PLATE EFFICIENCY OF BUBBLE CAP RECTIFYING COLUMNS

by

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Chem
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Thesis
1930

Cambridge, Mass.
November 12, 1929

Professor A. L. Merrill
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Mass.

Dear Sir:

I am submitting herewith my thesis, "Plate Efficiency of Bubble Cap Rectifying Columns", as partial fulfillment of the requirements for the degree of Doctor of Science in Chemical Engineering.

Very respectfully yours,
Signature redacted
James S. Carey

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A. ABSTRACT

Plate Efficiency of Bubble Cap Rectifying Columns.

Rectification in bubble cap rectifying columns is a process of material transfer by diffusion in which the gas film frequently offers the controlling resistance. Based upon this concept, and the fundamental law for diffusion of gases through gases, equations have been developed for binary mixtures which relate the enrichment of the vapor during its passage through the plate to the several factors influencing the material transfer.

For the case of equi-molal rates of transfer of the two constituents in opposite directions through the film, the equation is:

$$y_n = E_M y_n^* + (1-E_M)y_{n-1} \quad - - - - (1)$$

where y_{n-1} is the mol fraction of the more volatile constituent in the vapor entering the plate, y_n the mol fraction of the same constituent in the vapor leaving the plate, while y_n^* represents the vapor

composition which would be in equilibrium with the plate liquid. E_M is the plate efficiency of the column, ②

From the derivation of this equation the relation of E_M to the factors influencing plate efficiency is shown to be:

$$E_M = 1 - e^{\frac{-k_m S\theta}{X\,V'}} \qquad \text{- - - - - - - - (2)}$$

in which k_m is the specific diffusion coefficient for a given pair of components expressed in molal units, S the average interfacial surface area of a bubble of vapor passing through ~~a plate~~ the liquid, V', the average mols of vapor contained in a bubble, X the gas film thickness and θ the time of bubble contact with liquid on the plate. The factors influencing plate efficiency are thus seen to include type of mixture, as it influences k_m, as well as the interdependent terms involving film thickness, bubble size and time of contact.

If the molal rates of transfer of the two constituents are not equal, application of the rigorous gas film equation for this case gives:

$$\int_{y_{n-1}}^{y_n} \frac{dy}{\ln \dfrac{1-\left(1-\frac{Mr_A}{Mr_B}\right)y^*}{1-\left(1-\frac{Mr_A}{Mr_B}\right)y}} = \left(\frac{1}{1-\frac{Mr_A}{Mr_B}}\right) \frac{k_m S\theta}{X\,V'} \qquad \text{- - - -(3)}$$

Note

The additional terms involved in this equation are Mr_A and Mr_B, the molal latent heats of the two componets. It is shown that the left-hand side of the equation may be put into a form, the integrals of which have been evaluated over a range covering all values of the variables ordinarily to be met in practice.

The major experimental data were obtained with two pieces of equipment.

1. A seven plate column of semi-commercial size, 8" inside diameter and plate sections 12" high, each plate section being provided with one four-inch bubble cap. The still was heated by steam condensing in a closed coil.

2. A single plate column consisting of a still and single plate-section mounted directly above. The plate section was 6" in diameter and 10" high. Interchangeable bubble caps of various slot widths, and provision for varying the liquid depths on the plate, permitted the effect of these factors to be studied. The still was heated by electrical immersion heaters.

Binary mixtures employed in the seven plate column runs were benzene-toluene and carbon-tetrachloride-toluene. In the single plate column, mixtures of benzene-toluene and alcohol-water were used.

The runs with the seven plate column covered the effect of vapor velocity on plate efficiency in the range of superficial vapor velocities from 0.25 to 1.65 ft. per second, corresponding to "nominal" slot velocities of 3.72 to 24.6 ft. per second. The variation in plate efficiency was from 57 to 70%. Several runs at approximately 1 ft. per second superficial vapor velocity were made with carbon tetrachloride-toluene mixtures to obtain comparative data on the effect of the nature of components on plate efficiency. The carbon-tetrachloride-toluene runs gave efficiencies of 47% versus 57% for benzene-toluene.

Runs with the single plate column covered the range in superficial vapor velocities from 0.026 to 0.55 ft. per second, corresponding to "nominal" slot velocities of 0.74 to 15.6 ft. per second. Plate efficiencies between 50% and 90% resulted, depending upon the slot width and liquid depth employed. Comparative data were obtained on plate efficiencies obtained with benzene-toluene and alcohol-water mixtures under the same operating conditions. The efficiencies were 51.2% for benzene-toluene as compared with 72.6% for alcohol-water. The effect of the concentration of the plate liquid with respect to the more volatile component was studied for benzene-toluene between the limits of 15 and 65 mol per cent benzene; in the case of alcohol-water the concentration limits were 28 and 55 mol per cent alcohol. In the case of benzene-toluene the change in efficiency for the concentration limits noted was from 53 to 58%. For alcohol-water, no change in efficiency with concentration was had. Employing alcohol-water mixtures the effect of cap slot width on plate efficiency was studied using slot widths of 1/2", 1/4", 1/8" and 1/16", the total free area through the slots being kept constant at 1 square inch. For each slot width employed, liquid depths were varied from 0.75" to 1.75" in individual runs. Efficiencies ranging from 68% to 99.9% were obtained. Data showing the temperatures of the vapor entering and leaving a plate were secured in a portion of the runs.

The major conclusion to be derived from these rectification studies is that plate efficiency is satisfactorily defined by the theoretical equations presented.

In the range of vapor rates within which the majority of the experimental data were obtained, the mechanism of bubble cap rectification is essentially one in which the principle source of vapor-liquid contact is that due to bubbling action. At higher vapor rates the bubbling mechanism to which the equations apply is supplemented by an additional source of liquid-vapor contact due to spray thrown up from the plate liquid, leading to an increase in plate efficiency.

From known data on one binary mixture, plate efficiencies may be estimated semi-quantitatively for another binary mixture by applying Equation 2.

The effects of variations in slot widths and liquid depths are correctly indicated by Equation 2. For the case of alcohol-water mixtures, at a fixed superficial vapor rate of 0.2 ft. per second in the single plate column, the relation of plate efficiency to slot width and liquid depth is given by the equation:

$$\log\,(1-E_M) = -0.0616\left(\frac{i}{w}\right) - 0.713\,(i) - 0.193$$

in which "i" is the distance in inches from the liquid surface to the center of the bubble stream emerging from the slots, and w is the slot width in inches.

Additional data, incidental to the major problem, included determinations of the liquid-vapor equilibrium relationships for carbon tetrachloride-toluene and alcohol-water. The data for carbon tetrachloride-toluene showed an appreciable deviation from Raoult's law. The alcohol-water equilibrium data covered the range in composition from zero alcohol concentration to that of the constant boiling mixture. These data agree well with one of the previously determined sets of values from the literature and are believed to be the most accurate yet obtained for the alcohol-water liquid-vapor equilibrium relation.

Near the close of the work a method was developed for computing plate efficiencies based merely on vapor and liquid temperatures. When the available data were examined by this method excellent correlation was obtained. Incidentally the efficiencies so obtained were numerically almost equal to those calculated from the point of view of vapor diffusion.

I - INTRODUCTION

The goal toward which efforts have been directed in recent years in Chemical Engineering design is the attainment of methods of computation soundly based upon the fundamental principles involved. The realization of this end means that, with proper application of data on the physical and chemical properties of the materials concerned, one can accurately determine the form and performance of new types of equipment or the effects of modifications in equipment already in use. In certain of the unit processes of Chemical Engineering progress has been very rapid toward the objective, for others the state of knowledge has remained to a great extent empirical, the latter being particularly true of Rectification.

Rectification may be broadly defined as a distillation carried out in such a way that an interaction takes place between the vapor evolved and a condensed portion of vapor previously evolved from the same still. This interaction involves a transfer of material, with its accompanying heat interchange, between a vapor and a liquid phase and serves to partially remove the less volatile components from the vapor and the more volatile components from the liquid. The effectiveness with which this material transfer is carried out is a measure of the completeness of rectification.

To secure good rectification intimate contact between liquid and vapor is necessary. Plate rectifying columns were developed through experience as one of the best methods for securing this result. First applied in the alcohol industry, their use has been extended to the industrial separation of a wide range of materials.

One of the major problems in the design of commercial rectification equipment is the estimation of the number of plates required in a column to effect a given separation. This computation of necessity involves an efficiency factor relating the actual performance of the plates to that theoretically obtainable.

At the start of the present work early in 1928 published data on the performance of rectifying columns from which the efficiency of the plates could be determined were practically nonexistant. Due to this complete lack of information the securing of good experimental data on the rectification of binary mixtures in plate columns was believed to be the first step necessary to place the design of such equipment upon a firm fundamental basis.

The material herein presented covers a study of the factors influencing the plate efficiency of bubble cap rectifying columns handling binary mixtures from both the theoretical and the experimental points of view. The data has been interpreted in the light of the theoretical developments and the relative influences of the several factors involved upon plate efficiency has been shown.

II - GENERAL METHODS OF COMPUTATION OF CONTINUOUS PLATE RECTIFYING COLUMNS

In the design of complete rectification equipment several problems, all interdependent, must be solved. Viewing the rectifying column separately two inter-related problems must be dealt with, namely (1) design from the rectification or separation standpoint; (2) design with regard to the flow of fluids, both liquid and vapor in the column.

Considering column design from the rectification point of view, several useful methods for the estimation of the number of plates necessary to effect a desired degree of separation have been developed. All of these methods involve an efficiency factor which relates the actual column performance to that theoretically obtainable. The exact definition of the efficiency factor depends upon the fundamental basis of development of the method in conjunction with which the factor is used.

Methods for column computation can be classified with respect to the principles upon which they are based as follows:

1. Methods based upon the concept of the theoretically perfect plate.

A. Algebraic stepwise method.

B. Graphical stepwise method, limited to binary mixtures.

C. Differential enrichment method.

2. Methods based upon diffusional mechanism.

These methods will be considered in some detail.

The theoretically perfect plate is one in which the vapor passing through the plate comes to equilibrium with the liquid on the plate. This concept was first applied by Sorel (1) (2) (3) to the stepwise calculation of a column and treated in slightly varying ways by Hausbrand (4), Gay (5) and others (6) (7) (8), and clarified by Lewis (9). If certain simplifying assumptions are made, viz.,

1. Molal latent heats are the same for all components.

2. No heat of mixing of components.

3. Sensible heat changes are negligible compared with latent heat changes.

4. Heat losses from the column are negligible.

this method involves the use of two relationships in order to work from plate to plate of a column of theoretically perfect plates:

(a) A material balance cutting through a section immediately beneath the plate under consideration and either the product or waste streams, depending upon whether one is considering a plate above or below the point of introduction of the feed.

For plates above the feed (A) $V_{n-1}\, y_{n-1} = O_n x_n + P x_c$

" " below " " (B) $V_{m-1}\, y_{m-1} = O_m x_m - W x_w$

(b) The liquid vapor equilibrium relationship.

In case the simplifying assumption of equimolal latent heats does not hold a heat balance can be applied to each plate to estimate the change in overflow from plate to plate.

In the case of binary mixtures for which the liquid-vapor equilibrium data can be conveniently represented graphically, McCabe and Thiele(10) developed their well-known graphical method for computing the number of perfect plates required in a column. This consists in plotting equations (A) and (B) together with the equilibrium data for the mixture on a graph of y vs. x. If the four simplifying assumptions previously noted hold, equations (A) and (B) are straight lines; in case heat balances must be used these lines will be curves. To carry out the column computation graphically it is necessary simply to go in stepwise fashion between the material balance, or operating lines, and the equilibrium curve from the composition of the waste to that of the overhead. The number of steps necessary to effect the desired separation then represents the number of perfect plates required.

In the algebraic stepwise method, however applied, plate efficiency is defined as:

$$E_S = \frac{\text{No. of theoretical plates required}}{\text{No. of actual plates required}} \times 100 \quad - - - (C)$$

If the number of perfect plates required has been computed for a column, by dividing by the plate efficiency the number of actual plates is obtained, or given data on an actual column one can calculate the equivalent theoretical column and thus determine the efficiency. It should be noted in connection with this use of plate efficiency that a common error in application consists in considering the still or kettle as a plate. This is erroneous, as vapor given off by boiling liquid in the still is actually in equilibrium with the liquid. Thus if it is found by stepwise computation that 11 theoretical steps are necessary to effect a given separation the theoretical column consists of 10 perfect plates and a still. If, in an actual column, operating under the same conditions, 15 plates in the column are necessary the plate efficiency of the column is $\frac{10}{15} \times 100 = 66.6\%$, instead of $\frac{11}{15} \times 100 = 73.3\%$, or $\frac{11}{16} \times 100 = 68.7\%$.

The differential enrichment equation developed by Lewis(11) is derived from a material balance, e.g.

$$x_{n+1} = y_n - \frac{P}{O_{n+1}} (x_c - y_r) \quad - - - \text{(D)}$$

by subtracting x_n fromboth sides and assuming that $x_n+1 - x_n = \frac{dx}{dn}$, giving $\frac{dx}{dn} = y_n - x_n - \frac{P}{O_n+1} (x_c - y_n) \quad - - \text{(E)}$

Lewis pointed out that this equation was only safely applicable where the enrichment from plate to plate is small. Where this conditions is met such as in the upper portion of an alcohol column this equation permits the evaluation of the number of perfect plates by a single graphical integration. An efficiency factor can be multiplied into the right-hand side of Equation (E) thus defining plate efficiency as $\frac{dx/dn \text{ actual}}{dx/dn \text{ theoretical}}$ which is equivalent to

$$E_L = \frac{\text{actual enrichment per plate}}{\text{theoretical enrichment per plate}} \quad - - - \text{(F)}$$

If the efficiency factor is made use of in conjunction with equation (E) the number of actual plates is obtained by the integration.

The first published application of the material transfer by diffusion concept to plate rectification was by Murphree.(12)(13) By integration of the Whitman(14) absorption equation for conditions obtaining on a plate of a continuous rectifying column he obtained the following equation, a modified deviation of which will be given under "Deviation of Equations":

$$y_n = (1-M)y_n^* + M\, y_{n-1} \quad - - - - \text{(G)}$$

This equation states that the mol fraction of a given constituent y_n in the vapor leaving the nth plate of a column, is equal to (1-M) times the vapor composition expressed in mol fraction, which would be in equilibrium with the liquid on the nth plate, plus M times the mol fraction of the given constituent in the vapor from the n-1 plate. In this equation 1-M is the factor representing the efficiency of the plate. Rearranging equation (G) efficiency is thus defined as:

$$E_M = 1 - M = \frac{y_n - y_{n-1}}{y_n^* - y_{n-1}} = \frac{\text{actual enrichment of vapor}}{\text{theoretically obtainable enrichment}} \quad \text{--(H)}$$

The Murphree equation (H) may be combined with a material balance, e.g. $V_{n-1}\, y_{n-1} = O_n X_n + P X_c$, giving

$$y_n = E_{y^*} + (1-E)\left\{\frac{O_n x_n}{V_{n-1}} + \frac{P x_c}{V_{n-1}}\right\} \quad \text{- - (I)}$$

It will be seen by inspection of Equation I that, given equilibrium data and the value of E, the composition of vapor, y_n, given off by any plate can be calculated if the liquid composition x_n and the values of O, P and V are known. A material balance e.g. Equation A, will then permit the calculation of liquid strength on the plate above and Equation I can be again applied. In comparison with the algebraic stepwise method in which equilibrium is assumed on every plate the Murphree method replaces the liquid-vapor equilibrium relationship with Equation I. An efficiency term having been introduced in the calculation of every step of the column, the total number of stepwise calculations indicates the number of actual plates required. In addition the Murphree method of calculating gives the actual material compositions to be expected upon the various plates of a column, which is impossible by the perfect plate method.

For the case of binary mixtures the Murphree method permits a graphical solution similar to that given by McCabe-Thiele.(10) The material balances for plates above and below the feed are plotted on a y vs. x diagram as was done by McCabe and Thiele. The liquid-vapor equilibrium curve however is replaced by the Murphree Equation I and a similar equation written for plates below the point of introduction of the feed. The curves representing these equations intersect at the feed plate composition as do the material balance lines. The graphical computation is then carried out by running perpendicular and horizontal lines in a stepwise manner between the operating lines and the Murphree curves.

The second application of the diffusional concept to plate column calculations was by Lewis and Wilde.(14a) While they do not present an actual derivation such as Murphree's they had the diffusion point of view clearly in mind when they defined plate efficiency as the ratio of the amount of a particular component actually absorbed from the vapor by the liquid to the amount theoretically absorbable under equilibrium conditions, or

$$E_{L-W} = \frac{Y_{n-1} - Y_n}{Y_{n-1} - Y_{n*}} \quad - - - - (J)$$

It will be noted that the "Y's" appearing in equation J represent total mols of a given component in the vapor passing a given section per unit of time. If the usual simplifying assumptions p 13 apply:

$$V_{n-1} = V_n \text{ and}$$

$$\frac{Y_{n-1} - Y_n}{Y_{n-1} - Y_{n*}} = \frac{V_{n-1}\, y_{n-1}\; V_n\, y_n}{V_{n-1}\, y_{n-1}\; V_n\, y_{n*}} = \frac{y_n - y_{n-1}}{y_{n*} - y_{n-1}} \quad - - - (K)$$

which is the same as the Murphree definition of efficiency.

The Lewis and Wilde equation (J) can also be combined with a material balance in a manner similar to that of the Murphree equation (I).

Summary of Definitions of Plate Efficiency:

1. Efficiency used in conjunction with the theoretically perfect plate

$$E_S = \frac{\text{No. of perfect plates}}{\text{No. of actual plates}} \times 100$$

2. Efficiency used with differential enrichment equation:

$$E_L = \frac{\text{actual enrichment of liquid per plate}}{\text{Theoretical enrichment of liquid per plate}}$$

3. Murphree Efficiency:

$$E_M = \frac{\text{Actual enrichment of vapor}}{\text{Theoretical enrichment of vapor}}$$

4. Lewis and Wilde Efficiency:

$$E_{L-W} = \frac{\text{Total mols of component actually absorbed}}{\text{Total mols of component theoretically absorbed.}}$$

Comparison of Efficiencies: The efficiency defined in terms of the perfect plate is convenient to use and makes rapid computation possible, especially in the case of binary mixtures. Where experience has shown the performance to be expected from a given design of column handling certain mixtures it can be applied with assurance. Being an empirical factor, however, it does not indicate the exact effect of variables which may affect plate efficiency and therefore does not facilitate the estimation of the efficiency to be expected from a change in plate design, operating conditions or materials undergoing separation.

The differential enrichment efficiency is similar to the Murphree efficiency except that liquid compositions are used to express enrichments instead of vapor compositions as in the Murphree definition. In cases in which the differential enrichment equation can be applied it is to be expected that the same influence of the several factors upon efficiency will be had that is indicated by the Murphree equation (G).

The Murphree relation, Equation G, will be later shown to indicate the probable effect of the variables upon which efficiency depends. This factor permits the evaluation of a separate efficiency for every plate in a column and also for the various components in a multicomponent mixture. Being based upon a material transfer mechanism, granted a sound derivation, it should interpret actual data satisfactorily. Consequently the Murphree efficiency was used as a starting point in treating the investigation from the theoretical side.

The Lewis and Wilde efficiency is, as indicated previously, identical with the Murphree efficiency if the assumption of equal molal vapor rates passing all sections of the column can be made. If this assumption is not valid a variation in the Murphree derivation is necessary to obtain the Lewis and Wilde equation from the diffusion equations.

III - EQUATIONS FOR MATERIAL TRANSFER BETWEEN GASES AND LIQUIDSBY DIFFUSION THROUGH INTERFACIAL FILMS.

It is now generally accepted that when a transfer of material takes place between a liquid and a vapor phase that the mechanism of the transfer must consist in diffusion through the liquid and vapor films existing on either side of the interface. The basic laws followed by diffusing materials must therefore apply to the transfer of materials which are diffusing through interfacial films. As rectification involves such material transfer it is necessary to briefly summarize the theoretical principles and applications which are available.

The law governing the rate of diffusion of one gas through another was first derived by Maxwell(15) from the kinetic theory of gases and later by Stefan,(16) employing hydrodynamic considerations. This basic law was re-investigated and applied to the diffusion of gases in the steady state through gas films by Lewis and Chang(16a) and (17) Hanks and McAdams, the equations derived being supported by experimental data. A similar application was made of Fick's(18) analogous law for the diffusion of liquids through liquid films. Fick's law was also derived by Stefan.(16)

IIIA- SUMMARY OF EQUATIONS APPLYING TO GAS FILMS

For the case of the steady diffusion of two gases, A and B through one another in opposite directions through a cross section of unit area the differential equation may be written:

$$-\frac{dp_A}{dX} = \alpha_{A-B}\;\rho_A\rho_B\;(u_A - u_B)^{*} \quad ---(1)$$

To express the right-hand side of equation (1) in terms of partial pressures to permit integration the following substitutions may be made:

By definition $\frac{\rho_A u_A}{M_A} = N_A$ and

$$\frac{\rho_B u_B}{M_B} = N_B$$

From the perfect gas laws: $\frac{\rho_A}{M_A} = \frac{p_A}{RT}$

$$\frac{\rho_B}{M_B} = \frac{p_B}{RT}$$

$$-\frac{dp_A}{dX} = \frac{\alpha M_A M_B}{RT}\;(p_B N_A - p_A N_B) \quad - - (2)$$

The term $\frac{\alpha M_A M_B}{RT}$ can be conveniently replaced by $\frac{1}{k_m}$, giving

$$-\frac{dp_A}{dX} = \frac{1}{k_m}(p_B N_A - p_A N_B) \quad - - (2a)$$

For constant total pressure $p_A + p_B = \pi$. Equation 2a may be written as:

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*Footnote- The complete table of Nomenclature is given on page 328.

$$\frac{-dpA}{dX} = \frac{1}{km}\left[N_A(\pi-p_A)-N_B\,p_A \right] \quad - - - (3)$$

Rearranging equation 3:

$$\frac{-dpA}{dX} = \frac{1}{k_m}\left[(N_A\,\pi) - (N_A+N_B)p_A \right] \quad - - - (4)$$

If equal numbers of mols of A and B are diffusing per unit time per unit cross section $N_A = - N_B$*. For this case Equation (4) becomes:

$$\frac{-dpA}{dX} = \frac{\pi}{k_m}\,N_A \quad - - - (5)$$

If one of the gases, B, is stationary its velocity, u_B, in Equation (1) is zero and there is obtained:

$$\frac{-dpA}{dX} = \frac{N_A\ p_B}{k_m} \quad - - - (6)$$

To apply Equations 4, 5 and 6 to material transfer under steady conditions through a film of thickness X upon a liquid vapor interface it is necessary to integrate the equations between values of the partial pressures at the interface, pAi, and in the main body of the gaseous mixture, pAg, and from 0 to the film thickness X. Expressions will then be obtained giving the molal rate of transfer of gas A per unit area through the film under steady conditions.

For diffusion of components A and B in opposite directions through a film of thickness X there is obtained by integration of Equation (4)

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*N_A and N_B are vector quantities, hence the algebraic sign denoting direction.

$$N_A = \frac{k_m}{X} \left(\frac{1}{1+\frac{N_B}{N_A}} \right) \ln \left[\frac{1-\left(1+\frac{N_B}{N_A}\right)\frac{pAi}{\pi}}{1-\left(1+\frac{N_B}{N_A}\right)\frac{pAg}{\pi}} \right] \text{ ---(7)}$$

For the special case in which $N_A = -N_B$ integration of Equation 5 gives

$$N_A = \frac{k_m}{X\,\pi} (pAi - pAg) \text{ - - - (8)}$$

When component B is stationary, integration of Equation (6) gives

$$N_A = \frac{k_m}{X} \ln \frac{\pi - pAi}{\pi - pAg} \text{ - - - (9)}$$

$$N_A = \frac{k_m}{X} \ln \frac{pBi}{pBg} \text{ - - - (9a)}$$

If the ratio $\frac{pBi}{pBg}$ does not differ too widely from unity, pB can be assumed constant in Equation 6 and equal to pB ave. This permits the integrated equation to take the form:

$$N_A = \frac{k_m}{X\ p_{Bave}} (p_{Ai} - p_{Ag}) \text{ - -- (10)}$$

On account of subsequent use to be made of Equations, 7, 8, 9 and 10 it is desirable to investigate the factors influencing the value of k_m and of the film thickness, X.

IIIB - METHODS FOR ESTIMATING k_m FROM DATA IN THE LITERATURE.

The value k_m, as indicated previously, replaces the term $\frac{R\,T}{\alpha M_A M_B}$ * employed by Lewis and Chang.(16a) From inspection of Equations 7, 8, 9, and 10 the units in which k_m must be expressed are:

$$k_m = \frac{(\text{gm. mols})(\text{cm})}{(\text{sec.})(\text{sq. cm.})} \quad - - - \ (11)$$

if consistent c.g.s. units are employed.

Values of diffusion coefficients in the literature are expressed as:

$$k_v = \frac{(\text{cm})^2}{\text{sec}} = \frac{(\text{cu.cm})(\text{cm})}{(\text{sec.})(\text{sq.cm.})} \quad - - - \ (12)$$

By employing the gas laws a conversion can be worked out immediately. However it is desirable to employ Stefan's(19) original equations and show that the relation obtained is consistent with the fundamental derivation of his equations

$$k_m = \frac{R\,T}{\alpha\, M_A\, M_B} \qquad \text{by definition.}$$

From Stefan's derivation:

$$\alpha = \frac{1}{k_v}\left|\frac{\pi_0}{\pi}\right|^2 \left|\frac{T^2}{T_0^2}\right| \delta_A \delta_B$$

Therefore:

$$k_m = \frac{R\,T}{M_A M_B}\left|\frac{\pi}{\pi_0^{\,2}}\right|\frac{T_0^2}{T^2}\left|\delta_A\delta_B\right| k_v$$

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* α as used by Lewis and Chang is identical with A_{1-2} used by Stefan.

Employing the gas laws

$$\delta_A = \frac{M_A}{22400}, \quad \delta_B = \frac{M_B}{22400}$$

and $22400 = \frac{R\,T_0}{\pi_0}$

Therefore:

$$k_m = \frac{R\,T}{M_A M_B}\Big|\frac{\pi}{\pi_0}{}^2\Big|\frac{T_0{}^2}{T^2}\Big|\frac{M_A}{22400}\Big|\;M_B\Big|\frac{\pi_0}{RT_0}\Big|\,k_v$$

Cancelling terms there results

$$k_m = \frac{k_v}{22400}\,\frac{(\pi)}{(\pi_0)}\,\frac{(T_0)}{T} \quad - - - (13)$$

which is i~~n~~dentical with the relation which may be directly determined. Equation 13 affords a means for calculating k_m at a given temperature, T, from the value of k_v reported at the same temperature.

IIIC- FACTORS INFLUENCING k_m

Much of the data available in the literature on k_v are given for standard conditions of temperature and pressure, viz. 0°C. and 1 atmosphere. It is therefore necessary to show how k_m at any temperature may be calculated from a reported value of k_{vo}.

The variation of k_v with temperature and pressure is expressed in an equation due to Von Obermayer(19):

$$k_v = (k_{vo}) \left(\frac{T}{T_o}\right)^n \left(\frac{\pi_o}{\pi}\right) \quad - - (14)$$

Von Obermayer states that the value of "n" lies between 1.7 and 2.0. Where actual data are lacking the value of 2.0 may be assumed, bearing in mind the following limitations. Values of k_v in the literature are plotted in Figure (1) against $\frac{T°K}{273}$, log-log paper being employed. From the slopes of these lines the values of n for the data available are indicated. It will be noted that certain of the lines tend to flatten out at the higher temperatures indicating a disappearance of further temperature effect. Extrapolation for values of k_v over a wide temperature range by use of Equation (14) is therefore at the best uncertain.

Combining Equation 14 with Equation 13 and assuming n = 2.0 there results

$$k_m = \frac{k_{vo}}{22400} \left(\frac{T}{T_o}\right) \quad - - - (15)$$

The limitations on temperature extrapolations pointed out should be borne in mind in employing this relation to interpret data involving diffusion coefficients.

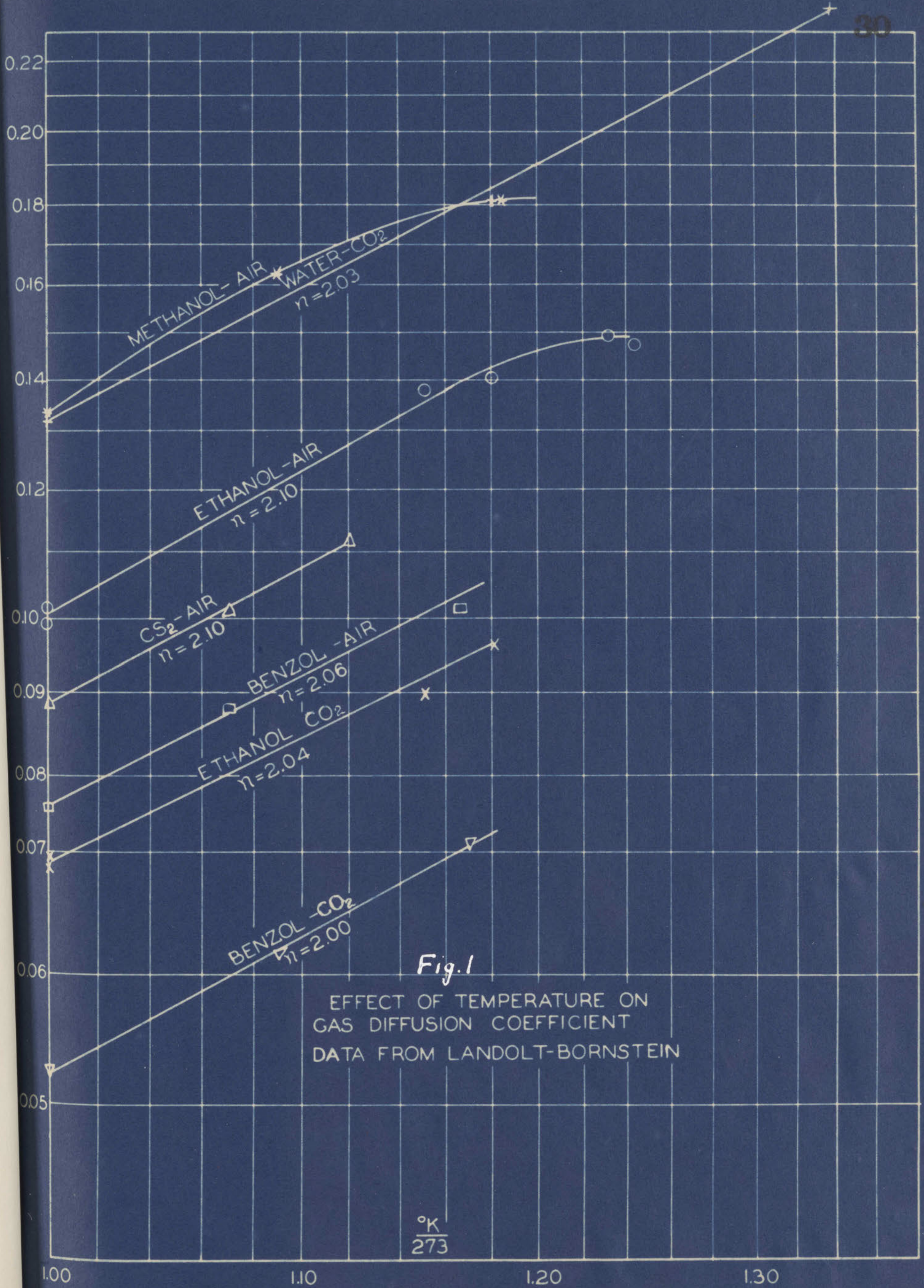


Fig. 1

EFFECT OF TEMPERATURE ON GAS DIFFUSION COEFFICIENT DATA FROM LANDOLT-BORNSTEIN

IIID - ESTIMATION OF k_{vo} WHEN DIRECT DATA ARE NOT AVAILABLE.

The bulk of the data on k_{vo} available in the literature is for various alcohols, esters and a few other organic compounds diffusing through air, CO_2 or H_2. Therefore for most cases of diffusion met with in rectification direct values of k_{vo} are not at present available. It is therefore necessary to attempt to find a generalization which will make possible the estimation of k_{vo} for a pair of substances, upon which data are lacking. It has been noted by Chang(16a) and Hanks(17) that k_{vo} is approximately proportional to $\frac{1}{\sqrt{M_A M_B}}$. The relationship $k_{vo} = \frac{B}{\sqrt{M_A M_B}}$ is therefore suggested. Table (/) gives the calculation of the constant B for the various ethers, esters and alcohols and also Water Vapor, Methane and Benzol diffusing through Air, H_2 and CO_2. A mean value of the constant $B = 3.42$ is found to have an average deviation from the mean of 12.7%. Therefore the equation

$$k_{vo} = \frac{3.42}{\sqrt{M_A M_B}} \quad \text{- - - - (16)}$$

is given as one method of estimating values of k_{vo}.

TABLE (1)

Determination of Constant, B in $k_{vo} = \frac{B}{\sqrt{M_A M_B}}$
Data from Landolt-Bornstein.

System A	B	k_{vo}	M_A	M_B	$\sqrt{M_A M_B}$	B	% Dev. from mean
Ethyl Ether	Air	0.0775	74.1	29	46.2	3.58	+4.66
	CO_2	.0552		44	57.1	3.15	-7.85
	H_2	.296		2.0	12.2	3.51	+2.52
Ethyl Acetate	Air	.0709	88.1	29	50.5	3.58	+4.66
	CO_2	.0666		44	62.3	4.15	+21.20
	H_2	.3729		2.0	13.3	4.95	+45.8
Ethyl Formate	Air	.0852	74.1	2.9	46.2	3.94	+15.2
	CO_2	.0572		44	57.1	3.27	-4.48
	H_2	.3357		2.0	12.2	4.10	+19.9
Ethyl Propionate	Air	.0631	102.1	29	54.4	3.44	+.06
	CO_2	.0450		44	67.0	3.02	-11.40
	H_2	.2373		2.0	14.3	3.39	-.09
Ethyl Valerate	Air	.0505	130.1	29	61.5	3.11	-9.1
	CO_2	.0366		44	75.8	2.77	-19.0
	H_2	.2050		2.0	16.1	3.30	-3.51
Ethyl Alcohol	Air	.1016	46.0	29	36.6	3.72	+8.77
	CO_2	.0685		44	44.9	3.07	-10.20
	H_2	.378		2.0	9.6	3.63	+6.14
Ethyl Alcohol	Air	.0994	46.0	29	36.6	3.63	+6.14
	CO_2	.0693		44	44.9	3.11	-9.05
	H_2	.3806		2.0	9.6	3.66	+7.02

Table (1) (Continued

System A	B	k_{vo}	M_A	M_B	$\sqrt{M_A \quad M_B}$	B	% Dev. from mean
Ethyl Iso- Butyrate	Air	.0552	116.1	29	58.0	3.20	-6.43
	CO_2	.0400		44	71.5	2.88	-15.80
	H_2	.2237		2.0	15.2	3.40	-0.06
N-Amyl Alcohol	Air	.0589	88.1	29	50.6	2.98	-12.88
	CO_2	.0422		44	62.3	2.63	-23.10
	H_2	.2351		2.0	13.3	3.12	-8.77
Amyl iso- Butyrate	Air	.0423	158.1	29	67.7	2.86	-16.38
	CO_2	.0308		44	83.4	2.57	-24.85
	H_2	.1694		2.0	17.8	3.02	-11.70
Amyl Propionate	Air	.0466	144.1	29	64.6	3.01	-11.70
	CO_2	.0341		44	79.6	2.72	-20.45
	H_2	.1891		2.0	17.0	3.22	-5.85
	Air	.0751	78.0	29	47.5	3.57	+4.38
	CO_2	.0527		44	58.5	3.09	-9.65
	H_2	.294		2.0	12.5	3.67	+10.72
N-Butyl Alcohol	Air	.0681	74.1	29	46.2	3.15	-7.89
	CO_2	.0476		44	57.1	2.72	-20.50
	H_2	.2716		2.0	12.2	3.32	-2.92
Acetic Acid	Air	.1061	60.0	29	41.7	4.43	+29.50
	CO_2	.0713		44	51.3	3.65	+6.73
	H_2	.4040		2.0	10.9	4.40	+28.70
N-Hexyl Alcohol	Air	.0499	102.1	29	54.4	2.72	-20.45
	CO_2	.0351		44	67.0	2.35	-31.30
	H_2	.1998		2.0	14.3	2.86	-16.40
Iso-Butyl Alcohol	Air	.0688	74.1	29	46.2	3.18	-7.02
	CO_2	.0483		44	57.1	2.76	-19.30
	H_2	.2771		2.0	12.2	3.35	-2.05

Table (1) (Continued)

System A	B	k_{vo}	M_A	M_B	$\sqrt{M_AM_B}$	B	% Dev. from mean
Methanol	Air	.1325	32.0	29	30.4	4.02	+17.55
	CO_2	.0880		44	37.5	3.30	-3.51
	H_2	.5001		2.0	8.0	4.00	+16.95
Propyl Alcohol	Air	.0803	60.1	29	41.7	3.35	-2.05
	CO_2	.0577		44	51.4	2.97	-13.15
	H_2	.3153		2.0	10.9	3.43	+0.03
Carbon Bisulfide	Air	.0883	76.1	29	47.0	4.24	+24.00
	CO_2	.0630		44	57.9	3.65	+15.50
	H_2	.369		2.0	12.3	4.54	+32.70
Water	Air	.198	18.0	29	22.8	4.51	+31.90
	CO_2	.132		44	28.2	3.72	+8.77
	H_2	.687		2.0	6.0	4.12	+20.45
Methane	CO_2	.146	16.0	29	21.7	3.17	-7.31
	H_2	.625		2.0	5.6	3.50	+2.34
Methyl Acetate	Air	.0840	74.1	29	46.2	3.86	+12.88
	CO_2	.0557		44	57.1	3.18	-7.01
	H_2	.3277		2.0	12.2	3.99	+16.65
					Mean=	3.42	Ave Dev. = 12.65

$$k_{vo} = \frac{3.42}{\sqrt{M_AM_B}}$$

If the data given in Table (1) are examined it is noted, as was shown by McAdams and Hanks(17), that for the various classes of compounds, e.g. alcohols, diffusing through a certain gas, as H_2, values of k_{vo} for the various alcohols were inversely proportional to the 3/4 power of M_A. Replacing the H_2 by Air, or CO_2 changes the proportionality constant in each case. McAdams and Hanks(17) suggest the equation

$$k_{vo} = \frac{b}{(M_A)^{.75}(M_B)^{.5}} \quad - - - (17)$$

in which A refers to the vapor (e.g. alcohol, ester, etc.) while B is the gas (e.g. Air, H_2, CO_2) in the various systems for which diffusion data are available. These authors report the following values of b.

System A	B	b	Ave. deviation %
Alcohols, 1 to 6 C atoms	Air, H_2 or CO_2	8.91	7.6
Water Vapor	Air, H_2 or CO_2	8.49	6.6
Esters	Air, H_2 or CO_2	10.1	8.4

Equation (17) thus represents the data satisfactorily for given types of vapor diffusing through Air, H_2 or CO_2.

In interpreting data to be presented on plate efficiencies obtained with different mixtures it will be necessary to estimate values of k_{vo} for mixtures of Alcohol-Water, Benzene-Toluene and CCl_4-Toluene. The extrapolations are here given affording a means of comparison of Equations 16 and 17.

1. Employing Equation 16: $k_{vo} = \frac{3.42}{\sqrt{M_A M_B}}$

   (a) Alcohol-Water: $k_{vo} = \frac{3.42}{\sqrt{18 \times 46}} = 0.1194$

   (b) Benzene-Toluene: $k_{vo} = \frac{3.42}{\sqrt{78 \times 92}} = 0.0405$

   (c) CCl_4-Toluene: $k_{vo} = \frac{3.42}{\sqrt{154 \times 92}} = 0.0287$

2. Using Equation 17: $k_{vo} = \frac{b}{(M_A)^{.75}(M_B)^{.5}}$

   (a) Alcohol-Water. Data available are

k_{vo} (Alc.-Air) = (.1016)ave (.0994)1005 k_{vo} (H_2O-Air) = 0.198

k_{vo} (Alc-CO_2) = (.0685)ave (.0693). 0684 k_{vo} (H_2O-CO_2) = 0.132

k_{vo} (Alc.-H_2) : (.378) ave. (.3806).3793 k_{vo} (H_2O-H_2) = 0.687

On the alcohol basis the values of b would be determined from the data on alcohol and Equation 17 applied replacing M_B by the molecular weight of water vapor.

Calculation of b (Alcohol basis)

System	k_{vo}	M_A	M_B	$b = k_{vo} M_A^{.75} M_B^{.5}$
Alcohol-air	0.1005	46	29	9.51
" CO_2	.0684	46	44	7.96
" H_2	.3793	46	2.0	24.6 (Rejected)
			Ave.	8.73

k_{vo}, alcohol-water (Alcohol basis):

$$k_{vo} = \frac{8.73}{(46)^{.75}(18)^{.5}} = 0.1170$$

Calculation of b: (Water basis)

System	k_{vo}	M_A	M_B	$b = k_{vo}\ M_A^{.75} M_B^{.5}$
Water-Air	0.198	18	29	9.29
" CO_2	.132	18	44	7.64
" H_2	.687	18	2.0	8.48
				Ave 8.47

k_{vo}, Alcohol-water (Water basis)

$$k_{vo} = \frac{8.47}{(18)^{.75}(46)^{.5}} = 0.1432$$

(b) Benzene-Toluene:

Data are available only on k_{vo} for Benzene vs. Air, H_2 and CO_2.

Calculation of b:

System	k_{vo}	M_A	M_B	$b = k_{vo}\ M_A^{.75} M_B^{.5}$
Benzene-Air	0.0751	78	29	10.64
" CO_2	.0527	78	44	9.19
" H_2	.294	78	2.0	10.95
				Ave. 10.3

k_{vo}, Benzene-Toluene:

$$k_{vo} = \frac{10.3}{(78)^{.75}(92)^{.5}} = 0.0408$$

(c) CCl_4-Toluene:

No values of k_{vo} for either component are available. Data for CS_2 are therefore used to compute b.

Calculation of b:

System	k_{vo}	M_A	M_B	$b = k_{vo}\ M_A^{.75} M_B^{.5}$
CS_2 - Air	0.0883	76.1	29	12.50
" - CO_2	.0630	76.1	44	10.78
" - H_2	.3690	76.1	2.0	13.72
				Ave 12.3

k_{vo}, CCl_4 - Toluene:

$$k_{vo} = \frac{12.3}{(154)^{.75}(92)^{.5}} = 0.0293$$

III E- FACTORS INFLUENCING THE GAS FILM THICKNESS

Inspection of Equations 7, 8, 9 and 10 shows a film thickness, X, to be involved. As the rate of material transfer for any fixed driving force is proportional to both k_m and 1/X it is desirable to summarize briefly the factors influencing X.

From both heat transfer and absorption data the factors influencing film thickness are found to include a shape factor for the apparatus, the turbulence of the fluid and the viscosity of the fluid in the film. Turbulence in a given type of apparatus is a function of the mass velocity of the fluid but the nature of the function changes for different types of apparatus, hence the shape factor differs. Assuming that for geometrically similar types of apparatus film thickness is defined by a function of a shape factor, the film fluidity and the mass velocity of the fluid, Greenawalt(20) has shown by dimensional analysis that, similarly to heat transfer,

$$\frac{X}{D} = \phi\left(\frac{Z}{Du\rho}\right)$$

For turbulent motion in heat transfer work it has been shown(21) that the function, ϕ, is represented by a power function of the modulus.

$$(18) \qquad \chi = a \quad D\left(\frac{z}{Du\rho}\right)^{n}$$

The constant, a, and the exponent, n, are characteristics of the type of apparatus and must be experimentally determined for each geometrically different type. n is approximately 0.8 for turbulent flow inside tubes.

IIIF - SUMMARY OF EQUATIONS FOR LIQUID FILM DIFFUSION

Application will be made of the gas film equations only, for reasons to be presently discussed. The liquid film equations are derived in a manner similar to that outlined for the gas film equations except that the partial pressure gradient, $\frac{dpA}{dx}$, is replaced by the concentration gradient, $\frac{dv_A}{dx}$, while the partial densities, d_A and d_B, refer to the liquid state. The integrated equations follow:

Equation for the rate of diffusion of 2 liquid components, A and B, through a liquid film.

$$(19)\quad N_A = \frac{1}{(B\ M_A d_B X')\left(1+\frac{M_B d_A N_B}{M_A d_B N_A}\right)} \ln \left[\frac{1-\left(1+\frac{M_B d_A N_B}{M_A d_B N_A}\right)V_{AL}}{1-\left(1+\frac{M_B d_A N_B}{M_A d_B N_A}\right)V_{Ai}}\right]$$

When one component, B, is stationary.

$$(20)\quad N_A = \frac{1}{B\ M_A d_B X'} \ln \frac{1 - V_{AL}}{1 - V_{Ai}}$$

If V_A is small compared unity equation (20) becomes:

$$(21)\quad N_A = \frac{1}{d_A d_B B\ X'}(C_{Ai} - C_{Ag})$$

If the gas film is absent an equation similar to 21 is obtained from (20)

$$(22)\quad N_A = \frac{1}{B\ M_B d_A m_{X'}}(C_{ag} - C_{AL})$$

Equations 7, 8, 9, 10 and 19, 20, 21, 22 are for steady conditions, i.e., the values of the driving forces, partial pressures or concentrations, do not change with respect to time. To apply these equations to actual equipment such as absorption towers or plate rectifying columns it is necessary to integrate them for the conditions involved or to introduce the proper average values of the driving forces.

IV -DERIVATION OF EQUATIONS

IV-A- INTRODUCTORY:

Granting that rectification must be inherently a diffusional process it is evident that any mathematical treatment must be based upon the fundamental laws of diffusion. In applying the film diffusion equations of Chang(16) and Hanks(17) to the present purpose two objectives were borne in mind:

1. The relations should be capable of interpretation in terms of experimental rectification data.
2. The equations obtained should permit of sufficient simplification to make them readily applicable for engineering purposes.

In rectification as carried out in plate columns bubbles of vapor pass up through a depth of liquid on each plate. Conditions on a plate are always such that the vapor entering the plate is leaner in the more volatile constituents of the mixture and richer in the less volatile than would correspond to equilibrium with the liquid on that plate. Furthermore, if the column is in continuous, balanced operation the composition of the liquid on any plate is fixed. During the bubble passage material transfer between the

the vapor and liquid takes place causing the vapor to emerge from the liquid enriched in the more volatile materials, and stripped of a portion of the less volatile. On any single plate the process is thus continuous with respect to the liquid but batch with respect to the vapor.

It was noted by Lewis and Whitman(22) that gas bubbles passing through a liquid furnish a case in which the film on the liquid side of the interface would tend to be very thin due to the shearing action to which such a film would be subjected during the progress of the bubbles. On the other hand the vapor in a bubble would be subjected to little disturbance tending to cause turbulence. Therefore when material interchange takes place between vapor in a bubble and a liquid, conditions favor a small or negligible liquid film resistance compared with that of the vapor film. On the plate of a rectifying column agitation is usually very thorough tending to cause considerable bubble deformation which in turn favors further thinning of the liquid film. In addition to these effects, the fact that the liquid on any plate of a column is at or near its boiling point and that materials subjected to rectification are usually ones completely soluble in one another also tend to cause low liquid film resistance. In view of these considerations the working hypothesis was adopted that in plate rectification the resistance of the liquid film is negligible compared with that of the gas film.

Concurrently with the material transfer involved in rectification there must be a latent heat interchange taking place at the liquid-vapor interface. The less volatile material condenses continuously and the latent heat so liberated must be absorbed by the evaporation of an amount of the more volatile sufficient to absorb this heat quantity if the temperature conditions are steady at any given point in the process. This means that the ratio of the molal rates of transfer of the two components in a binary mixture must be defined by a latent heat balance, i.e., (neglecting changes in sensible heat)

$$Mr_A N_A = - Mr_B N_B$$

$$\text{or} \quad \frac{N_A}{N_B} = - \frac{Mr_B}{Mr_A} \qquad \text{------} \quad (23)$$

IV-B -DERIVATION OF EQUATIONS FOR THE RECTIFICATION OF A BINARY MIXTURE IN A PLATE COLUMN.

Summary of Assumptions:

1. Rectification in plate columns is a process in which the gas film is the controlling resistance to diffusion.
2. On any plate of a column mixing is so thorough that the plate liquid composition is constant throughout and

equal to that of the overflow from the plate.

3. Sensible heat changes are negligible compared with latent heat changes.

4. The heat of mixing of the components is negligible.

5. Heat losses from the column are negligible.

Case I - The molal latent heats of the two components, A and B, are equal, i.e. $N_A = - N_B$.

