doctoral Dissertation. University of Michigan, 1956.

5. "Discussion on the Absolute Measurement of Electrical Resistance and Instruments Based on the Temperature Variation of Resistance." Proceedings, Physical Society, London, 1921.

6. Lamb, Owen P., and Killen, John M. "An Electrical Method for Measuring Air Concentration in Flowing Air - Water Mixtures." St. Anthony Falls Hydraulic Laboratory, 1950.

7. Perry, J. H., ed. Chemical Engineer's Handbook. 3d ed. McGraw-Hill Book Company, Inc., New York City, New York, 1950.

APPENDIX

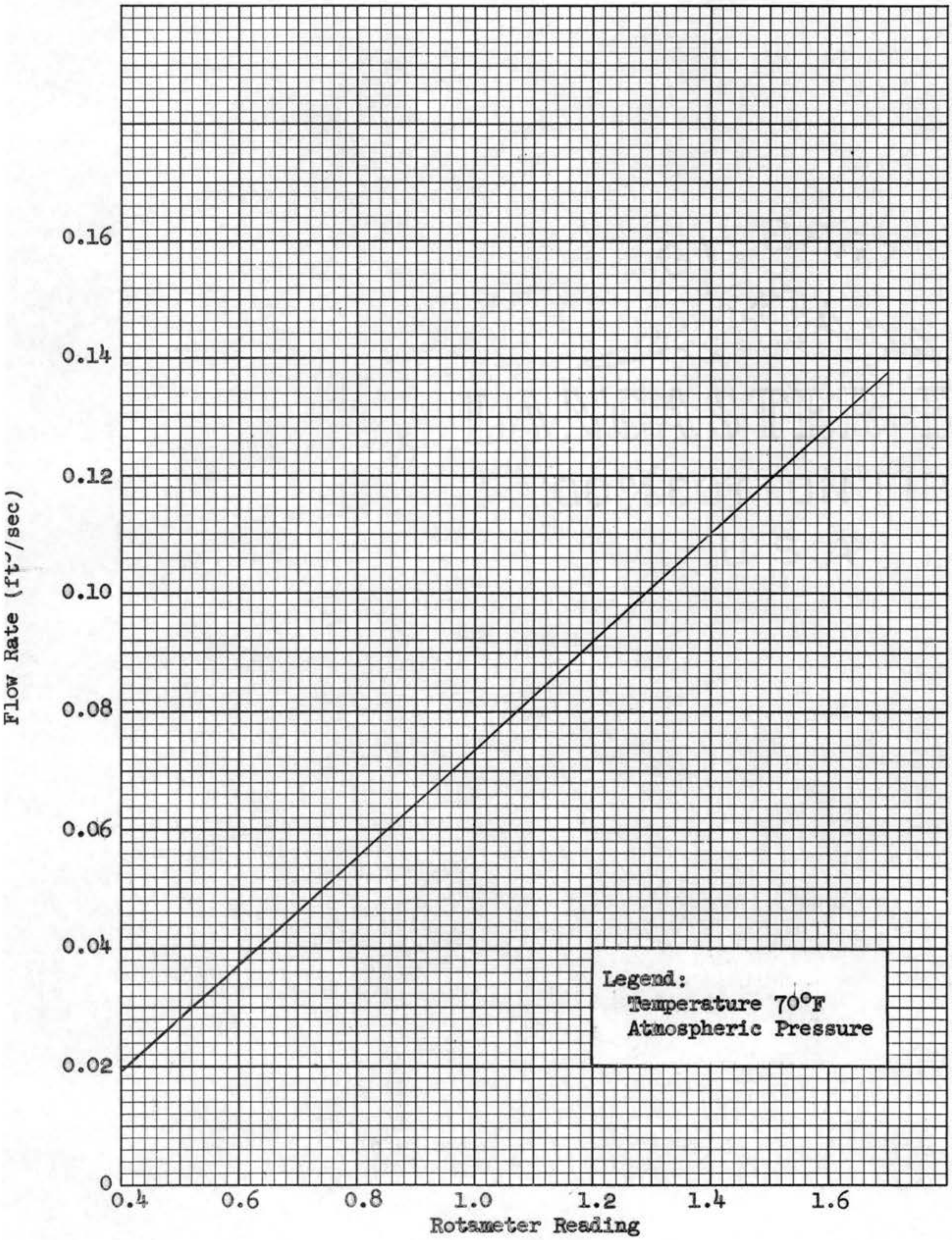


FIGURE 21

Calibration Curve Air Rotameter, R_3

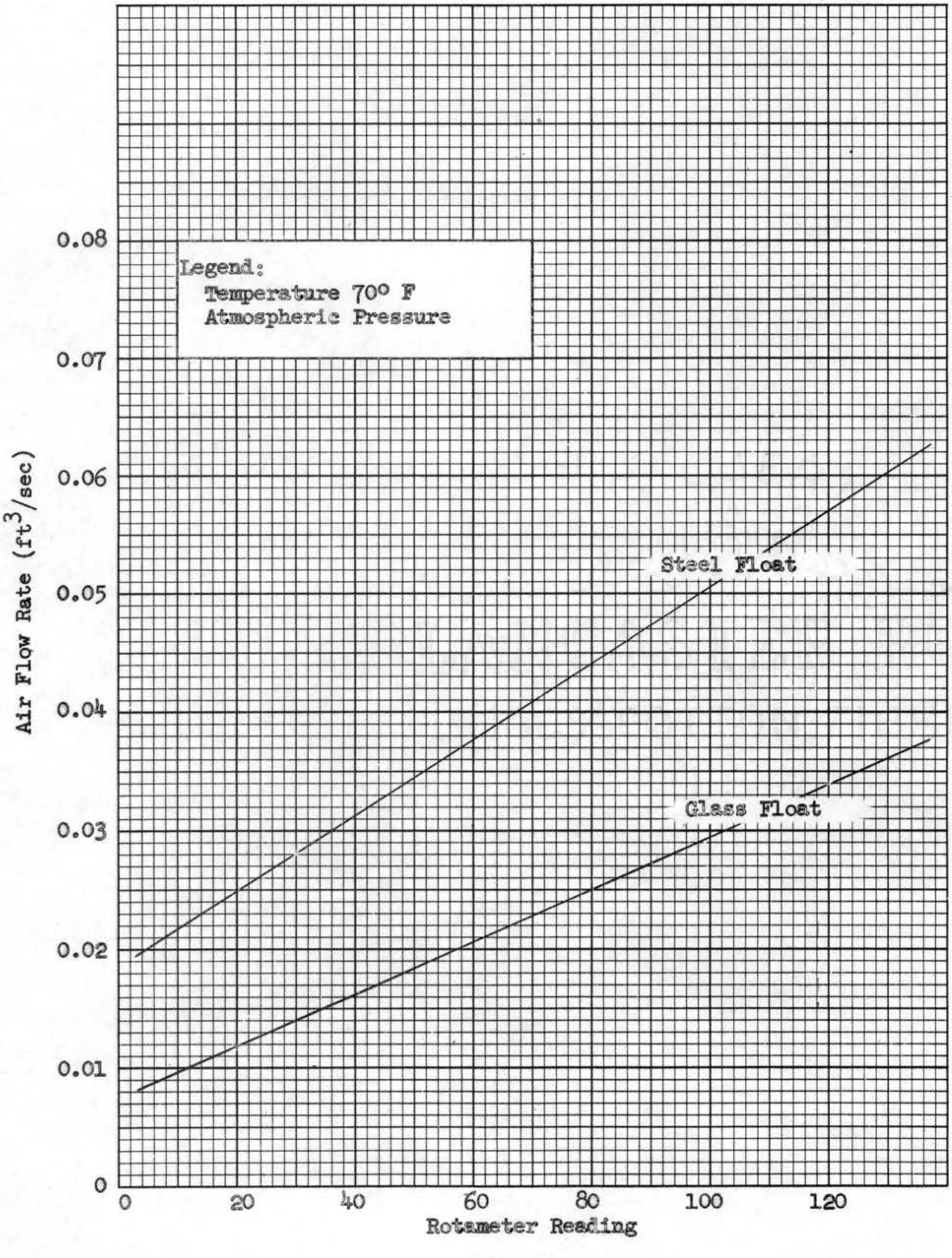


FIGURE 22

Calibration Curve Air Rotameters, R_1 & R_2

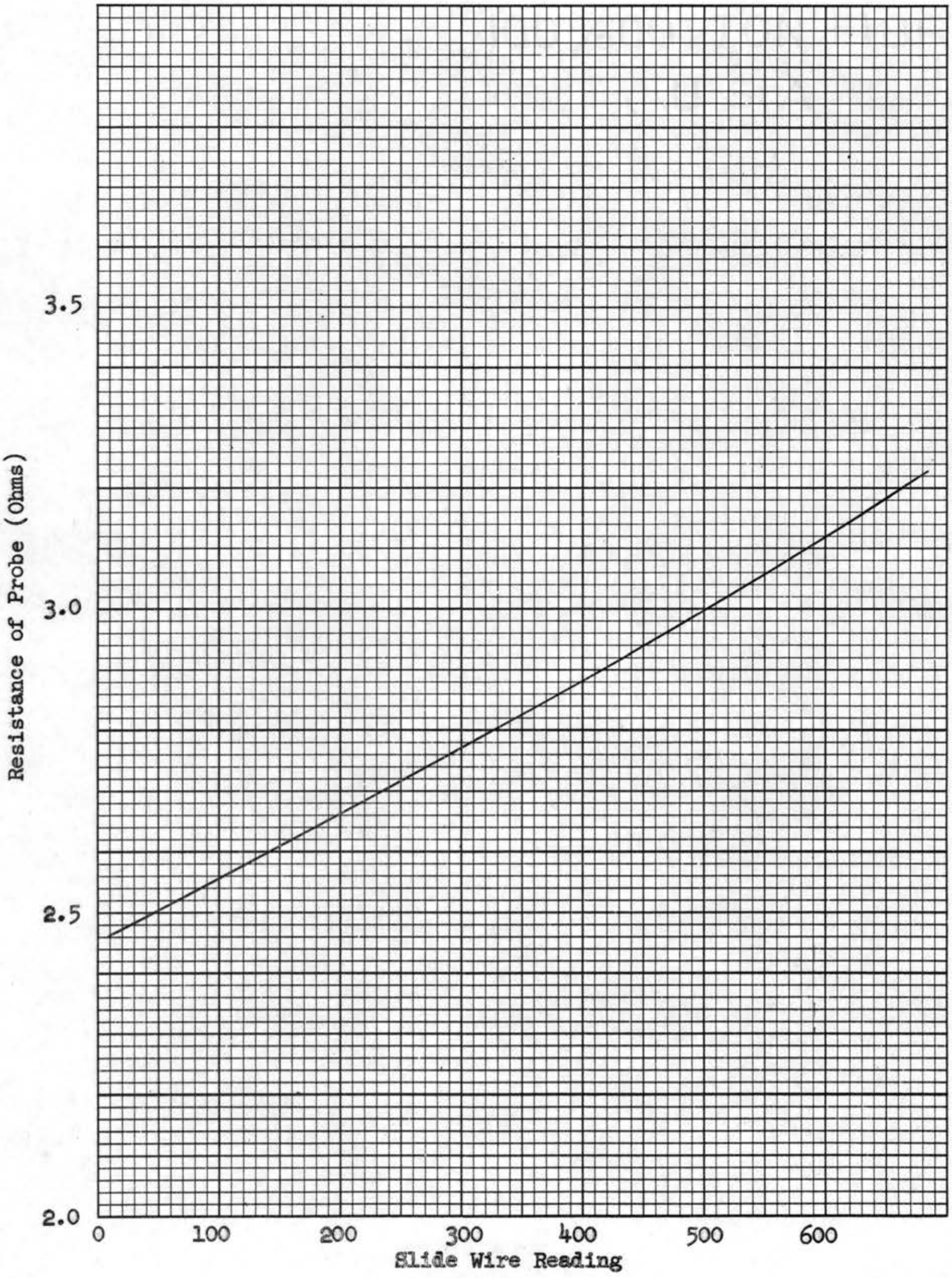


FIGURE 23

Probe Calibration Curve

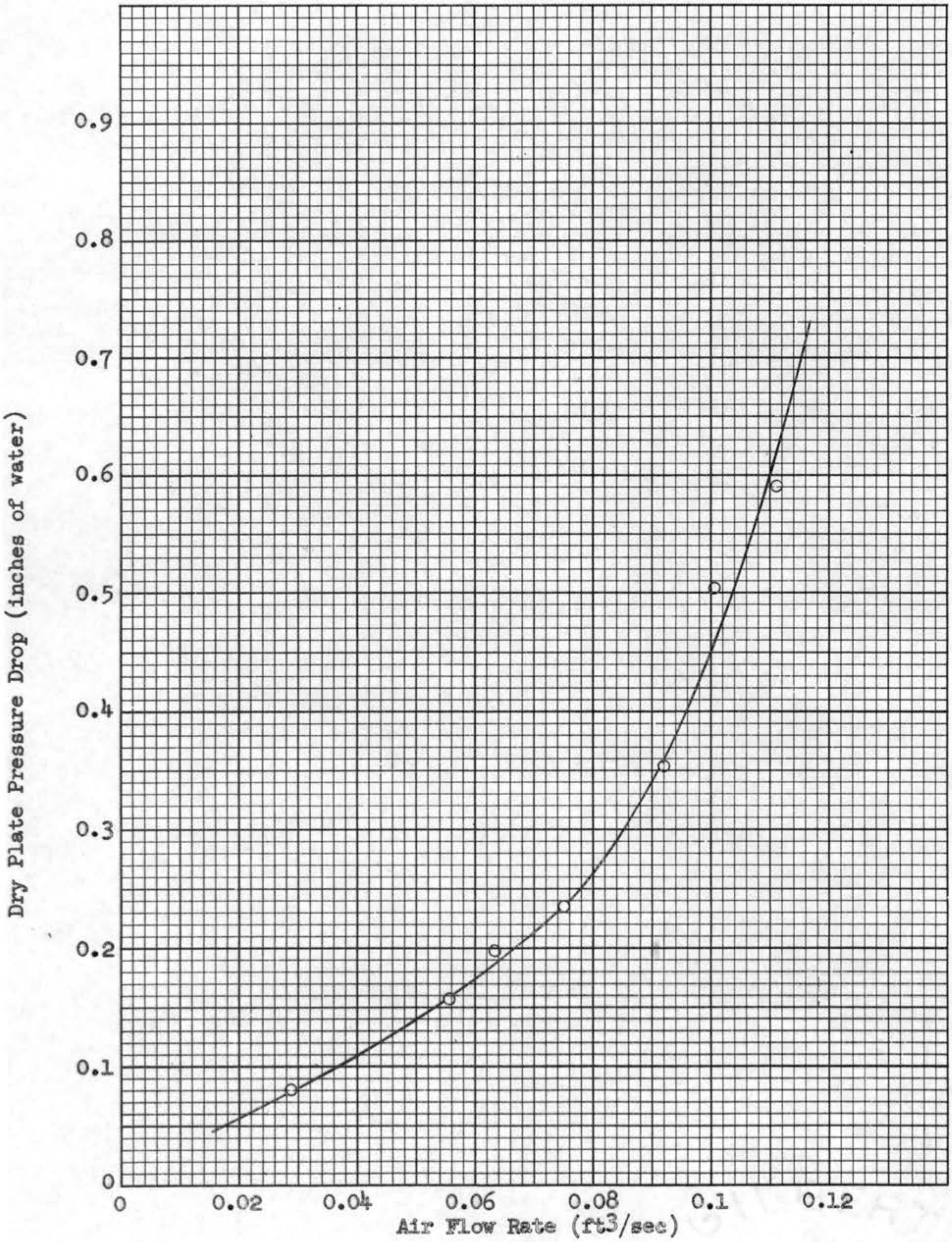


FIGURE 24

Dry Plate Pressure Drop

TABLE II

EXPERIMENTAL DATA FOR RUN 1

Clear Liquid Level = 2.0 in.
Resistance Box = 3.0 ohms
Temperature of Froth = 63° F.
Rotameter Reading = 10.0 (glassfloat)
Position of Tray = Probe reading of 15.7 cm.

Probe Reading	Slide Wire Reading	Height of Probe above tray	Probe Resistance
cm		inches	ohms
8	437	3.03	2.925
7	437	3.42	2.925
6.5	437	3.62	2.925
6.0	437	3.82	2.925
5.5	442	4.02	2.931
5.0	449	4.22	2.940
4.5	457	4.42	2.949

Froth Height from probe data = 4.10 inches
Froth height by visual observations = 4.02 inches

TABLE III

EXPERIMENTAL DATA FOR RUN 2

Clear Liquid Level = 1.57 in.
Resistance Box = 3.0 ohms
Temperature of Froth = 53° F
Rotameter Reading; R_1 = 12 (steelfloat)
R_2 = 15 (glassfloat)
Position of Tray = Probe reading of 15.7 cm.