Consider a bubble of vapor rising through the liquid on the nth plate of a continuous rectifying column. Calling V' the mols of vapor contained in the bubble and S its interfacial area it is obvious that:-

$$\frac{d(V'y)}{S\ d\ \theta} = N_A \text{ - - - - - - - - - } (24)$$

For this case Equation 8 expresses N_A for point conditions. Therefore

$$\frac{d(V'y)}{S\ d\ \theta} = \frac{k_m}{X\pi} (p_{Ai} - p_{Ag}) \text{ - - - - } (25)$$

By assumption 1 p_{Ai} equals the partial pressure of A in the vapor which would be in equilibrium with the liquid on the plate. Calling this value p_A*, $pAi = p_A*$. By Dalton's Law $p_A* = \pi y*$ and $p_{Ag} = \pi y$. V' is obviously a constant. Neglecting the effect of the small hydrostatic pressure change on S, there results:

$$\frac{dy}{y* - y} = \frac{k_m S}{xV'} d\theta \text{ - - - - - - - } (26)$$

If the mol fraction of the more volatile component in the vapor entering the nth plate is called y_{n-1} while that in the vapor leaving the nth plate is denoted by y_n, and the total time of liquid-vapor contact of the bubble, θ, Equation 26 may be integrated between the limits noted:

$$\int_{y_{n-1}}^{y_n} \frac{dy}{y_* - y} = \frac{k_mS}{x\ V'}\int_{0}^{\theta} d\theta \qquad - - - \quad (26a)$$

Performing the integration there results:

$$\ln \left\{ \frac{y_n^* - y_n}{y_n^* - y_{n-1}} \right\} = - \frac{k_mS\theta}{x\ V'}$$

which may be written as

$$\frac{y^* - y_n}{y_n^* - y_{n-1}} = e^{-\frac{k_mS\theta}{X\ V'}}$$

Subtracting unity from both sides and transposing:

$$\frac{y_n - y_{n-1}}{y_n^* - y_{n-1}} = 1 - e^{-\frac{k_mS\theta}{X\ V'}} \qquad - - - \ (27)$$

(This method of derivation is similar to that originally given by Murphree(12) except for differences in the definitions of the terms S and V' and the employment of the rigorous gas film diffusion equation applying to this case).

Equation (27) may be written, calling $1 - e^{\frac{-k_m S\theta}{X\,V'}} = E_M$

$$y_n = E_m\, y^*_m + (1-E_M)\, y_{n-1} \quad - - - \quad (28)$$

which is identical with Equation (G) given previously.

Case II - The molal latent heats of the two components, A and B, are not equal. By Equation 23, $\frac{N_A}{N_B} = -\frac{Mr_B}{Mr_A}$. If V' is called in this case the average mols of vapor per bubble during its rise through the liquid and S the average interfacial area of contact, as in Case I:

$$\frac{V'\,dy}{S\,d\,\theta} = N_A \quad - - - - \quad (29)$$

For this case however, Equation 7 defines N_A for point conditions. Employing Equation 7 and noting that

$\frac{N_A}{N_B} = -\frac{Mr_B}{Mr_A}$, $\frac{p_{Ai}}{\pi} = y_A{}^*$, $\frac{p_{Ag}}{\pi} = y$:

$$\frac{V'dy}{Sd\theta} = \frac{k_m}{X} \left(\frac{1}{1 - \frac{Mr_A}{Mr_B}}\right) \ln\left[\frac{1-\left(1-\frac{Mr_A}{Mr_B}\right)y^*}{1-\left(1-\frac{Mr_A}{Mr_B}\right)y}\right] \quad - - - \quad (30)$$

Transposing and placing the same limits on the integration as in Case I:

$$\int_{y_{n-1}}^{y_n} \frac{dy}{\ln\left[\frac{1-\left(1-\frac{Mr_A}{Mr_B}\right)y^*}{1-\left(1-\frac{Mr_A}{Mr_B}\right)y}\right]} = \frac{k_m}{X} \left(\frac{S}{V'}\right)\left(\frac{1}{1-\frac{Mr_A}{Mr_B}}\right) \int_0^{\theta} d\theta \quad - - \quad (30a)$$

The left-hand side of Equation 30a is not directly integrable. By the following treatment however it can be thrown into a form for which integrated values have been obtained and are available.

For simplification let $\frac{1}{1 - \frac{Mr_A}{Mr_B}} = C$

Then $\int_{y_{n-1}}^{y_n} \frac{dy}{\ln \frac{c-y^*}{c-y}}$ is the form to be integrated.

Let $\ln \frac{c - y^*}{c - y} = z$

$$\frac{c - y^*}{c - y} = e^{z}$$

$$dz = \frac{1}{\frac{c - y^*}{c - y}} \frac{(c - y^*)\, dy}{(c - y)^2} = \frac{dy}{c-y}$$

$$c - y = \frac{c - y^*}{e^{z}}$$

$$dz = \frac{e^{z}}{c - y^*}\, dy$$

$$dy = \frac{c-y^*}{e^{z}}\, dz$$

Substituting,

$$\int_{y_{n-1}}^{y_n} \frac{dy}{\ln \frac{c - y^*}{c - y}} = \int_{\lim z_1}^{\lim. z_2} \frac{(c - y^*)\, dz}{e^{z}\, z} = (c-y^*)\int_{\lim. z_1}^{\lim z_2} \frac{e^{-z}\, dz}{z}$$

$\text{limit } z_1 = \ln \frac{c - y^*}{c - y_{n-1}}$ and

$\text{limit } z_2 = \ln \frac{c - y^*}{c - y_n}$

The integral $\int_{\infty}^{-x} \frac{e^{-u} du}{u}$ has been evaluated by

Jahnke and Emde[(23)] and termed EiX. Values of EiX for various values of X are plotted in Figure (2) for ready interpolation. It follows that

$$\int_{-X_1}^{-X_2} \frac{e^{-u}\,du}{u} = EiX_2 - EiX_1$$

Applying to the left-hand side of Equation 30a=

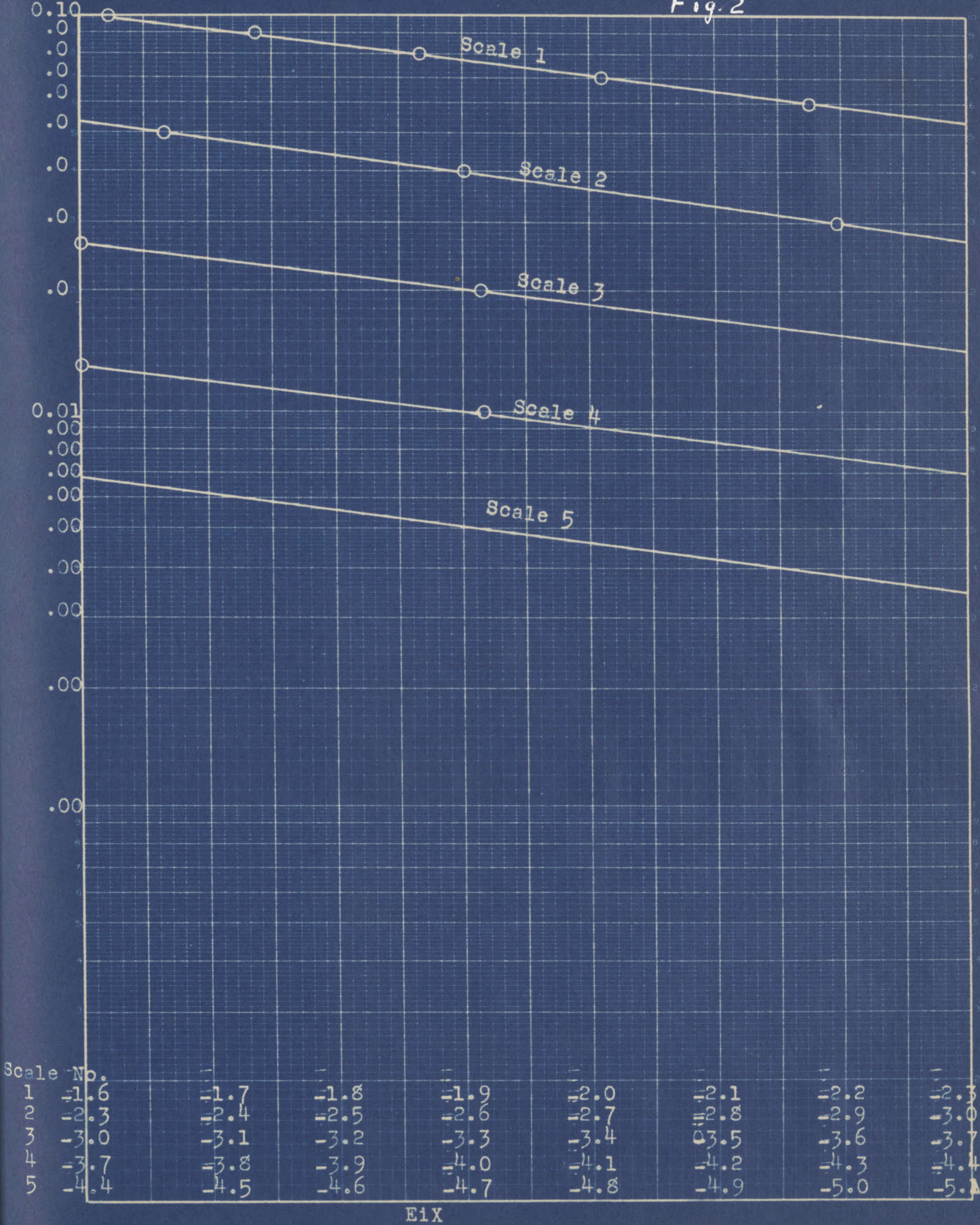
$$\int_{y_{n-1}}^{y_n} \frac{dy}{\ln\left[\dfrac{1-\left(\frac{Mr_A}{Mr_B}\right)y^*}{1-\left(\frac{Mr_A}{Mr_B}\right)y}\right]} = \left(\frac{1}{1-\frac{Mr_A}{Mr_B}} - y^*\right)\left[Ei\left(-\ln\left\{\frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}}\right\}\right) - Ei\left(-\ln\left[\frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_{n-1} - \frac{1}{1-\frac{Mr_A}{Mr_B}}}\right]\right)\right]$$

Equation 30a may be rewritten in integrated form as:

$$\left\{\frac{\frac{1}{1-\frac{Mr_A}{Mr_B}} - y^*}{\frac{1}{1-\frac{Mr_A}{Mr_B}}}\right\}\left[Ei\left(-\ln\left[\frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}}\right]\right) - Ei\left(-\ln\left[\frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}}\right]\right)\right] = \frac{k_m S\theta}{X\ V'} \qquad - - (31)$$

Thus while for the case of unequal molal latent heats no simple definition of plate efficiency may be given, Equation 31 permits the evaluation of the term $\frac{k_m S\theta}{X\ V'}$

Fig. 2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Scale No.
1 -1.6 -1.7 -1.8 -1.9 -2.0 -2.1 -2.2 -2.3
2 -2.3 -2.4 -2.5 -2.6 -2.7 -2.8 -2.9 -3.0
3 -3.0 -3.1 -3.2 -3.3 -3.4 -3.5 -3.6 -3.7
4 -3.7 -3.8 -3.9 -4.0 -4.1 -4.2 -4.3 -4.4
5 -4.4 -4.5 -4.6 -4.7 -4.8 -4.9 -5.0 -5.1
EiX

which is the exponential equivalent of plate efficiency.

IV-C - APPLICATION OF GAS FILM DIFFUSION EQUATION TO CONTINUOUS STEAM DISTILLATION IN STEAM STILL.

Consider a steam still in which bubbles of steam are blown through a mixture of a volatile material with a nonvolatile one. The steam entering contains no volatile material while it leaves carrying with it a partial pressure of the volatile determined by the nature of the materials and the conditions of the distillation.

Case I: The materials in the still are immiscible with water. Assume that the latent heat of vaporization of the volatile material is supplied by a source other than by condensation of a portion of the open steam. Assume further that the amount of volatile picked up by the steam is small so that average values of V' and S may be employed. Employing the five general assumptions noted on page (45) suitably modified in terminology and applying the same concepts made use of in the derivation of the Rectification Equations one can write:

$$\frac{V'dy}{Sd\theta} = N_A \quad - - - - (32)$$

N_A for this case is defined for point conditions by Equation (10) derived for the case of 1 component stationary. Employing Equation (10) and recalling that $p_{Ai} = \pi y^*$ and $p_{Ag} = \pi y$

$$\frac{V'dy}{Sd\theta} = \frac{k_m}{X} \left(\frac{1}{p_{Bave}}\right) (y^* - y) \text{ - - - - - -(33)}$$

Upon integration of (33) between the limits y = 0 to $y = y_s$ and 0 to θ there is had:

$$\ln \frac{y^* - y_s}{y^*} = - \frac{k_m S\theta}{X\ V'} \left(\frac{1}{p_{B\ ave}}\right) \text{ - - - -(34)}$$

Or, writing in exponential form

$$\frac{y^* - y_s}{y^*} = e^{\frac{-k_m S\theta}{X\ V'} \left(\frac{1}{p_{Bave}}\right)} \text{ - - - (35)}$$

Defining efficiency of steam distillation as follows,

$$1 - E_v = \frac{y^* - y_s}{y^*}$$

$$E_v = \frac{y_s}{y^*} = \frac{p}{p^*} = 1 - e^{\frac{-k_m S\theta}{X\ V'} \frac{1}{p_{B\ Ave}}} \text{ - - - (36)}$$

Equation 36 is identical with the "Vaporization Efficiency" used in Steam Distillation. Hence an exponential term contains the factors which may be expected to influence Vaporization Efficiency.

Case II: The materials in the steam still are miscible with water. In this case water may be expected to pass from the steam to the liquid and condense. A case of two components diffusing in opposite directions through a film is then had. Assuming for simplification that the molal latent heats of the steam and volatile material are equal, Equation 26 may be integrated between the limits $y = 0$ and $y = y_s$, giving:

$$\ln \frac{y^* - y_s}{y^*} = - \frac{k_m S \theta}{X\ V'} \qquad - - - - - (37)$$

Or writing in exponential form

$$\frac{y^* - y_s}{y^*} = e^{\frac{-k_m S \theta}{V'}} \qquad - - - - - - (38)$$

$$\text{Therefore } E_v = \frac{y_s}{y^*} = \frac{p}{p^*} = 1 - e^{\frac{-k_m S \theta}{V'}} \quad - - - (39)$$

IV-D - INTEGRATION OF NEWTON'SLAW FOR TRANSFER OF SENSIBLE HEAT FROM A BUBBLE OF VAPOR TO THE LIQUID ON A PLATE:

In addition to previous terminology, M_c, denotes the molal specific heat of the vapor, t_L, the plate liquid temperature, t_1, the temperature of vapor entering the plate, t_2 the temperature of vapor leaving and H the coefficient of sensible heat transfer vapor to liquid.*

$$- \frac{M_c V' dt}{d\,\theta} = H\ S\ (t - t_L)$$

$$\int_{t_1}^{t_2} \frac{dt}{t - t_L} = \frac{H\ S}{M_c V'} \int_{o}^{\theta} d\theta$$

Integrating

$$\ln \frac{t_1 - t_L}{t_2 - t_L} = \frac{H\ S\ \theta}{M_c V'}$$

$$\frac{t_2 - t_L}{t_1 - t_L} = e^{\frac{-HS\theta}{M_c V'}} \qquad - - - - - - (40)$$

*Constancy of M_c, V', H and S are assumed

Calling "temperature efficiency", E_T, equal to $\frac{t_1 - t_2}{t_1 - t_L}$,

$$E_T = \frac{t_1 - t_2}{t_1 - t_L} = 1 - e^{-\frac{HS\theta}{M_cV'}} \quad - - - - (41)$$

Equations 40 and 41 are identical with that found by Walker, Lewis and McAdams(9) for adiabatic dehumidification.

IV-E - DIMENSIONAL EXAMINATION OF EFFICIENCY:

From Equation 27, $E_M = 1-e^{\frac{-k_mS\theta}{X\ V'}}$

Efficiency is a dimensionless quantity hence the term $\frac{k_mS\theta}{X\ V'}$ should be shown to be dimensionless.

Dimensionally:

$$\frac{k_mS\theta}{X\ V'} = \frac{(\text{gm. mols})(\text{cm})}{(\text{sec.})(\text{cm})^2} \Bigg| \frac{}{\text{cm.}} \Bigg| \frac{(\text{cm})^2}{} \Bigg| \frac{(\text{sec})}{(\text{gm.mols})}$$

The terms on the right all cancel which shows the group to be dimensionless.

For the values of E_M to approach unity, $\frac{-k_mS\theta}{X\ V'}$ must approach minus infinity. This will be realized only for an infinite value of k_m, an infinite time of contact, θ, infinitely small bubbles or an infinitely thin film.

V- METHODS OF APPLYING DERIVED EQUATIONS

Equations 28, 31, 36, and 39 have been derived for the several cases of rectification and steam distillation. These equations may be utilized for two purposes:

1. Calculation of plate efficiency, or its equivalent, from experimental data.

2. Granted the existence of data enabling the efficiency , or its equivalent, to be estimated the equations may be directly applied to column or still design.

V-A - CALCULATION OF PLATE EFFICIENCIES OR THEIR EQUIVALENTS:

(a) By use of Equation (28): For this purpose the equivalent form of Equation (28) may be conveniently used

$$E_M = \frac{y_n - y_{n-1}}{y_{n*} - y_{n-1}}$$

By inspection it is seen that data giving the compositions of the vapor entering and leaving the plate, together with the composition of the plate liquid are the quantities it is necessary to determine. It is also necessary to have available liquid-vapor equilibrium data.

In a column under actual operating conditions, measurement of the liquid compositions on two adjacent plates together with a knowledge of the relative amounts of the overflow, vapor, and product or waste stream enable y_{n-1} and y_n to be computed. Consider the nth and n+ 1th plates of a column continuous operation. Assume the values of x_n and x_{n+1} have been measured, and the relative quantities of O, V and P are known. Material balances, $V_{n-1}y_{n-1} = O_nx_n+Px_c$ and

$$V_n y_n = O_{n+1} x_{n+1} + Px_c$$ enable

y_{n-1} and y_n respectively to be calculated.

It has been found in calculation of actual column data that the efficiencies of individual plates computed in this way vary rather widely (e.g. ± 15-20%) from a mean value for the efficiency of the column as a whole. However if the Murphree Equation (28) be applied in conjunction with the necessary material balances, by assuming values for the efficiency term, E_M, and calculating up or down the column, by trial and error a value of E_M will be found which enables the actual measured compositions on each plate to be calculated. This method is recommended for the determination of the plate efficiency of an operating column.

(b) Application of Equation 31: It will be recalled that for the case of unequal molal latent heats no simple definition of efficiency is possible but that evaluation of the term $\frac{k_m S\theta}{X V'}$ can be carried out from experimental data. In general, the same quantities must be determined as in the application of Equation 28. In addition a knowledge of the molal latent heat ratio is necessary in this case.

(c) Use of Equations 36 and 39 for Steam Distillation: Inspection of these equations indicates that the molal ratio of steam to volatile vapor must be determined and data on the liquid-vapor equilibrium relationship of the liquid mixture being subjected to steam distillation must be known.

V-B - APPLICATION OF EQUATIONS TO DESIGN IF EFFICIENCIES FOR THE CONDITIONS IMPOSED ARE KNOWN OR CAN BE ESTIMATED:

(a) Application of the Murphree Equation (28). The general method of application of this equation in conjunction with material balances if the efficiency term is known has already been discussed in the section on General Methods of Computation, p.p. (12-21).

(b) Application of Equation 31: If the term $\frac{k_m S\theta}{X V'}$ is known Equation 31 may be used similarly to the

Murphree Equation. A trial and error solution is necessary in the calculation of each step or plate.

Consider the nth plate in a continuous column. Assume $y_n - 1$ is known. x_n may then be computed by applying a material balance:

$$V_{n-1}\, y_{n-1} = O_n\, x_n + P_{xc}$$

The determination of x_n fixes y_n^* from the liquid-vapor equilibrium. Inspection of Equation 31,

$$\left(\frac{\frac{1}{1-\frac{Mr_A}{Mr_B}} - y^*}{\frac{1}{1-\frac{Mr_A}{B}}} \right) \left[Ei \left(-\ln \left[\frac{y_n^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}} \right] \right) - Ei \left(-\ln \left[\frac{y_n^* \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_{n-1} \frac{1}{1-\frac{Mr_A}{Mr_B}}} \right] \right) \right] = \frac{k_m S \theta}{X\, V'}$$

shows that various values may then be assigned to y_n until the numerical value of the left-hand side of the equation equals that of the right, fixed by previously determined data.

VI - SUMMARY OF EXPERIMENTAL WORK

The experimental work to be described in the following sections was undertaken to investigate the effect of various factors which may be expected to influence plate efficiency. The studies were confined to binary mixtures in order to provide a firm foundation for future work with mixtures of greater complexity. The work may be grouped in four major divisions.

A. Runs with seven plate column:

The initial experimental work consisted of a series of runs made with a seven plate column of semi-commercial size. These data will be utilized to discuss or show the following:

1. A comparison of Sorel (basis of theoretical plate), Murphree plate to plate and Murphree overall efficiencies.

2. The effect of vapor velocity upon plate efficiency in the range 0.25 to 1.7 ft. per second superficial vapor velocity.

3. The effect of different components on plate efficiencies, CCl_4-Toluene compared with Benzene-Toluene.

4. Actual plate liquid temperatures compared with theoretical boiling temperatures.

5. Overall coefficient of heat transfer from steam in closed coil to boiling organic liquids.

B. Runs with single plate column.

Following the work upon the seven plate column, a single plate column reproducing one plate of an actual column was designed and built. A long series of runs were carried out, resulting in data which may be used to show:

1. The effect of concentration of components on plate efficiency.

2. The influences of cap slot width and depth of immersion of cap slots.

3. The effect of the nature of components on plate efficiency: alcohol-water compared with Benzene-Toluene.

4. Effect of vapor velocity at low vapor rates (.026 to .2 ft./sec. superficial vapor velocity). Rectification secured with no bubbling action and zero cap slot immersion.

5. Effects of vapor velocity at higher ranges (.2 to .55 ft/sec. superficial vapor velocity).

6. Comparison of efficiencies obtained with differing numbers of slots per cap all of same with. (Variable free area through slots.)

7. Comparison of triangular with rectangular slots.

8. Experimental results on temperature drop (sensible heat loss) of vapor passing through a plate and comparison with plate efficiency.

C. Measurements of spraying and pressure drop effects obtained by blowing air through a bubble cap immersed in water. Data shows:

1. Grams of water per minute per sq. ft. thrown up as spray at several heights above the liquid.

2. Overall pressure dropsthrough a bubble cap and pressure drops through the cap slots.

3. A motion picture record of the effects of different air rates on bubble cap action. was made.

D. Data required in carrying out the major problems.

1. Experimental verification of Benzene-Toluene boiling point curves.

2. Specific gravity - composition curves for analysis of CCl_4 - Toluene mixtures.

3. Determination of equilibrium (y vs. x) diagram for CCl_4 - Toluene mixtures.

4. Determination of equilibrium diagram for Alcohol-Water mixtures.

VII- GENERAL DISCUSSION OF EQUIPMENT, MATERIALS AND TECHNIQUE.

The general nature of the equipment and technique employed and considerations governing the choice of mixtures used will be briefly treated at this point as an introduction to the discussion of results which will be taken up in the following sections. Detailed descriptions of the several pieces of apparatus, manipulation, and analytical procedures may be found in the Appendix.

The seven plate column with which a portion of the rectification data was obtained consisted of plate sections of 8-inch standard pipe, joined by flanges. The plate sections were 12"/4 inches high and each plate was fitted with one 4-inch Badger bubble cap*. The height of the overflow pipes was such that the depth of immersion of the top of the cap slots was 1/8", excluding the height of the liquid weir. Heating of the liquid in the still was by means of steam condensing in a closed coil. The vapors passed to a total condenser from which they were returned as liquid reflux through a trap to the top plate of the column, i.e., the operation was at total reflux, introducing no feed and with-

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*For dimensions of cap see p. 178.

drawing no product or bottom streams. The column was well lagged with magnesia lagging. Heat input to the still was measured by collecting and weighing the condensate from the steam coil. For the runs in which reliable condenser data were obtained a heat balance was made on the column and the magnitude of the heat loss thus determined. Thermometers set into wells in the plate sections permitted plate temperatures to be read. Sample pipes were provided to obtain samples of the various plate liquids as well as of the bottoms and reflux during each run.

The general method followed in the operation of the seven plate column was to bring it to steady operating conditions, as determined by constancy of plate temperature readings, by holding the steam pressure in the coil steady. This usually required about forty minutes. Samples were not taken until conditions had remained constant for approximately one hour. During this period the data necessary for the heat balance were obtained. The data obtained as a result of runs with this apparatus consisted of:

1. Steam pressure and temperature.

2. Weight of steam condensate over a measured time interval.

3. Temperature rise of cooling water.

4. Weight of cooling water through condenser over a measured time interval.

5. Temperatures on the several plates.

6. Analyses of samples taken of the liquids from the plates, reflux and still.

The single plate column, developed in order to study the influence of certain factors such as bubble cap design and slot immersion, consisted of a boiler, or still, the plate section and vertical total condensers. The plate section was of sheet copper, cylindrical in shape, 6 inches in diameter and 10 inches high. A vapor riser of 1-inch standard pipe introduced the vapor from the still underneath the single bubble cap on the plate. A series of interchangeable bubble caps with varying slot widths were provided. An overflow pipe, adjustable in height returned liquid overflow from the plate section to the still. The top of the plate section was bolted in place through a gasket to permit its removal for interchange of the bubble caps and adjustment of the overflow pipe. Vapor from the plate section passed through a vapor take-off, located at the side of the chamber near the top, to vertical reflux condensers which returned all condensate as reflux to to the plate section through a trap. Operation of this apparatus was thus also based upon the principle of total reflux. Sample pipes suitably located permitted samples of plate liquid and of reflux to be obtained. Heat loss from the apparatus was reduced to a negligible quantity by an insulation of magnesia lagging upon which was wound an electric heating element followed by another layer of lagging. The lagging temperature could thus be maintained at a temperature very close to that obtaining inside the apparatus. Temperatures of the vapor leaving the plate, or in certain runs both liquid and vapor temperatures, as well as lagging temperatures could be read by means of thermometers. Heating of the still was by means of electric immersion heaters thus permitting close control and accurate measurement of the heat input.

Operation of the single plate column consisted of a warming up period during which the apparatus was brought up to steady operating conditions at the desired distillation rate, governed by the rate of heat input. Conditions were considered satisfactory when the plate temperature, liquid or vapor, remained constant and the lagging temperatures closely approached the respective temperatures inside the still and plate sections. Conditions were maintained constant in most of the runs for approximately 1 hour before samples were withdrawn. Samples of plate liquid and reflux were taken simultaneously, a time study showing the time required for actual withdrawal of samples was from three to five seconds. Data obtained were:

1. Heat input to still measured electrically.
2. Plate liquid or vapor temperatures, or both.
3. Temperatures in the lagging around the plate section and still midway between the heating elements and the walls of the apparatus.
4. Height of the liquid overflow pipe and cap slot width employed during the run.
5. Analyses of liquid and reflux samples.

The principle of operation of a column at total reflux originally suggested by Professor W. H. McAdams was employed throughout this work. This greatly simplifies operation and has the following advantages for experimental work:

1. Steady operation with regard to material flow can be secured if the heat input to the still and the condenser cooling water rate are maintained constant. In a column to which feed is introduced continuously and product and waste streams are withdrawn, true continuous operation at any instant is had only if these three streams

are exactly balanced, e.g.

Feed = Product + Waste.

Variations in one or more of these streams together with changes in the rate of heat input undoubtedly explain the difficulty in some cases of securing good material balances from tests of plant equipment.(24.) If the scale of the operation is reduced to laboratory size these problems become more serious. With operation at total reflux, however, constancy of heat supply remains as the chief requisite to the attainment of steady conditions. To the close regulation possible with electric heating is attributed the consistently reproducable results obtained with the single plate column.

2. A second and minor advantage of operation at total reflux is that calculations are greatly simplified. If a material balance is drawn around the nth plate section cutting the vapor streams from the n-1th plate and the overflow returning to the (n-1)th plate, of necessity:

$$V_{n-1} = O_n$$

A balance on the more volatile component requires that

$$V_{n-1}\, y_{n-1} = O_n\, x_n \text{ or } y_{n-1} = x_n$$

In terms of the McCabe-Thiele diagram, the operating lines thus coincide with the 45° line.

Operation attotal reflux in no manner alters the factors influencing plate efficiency, however defined. It should be noted that earlier writers on rectification, particularly Mariller(25) confuse degree of separation with the efficiency of a column. Degree of separation however depends both upon the reflux ratio and the plate efficiency.

Several requirements govern the choice of mixtures for experimental studies in rectification:

1. The liquid-vapor equilibria relationships for all mixtures of the components must be accurately known.

2. The mixtures should lend themselves to rapid and accurate analysis.

3. The relative volatilities of the components should be such that a fairly wide degree of separation in each step of the rectification is possible. (E.g. CCl_4 and Benzene, boiling points at 1 atmosphere being 76°C and 80°C, respectively, were not considered suitable for the present purpose whereas CCl_4 and Toluene mixtures covering the range of atmospheric boiling points from 76°C to 110°C were satisfactory).

4. The temperature level of the rectification, governed by the vapor pressure of the mixtures employed,

should be neither too high nor too low to avoid experimental complications.

5. Latent heat of vaporization data for the components of a mixture should be available.

6. The materials should preferably be noncorrosive.

These requirements were fairly satisfactorily met by the three binary mixtures chosen, viz. Benzene-Toluene, CCl_4-Toluene and Alcohol-Water. In each case however the liquid-vapor equilibria was investigated. In the case of Benzene-Toluene mixtures data in the literature(26) as well as experimental boiling point determinations showed that these materials followed Raoult's Law closely. For Carbon Tetrachloride-Toluene mixtures no equilibrium data were available. An experimental determination of the equilibrium (y vs. x) diagram showed the assumption of Raoult's Law for these mixtures to be inaccurate. Examination of the literature revealed several sets of data on Alcohol-Water liquid-vapor equilibria, none of which agree closely. Consequently an experimental set of y-x values, which is believed to accurately represent the true y-x curve, was determined. Determinations of the equilibrium data will be fully treated in Section (X).

The method of analysis employed with the Benzene-Toluene mixtures was by observation of the boiling point of the same under barometric pressure and reference to experimentally verified boiling point curves. The alcohol-water mixtures were analyzed by specific gravity determinations making use of the published specific gravity data for these mixtures. In the case of CCl_4-Toluene mixtures analysis by specific gravity is especially good due to the wide difference in the specific gravities of CCl_4 and Toluene. An experimental curve of composition versus specific gravity at several different temperatures was determined for these mixtures.

VIII - RESULTS AND DISCUSSIONS OF PLATE EFFICIENCY STUDIES.

A. EFFECT OF VAPOR VELOCITY:

1. Results obtained with seven plate column.

Results of runs made with Benzene-Toluene mixtures in the seven plate column at superficial vapor velocities varying from 0.25 to 1.65 ft. per second are shown in Figure (3), in which E_M the overall Murphree plate efficiency required to trace the benzene concentration through the column, is plottedagainst the superficial vapor velocity. Examination of Figure (3) shows efficiency to be independent of vapor velocity in this apparatus over the range from 0.25 to slightly over 1 ft. per second. The several runs reported at vapor velocities greater than 1 ft. per second indicate an increase in efficiency with vapor velocity in this range.

From Equation 27, $E_M = 1 - e^{\frac{-k_m S\theta}{X\,V'}}$. Of the factors influencing efficiency k_m can be safely considered constant. While the composition of the plate liquids and hence the plate temperatures varied from run to run the widest variation in the overall average of the column temperatures was 10°C. For given components temperature is the only factor influencing k_m. A numerical illustration of the theoretical influence of

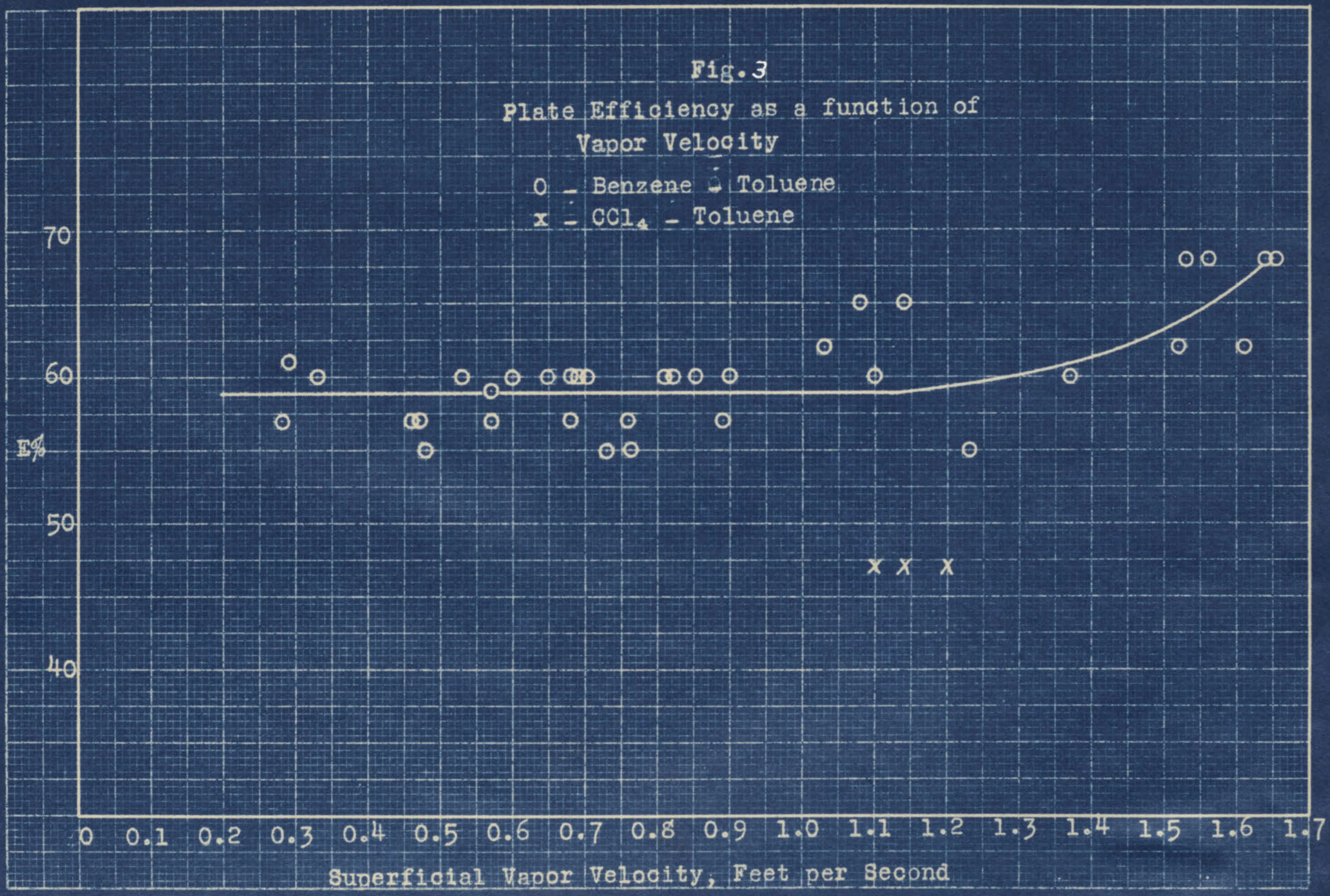


Fig. 3

Plate Efficiency as a function of Vapor Velocity temperature differences in these runs can be given as follows: Assume an efficiency, E_M, of 0.57 is obtained at a temperature of 95°C. To determine the extent to which the efficiency will be affected by a drop in temperature to 85°C considering only a change in k_m, Equation 27, rearranging and taking the logarithms of both sides, may be written as:

$$\log (1 - E_M) = - \frac{1}{2.3} \frac{k_m S \theta}{X V'}$$

$$\text{But } k_m = \frac{k_{vo}}{22400} \frac{T}{T_o}$$

$$\frac{\log (1 - .57)}{\log (1 - E_{m850})} = \frac{368}{358}$$

$$\log (1 - E_{M850}) = .356$$

$E_{M850} = 0.56$ or a difference of 0.01 in efficiencies which is within the experimental error of these runs.

Examining the remaining terms of the group an explanation for the constancy of the ratio $\frac{S\theta}{X V'}$ over the range in vapor velocity covered by the flat portion of the curve of Figure (37) is necessary to justify the results on a theoretical basis.

It will be noted that the ratio of S, the interfacial area per bubble, to the mols of vapor per bubble can be interpreted as the reciprocal of the mean effective diameter of the bubble stream. It is desirable therefore to consider if bubble size may be expected to change appreciably with vapor rate through the cap. Harkins and Brown(27) rederive the expression for the disengaging weight of a drop of liquid formed on the end of a dropping tip and give the following relation:

$W = 2\pi r\gamma \; \psi\left(\frac{r}{l}\right)$ in which W is the disengaging weight of the drop, r the radius of the tip, γ the surface tension of the liquid and l a linear dimension of the drop. The term $\psi\left(\frac{r}{l}\right)$ is thus a shape factor correction. Applying this relation qualitatively to the formation of bubbles from an orifice under the surface of a liquid the term W must be interpreted as the difference in weight between the displaced liquid and the vapor in a bubble. If the radius and shape factor of the submerged orifice from which the bubble emerges do not change, increase in rate of bubble formation might be expected to decrease the size of bubbles formed due to a crowding effect preventing the bubbles attaining full growth before disengaging. However, in the case of a bubble cap the amount of opening in the slots is a function of the rate of vapor passage through the cap, the greater the vapor rate, the lower the liquid level inside the cap and the greater the slot opening. Experiments in which air was blown through a bubble cap immersed in water showed the slot opening to be a power function of the vapor rate. This will obviously increase the "r" term in the formula of Harkins and Brown, and also alter the shape factor, the effect of these changes pointing to larger bubble size. An additional influence upon bubble size in the case of the Badger caps used in the seven plate column is that the slots were cut at an angle of 45° to the periphery of the cap. A motion picture study of one of these caps through which air was blown at various rates while the cap was immersed in water showed these caps to produce a pronounced rotary agitation of the liquid especially at the higher vapor rates. The net effect of these counterbalancing influences upon mean bubble size in the case of the caps used in this column is probably that bubble size is not greatly affected by vapor rate through the cap provided, however, that bubbles are not escaping beneath the bottom of the slots. This was roughly confirmed by visual examination of the bubble streams in the experiments with a bubble cap immersed in water.

The gas film thickness, X, is probably also not appreciably influenced by vapor rates. Increase in vapor rate can have little influence upon the turbulence of the vapor inside a bubble, once the bubble has disengaged and is rising through the liquid. On the other hand, if the liquid film had an appreciable influence upon the diffusional process the liquid film thickness would be markedly affected by the greater agitation of the liquid as the vapor rate is increased.

Finally time of contact, θ, undoubtedly remains practically unchanged with change in vapor rate. The greater the vapor rate the greater the horizontal velocity with which the bubble enters the liquid. Time of rise however depends only upon the buoyant force exerted upon the bubble by the liquid and the retarding force due to frictional resistance to the passage of the bubble through the liquid. This is analogous to knocking a marble from a table horizontally. No matter how far the horizontal travel of the marble may be it will reach the floor in the same time.

Additional considerations apply to the portion of the curve in Figure (3), for superficial vapor velocities above 1.0 ft. per second in which an increase in efficiency with vapor velocity is noted. It will be recalled from the derivation of Equation 27 that the mechanism to which it applies is bubbling action. At the vapor rates in which an increase in efficiency was noted appreciable amounts of spray undoubtedly began to be thrown into the vapor spaces above the liquid on the respective plates. This furnishes an additional source of contact by means of which rectification may take place. The individual factors entering into this mechanism are such that adequate mathematical treatment is difficult.

As vapor rate is increased in the region beyond the highest value indicated in Figure (3) a point will undoubtedly be reached beyond which sufficient quantities of spray will be carried over to the plate above as entrained liquid to cause a falling off in efficiency with higher vapor rates. The limiting case can be visualized at that vapor rate at which all of the liquid will be blown from plate to plate of the column which would reduce the efficiency to zero. With the column with which these data were obtained the "puking point" was only slightly above the highest vapor velocity reported so that the entrainment effect could not be obtained. Results of tests on large scale refinery equipment operated both at atmospheric pressure and under vacuum showed the efficiency increase and entrainment effects to follow one another.

2. Results obtained with single plate column:

Figure (4) shows the results of a series of runs in which vapor velocity effects were studied in the single plate column employing alcohol-water mixtures. Three different liquid depths were used, which accounts for the three curves obtained. A flat portion is noticed in the case of each curve. At vapor velocities below 0.14 ft. per second a rise in efficiency with decreasing vapor velocity is noted. This was attributed to diffusion taking place between the vapor in the vapor space above the liquid and the free liquid surface. To confirm this a series of runs were made with no bubble cap in place, i.e. the only source of liquid- vapor contact in the plate section was between the vapor and the free surface of the liquid. At the higher vapor rates little rectification resulted from this source of contact but the rapid increase of this effect at very low vapor velocities is apparent. (Fig. 5a) Figure (5) shows two curves, the upper one of which was obtained by making runs in which the plate liquid level was flush with top of the cap slots, in the case of the lower curve the liquid level was 1/4" below the top of the cap slots. In both cases the surface effect is evident.

Fig. 4

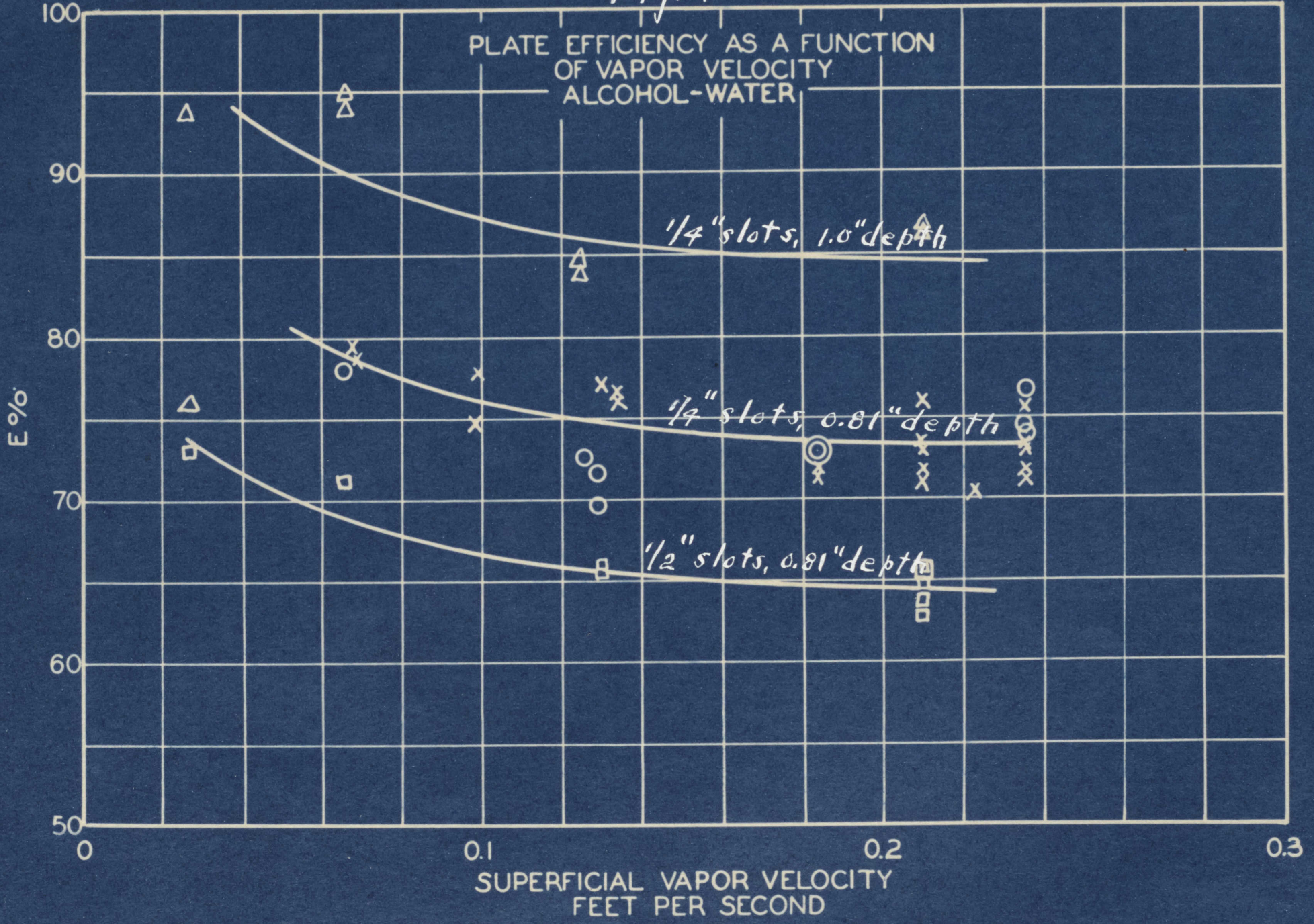


PLATE EFFICIENCY AS A FUNCTION
OF VAPOR VELOCITY
ALCOHOL-WATER
E %
100
90
80
70
60
50
0
0.1
0.2
0.3
SUPERFICIAL VAPOR VELOCITY
FEET PER SECOND
1/4" slots, 1.0" depth
1/4" slots, 0.81" depth
1/2" slots, 0.81" depth

Fig. 5

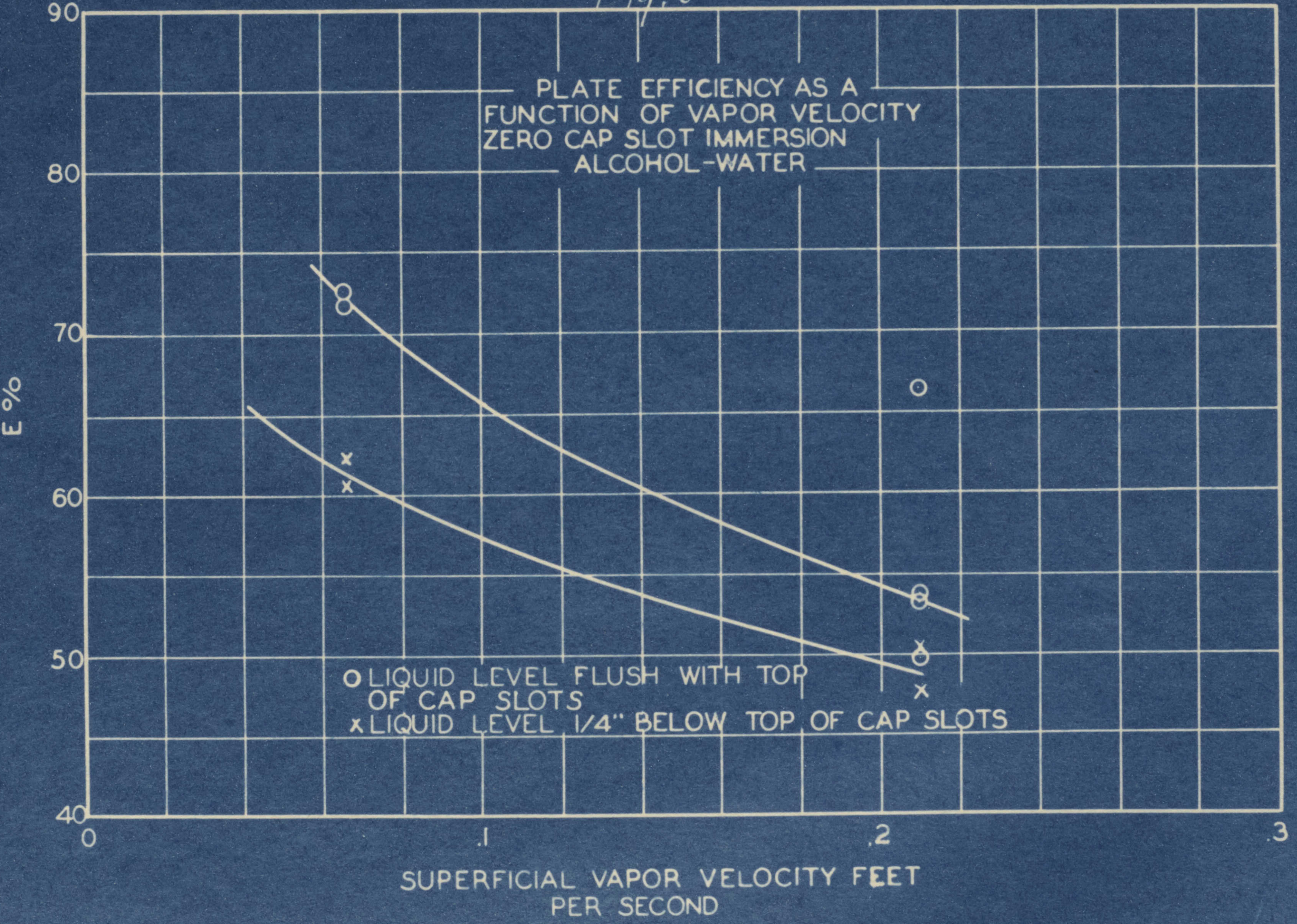


PLATE EFFICIENCY AS A
FUNCTION OF VAPOR VELOCITY
ZERO CAP SLOT IMMERSION
ALCOHOL-WATER
E %
90
80
70
60
50
40
0
.1
.2
.3
SUPERFICIAL VAPOR VELOCITY FEET PER SECOND
○ LIQUID LEVEL FLUSH WITH TOP OF CAP SLOTS
x LIQUID LEVEL 1/4" BELOW TOP OF CAP SLOTS

FIGURE 5a

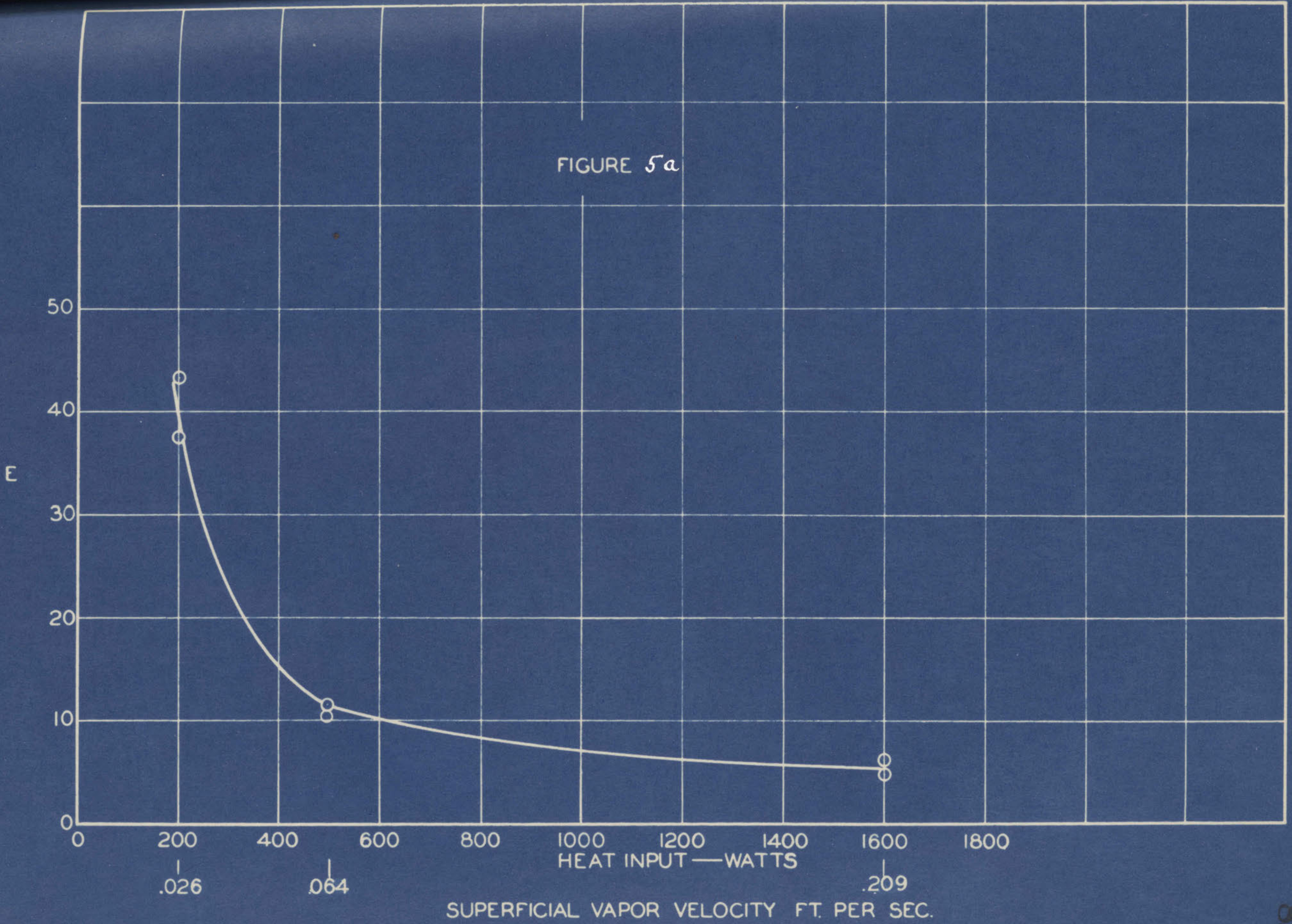

E
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
1800
HEAT INPUT — WATTS
.026
.064
.209
SUPERFICIAL VAPOR VELOCITY FT. PER SEC.

Figure (6) shows the results of runs made with the same single plate section in which superficial vapor velocities were carried to higher values than previously, i.e. to 0.56 ft. per second. The lower four curves were obtained at the same liquid depth but with several cap slot arrangements, while the upper curve represents results at a deeper liquid depth.

As previously obtained a fairly flat region in which vapor velocity has little effect upon efficiency is noted. These curves show a falling off in efficiency at the higher rates employed, however, instead of the rise obtained in the runs with seven plate column. Consideration of differences in conditions in the two sets of experiments will show why this may be expected. The maximum superficial vapor velocities attained in these single plate column runs were only roughly half those obtaining in the seven plate column at the point where efficiency began to increase with vapor velocity. Therefore little contact due to spray in the vapor space was likely to be afforded. The slots in the bubble caps used in the single plate column were so cut that the bubble streams emerged radially whereas in the seven plate column the slots were cut at an angle to radii drawn from the center of the cap. Therefore in the case of the

Fig 6

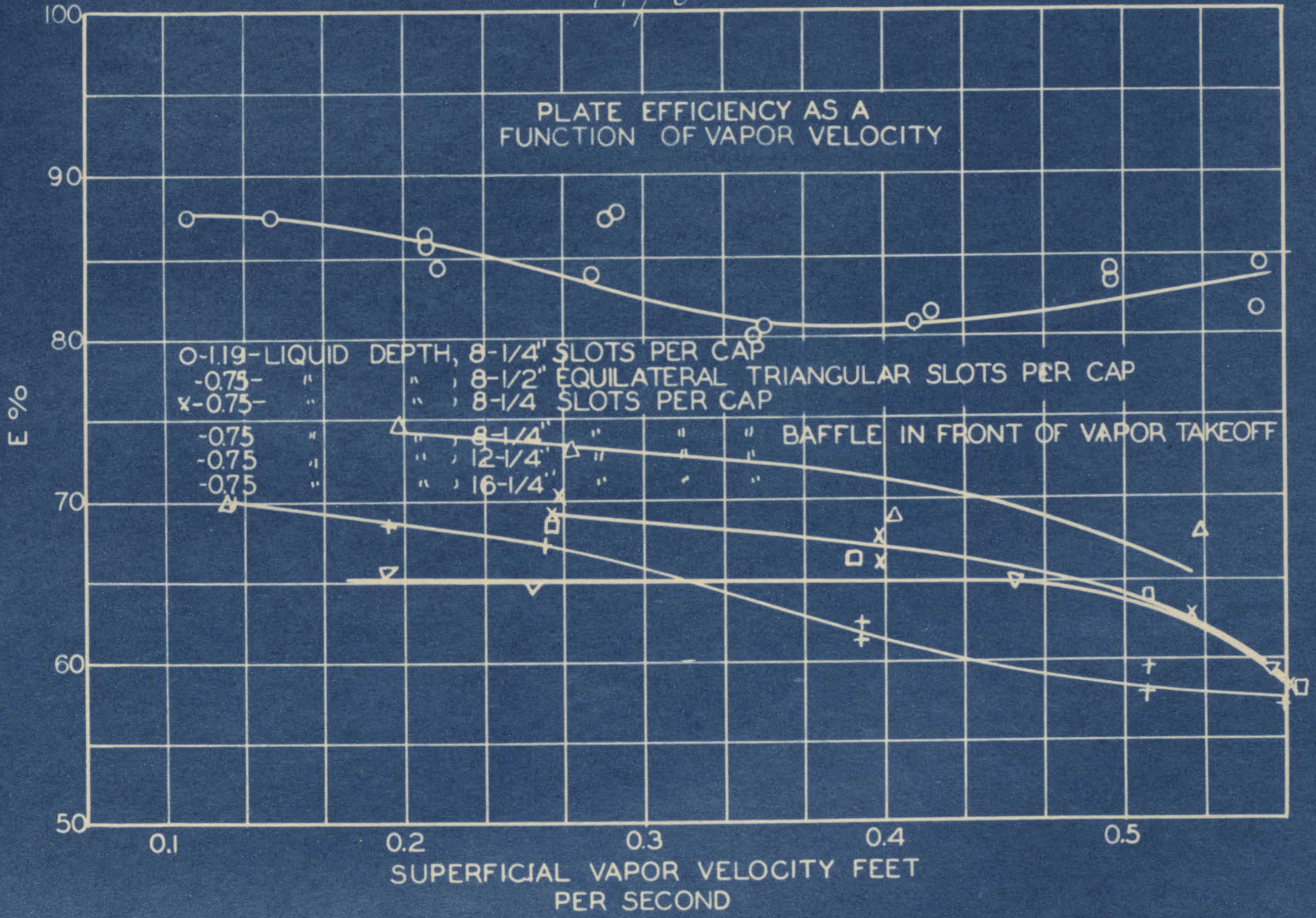


PLATE EFFICIENCY AS A
FUNCTION OF VAPOR VELOCITY
O-1.19-LIQUID DEPTH, 8-1/4" SLOTS PER CAP
-0.75- " " , 8-1/2" EQUILATERAL TRIANGULAR SLOTS PER CAP
x-0.75- " " , 8-1/4 SLOTS PER CAP
-0.75 " " , 8-1/4" " " " BAFFLE IN FRONT OF VAPOR TAKEOFF
-0.75 " " , 12-1/4" " " "
-0.75 " " , 16-1/4" " " "
E %
100
90
80
70
60
50
0.1
0.2
0.3
0.4
0.5
SUPERFICIAL VAPOR VELOCITY FEET
PER SECOND

single plate bubble caps at the higher vapor rates it is likely that the bubble streams took the form of continuous curved cylinders describing parabolic paths from the slots to the liquid surface. If this is the correct picture of the mechanism the mean effective bubble size would be thus increased and a lower efficiency to be expected.

B. EFFECT OF PLATE LIQUID COMPOSITION:

A number of references to changes of plate efficiency with concentration occur in the literature. Peters(29) reports a change in efficiency with concentration for alcohol-water mixtures when the alcohol concentration is above 90% in the mixture. Courtney(30) reports an increase in efficiency with increasing alcohol concentration, as does Noyes.(31) Vivian(32) does not mention the influence of concentration in the case of the rectification of ammonia-water mixtures. Examination of all of these data indicate that efficiencies in terms of the differential enrichment equation, (Equation E) were rereferred to.

Figure (7) shows the results obtained in the single plate column with varying concentrations of Benzene in the plate liquid, for Benzene-Toluene Mixtures.

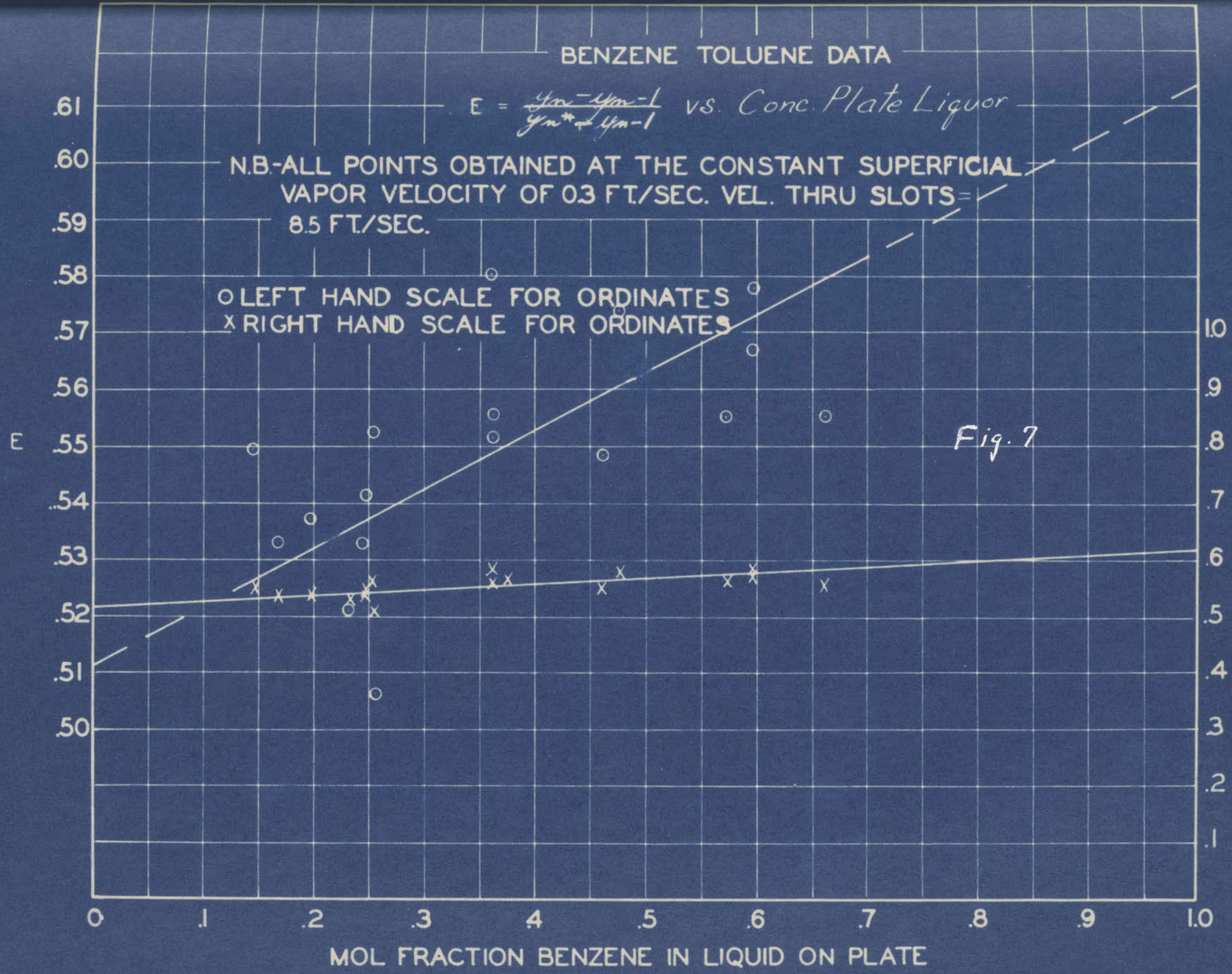

BENZENE TOLUENE DATA
E = $\frac{y_n - y_{m-1}}{y_n^* - y_{m-1}}$ vs. Conc. Plate Liquor
N.B.-ALL POINTS OBTAINED AT THE CONSTANT SUPERFICIAL VAPOR VELOCITY OF 0.3 FT./SEC. VEL. THRU SLOTS = 8.5 FT./SEC.
○ LEFT HAND SCALE FOR ORDINATES
X RIGHT HAND SCALE FOR ORDINATES
E
.61
.60
.59
.58
.57
.56
.55
.54
.53
.52
.51
.50
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
MOL FRACTION BENZENE IN LIQUID ON PLATE

Fig. 7

A marked trend of efficiency with concentration is apparent. To test these data values of $-\frac{k_m S\theta}{X\,V'}$ were calculated employing Equations (27) and (31) for the cases of equal and unequal molal latent heats. In employing the Equation (31) the molal latent heat ratio of Benzene to Toluene was taken as 0.87 from an examination of values reported in the literature for these materials. The results of these calculations are shown in Figure (8) and Tables (2) and (3). It will be noticed that the values of $-\frac{k_m S\theta}{X\,V'}$ calculated from the rigorous Equation (31) show no change in this term with concentration.

It is desirable to show that from the nature of Equations (27) and (31) these results are to be expected. These Equations may be written in differential form as:

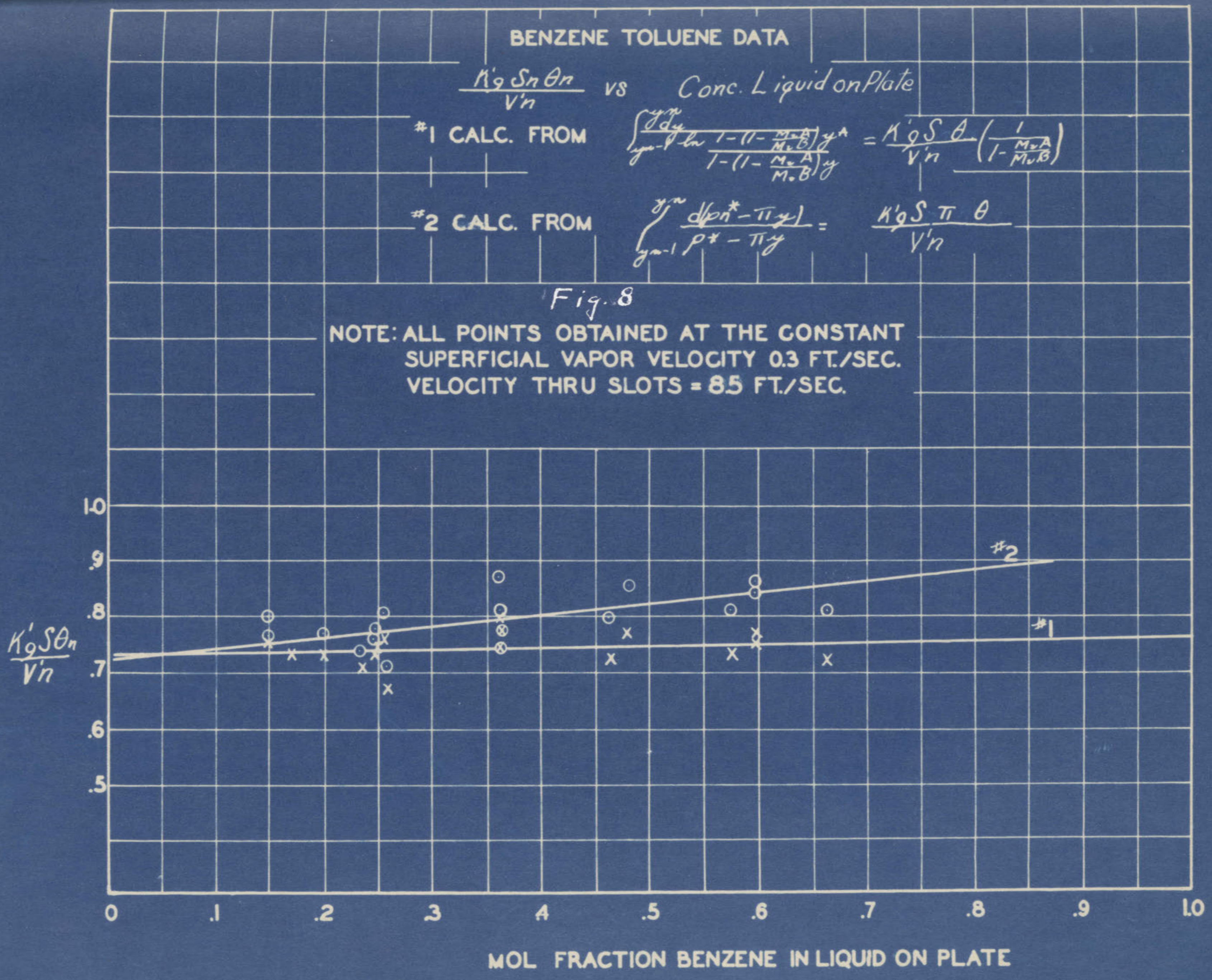
$$\frac{d(V'y)}{Sd\theta} = \frac{k_m}{X} \qquad (y^* - y) \quad - - - - (42)$$

$$\frac{d(V'y)}{Sd\theta} = \frac{k_m}{X} \quad \left(\frac{1}{1-\frac{Mr_A}{Mr_B}} \right) \ln \quad \frac{1-\left(1-\frac{Mr_A}{Mr_B}\right) y}{1-\left(1-\frac{Mr_A}{Mr_B}\right) y^*} \quad - - (43)$$

For the equations to yield the same results the ratio of the right-hand sides should equal unity. Dividing the right-hand sides of Equations (42) and (43) the ratio is:

$$\frac{y^* - y}{\frac{1}{\left(1-\frac{Mr_A}{Mr_B}\right)} \ln \frac{1-\left(1-\frac{Mr_A}{Mr_B}\right) y}{1-\left(1-\frac{Mr_A}{Mr_B}\right) y^*}}$$

FIG.



BENZENE TOLUENE DATA

$\frac{K'_g S_n \theta_n}{V'_n}$ vs Conc. Liquid on Plate

#1 CALC. FROM $\int_{y_{n-1}}^{y_n} \frac{dy}{\ln \frac{1-\left(1-\frac{M_vB}{M_vB}\right)y^*}{1-\left(1-\frac{M_vA}{M_vB}\right)y}} = \frac{K'_g S \theta}{V'_n}\left(\frac{1}{1-\frac{M_vA}{M_vB}}\right)$

#2 CALC. FROM $\int_{y_{n-1}}^{y_n} \frac{d(p_n^* - \pi y)}{p^* - \pi y} = \frac{K'_g S \pi \theta}{V'_n}$

Fig. 8

NOTE: ALL POINTS OBTAINED AT THE CONSTANT SUPERFICIAL VAPOR VELOCITY 0.3 FT./SEC. VELOCITY THRU SLOTS = 8.5 FT./SEC.

Table 2

Calculation of $\frac{k'_m S\theta}{XV'}$ from Murphree Efficiency Benzene-Toluene Data

\- - -

1	2	3	4	5	6	7
Run No.	X_p	E	log (1-E)	2.3 log (1-E) $= -\frac{k'_m S\theta}{XV'}$	Plate Temp. °K	$\frac{k'_m S\theta}{XV'}$ reduced to basis of t=95°C.
1	0.476	0.574	-0.370	-0.850	365.9	-0.856
2	0.461	0.548	-0.345	-0.793	366.4	-0.797
10	0.168	0.533	-0.331	-0.761	375.8	-0.745
12	0.146	0.549	-0.346	-0.795	377.8	-0.775
13	0.245	0.532	-0.330	-0.758	374.2	-0.746
14	0.233	0.521	-0.319	-0.733	374.5	-0.721
19	0.199	0.537	-0.334	-0.767	375.1	-0.753
25	0.599	0.569	-0.364	-0.836	364.5	-0.845
26	0.597	0.578	-0.374	-0.860	364.7	-0.868
34	0.575	0.555	-0.352	-0.809	365.5	-0.815
45	0.664	0.555	-0.352	-0.809	362.9	-0.820
49	0.362	0.580	-0.377	-0.866	371.3	-0.859
50	0.362	0.555	-0.352	-0.809	371.3	-0.802
51	0.362	0.551	-0.348	-0.800	371.5	-0.792
52	0.256	0.506	-0.306	-0.704	374.6	-0.691
53	0.254	0.552	-0.348	-0.801	374.8	-0.788
54	0.248	0.541	-0.338	-0.777	374.8	-0.764

TABLE 3

Calculation of $\frac{k_m S\theta}{XV'}$ by $\int_{y_{n-1}}^{y_n} \frac{dy}{\ln \frac{1-(1-\frac{Mr_A}{Mr_B})y^*}{1-(1-\frac{Mr_A}{Mr_B})y}}$

1 Run No.	2 y_{n-1}	3 y_n	4 y_n^*	5 -*	6 -**	7 Ei (Item 5)	8 Ei Item 6)	9 Item 7 minus Item 8	10 -***	11 $\frac{k_m S\theta}{XV'}$	12 Plate Temp °K	13 $\frac{k_m S\theta}{XV'}$
1	0.476	0.601	0.694	0.0132	0.0307	-3.725	-2.885	-0.840	0.910	-0.763	365.9	-0.768
2	0.461	0.581	0.680	0.0140	0.0308	-3.665	-2.883	-0.782	0.912	-0.713	366.4	-0.716
10	0.168	0.252	0.326	0.0100	0.0212	-4.018	-3.256	-0.762	0.958	-0.730	375.8	-0.715
12	0.146	0.225	0.290	0.0088	0.0193	-4.135	-3.355	-0.780	0.963	-0.750	377.8	-0.730
13	0.245	0.3490	0.440	0.0124	0.0265	-3.790	-3.020	-0.770	0.943	-0.725	374.2	-0.713
14	0.233	0.332	0.423	0.0125	0.0259	-3.790	-3.050	-0.740	0.945	-0.700	374.5	-0.688
19	0.199	0.293	0.373	0.0110	0.0235	-3.910	-3.145	-0.765	0.952	-0.728	375.1	-0.714
25	0.599	0.707	0.790	0.0120	0.0274	-3.825	-2.990	-0.835	0.897	-0.750	364.5	-0.758
26	0.597	0.707	0.789	0.0118	0.0275	-3.840	-2.986	-0.854	0.898	-0.766	364.7	-0.773
34	0.575	0.685	0.774	0.0127	0.0283	-3.770	-2.960	-0.810	0.899	-0.728	365.5	-0.734
45	0.664	0.758	0.834	0.0110	0.0244	-3.910	-3.105	-0.805	0.892	-0.719	362.9	-0.728
49	0.362	0.489	0.581	0.0128	0.0303	-3.760	-2.890	-0.870	0.925	-0.796	371.3	-0.790
50	0.362	0.489	0.581	0.0131	0.0303	-3.735	-2.890	-0.845	0.923	-0.780	371.3	-0.774
51	0.362	0.483	0.581	0.0136	0.0303	-3.700	-2.890	-0.810	0.926	-0.749	371.5	-0.742
52	0.256	0.356	0.454	0.0134	0.0269	-3.710	-3.010	-0.700	0.942	-0.660	374.6	-0.649
53	0.2540	0.363	0.452	0.0122	0.0269	-3.810	-3.010	-0.800	0.941	-0.752	374.8	-0.722
54	0.248	0.353	0.443	0.0123	0.0266	-3.800	-3.020	-0.780	0.943	-0.735	374.8	-0.722

Note-*

5-* $-\ln \frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}}$

6-** $-\ln \frac{y^*_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}}$

10-*** $\frac{\frac{1}{1-\frac{Mr_A}{Mr_B}} - y^*}{\frac{1}{1-\frac{Mr_A}{Mr_B}}}$

Table (4) shows the results of testing this ratio assuming the molal latent heat ratio to be 0.87 its value for Benzene-Toluene. Item 1 gives values of y from.05 to 0.90. In item 2 are recorded values of y* corresponding to the various values of y (=X) from Benzene-Toluene equilibrium data. (N.B. y, the mol fraction of Benzene in the vapor was assumed to be the same as X, the mol fraction of Benzene in the liquid. For the single plate column data this relation held at the instant the vapor from the still entered the plate liquid). Items 3 and 4 show the values of the numerator and denominator of the ratio and item 5 the values of the ratio for the assigned values of y. It is thus seen that Equations (27) and (31) are not identical and can be expected to show a progressive deviation thus indicating that the results computed from experimental data by use of these equations lie in the right direction.

TABLE (4) $\frac{Mr_A}{Mr_B} = 0.87$

(1) y	(2) y^*	(3) $\left(1-\frac{Mr_A}{Mr_B}\right)(y-y^*)$	(4) $2.303 \log \frac{1-\left(1-\frac{Mr_A}{Mr_B}\right)y}{1-\left(1-\frac{Mr_A}{Mr_B}\right)y^*}$	(5) = $\frac{(3)}{(4)}$
0.05	0.111	0.00793	0.00800	0.991
.10	.209	.0142	.0145	.979
.20	.375	.0228	.0236	.966
.30	.508	.0270	.0286	.944
.40	.621	.0287	.0307	.935
.50	.715	.0280	.0304	.921
.60	.791	.0248	.0274	.908
.70	.855	.0202	.0224	.902
.80	.911	.0144	.0163	.883
.90	.959	.00767	.00875	.876

It remains to be shown that the molal latent heat ratio is responsible for the deviations of Equations (27) and (31) from one another. In making the calculations shown in Table (5) the values of y (=X) of 0.400 and its corresponding y^* of 0.621 were arbitrarily chosen. Item 1 shows the various values assigned to the molal latent heat ratio, Item 2 the numerator of the ratio, Item 3 the denominator and Item 5 the value of the ratio. It will be noticed that the ratio, Item 5, is unity only if the molal latent heat ratio be unity.

TABLE (5) $y = 0.400$, $y^* = 0.621$

(1) $\frac{Mr_A}{Mr_B}$	(2) $(1-\frac{Mr_A}{Mr_B})(y^*-y)$	(3) $2.303 \log \frac{1-(1-\frac{Mr_A}{Mr_B})y}{1-(1-\frac{Mr_A}{Mr_B})y^*}$	(4) = $\frac{(2)}{(3)}$
0.70	0.0664	0.0784	0.846
.75	.0553	.0634	.871
.80	.0442	.0492	.898
.85	.0332	.0359	.923
.90	.0221	.0233	.947
.95	.01105	.0113	.978
1.00	- -	- -	1.000
1.05	-.01105	-.01079	1.025
1.10	-.0221	-.02105	1.049
1.15	-.0332	-.03075	1.078
1.20	-.0442	-.04020	1.100

Figure (9) showsthe results of concentration studies made with alcohol-water mixtures. Little change over the concentration range covered was apparent. The value of the molal latent heat ratio for temperatures in the range covered by these runs is roughly 0.95. Hence less effect of concentration upon efficiency should be expected for these mixtures. To test these results calculations similar to those made for Benzene and Toluene were made.

For Table (6) the value of 0.95 was assigned to the molal latent heat ratio. Item 1 gives the various values assigned to y (=X) and Item 2 the corresponding values of y*. Item (5) shows that for a change in y from 0.1 to 0.8 the ratio changed only from 0.985 to 0.953 indicating that concentration effect may be expected to

Fig. 9

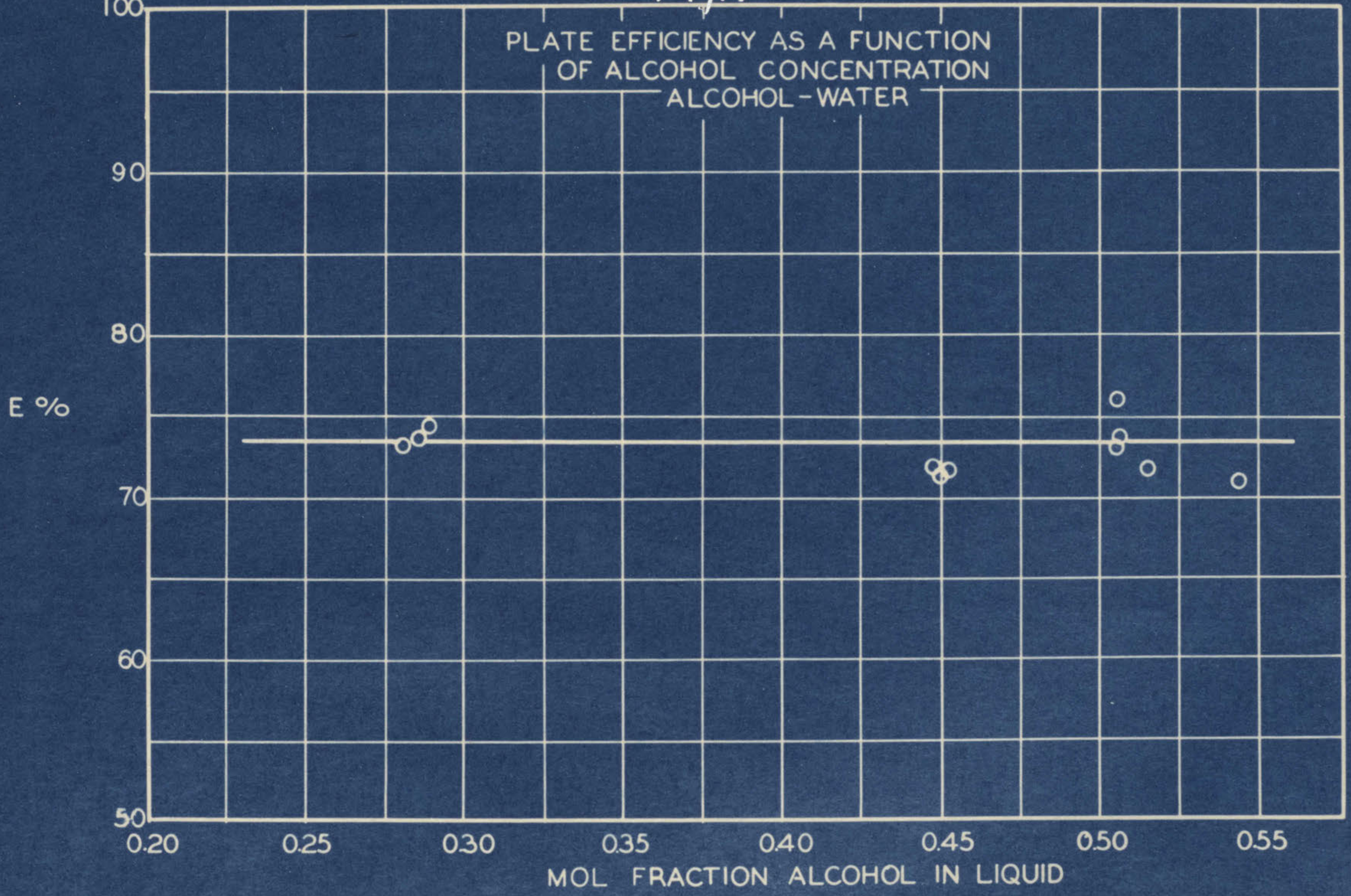


PLATE EFFICIENCY AS A FUNCTION
OF ALCOHOL CONCENTRATION
ALCOHOL-WATER
E %
100
90
80
70
60
50
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
MOL FRACTION ALCOHOL IN LIQUID

be small for alcohol-water mixtures.

TABLE (6)

(1) y	(2) y^*	(3) $\left(1-\frac{Mr_A}{Mr_B}\right)(y^*-y)$	(4) $2.303 \log \frac{1-\left(1-\frac{Mr_A}{Mr_B}\right) y}{1-\left(1-\frac{Mr_A}{Mr_B}\right) y^*}$	(5) = $\frac{(3)}{(4)}$
0.1	0.4410	0.01705	0.01730	0.985
.2	.5285	.01643	.01673	.982
.3	.5730	.01365	.01399	.977
.4	.6125	.01063	.01090	.975
.5	.6520	.00760	.00780	.974
.6	.6965	.00483	.00497	.970
.7	.7525	.00263	.00272	.965
.8	.8180	.00090	.000944	.953

VIII-C EFFECT OF NATURE OF COMPONENTS:

Data on three binary mixtures are available for comparison. Runs with the seven plate column permit comparison of efficiencies obtained with Benzene-Toluene mixtures with those had using CCl_4-Toluene, while data obtained with the single plate column yield a comparison between Benzene-Toluene and Alcohol-Water Mixtures. A summary of these data follows:

TABLE (7)

Apparatus	Mixture	E_M	$\frac{k_m S\theta}{X\ V'}$ (experimental
7 plate	Benzene-Toluene	0.57(1)	-0.818
" "	CCl_4-Toluene	0.47(2)	-0.635
Single plate	Benzene-Toluene	0.512(3)	-0.738
" "	Alcohol-Water	0.726(4)	-1.298

(1) Average value for whole column for Benzene-Toluene runs in seven plate column, vapor velocities .7 to 1.2 ft/sec. Average column temperature assumed at 88°C.

(2) Average value for whole column for CCl_4-Toluene runs in seven plate column. Vapor velocities 1.1 to 1.2 ft/sec. Average column temperature assumed as 88°C.

(3) Average of Benzene-Toluene runs in single plate column, corrected for concentration effect, vapor velocities 0.3 ft/sec., liquid depth 13/16", cap slot width 1/4". Average temperature for runs = 98°C.

(4) Average of Alcohol-Water data, single plate column, vapor velocity 0.21 ft./sec., liquid depth 13/16", cap slot width 1/4". Average temperature for runs = 81.9°C.

To apply Equation 27 to the seven plate column data, by taking the logarithms of both sides, it may be written as:

$$\log (1 - E_M) = - \frac{k_m S \theta}{2.303 \times X V'}$$

From the respective experimental values for E_M for Benzene-Toluene and CCl_4-Toluene the ratio of the left-hand sides of this equation can be calculated. If on a theoretical basis the ratio of the terms in the right-hand side of the equation for the two mixtures can be shown to check the experimental ratio it is obvious this method may be used to estimate the efficiency to be expected in a given column for a binary mixture if data on the efficiency obtained in the same column with another mixture are available.

The evaluation of the experimental ratio is direct,

e.g. $$\frac{\log(1-E_M)(\text{Benz-Tol})}{\log(1-E_M)(CCl_4\text{-Tol})} = \frac{\log(1-.57)}{\log(1-.47)} = 1.325$$

For evaluation of the ratio of the $\frac{k_mS\theta}{X\ V'}$ terms on a theoretical basis the subscript 1 refers to Benzene-Toluene, 2 to CCl_4-Toluene.

$$\frac{\frac{k_{m_1}\ S_1\ \theta_1}{X_1\ V'}}{\frac{k_{m_2}\ S_2\ \theta_2}{X_2\ V'_2}} = \frac{k_{m_1}\ S_1\ V'_2\ \theta_1\ X_2}{k_{m_2}\ S_2\ V'_1\ \theta_2\ X_1}$$

If the assumption that, for a given cap design and liquid depth, the terms S_1, V_1, θ_1 equal S_2, V'_2, θ_2 respectively is made the ratio becomes by cancellation: $\frac{k_{m_1}\ X_2}{k_{m_2}\ X_1}$

k_{m1} and k_{m_2} may be estimated from values of k_v in the literature. Equation 18 states that

$$X = a\ D \left(\frac{z}{Du\rho}\right)^n \quad - - - - (18)$$

The same shape Factor "D" should hold in the cases of both mixtures. Data are for the same range in vapor velocities. Therefore, assuming $n = 1$, $a_1 = a_2$,

$$\frac{X_2}{X_1} = \frac{z_2\ \rho_1}{\rho_2\ z_1}$$

Therefore $\frac{k_{m1}\ X_2}{k_{m_2}\ X_1} = \frac{k_{m1}\ z_2\ \rho_1}{k_{m_2}\ z_1\ \rho_2}$

Direct data are not available for the viscosities of the vapors of CCl_4 or Toluene, therefore complete evaluation of this ratio is impossible. However the viscosity of

Chloroform (Figure 10) from the literature is higher than that of Benzene, consequently that of CCl_4 is probably also higher. On the other hand the vapor density of CCl_4-Toluene mixtures is greater than that of Benzene-Toluene mixtures at the same temperatures. Since film thickness is directly proportional to a function of film viscosity and inversely proportional to film density these factors probably very nearly counterbalance one another in the ratio $\frac{X_2}{X_1}$. For these reasons the further assumption will be made that $X_1 = X_2$. Therefore $\frac{k_{m1}\ X_2}{k_{m2}\ X_1} = \frac{k_{m1}}{k_{m2}}$

From Equation (16) as calculated on page ( ):

$$CCl_4 \text{ - Toluene, } k_{vo} = 0.0287$$

$$\text{Benzene-Toluene, } k_{vo} = 0.0405$$

$$\text{Therefore } k_{m1} = \frac{0.0405}{22400}\ \frac{361}{273}$$

$$k_{m2} = \frac{0.0287}{22400}\ \frac{361}{273}$$

$$\text{Or} \qquad \frac{k_{m1}}{k_{m2}} = \frac{0.0405}{0.0287} = 1.41$$

Compared with the experimental ratio of 1.325 the deviation is 6.4% which is excellent agreement in view of the assumptions necessary.

If Equation 17 is employed to calculate the k_{vo} values as on page (37) for Benzene-Toluene, $k_{vo} = 0.0408$, for CCl_4-Toluene, $k_{vo} = 0.0293$, yielding a ratio of 1.39

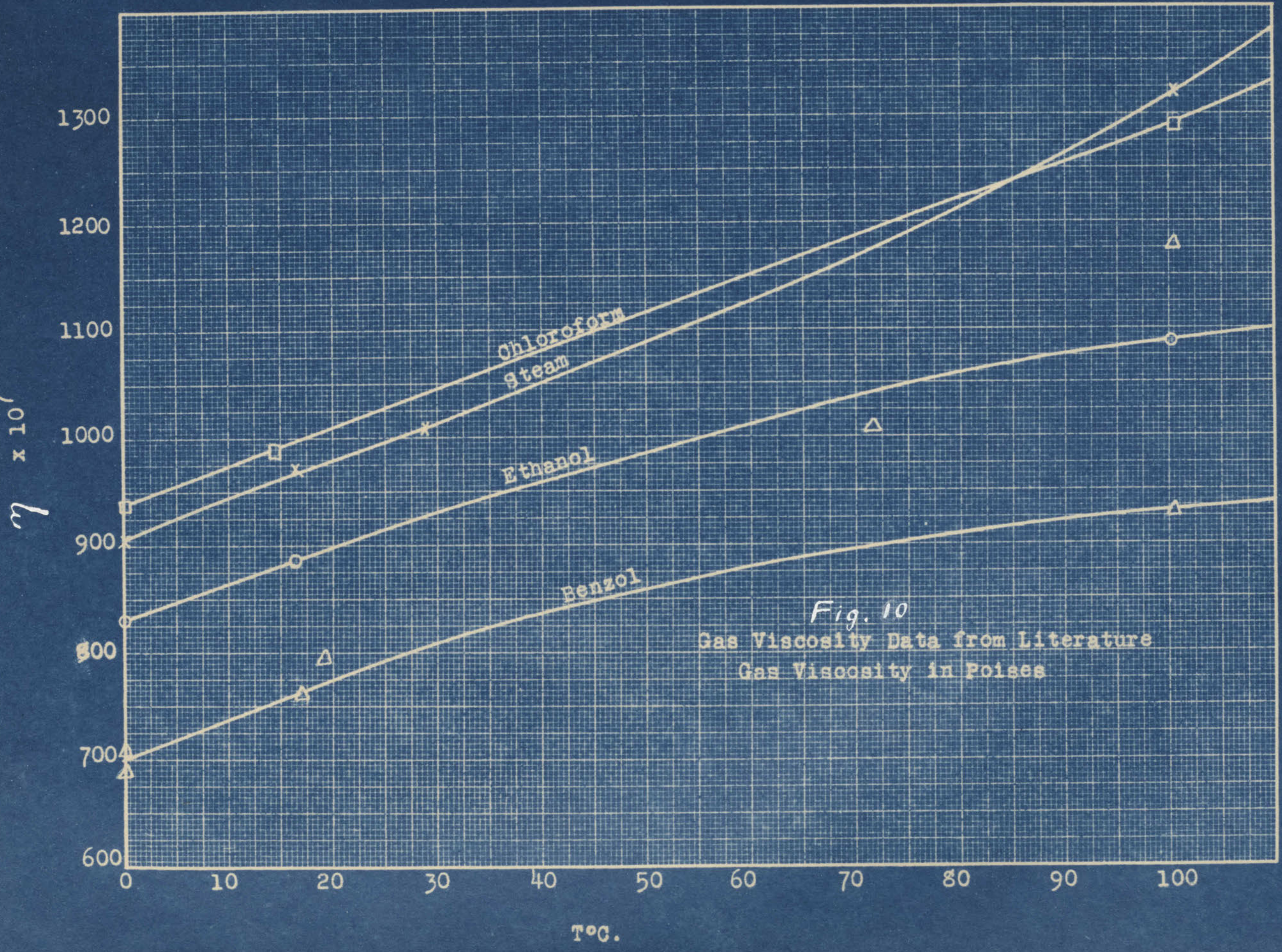


Fig. 10
Gas Viscosity Data from Literature
Gas Viscosity in Poises

with a deviation of 4.9% from the experimental

In considering the single plate column data for Benzene-Toluene and Alcohol-Water mixtures the experimental ratio from Table (7) to be tested theoretically is:

$$\frac{\log\,(1 - E_M)\ \text{Alc.-Water}}{\log\,(1 - E_M)\ \text{Benz-Tol.}} = \frac{-1.298}{-0.738} = 1.76$$

Employing the subscripts 3 and 4 to denote Alcohol-Water and Benzene-Toluene mixtures respectively,

$$\frac{\dfrac{k_{m_3}\ S_3\ \theta_3}{X_3\ V_3'}}{\dfrac{k_{m_4}\ S_4\ \theta_4}{X_4\ V'_4}} = \frac{k_{m_3}\ X_4}{k_{m_4}\ X_3}$$

under the assumptions previously noted as to constancy of the terms S, V' and θ.

From Equation 16, as calculated on page (36),

for Benzene-Toluene, $k_{vo} = 0.0405$

for Alcohol-Water, $k_{vo} = 0.1194$

From Table (7), the average temperature for the Alcohol-Water runs is 81.9°C, for the Benzene-Toluene runs, 98°C. The values for k_m may be calculated by use of Equation (15).

$$k_{m_3} = \frac{0.1194 \quad 354.9}{22400 \quad 273} = 0.00000693$$

$$k_{m_4} = \frac{0.0405 \quad 371}{22400 \quad 273} = 0.000002455$$

$$\frac{k_{m_3}}{k_{m_4}} = \frac{0.1194 \quad 354.9}{0.0405 \quad 371} = 2.82$$

Employing Equation (17) to estimate k_{vo} these results (page 37) for Benzene-Toluene, $k_{vo} = 0.0408$

" Alcohol-Water (Alc. basis), $k_{vo} = 0.1170$

" " " (H_2O basis), $k_{vo} = 0.1432$

Values of k_{m_3}/k_{m_4} are therefore,

(Alcohol basis), $\frac{k_{m_3}}{k_{m_4}} = \frac{0.1170 \quad 354.9}{0.0408 \quad 371} = 2.74$

(H_2O basis), $\frac{k_{m_3}}{k_{m_4}} = \frac{0.1432 \quad 354.9}{0.0408 \quad 371} = 3.36$

It is obvious that in this case values of the ratio $\frac{k_{m_3}}{k_{m_4}}$ cannot alone account for the experimental ratio of 1.76. Therefore examination of the ratio:

$$\frac{k_{m_3} \; X_4}{k_{m_4} \; X_3} = \frac{k_{m_3} \; Z_4 \; \rho_3 \quad u_3}{k_{m_4} \; Z_3 \; \rho_4 \quad u_4}$$

must be undertaken to account for the discrepancy.

The mean arithmetic average film composition for the Benzene-Toluene runs was 0.487 mol fraction Benzene, that for the Alcohol-Water runs 0.564 mol fraction Alcohol.

Employing the Equation of Meyer$^{(33)}$ to calculate the viscosity of the Alcohol-Water film, $Z_3 = 1130 \times 10^{-7}$ poises at the temperature in question, 81-9°C. Viscosity data for Toluene being lacking its viscosity was assumed to be the same as that of Benzene, e.g. $Z_4 = 930 \times 10^{-7}$ poises at 98°C.

For the three values of $\frac{k_{m_3}}{k_{m_4}}$ available from different methods of extrapolation:

$$\frac{k_{m_3}\, z_4\, \rho_3\, u_3}{k_{m_4}\, z_3\, \rho_4\, u_4} = \overset{k_{m_3}/k_{m_4}}{2.82}\ \frac{\overset{z_4/z^3}{930}}{1130}\ \frac{\overset{\rho_3/\rho^4}{33.8 \times 371}}{85.1 \times 354.9}\ \frac{\overset{u_3/u^4}{0.21}}{0.30} = 0.675$$

$$'' \quad = 2.74 \quad '' \quad '' \quad = 0.655$$

$$'' \quad = 3.36 \quad '' \quad '' \quad = 0.804$$

All of these are values less than the experimental ratio of 1.76. However, the arbitrary assumption that the exponent of the power function of the modulus $\frac{z}{Du\rho}$ was unity was made in evaluating relative film thickness. This is undoubtedly far from correct. A value of n in $\left(\frac{z}{Du\rho}\right)^n$ of approximately 0.33 will make the theoretical ratios check the experimental, 1.76, in the first two calculations, while n = 0.45 is required if the ratio $\frac{k_{m_3}}{k_{m_4}} = 3.36$ is assumed correct.

The results discussed in this section thus indicate that exact calculation of the plate efficiency to be expected with a given binary mixture granted data on another mixture is rendered difficult due partly to lack of fundamental diffusional data and in part to the unknown nature of the function evaluating film thickness. However, in all cases the results are in the right direction and are therefore of use in estimation. It is reasonable to believe that estimations between mixtures of the same general type of compounds, e.g. hydrocarbons will be more accurate than when for example alcohol mixtures are compared with hydrocarbons.

VIII-D. EFFECTS OF LIQUID DEPTH AND BUBBLE CAP SLOT WIDTH.

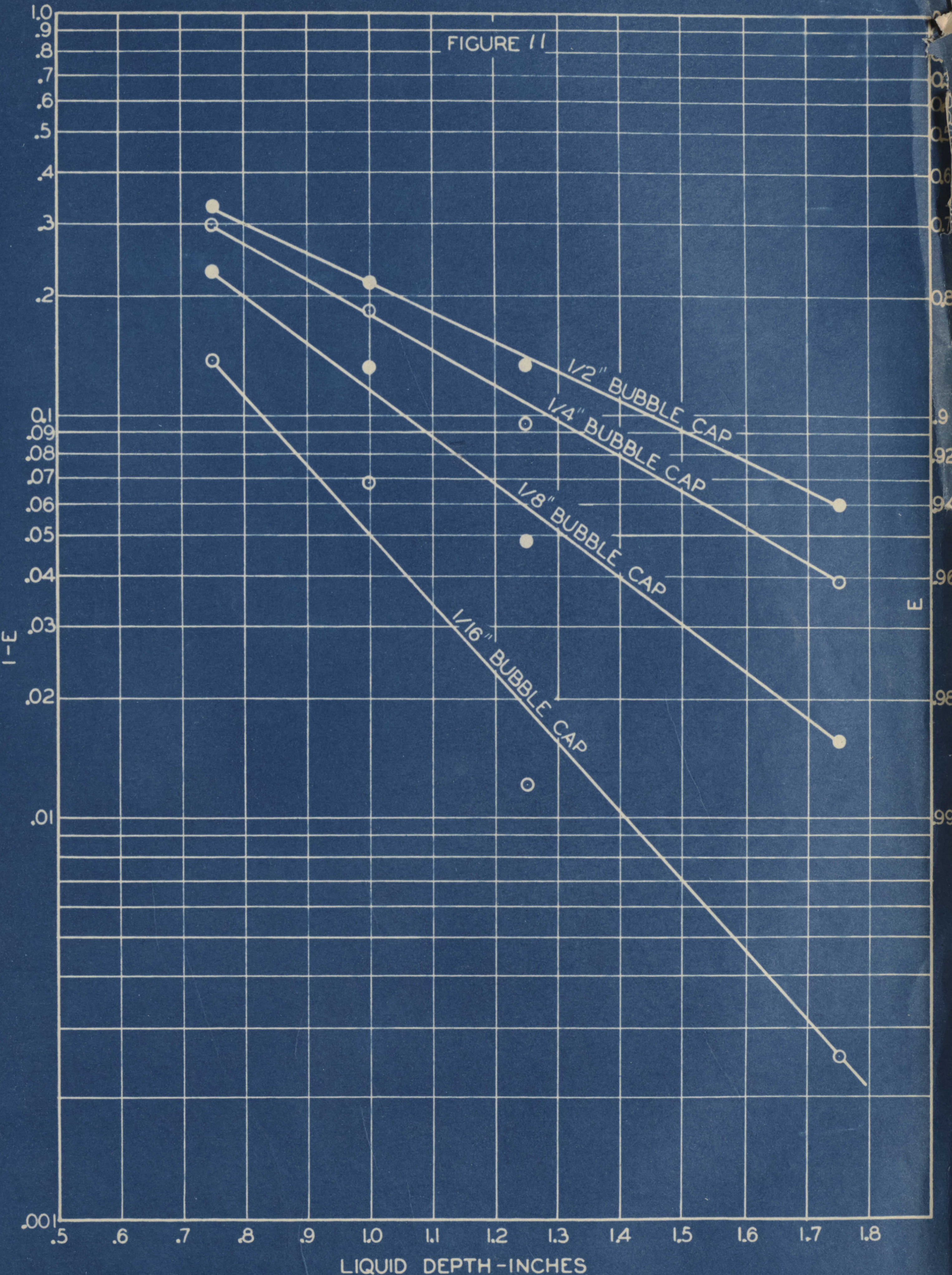
The results of runs 12A to 43A inclusive with Alcohol-Water Mixtures in the single plate column are shown in Figures (11) and (12). In Figure (11) $1 - E_M$ on a logarithmic scale is plotted against total liquid depth, measured from the plate to the top of the overflow pipe, plotted on a straight scale. Figure (12) shows $1 - E_M$ on a logarithmic scale plotted against the reciprocal of the slot width on a straight scale. For all of these runs the bubble cap slots were 1/2 inch high, while the total free area through the slots was kept constant at one square inch. Vapor velocity, controlledby heat input to the still, was maintained constant at 0.21 ft./sec.