Probe Reading cm.	Slide Wire Reading	Height of Probe above Tray inches	Probe Resistance ohms
12.0	398	1.46	2.878
11.0	398	1.85	2.878
10.0	398	2.24	2.878
9.00	398	2.64	2.878
8.00	398	3.03	2.878
7.00	398	3.42	2.878
6.75	399	3.52	2.879
6.50	399	3.62	2.879
6.00	399	3.82	2.879
5.75	400	3.93	2.880
5.50	401	4.03	2.881
5.25	401	4.13	2.881
5.00	402	4.22	2.882
4.75	403	4.32	2.883
4.50	404	4.42	2.884
4.25	405	4.52	2.885
4.00	406	4.62	2.886
3.75	406	4.72	2.886
3.50	406	4.82	2.886
3.25	406	4.92	2.886
3.00	407	5.01	2.887
2.5	407	5.21	2.887
2.0	408	5.40	2.888
1.0	408	5.80	2.888
0	408	6.20	2.888

Froth height from probe data = 4.80 inches
Froth height from visual observation = 4.45 inches

TABLE IV

EXPERIMENTAL DATA FOR RUN 3

Clear Liquid Level = 1.57 in.	Resistance Box = 3.0 ohms
Rotameter Reading = 0.7	Pressure Drop Across Tray = 1.93 in. wate
Air Velocity = 0.527 ft/sec	F Value = 0.146
Position of Tray = Probe Reading of 28.0 cm.	
System Studied; air-water	Slide Wire = 320

Probe Reading cm.	Current to Probe milliamps	Height of Probe above Tray inches	Heat Loss from Probe watts	Change in Heat Loss watts
24	480	1.57	.644	
				.000
23	480	1.97	.644	
				.051
22	460	2.36	.593	
				.000
21	460	2.76	.593	
				.025
20	450	3.15	.568	
				.246
19	340	3.54	.322	
				.161
18	240	3.94	.161	
				.060
17	190	4.34	.101	

Froth Height = 3.54 in.

TABLE V

EXPERIMENTAL DATA FOR RUN 4

Clear Liquid Level = 1.42 in.
Rotameter Reading = 0.7
Air Velocity = 0.527 ft/sec
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water

Resistance Box = 3.0 ohms
Pressure Drop Across Tray = 1.77 in. wa
F Value = 0.0893
Slide Wire = 294

Probe Reading cm.	Current to Probe milliamps	Height of Probe above Tray inches	Heat Loss from Probe watts	Change in Heat Loss watts
26	465	0.78	0.598	0.00
25	465	1.18	0.598	0.00
24	465	1.57	0.598	0.064
23	440	1.97	0.534	0.046
22	420	2.36	0.488	0.272
21	280	2.76	0.216	0.1263
20	180	3.15	0.0897	0.0273
19	150	3.54	0.0624	

Froth Height = 2.6 in.

TABLE VI

EXPERIMENTAL DATA FOR RUN 5

Clear Liquid Level = 1.57 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 0.85
Pressure Drop Across Tray = 2.01 in. wate
Air Velocity = 0.688 ft/sec
F Value = 0.191
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 320

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
22	480	2.36	0.644	
				0.000
21	480	2.76	0.644	
				0.000
20	480	3.15	0.644	
				0.194
19	400	3.54	0.450	
				0.213
18	290	3.94	0.237	
				0.075
17	240	4.34	0.162	
				0.037
16	210	4.73	0.125	

Froth Height = 3.58 in.

TABLE VII

EXPERIMENTAL DATA FOR RUN 6

Clear Liquid Level = 1.57 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.0
Pressure Drop Across Tray = 2.12 in. wat
Air Velocity = 0.836 ft/sec
F Value = 0.236
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 306

Probe Reading cm.	Current to Probe milliamps	Height of Probe above Tray inches	Heat Loss from Probe watts	Change in Heat Loss watts
21	480	2.76	0.640	
				0.104
20	440	3.15	0.536	
				0.175
19	360	3.54	0.361	
				0.173
18	260	3.94	0.188	
				0.065
17	210	4.34	0.123	

Froth Height = 3.54 in.

room temp ?

TABLE VIII

EXPERIMENTAL DATA FOR RUN 7

Clear Liquid Level = 1.57 in.	Resistance Box = 3.0 ohms
Rotameter Reading = 1.1	Pressure Drop Across Tray = 2.20 in. wat
Air Velocity = 0.940 ft/sec	F Value = 0.261
Position of Tray = Probe Reading of 28.0 cm.	
System Studied; air-water	Slide Wire = 3.06

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
22	480	2.36	0.640	
				0.000
21	480	2.76	0.640	
				0.023
20	470	3.15	0.617	
				0.172
19	400	3.54	0.445	
				0.211
18	290	3.94	0.234	
				0.087
17	230	4.34	0.147	
				0.024
16	210	4.73	0.123	

Froth Height = 3.66 in.

TABLE IX

EXPERIMENTAL DATA FOR RUN 8

Clear Liquid Level = 1.57 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.2
Pressure Drop Across Tray = 2.28 in. wat
Air Velocity = 1.05 ft/sec
F Value = 0.290
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 306

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
22	460	2.36	0.590	0.000
21	460	2.76	0.590	0.000
20	460	3.15	0.590	0.123
19	380	3.54	0.467	0.217
18	260	3.94	0.250	0.102
17	220	4.34	0.148	0.036
16	190	4.73	0.112	

Froth Height = 3.74 in.

TABLE X

EXPERIMENTAL DATA FOR RUN 9

Clear Liquid Level = 1.57 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.3
Pressure Drop Across Tray = 2.36 in. wat
Air Velocity = 1.158 ft/sec
F Value = 0.322
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 295

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
21	490	2.76	0.665	
				0.078
20	460	3.15	0.587	
				0.188
19	380	3.54	0.399	
				0.212
18	260	3.94	0.187	
				0.053
17	220	4.34	0.134	
				0.034
16	190	4.73	0.100	

Froth Height = 3.62 in.

TABLE XI

EXPERIMENTAL DATA FOR RUN 10

Clear Liquid Level = 1.57
Resistance Box = 3.0 ohms
Rotameter Reading = 1.4
Pressure Drop Across Tray = 2.44 in. wat
Air Velocity = 1.26 ft/sec
F Value = 0.35
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 295

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
21	480	2.76	0.640	
				0.050
20	460	3.15	0.590	
				0.098
19	420	3.54	0.492	
				0.242
18	300	3.94	0.250	
				0.090
17	240	4.34	0.160	
				0.000
16	240	4.73	0.160	

Froth Height = 3.74 in.