In discussing these data, Equation (27) written in logarithmic form will be required:

$$\log(1 - E_M) = -\left(\frac{1}{2.303}\right)\frac{k_m S\theta}{X\,V'}$$

As previously pointed out the factors $\frac{S}{V'}$ can be interpreted as a mean effective diameter of the bubble stream. Evidence is ample (cf. page 75) that bubble size is directly proportional to cap slot width. Therefore other factors remaining constant $\log(1 - E_M)$ should be linear in the reciprocal of cap slot width. as shown by Fig. (12).

FIGURE 11


1/2" BUBBLE CAP
1/4" BUBBLE CAP
1/8" BUBBLE CAP
1/16" BUBBLE CAP
1-E
1.0
.9
.8
.7
.6
.5
.4
.3
.2
0.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.001
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
LIQUID DEPTH - INCHES
E
.9
.92
.94
.96
.98

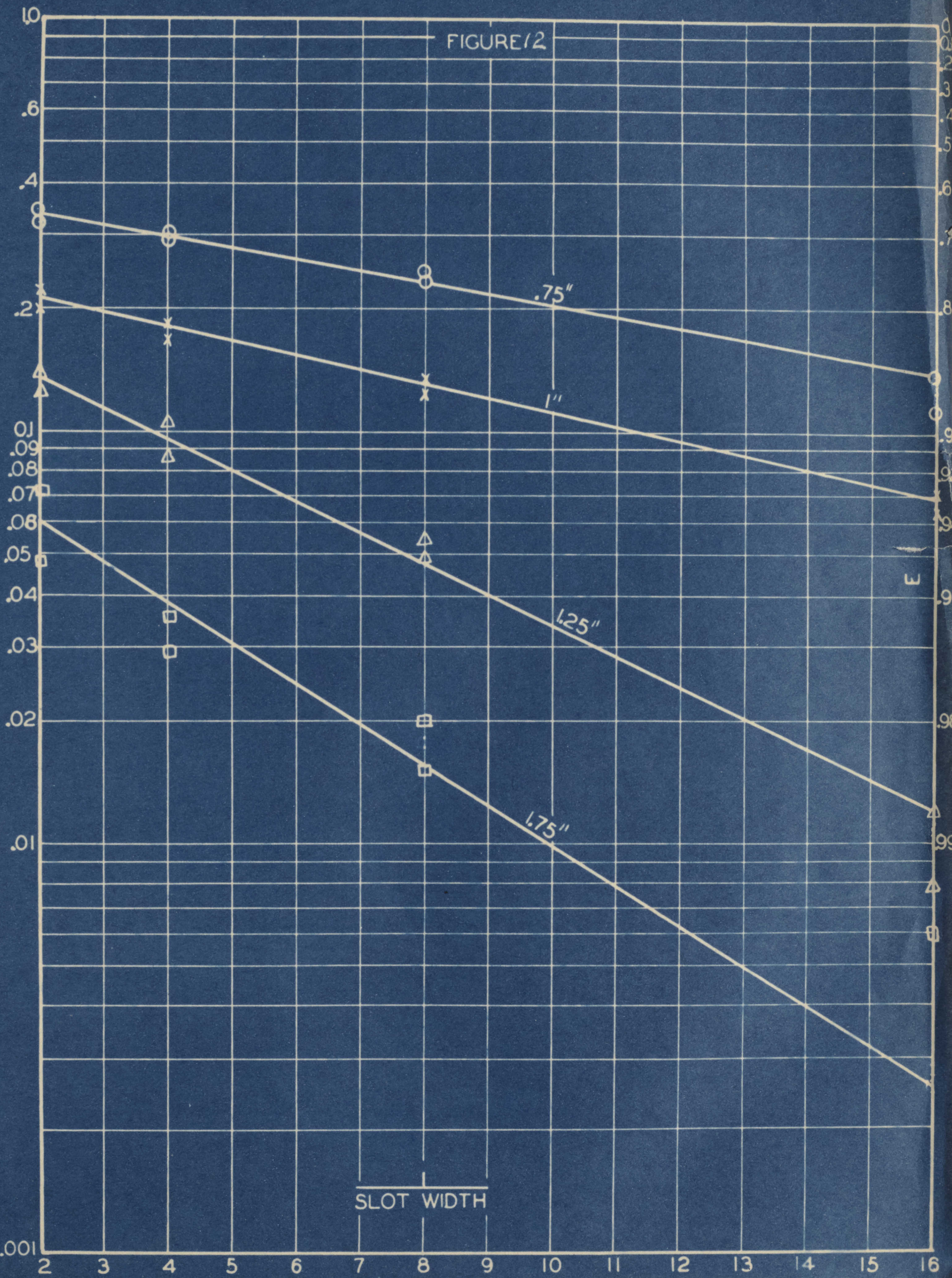


FIGURE 12

1.0
.6
.4
.2
0.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.001
1-E
E
.75"
1"
1.25"
1.75"
SLOT WIDTH
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

The factor influenced by variation in liquid depth is time of contact, θ. Figure (11) shows that θ is directly proportional to liquid depth. The ratio of liquid density to vapor density under the conditions in these experiments is high, roughly 700 to 1. The buoyant force acting on a vapor bubble is thus large compared with the mass of the bubble which means a very high initial acceleration as the bubble enters the liquid. It therefore followsthat a bubble will practically instantaneously reach a uniform upward velocity in which the buoyant force acting on the bubble is just balanced by the frictional resistance of the liquid. Granted a uniform upward velocity, the time of contact of a bubble will depend directly upon liquid depth.

It was observed that if the lines of Figure (11) were prolonged to the left a well defined point of intersection was obtainedat a point corresponding to a liquid depth of 0.35 inch and a value of $1 - E_M$ of 0.64. This led to the following interpretation.

The height of the cap slots used in these runs was, as noted, 0.5 inch. The value of $h_o = 0.35''$ defined by the point of intersection on Figure (11) must therefore correspond to zero cap slot immersion, i.e. the liquid depth at which bubbling action just ceases.

Reference to the lower curve of Figure (5) page (81), shows that for runs made with 1/4" of the cap slots open above the liquid surface $1 - E_M = 0.52$ for the same vapor rate as used in the present experiments, which is reasonably close to the value 0.64 defined by these data.

Time of contact due to bubbling action depends upon the vertical distance from the centers of the bubble streams, as they emerge from the slots to the surface of the liquid on the plate. Defining this distance as cap slot immersion and interpreting h_o as the distance from the plate to the center of the bubble stream,

$$i = h - h_o \text{ - - - - - } (44)$$

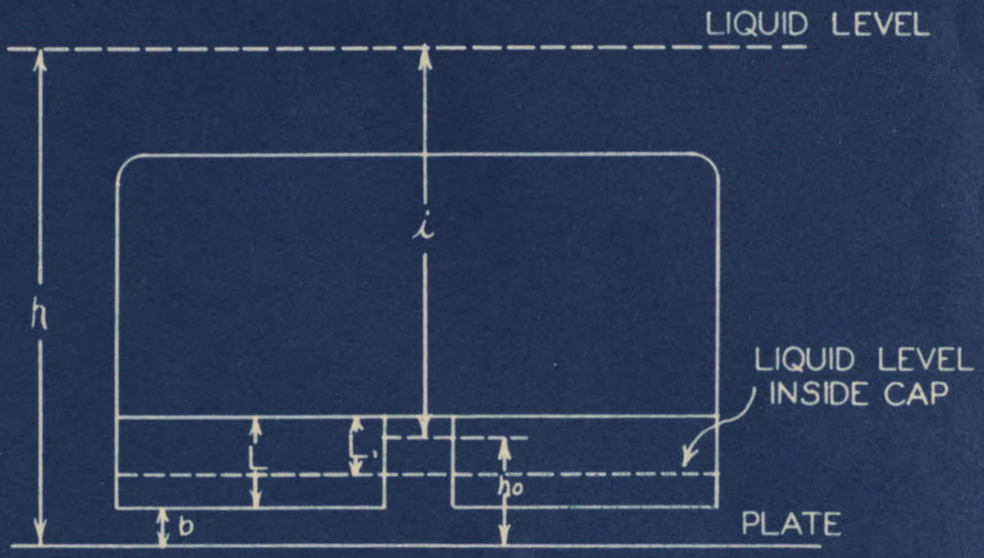
h being the total liquid depth on the plate. Referring to Figure (13) if L is the total slot length, L' the length of slot open under givenconditions and b the distance from the plate to the bottom of the slots:

$$L' = 2\left[L - (h_o - b)\right] \text{ - - - - } (45)$$

For conditions in which all of the slot is working the limiting value of $h_o - b$ is obviously $\frac{L'}{2}$.

In the arrangement used, $b = 0$. Thus, had all of the slot been open, from Equation 45, h_o would have been 0.25 inch. For an h_o of 0.35 inch $L' = 0.3$ inch.

FIGURE 13



From Figures (11) and (12) the following equations may be written:

$$\log (1 - E_M) = k_1 (i) + a_1 \quad - - - - - (46)$$

$$k_1 = c_1 \left(\frac{1}{W}\right)$$

$$a_1 = \log (1 - E_o)$$

$$\log (1 - E_M) = k_2 \left(\frac{1}{W}\right) + a_1 + a_2 \quad - - - (47)$$

$$k_2 = c_2 (i)$$

a_2 is the value of log (1-E) when cap slots are infinitely wide. It should be noted that when cap slots are infinitely wide the reciprocal of cap slot width is zero. However, bubbles of infinite size rising through various depth of liquid will show differences in the degree of approach of efficiency to a limiting value. From Figure (12)

$$a_2 = c_3 (i)$$

Adding Equations 46 and 47 and dividing by 2 there results:

$$\log (1-E_M) = C',\left(\frac{i}{w}\right) + C_2 (i) + \log (1-E_o) \quad - - - (48)$$

Determining the constants in Equation 48 from the present data:

$$C'_1 = -0.0616$$

$$C_2 = - 0.713$$

$$(1-E_o) = 0.64, \quad a_1 = -0.193$$

$$h_o = 0.35, \quad i = h - 0.35$$

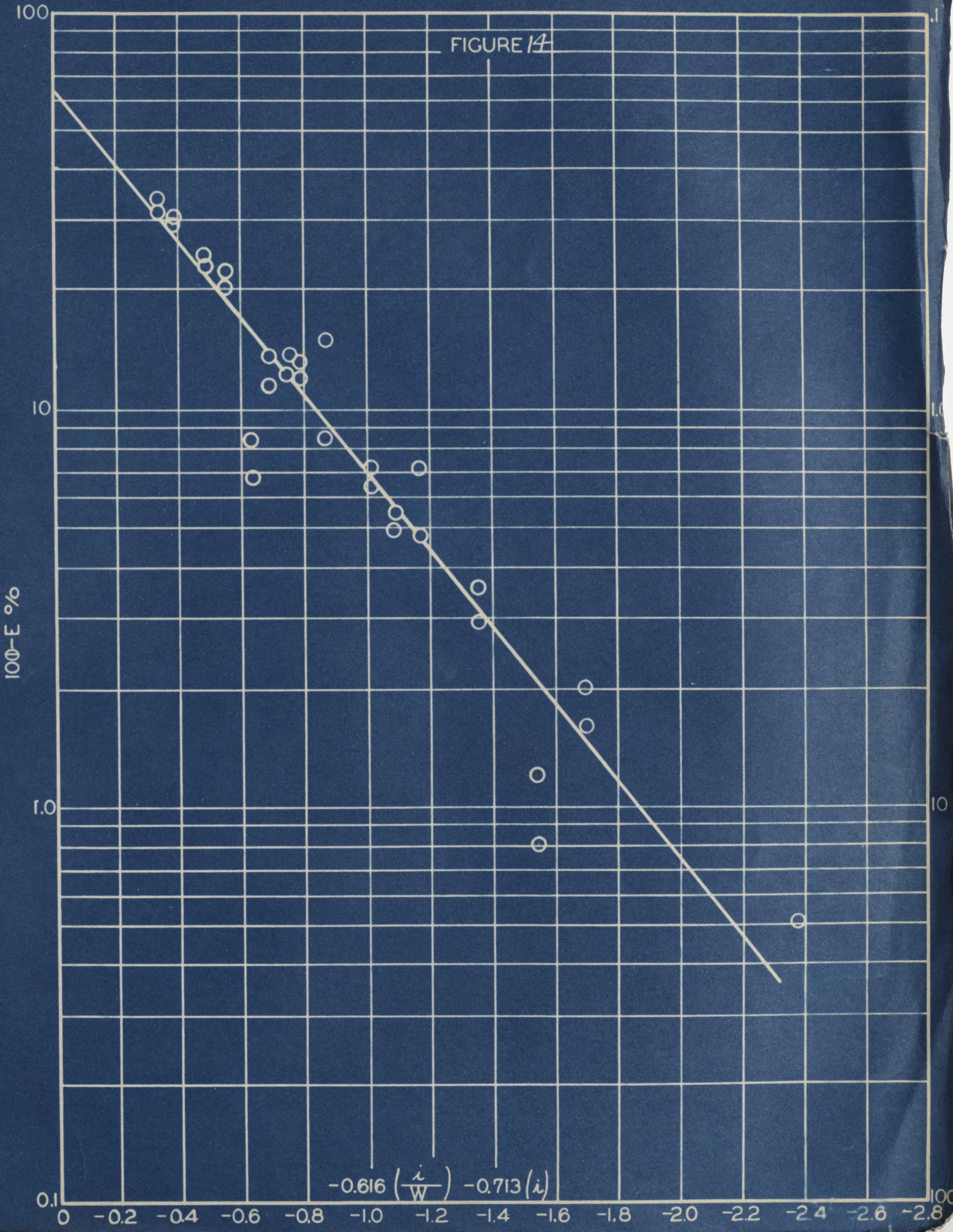
These data are well represented by the following equation~~s~~:

$$\log (1-E_M) = -0.0616 \left(\frac{i}{w}\right) - 0.713 (i) - 0.193 \quad - - - - (48a)$$

Figure (14) shows values of $(1-E_M)$ for Runs 12A to 43A plotted against the terms in Equation 48a involving i and w.

The results of a previous set of liquid depth and slot width studies made by Messrs. Page and Wicker together with those plotted in Figures (11+12) are shown on Figure (15), $1 - E_M$ on a log scale being plotted against the reciprocal of slot width on a straight scale. It will be noticed that while the earlier data yields straight lines on this plot liquid depth does not appear to have much effect at the deeper liquid depths. It was suspected that the overflow from the plate section was running down the vapor riser thus preventing the liquid depth building up to the height of the overflow pipe. This was confirmed by making runs (Runs 167 to 187) at lower vapor velocities. A decrease in efficiency at lower vapor velocities was obtained. At the lower vapor rates a smaller head of liquid sufficed to cause liquid to run down the vapor riser thus decreasing the liquid depth. For runs 12A to 43A, the

FIGURE 14


100
10
1.0
0.1
.1
1.0
10
100
100-E %
$-0.616\left(\frac{i}{W}\right) -0.713(i)$
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
-2.6
-2.8

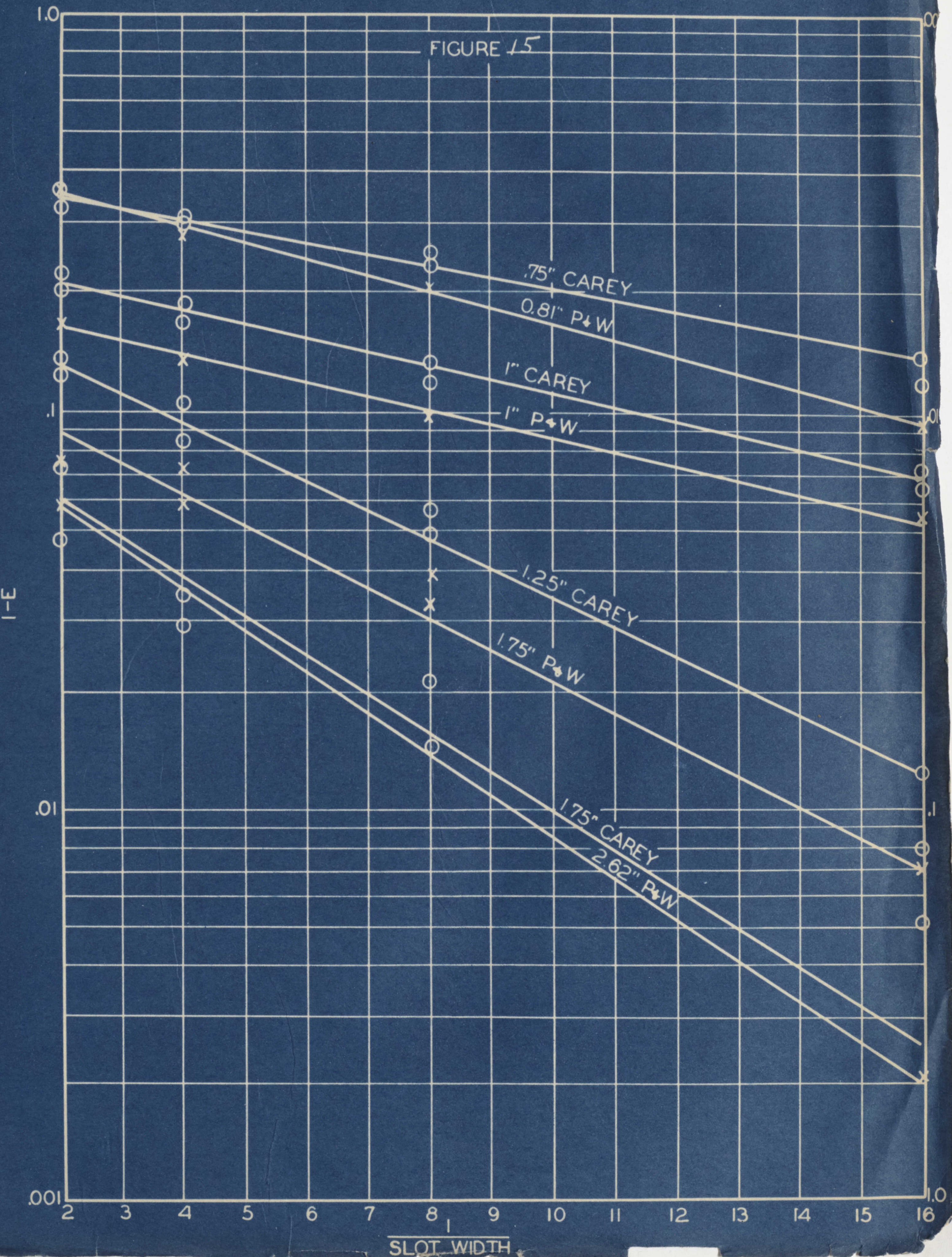


FIGURE 15

1.0
.1
.01
.001
1-E
.00
.01
.1
1.0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
1 / SLOT WIDTH
.75" CAREY
0.81" P+W
1" CAREY
1" P+W
1.25" CAREY
1.75" P+W
1.75" CAREY
2.62" P+W

the height of the vapor riser was increased to 2 5/8", a height greater than the highest liquid depth studied. This change yielded the consistent results already discussed.

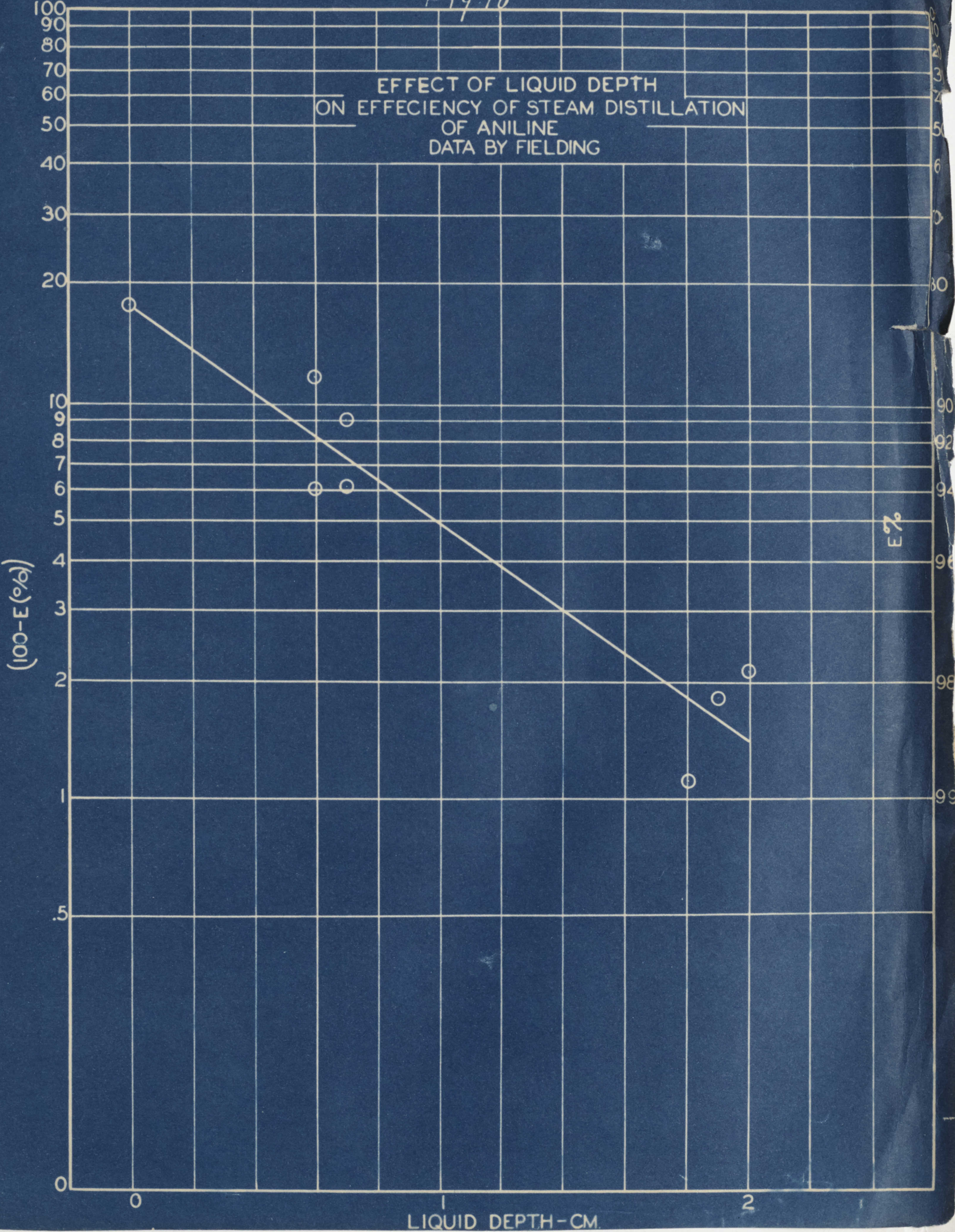
The correlation yielded by the data discussed in this section furnishes conclusive proof of the correctness of the manner in which the terms involving bubble size and time of contact appear in the efficiency equation. The mechanism of the rectification process is undoubtedly entirely confined to bubbling action in these experiments, the superficial vapor velocity being sufficiently low, e.g. 0.2 ft/sec., so that no spraying effect should be involved while data shows the free liquid surface contact effect to be negligible at this vapor velocity.

VIII-E. EFFECT OF LIQUID DEPTH ON EFFICIENCY OF STEAM DISTILLATION.

Data obtained by Fielding (34) include the effect of liquid depth on the efficiency of steam distillation of Aniline. These data were obtained in a small steam still surrounded by a thermostatic bath, the temperatures of the bath being maintained slightly higher than the temperature of the Aniline in the still. The steam was passed into the Aniline in the still by means of a bubble tip consisting of an inverted glass funnel about 0.5 inch in diameter. Fielding concluded that liquid depth had very little effect above a depth of 1 cm., but that below 0.5 cm. efficiency drops off rapidly with decrease in liquid depth.

Equations 36 and 39 show that the same factors influence vaporization efficiency in steam distillation as are involved in plate efficiency. Therefore for a given material a plot of log $(1 - E_V)$ against liquid depth should yield a straight line, if times of contact is proportional to liquid depth. Certain of Fielding's data are so plotted in Figure (16). The liquid depths reported are evidently measured from the bubbler tip to the liquid surface. Fielding carried the liquid depths up to 10.9 cm., but in all cases for liquid depths

Fig 16



EFFECT OF LIQUID DEPTH ON EFFECIENCY OF STEAM DISTILLATION OF ANILINE
DATA BY FIELDING

greater than 3 cm. the efficiencies reported are 100% or greater. Inspection of Figure (16) shows that for a depth of 3 cm. efficiency may be expected to be 99+%. The probable experimental error and inaccuracies in the vapor pressure data used render these data at the deeper liquid depths of little value.

It may be safely concluded from this interpretation of Fielding's data that an equation of the form of Equations 36 or 37 correctly relates the several factors influencing the efficiency of steam distillation in a steam still. More data are required to examine the other factors in the efficiency relation quantitatively however.

VIII-F. LIQUID AND VAPOR TEMPERATURE RELATIONS ON THE PLATE OF A RECTIFYING COLUMN.

Ror Runs 1B to 45B in the single plate column temperatures of both the plate liquid and of the vapor leaving the plate were measured. It was observed that the liquid and vapor temperatures only approached one another when conditions were such that plate efficiency approached 100%. Consequently Newton's Law for the transfer of sensible heat from vapor to liquid was integrated for conditions on a plate resulting in Equation (41)

$$E_T = \frac{t_1 - t_2}{t_1 - t_L} = 1 - e^{\frac{-HS\theta}{M_c V'}}$$

Comparing with Equation 27, H replaces $\frac{k_m}{X}$ while M_c is introduced into the denominator of the exponential term. The factors S, θ and V' remain the same.

Table (8) affords a means for comparison of the several temperatures measured and calculated. Item 3 gives the composition of the vapor entering the plate, which by a material balance is identical with the composition of the plate liquid. Under Item 4 are the compositions of the vapor leaving the plate, these being the same as the compositions of the reflux liquids returned to the plate. The temperatures of the vapor from the still determined from the composition of the liquid in the still by use of Noyes and Warfle's(35) boiling point data for alcohol-water mixtures are listed under Item 5. Item 6 gives the observed plate liquid temperature, while Item 7 gives the boiling temperature of the plate liquid from Noyes and Warfle's data. Item 8 gives the observed temperature of the vapor leaving the plate. Item 9 gives the temperature of the reflux estimated from Noyes and Warfle's data. (Vertical reflux condensers returned the vapor from the plate as total reflux so the assumption

TABLE 8

Comparison of Temperatures at Various Points in

Single Plate Column

- - -

1 Run No.	2 Heat Input Watts	3 Mol. frac. Alc. in Vapor from still = X_p	4 Mol. frac. Alc. in Vapor from plate = X_R	5 Temp. Vapor from still °C (calc.	6 Temp. liq. on plate °C (Obs.)	7 Boiling Point Plate Liq. °C (calc.)	8 Temp. Vapor leaving Plate °C (Obs.)	9 Temp. Reflux °C (calc.)	10 E_M
1B	2200	.3355	.5555	90.2	81.2	81.2	82.1	79.3	87.6
2B	2180	.3380	.5565	90.0	81.3	81.1	82.1	79.3	87.3
3B	3780	.3035	.5285	91.2	82.0	81.6	83.3	69.5	83.3
4B	3780	.2950	.5255	91.4	82.1	81.7	83.4	79.5	83.6
5B	4260	.2690	.5150	92.6	82.4	82.2	83.9	79.7	84.3
6B	4260	.2665	.5055	92.6	82.4	82.3	84.0	79.8	81.5
7B	1600	.2965	.5320	91.8	81.8	81.8	82.8	79.6	85.5
8B	1600	.2950	.5330	91.8	81.9	81.8	82.9	79.5	86.2
9B	1100	.3050	.5405	91.4	81.8	81.7	82.5	79.5	87.3
10B	1080	.3080	.5420	91.4	81.8	81.7	82.5	79.5	87.3
11B	3160	.2655	.5025	92.6	82.2	82.2	83.6	79.8	80.9
12B	3200	.2575	.5010	92.8	82.2	82.4	83.7	79.8	81.3
13B	2680	.2730	.5055	92.4	82.2	82.1	83.4	79.8	80.5
14B	2640	.2515	.4925	93.4	82.5	82.6	83.9	80.0	79.9
15B	2120	.2600	.5085	93.0	82.4	82.4	83.6	79.8	83.7
16B	1640	.2770	.5185	92.5	82.3	82.1	83.3	79.8	84.2
17B	2020	.2510	.4635	93.4	82.6	82.7	85.4	80.3	70.2
18B	3040	.2410	.4446	93.7	82.9	82.8	86.0	80.4	66.0
19B	2000	.3000	.4880	92.0	82.2	82.0	84.7	80.2	68.8
20B	3040	.2835	.4745	92.5	82.4	82.3	85.0	80.3	67.6

Table 8 (Continued)

1	2	3	4	5	6	7	8	9	10
Run No.	Heat Input Watts	Mol. frac. Alc. in Vapor from still = X_p	Mol. frac. Alc. in Vapor from plate = X_R	Temp. Vapor from still °C (calc.)	Temp. liq. on plate °C (Obs.)	Boiling Point Plate Liq. °C (calc.)	Temp. Vapor leaving Plate °C (Obs.)	Temp. Reflux -°C (calc.)	E_M
21B	4040	.2790	.4580	92.7	82.6	82.3	85.5	80.4	62.7
22B	4360	.1635	.3595	96.1	84.5	84.3	89.3	81.3	57.2
23B	4400	.1455	.3470	96.2	84.8	84.4	89.3	81.2	58.0
24B	3900	.2545	.4460	92.9	82.4	82.4	85.5	80.2	63.7
25B	2960	.2790	.4680	92.2	82.2	82.0	85.0	80.0	66.2
26B	2000	.2840	.4740	92.0	82.0	82.0	84.7	80.0	67.3
27B	1980	.2825	.4730	92.3	82.2	82.1	84.9	80.1	67.1
28B	2000	.2832	.4775	92.3	82.2	82.0	84.9	80.1	68.7
29B	2980	.2715	.4485	92.7	82.4	82.3	85.7	80.3	61.1
30B-	2960	.2695	.4510	92.7	82.4	82.3	85.8	80.3	62.3
31B	3900	.2600	.4320	93.0	82.6	82.4	86.4	80.5	57.8
32B	3900	.2505	.4300	93.3	82.6	82.6	86.4	80.5	59.3
33B	4340	.1645	.3600	95.7	84.3	84.2	88.7	81.2	57.0
34B	1480	.2845	.4775	91.8	--	81.8	84.3	79.8	68.2
35B	960	.2950	.4880	91.5	--	81.7	83.8	79.8	69.9
36B	1940	.2685	.4570	92.4	82.3	82.2	84.9	80.1	64.5
37B	1480	.2750	.4635	92.2	82.2	82.1	84.7	80.1	65.4
38B	950	.2968	.4885	91.6	81.9	81.8	83.9	79.8	69.7
39B	4340	.2362	.4290	93.3	82.9	82.7	86.5	80.4	59.0
40B	3480	.2430	.4420	93.2	82.6	82.6	85.9	80.3	64.9
41B	2960	.2585	.4575	92.8	82.6	82.4	85.3	80.1	66.7
42B	1520	.2885	.4975	92.1	82.4	82.0	83.8	79.8	74.6
43B	2060	.2760	.4850	92.4	82.5	82.2	84.3	79.9	72.8
44B	3080	.2670	.4686	92.6	82.5	82.3	84.8	80.0	68.7

Table 8 (Continued)

1	2	3	4	5	6	7	8	9	10
Run No.	Heat Input Watts	Mol. frac. Alc. in Vapor from still = X_p	Mol. frac. Alc. in Vapor from plate = X_R	Temp. Vapor from still °C (Calc.	Temp. Liq. on plate °C (Obs.)	Boiling Point Plate Liq. °C (calc.)	Temp. Vapor Leaving Plate °C (Obs.)	Temp. Reflux °C. (Calc.)	E_M
45B	4080	.2450	.4515	93.3	82.6	82.6	85.6	80.2	67.7
46B	1980	.2778	.5535	93.2* 92.8	82.3	82.4	82.45	79.8	96.2
47B	1940	.2700	.5390	93.4* 93.1	82.3	82.5	82.5	79.9	92.5
12A	1600	.3422	.5636	89.7	81.2	81.0	81.8	79.1	89.5
13A	1600	.3395	.5675	89.8	81.2	81.1	81.8	79.1	91.5
14A	1600	.3265	.5805	90.3	81.5	81.2	81.5	79.1	98.8
15A	1600	.3145	.5800	90.8	81.6	81.3	81.6	79.0	100.0
16A	1600	.2910	.5315	91.5	81.8	81.6	82.7	79.4	86.2
17A	1600	.2880	.5335	91.6	81.9	81.7	82.8	79.4	87.7
18A	1600	.3270	.5712	90.3	81.5	81.2	81.7	79.1	95.1
20A	1600	.3225	.5635	90.6	81.6	81.3	81.9	79.2	92.9
21A	1600	.3185	.5680	90.7	81.6	81.4	81.9	79.2	95.3
22A	1600	.3140	.5770	90.9	81.6	81.4	81.7	79.1	99.5
23A	1600	.3055	.5750	91.2	81.8	81.5	81.8	79.1	100.0
24A	1600	.2900	.5520	91.8	81.9	81.8	82.3	79.3	93.9
28A	1600	.3125	.5335	91.1	81.6	81.5	83.1	79.5	83.2
29A	1600	.3080	.5265	91.2	81.7	81.6	83.1	79.5	81.6
30A	1600	.2908	.5518	91.8	82.1	81.8	82.6	79.4	93.6
31A	1600	.2860	.5475	91.9	82.3	81.9	82.8	79.4	92.9
32A	1600	.2800	.5275	92.2	82.4	82.0	83.6	79.6	86.8
36A	1600	.2905	.4855	91.9	82.2	81.9	84.7	79.9	70.0
37A	1600	.2855	.4835	92.0	82.3	82.0	84.8	79.9	70.3
38A	1600	.2865	.5290	92.0	82.5	82.0	83.5	79.6	86.2

*Observed

that the reflux returns at its boiling point is warranted).

By reference to Table (8) it will be noted that the vapor entering the plate is always a number of degrees above its dew point. The compositions of entering vapor and plate liquid being identical, Item 7 gives the dew point of the entering vapor. During the passage of the vapor through the plate liquid it loses in sensible heat but rectification is enriching the vapor in more volatile material causing the dew point to fall. Consequently the vapor emerges from the plate liquid above its dew point in all cases.

If Items 6 and 7 are compared, it is seen that the temperature of the plate liquid is its boiling temperature within the limits of the accuracy of the boiling point data and the observed temperature. That the temperature of the plate liquid should be nearly identical with its boiling point may be explained for this case as follows. Comparison of Items 6 and 9, Table (8) shows that the reflux must be warmed from 2° to 3°C. to reach plate temperature whereas the temperature drop of the vapor is from 7° to 9°C. Consequently the sensible content of the vapor is sufficient to heat the reflux up to plate temperature, as may be shown by a sample heat balance employing Run 17B as an example:

Data:

Compositions entering vapor = 0.2510 m.f. alcohol

" exit " = 0.4635 " " "

Temp. entering " = 93.4°C.

" exit " = 85.4°C.

" plate liquid = 82.6°C.

" reflux " = 80.3°C.

M_{cp} Alcohol vapor = 20.9

M_{cp} H_2O " = 8.3

M_c reflux liquid = 0.95

Basis 1 mol vapor entering plate section:

Heat content entering vapor above 80.3°C =

(0.2510 x 20.9 + 0.749 x 8.3)(93.4°-80.3°) = 140.3 cal.

Heat content exit vapor above 80.3°C =

(0.4635 x 20.9 + 0.5635 x 8.3)(85.4° - 80.3°) = 72.0 cal.

Sensible heat loss of vapor = 140.3 - 720 = 68.3 cal.

Heat required to warm reflux from 80.3°C to 82.6° =

0.95 x (.4635 x 46 + .5365 x 18)(82.6°-80.3°)= 67.5 cal.

Unaccounted for = 68.3 - 67.5 = 0.8 cal. or 1.2%.

Fall of the liquid temperature below its boiling point is impossible as this would furnish additional temperature difference for sensible heat transfer. Transfer of sensible heat in excess of the amount required to warm the reflux to plate temperature will be absorbed by boiling off the liquid with release of equilibrium vapor. This latter effect however cannot have an appreciable effect on plate efficiency as sensible heat changes are always small compared with latent heat changes. For example the total sensible heat loss of the vapor per mol from the heat balance given = 68.3 calories, compared with a molal latent heat of 9500 calories.

A comparison of plate temperature data for runs in the 7 plate column with the boiling points of the liquid samples shows the plate temperatures to be on the average several tenths of a degree higher than the boiling temperatures of the plate liquids. This can be ascribed to two causes: (1) the bubble streams probably impinged on the thermometer bulbs resulting in a higher temperature reading than corresponded to actual plate temperature. (2) the pressure gradient through the column was sufficient to raise the boiling point of the liquid slightly above its value under existing barometric pressure. Therefore, the plate liquid temperature was undoubtedly at its boiling point in these runs. (N.B. Allen and Eaton measured vapor temperatures rather than liquid so their data should be excluded from this comparison).

Generalizing as to probable plate liquid temperature in a column, it is reasonable to assume that the temperatures will be close to the boiling temperatures of the plate liquids under the pressure conditions in the column. Any considerable fall of liquid temperature below its boiling point will result in partial condensation of vapor tending to restore the temperature to a higher level while the boiling point of the liquid fixes the upper temperature limit.

Figure (17) and Table (9) summarize the data on "Temperature Efficiency" and its comparison with plate efficiency. From Figure (17) in which "Temperature Efficiency" is plotted against plate efficiency it is seen that the one is directly proportional to the other, both reaching 100% together, i.e. the temperature of the vapor leaving the plate is the same as that of the plate liquid only when conditions are such that plate efficiency is 100%. (Cf. Runs 15A and 23A, Table (8)). The line drawn through the experimental points is displaced slightly both in slope and position from a 45° line passing through the origin, temperature efficiency being higher than the corresponding plate efficiency. This is due to the fact that in the integration of Newton's Law of heat transfer, resulting in Equations 40 and 41 constancy of

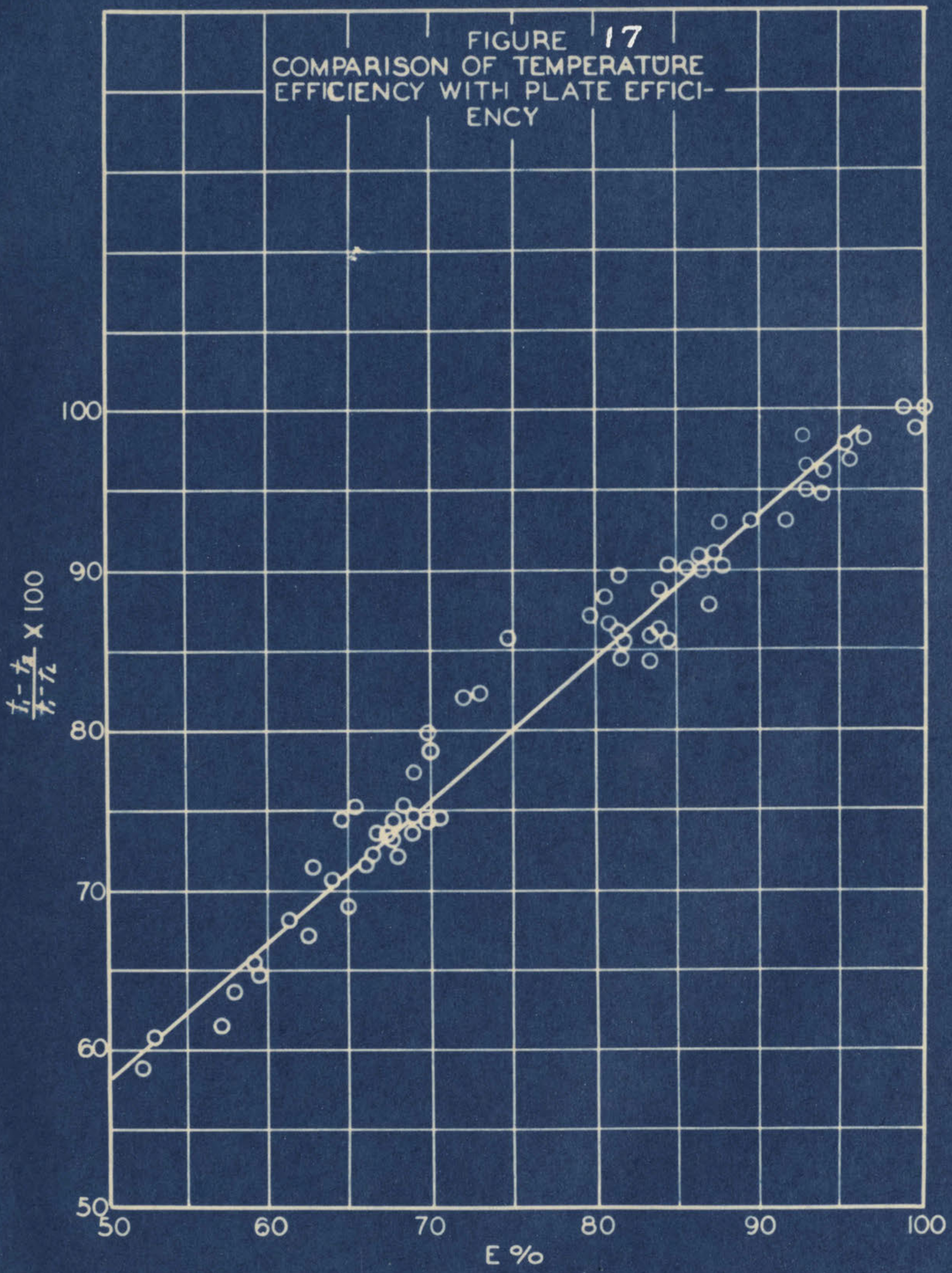


FIGURE 17
COMPARISON OF TEMPERATURE EFFICIENCY WITH PLATE EFFICIENCY

TABLE 9

Calculation of $\frac{t_1 - t_2}{t_1 - t_L}$ and Comparison with E

1	2	3	4	5	6
Run No.	Temp. Vapor Entering Plate °C t_1	Temp. Vapor Leaving Plate °C t_2	Temp. Liq. on Plate °C t_L	$\frac{t_1 - t_2}{t_1 - t_L}$ x 100	E
1B	90.2	82.1	81.2	90.0	87.6
2B	90.0	82.1	81.3	90.8	87.3
3B	91.2	83.3	82.0	85.8	83.3
4B	91.4	83.4	82.1	86.0	83.6
5B	92.6	83.9	82.4	85.4	84.3
6B	92.6	84.0	82.4	84.3	81.5
7B	91.8	82.8	81.8	90.0	85.5
8B	91.8	82.9	81.9	89.9	86.2
9B	91.4	82.5	81.8	92.8	87.3
10B	91.4	82.5	81.8	92.8	87.3
11B	92.6	83.6	82.2	86.5	80.9
12B	92.8	83.7	82.2	86.0	81.3
13B	92.4	83.4	82.2	88.1	80.5
14B	93.4	83.9	82.5	87.0	79.9
15B	93.0	83.6	82.4	88.6	83.7
16B	92.5	83.3	82.3	90.1	84.2
17B	93.4	85.4	82.6	74.1	70.2
18B	93.7	86.0	82.9	71.3	66.0
19B	92.0	84.7	82.2	74.5	68.8
20B	92.5	85.0	82.4	74.2	67.6
21B	92.7	85.5	82.6	71.3	62.7
22B	96.1	89.3	84.5	58.6	57.2
23B	96.2	89.3	84.8	60.5	58.0
24B	92.9	85.5	82.4	70.5	63.7
25B	92.2	85.0	82.2	72.0	66.2
26B	92.0	84.7	82.0	73.0	67.3
27B	92.3	84.9	82.2	73.3	67.1
28B	92.3	84.9	82.2	73.3	68.7
29B	92.7	85.7	82.4	68.0	61.1
30B	92.7	85.8	82.4	67.0	62.3

1	2	3	4	5	6
Run No.	t_1	t_2	t_L	$\frac{t_1 - t_2}{t_1 - t_L}$ x 100	E
31B	93.0	86.4	82.6	63.5	57.8
32B	93.3	86.4	82.6	64.5	59.3
33B	95.7	88.7	84.3	61.4	57.0
34B	91.8	84.3	81.8	75.0	68.2
35B	91.5	83.8	81.7	78.5	69.9
36B	92.4	84.9	82.3	74.2	64.5
37B	92.2	84.7	82.2	75.0	65.4
38B	91.6	83.9	81.9	79.5	69.7
39B	93.3	86.5	82.9	65.4	59.0
40B	93.2	85.9	82.6	68.8	64.9
41B	92.8	85.3	82.6	73.5	66.7
42B	92.1	83.8	82.4	85.6	74.6
43B	92.4	84.3	82.5	82.0	72.8
44B	92.6	84.8	82.5	77.2	68.7
45B	93.3	85.6	82.6	71.9	67.7
46B	93.2	82.5	82.3	98.1	96.2
47B	93.4	82.5	82.3	98.2	92.5
12A	89.7	81.8	81.2	92.9	89.5
13A	89.8	81.8	81.2	93.0	91.5
14A	90.3	81.5	81.5	100.0	98.8
15A	90.8	81.6	81.6	100.0	100.0
16A	91.5	82.7	81.8	90.7	86.2
17A	91.6	82.8	81.9	90.7	87.7
18A	90.3	81.7	81.5	97.7	95.1
20A	90.6	81.9	81.6	96.5	92.9
21A	90.7	81.9	81.6	96.8	95.3
22A	90.9	81.7	81.6	98.9	99.5
23A	91.2	81.8	81.8	100.0	100.0
24A	91.8	82.3	81.9	96.0	93.9
28A	91.1	83.1	81.6	84.2	83.2
29A	91.2	83.1	81.7	85.3	81.6
30A	91.8	82.6	82.1	94.8	93.6
31A	91.9	82.8	82.3	94.8	92.9
32A	92.2	83.6	82.4	87.7	86.8
36A	91.9	84.7	82.2	74.2	70.0
37A	92.0	84.8	82.3	74.2	70.3
38A	92.0	83.5	82.5	89.5	86.2

the molal heat capacity of the vapor was assumed. The concurrent rectification process causes a considerable change in molal specific heat as the vapor passes through the plate. The molal heat capacity of alcohol vapor being greater than that of water vapor (20.9 vs. 8.3) the vapor emerges from the liquid at a lower temperature than would be required for the transfer of a given amount of sensible heat were the molal heat capacity constant.

IX - CONCLUSIONS

The major conclusion to be derived from the rectification studies discussed is that plate efficiency is satisfactorily defined by an equation obtained by integration from the rigorous film diffusion equations under the hypothesis that the gas film resistance is controlling:

$$E_M = \frac{y_n - y_{n-1}}{y_n^* - y_{n-1}} = 1 - e^{\frac{-k_m S \theta}{X V'}}$$

For conditions where the ratio of the molal rates of material transfer in opposite directions through the film deviates appreciably from unity the following expression defines the variables influencing plate efficiency:

$$\int_{y_{n-1}}^{y_n} \left(\frac{dy}{\ln \dfrac{1-\left(1-\frac{Mr_A}{Mr_B}\right)y^*}{1-\left(1-\frac{Mr_A}{Mr_B}\right)y}} \right) = \left(\frac{k_m}{X}\right) \left(\frac{S}{V'}\right) \left(\frac{1}{1-\frac{Mr_A}{Mr_B}}\right) \theta$$

At higher vapor rates the bubbling mechanism to which these equations apply is supplemented by an additional source of liquid- vapor contact due to spray thrown up from the plate liquid leading to an increase in plate efficiency.

Plate efficiencies for a given column may be estimated with a fair degree of accuracy for various binary mixtures if the efficiency obtained with one mixture is known.

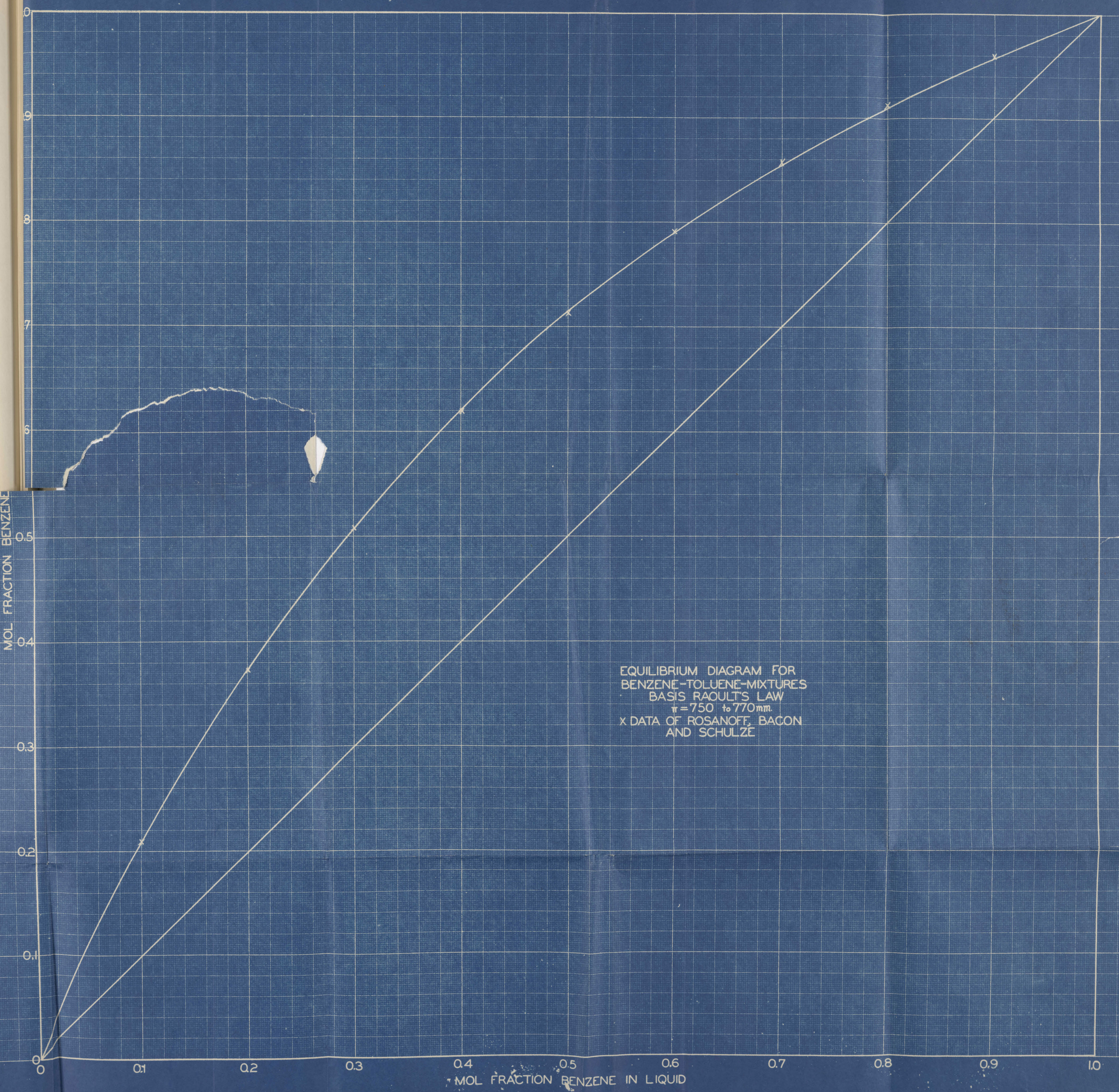
The quantitative effects of variations in cap slot width and liquid depths upon plate efficiency are correctly indicated by the efficiency relation, and the importance of these factors in design are emphasized.

X- APPENDIX

A. LIQUID-VAPOR EQUILIBRIA DATA

1. Liquid-Vapor Equilibria of Benzene-Toluene Mixtures.

It has been generally assumed that Benzene-Toluene mixtures represent a case in which Raoult's Law may be expected to hold with little deviation. Since in problems of rectification liquid-vapor equilibria are most conveniently represented on a plot showing the composition of vapor given off by boiling liquid mixtures (i. e. pressure constant, variable temperature), the so-called y - x diagram for Benzene-Toluene was computed from the vapor pressure data of Young and Kahlbaum respectively, assuming Raoult's Law. These results are given in Table (10) and Figure (18). A search of the literature revealed that Rosanoff, Bacon and Schulze(26) had made a series of isothermal measurements of the total vapor pressures of Benzene-Toluene mixtures, as given in Table (11). Employing thermodynamic reasoning these authors then calculated the y - X values for these mixtures at their boiling points under constant pressure. These data are given in Table (12) and are shown plotted on the diagram calculated by assuming Raoult's Law, Figure (18). The points from



EQUILIBRIUM DIAGRAM FOR
BENZENE-TOLUENE-MIXTURES
BASIS RAOULT'S LAW
π = 750 to 770 mm.
X DATA OF ROSANOFF, BACON
AND SCHULZE

TABLE 10

Calculation of Boiling Points and y - x Values for Benzene-Toluene Mixtures.

Basis - Raoult's Law

1	2	3	4	5	6	7	8	9	10	11	12
Temp. °C	P_B m.m.Hg.	P_T m.m. Hg.	π m.m.Hg.	$x=\frac{\pi-P_T}{P_B-P_T}$	$y=\frac{P_B x}{\pi}$	π m.m.Hg.	$x=\frac{\pi-P_T}{P_B-P_T}$	$y=\frac{P_B x}{\pi}$	π m.m.Hg	$x=\frac{\pi-P_T}{P_B-P_T}$	$y=\frac{P_B x}{\pi}$
82.00	802.0	312.0	760	0.9143	0.9648	750	0.8939	0.9559	770	0.9347	0.9735
84.00	852.0	333.0	"	0.8227	0.9223	"	0.8035	0.9128	"	0.8420	0.9317
86.00	903.0	355.5	"	0.7388	0.8778	"	0.7205	0.8675	"	0.7571	0.8879
88.00	957.0	379.5	"	0.6589	0.8297	"	0.6416	0.8187	"	0.6762	0.8404
90.00	1016.1	404.5	"	0.5813	0.7772	"	0.5649	0.7653	"	0.5976	0.7886
92.00	1078.0	432.0	"	0.5077	0.7201	"	0.4923	0.7076	"	0.5232	0.7325
94.00	1140.0	462.0	"	0.4395	0.6593	"	0.4248	0.6457	"	0.4543	0.6726
96.00	1204.0	492.5	"	0.3760	0.5957	"	0.3619	0.5810	"	0.3900	0.6098
98.00	1271.0	525.0	"	0.3150	0.5268	"	0.3016	0.5111	"	0.3284	0.5421
100.00	1344.3	559.0	"	0.2560	0.4528	"	0.2432	0.4359	"	0.2687	0.4691
102.00	1419.0	591.0	"	0.2041	0.3811	"	0.1920	0.3633	"	0.2162	0.3982
104.00	1495.0	625.5	"	0.1547	0.3043	"	0.1432	0.2854	"	0.1662	0.3227
106.00	1575.0	663.5	"	0.1059	0.2195	"	0.0949	0.1993	"	0.1168	0.2389
108.00	1659.0	704.5	"	0.0581	0.1278	"	0.0477	0.1055	"	0.0686	0.1478

TABLE 12

Benzene-Toluene Equilibrium Data (Isopiestic, π = 750 m.m.)
Calculated from Isothermal Data by Rosanoff, Bacon & Schulze, J.A.C.S. XXXVI, 1999 (1914)

\- - -

Mol % C_6H_6 in Liquid	Mol % C_6H_6 in Vapor	B. P. at 750 m.m. °C
0	0	109.59
10	20.8	104.85
20	37.2	101.00
30	50.7	97.55
40	61.9	94.60
50	71.3	91.85
60	79.1	89.30
70	85.7	86.85
80	91.2	84.55
90	95.9	82.55
95	98.0	81.00
100	100.0	79.70

Calculated by:

$$\frac{d\pi}{dx} = \frac{P_1 - P_2}{\log P_1 - \log P_2} \text{ by } \frac{[p_1(1-x)]}{p_2 x}$$

TABLE 11

Benzene-Toluene Equilibrium Data (Isothermal, t=79.70°C

Data of Rosanoff, Bacon & Schulze, J.A.C.S. XXXVI, 1999, (1914)

Mol % C_6H_6 in Liquid	Mol % C_6H_6 in Vapor	Observed m.m. Hg.	Calculated m.m. Hg.
100.00	100.00	748.7	748.8
95.65	98.27	729.0	728.9
91.89	96.72	711.4	711.6
82.43	92.49	668.0	667.7
73.27	87.82	624.9	625.0
63.44	81.97	579.2	579.2
54.51	75.74	537.5	537.8
43.52	66.56	487.0	487.2
33.83	56.75	443.1	443.0
22.71	42.95	392.8	392.5
11.61	25.30	341.5	342.0
0	0	288.5	288.4

$$= 288.438 + 466.519X - 56.464X^2 + 100.281x^3 - 49.971X^4$$

TABLE 13

ORIGINAL DATA, EXPERIMENTAL DETERMINATION OF BOILING POINTS OF BENZENE-TOLUENE MIXTURES.

1 Run No.	2 Wt. Flask + Toluene gms.	3 Wt. Flask gms.	4 Wt. Toluene gms.	5 Wt. Flask+ Sample gms.	6 Wt. Sample gms.	7 Wt. Benzene gms.	8 Mol. Frac C_6H_6	9 Barometer (Corr. to °C)m.m.Hg.	10 Boiling Point °C(corr.)
1	82.4073	42.5344	39.8729	86.9120	44.3776	4.5047	0.1176	760.9	105.30
2	83.0857	46.2364	36.8493-	91.5843	45.3479	8.4486	0.2138	"	101.71
3	74.6736	41.9359	32.7377	87.4855	45.5496	12.8119	0.3158	"	98.19
4	76.8779	49.1891	27.6888	97.5643	48.3752	20.6864	0.4684	761.4	93.29
5	68.8354	42.5008	26.3346	89.2234	46.7226	20.3880	0.4773	"	93.00
6	59.0223	39.7062	19.3161	84.8539	45.1477	25.8316	0.5722	762.2	89.21
7	46.2640	30.3973	15.8667	76.2484	45.8511	29.9844	0.6903	"	87.25
8	52.5545	42.3630	10.1915	88.5077	46.1447	35.9532	0.8062	763.0	84.46
9	49.8398	44.5583	5.2815	90.5444	45.9861	40.7046	0.9008	763.3	82.29
			"Pure" Benzene					759.9	80.07
			"Pure" Toluene					763.3	110.41

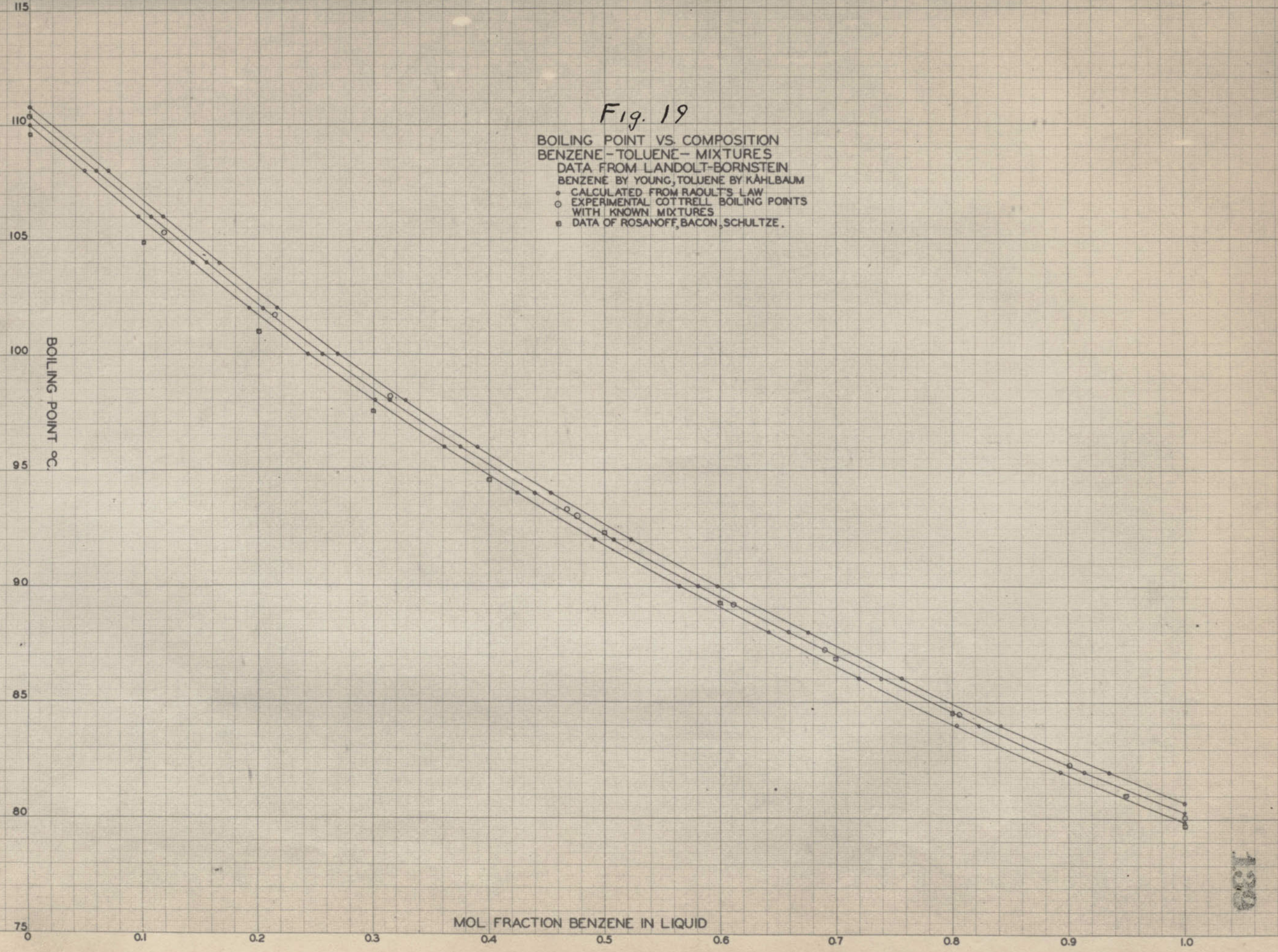


Fig. 19

BOILING POINT VS. COMPOSITION
BENZENE - TOLUENE - MIXTURES
DATA FROM LANDOLT-BORNSTEIN
BENZENE BY YOUNG, TOLUENE BY KÅHLBAUM

- • CALCULATED FROM RAOULT'S LAW
- ○ EXPERIMENTAL COTTRELL BOILING POINTS WITH KNOWN MIXTURES
- ▣ DATA OF ROSANOFF, BACON, SCHULTZE.

Rosanoff, Bacon and Schulze's data fall nearly exactly on the curve computed from Raoult's Law.

For analysis of the Benzene-Toluene mixtures it was desired to employ the known boiling points of mixtures under barometric pressure. These data were calculated on the assumption of Raoult's Law and are given in Table (10) and Figure (19). As a further verification of Raoult's Law a series of known mixtures were made up and their boiling points determined. These data are given in Table (13) and are plotted with the calculated curves in Figure (19). It is seen that the experimental points check the computed values within the experimental errors of the boiling point readings.

From the data from these two sources it was concluded that Benzene-Toluene mixtures follow Raoult's Law and equilibrium values calculated on this basis are correct.

2. Liquid-Vapor Equilibria of Carbon-Tetrachloride Toluene Mixtures.

No data were available on the vapor-liquid equilibria of these mixtures. The assumption of Raoult's Law was considered of doubtful accuracy due to the difference in molecular structure between CCl_4 and Toluene. A set of eight determinations of liquid-vapor equilibrium compositions was obtained employing the method of Othmer,(36) using an apparatus designed by Mr. G. L. Mathieson and similar in principle to that to be described in connection with the Alcohol-Water determinations. The same precautions to avoid either refluxing or entrainment were observed as in the case of the Alcohol-Water runs.

The y - x values calculated on the basis of Raoult's Law are given in Table (14) and Figure (20). The experimentally determined points are given in Table (15) and are plotted for comparison on the same diagram with the curve calculated using Raoult's Law. The deviation from Raoult's Law is apparent. Table (16) gives the Raoult's Law deviation factors for the two components of these mixtures.

In the experimental rectification runs with CCl_4-Toluene mixtures equilibrium values from the curve drawn through the experimental points were used.

TABLE 14

Calculation of y - x Values for CCl_4 - Toluene Mixtures Assuming Raoult's Law

1 Temp. °C	2 P_{CCl_4} m.m. Hg.	3 P_T m.m. Hg.	4 π m.m.Hg.	5 $X = \frac{\pi - P_T}{P_{CCl_4} - P_T}$	6 $y = \underline{P_{CCl_4}X}$
76.72	760		760	1.0000	1.0000
80.00	839	291	"	0.8558	0.9447
82.50	901	317	"	0.7586	0.8993
85.00	969	344	"	0.6656	0.8487
87.50	1041	373	"	0.5793	0.7936
90.00	1117	404	"	0.4993	0.7338
92.50	1196	439	"	0.4241	0.6674
95.00	1279	477	"	0.3529	0.5939
97.50	1369	517	"	0.2852	0.5137
100.00	1462	559	"	0.2226	0.4282
102.50	1559	600	"	0.1668	0.3421
105.00	1663	688	"	0.0738	0.1614
107.50	1771	694	"	0.0613	0.1429
110.00	1883	750	"	0.0088	0.0218
110.40		760	"	0	0

TABLE 15

Original Data, Experimental Determination of Liquid-Vapor Equilibrium Relationships for CCl_4 - Toluene Mixtures

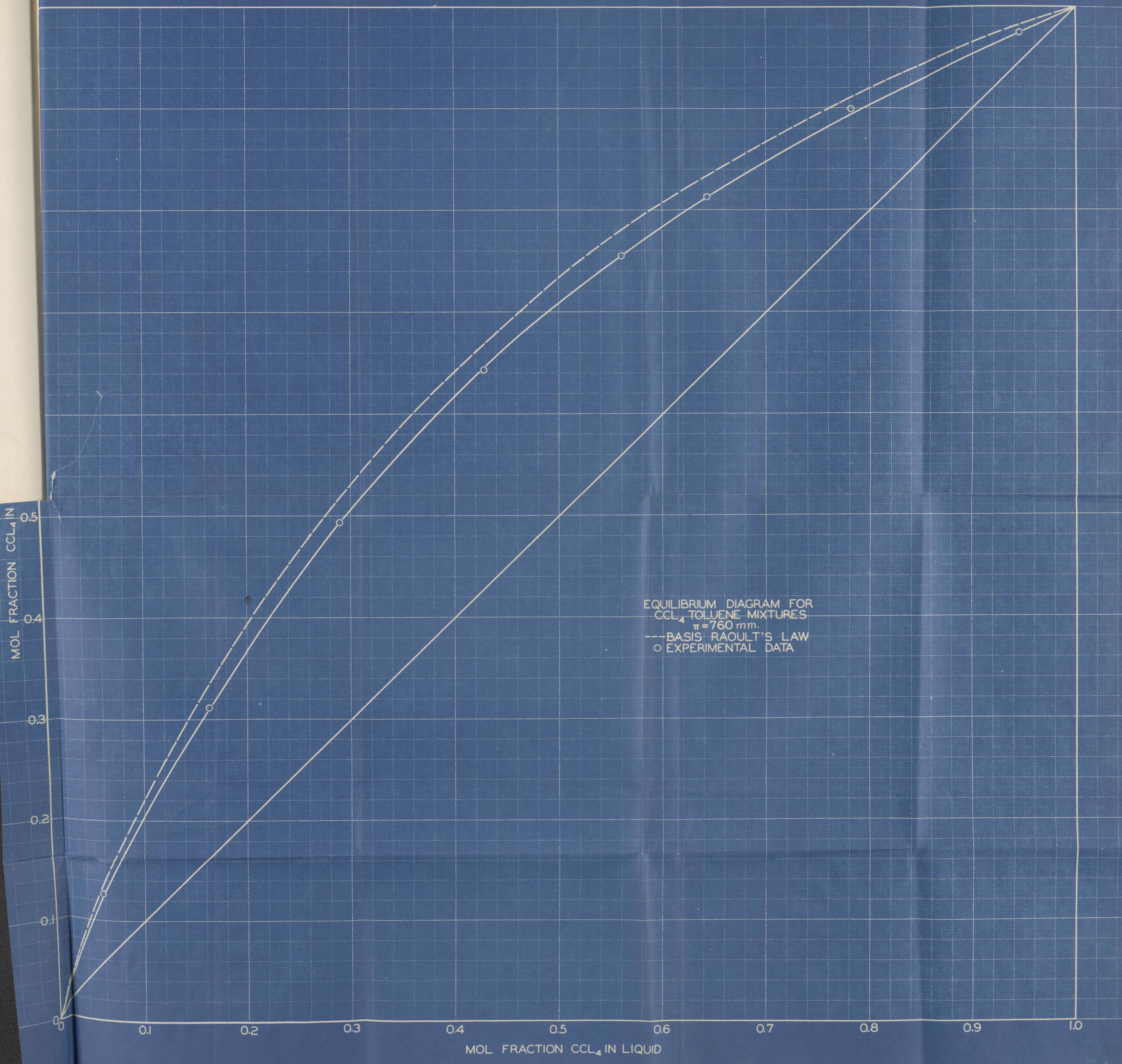
1 Run No.	2 Pressure in Still m.m. Hg.	3 Westphal Reading Liquid Sample	4 Temp Liquid Sample	5 Westphal Reading Vapor Sample	6 Temp. Vapor Sample	7 Mol. Frac. CCl_4 in Liquid	8 Mol Frac. CCl_4 in Vapor
1	762.1	0.9002	24.9	0.9452	25.0	0.0575	0.1265
2	"	0.9700	24.2	1.0731	25.0	0.1625	0.3105
3	"	1.0572	25.0	1.2034	25.0	0.2885	0.4935
4	"	1.1545	25.2	1.3128	25.0	0.4260	0.6425
5	"	1.2529	25.0	1.3965	25.0	0.5605	0.7550
6	"	1.3124	25.0	1.4407	25.0	0.6425	0.8122
7	"	1.5483	23.2	1.5717	23.0	0.9455	0.9735
8	"	1.4185	24.0	1.5114	23.5	0.7820	0.8995

TABLE 16

Raoult's Law Deviation Factors

For CCl_4 - Toluene Mixtures

x_{CCl_4}	y_{CCl_4}	$y = \frac{P_x}{\pi}$	$f_{CCl_4} = \frac{y\ Obs.}{y\ Theo.}$	f_{tol}
0.1	0.2040	0.2100	0.970	1.008
0.2	0.3680	0.3940	0.934	1.041
0.3	0.5050	0.5335	0.947	1.061
0.4	0.6180	0.6435	0.961	1.071
0.5	0.7095	0.7345	0.967	1.094
0.6	0.7835	0.8080	0.970	1.128
0.7	0.8480	0.8680	0.977	1.151
0.8	0.9040	0.9200	0.982	1.200
0.9	0.9540	0.9645	0.990	1.295


EQUILIBRIUM DIAGRAM FOR
CCL4 TOLUENE MIXTURES
π=760 mm.
---BASIS RAOULT'S LAW
○ EXPERIMENTAL DATA
MOL FRACTION CCL4 IN
MOL FRACTION CCL4 IN LIQUID
0
0.1
0.2
0.3
0.4
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

3. Liquid-Vapor Equilibria of Alcohol-Water Mixtures.

An examination of the literature showed considerable data to be available on this subject. A comparison of the various data however revealed wide variations in the y - x curves obtained from the values reported by the several authors, a comparison of which will be presently given.

Due to the disagreement of available data it was considered necessary to obtain another set of experimental determinations. Especial care was exercised in selection of method and technique of application in order to secure data which would stand on their own merit irrespective of checks obtained with any of the previously reported data.

A survey of the literature showed the following methods for obtaining liquid-vapor equilibrium data to have been used or suggested.

(1) Compress a vapor mixture at constant temperature until condensation occurs. This is one of the earliest methods noted. It has obvious disadvantages and so far as known none of the reliable data have been secured by this method.

(2) Distillation of a small portion from a large volume of liquid mixture. Von Zawidiski,(37) Brown,(38) Schfeldt(39) and Carveth(40) appear to have been among the early users of this method. Rayleigh(41) pointed out the desirability of estimation of the change in liquid composition upon distillation of a portion from a liquid mixture and derived for this purpose his well-known batch distillation equation. This method should yield good results if suitable precautions are taken to avoid refluxing or entrainment.

(3) Saturate an inert gas with the constituents of a mixture by bubbling it through the mixture. This was employed by Linebarger(42) and Walker.(43) This method is limited in its applicability and where applied there may be doubt of complete saturation of the inert gas withthe volatile vapor.

(4) Pass a saturated vapor of constant composition through a liquid mixture of the same substance. As long as the liquid is not in equilibrium with the vapor the composition of the liquid changes and therefore both the boiling point and the composition of the escaping vapor change.

(5) A modification of the batch distillation method, devised by Rosanoff (48) and (26) co-workers, consisted in batch distilling a sample, avoiding refluxing, and collecting and analyzing separately successive fractions. The compositions and weights of fraction 1, fractions 1 and 2, etc. are determined and plotted on a composition vapor versus weight of distillate plot. A moderate extrapolation back to zero weight of distillate gives the composition of the first vapor coming off. By reversing the order of calculation, e.g. by taking composition and weight of, say, the 7th fraction, then 7th plus 6th, etc. the composition of the first vapor returned to the residue may be obtained by extrapolation. Thus two pairs of liquid-vapor equilibrium compositions are had for each run made.

A number of analyses must be made for each run in using this method. This method of estimation of the initial vapor composition is directly obtained from experimental data.

(6) Simple continuous distillation without reflux.(49) If conditions are constant the residue and distillate represent a liquid and its equilibrium vapor. The chief experimental difficulty with this method is insuring that

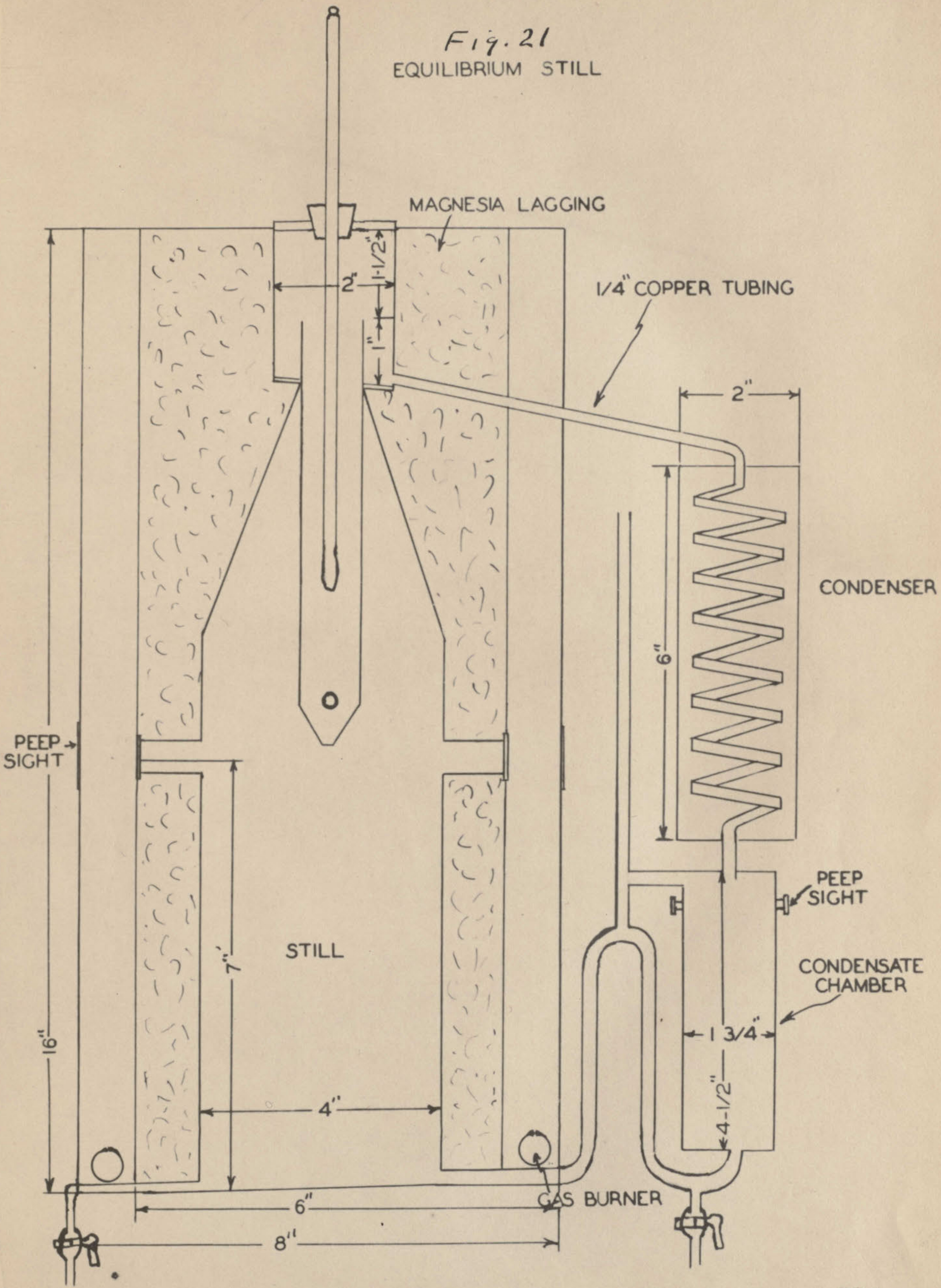
the three steams, feed, distillate and residue are exactly balanced.

(7) Distillation in an apparatus so arranged that after a certain quantity of distillate has collected in the receiver, the receiver overflows back to the still. After this point is reached liquid from the receiver returns to the still at the same rate as condensate falls into the receiver. Recycling of distillate may be continued until the composition of vapor passing over to the receiver is the same as that of the condensate returned to the still. The material in the receiver then represents the composition of vapor in equilibrium with the liquid in the still and an analysis of the two liquids will establish their relationship. The essential principles of this method were originated by Carveth(50). Carveth's apparatus however was so arranged that the boiling temperatures of the liquid and vapor samples were depended upon to fix the composition. The first utilizations of this recycling principle in which provision was made for sampling and analysis of the liquid and vapor samples were by Yamaguchi(51) and later by Sameshima(52). Othmer(36) employed the same principle but with a different arrangement of apparatus.

The survey of these various methods led to the adoption of the last method cited due to its simple technique and probably accuracy. Prevention of refluxing and entrainment is imperative if reliable data are to be secured however. An apparatus, illustrated in Figure (21), which was designed by E. R. Smoley of this laboratory fulfilled all the requirements for this purpose and was used in obtaining the data. This apparatus consists of a still, condenser and receiver, all constructed of copper with brazed seams and joints. The receiver, provided with a pressure vent, permits liquid to return to the still through an inverted U tube. The body of the still is lagged thoroughly. Outside of the lagging an annular space between the lagging and an external galvanized iron shell permits the sides of the still body to be surrounded by hot gases arising from the circular gas burner located at the bottom of the annular space. The special construction of the still head as illustrated in Figure (21) prevents any slight condensation due to heat losses in this portion from falling back into the still. To guard against entrainment and to permit observation of any refluxing occurring in the

Fig. 21

EQUILIBRIUM STILL



E.R.S.
MAY 19,1929.

still the vapor was taken off by a tube set into the still head and projecting nearly to the middle of the still body. A thermometer inserted through a stopper projected into this central vapor takeoff. Observation of the lower tip of the vapor takeoff pipe was possible through the peep sights provided. When drops of liquid no longer collected on this tip refluxing was safely assumed to be absent. Another peep sight in the receiver permitted observation of distillation rate. The major dimensions of the apparatus are indicated in Figure (21).

The alcohol used in these determinations was a good grade of 95% reagent alcohol. Before use it was redistilled through a short Hempel column, the first and last 10% portions being rejected. Application of the usual qualitative tests as given by Murray (53) showed all ordinary impurities to be absent.

In making a run a charge of approximately 315 c.c. of alcohol-water mixture, of suitable composition depending upon the point on the y - x curve to be determined, was introduced into the still. A pressure regulating device was then connected to the vent pipe and so adjusted with respect to the barometric pressure that the pressure in the still was 760 m.m. After cooling water was started circulating through the condenser jacket heat was applied to the bottom of the still by means of a Bunsen burner and the hot gas jacket was brought up to temperature. Distillation was carried on at a rate of from 10 to 15 c. c. of condensate per minute. The rate was judged by observing drops of condensate falling into the receiver by means of the peep sight set into the upper part of the receiver. At this rate of distillation the superficial vapor velocity in the still was never more than 0.15 ft. per second which obviated any possibility of entrainment. The peep sights in the still body were utilized to observe any indication of refluxing. Usually 15 minutes served to bring the gas jacket and lagging up to temperature causing a cessation of refluxing. Runs were continued for at least 1/2 hour after refluxing stopped. This insured that the contents of the receiver were completely changed at least six times, in some of the runs more. At the conclusion of the run the burner was withdrawn from the still and samples of liquid from the still and the receiver, respectively, immediately withdrawn into stoppered test tubes, vented through air condensers, the tubes being immersed in ice baths. The cooling of the samples was nearly instantaneous so that no loss from flashing of alcohol-rich vapor was had.

Analysis of the liquids was by specific gravity determination using carefully calibrated 50 c.c. pycnometers of the type provided with thermometers set into the ground glass stoppers. The pycnometer thermometers were checked against a standard thermometer. Specific gravity data were therefore accurate to the fifth decimal place. The compositions corresponding to the observed specific gravities were obtained from the specific gravity tables of the U. S. Bureau of Standards, Circular No. 19. Before making the final weighings of the pycnometers filled with the samples they were permitted to stand for an hour and a half in a thermostatic bath maintained at constant temperature. This assured the samples being at the uniform temperature indicated by the thermometers in the pycnometers.

The data and results of these determinations are given in Tables (17) (18) ( ) and (19). Figure (22) shows the determined curve together with points from

TABLE 17

Original Data, Alcohol-Water Equilibria Runs

Run No.	Date	Time	Temp. at Still Head °C	Jacket Temps. °C	Barometer m.m.Hg. Corr.	Press. Regulator cm. Water	Press. in Still m.m.Hg.
1	7/2/29	3:55	79.40	84.78	752.4	+10.3	760.0
		4:10	79.45	75.80			
		4:35	79.48	75.80			
2	7/2/29	6:20	80.75	75.78	752.4	+10.3	760.0
		7:00	80.90	80.78			
3	7/3/29	12:25	78.65	75.70	758.6	+ 1.9	760.0
		12:35	78.65	78.76			
		1:05	78.65	82.78			
4	7/3/29	2:45	78.85	65.76	758.2	+ 2.5	760.0
		3:00	78.90	94.75			
		3:05	78.90	80.75			
		3:20	78.90	78.75			
		3:30	78.90	78.75			
		3:35	78.90	78.77			
5	7/3/29	5:10	79.80	61.70	759.2	+ 1.1	760.0
		5:20	79.86	73.78			
		6:00	79.90	73.90			
6	7/4/29	11:15	81.10	66.73	763.0	- 4.1	760.0
		11:25	80.95	79.75			
		11:35	80.95	79.77			
		11:50	80.95	79.78			
		12:00	80.95	77.78			
7	7/4/29	1:55	81.90	70.75	761.7	- 2.3	760.0
		2:35	82.05	74.80			
		2:45	82.05	77.80			
		3:00	82.05	80.82			
8	7/4/29	6:20	83.80	77.75	760.4	- 0.5	760.0
		6:25	83.85	78.76			
		6:30	83.85	78.75			
		6:35	83.90				
		6:45	83.90	78.77			

TABLE 17 (Continued)

Run No.	Date	Time	Temp. at Still Head °C	Jacket Temps. °C.	Barometer m.m.Hg. Corr.	Press. Regulator cm. Water	Press. in Still m.m.Hg.
9	7/5/29	10:15	86.80	70.50	761.0	-1.4	760.0
		10:20	86.40	74.90			
		10.40	86.40	80.90			
		10:55	86.40	82.88			
		11:05	86.40	81.92			
10	7/5/29	1:15	--	--	761.1	-1.5	760.0
		1:20	96.50	64.67			
		1:45	95.18	75.70			
		2:05	95.18	90.80			
		2:15	95.18	90.88			
11	7/5/29	4:00	79.56	60.73	761.8	-2.4	760.0
		4:20	79.71	78.73			
		4:40	79.75	79.74			
		4:50	79.75	77.77			
		5:00	79.75	78.78			
12	7/5/29	6:55	--	--	762.5	-3.4	760.0
		7:40	82.40	90.75			
		7:55	82.40	90.77			
13	7/6/29	9:00	83.75	53.64	765.3	-7.2	760.0
		9:15	85.00	68.68			
		9:55	84.50	75.75			
		10:05	82.30	70.75			
14	7/6/29	10:40	--	--	765.3	-7.2	760.0
		11:10	86.00	70.70			
		11:34	86.20	74.74			

TABLE 17 (Continued)

Analytical Data, Alcohol-Water Equilibria Runs

Run No.	Pycnometer No.	Wt. Pyc. + Liquid	Temp. Sample °C	Volume Pyc. c.c.*	S.G. t/4°C.	Pycnometer No.	Wt. Pyc. + Vapor Sample Gms.	Temp. Sample °C.	Volume Pyc. c.c.*	S.G. t/4°C
1	0	78.8625	22.45	49.6486	0.84769	1	77.2006	22.45	50.5796	0.82958
2	0	80.6360	21.80	49.6473	0.88343	1	77.8008	21.85	50.5784	0.84149
3	0	77.5773	20.65	49.6450	0.82186	1	76.5617	20.65	50.5760	0.81703
4	0	78.0991	20.60	49.6450	0.83236	1	76.8718	20.60	50.760	0.82316
5	0	79.5432	20.25	49.6440	0.86144	1	77.5112	20.20	50.5750	0.83582
6	1	80.8324	20.15	50.5750	0.90148	1	78.1312	20.05	50.5750	0.84808
7	1	81.7266	20.45	50.5760	0.91914	1	78.3259	20.55	50.5760	0.85191
8	1	83.1239	20.70	50.5760	0.94678	1	78.7815	20.65	50.5760	0.86092
9	1	84.0967	21.40	50.5775	0.96598	1	79.4698	21.65	50.5780	0.87449
10	1	85.2796	22.10	50.5790	0.98934	1	83.0224	22.05	50.5790	0.94471
11	1	78.6677	20.85	50.5760	0.85867	1	77.4452	21.10	50.5770	0.83448
12	1	82.0689	21.85	50.5780	0.92588	1	78.3881	22.00	50.5790	0.85309
13	1	83.7217	21.45	50.5780	0.95856	1	79.1232	21.65	50.5780	0.86764
14	1	84.4268	21.65	50.5780	0.97250	1	80.0047	21.85	50.5780	0.88507

*Volumes Read from Figure ( ) for given temperature.

Wt. Pycnometer #0, gms. = 36.7768
" " "1, " = 35.2399

Calibration of Pycnometers

Pyc.No.	Wt. in Air.	Wt.+ Dist.Water	Wt. Water	Temp.	Density Water	Absolute Volume pyc.c.c.
0	36.7768	86.3313	49.5545	20.00	0.998203	49.6437
0	"	86.3033	49.5265	23.10	0.997514	49.6499
1	35.2399	85.6945	50.4546	23.05	0.997526	50.5807
1	"	85.7238	50.4839	20.00	0.998203	50.5747

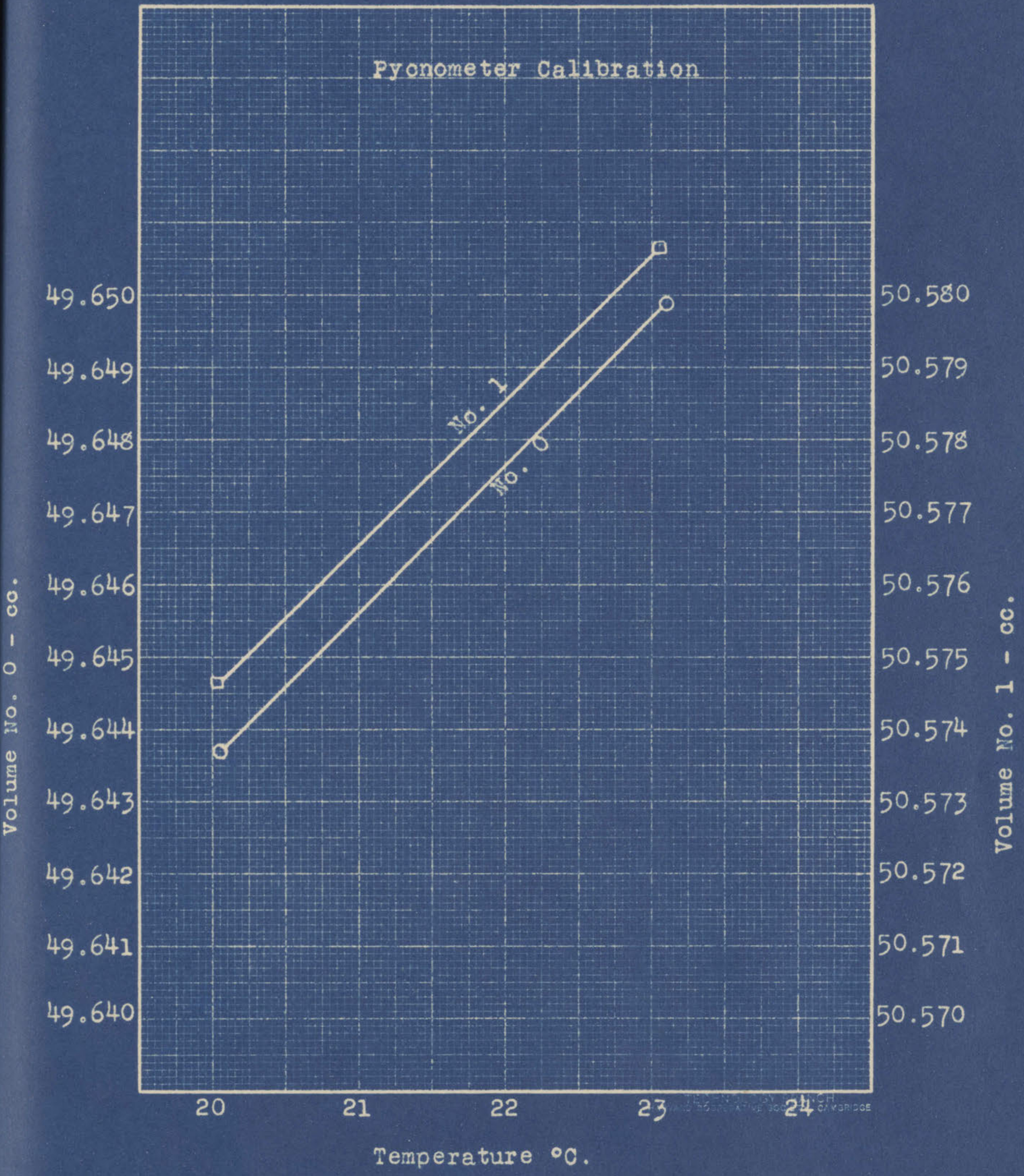

Pyconometer Calibration
49.650
49.649
49.648
49.647
49.646
49.645
49.644
49.643
49.642
49.641
49.640
50.580
50.579
50.578
50.577
50.576
50.575
50.574
50.573
50.572
50.571
50.570
No. 1
No. 0
Volume No. 0 - cc.
Volume No. 1 - cc.
20
21
22
23
24
Temperature °C.

TABLE 18

LIQUID AND VAPOR COMPOSITIONS, ALCOHOL-WATER EQUILIBRIA RUNS

1 Run No.	2 Specific Gr. Liq. Samples t/4°C.	3 Temp. °C	4 Wt. % Alcohol in Liq.	5 Mol. Frac. Alcohol in Liquid	6 Sp. Gr. Vap. Sample t/4°C.	7 Temp. °C.	8 Wt. % Alcohol in Vapor	9 Mol. Frac. Alc. in Vapor
1	0.84769	22.45	77.44	0.5732	0.82958	22.45	84.70	0.6841
2	0.88343	21.80	62.68	0.3965	0.84149	21.85	80.14	0.6122
3	0.82186	20.65	88.31	0.7472	0.71703	20.65	90.14	0.7815
4	0.83236	20.60	84.23	0.6763	0.82316	20.60	87.83	0.7385
5	0.86144	20.25	72.51	0.5079	0.83582	20.20	83.00	0.6564
6	0.90148	20.15	55.43	0.3273	0.84808	20.05	78.11	0.5826
7	0.91914	20.45	47.42	0.2608	0.85191	20.55	76.34	0.5580
8	0.94678	20.70	33.74	0.1661	0.86092	20.65	72.59	0.5089
9	0.96598	21.40	21.47	0.0966	0.87449	21.65	66.53	0.4375
10	0.98934	22.10	4.72	0.0190	0.94471	22.05	34.36	0.1700
11	0.85867	20.85	73.45	0.5198	0.83448	21.10	83.22	0.6599
12	0.92588	21.85	43.80	0.2337	0.85309	22.00	75.34	0.5445
13	0.95856	21.45	26.53	0.1238	0.86764	21.65	69.42	0.4704
14	0.97250	21.65	16.57	0.0721	0.88507	21.85	61.95	0.3891

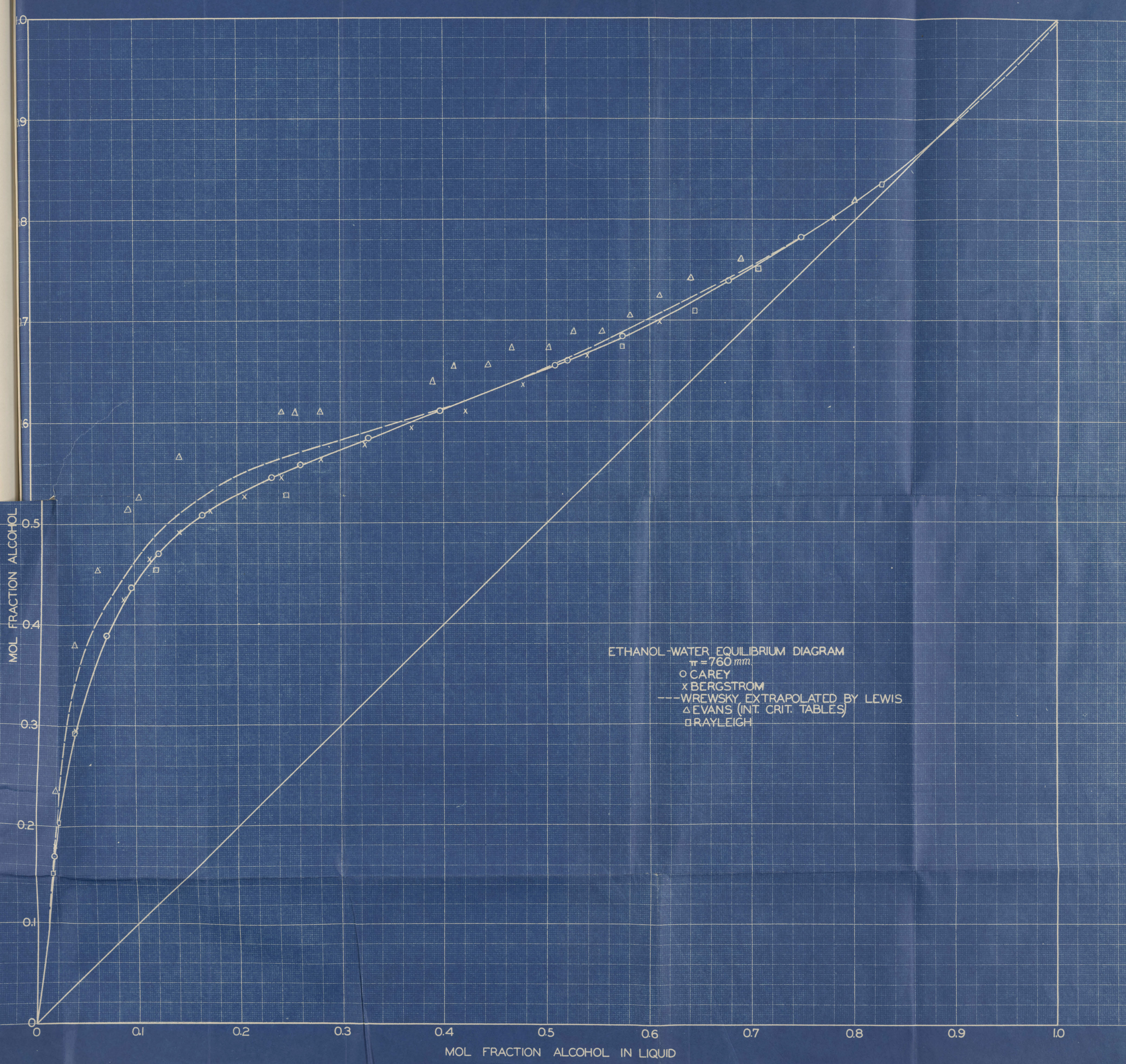
TABLE 19

Co-Ordinate of Curve Drawn Through Experimental Points, Alcohol-Water Equilibria Data

Mol. Frac. Alcohol in Liquid x	Mol. Frac. Alcohol in Vapor y
0.0190	0.1700
0.0400	0.2870
0.0600	0.3560
0.0800	0.4065
0.1000	0.4215
0.1200	0.4630
0.1400	0.4875
0.1600	0.5040
0.1800	0.5175
0.2000	0.5285
0.2200	0.5390
0.2400	0.5485
0.2600	0.5570
0.2800	0.5650
0.3000	0.5725
0.3200	0.5805
0.3400	0.5885
0.3600	0.5965
0.3800	0.6045
0.4000	0.6125
0.4200	0.6200
0.4400	0.6280
0.4600	0.6365
0.4800	0.6440
0.5000	0.6520
0.5200	0.6600
0.5400	0.6690
0.5600	0.6775
0.5800	0.6870
0.6000	0.6965
0.6200	0.7065

TABLE 19 (Continued)

Mol. Frac. Alcohol in Liquid x	Mol. Frac. Alcohol in Vapor y
0.6400	0.7175
0.6600	0.7290
0.6800	0.7410
0.7000	0.7525
0.7200	0.7650
0.7400	0.7775
0.7600	0.7905
0.7800	0.8040
0.8000	0.8175
0.8200	0.8320
0.8400	0.8470
0.8600	0.8640
0.8800	0.8820
0.8943	0.8943


ETHANOL-WATER EQUILIBRIUM DIAGRAM
π = 760 mm
○ CAREY
x BERGSTROM
--- WREWSKY EXTRAPOLATED BY LEWIS
△ EVANS (INT. CRIT. TABLES)
□ RAYLEIGH
MOL FRACTION ALCOHOL
MOL FRACTION ALCOHOL IN LIQUID
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
.6
.7
.8
.9
1.0

the data of other workers.