TABLE XII

EXPERIMENTAL DATA FOR RUN 11

Clear Liquid Level = 1.57 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.5
Pressure Drop Across Tray = 2.56 in wate
Air Velocity = 1.365 ft/sec
F. Value = 0.379
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 295

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
20	460	3.15	0.588	
				0.098
19	420	3.54	0.490	
				0.208
18	320	3.94	0.282	
				0.095
17	260	4.34	0.187	
				0.040
16	230	4.73	0.147	
				0.024
15	210	5.13	0.123	

Froth Height = 3.74 in.

TABLE XIII

EXPERIMENTAL DATA FOR RUN 12

Clear Liquid Level = 2.36 in. Resistance Box = 3.0 ohms
Rotameter Reading = 0.7 Pressure Drop Across Tray = 2.72 in. wat
Air Velocity = 0.527 ft/sec F Value = 0.146
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water Slide Wire = 308

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
21	490	2.76	0.665	
				0.000
20	490	3.15	0.665	
				0.000
19	490	3.54	0.665	
				0.019
18	480	3.94	0.646	
				0.084
17	450	4.34	0.562	
				0.244
16	340	4.73	0.318	
				0.184
15	220	5.13	0.134	
				0.012
14	210	5.52	0.122	

Froth Height = 4.53 in.

TABLE XIV

EXPERIMENTAL DATA FOR RUN 13

Clear Liquid Level = 2.36 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 0.85
Pressure Drop Across Tray = 2.79 in. wa
Air Velocity = 0.688 ft/sec
F Value = 0.191
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 304

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
19	490	3.54	0.664	
				0.000
18	490	3.94	0.664	
				0.130
17	440	4.34	0.534	
				0.216
16	340	4.73	0.318	
				0.131
15	260	5.13	0.187	
				0.064
14	210	5.52	0.123	

Froth Height = 4.53 in.

TABLE XV

EXPERIMENTAL DATA FOR RUN 14

Clear Liquid Level = 2.36 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.0
Pressure Drop Across Tray = 2.88 in. wat
Air Velocity = 0.836 ft/sec
F Value = 0.236
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 298

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
19	470	3.54	0.614	
				0.000
18	470	3.94	0.614	
				0.149
17	410	4.34	0.465	
				0.105
16	360	4.73	0.360	
				0.144
15	280	5.13	0.216	
				0.069
14	230	5.52	0.147	
				0.000
13	230	5.92	0.147	

Froth Height = 4.68 in.

TABLE XVI

EXPERIMENTAL DATA FOR RUN 15

Clear Liquid Level = 2.36 in.
Rotameter Reading = 1.1
Air Velocity = 0.940 ft/sec
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water

Resistance Box = 3.0 ohms
Pressure Drop Across Tray = 2.95 in. wa
F Value = 0.261
Slide Wire = 296

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
18	480	3.94	0.637	
				0.124
17	430	4.34	0.513	
				0.175
16	350	4.73	0.338	
				0.150
15	260	5.13	0.188	
				0.041
14	230	5.52	0.147	
				0.024
13	210	5.92	0.123	

Froth Height = 4.60 in.

TABLE XVII

EXPERIMENTAL DATA FOR RUN 16

Clear Liquid Level = 2.36 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.2
Pressure Drop Across Tray = 3.03 in. wate
Air Velocity = 1.05 ft/sec
F Value = 0.290
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 2.94

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
18	480	3.94	0.637	
				0.075
17	450	4.34	0.562	
				0.142
16	390	4.73	0.420	
				0.163
15	310	5.13	0.267	
				0.065
14	270	5.52	0.202	
				0.029
13	250	5.92	0.173	
				0.026
12	230	6.31	0.147	

Froth Height = 4.8 in.

TABLE XVIII

EXPERIMENTAL DATA FOR RUN 17

Clear Liquid Level = 2.36 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.3
Pressure Drop Across Tray = 3.11 in. wate
Air Velocity = 1.158 ft/sec
F Value = 0.322
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 294

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
18	470	3.94	0.615	
				0.080
17	440	4.34	0.535	
				0.091
16	400	4.73	0.444	
				0.106
15	350	5.13	0.338	
				0.105
14	290	5.52	0.233	
				0.074
13	240	5.92	0.159	
				0.036
12	210	6.31	0.123	
				0.000
11	210	6.70	0.123	

Froth Height = 4.92 in.

TABLE XIX

EXPERIMENTAL DATA FOR RUN 18

Clear Liquid Level = 2.36 in. Resistance Box = 3.0 ohms
Rotameter Reading = 1.4 Pressure Drop Across Tray = 3.2 in. wate
Air Velocity = 1.26 ft/sec F Value = 0.350
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water Slide Wire = 286

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliams	inches	watts	watts
17	480	4.34	0.635	
				0.123
16	430	4.73	0.512	
				0.114
15	380	5.13	0.398	
				0.132
14	310	5.52	0.266	
				0.040
13	280	5.92	0.216	
				0.043
12	250	6.31	0.173	
				0.014
11	240	6.70	0.159	

Froth Height = 5.0 in.

TABLE XX

EXPERIMENTAL DATA FOR RUN 19

Clear Liquid Level = 3.15 in. Resistance Box = 3.0 ohms
Rotameter Reading = 0.7 Pressure Drop Across Tray = 3.5 in. water
Air Velocity = 0.527 ft/sec F Value = 0.146
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water Slide Wire = 310

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
18	470	3.94	0.616	
				0.000
17	470	4.34	0.616	
				0.081
16	440	4.73	0.535	
				0.135
15	380	5.13	0.400	
				0.132
14	310	5.52	0.268	
				0.121
13	230	5.92	0.147	
				0.047
12	190	6.31	0.100	

Froth Height = 5.16 in.