Reference to the data shows that the present experimental determinations only cover the range in compositions below that of the constant boiling mixture, as this was the only portion of the curve required in the present work. Due to the small differencesin liquid and vapor compositions in the region above the constant boiling mixture composition the exact determination of this portion of the curve is difficult. The composition of the constant boiling mixture at 760 m.m. has been fixed by Young and Fortey (54) at 95.5% alcohol by weight (0.8941 mol fraction alcohol) and by Wade and Merriman (55) at 95.59% by weight (0.8945 mol fraction alcohol) which values are in excellent agreement.

A comparison of the curve drawn through the points of the experimental data here presented with the data of several other investigators is given by Figure (22). The curve agrees well with the data of Bergstrom as given by Hausbrand (4) in the left-hand portion of the curve. In the middle portion the curve lies above Bergstrom's data while in the right-hand portion all data converge to practically the same curve.

The data of Evans (56) are shown on Figure (22) for the reason that they are the values given in the

International Critical Tables. Reference to the original paper shows that Evans unquestionably permitted rectification to take place in the determinations, this explaining the high and inconsistent values obtained.

Lord Rayleigh (41) does not give the rate of distillation employedin his determinations, but the lower values of vapor composition reported by him indicate that entrainment may have reduced the vapor composition.

The curve given by Lewis (57) was extrapolated from data due to Wrewsky (58). The data given by Wrewsky consisted of several sets of isothermal measurements of vapor-liquid compositions. For each liquid composition Lewis plotted vapor composition against temperature and extrapolated to the boiling point at atmospheric pressure. Change in vapor composition with change in boiling point was determined by Lewis from the slope of the temperature-vapor composition curves and plotted as a correction curve expressed as change in composition per degree decrease in boiling point to the vapor composition curve.

Item (3) Table (20) gives the increase in vapor strength, expressed as wt. % alcohol, per de-

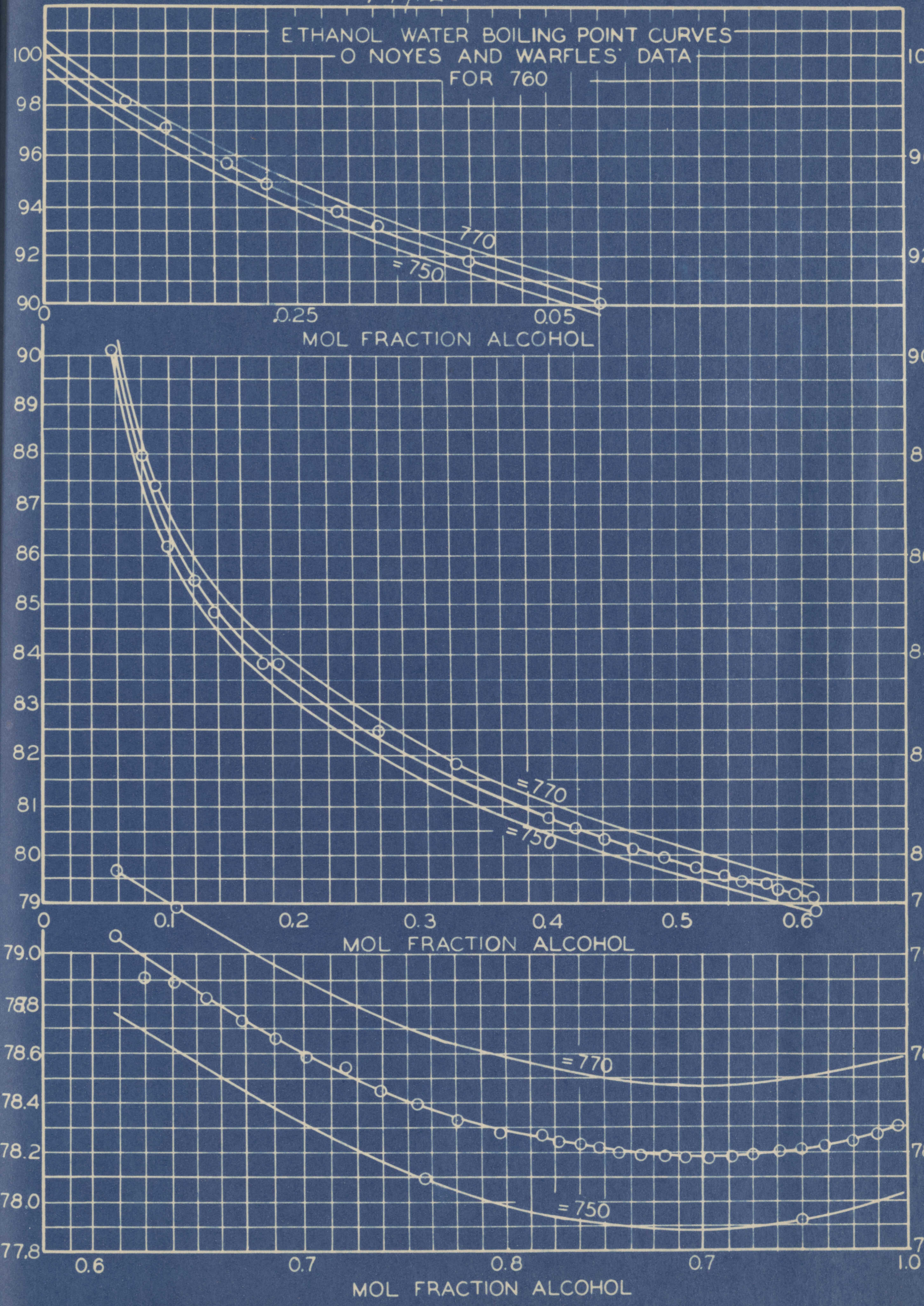
TABLE (20)

1 Wt. % Alcohol	2 Mol Fraction Alcohol	3 Increase in Vapor Strength, Wt. % Alc. per °C decrease in Boiling Point	4 Increase in Vapor Strength, M.F. Alc. per °C decrease in Boiling Point	5 Slope of Temp. Total Press. Curve °C/m.m.	6 Increase in Vapor Strength, M.F. Alcohol per m.m. decrease in pressure.
0	0	0	0	0.0497	0
10	0.043	0.032	0.000141	0.0426	0.00000601
20	.078	.044	.000220	0.0396	.00000871
30	.145	.050	.000310	0.0376	.00001165
40	.208	.052	.000338	0.0367	.00001240
50	.282	.052	.000405	0.0357	.00001445
60	.370	.049	.000500	0.0346	.00001730
70	.480	.039	.000452	0.0327	.00001478
80	.612	.027	.000394	0.0265	.00001045
90	.782	.014	.000272	0.0286	.00000778
100	1.000	0	0	0.0283	0

gree C decrease in boiling point. Item 4 gives the same values expressed as mol fractions alcohol. Item 5 gives the slopes of the total vapor pressure-temperature curves from Wrewsky's data. Multiplying Item 4 by Item 5 one obtains the increase in vapor strength expressed as mol fraction of alcohol per m.m. decrease of total pressure. From the slopes of the total vapor pressure-temperature curves the boiling point curves (Fig. 23) for 750 and 770 m.m. were estimated from Noyes and Warfle's (35) boiling point data.

The experimental values of Alcohol-Water liquid-vapor equilibrium relations reported in this section are believed to be the most reliable yet obtained. Experimental technique was such that the pressure at which they were determined was 760 m.m. ± 0.2 m.m. Hg. The changes in vapor composition for change in pressure calculated from Wrewsky's data and tabulated in Table (20) will be found useful in estimating shifts in the equilibrium values for small changes in pressure and corresponding boiling temperatures. However, this correction data should not be used for a wide change in pressure where accuracy is desired.

Fig. 23


ETHANOL WATER BOILING POINT CURVES
O NOYES AND WARFLES' DATA
FOR 760
100
98
96
94
92
90
770
=750
0
0.25
0.05
MOL FRACTION ALCOHOL
90
89
88
87
86
85
84
83
82
81
80
79
=770
=750
0
0.1
0.2
0.3
0.4
0.5
0.6
MOL FRACTION ALCOHOL
79.0
78.8
78.6
78.4
78.2
78.0
77.8
=770
=750
0.6
0.7
0.8
0.7
1.0
MOL FRACTION ALCOHOL

B. METHODS OF ANALYSIS

1. Benzene-Toluene Mixtures:

The mixtures of Benzene and Toluene were analyzed by observation of the boiling points of the samples employing an apparatus developedby the Department of Physical Chemistry, M. I. T.(59) The thermometer bulb is so located in this apparatus that slugs of liquid and vapor from the boiling sample impinge continually on the bulb. About fifteen minutes are required to obtain a constant temperature reading. A record of the barometric pressure and reference to the boiling-point composition curves of Figure (19) thus determine the composition for a given temperature reading. As was noted in the discussion of Benzene-Toluene liquid-vapor equilibria these curves were checked experimentally. The thermometers used in the boiling point determinations were fractionating thermometers calibrated to 0.1°C enabling hundredths of a degree to be estimated. The calibrations were carefully checked against a standard thermometer.

The accuracy of the analyses by this method is approximately ± 0.002 mol fraction.

2. CCl_4-Toluene Mixtures: These mixtures are well adapted to analysis by specific gravity due to the wide separation in the specific gravities of the two constituents. No reliable data were found giving the specific gravities of these mixtures. Hence a series of known mixtures were made up and their specific gravities at several temperatures read with a Westphal balance. For each experimental composition a plot of specific gravity versus temperature enabled the specific gravities at 20° and 25° referred to water at 15° to be determined. These data are plotted in Figure (24) for the temperatures 20° and 25° affording a ready means of interpolation between these temperatures and obviating the necessity of bringing a sample exactly to a specified temperature.

It should be noted that an accurately made plummet for a Westphal balance is so adjusted that the instrument reads unity when the plummet is immersed in recently boiled distilled water at 15°C. This point was checked with the instrument employed.


SPECIFIC GRAVITIES CCL_4-TOLUENE MIXTURES AT 25°/15° AND 20°/15°

In the neighborhood of 15°C, the instrument reads specific gravity of a liquid at $t^\circ/15^\circ$, t being the temperature of the sample. The slight change in volume of the plummet with temperature is the only factor which may cause an error. Up to temperatures of 25°C this error is within the experimental error in reading the instrument. However, a small rider placed on the balance arm served to correct for this factor.

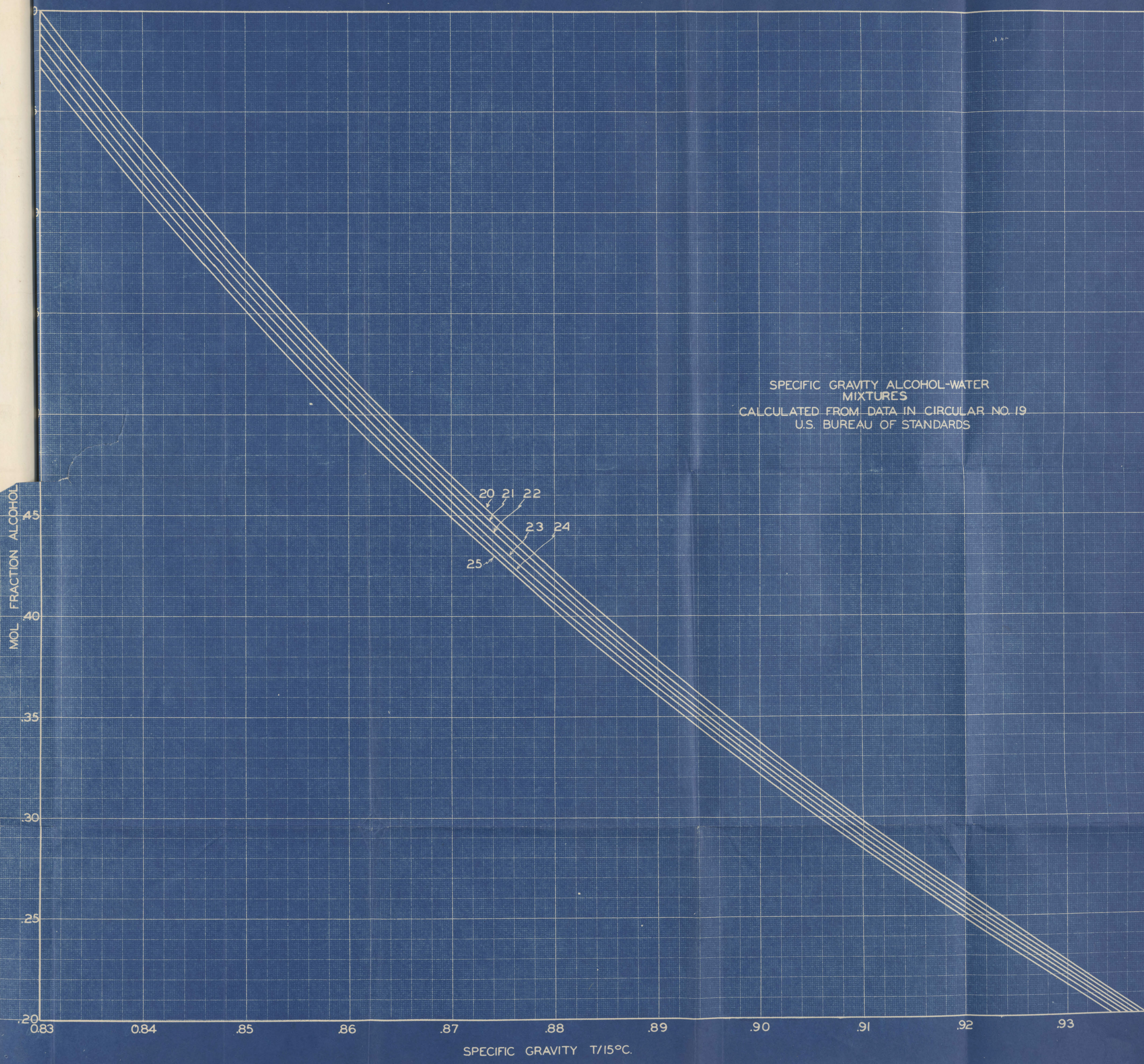
The temperatures of the samples were read by means of the thermometer enclosed in the Westphal plummet. This thermometer was calibrated against a standard thermometer.

In carrying out the specific gravity readings on the samples the latter, contained in stoppered 6" test tubes were placed in a water bath for 20 minutes. Experience showed that with occasional stirring of the bath this served to bring the samples to a uniform temperature. The bath was so adjusted that the temperature of the samples was always between 20°C and 25°C when the specific gravity was read. After the samples came to temperature the specific gravities were quickly read by removing the stoppers from the test tubes in turn and immersing the dried plummet in the liquid and adjusting the weights on the balance arm, the tubes remaining in the water bath during the reading.

The accuracy of the analyses of CCl_4-Toluene mixtures was within ± 0.0002 mol fraction.

3. Alcohol-Water Mixtures: These mixtures were also analyzed in the rectification runs by specific gravity readings obtained with a Westphal balance. In the case of the liquid-vapor equilibria runs, the greater accuracy secured by use of pycnometers was required, as described in Section A.

The specific gravity-composition data for alcohol water mixtures contained in Circular 19, U. S. Bureau of Standards were employed. These data are given for various temperatures of mixtures referred to water at 4°C and the compositions given in weight per cent. To put the data in a form convenient for use in conjunction with the Westphal balance readings the data were calculated to the basis of water at 15°C, compositions also being converted to mol fractions. These values were plotted in Figure (25) for the temperatures 20° to 25° to render temperature interpola-



SPECIFIC GRAVITY ALCOHOL-WATER MIXTURES
CALCULATED FROM DATA IN CIRCULAR NO. 19
U.S. BUREAU OF STANDARDS

tion easy. The method of reading the specific gravity of the samples was the same as in the case of the CCl_4-Toluene mixtures. The same temperature corrections were applied.

The accuracy of the analysis of the alcohol-water samples was within ± 0.0002 mol fraction in the range of composition covered in the experimental work.

C. DESCRIPTION OF SEVEN PLATE COLUMN AND OPERATING TECHNIQUE.

1. Description of Apparatus.

The seven plate column was originally assembled by Messrs. Allen and Eaton(60) and the writer and used by the former to secure a portion of the data here given. In subsequent work, modifications in the original apparatus were made by the writer and Messrs. Page and Wicker.(61)

The apparatus as used in the work subsequent to that of Allen and Eaton is shown in elevation in Figure (26). It consisted of a still and seven plate sections. The still was a section of 8" standard pipe screwed into flanges at either end, bolted through a gasket at the bottom to a 1/2" iron plate which in turn rested upon a brickwork setting. The still was provided with a steam coil, gage glass and drain pipe flush with the bottom.

The entering steam line passed through a superheater consisting of several Meker burners enclosed in brickwork, playing directly on the steam pipe. A hand controlled valve admitted steam to the coil and permitted throttling to desired pressure. A thermometer well set into the steam line after it passed the superheater and a Bourden pressure gage

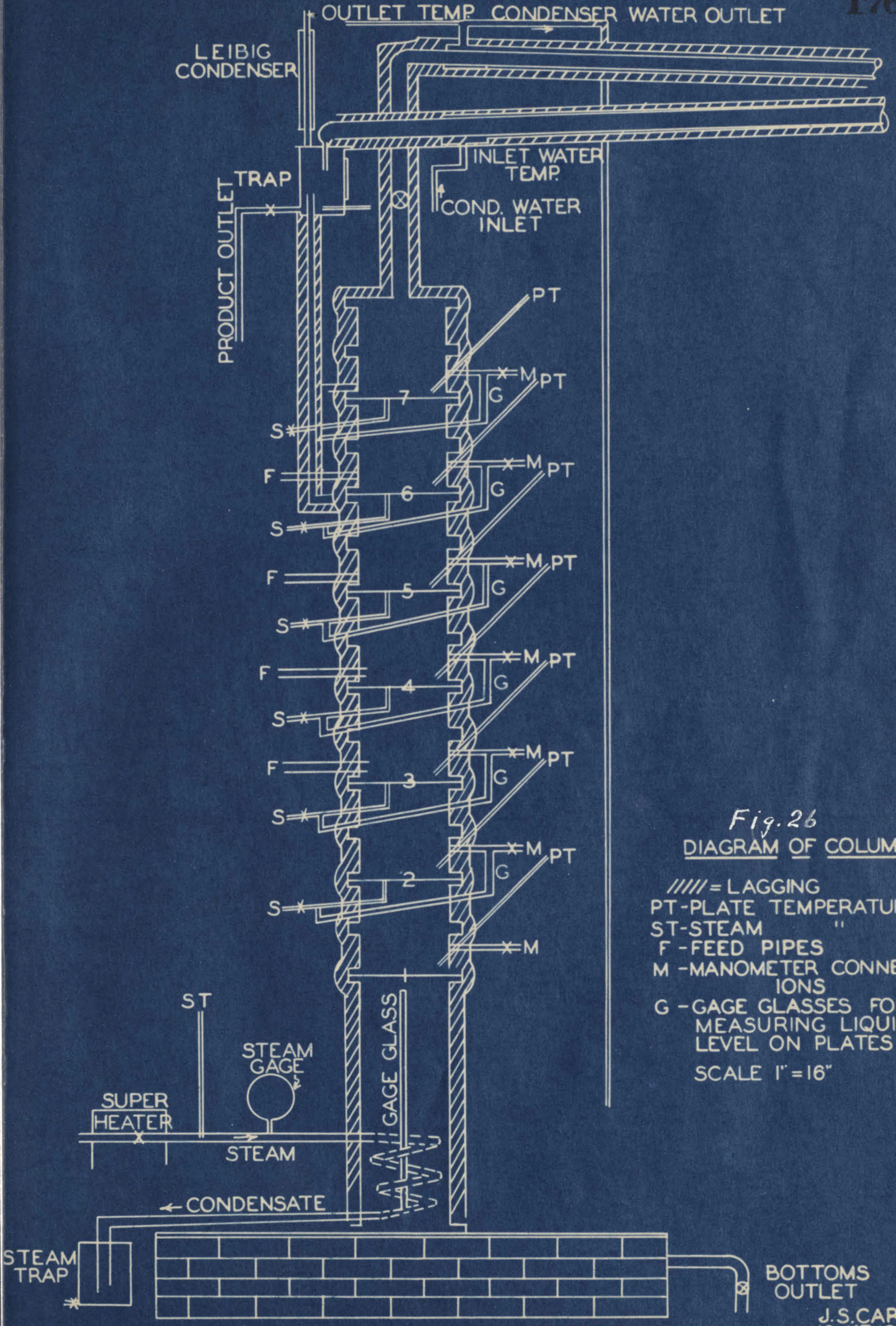


Fig. 26
DIAGRAM OF COLUMN

////// = LAGGING
PT - PLATE TEMPERATURES
ST - STEAM "
F - FEED PIPES
M - MANOMETER CONNECTIONS
G - GAGE GLASSES FOR MEASURING LIQUID LEVEL ON PLATES

SCALE 1" = 16"

J. S. CAREY
10/17/28

plus a manometer connection enabled the steam temperature and pressure to be determined. The steam coil was a spiral bend of 1" standard pipe set into the lower portion of the still. The steam condensate was removed through a steam trap.

The plate sections were also of 8" standard pipe screwed into flanges. Thermometer inlets were provided in each plate section. In Allen and Eaton's work the thermometers were set into wells projecting into the vapor space above the liquid on each plate. In the later work the thermometers were introduced through pressure gaskets so that the bulbs of the thermometers were immersed in the plate liquids. Each plate had holes drilledfor the vapor riser of the bubble cap, the overflow pipe and the sample pipe. The sample pipe on each plate except the first was flush with the plate and was led out through the plate section below. In the case of the first plate the sample pipe was of inverted U shape. (This pipe was not installed for all runs so that in some cases analyses of first plate liquid is lacking.) An extra opening in every plate section permitted vapor samples to be taken when desired.

The condenser used by Allen and Eaton consisted of standard 2" pipe immersed in a galvanized iron trough. This did not permit of accurate measurement of the rise in temperature of the water so that for the later work a two pass double pipe condenser was installed. The condensate ran by gravity from the condenser into a trap, vented to the atmosphere through an upright Leibig condenser which prevented loss of vapor from the system. From the trap the total condensate was returned to the top plate through a U.

The column, still, metal base, condenser, reflux trap and steam condensate trap were well lagged with magnesia lagging.

Dimensions of Apparatus

Inside diameter still and column	8"
Height of still	32"
Distance between plates	12 1/4"
Thickness of plates	3/32"
Inside diameter bubble cap vapor riser	1 1/4"
Outside diameter buble caps	4 1/8"
Overall height	2"
Number of slots per cap	36
Height of slots	3/4"
Width slots (approx.)	1/8"
Angle of slots with radii of cap	45°
Outside diameter overflow pipe	1 3/16"
Inside " " "	1"
Distance from plate to top overflow pipe	1"
" " " " " vapor riser	1 1/4"

Distance from plate to end of overflow pipe from plate above	5/8"
Distance between centers of overflow pipe and vapor riser	3 1/2"
Diameter sampling pipes	1/4"
Distance between centers sample pipes and vapor riser	3"
Outside surface area heating coil	2.7 sq. ft.
Inside diameter inner condenser pipe,	2.07 " "
" " outside " "	3.07 " "
Length 1st pass of condenser	6', 1" "
" 2nd " " "	7', 1" "
Inside diameter vapor pipe to condenser	3.07 "
Inside diameter reflux return pipe	0.62"

2. Experimental Technique:

In preparing for a run the column was charged with about 15 liters of the mixture. The condenser water was turned on and the steam line cleared of water by allowing steam to blow out the condensate trap. The steam pressure was then adjusted to the value shown by experience to cause sufficient heat transfer to give the desired vapor velocity. The superheater was regulated to give the entering steam several degrees of superheat. Steam pressure was held reasonably constant by hand control of the inlet valve. After about an hour the column was found to reach steady operating conditions as determined by constancy of the plate temperatures. A run of one hour's duration was then made in which the steam condensate was weighed in tared buckets, the cooling water rate determined by weighing in a tared barrel, and the temperatures of inlet and outlet cooling water, steam pressure and temperature and plate temperature were read.

At the conclusion of the period in which heat data were taken samples of liquid in the still, reflux, and liquid on each plate were withdrawn rapidly into sampling tubes immersed in ice baths. The size of samples was 50 c.c. The order of sampling was studied but was found to have no effect on efficiency results.

D. DESCRIPTION OF SINGLE PLATE COLUMN AND OPERATING TECHNIQUE.

1. Description of Single Plate Column.

The major dimensions of the apparatus as used in Runs 1 to 229 inclusive are given in Figures (27), (28) and (30). The same plate section was used in Runs 12A to 43A and 1B to 44B with certain modifications to be noted. Figure (29) gives a photographic view of the apparatus as used in later runs.

The apparatus consisted of a still and plate section with condensers arranged to return all vapor from the plate back to the plate as reflux.

The plate section was constructed of sheet copper. A vapor riser in the center of the plate introduced vapor from the still underneath the interchangeable bubble caps, while an overflow pipe adjustable in height returned overflow from the plate section to the still. A wicket of heavy steel wire held the bubble cap in place. The overflow pipe was in two sections joined by a union between the still and plate section. The adjustment of height of the overflow pipe by means of the locknuts at the points of its introduction to the plate section and the still

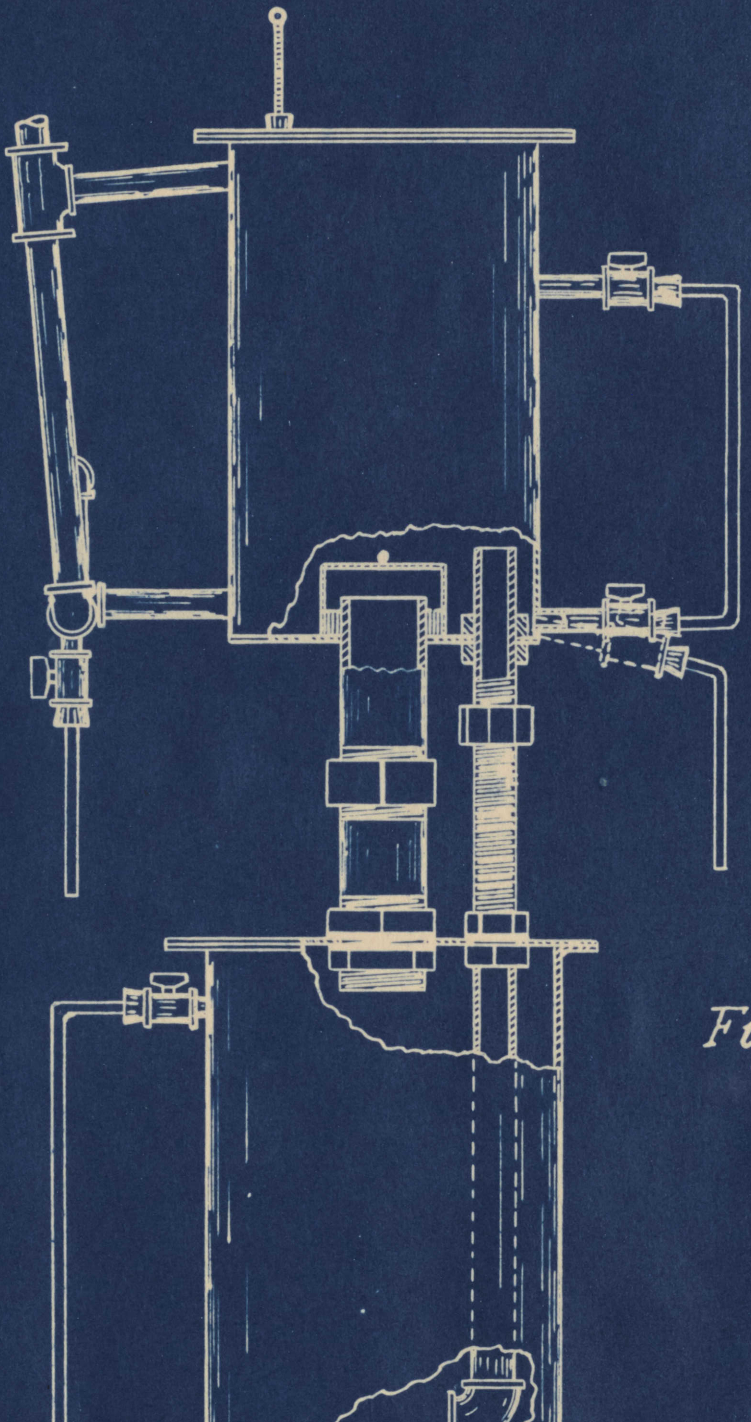


Fig. ~~4~~ 27

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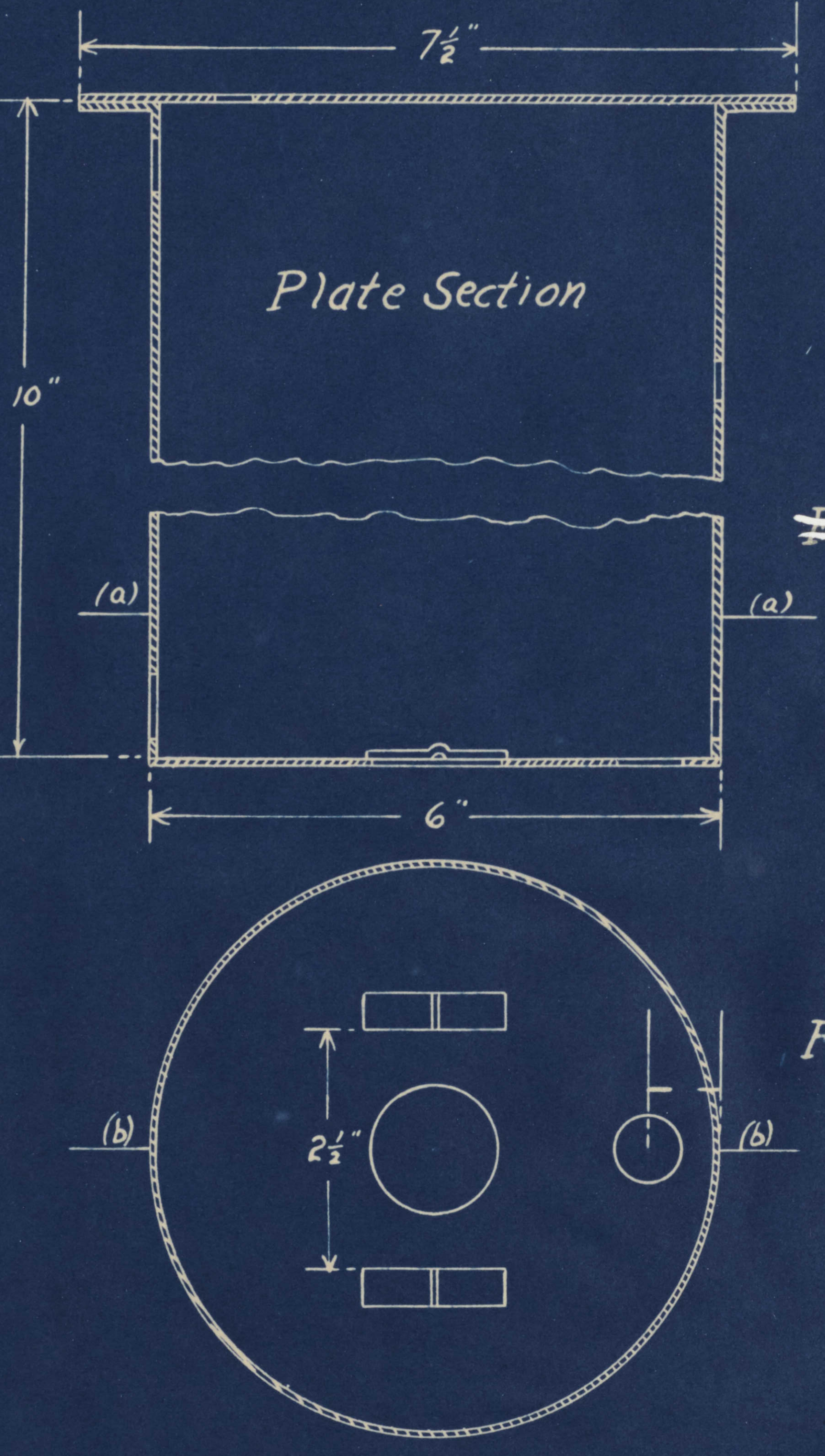


~~Fig 1~~

Fig.28

GA - 5/19/29

Fig. 29

Fig. 30

GA. 5/19/29.

will be apparent from Figure (27). The vapor takeoff left the side of the plate section near the top and was sloped slightly away from the column to prevent any condensed material returning through the vapor pipe. The vapor line extended to a three way tee (later replaced by a funnel shaped header) to which were connected three vertical reflux condensers. The refluxed liquid passed through a trap of sufficient height to prevent plate liquid from flowing into the reflux line. This trap had a sample cock at its lowest point. The sample pipe for the plate liquid was located at the bottom of the plate section, immediately back of the overflow pipe and diametrically opposite to the point at which the reflux pipe from the reflux trap returned liquid to the plate section. The plate section had a removable top, bolted in place through a gasket.

The still used in Runs 1 to 229 was cylindrical in shape and of copper construction. The overflow pipe from the plate section projected to within a short distance of the bottom of the still. This still was provided with one immersion electrical heating unit of 2 K.W. capacity set into the bottom of the still.

For Runs 12A to 44A and 1B to 44B greater heat input was desired so the original still was replaced by one constructed from a five gallon square can in the bottom of which were introduced four 2 K. W. heaters.

The entire apparatus was lagged and wound with Nichrome resistance wire which was followed by another layer of lagging. The temperature of the lagging midway between the still or plate section walls could be maintained at a temperature closely approximating that inside the apparatus by regulation of the heater current, thus rendering heat losses negligible.

Thermometers were employed to measure the temperatures in the plate section and in the lagging.

Heat input was measured by an indicating wattmeter and regulated by rheostats of suitable capacity combined with the three heat control permitted by the heating elements used.

Dimensions of Single Plate Section

Diameter plate section	6"
Height " "	10"
Overflow pipe (standard steel)	3/8"
Vapor rise " "	1"
Distance center plate section to center overflow pipe	2 1/4"

Vapor take-off (standard steel)	1"
Plate sample pipe (" ")	1/8"
Reflux trap pipe " "	3/8"
Maximum height reflux trap above plate	4"
Height vapor riser (Runs 1 to 229)	11/16"
" " " (Runs 12A to 43A) (1B to 44B)	2 5/8"

Still dimensions:

Runs 1 - 229:	
Diameter	7"
Height	12"

Runs 12A - 43A, 1B to 44B:
9 1/4" x 9 1/4" x 14" high.

Bubble caps:

Runs 1 - 229:	
Total height	1 1/2"
Height of slots	1/2"
Total free area through slots	1 sq. in.
Diameter	2 1/4"

Runs 12A - 43A, 1B - 44B:	
Total height caps	3 1/4"
Height slots	1/2"
Diameter caps	2 3/8"

Heaters - General Electric Helicoil Immersion,

2 K. W. 3 heat.

2. Experimental Technique.

The column was charged with sufficient mixture of the desired composition, the condenser cooling water turned on, and the current to the immersion heaters and the lagging elements switched on. After ebullition started the heat input was regulated to the value giving the vapor rate desired and the current to the lagging elements adjusted to bring the lagging to temperature.

Constancy of the temperature inside the plate section whether that of liquid or vapor was found to be and excellent criterion of whether or not steady conditions were established. In all cases when a rising temperature was noted after the initial warming up period a check would reveal a leak at some point in the apparatus, which when remedied, permitted a constant temperature to be obtainedin the plate section.

The standard length of runs after steady conditions were reached waa approximately 1 hour. Fifteen minutes before the conclusion of the runs a "purge" sample of 10 c.c. was withdrawn from the plate sampling pipe and 2 c.c. from the reflux sample cock, these amounts having been found by calibration ample to flush the respective pipes. At the end of the hour period samplesof reflux liquid from the trap and plate liquid were simultaneously withdrawn into test tubes surrounded by ice baths. The test tubes were immediately stoppered. A time study, using a stop watch, of the time required for the simultaneous withdrawal of the two samples was made showing that the time required lay between 3 and 5 seconds. This insured the samples being "snap" samples and representative of the respective compositions at the time of sampling.

After analysis the samples were returned to the system and the apparatus was in readiness for another run.

E. SAMPLE CALCULATIONS, 7 PLATE COLUMN:

1. Murphree plate to plate efficiencies.

Example, Run 1A (Carey) plates 2 to 3:

$x_3 = y_2 = 0.900$

$x_2 = y_1 = 0.836$

$y_2^* = 0.928$ (From Equilib. Diagram)

$$E_M = \frac{y_2 - y_1}{y_2^* - y_1} = \frac{0.900 - 0.836}{0.928 - 0.836} = 0.695$$

2. Murphree Overall Efficiencies.

Example, Run No. 4 (P & W).

See Figure (31).

Plate No. 1, $x_1 = 0.410$

$y_n = E_M y_n^* + (1-E) y_{n-1}$

$y_n = \frac{0}{v} \quad x = x_n$

(a) Assume $E_M = 0.6$

$y_1 = x_2 = 0.6 \times 0.630 + 0.4 \times 0.410 = 0.542$

$y_2 = x_3 = 0.6 \times 0.748 + 0.4 \times 0.542 = 0.666$

$y_3 = x_4 = 0.6 \times 0.835 + 0.4 \times 0.666 = 0.767$

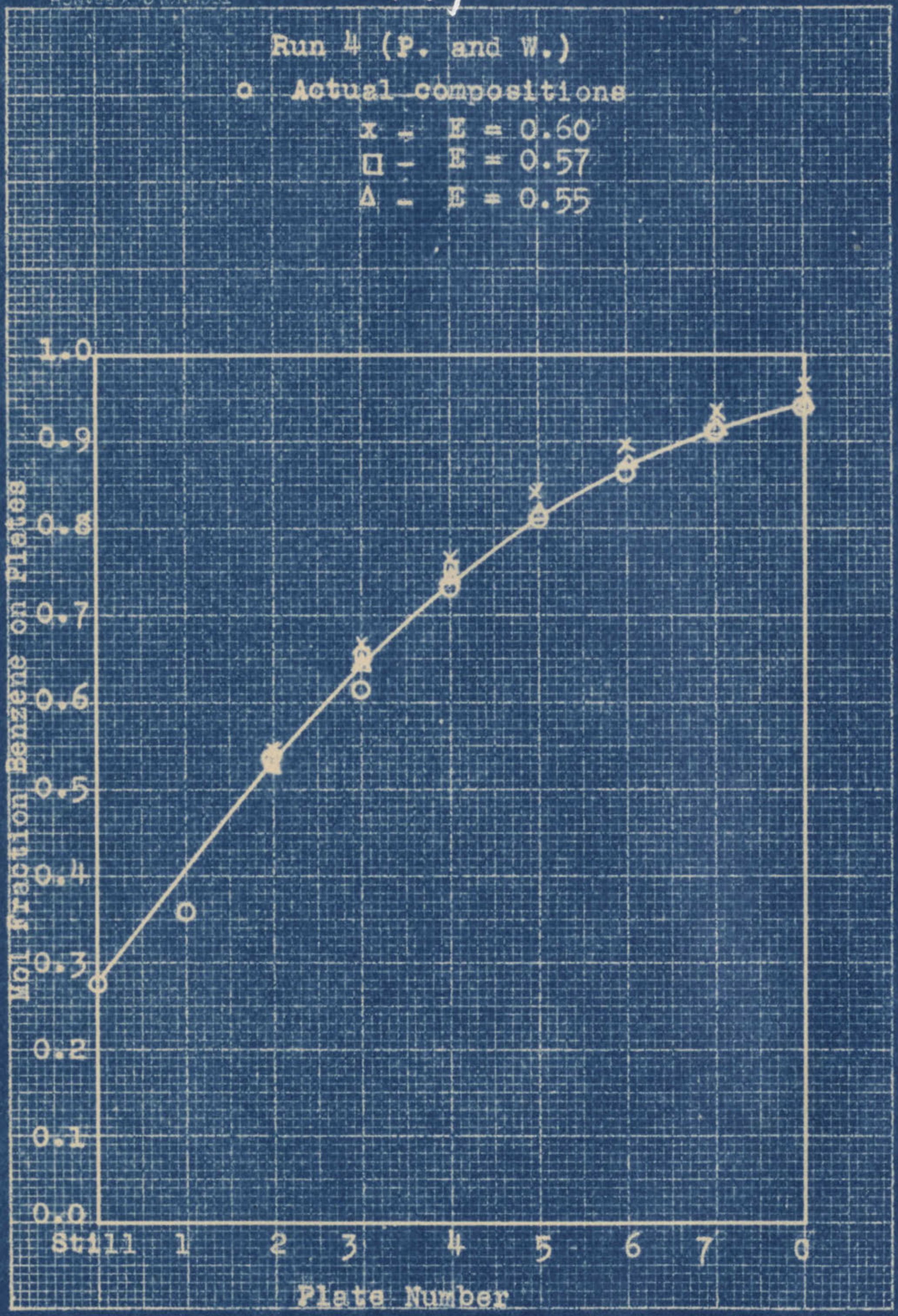
$y_4 = x_5 = 0.6 \times 0.894 + 0.4 \times 0.767 = 0.843$

$y_5 = x_6 = 0.6 \times 0.932 + 0.4 \times 0.843 = 0.896$

$y_6 = x_7 = 0.6 \times 0.958 + 0.4 \times 0.896 = 0.933$

$y_7 = x_c = 0.6 \times 0.974 + 0.4 \times 0.933 = 0.968$

Fig. 31


Run 4 (P. and W.)
o Actual compositions
x - E = 0.60
□ - E = 0.57
Δ - E = 0.55
Mol Fraction Benzene on Plates
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Still
1
2
3
4
5
6
7
C
Plate Number

These values when plotted on Figure (31) lie above the actual plate composition curve. Therefore a lower efficiency must be assumed

(b) Assume $E_M = 0.55$

$y_1 = x_2 = 0.55 \times 0.630 + 0.45 \times 0.410 = 0.531$

$y_2 = x_3 = 0.55 \times 0.740 + 0.45 \times 0.531 = 0.646$

$y_3 = x_4 = 0.55 \times 0.821 + 0.45 \times 0.646 = 0.742$

$y_4 = x_5 = 0.55 \times 0.880 + 0.45 \times 0.742 = 0.818$

$y_5 = x_6 = 0.55 \times 0.920 + 0.45 \times 0.818 = 0.874$

$y_6 = x_7 = 0.55 \times 0.947 + 0.45 \times 0.874 = 0.914$

$y_7 = x_c = 0.55 \times 0.966 + 0.45 \times 0.914 = 0.942$

These values agree well with the actual composition curve, therefore the assumed E_M is correct.

3. Efficiency in terms of perfect plates.

Graphical solution:

x_1 (actual) = 0.141

Using Figure (18) starting on 45° line at $x_1 = 0.141$, running up vertically to equilibrium curve $y_1 = 0.282$, going horizontally to operating (45°) line, x_2, = 0.282, going vertically to equilibrium curve $y_2 = 0.486$, horizontally to operating line $x_3 = 0.486$, vertically $y_3 = 0.702$, horizontally $x_4 = 0.702$, $y_4 = 0.856$, $x_5 = 0.856$.

x_c actual = 0.784

Number of steps required = 4 +

To estimate the fractional plate, it is assumed to be given by,

$$\frac{x_c - x_4}{x_5 - x_4} = \frac{0.784 - 0.702}{0.856 - 0.702} = 0.53 \text{ plates}$$

Therefore, the number of theoretically perfect plates = 4.53, Actual plates = 7

$$E_s = \frac{4.53}{7} \times 100 = 64.7\%$$

4. Heat Balances and Heat Transfer Coefficient.

Example Run 1A (Carey)

Steam pressure = 22.72#/in^2 Abs.

Superheat = 3.3°F.

Lbs. steam condensate (41 min) = 29.87#

Latent heat steam = 955.6 B.t.u./lb.

Basis 1 hour,

$$\text{Heat input} = 955.6 \times 29.87 \times \frac{60}{41} + 0.45 \times 3.3 \times 29.87 \times \frac{60}{41}$$

$$= 41865 \text{ B.t.u./hr.}$$

Steam temp. - - - - - - - - - - - - - - =234.8°F.

Temp. Boiling Liquid in Still - - - - - 194.9

$$\overline{39.9}$$

$$H = \frac{Q}{\theta A \Delta t} = \frac{41865}{2.7 \times 39.9} = 388 \frac{\text{B.t.u.}}{(\text{Hr.})(\text{Sq.ft.})(^\circ\text{F})}$$

Lbs. cooling water to condenser/41 m.m. = 282.4

Temp. Rise = 89.3°F. ave.

Heat appearing in condenser, B.t.u./hr. =

$$282.4 \times 89.3 \times \frac{60}{41} = 36950$$

Heat loss B.t.u./hr. = 41865 - 36950 = 4915

5. Vapor Velocity.

Example Run 1A (Carey)

Still temp. = 91°C

Latent heat Benzene = 13020 B.t.u./lb.mol

" " Toluene = 15190 " " "

Pressure in still = 774.8 m.m. Hg.

Vap. Vel. ft./sec. =

$$\frac{41865}{13020 \times .576 + 15190 \times .424} \; \frac{359 \times 760 \times 358.4}{3600 \times 774.8 \times 273} \; \frac{144}{.785 \times 64}$$

$$= 1.11$$

6. Vapor Velocity, basis 1st plate.

Due to heat losses in runs with the 7 plate column the vapor velocity changes somewhat up the column. To place values reported on the same basis they were calculated on the basis of plate 1 by assuming that 20% of the total heat loss occurred at and below this point.

Therefore:

Sup. Vap. Vel. =

$$\frac{(\text{Heat Input} - 0.2 \times \text{heat loss})\ 359}{3600 \times \text{Latent Heat}} \; \frac{T_1}{273} \; \frac{760}{.785 \times (.667)^2}$$

Example Run 1

Sup. Vap. Vel =

$$\frac{(21955 - 0.2 \times 6692) \quad 359 \quad 378.3 \quad 760}{14100 \times 3600 \qquad\qquad\quad 273 \quad 782.5 \quad .785 \times (.667)^2}$$

$= 0.569$ ft./sec.

F. SAMPLE CALCULATIONS, SINGLE PLATE COLUMN:

1. Plate Efficiency:

$$E_M = \frac{y_n - y_{n-1}}{y_n^* - y_{n-1}} = \frac{x_R - x_p}{y_o^* - x_p}$$

Example, Run #34:

$x_p = 0.575$

$x_R = 0.685$

$y_p^* = 0.774$

$$E_M = \frac{0.685 - 0.575}{0.774 - 0.575} = 0.553$$

$$E_M = 1 - e^{-\frac{k_m S\theta}{x\,V'}}$$

$$2.3 \log (1 - E_M) = -\frac{k_m S\theta}{x\,V'} = 2.3 \times (.3495) = -0.802$$

2. $-\frac{k_m S\theta}{x\,V'}$ calculated from:

$$\int_{y_{n-1}}^{y_m} \ln \frac{dy}{\frac{1-\left(1-\frac{Mr_A}{Mr_B}\right)y^*}{1-\left(1-\frac{Mr_A}{Mr_B}\right)y}} = \left(\frac{1}{1 - \frac{Mr_A}{Mr_B}}\right) \frac{k_m S\theta}{x\,v'}$$

As shown in Equation 31:

$$\frac{k_m S\theta}{x\ V'} = \frac{\left(\frac{1}{1-\frac{Mr_A}{Mr_B}}\right)-y^*}{\left(\frac{1}{1-\frac{Mr_A}{Mr_B}}\right)} \quad \mathrm{Ei}\left(-\ln \frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}}\right)$$

$$- \mathrm{Ei}\left(-\ln \frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_{n-1} - \frac{1}{1-\frac{Mr_A}{Mr_B}}}\right)$$

Using Run 34:

$x_p = y_{n-1} = 0.575$

$x_R = y_n = 0.685$

$y^* = 0.774$

$$\frac{Mr_A}{Mr_B} = 0.87 \qquad \frac{1}{1-\frac{Mr_A}{Mr_B}} = 7.692$$

$$-\ln \frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_n - \frac{1}{1-\frac{Mr_A}{Mr_B}}} = -\ln \frac{6.9185}{7.007} = 0.0127$$

$$-\ln \frac{y^* - \frac{1}{1-\frac{Mr_A}{Mr_B}}}{y_{n-1} - \frac{1}{1-\frac{Mr_A}{Mr_B}}} = -\ln \frac{6.9185}{7.117} = 0.0283$$

From Fig. (2)

$$\mathrm{Ei}\ (0.0127) = -\ 3.770$$

$$\mathrm{Ei}\ (0.0283) = \underline{-\ 2.960}$$

$$-\ 0.810$$

$$\frac{-k_m S\theta}{x\ v'} = (-0.810)\ \frac{\dfrac{1}{1-\dfrac{Mr_A}{Mr_B}} - y^*}{\dfrac{1}{1-\dfrac{Mr_A}{Mr_B}}} = (-0.810)\frac{(6.918)}{(7.692)} = 0.728$$

3. Vapor Velocity:

Example - Run No. 1

T_1 = 365.9 °K (data)

= 766.4 m.m. Hg.