TABLE XXI

EXPERIMENTAL DATA FOR RUN 20

Clear Liquid Level = 3.15 in. Resistance Box = 3.0 ohms
Rotameter Reading = 0.85 Pressure Drop Across Tray = 3.58 in. wate
Air Velocity = 0.688 ft/sec F Value = 0.191
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water Slide Wire = 310

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
17	480	4.34	0.638	
				0.000
16	480	4.73	0.638	
				0.102
15	440	5.13	0.536	
				0.098
14	350	5.52	0.338	
				0.105
13	290	5.92	0.233	
				0.073
12	240	6.31	0.160	
				0.037
11	210	6.70	0.123	

Froth Height = 5.31 in.

TABLE XXII

EXPERIMENTAL DATA FOR RUN 21

Clear Liquid Level = 3.15 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 1.0   Pressure Drop Across Tray = 3.66 in. wat
Air Velocity = 0.836 ft/sec   F Value = 0.236
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water   Slide Wire = 304

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
18	480	3.94	0.637	
				0.000
17	480	4.34	0.637	
				0.075
16	450	4.73	0.562	
				0.097
15	410	5.13	0.465	
				0.066
14	380	5.52	0.399	
				0.132
13	310	5.92	0.267	
				0.094
12	250	6.31	0.173	
				0.039
11	220	6.70	0.134	

Froth Height = 5.35 in.

TABLE XXIII

EXPERIMENTAL DATA FOR RUN 22

Clear Liquid Level = 3.15 in. Resistance Box = 3.0 ohms
Rotameter Reading = 1.0 Pressure Drop Across Tray = 3.74 in. wate
Air Velocity = 0.940 ft/sec F Value = 0.261
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water Slide Wire = 298

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
17	480	4.34	0.637	
				0.102
16	440	4.73	0.535	
				0.092
15	400	5.13	0.443	
				0.022
14	390	5.52	0.421	
				0.171
13	300	5.92	0.250	
				0.063
12	260	6.31	0.187	
				0.040
11	230	6.70	0.147	

Froth Height = 5.70 in.

TABLE XXIV

EXPERIMENTAL DATA FOR RUN 23

Clear Liquid Level = 3.15 in.
Rotameter Reading = 1.2
Air Velocity = 1.05 ft/sec
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water

Resistance Box = 3.0 ohms
Pressure Drop Across Tray = 3.82 in. wat
F Value = 0.290
Slide Wire = 298

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
17	470	4.34	0.616	
				0.028
16	460	4.73	0.588	
				0.053
15	440	5.13	0.535	
				0.091
14	400	5.52	0.444	
				0.106
13	350	5.92	0.338	
				0.070
12	310	6.31	0.268	
				0.094
11	250	6.70	0.174	
				0.027
10	230	7.10	0.147	

Froth Height = 5.70 in.

TABLE XXV

EXPERIMENTAL DATA FOR RUN 24

Clear Liquid Level = 3.15 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.3
Pressure Drop Across Tray = 3.92 in. wate
Air Velocity = 1.158 ft/sec
F Value = .322
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire @ 294

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
17	470	4.34	0.614	
16	470	4.73	0.614	0.000
15	440	5.13	0.533	0.081
14	400	5.52	0.442	0.091
13	370	5.92	0.378	0.064
12	320	6.31	0.282	0.096
11	290	6.70	0.232	0.050
10	250	7.10	0.173	0.059

Froth Height = 5.90 in.

TABLE XXVI

EXPERIMENTAL DATA FOR RUN 25

Clear Liquid Level = 3.98 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 0.7
Pressure Drop Across Tray = 4.29 in. water
Air Velocity = 0.527 ft/sec
F Value = 0.146
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 318

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
16	490	4.73	0.672	
				0.000
15	490	5.13	0.672	
				0.103
14	450	5.52	0.569	
				0.185
13	370	5.92	0.384	
				0.180
12	270	6.31	0.204	
				0.035
11	230	6.70	0.149	

Froth Height = 5.90 in.

TABLE XXVII

EXPERIMENTAL DATA FOR RUN 26

Clear Liquid Level = 3.98 Resistance Box = 3.0 ohms
Rotameter Reading = 0.85 Pressure Drop Across Tray = 4.37 in. wate
Air Velocity = 0.688 ft/sec F Value = 0.191
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water Slide Wire = 318

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
15	490	5.13	0.672	0.027
14	480	5.52	0.645	0.127
13	430	5.92	0.518	0.212
12	330	6.31	0.306	0.102
11	270	6.70	0.204	0.045
10	230	7.10	0.149	

Froth Height = 6.10 in.

TABLE XXVIV

EXPERIMENTAL DATA FOR RUN 27

Clear Liquid Level = 3.98 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 1.0   Pressure Drop Across Tray = 4.42 in. wat
Air Velocity = 0.836 ft/sec   F Value = 0.236
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water   Slide Wire = 312

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
15	480	5.13	0.638	
				0.051
14	460	5.52	0.587	
				0.074
13	430	5.92	0.513	
				0.115
12	380	6.31	0.398	
				0.131
11	310	6.70	0.267	
				0.094
10	250	7.10	0.173	
				0.026
9	230	8.49	0.147	

Froth Height = 6.49 in.

TABLE XXIX

EXPERIMENTAL DATA FOR RUN 28

Clear Liquid Level = 3.98 in. Resistance Box = 3.0 ohms
Rotameter Reading = 1.1 Pressure Drop Across Tray = 4.61 in. wat
Air Velocity = 0.940 ft/sec F Value = 0.261
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water Slide Wire = 308

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
15	490	5.13	0.665	
				0.000
14	490	5.52	0.665	
				0.000
13	490	5.92	0.665	
				0.130
12	440	6.31	0.535	
				0.092
11	400	6.70	0.443	
				0.161
10	320	7.10	0.282	
				0.080
9	270	7.49	0.202	
				0.042
8	240	7.89	0.160	

Froth Height = 6.88 in.