Watts input = 1770

Ave. latent heat

0.475 x 12780 = 6060

0.525 x 14850 = 7800

13860 B.t.u./lb. mol

Superificial Vap. Vel.=

$$\frac{1700 \times 4.18 \qquad\qquad 365.9 \quad 760}{252 \qquad 13860 \quad 273 \quad 766.4 \quad .785\,(.5)^2}$$

= 0.294 ft./sec.

G.- CALCULATED RESULTS, 7 PLATE COLUMN

TABLE 21

Operating Characteristics - Seven-Plate Column

1	2	3	4	5	6	7
Run No.	Data taken by	Mixture	B.t.u./hr. from steam	Temp. Plate 1 °C.	Superficial Vapor Vel. Basis Plate 1 ft. per sec.	Pressure Drop Column Inches Water
1	P & W	Benz-Tol	21955	104.9(1)	0.57	7.5
2	"	"	44860	106.3(1)	1.23	7.5
3	"	"	59790	105.6	1.61	6.6
4	"	"	18156	97.2	0.48	3.3
6	"	"	53180	--	1.47*	--
7	"	"	58600	106.0	1.52	15.4
8	"	CCl$_4$-Tol	38300	100.4	1.14	--
9	"	"	38080	103.0	1.20	12.7
10	"	"	34800	--	1.10	10.7
1A	A & E	Benz-Tol	39500	94.9	1.10	--
2A	"	"	16920	95.0	0.47	--
3B	"	"	24450	96.4	0.68	--
4A	"	"	27000	96.4	0.76	--
5A	"	"	25800	95.6	0.73	--
5B(1)	"	"	29180	95.8	0.81	--
5B(2)	"	"	24400	97.8	0.69	--
5B(3)	"	"	21400	98.4	0.60	--
5C	"	"	25200	95.8	0.70	--
6A	"	"	30250	97.3	0.85	--
6B	"	"	28700	99.7	0.81	--
7	"	"	31300	100.0	0.89	--

TABLE 21 (Continued

1	2	3	4	5	6	7
Run No.	Data taken by	Mixture	B. t. u. /hr. from steam	Temp. Plate/ °C.	Superficial Vapor Vel. Basis Plate 1 ft. per sec.	Pressure Drop Column Inches Water
8A	A & E	Benz-Tol	19100	96.8	0.53	--
8B	"	"	23400	95.5	0.65	--
9	"	"	11980	95.6	0.33	--
9A	"	"	10300	96.1	0.29	--
10	"	"	25400	95.2	0.68	--
10A	"	"	20240	96.6	0.57	--
11	"	"	10025	97.6	0.28	--
12	"	"	16400	99.2	0.46	--
1A	Carey	"	41865	86.3	1.08	5.6
2A	"	"	44211	87.1	1.14	6.3
3A	"	"	58500	87.3	1.53	10.9
4A	"	"	61500	88.1	1.64	12.1
5A	"	"	59400	88.5	1.56	11.2
6A	"	"	63900	90.4	1.65	13.4
7A	"	"	40000	93.6	1.03	5.1
8A	"	"	33380	92.0	0.90	3.1
9A	"	"	50850	92.7	1.37	8.2
10A	"	"	32400	94.3	0.82	3.4

TABLE 22

Heat Balances on Seven-Plate Column

1 Run No.	2 Data taken by	3 B.t.u. per hour from steam	4 Ave. Temp. Diff. Cooling water °F	5 Lbs. Water to condenser per hr.	6 Heat Transfer in condenser B.t.u. per hr.	7 Heat Loss from column B.t.u. per hr.	8 Room Temp. °F
1A	Carey	41865	89.30	282.4	36950	4915	75.2
2A	"	44211	90.43	425.0	38450	5761	73.4
3A	"	58500	85.00	624.0	53000	5500	75.2
4A	"	61500	81.50	698.0	56800	4700	74.9
5A	"	59400	79.40	706.0	56100	3300	63.5
6A	"	63900	85.40	670.0	57200	6700	63.5
7A	"	40000	84.30	414.0	34850	5150	64.8
9A	"	50850	88.40	489.0	43300	7550	70.0
10A	"	32400	90.40	287.5	26000	6400	69.0
1	P & W	21955	62.23	245.25	15263	6692	--
2	"	44860	64.60	633.25	40800	4060	--
3	"	59790	43.81	643.56	56390	3400	--
4	"	18156	66.00	204.70	13510	4646	--
6	"	53180	54.87	950.00	52150	1030	--
7	"	58600	65.55	832.20	54550	4050	--
8	"	38300	93.02	359.00	33400	4900	--
9	"	38080	97.99	355.00	34780	3300	--
10	"	34800	69.70	438.50	30400	4400	--

TABLE 23

Overall Coefficient of Heat Transfer, Steam to Boiling Organic Liquid

1 Run No.	2 Data taken by	3 Mixture	4 B.t.u.per hour transferred	5 Ave. Temp. Steam °F.	6 Temp. of Liquid °F	7 Overall Temp. Diff. °F.	8 H $\frac{\text{B.t.u.-hr}}{(\text{ft}^2)(^\circ\text{F})}$
1A	A & E	Benz-Tol.	39500	256.2	209.4	46.8	312
2A	"	"	16920	241.0	213.2	27.8	226
3B	"	"	24450	246.0	214.2	31.8	285
4A	"	"	27000	251.8	217.8	34.8	286
5A	"	"	25800	243.6	220.1	23.5	407
5B(1)	"	"	29189	243.6	210.4	33.2	326
5B(2)	"	"	24400	244.0	214.6	29.4	308
5B(3)	"	"	21400	244.3	214.8	29.5	269
5C	"	"	25200	252.4	211.6	40.8	229
6A	"	"	30250	249.6	213.4	36.2	310
6B	"	"	28700	250.1	216.1	34.0	313
7	"	"	31300	253.8	217.4	35.4	319
8A	"	"	19100	236.1	208.0	28.1	252
8B	"	"	23400	235.9	208.1	27.8	312
9	"	"	11980	231.6	208.7	22.9	178
9A	"	"	10300	230.4	209.4	21.0	182
10	"	"	25400	243.2	209.7	33.5	281
10A	"	"	20240	241.2	212.0	29.2	257
11	"	"	10025	234.4	213.2	21.2	175
12	"	"	16400	240.6	215.2	25.4	240

TABLE 23 (CONTINUED)

1 Run No.	2 Data taken by	3 Mixture	4 B.t.u. per hour transferred	5 Ave. Temp. Steam °F.	6 Temp. of Liquid °F	7 Overall Temp. Diff. °F	8 H $\frac{\text{B.t.u.-hr}}{(\text{ft}^2)(^\circ\text{F})}$
1	P & W	Benz-Tol	21955	249.8	222.7	27.1	299
2	"	"	44860	267.3	227.3	40.0	415
3	"	"	59790	274.0	224.2	49.8	444
4	"	"	18156	237.7	210.7	27.0	250
7	"	"	58600	275.8	275.8	48.6	446
8	"	CCl_4-Tol	38300	258.8	215.0	43.8	326
9	"	"	38020	264.5	224.1	40.4	350
10	"	"	34800	259.0	221.3	37.7	342
1A	Carey	Benz-Tol	41865	234.8	194.9	39.9	388
2A	"	"	44211	238.4	196.5	41.9	391
3A	"	"	58500	242.6	195.5	47.1	460
4A	"	"	61500	248.2	199.1	49.1	464
5A	"	"	59400	248.6	199.5	49.1	448
6A	"	"	63900	252.3	203.0	49.3	480
7A	"	"	40000	242.6	204.6	38.0	390
8A	"	"	33380	246.8	206.5	40.3	306
9A	"	"	50850	250.7	209.2	41.5	454
10A	"	"	32400	242.6	209.5	33.1	362

Fig. 32

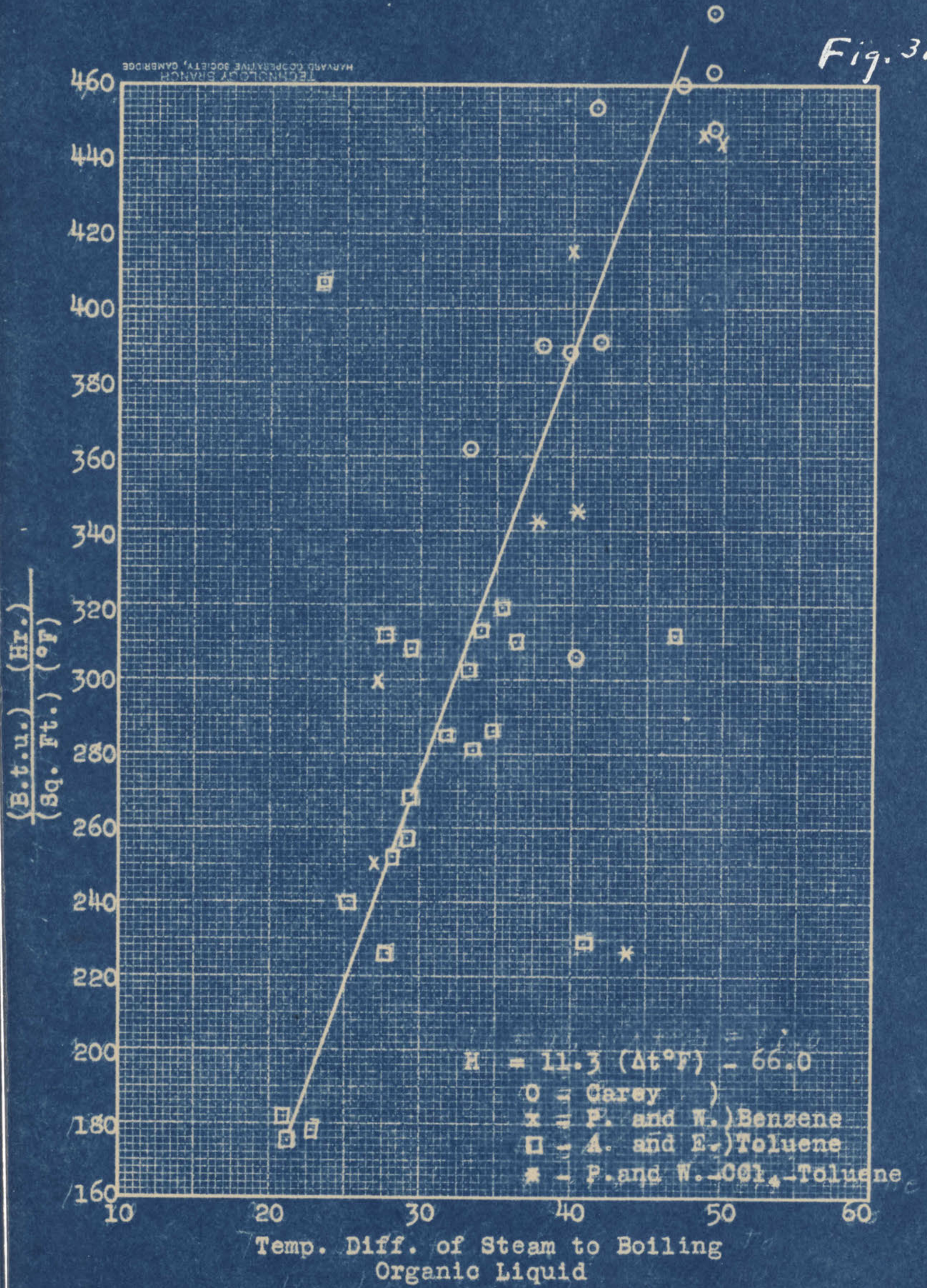

460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
10
20
30
40
50
60
(B.t.u.) (Hr.) / (Sq. Ft.) (°F)
Temp. Diff. of Steam to Boiling Organic Liquid
H = 11.3 (Δt°F) - 66.0
O = Carey)
x = P. and W.)Benzene
□ - A. and E.)Toluene
* - P.and W.-CCl₄-Toluene

TABLE 24

Actual Plate Concentrations and Murphree Efficiency Required To Trace the More Volatile Component Through the Column

- -

		Mol Fraction More Volatile Component									
Run No.	Data taken by	Still	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6	Plate 7	Condensate	E (Column)
1	P & W	0.109	0.141	0.263	0.376	0.476	0.600	0.698	0.784	--	59.0
2	"	0.046	0.095	0.143	0.225	0.314	0.459	0.564	0.695	0.789	55.0
3	"	0.073	0.139	0.205	0.322	0.486	0.618	0.737	0.853	0.907	62.0
4	"	0.278	0.360	0.538	0.615	0.731	0.813	0.866	0.912	0.940	55.0
6	"	--	--	--	--	0.660	0.772	0.835	--	--	--
7	"	0.089	--	0.250	0.363	0.500	0.614	0.746	0.851	0.911	62.0
8*	"	0.188	--	0.226	0.264	0.559	0.650	0.727	0.780	0.811	47.0
9*	"	0.134	--	0.276	0.446	0.543	0.653	0.714	0.771	0.801	47.0
10*	"	--	--	0.261	0.385	0.481	0.604	0.672	0.724	0.778	47.0
1A	Carey	0.576	0.742(1)	0.836	0.900	0.934	0.966	0.980	0.995	0.998	65.0
2A	"	0.542	0.700(1)	0.810	0.880	0.920	0.954	0.972	0.986	0.994	65.0
3A	"	0.549	0.700(1)	0.814	0.894	0.934	0.964	0.984	0.990	1.000	68.0
4A	"	0.500	0.694(1)	0.780	0.868	0.939	0.948	0.967	0.985	0.994	68.0
5A	"	0.472	0.650(1)	0.774	0.862	0.916	0.950	0.966	0.984	0.990	68.0
6A	"	0.412	0.575(1)	0.714	0.818	0.875	0.930	0.949	0.978	0.986	68.0
7A	"	0.393	0.540(1)	0.661	0.769	0.828	0.895	0.926	0.953	0.972	62.0
8A	"	0.348	0.516(1)	0.658	0.762	0.828	0.902	0.922	0.948	0.966	60.0
9A	"	0.306	0.490(1)	0.638	0.747	0.815	0.886	0.917	0.950	0.966	60.0
10A	"	0.296	0.465(1)	0.608	0.726	0.792	0.868	0.904	0.936	0.958	60.0
1A	A & E	0.294	--	0.505	0.705	0.773	0.854	0.902	0.914	0.957	60.0

TABLE 24(Continued)

Run No.	Data taken by	Still	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6	Plate 7	Condensate	E (Column)
2A	A & E	0.235	--	0.516	0.626	0.736	0.820	0.845	0.916	0.943	57.0
3B	"	0.216	--	0.479	0.599	0.697	0.803	0.849	0.905	0.934	57.0
4A	"	0.179	--	0.406	0.526	0.647	0.746	0.817	0.873	0.913	55.0
5A	"	0.137	--	0.236	0.305	0.387	0.564	0.761	0.893	0.889	55.0
5B(1)	"	0.278	--	0.563	0.696	0.780	0.853	0.890	0.928	0.966	60.0
5B(2)	"	0.217	--	0.487	0.632	0.731	0.811	0.853	0.895	0.935	60.0
5B(3)	"	0.215	--	0.515	0.610	0.726	0.799	0.849	0.904	0.944	60.0
5C	"	0.264	--	0.536	0.684	0.776	0.842	0.883	0.930	0.963	60.0
6A	"	0.234	--	0.479	0.648	0.754	0.833	0.865	0.919	0.959	60.0
6B	"	0.200	--	0.478	0.590	0.707	0.773	0.839	0.902	0.938	57.0
7	"	0.187	--	0.445	0.547	0.628	0.760	0.813	0.887	0.927	57.0
8A	"	0.323	--	0.630	0.719	0.822	0.884	0.917	0.952	0.970	60.0
8B	"	0.320	--	0.636	0.728	0.836	0.863	0.907	0.945	0.964	60.0
9	"	0.320	--	0.632	0.726	0.829	0.873	0.920	0.959	0.973	60.0
9A	"	0.303	--	0.627	0.714	0.825	0.866	0.909	0.947	0.974	61.0
10	"	0.291	--	0.589	0.687	0.774	0.838	0.892	0.938	0.958	60.0
10A	"	0.255	--	0.557	0.644	0.754	0.814	0.872	0.912	0.950	57.0
11	"	0.230	--	0.599	0.654	0.760	0.821	0.883	--	0.948	57.0
12	"	0.209	--	0.490	0.592	0.723	0.790	0.840	0.903	0.934	57.0

TABLE 25

Murphree Plate to Plate Efficiencies

1	2	3	4	5	6	7	8	9	10	11	12
Run No.	Data taken by	E_{1-2} %	E_{2-3} %	E_{3-4} %	E_{4-5} %	E_{5-6} %	E_{6-7} %	E_{7-C} %	Ave. E %	E to trace component up column	Superficial Vapor vel. ft/second.
1	P & W	87.2	56.5	45.4	59.9	51.8	55.1	--	59.3	59.0	0.57
2	"	89.0	57.7	47.5	68.7	48.0	77.0	59.8	64.0	55.0	1.23
3	"	47.5	66.1	77.3	61.1	64.3	82.8	64.3	66.2	62.0	1.61
4	"	81.6	71.9	57.1	57.7	50.4	59.7	53.8	61.8	55.0	0.48
7	"	--	57.6	62.5	53.0	71.0	77.2	70.6	65.3	62.0	1.52
8*	"	--	21.1	150.5	46.6	46.1	38.4	27.4	55.0	47.0	1.14
9*	"	--	85.0	44.6	55.3	36.7	40.1	25.6	47.9	47.0	1.20
10*	"	--	63.9	44.2	58.0	37.4	32.7	39.4	45.9	47.0	1.10
1A	Carey	68.1	68.8	57.6	80.0	66.7	115.2	100.0	79.5	65.0	1.08
2A	"	71.0	65.0	57.2	70.8	64.3	77.8	80.0	69.4	65.0	1.14
3A	"	73.5	76.9	64.5	75.0	86.9	60.0	150.0	72.8	68.0	1.53
4A	"	54.8	72.7	93.4	24.3	57.5	85.6	90.0	68.3	68.0	1.64
5A	"	71.3	70.9	68.3	67.9	51.6	85.6	60.0	69.2	68.0	1.56
6A	"	70.2	69.8	55.9	75.3	45.2	87.8	57.1	65.9	68.0	1.65
7A	"	58.5	63.5	46.8	69.8	50.0	60.0	65.5	59.1	62.0	1.03
8A	"	66.9	60.8	51.1	77.0	34.5	55.3	55.2	57.3	60.0	0.90
9A	"	68.5	61.2	50.0	68.9	46.3	66.0	51.6	58.9	60.0	1.37
10A	"	65.3	62.7	45.8	66.1	47.4	56.1	56.2	57.1	60.0	0.82
1A	A & E	--	93.8	44.5	65.3	57.1	20.7	82.6	72.8	60.0	1.10
2A	"	--	52.1	60.4	60.0	25.0	80.7	54.0	55.4	57.0	0.47
3B	"	--	55.3	51.3	68.0	42.2	65.0	51.7	56.6	57.0	0.68

*CCl_4-Toluene mixture. All other runs with Benzene-Toluene

TABLE 25 (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
Run No.	Data taken by	E_{1-2} %	E_{2-3} %	E_{3-4} %	E_{4-5} %	E_{5-6} %	$E_{6\circ 7}$ %	E_{7-C} %	Ave. E%	E to trace component up column	Superficial Vapor vel. ft/second
4A	A & E	--	54.5	57.6	56.5	52.2	54.9	54.1	54.9	55.0	0.76
5A	"	--	36.1	39.2	80.5	97.8	101.5	--	--	55.0	0.73
5B(1)	"	--	66.1	53.8	60.3	44.0	58.5	86.3	61.5	60.0	0.81
5B(2)	"	--	67.1	55.0	56.3	40.0	50.0	64.5	55.7	60.0	0.69
5B(3)	"	--	44.8	61.7	50.3	45.0	64.0	70.2	56.0	60.0	0.60
5C	"	--	71.1	57.1	53.6	45.6	68.1	78.5	62.3	60.0	0.70
6A	"	--	77.9	60.5	59.4	34.1	69.2	81.6	63.8	60.0	0.85
6B	"	--	51.6	60.3	43.4	53.2	69.2	62.0	56.6	57.0	0.81
7	"	--	46.4	39.5	72.5	40.8	71.1	60.6	55.2	57.0	0.89
8A	"	--	49.1	70.0	62.0	48.5	70.0	60.0	59.9	60.0	0.53
8B	"	--	51.4	75.0	29.3	55.6	69.1	55.8	56.0	60.0	0.65
9	"	--	52.2	71.0	45.8	63.5	81.3	56.0	66.6	60.0	0.33
9A	"	--	47.8	74.0	41.8	55.1	70.3	84.3	62.2	61.0	0.29
10	"	--	50.5	54.4	51.6	58.6	77.9	52.6	57.6	60.0	0.68
10A	"	--	42.8	62.5	45.1	56.3	54.0	71.7	55.4	57.0	0.57
11	"	--	28.8	61.6	46.9	62.0	--	--	--	57.0	0.28
12	"	--	47.2	67.9	45.9	43.0	70.0	53.4	54.6	57.0	0.46

*CCl_4-Toluene mixture. All other runs with Benzene-Toluene

TABLE 26

Theoretical Plate Concentrations and Number of Theoretically Perfect Plates Necessary to Obtain Given Concentration in Overhead Product.
N.B. Calculated by McCabe-Thiele Method, Basis First Plate.

Run No.	Data taken by	X_1 Actual	X_2 Actual	X_3 Theo.	X_4 Theo.	X_5 Theo.	X_C Actual	No. of Theo. Perfect Plates	Overall Efficiency % Basis 6 plates
1	P & W	0.141	0.282*	0.486	0.702	0.856	0.784	4.53	64.7 (1)
2	"	0.095	0.199*	0.374	0.593	0.786	0.789	5.02	71.7 (1)
3	"	0.139	0.278*	0.482	0.699	0.854	0.907	5.64	80.5 (1)
4	"	0.360	0.578*	0.775	0.898	0.958	0.940	4.70	67.1 (1)
7	"	--	0.446	0.666	0.834	0.927	0.911	3.83	63.8
8(2)	"	--	0.406	0.626	0.808	0.915	0.811	3.03	50.5
9(2)	"	--	0.476	0.693	0.851	0.936	0.801	2.68	44.6
10(2)	"	--	0.456	0.675	0.840	0.931	0.778	2.62	43.6
1A	Carey	--	0.836	0.929	0.972	0.990	0.998	5.00	83.4
2A	"	--	0.810	0.916	0.966	0.988	0.994	4.75	79.2
3A	"	--	0.814	0.918	0.967	0.988	1.000	5.05	84.2
4A	"	--	0.780	0.901	0.960	0.985	0.994	4.90	81.6
5A	"	--	0.774	0.898	0.958	0.984	0.990	4.60	76.7
6A	"	--	0.714	0.864	0.942	0.978	0.986	4.57	76.2
7A	"	--	0.661	0.831	0.926	0.971	0.972	4.06	67.8
8A	"	--	0.658	0.829	0.925	0.970	0.966	3.91	65.2
9A	"	--	0.638	0.816	0.919	0.968	0.966	3.96	66.0
10A	"	--	0.608	0.796	0.909	0.963	0.958	3.91	65.1
1A	A & E	--	0.505(1)	0.718	0.866	0.943	0.957	4.40	73.3
2A	"	--	0.516(1)	0.727	0.871	0.946	0.943	3.96	66.0

Table 26 (Continued)

Run No.	Data taken by	X_1 Actual	X_2 Actual	X_3 Theo.	X_4 Theo.	X_5 Theo.	X_C Actual	No. of Theo. Perfect Plates	Overall Efficiency % Basis 6 Plates
3B	A & E	--	0.479(1)	0.696	0.852	0.936	0.934	3.98	66.3
4A	"	--	0.406(1)	0.626	0.808	0.915	0.913	3.98	66.3
5A	"	--	0.236(1)	0.427	0.647	0.822	0.889	4.67	77.8
5B(1)	"	--	0.563(1)	0.764	0.893	0.956	0.966	4.37	72.8
5B(2)	"	--	0.487(1)	0.703	0.857	0.939	0.935	3.95	65.8
5B(3)	"	--	0.515(1)	0.727	0.871	0.946	0.944	3.97	66.2
5C	"	--	0.536(1)	0.744	0.881	0.951	0.963	4.40	73.3
6A	"	--	0.479(1)	0.696	0.852	0.936	0.959	4.59	76.4
6B	"	--	0.478(1)	0.695	0.852	0.936	0.938	4.05	67.4
7	"	--	0.445(1)	0.665	0.834	0.927	0.927	4.00	66.6
8A	"	--	0.630(1)	0.811	0.916	0.966	0.970	4.19	69.8
8B	"	--	0.636(1)	0.815	0.918	0.967	0.964	3.94	65.7
9	"	--	0.632(1)	0.812	0.917	0.967	0.973	4.29	71.4
9A	"	--	0.627(1)	0.809	0.915	0.986	0.974	3.83	63.8
10	"	--	0.589(1)	0.783	0.902	0.961	0.958	3.95	65.8
10A	"	--	0.557(1)	0.760	0.890	0.955	0.950	3.92	65.3
11	"	--	0.599(1)	0.790	0.906	0.962	0.948	3.75	62.5
12	"	--	0.490(1)	0.706	0.859	0.940	0.934	3.93	65.5

-*Theoretical Composition
-(1) Basis 7 plates
-(2) CCl_4-Toluene Mixture
(All other runs Benzene-Toluene)

H. - STUDIES OF BUBBLE CAP ACTION.

In conjunction with the rectification investigations constituting the major portion of the present work, it was considered that a study of the effects produced by blowing air through bubble caps immersed in water might throw additional light upon bubble cap rectification.

This problem was undertaken by Volante(62) who constructed the apparatus shown in Figure (33). It consisted of three plate sections of the same diameter as the seven plate column used in a portion of the rectification runs, viz. 8". Each section was one foot in height, the top section being open to the atmosphere. One 4" Badger bubble cap identical with those used in the seven plate column was located in the center of each plate. A centrifugal blower provided a source of low pressure air. The air, after metering in a sharp edged orifice, was led into the vapor riser of the lowest plate. An Ellison draft gage permitted the overall pressure drop through the top cap as well as the drop through the slots to be read.

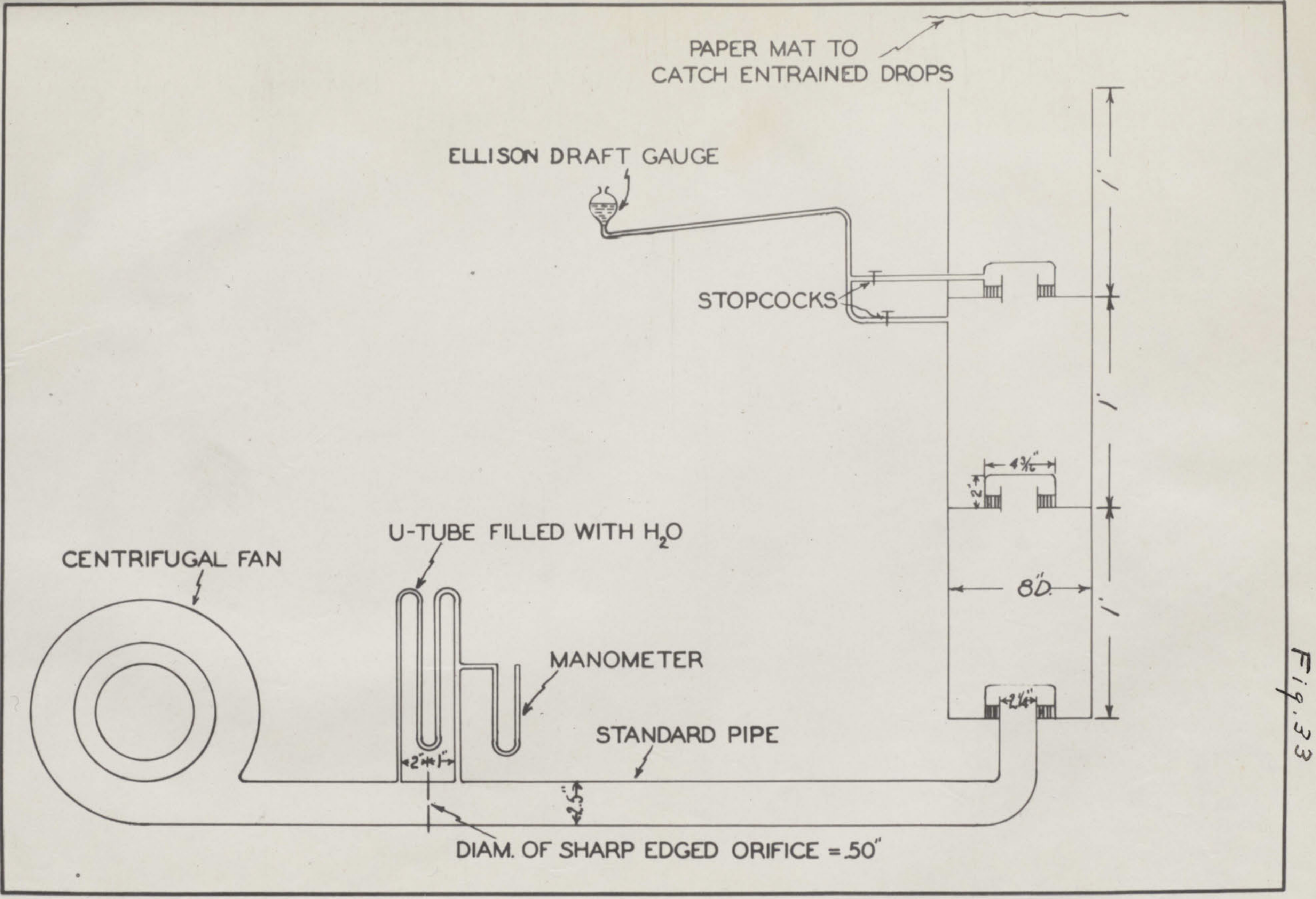

PAPER MAT TO CATCH ENTRAINED DROPS
ELLISON DRAFT GAUGE
STOPCOCKS
1'
1'
1'
4 3/16"
2"
8" D.
2 1/4"
U-TUBE FILLED WITH H_2O
CENTRIFUGAL FAN
MANOMETER
STANDARD PIPE
2"
1"
2.5"
DIAM. OF SHARP EDGED ORIFICE = .50"

Fig. 33

In making a run with this apparatus, water was placed in all three plates. The lower two plates served to humidify the air. (In calculating the air rates in these runs the air was considered saturated with water vapor as it entered the top plate). The blower was started and the air rate adjusted by throttling until the desired orifice reading was obtained. The amount of liquid thrown up as spray above the top plate was determined by supporting weighed pieces of porous paper, square in shape and slightly wider than the diameter of the column, at various heights above the plate. After a short time interval, clocked by a stopwatch, the sheet was removed and weighed. The porous sheets were backed with paraffin paper during exposure and were rolled up for weighing with the paraffin paper facing outward, thus reducing loss by evaporation in the weighing process. These entrainment data were computed to the basis of grams of water per minute per square foot of cross section.

A portion of the data from Volante's runs is summarized in Table (27).

TABLE (27)

Run No.	Sup. Vap. Vel. Ft. per Sec.	Overall Pressure drop through cap "H_2O	Pressure Drop through Slots "H_2O	Height Above Plate, In.	Gms. H_2O per min. per sq.ft.	Depth Liq. on Plate
11	0.753	0.830	0.780	9.0	19.60	1 3/16"
	.675	.800	.770	9.0	8.70	1 3/16"
	.590	.780	.765	9.0	4.90	1 3/16"
	.478	.740	.715	9.0	1.76	1 3/16"
	.358	.690	.650	9.0	0.62	1 3/16"
18	0.739	0.865	0.815	7.0	91.80	1 3/16"
	.627	.795	.755	7.0	25.90	1 3/16"
	.513	.740	.715	7.0	11.00	1 3/16"
	.328	.645	.635	7.0	2.14	1 3/16"
19	0.737	0.791	0.733	13.5	0.917	1 3/16"
	.630	.770	.735	13.5	.549	1 3/16"
	.509	.700	.670	13.5	.208	1 3/16"
	.338	.620	.600	13.5	.0573	1 3/16"

Figure (34) shows the result of plotting the entrainment rate against the air rate on semi-log paper, the entrainment rate being on the logarithmic scale. An empirical equation of the form:

log (Entrainment rate) = k u + C

applies, u being the air rate and k and C constants for any given height above the plate.

In Figure (35) entrainment rate is plotted against the height above the plate at which the determination was made, both quantities being on logarithmic scales.

The correlations expressed in Figures (34) and (35) are regarded at present as being entirely empirical. The data, although only semi-quantitative insofar as application to actual problems in column design is concerned, probably indicate the effects on spray density of height above the disengaging surface and vapor rate in apparatus of this type.

The entrainment measured by this procedure in reality represents the spray thrown up by the bursting of bubbles at the liquid surface, plus spray particles swept along by the vapor. The surface

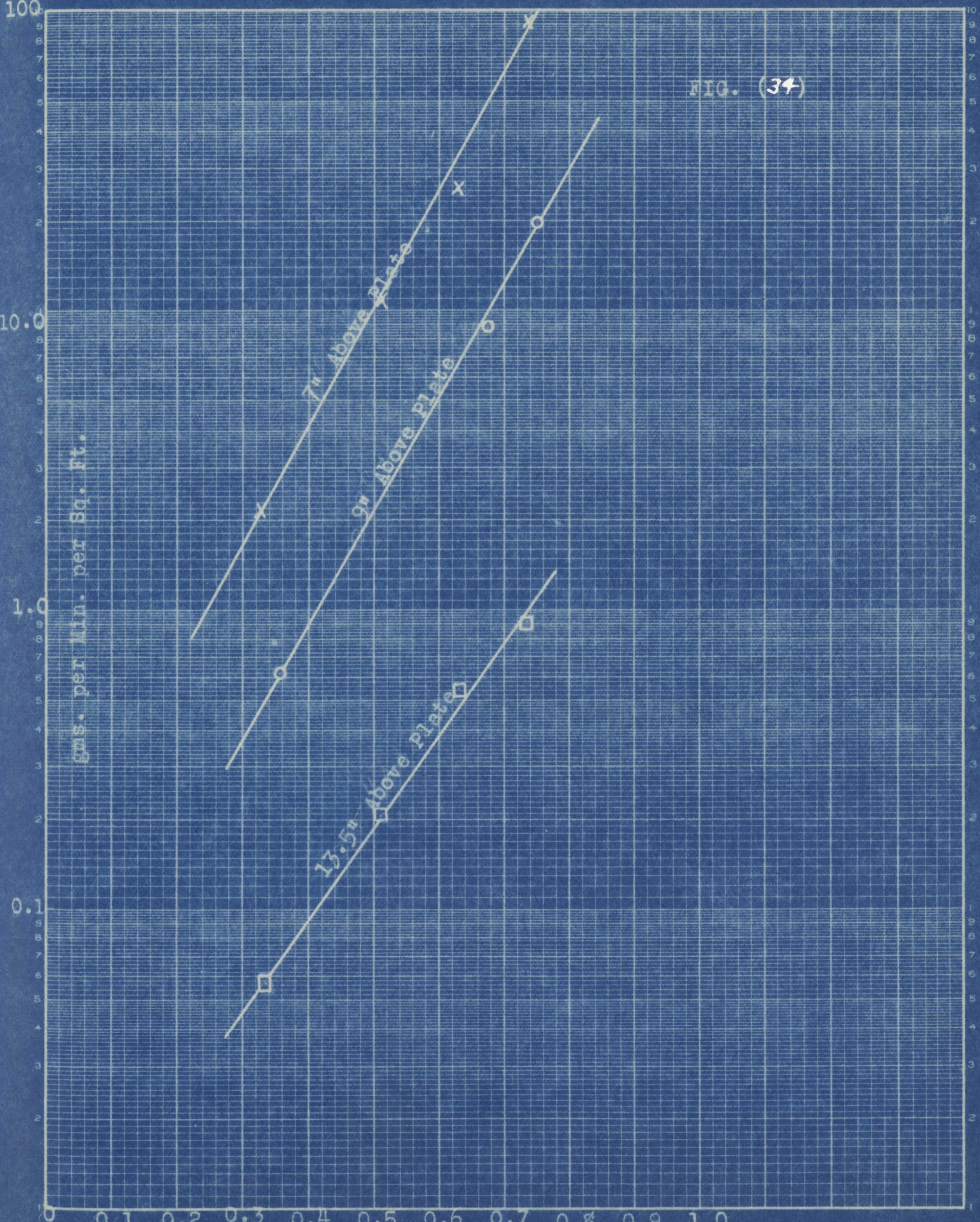
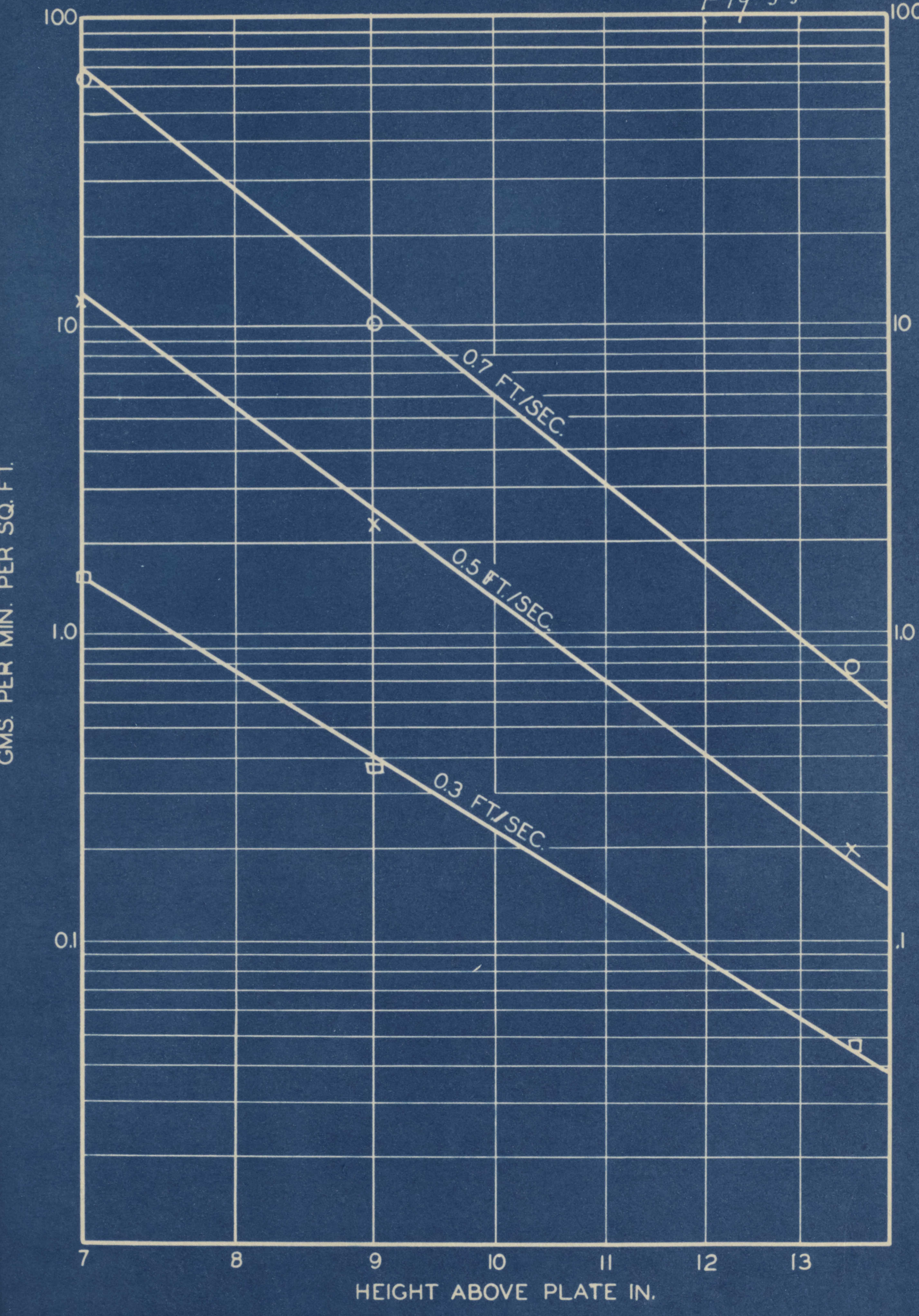


FIG. (34)
100
10.0
1.0
0.1
7" Above Plate
9" Above Plate
13.5" Above Plate
gms. per Min. per Sq. Ft.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Superficial Vapor Velocity, Ft. per sec.

Fig 35


100
10
1.0
0.1
100
10
1.0
.1
0.7 FT./SEC.
0.5 FT./SEC.
0.3 FT./SEC.
GMS. PER MIN. PER SQ. FT.
7
8
9
10
11
12
13
HEIGHT ABOVE PLATE IN.

energy of the bubbles, represented by the product of bubble area and the surface tension of the liquid, upon breaking of a bubble supplies a propulsive force to the liquid droplets. The direction in which drops may be thrown depends upon factors such as the point of rupture of the bubble. This spraying action may therefore be expected to be a function of the surface tension of the liquid from which the vapor bubbles emerge. Since the present data were obtained with water at room temperature the absolute values of entrainment rates are probably much higher than would be obtained in a column under working conditions, i.e. the plate liquids being at or near their boiling points in an actual column, their surface tensions would be much lower than that of water at room temperature.

At sufficiently high vapor rates a portion of the spray thrown into the vapor space of a plate section of a column will be swept along by the vapor and entrain to the next plate. This is not susceptible of measurement by the present method. Introduction of a nonvolatile dye on one plate of a column and sampling the plate above to test for its appearance probably affords the best means for measuring plate to plate entrainment. Copper Oleate and Ethyl Red have been used successfully for this purpose in commercial columns operating on petroleum fractions.

Data taken by the writer in conjunction with a motion picture study of bubble cap action show the variation in length of cap slots open with the vapor rate through the cap. These data are summarized in Table (28).

TABLE (28)

Vapor Rate Thru Cap cu.ft./sec.	Vapor Rate Sup.Vap.Vel. Thru 8" dia. column,ft/sec.	Fractional Length Slots Open	Actual Length Slots Open In.	Velocity Thru Slots Ft/sec.
0.0409	0.117	1/4	0.188	6.99
0.1278	0.366	1/2	0.375	10.91
0.3695	1.06	3/4	0.562	21.00
0.5750	1.65	1	0.750	24.60

These data show that the actual length of slot open and the actual slot velocities are roughly proportional to the square root of the vapor rate. Examining Table (29) it will be noticed that the overall pressure drop through the caps as well as the pressure drop measured from the inside of the cap do not change rapidly with vapor rate. This is due to the slot apertures opening up with increase in vapor rate thus preventing frictional drop through the slots increasing as rapidly as would be the case were the slot opening fixed

The observations in Table (28) were made in a modification of Volante's apparatus in which the top plate section was replaced by a bubble cap enclosed in a square box with plate glass sides, open at the top. Water to any desired depth of immersion of the cap slots could be placed in the box and the bubbling action observed. The length of working slots reported in Table (28) was roughly measured by means of a scale held against the cap while the air rate was adjusted to the several values.

Subsequent to the writing of the discussions of results of the rectification studies (Section VIII) the work of Nryagi(63) on the "Flow of Bubbles Through Liquids" was called to the writer's attention. It is recommended that a study be made of these data prior to further work in the field of bubble cap rectification.

I - ORIGINAL DATA -

7 PLATE COLUMN

Run No. 1A (Carey) - Date 11/15/28

STEAM DATA

1 Time	2 Barometer m.m. Hg.	3 Steam Press. Lbs. Sq.In. Gage	4 Steam Manometer cm. Hg. Right	5 Left	6 Diff.	7 True Press. Lbs./in² Abs.	8 Steam Temp. °C.	9 Weight Condensate Lbs. Gross	10 Tare	11 Net
1:08	769.5 (24°)	8.0						19.750	2.688	17.062
1:13			70.1	30.0	40.1		114.0	19.938	2.938	17.000
1:17			70.4	29.8	40.6		113.8	18.375	2.688	15.687
1:23			70.2	30.0	40.2		113.6	10.813	2.938	7.875
1:32			70.4	29.8	40.6		113.7			57.624
1:37			70.5	29.7	40.8		113.6	Wt. Cold Water		
1:43			70.9	29.3	41.6		113.6	19.250	3.125	
1:47			70.6	29.5	41.1		113.7	21.313	9.688	27.750
1:49	768.3 (25.5°)		70.6	29.6	41.0		113.7	Net Wt. Condensate		29.874
41 min.	Ave 768.9			Ave	40.75	22.72	Ave 113.69			
	Corr. 3.1					Corr	0.98			
	765.8						114.67			
						Temp.Sat. St.	112.8			
						Superheat °C	1.87			

CONDENSER DATA

1 Time	2 Cooling Water Temp. °C Inlet	3 Outlet	4 Rise	5 Time Ave. Rise °C.	6 Trap Temp. °C.	7 Time	8 Weight Cooling Water Lbs. Gross	9 Tare	10 Net
1:10	10.90	58.35	47.45		46.6	1:08 1/2	406.0	123.6	282.4
1:22	11.00	60.15	49.15		47.8	1:49 1/2			
1:30	10.90	59.90	49.00		48.1	41 min.			
1:42	10.95	62.20	51.25		50.0				
1:51	11.10	62.20	51.10	49.60	50.0				
					Ave.48.40				

Run No. 1A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C.	3 Plate 2 °C.	4 Plate 3 °C.	5 Plate 4 °C.	6 Plate 5 °C.	7 Plate 6 °C.	8 Plate 7 °C.	9 Trap Ave. °C.	10 Press. on Plate2 Inches Water
1:15	86.4	84.8	83.0	82.3	81.6	81.2	80.5		4.8
1:25	86.4	84.8	83.0	82.3	81.6	81.15	80.5		4.8
1:35	86.4	84.8	83.0	82.3	81.6	81.15	80.5		4.8
1:45	86.4	84.8	83.0	82.3	81.6	81.15	80.5		4.8
Ave.	86.40	84.80	83.00	82.30	81.60	81.16	80.50		4.8
Corr.	-0.14	-0.20	+0.04		+0.06	-0.23	-0.08		
Ave.Corr.	86.26	84.60	83.04	82.30	81.66	80.93	80.42	48.40	

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling Point °C.	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer m.m. Hg.	7 Mol Fraction Benzene
Still	1:51	90.45	+0.026	90.48		0.576
Plate 1		--	--	86.25*		0.742
" 2		84.09	-0.043	84.05		0.836
" 3		82.63	-0.055	82.58	767.3 (25°)	0.900
" 4		81.93	-0.061	81.87	3.1	0.934
" 5		81.33	-0.066	81.27	764.2	0.966
" 6		81.05	-0.068	80.98		0.980
" 7		80.75	-0.069	80.68		0.995
Trap	1:55	80.55	-0.070	80.48	768.0 (25.5°)	0.998
					3.1	
					764.9	

*Estimated from
B.P. vs. Plate No. Curve

Run No. 2A (Carey) - Date 11/16/28

STEAM DATA

1 Time	2 Barometer m.m. Hg.	3 Steam Press. Lbs./sq.in. Gage	4 Steam Manometer cm. Hg. Right	5 Left	6 Diff.	7 True Press. Lbs./sq.in. Absolute	8 Steam Temp. °C	9 Weight Condensate Lbs. Gross	10 Tare	11 Net
1:05	768.0(23°)	10.0	74.6	25.6	49.0		116.75	19.938	2.625	17.313
1:15			74.8	25.4	49.4		117.50	19.938	2.938	17.000
1:20			74.6	25.6	49.0		117.20	21.125	2.625	19.500
1:25			74.8	25.4	49.4		117.18	19.375	2.938	16.337
1:30			74.8	25.4	49.4		117.50	14.500	2.625	11.875
1:40			74.8	25.4	49.4		117.75			82.025
1:45			74.8	25.4	49.4		117.65	Wt. Cold Water		
1:50	767.5(24°)		74.8	25.4	49.4		117.65	22.563	3.313	
45 min.			74.8	25.4	49.4		117.70	20.875	3.313	
Ave.	767.75			Ave.	49.31	24.26	Ave. 117.43	13.875	3.313	47.374
Corr.	2.92					Temp.Sat. St.	114.65	Net Wt. Condensate		34.651
	764.83					Superheat °C	2.78			

CONDENSER DATA

1 Time	2 Cooling Water Temperature °C Inlet	3 Outlet	4 Rise	5 True Ave. Rise °C	6 Trap Temp. °C	7 Time	8 Weight Cooling Water Lbs. Gross	9 Tare	10 Net
1:09	11.70	57.55	45.85		50.5	1:07	431.75	123.50	308.25
1:19	11.88	60.00	48.12		52.0	1:50 1/2			
1:24	11.95	61.50	49.55		53.2				
1:29	12.03	63.20	51.17		54.8	43 1/2min			
1:34	11.80	64.20	52.40		55.8				
1:41	11.82	65.20	53.38		56.3				
1:45	11.88	65.70	53.82		56.8				
2:03	12.05	66.50	54.45	50.24	56.8				
				Ave.	54.5				

Run No. 2A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	8 Trap Ave. °C	10 Press on Plate 2 Inches Water
1:12	87.20	85.40	83.40	82.60	81.80	81.20	80.55		
1:24	87.20	85.45	83.40	82.60	81.75	81.25	80.66		
1:34	87.20	85.45	83.40	82.60	81.80	81.25	80.55		
1:44	87.20	85.45	83.40	82.60	81.80	81.25	80.55		
Ave.	87.20	85.44	83.40	82.60	81.79	81.24	80.56		
Corr.	-0.12	-0.20	+0.04		+0.07	-0.24	-0.08		
Ave. Corr.	87.08	85.24	83.44	82.60	81.86	81.00	80.48	54.50	5.4

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer m.m. Hg.	7 Mol Fraction Benzene
Still	--	91.30	+0.040	91.34	768.8 (24°)	0.542
Plate 1	--	--	--	87.25*	3.0	0.700
" 2	--	84.70	-0.039	84.66	765.8	0.810
" 3	--	83.07	-0.049	83.02		0.880
" 4	--	82.20	-0.058	82.14	768.4(24.5°)	0.920
" 5	--	81.52	-0.064	81.46	3.0	0.954
" 6	--	81.20	-0.066	81.13	765.4	
" 7	--	80.89	-0.069	80.82	768.2(24.5°)	0.972
					3.0	
					765.2	0.986
Trap	--	80.64	-0.070	80.57	767.5(24°)	0.994
					3.0	
					764.5	

*Estimated from B.P. vs. Plate No. Curve

Run No. 3A (Carey) - Date 11/20/28

STEAM DATA

1 Time	2 Barometer m.m. Hg.	3 Steam Press. Lbs./sq. in.Gage	4 Steam Manometer cm. Hg. Right	5 Left	6 Diff.	7 True Press. Lbs./sq. in. absolute	8 Steam Temp. °C	9 Weight Condensate Lbs. Gross	10 Tare	11 Net
11:05	757.7(24°)							19.063	2.625	16.438
11:06		12.0	79.5	20.5	59.0		118.20	19.688	2.938	16.750
11:11			80.2	19.9	60.4		118.35	21.063	2.625	18.438
11:16			80.3	19.7	60.6		118.50	19.125	2.938	16.187
11:21			80.3	19.8	60.5		118.40			67.813
11:26			80.3	19.7	60.6		118.40	Wt.Cold	Water	
11:31			80.2	19.8	60.4		118.50	10.313	2.625	
11:36			80.0	20.0	60.0		118.20	10.250	2.938	
11:41	758.0(24°)		79.8	20.2	59.6		118.20	22.125	3.250	
36 min	757.85			Ave.	60.0	26.17	Ave. 118.34	19.875	2.313	30.874
	2.94					Temp.Sat.St.	117.00	Net.Wt.Conden-		36.939
	754.87					Superheat °C	1.34		sate	

CONDENSER DATA

1 Time	2 Cooling Water Temperature °C Inlet	3 Outlet	4 Rise	5 True Ave. Rise °C	6 Trap Temp. °C	7 Time	8 Weight Cooling Water Lbs. Gross	9 Tare	10 Net
11:04	11.50	59.15	47.65		63.0	11:05	488.00	124.25	363.75
11:09	11.52	58.55	47.03		62.3	11:40			
11:14	11.48	58.55	47.07		63.5	35 minutes			
11:19	11.45	58.70	47.25		63.5				
11:24	11.28	59.65	48.37		64.0				
11:29	11.55	63.90	52.35		74.5				
11:34	11.45	56.45	45.00		61.9				
11:39	11.40	54.40	43.00	47.22	59.2				
				Ave.	64.0				

Run No. 3A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	9 Trap Ave. °C	10 Press on Plate 2 Inches water
11:12	87.40	85.05	82.90	82.10	81.35	80.70	80.10		9.4
11:22	87.40	85.00	82.90	82.10	81.35	80.65	80.05		9.4
11:32	87.55	85.05	82.90	82.00	81.20	80.55	79.85		9.4
11:45	87.30	84.90	82.90	82.00	81.30	80.65	80.05		9.4
Ave.	87.41	85.00	82.90	82.05	81.30	80.64	80.02		
Corr.	-0.13	-0.20	+0.04		+0.06	-o.24	-0.08		
Ave.Corr	87.28	84.80	82.94	82.05	81.36	80.40	79.94	64.0	9.4

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling Point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer inches Hg.	7 Mol Fraction Benzene
Still		90.83	+0.03	90.86	30.13(73°F)	0.549
Plate 1						0.700*
" 2		84.26	-0.04	84.22	30.13(67°F)	0.814
" 3		82.49	-0.06	82.43	29.98(73°F)	0.894
" 4		81.61	-0.06	81.55		0.934
" 5		81.06	-0.07	80.99	29.98(73°F)	0.964
" 6		80.68	-0.07	80.61		0.984
" 7		80.39	-0.07	80.32	29.96(73°F)	0.990
Trap		80.11	-0.07	80.04		1.000

* Estimated from Plot of Composition vs. Plate No.