TABLE XXX

EXPERIMENTAL DATA FOR RUN 29

Clear Liquid Level = 3.98 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 1.2   Pressure Drop Across Tray = 4.64 in. wat
Air Velocity = 1.05 ft/sec   F Value = 0.290
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water   Slide Wire = 304

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
14	490	5.52	0.665	0.000
13	490	5.92	0.665	0.067
12	460	6.31	0.588	0.145
11	400	6.70	0.443	0.141
10	330	7.10	0.302	0.068
9	290	7.49	0.234	0.032
8	270	7.89	0.202	

Froth Height = 6.69 in.

TABLE XXXI

EXPERIMENTAL DATA FOR RUN 30

Clear Liquid Level = 3.98 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.3
Pressure Drop Across Tray = 4.88 in. wat
Air Velocity = 1.158 ft/sec
F Value = 0.322
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-water
Slide Wire = 300

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
14	470	5.52	0.615	
13	460	5.92	0.587	0.028
12	440	6.31	0.534	0.053
11	420	6.70	0.490	0.044
10	370	7.10	0.379	0.111
9	330	7.49	0.302	0.077
8	270	7.89	0.202	0.100
7	240	8.28	0.159	0.043

Froth Height = 7.12 in.

Purity of the oil?

TABLE XXXII

EXPERIMENTAL DATA FOR RUN 31

Clear Liquid Level = 3.15 in. Resistance Box = 3.0 ohms
Rotameter Reading = 0.70 Pressure Drop Across Tray = 2.83 in. wate
Air Velocity = 0.527 ft/sec F Value = 0.146
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil Slide Wire = 408

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
20	440	3.15	0.558	
				0.094
19	400	3.54	0.464	
				0.046
18	380	3.94	0.418	
				0.139
17	310	4.34	0.279	
				0.112
16	240	4.73	0.167	
				0.073
15	180	5.13	0.094	

Froth Height = 4.13 in.

TABLE XXXIII

EXPERIMENTAL DATA FOR RUN 32

Clear Liquid Level = 3.15 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 0.85   Pressure Drop Across Tray = 2.87 in. wate
Air Velocity = 0.688 ft/sec   F Value = 0.191
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil   Slide Wire = 412

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
19	480	3.54	0.668	
				0.108
18	440	3.94	0.560	
				0.118
17	390	4.34	0.442	
				0.088
16	350	4.73	0.354	
				0.143
15	270	5.13	0.211	
				0.015
14	260	5.52	0.196	
				0.078
13	210	5.92	0.128	

Froth Height = 4.33 in.

TABLE XXXIV

EXPERIMENTAL DATA FOR RUN 33

Clear Liquid Level= 3.15 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.0
Pressure Drop Across Tray = 2.99 in. wat
Air Velocity = 0.836 ft/sec
F Value = 0.236
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil
Slide Wire = 412

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
18	460	3.94	0.615	
				0.102
17	420	4.34	0.513	
				0.049
16	400	4.73	0.464	
				0.148
15	330	5.13	0.316	
				0.105
14	270	5.52	0.211	
				0.044
13	240	5.92	0.167	

Froth Height = 4.92 in.

TABLE XXXV

EXPERIMENTAL DATA FOR RUN 34

Clear Liquid Level = 3.15 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 1.1   Pressure Drop Across Tray = 3.11 in. wate
Air Velocity = 0.940 ft/sec   F Value = 0.261
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil   Slide Wire = 414

Probe Reading cm.	Current to Probe milliamps	Height of Probe above Tray inches	Heat Loss from Probe watts	Change in Heat Loss watts
18	450	3.94	0.592	
				0.077
17	420	4.34	0.515	
				0.032
16	400	4.73	0.483	
				0.128
15	350	5.13	0.355	
				0.093
14	300	5.52	0.262	
				0.080
13	250	5.92	0.182	
				0.041
12	220	6.31	0.141	

Froth Height = 5.0 in.

TABLE XXXVI

EXPERIMENTAL DATA FOR RUN 35

Clear Liquid Level = 3.15 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 1.2   Pressure Drop Across Tray = 3.19 in. wate
Air Velocity = 1.05 ft/sec   F Value = 0.290
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil   Slide Wire = 412

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
17	440	4.34	0.560	
				0.073
16	410	4.73	0.487	
				0.090
15	370	5.13	0.397	
				0.081
14	330	5.52	0.316	
				0.090
13	280	5.92	0.226	
				0.045
12	250	6.31	0.181	
				0.027
11	230	6.70	0.154	

Froth Height = 5.32 in.

TABLE XXXVII

EXPERIMENTAL DATA FOR RUN 36

Clear Liquid Level = 2.36 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 0.70   Pressure Drop Across Tray = 2.4 in. water
Air Velocity = 0.527 ft/sec   F Value = 0.146
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil   Slide Wire = 408

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Changes in Heat Loss
cm.	milliamps	inches	watts	watts
22	420	2.36	0.513	
				0.062
21	390	2.76	0.441	
				0.065
20	360	3.15	0.376	
				0.132
19	290	3.54	0.244	
				0.033
18	270	3.94	0.211	
				0.083
17	210	4.34	0.128	
				0.015
16	170	4.73	0.113	

Froth Height = 3.34 in.

TABLE XXXVIII

EXPERIMENTAL DATA FOR RUN 37

Clear Liquid Level = 2.36 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 0.85   Pressure Drop Across Tray = 2.48 in. wate
Air Velocity = 0.688 ft/sec   F Value = 0.191
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil   Slide Wire = 408

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
21	430	2.76	0.547	0.082
20	400	3.15	0.465	0.111
19	350	3.54	0.354	0.127
18	280	3.94	0.227	0.086
17	220	4.34	0.141	0.047
16	180	4.73	0.094	

Froth Height = 3.66 in.

TABLE XXXIX

EXPERIMENTAL DATA FOR RUN 38

Clear Liquid Level = 2.36 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.0
Pressure Drop Across Tray = 2.52 in. wat
Air Velocity = 0.836 ft/sec
F Value = 0.236
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil
Slide Wire = 402

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
21	340	2.76	0.397	
				0.081
20	330	3.15	0.316	
				0.055
19	300	3.54	0.261	
				0.050
18	270	3.94	0.211	
				0.070
17	220	4.34	0.141	
				0.025
16	200	4.73	0.116	

Froth Height = 3.74 in.

TABLE XXXX

EXPERIMENTAL DATA FOR RUN 39

Clear Liquid Level = 2.36 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 1.1
Pressure Drop Across Tray = 2.56 in. wat
Air Velocity = 0.940 ft/sec
F Value = 0.261
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil
Slide Wire = 402

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
20	330	3.15	0.316	
				0.020
19	320	3.54	0.296	
				0.070
18	280	3.94	0.226	
				0.045
17	250	4.34	0.181	
				0.040
16	220	4.73	0.141	
				0.036
15	190	5.13	0.105	
				0.031
14	160	5.52	0.074	
				0.009
13	150	5.92	0.065	

Froth Height = 3.74 in.

TABLE XXXXI

EXPERIMENTAL DATA FOR RUN 40

Clear Liquid Level = 2.36 in. Resistance Box = 3.0 ohms
Rotameter Reading = 1.2 Pressure Drop Across Tray = 2.67 in. wate
Air Velocity = 1.05 ft/sec F Value = 0.290
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil Slide Wire = 402

Probe Reading cm.	Current to Probe milliamps	Height of Probe above Tray inches	Heat Loss from Probe watts	Change in Heat Loss watts
20	350	3.15	0.354	
				.020
19	340	3.54	0.334	
				0.073
18	300	3.94	0.261	
				0.037
17	280	4.34	0.226	
				0.059
16	240	4.73	0.167	
				0.051
15	200	5.13	0.116	
				0.022
14	180	5.52	0.094	
				0.020
13	160	5.92	0.074	
				0.009
12	150	6.31	0.065	

Froth Height = 4.13 in.

TABLE XXXXII

EXPERIMENTAL DATA FOR RUN 41

Clear Liquid Level = 1.57 in.
Resistance Box = 3.0 ohms
Rotameter Reading = 0.70
Pressure Drop Across Tray = 1.77 in. wate
Air Velocity = 0.527 ft/sec
F Value = 0.146
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil
Slide Wire = 400

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
24	360	1.57	0.477	0.043
23	340	1.97	0.334	0.073
22	300	2.36	0.261	0.094
21	240	2.76	0.167	0.062
20	190	3.15	0.105	0.040
19	150	3.54	0.065	0.008
18	140	3.94	0.057	

Froth Height = 2.56 in.

TABLE XXXXIII

EXPERIMENTAL DATA FOR RUN 42

Clear Liquid Level = 1.57 Resistance Box = 3.0 ohms
Rotameter Reading = 0.85 Pressure Drop Across Tray = 1.69 in. wate
Air Velocity = 0.688 ft/sec F Value = 0.191
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil Slide Wire = 398

Probe Reading cm.	Current to Probe miliamps	Height of Probe above Tray inches	Heat Loss from Probe watts	Change in Heat Loss watts
24	370	1.57	0.397	0.000
23	370	1.97	0.397	0.063
22	340	2.36	0.334	0.090
21	290	2.76	0.244	0.090
20	230	3.15	0.154	0.060
19	180	3.54	0.094	0.020
18	160	3.94	0.074	

Froth Height = 2.75 in.

TABLE XXXXIV

EXPERIMENTAL DATA FOR RUN 43

Clear Liquid Level = 1.57 Resistance Box = 3.0 ohms
Rotameter Reading = 1.0 Pressure Drop Across Tray = 1.75 in. wate
Air Velocity = 0.836 ft/sec F Value = 0.236
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil Slide Wire = 396

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
24	370	1.57	0.396	
				0.020
23	360	1.97	0.376	
				0.043
22	340	2.36	0.333	
				0.065
21	310	2.76	0.278	
				0.067
20	270	3.15	0.211	
				0.071
19	220	3.54	0.140	
				0.046
18	180	3.94	0.094	

Froth Height = 3.15 in.

TABLE XXXXV

EXPERIMENTAL DATA FOR RUN 44

Clear Liquid Level = 1.57 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 1.1   Pressure Drop Across Tray = 1.81 in. wate
Air Velocity = 0.940 ft/sec   F Value = 0.261
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil   Slide Wire = 394

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
23	370	1.97	0.396	
				0.043
22	350	2.36	0.353	
				0.038
21	330	2.76	0.315	
				0.072
20	290	3.15	0.243	
				0.077
19	240	3.54	0.166	
				0.061
18	190	3.94	0.105	
				0.011
17	180	4.34	0.094	

Froth Height = 3.34 in.

TABLE XXXXVI

EXPERIMENTAL DATA FOR RUN 45

Clear Liquid Level = 1.57 in.   Resistance Box = 3.0 ohms
Rotameter Reading = 1.3   Pressure Drop Across Tray = 1.93 in. wate
Air Velocity = 1.158 ft/sec   F Value = 0.322
Position of Tray = Probe Reading of 28.0 cm.
System Studied; air-oil   Slide Wire = 388

Probe Reading	Current to Probe	Height of Probe above Tray	Heat Loss from Probe	Change in Heat Loss
cm.	milliamps	inches	watts	watts
23	330	1.97	0.315	
				0.037
22	310	2.36	0.278	
				0.018
21	300	2.76	0.260	
				0.050
20	270	3.15	0.210	
				0.044
19	240	3.54	0.166	
				0.051
18	200	3.94	0.115	
				0.032
17	170	4.34	0.083	
				0.018
16	150	4.73	0.065	

Froth Height = 3.74 in.

VITA

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