Run No. 4A (Carey) - Date 11/20/28

STEAM DATA

1	2	3	4	5	6	7	8	9	10	11
Time	Barometer m.m. Hg.	Steam Press. Lbs./sq. in.Gage	Steam Manometer cm.Hg. Right	Left	Diff.	True Press Lbs./sq. in. absolute	Steam Temp. °C	Weight Condensate Lbs. Gross	Tare	Net
12:45								9.813	2.630	7.18
12:46		15.0	86.3	12.1	74.2		121.5	10.313	2.940	7.37
12:51			86.4	12.1	74.3		121.5	21.000	3.250	17.75
12:56			85.9	12.6	73.3		121.4	18.190	2.310	15.88
1:01			86.1	12.4	73.7		121.0			48.18
1:06			86.5	11.9	74.6		121.5	Wt.Cold	Water	
1:11			86.2	12.3	73.9		121.5	21.063	3.250	17.81
1:13	758.3(23.8°)			Ave.	74.0	28.89	Ave.121.4			
28 minutes										
	2.9					Temp.Sat.St.	120.3	Net wt.	Conden-sate	30.37
	755.4					Superheat °C	1.1			

CONDENSER DATA

1	2	3	4	5	6	7	8	9	10
Time	Cooling Water Temperature °C Inlet	Outlet	Rise	True Ave. Rise °C	Trap Temp. °C	Time	Weight Cooling Water Lbs. Gross	Tare	Net
12:47	11.30	55.45	44.15		64.1	12:45½	451.50	121.75	325.75
12:52	11.28	56.00	44.72		65.0	1:13½			
12:57	11.30	56.25	45.95		65.2	28 min.			
1:02	11.30	56.55	45.25		66.8				
1:07	11.30	57.55	46.25		70.8				
1:12	11.25	56.65	45.40	45.29	68.3				
25 min.				Ave.	66.7				

Run No. 4A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1	2	3	4	5	6	7	8	9	10
Time	Plate 1 °C	Plate 2 °C	Plate 3 °C	Plate 4 °C	Plate 5 °C	Plate 6 °C	Plate 7 °C	Trap Ave. °C	Press on Plate 2 inches water
12:49	88.25	85.80	83.00	82.50	81.70	80.80	79.90		10.4
12:58	88.00	85.75	83.40	82.40	81.50	80.75	80.00		10.4
1:08	88.25	86.00	83.40	82.40	81.70	80.80	79.90		10.4
1:15	88.25	85.80	83.50	82.50	81.70	80.80	79.90	66.7	10.4
Ave	88.18	85.77	83.33	82.45	81.65	80.79	79.93		
Corr.	-0.11	-0.19	+0.04		+0.07	-0.24	-0.08		
Ave Corr.	88.07	85.58	83.37	82.45	81.72	80.55	79.85		

SAMPLE DATA

1	2	3	4	5	6	7
Source of Sample	Time of Sampling	Observed Boiling Point °C	Therm. Corr. °C	True Boiling Point °C	Barometer Inches Hg.	Mol Fraction Benzene
Still		92.70	+0.09	92.79		0.500
Plate 1						0.694*
" 2		85.05	-0.04	85.01	30.12(67°F)	0.780
" 3		83.10	-0.05	83.05		0.868
" 4		82.00	-0.06	81.94		0.939
" 5		81.30	-0.07	81.23	30.12(68°F)	0.948
" 6		80.90	-0.07	80.83		0.967
" 7		80.50	-0.07	80.43	30.12(68°F)	0.985
Trap		80.31	-0.07	80.24	30.14(68°F)	0.994

* Estimated from Plot of Plate No. vs. Composition

Run No. 5A (Carey) - Date 11/26/28

STEAM DATA

1	2	3	4	5	6	7	8	9	10	11
Time	Barometer m.m. Hg.	Steam Press. Lbs./sq. in. Gage	Steam Manometer cm. Hg.			True Press Lbs./sq. in. absolute	Steam Temp. °C	Weight Condensate Lbs.		
			Right	Left.	Diff.			Gross	Tare	Net
11:07	764.5(175°C)							18.75	2.69	16.06
11:08		15.0	86.4	12.1	74.3		121.7	18.81	2.94	15.87
11:13			86.4	12.0	74.4		121.7	18.75	2.69	16.06
11:18			86.0	12.6	73.3		121.7	17.94	2.94	15.00
11:23			86.0	12.5	73.4		121.8			62.99
11:28			86.3	12.2	74.0		122.0			
11:34			86.7	11.6	74.9		122.0	18.38	2.31	
11:36			86.9	11.4	75.3		122.0	10.25	3.69	
29 min.				Ave.	74.2	29.05 Ave.	121.83	9.88	2.94	30.57
						Temp.Sat.St.	120.50	Net wt. condensate		32.42
						Superheat °C	1.33			

CONDENSER DATA

1	2	3	4	5	6	7	8	9	10
Time	Cooling Water Temperature °C			True Ave. Rise °C	Trap Temp. °C	Time	Weight Cooling Water Lbs.		
	Inlet	Outlet	Rise				Gross	Tare	Net
11:09	9.82	55.61	45.79		63.0	11:08	443.0	125.0	318.0
11:14	9.78	55.82	46.04		62.5	11:35			
11:19	9.70	55.20	45.50		61.9	27 min.			
11:24	9.70	55.30	45.60		62.0				
11:29	9.70	55.60	45.90		62.2				
11:34	9.70	55.70	46.00	44.13	62.8				
				Ave.	62.4				

Run No. 5A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	9 Trap Ave. °C	10 Press on Plate 2 Inches water
10:30	88.60	86.35	83.70	82.60	81.80	81.10	80.45		9.6
10:35	88.50	86.40	83.80	82.60	81.80	81.10	80.45		9.6
11:00	88.50	86.30	83.70	82.65	81.80	81.10	80.50		9.6
11:20	88.50	86.30	83.70	82.60	81.80	81.10	80.50		9.6
11:25	88.50	86.20	83.70	82.60	81.80	81.10	80.50		9.6
11:38	88.60	86.35	83.80	82.60	81.80	81.10	80.50		9.6
Ave.	88.53	86.31	83.77	82.60	81.80	81.10	80.50		
Corr.	-0.10	-0.20	+0.04		+0.07	-0.24	-o.08		
Ave. Corr.	88.43	86.11	83.81	82.60	81.87	80.86	80.42	62.4	9.6

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling Point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer inches Hg	7 Mol Fraction Benzene
Still		92.90	+0.09	92.99	30.01(68°)	0.472
Plate 1						0.650*
" 2		85.21	-0.04	85.17		0.774
" 3		83.18	-0.05	83.13		0.862
" 4		82.02	-o.06	81.96		0.916
" 5		81.26	-0.07	81.19		0.950
" 6		80.91	-0.07	80.84		0.966
" 7		80.53	-0.07	80.46		0.984
Trap		80.39	-0.07	80.32	30.01(68°)	0.990

* Estimated from a plot of Plate No.vs. Concentration

Run No. 6A (Carey) - Date 11/26/28

STEAM DATA

1 Time	2 Barometer m.m. Hg.	3 Steam Press Lbs./sq. in. Gage	4 Steam Manometer cm. Hg. Right	5 Left	6 Diff.	7 True Press Lbs./sq.in absolute	8 Steam Temp. °C	9 Weight Condensate Lbs. Gross	10 Tare	11 Net
12:26	764.5(17.5°C)							18.19	2.69	15.50
12:27		17.0	91.8	5.6	86.2		124.9	18.88	2.94	16.94
12:32			91.6	5.8	85.8		124.7	17.56	2.69	14.87
12:37			91.4	6.1	85.3		124.6	17.06	2.94	14.12
12:42			91.7	5.7	86.0		124.6			61.43
12:47			91.6	5.9	85.7		124.5	Wt.Cold	Water	
12:52			91.1	6.4	84.7		124.5	19.50	3.25	
26 min					85.6	31.25	Ave.124.6	10.38	2.69	
						Temp. Sat.St	122.77	11.06	2.94	32.06
						Superheat °C	1.83	Net Condensate		29.37

CONDENSER DATA

1 Time	2 Cooling Water °C Inlet	3 Outlet	4 Temperature Rise	5 True Ave. Rise °C	6 Trap Temp. °C	7 Time	8 Weight Cooling Water Lbs. Gross	9 Tare	10 Net
12:29	9.60	56.40	46.80		62.0	12:28	404.0	124.8	279.2
12:34	9.60	56.45	46.85		62.2	12:53			
12:39	9.60	56.40	46.80		62.3	25 minutes			
12:44	9.60	56.80	47.20		63.0				
12:49	9.60	57.25	47.65		63.0				
12:54	9.60	58.40	49.80	47.40	64.2				
	9.60	56.95			62.8				
	-0.10	-.03							
	9.50	56.92							

Run No.6A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	9 Trap Ave. °C	10 Press on Plate 2 Inches Water
11:45	90.70	88.00	84.90	83.40	82.40	81.30	80.60		11.5
12:00	90.30	87.80	84.70	83.30	82.30	81.30	80.55		11.5
12:15	90.60	87.80	84.60	83.30	82.30	81.30	80.50		11.5
12:35	90.50	88.00	84.70	83.40	82.30	81.30	80.55		11.5
12:45	90.30	87.80	84.80	83.50	82.30	81.30	80.50		11.5
Ave.	90.50	87.88	84.74	83.38	82.30	81.30	80.53		
Corr.	-0.07	-0.17	+0.03		+0.07	-0.24	-0.08		
Ave.Corr	90.43	87.71	84.77	83.38	82.37	81.06	80.45	62.8	11.5

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling Point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer inches Hg.	7 Mol Fraction Benzene
Still		94.90	+0.14	95.04		0.412
Plate 1						0.575*
" 2		86.88	-0.02	86.86	30.24(68°C)	0.714
" 3		84.37	-0.04	84.33		0.818
" 4		83.12	-0.05	83.07		0.875
" 5		81.92	-0.06	81.86		0.930
" 6		81.50	-0.06	81.44		0.949
" 7		80.92	-0.07	80.85		0.978
Trap		80.71	-0.07	80.64	30.24(68°F)	0.986

* Estimated from Plot of Plate No. vs. Concentration

Run No. 7A (Carey) - Date 11/27/28

STEAM DATA

1 Time	2 Barometer m.m. Hg.	3 Steam Press. Lbs./sq. in Gage	4 Steam Manometer cm. Hg. Right	5 Left	6 Diff.	7 True Press Lbs./sq./in absolute	8 Steam Temp. °C	9 Weight Condensate Lbs. Gross	10 Tare	11 Net
11:24								19.00	2.69	16.31
11:25	767.5(18.2°)	12.0	79.7	20.9	58.8		118.4	18.06	2.94	15.12
11:30			79.7	20.8	58.9		118.4	19.50	2.69	16.81
11:35			79.2	21.3	57.9		118.2			48.24
11:40			79.7	20.8	58.9		119.5	Wt.Cold	Water	
11:45			79.8	20.7	59.1		120.1	10.31	2.69	
11:50			79.9	20.7	59.2		119.7	9.81	2.94	
11:55			79.8	20.7	59.1		119.7	10.32	3.19	21.62
12:00			80.1	20.4	59.7		119.5	Net wt.	Con-	26.62
12:02				Ave.	58.95	26.20	Ave.119.2	densate		
38 min.										

CONDENSER DATA

1 Time	2 Cooling Water Temperature °C Inlet	3 Outlet	4 Rise	5 True Ave. Rise °C	6 Trap Temp. °C	7 Time	8 Weight Cooling Water Lbs. Gross	9 Tare	10 Net
11:26	9.50	55.40			42.5	11.26	378.75	123.75	255.0
11:31	9.58	56.58			43.2	12:03			
11:36	9.55	57.00			43.5	37 min.			
11:41	9.50	56.30			43.8				
11:46	9.45	55.80			43.3				
11:51	9.50	55.85			42.7				
11:56	9.40	56.00			43.2				
12:01	9.42	56.88			43.7				
35 min	9.48	56.22		Ave.	43.2				
Ave		-0.03							
	-0.1								
	9.38	56.19	46.81	46.81					

Run No. 7A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	9 Trap Ave. °C	10 Press on Plate 2 Inches Water
11:28	93.60	89.30	85.95	84.50	83.20	82.10	81.20		4.4
11:42	93.60	89.35	85.95	84.50	83.20	82.10	81.20		4.4
11:53	93.70	89.40	86.00	84.50	83.20	82.15	81.10		4.4
Ave.	93.63	89.35	85.97	84.50	83.20	82.12	81.13		
Corr.	+0.01	-0.15	+0.02	+0.01	+0.08	-0.24	-0.08		
Ave. Corr.	93.64	89.20	85.99	84.51	83.28	81.88	81.05	43.2	4.4

SAMPLE DATA

1 Source of Sampling	2 Time of Sampling	3 Observed Boiling Point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer inches Hg.	7 Mol Fraction Benzene
Still		95.70	+0.16	95.86	30.37(69°F)	0.393
Plate 1				91.60*		0.540
" 2		88.40	-0.01	88.39	30.36(69°F)	0.661
" 3		85.68	-0.03	85.65	30.36 "	0.769
" 4		84.28	-0.04	84.24	30.36 "	0.828
" 5		82.76	-0.05	82.71	30.34 "	0.895
" 6		82.14	-0.06	82.08	30.32 "	0.926
" 7		81.52	-0.06	81.46	30.31(68°)	0.953
Trap		81.12	-0.07	81.05	30.31 "	0.972

* Estimated from Plot of Plate No. vs. Boiling Points

Run No. 8A (Carey)-Date 11/30/28

STEAM DATA

1	2	3	4	5	6	7	8	9	10	11
Time	Barometer m.m. Hg.	Steam Press. Lbs./sq. in.Gage	Steam Manometer cm. Hg. Right	Left	Diff.	True Press Lbs./sq. in absolute	Steam Temp. °C	Weight Condensate Gross	Tare	Net
10:53	767.0(21°C)	14.0	84.6	15.0	69.6		120.6	17.69	2.81	14.88
10:58			84.6	14.8	69.8		120.7	18.38	2.94	15.44
11:01			84.0	15.6	68.4		120.5	16.69	2.81	13.88
11:08			84.4	15.2	69.2		132.4	14.88	2.94	11.94
11:13			84.7	14.8	69.9		127.3			56.14
11:18			84.6	14.8	69.8		122.0	Wt.Cold	Water	
11:23			84.4	15.0	69.4		121.3	9.50	2.81	
11:28			84.8	14.7	70.1		121.5	8.44	2.94	
11:33			84.9	14.5	70.4		121.5	20.13	3.31	
11:33½				Ave.	69.62	28.15	Ave. 123.1	18.06	14.69	32.38
40:5 minutes						Temp.Sat.St.	119.4	Net Weight Con-		23.76
						Superheat °C	3.7	densate		

CONDENSER DATA

1	2	3	4	5	6	7	8	9	10
Time	Cooling Water Temperature °C Inlet	Outlet	Rise	True Ave. Rise °C	Trap Temp. °C	Time	Weight Cooling Water Lbs. Gross	Tare	Net
10:55½	9.07	58.65			49.1	10.55	411.5	124.0	287.5
10:56	9.03	58.45			49.0	11.35			
11:01	9.15	58.90			48.8	40 min.			
11:06	9.30	58.70			48.7				
11:11	9.30	59.85			49.8				
11:16	8.82	60.03			50.0				
11:21	9.13	60.29			50.1				
11:26	9.35	60.90			50.2				
11:31	9.40	60.30			50.2				
11:34	9.42	60.00	50.48	50.48	50.2				
	9.20	59.61							
				Ave.	49.61				
	-0.10	-0.03							
	9.10	59.58							

Run No. 8A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	9 Trap Ave. °C	10 Press on Plate 2 Inches Water
11:05	92.00	89.50	86.00	84.55	83.20	82.15	81.35		
11:15	92.00	89.42	85.95	84.50	83.20	82.20	81.35		
11:20	92.00	89.42	86.00	84.55	83.20	82.15	81.35		
Ave.	92.00	89.45	85.98	84.53	83.20	82.17	81.35		
Corr.	-0.04	-0.15	+0.02	+0.01	+0.08	-0.24	-0.08		
Ave. Corr.	91.96	89.30	86.00	84.54	83.28	81.93	81.27	49.61	3.1

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling Point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer inches Hg.	7 Mol Fraction Benzene
Still		97.21	-0.20	97.01	30.20(70°F)	0.348
Plate 1		-----	------	91.70*		0.516
" 2		88.19	-0.01	88.18	30.18(70°F)	0.658
" 3		85.60	-0.03	85.57	30.18 "	0.762
" 4		84.12	-0.04	84.08	30.17 "	0.828
" 5		82.45	-0.06	82.39	30.17 "	0.902
" 6		81.98	-0.06	81.92	30.17 "	0.922
" 7		81.39	-0.06	81.33	30.17 "	0.948
Trap		81.00	-0.07	80.93	30.17 "	0.966

* Estimated from plot of Plate No. vs. Boiling Point

Run No. 9A (Carey) - Date 11/30/28

STEAM DATA

1 ~~Time~~	2 Barometer m.m. Hg.	3 Steam Press. Lbs./sq. in. Gage	4 Steam Manometer cm. Hg. Right	5 Left	6 Diff.	7 True Press Lbs./sq.in. absolute	8 Steam Temp- °C	9 Weight Condensate Lbs. Gross	10 Tare	11 Net
12:25	764.4	14.0						17.56	2.81	14.75
12:27	(corr.)		89.1	9.2	79.9		122.8	18.69	2.94	15.75
12:32			89.2	9.1	80.1		122.8	17.13	2.81	15.32
12:37			89.2	9.1	80.1		122.8	14.69	2.94	12.75
12:42			88.9	9.4	79.5		122.8			58.57
12:47			88.8	9.6	79.2		122.6	~~Wt~~ Wt.Cold Water		
12:52			89.0	9.3	79.7		122.8	10.13	2.81	
12:57			89.3	9.0	80.3		122.8	9.88	2.94	
1:00				Ave	79.83	30.15	Ave 122.8	19.38	6.50	27.14
35 minutes						Temp.Sat.St.	121.5	Net Weight Condensate		31.43
						Superheat °C	1.3			

CONDENSER DATA

1 Time	2 Cooling Water Temperature °C Inlet	3 Outlet	4 Rise	5 True Ave. Rise °C	6 Trap Temp. °C	7 Time	8 Weight Cooling Water Lbs. Gross	9 Tate	10 Net
12:28	9.00	55.50			49.6	12:26	409.5	124.0	285.5
12:33	9.10	57.70			52.0	1:01			
12:38	9.10	58.65			52.5	35 min.			
12:43	9.03	58.45			52.1				
12:48	9.00	58.45			52.0				
12:53	9.00	58.30			52.1				
12:58	9.00	58.05			52.0				
1:01	9.00	59.20			52.5				
	9.03	58.04		Ave.	51.8				
	-0.10	-0.03							
	8.93	58.01	49.08	49.08					

Run No. 9A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	9 Trap Ave. °C	10 Press on Plate 2 Inches Water
12:29	92.70	90.05	86.45	84.85	83.35	82.25	81.40		7.0
12:39	92.65	90.00	86.40	84.85	83.35	82.25	81.35		7.0
12:50	92.70	90.10	86.45	84.85	83.35	82.25	81.40		7.0
Ave.	92.68	90.05	86.42	84.85	83.35	82.25	81.37		
Corr.	-0.02	-0.14	+0.01	+0.01	+0.08	-0.24	-0.08		
Ave. Corr.	92.66	84.91	86.43	84.86	83.43	82.01	81.29	51.8	7.0

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling Point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer inches Hg.	7 Mol Fraction Benzene
Still		98.25	+0.23	98.48	30.17(70°)	0.306
Plate 1				92.60*		0.490
" 2		88.70	0.00	88.70	30.17 "	0.638
" 3		85.97	-0.03	85.94	30.17 "	0.747
" 4		84.40	-0.04	84.36	30.15(71°F)	0.815
" 5		82.82	-0.05	82.77	30.14 "	0.886
" 6		82.11	-0.06	82.05	30.13 "	0.917
" 7		81.41	-0.07	81.34	30.13 "	0.950
Trap		81.02	-0.07	80.95		0.966

* Estimated from plot of Plate No. vs. Boiling Point

Run No.10A (Carey) - Date 12/1/28

STEAM DATA

1 Time	2 Barometer m.m. Hg.	3 Steam Press. Lbs./sq. in.Gage	4 Steam Manometer cm. Hg. Right	5 Left.	6 Diff.	7 True Press Lbs./sq. in absolute	8 Steam Temp- °C	9 Weight Condensate Lbs. Gross	10 Tare	11 Net
11:27	24.70(69°F)	12.0	80.6	20.0	60.6		119.7	18.25	2.69	16.56
11:32			80.7	19.8	60.9		119.9	17.69	2.94	14.75
11:37			80.6	19.9	60.7		119.8	16.63	2.69	13.94
11:42			80.6	19.9	60.7		119.5			45.25
11:47			80.3	20.4	59.9		119.6	Wt.Cold Water		
11:52			80.6	19.9	60.7		119.5	23.13	15.63	
11:57			80.8	19.6	61.2		119.9	10.94	2.69	
12:02			80.9	19.7	61.2		119.8	9.81	2.94	22.62
12:07			81.1	19.4	61.7		119.8	Net Weight Con-		
40 minutes					Ave60.84	26.20	Ave.119.73	densate		22.63
							+1.00			
	751.9 m.m.Hg.					[illegible]	120.73			
	corr.					Temp.Sat.St.	116.89			
						Superheat °C	3.84			

CONDENSER DATA

1 Time	2 Cooling Water Temperature °C Inlet	3 Outlet	4 Rise	5 True Ave. Rise °C	6 Trap Temp °C	7 Time	8 Weight Cooling Water Lbs. Gross	9 Tare	10 Net
11:29	9.65	58.70				11:30½	288.75	123.25	165.5
11:34	9.70	59.55				12:05			
11:39	9.75	60.05				34.5 min.			
11:44	9.72	60.40							
11:49	9.70	60.62							
11:54	9.72	60.45							
11:59	9.65	60.42							
12:04	9.65	60.20							
	9.94	60.05							
	-0.10	-0.03							
	9.84	60.02	50.18	50.18					

Run No. 10A (Continued)

PLATE TEMPERATURE AND PRESSURE DROP DATA

1 Time	2 Plate 1 °C	3 Plate 2 °C	4 Plate 3 °C	5 Plate 4 °C	6 Plate 5 °C	7 Plate 6 °C	8 Plate 7 °C	9 Trap Ave. °C	10 Press on Plate 2 Inches Water
11:00	92.65	90.20	86.45	84.85	83.30	82.10	81.10		2.9
11:20	92.65	90.20	86.45	84.85	83.30	82.10	81.10		2.9
11:45	92.65	90.20	86.45	84.90	83.30	82.10	81.10		2.9
11:55	92.70	90.25	86.45	84.90	83.35	82.10	81.10		2.9
Ave	92.66	90.21	86.45	84.88	83.31	82.10	81.10		
Corr.	-0.02	-0.14	+0.01	+0.01	+0.08	-0.24	-0.08		
Ave. Corr	92.64	90.07	86.46	84.89	83.39	81.86	81.02		2.9

SAMPLE DATA

1 Source of Sample	2 Time of Sampling	3 Observed Boiling Point °C	4 Therm. Corr. °C	5 True Boiling Point °C	6 Barometer inches Hg.	7 Mol Fraction Benzene
Still		98.35	+0.23	98.58	29.82 (73°F)	0.296
Plate 1				93.20*		0.465
" 2		89.24	0.00	89.24	29.82 "	0.608
" 3		86.31	-0.03	86.28	29.82 "	0.726
" 4		84.70	-0.04	84.66	29.83 "	0.792
" 5		83.00	-0.05	82.95	29.84 "	0.868
" 6		82.20	-o.06	82.14	29.85 "	0.904
" 7		81.50	-0.06	81.44	29.86 "	0.936
Trap		81.00	-0.07	80.93	29.86 "	0.958

* Estimated from Plot of Plate No. vs. Boiling Point

Run No. 1 January 8, 1929 Time: 2:15-3:05

Time	Steam Press. lbs./sq.in. Abs.	Steam Temp. °C	Condenser Water Rise °C	Condenser Water-lbs.	Condensate lbs.
1 hr.	29.65	134.04	34.57	245.25	22.81

Plate Temperatures °C

Time	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	Plate #7
2:15		100.6	96.6	94.4	90.5	88.1	85.2
2:20		100.4	96.3	94.5	90.5	88.1	85.3
2:30		100.5	96.4	94.6	90.6	88.2	85.4
2:40		100.6	96.9	94.6	90.7	88.3	85.4
2:55		100.5	97.0	94.8	90.8	88.3	85.4
3:05		100.7	97.0	94.7	90.8	88.3	85.5
Ave (corr		100.5	96.5	94.7	90.7	88.2	85.4

Sample Log

Time	Source	Obs. B.P.	Corr.	True B.P.	Barometer (Corr.)	Mol Fraction
2:39	Pl. #1	104.90	0	104.90	768.5	.141
2:39	Pl. #2	100.10	0	100.10	768.5	.263
3:05	Pl. #3	96.20	.17	96.37	768.7	.376
3:05	Pl. #4	93.18	.09	93.27	768.7	.476
3:20	Pl. #5	89.80	.02	89.82	768.9	.600
3:20	Pl. #6	87.40	.02	87.38	768.9	.698
3:25	Pl. #7	85.31	-.03	85.28	768.9	.784
3:25	Botts.	106.21	-.02	106.23	769.1	.109

Pressure above Pl. #1 :14 mm.Hg.

Run No. 2 January 12, 1929 Time: 12:05-2:00

Time	Steam Press. lbs./sq.in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
1 hr.	39.68	145.28	35.89	633.25	48.06

Time	Plate Temperatures °C						
	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	Plate #7
1:15		104.40	100.3	97.60	93.45	89.85	86.60
1:25		104.50	100.7	98.10	93.87	90.30	86.90
1:35		104.80	101.1	98.40	94.15	90.65	87.20
1:45		104.75	101.1	98.54	94.30	90.75	87.35
1:55		104.60	101.1	98.55	94.40	90.85	87.40
2:05		104.70	101.1	98.65	94.40	90.85	87.41
2:15		104.90	102.2	98.59	94.35	90.65	87.20
Ave.		104.42	100.86	98.01	93.92	89.87	86.80

Sample Log

Time	Source	Obs. B.P.	Corr.	True B.P.	Barometer (corr.)	Mol Fraction
1:20	Pl. #1	106.27	.02	106.29	756.0	.095
1:35	Pl. #2	104.27	.00	104.27	756.1	.143
1:30	Pl. #3	100.95	.00	100.95	755.4	.225
1:35	Pl. #4	97.75	.22	97.97	755.0	.314
1:40	Pl. #5	93.18	.09	93.27	754.7	.459
1:45	Pl. #6	90.28	.02	90.30	754.4	.564
1:50	Pl. #7	86.86	.02	86.84	753.9	.695
1:15	Reflux	84.57	.04	84.53	756.6	.789
2:00	Botts.	108.31	.06	108.37	756.6	.046

Pressure above Pl. #1: 14 mm. Hg.

Run No. 3 January 28, 1929 Time: 4:15 - 6:00

Time	Steam Press. lbs./sq.in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
1 hr.	44.62	146.4	24.34	429.04(40min)	63.724

Time	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	Plate #7
			Plate Temperatures °C				
4:15	105.0	100.8	95.2	90.7	87.3	84.6	82.7
4:25	104.7	100.7	95.3	90.8	87.3	84.6	82.6
4:35	104.9	100.7	95.3	90.7	87.4	84.6	82.6
4:45	105.0	100.6	95.3	90.7	87.5	84.6	82.6
4:55	105.9	102.3	97.4	92.8	89.1	84.7	82.9
5:05	106.0	102.3	97.4	92.8	88.9	85.6	82.8
5:15	106.2	102.7	97.8	93.2	89.4	85.9	82.8
Ave.	105.6	103.3	98.5	93.4	89.5	85.9	83.0

Sample Log

Time	Source	Obs. B.P.	Cor.	True B.P.	Barometer (Cor.)	Mol Frac.
5:25	pl. #1	104.25	.00	104.25	751.5	.139
5:30	Pl. #2	101.58	.00	101.58	751.5	.205
5:35	Pl. #3	97.18	.20	97.38	751.5	.322
5:40	Pl. #4	92.20	.07	92.27	751.5	.486
5:45	Pl. #5	88.67	.00	88.67	751.4	.618
5:50	Pl. #6	85.70	-.03	85.67	751.5	.737
5:55	Pl. #7	83.02	-.05	82.97	751.5	.853
6:00	Reflux	81.80	-.06	81.74	751.5	.907
5:20	Botts.	107.03	.04	107.07	751.6	.073
5:20						

Press. above Pl. #2 :10 6mm. Hg.

Run No. 4　　January 29, 1929　　Time: 3:05 - 4:45

Time	Steam Pres. Lbs./Sq. in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
1 hr	23.95	134.73	36.67	204.7	19.813

Plate Temperatures °C

Time	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	Plate#7
3:05	97.8		88.8	87.3	84.6	83.1	81.6
3:15	98.2		88.8	87.1	84.6	83.3	81.7
3:20	98.6		88.4	87.1	84.6	83.3	81.7
3:30	98.4		88.9	87.3	84.7	83.3	81.8
3:46	98.2		88.8	87.3	84.7	83.4	81.8
3:50	98.6		88.9	87.1	84.7	83.3	81.8
4:00	98.3		88.9	87.3	84.7	83.5	81.8
Ave.	97.2		88.8	87.2	84.6	83.2	81.7

Sample Log

Time	Source	Obs. B.P.	Cor.	True B.P.	Barometer (cor.)	Mol Frac.
4:05	Pl. #1	96.13	.17	96.30	754.8	.360
4:10	Pl. #2	90.97	.03	91.00	754.9	.538
4:15	Pl. #3	88.00	-.01	87.99	755.1	.615
4:20	Pl. #4	86.00	-.03	85.97	755.2	.731
4:25	Pl. #5	83.95	-.04	83.91	752.3	.813
4:30	Pl. #6	82.70	-.05	82.65	752.1	.866
4:35	Pl. #7	81.70	-.06	81.64	751.9	.912
4:40	Reflux	81.21	-.07	81.14	754.4	.940
4:45	Botts.	99.81	.24	99.05	754.4	.278

Press. above Pl. #2 :5:25 mm. Hg.

Run No. 5 February 4, 1929 Time: 12:15 - 2:35

This run was made to determine the possibility of withdrawing vapor samples, but the results were worthless due to a broken vapor sampling pipe.

Run No. 6 February 6, 1929 Time: 10:30 - 11:30

Time	Steam Pres. lbs./sq.in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
1 hr.	39.96	132.4	30.48	364.0(23 min)	56.96

Plate Temperature °C

Time	Plate #3	Plate #4	Plate #5	Plate #6
#4 sam.	91.8	89.2		
#4 "	91.8	89.2		
#5 "			86.6	
#5 "			86.7	
#6 "				84.5

Sample Log

Source	Obs. B.P.	Cor.	True B.P.	Barometer (cor.)	Mol Frac.
Pl.#4 (liquid)	88.50	-.01	88.49	772.5	.660
Pl.#4 (vapor)	88.19	-.01	88.18	772.5	.674
Pl.#5 (liquid)	85.80	-.03	85.77	772.5	.772
Pl.#5 (vapor)	84.21	-.04	84.17	772.5	.840
Pl.#6 (liquid)	84.34	-.04	84.30	772.5	.835

Run No. 7 February 8, 1929 Time: 1:45 - 3:12

Time	Steam Pres. lbs./sq.in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
1 Hr.	46.85	139.1	36.43	693.5(50min)	63.09

Plate Temperatures °C

Time	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	Plate #7
1:55	105.0	100.0	94.9	91.6	88.2	85.3	83.2
2:20	105.6	101.6	96.6	93.1	89.3	86.1	83.3
2:55	105.9	101.2	96.2	93.0	89.4	86.0	83.3
3:05	106.0	101.5	96.3	92.9	89.3	86.1	83.4
3:12	106.0	101.5	96.0	91.9	88.5	85.7	83.4
Ave.	106.0	101.8	96.3	92.6	89.6	85.6	83.3

Sample Log

Time	Source	Obs. B.P.	Cor.	True B.P.	Barometer (cor.)	Mol Frac.
3:00	Pl.#1	100.52	.00	100.52		.250 #2
	Pl.#2	96.68	.19	96.87		.363 #3
	Pl.#3	92.40	.06	92.46	764.2	.500 #4
	Pl.#4	89.40	.00	89.40		.614 #5
	Pl.#5	86.13	-.03	86.10		.746 #6
	Pl.#6	86.63	-.04	85.59	764.1	.851 #7
	Pl.#7					
	Reflux	182.35		82.29		.911 refl
3:12	Botts.	106.90		106.92		.089 [illegible]

Pres. above Pl. #2: 24.6 mm.Hg.

Note: In the following runs carbon tetrachloride-toluene mixtures were used.

Run No. 8 February 15, 1929 Time: 4:40 - 5:45

Time	Steam Pres. lbs./sq.in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
5 hr.	34.7	155.5	51.68	179.5	19.875

Plate temperatures °C

Time	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	Plate #7
4:45	100.1	96.0	89.1	85.7	82.6	80.1	78.5
4:55	100.2	96.5	89.6	86.1	82.9	80.4	78.7
5:05	101.0	97.0	89.7	86.2	83.0	80.4	78.7
5:15	101.0	97.0	89.3	85.9	82.8	80.3	78.6
5:35	101.0		89.9	86.3	83.2	80.5	78.8
5:45	101.2	94.8	89.7	86.3	83.2	80.5	78.7
Ave.	100.4	95.2	89.8	86.3	83.2	80.3	78.7

Sample Log

Time	Source	Specific Gravity	Temp. oC	Mol. Frac.
5:35	Pl.#1V	1.0110	26.0	.2263
	Pl.#2V	1.0373	25.0	.2637
	Pl.#3V	1.2533	24.0	.5585
	Pl.#4V	1.3814	24.2	.6500
	Pl.#5V	1.3760	25.8	.7265
	Pl.#6V	1.4169	23.5	.7798
	Pl.#7V	1.4410	23.5	.8105
5:45	Botts L	0.9881	22.1	.1880

Press. above Pl. #1: 20. 3mm. Hg.

Run No. 9 February 18, 1929 Time: 2:45 - 3:45

Time	Steam Press. lbs./sq.in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
1 hr	38.2	159.2	54.4	355.0	39.4

Plate Temperatures °C

Time	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	#7 Plate
Before V	102.1		89.8	86.3	83.0	80.5	78.8
After V	102.6		89.9	86.4	83.2	80.6	78.8
After L	103.0		89.3	85.8	82.7	80.3	78.6

Sample Log

Time	Source	Specific Gravity	Temp. °C.	Mol. Frac.
	Pl. #1 V	.9971	23.0	.200
	Pl. #2 V	1.1640	22.2	.434
	Pl. #2 L	1.0490	23.0	.276
	Pl. #3 V	1.2552	24.2	.561
	Pl. #3 L	1.1572	23.2	.446
	Pl. #4 V	1.3234	--	.653
	Pl. #4 L	1.2424	22.9	.543
	Pl. #5 V	1.3776	22.8	.697
	Pl. #5 L	1.3260	22.5	.653
	Pl. #6 V	1.4170	20.5	.744
	Pl. #6 L	1.3720	22.3	.714
	Pl. #7 L	1.4143	22.0	.771
	Reflux	1.4377	22.0	.801
	Botts.	.9521	24.1	.134

Pres. above Pl. #1: 20.3 mm.Hg.

Run No. 10 February 22, 1929 Time: 1:00 - 3:25

Time	Steam Press. lbs./sq.in.	Steam Temp. °C	Condenser Water Rise	Condenser Water-lbs.	Condensate lbs.
.91 hr	34.8	127.8	38.72	223.0(.508hr)	33.75

Plate Temperatures °C

Time	Plate #1	Plate #2	Plate #3	Plate #4	Plate #5	Plate #6	Plate#7
Pl#2	104.8	97.0	91.8	88.2	84.6	81.6	79.5
Pl#2	104.9	97.0	92.0	88.4	84.6	81.6	79.5
Pl#4	104.9	97.0	92.0	88.4	84.6	81.7	79.6
Pl#5	104.9	97.0	92.0	88.5	84.7	81.8	79.6
Pl#6	104.9	97.0	92.2	88.6	84.8	81.8	79.7
Pl#7	104.9	97.0	92.6	88.0	84.0	82.0	79.8

Sample Log

Source	Specific Gravity	Temp. °C	Mol. Frac.
Pl.#2 V	1.0387	23.6	.2610
Pl.#3 V	1.1271	23.8	.3845
Pl.#4V	1.1961	24.0	.4810
Pl.#5 V	1.2862	24.0	.6035
Pl.#6 V	1.3371	24.0	.6715
Pl.#7 V	1.3861	24.0	.7238
Reflux	1.4161	24.2	.7780

Press. above Pl.#1: 20.0 mm. Hg.

Run 1A March 9, 1928 9:00 to 9:50

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(#/in.^{2})	15	15	15	15	15	15	15	15	15	15	15	15	15	15
t($^{\circ}$F.)	256	255	256	257	256.5	256	256	256	256.5	256	257			256.2
Condenser data														
t entrance ($^{\circ}$C.)	12.6	12.6	12.65	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6			12.6
t exit ($^{\circ}$C.)	29.1	28.9	29.3	29.5	29.4	29.6	29.5	29.4	29.7	29.8	29.9			29.46
Plate temp.														
Plate 1	94.5	94.5	94.5	46.8	94.5	95.6	94.5	95.0	95.0	94.8	94.9			94.9
Plate 2	91.8	91.2	91.8	91.7	91.8	91.8	91.7	92.0	92.0	91.9	91.8			91.8
Plate 3	89.3	89.2	89.2	89.2	89.2	89.2	89.3	89.3	89.4	89.3	89.2			89.3
Plate 4	86.0	85.8	85.8	86.0	86.0	85.9	85.8	86.0	85.8	85.8	85.9			85.9
Plate 5	82.5	82.5	82.5	82.8	82.7	82.8	82.6	82.6	82.5	82.5	82.6			82.6

#steam condensate

Wt. condensate+bucket	14.75	14.00	14.50	
Weight bucket+H_2O	2.75	2.75	2.75	
Total condensate	12.00	+11.25	11.75	= 35# in 50 min.

cooling water

Weight cooling H_2O + barrel	924.7
Weight barrel	61.0
Total cooling water	863.7

Analysis of liquids

	B.Pt.($^{\circ}$C.)	Comp.
Plate 2	91.98	0.505
3	86.63	0.705
4	85.03	0.773
5	83.19	0.854
6	82.16	0.902
7	81.86	0.914
Bottoms	98.56	0.294
Reflux	80.97	0.957

Barometer = 757 mm

Run 2A May 10, 1928 5:05 - 5:45

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Ave.
Steam Data														
P (#/in.^{2})	8	8	8	8	8	8	8	8	8					8
t (°F.)	239	240	240.5	241	242	242	244	242	242					241.4
Condenser data														12.80
t entrance (°C.)	12.7	12.75	12.80	12.80	12.80	12.80	12.80	12.80	12.80					24.70
t exit (°C.)	25.6	25.4	24.4	24.5	24.8	24.65	24.5	24.5	24.4					
Plate temp. (°C.)														
Plate 1														
Plate 2	93	93	93.2	93.1	93.2	93	93	93	93					93.1
Plate 3	90	90.1	90.1	90.2	90.2	90.1	90.1	90	90.1					90.1
Plate 4	87.2	87.5	87.4	87.2	87.1	87.4	87.5	87.3	87.3					87.3
Plate 5	83.8	83.8	83.8	83.8	83.7	83.8	83.8	83.8	83.8					83.8

steam condensate

Weight condensate bucket	38.0
Weight water bucket	26.15
Total condensate	11.85 in 40 min.

cooling water

Weight barrel water	492.0
Weight barrel	60.5
	431.5 in 40 min.

Analysis of liquids

	B.Pt. (°C.)	Comp.
Plate 2	41.64	0.516
Plate 3	88.67	0.626
Plate 4	85.89	0.736
Plate 5	83.96	0.820
Plate 6	83.41	0.845
Plate 7	81.84	0.916
Reflux	81.26	0.943
Bottoms	100.26	0.235

Barometer = 757 mm

Run 3B   May 11, 1928   2:10 - 3:10

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in^2)	11	11	11	11	11	11	11	11	11	11	11	11	11	11
t (°F.)	246	246.5	246	246	246	246	246	246	246	246	246.7	246	246	246
Condenser Data														
t entrance (°C.)	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.3	13.3	13.4	13.4	13.1	13.22
t exit (°C.)	73.8	73.9	74.2	74.4	74.3	74.4	74.3	74.3	74.4	74.4	74.5	74.6	75.1	73.55
Plate temp.														
Plate 1	96.5	96.5	96.3	96.3	96.3	96.3	96.5	96.5	96.4	96.5	96.5	96.5	96.5	96.4
Plate 2	93.4	93.6	93.5	93.5	93.4	93.4	93.4	93.5	93.5	93.5	93.5	93.5	93.5	93.45
Plate 3	90.0	90.1	90.2	90.2	90.2	90.2	90.1	90.2	90.2	90.2	90.1	90.2	90.2	90.15
Plate 4	87.7	87.4	87.4	87.3	87.3	87.5	87.6	87.6	87.4	87.4	87.5	87.5	87.5	87.5
Plate 5	83.7	83.7	87.8	83.7	83.7	83.7	83.8	83.7	83.7	83.8	83.8	83.7	83.7	83.7

Lbs. steam condensate				
Weight condensate	13.75	14.12	6.6	
Weight bucket + water	2.80	2.8	2.13	
Total	10.97 +	11.22 +	3.6	= 25.77 lbs.

Lbs. cooling water	
Weight cooling water	307.1
Weight barrel	60.5
Weight cooling water	246.6

Analysis of Liquids

	B.Pt.(°C.)	Comp.
Plate 2	92.61	0.479
Plate 3	89.28	0.599
Plate 4	86.76	0.697
Plate 5	84.26	0.803
Plate 6	83.21	0.849
Plate 7	81.96	0.905
Bottoms	101.25	0.216
Reflux	81.36	0.934

Barometer = 754 mm.

Run 4A May 13, 1928 1:10 - 2:10

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in^2)	12.5	12.7	12.5	12.7	12.7	12.7	12.7	12.6	12.6	12.6	12.6	12.5	12.6	12.6
t (°F.)	251.5	251.7	251.5	252	252	252	252	251.8	251.8	251.7	251.7	251.5	251.5	251.8
Condenser Data														
t entrance (°C.)	13.4	13.4	13.45	13.45	13.45	13.6	13.6	13.6	13.6	13.6	13.65	13.70	13.70	13.56
t exit (°C.)	69.7	69.7	69.75	69.8	69.75	69.8	69.75	69.75	69.75	69.75	69.75	69.75	69.75	69.75
Plate temp. (°C.)														
Plate 1	99.3	99.3	99.4	99.4	99.2	99.2	99.3	99.3	99.4	99.4	99.4	99.4	99.4	99.35
Plate 2	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0
Plate 3	92.5	92.5	92.6	92.6	92.6	92.6	92.6	92.5	92.6	92.7	92.6	92.6	92.6	92.6
Plate 4	90.2	90.1	90.1	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Plate 5	85.0	85.1	85.1	85.1	85.1	-	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.1
Plate 6	84.6	84.6	84.8	84.6	84.7	84.7	84.7	84.6	84.6	84.7	84.6	84.8	84.7	84.7

Lbs. steam condensate

Weight condensate + bucket	15.70	18.30	
Weight bucket	2.75	2.75	
Weight condensate	12.95 +	15.65	= 28.60

Lbs. cooling water

Weight water + barrel	456
Weight barrel	60.5
Weight water	395.5

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	95.29	0.406
Plate 3	91.71	0.526
Plate 4	88.46	0.647
Plate 5	85.99	0.746
Plate 6	84.34	0.817
Plate 7	83.08	0.873
Reflux	82.21	0.913
Bottoms	103.23	0.179

Barometer = 764 mm.

Run 5A May 31, 1928 2:24 - 3:24

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in^2)	10.0	10.0	-	-	10.0	-	-	10.0	-	-	10.0	-	10.0	10.0
t (°F.)	244.0	243.6	244.0	244.0	243.6	243.6	243.2	243.0	243.0	244.0	244.0	244.0	244.0	243.6
Condenser Data														
t entrance (°C.)	15.35	15.30	15.3	15.3	15.3	15.3	15.3	15.35	15.40	15.30	15.30	15.30	15.30	15.33
t exit (°C.)	73.25	73.27	73.25	73.25	73.25	73.25	73.30	73.53	73.53	73.90	73.90	73.40	75.0	73.65
Plate temps.														
Plate 1	94.8	95.0	94.8	94.8	94.8	94.8	94.8	94.7	94.3	95.0	95.0	94.5	94.5	94.6
Plate 2	92.0	92.7	92.8	92.8	92.8	92.8	92.8	92.8	92.8	92.8	92.8	92.8	92.8	92.8
Plate 3	90.2	90.2	90.2	90.2	90.2	90.2	90.2	90.3	90.3	90.2	90.2	90.2	90.2	90.2
Plate 4	87.0	87.0	87.0	87.0	87.0	87.0	87.0	-	-	-	-	-	-	87.0
Plate 5	84.8	84.8	84.8	84.8	84.8	-	-	-	-	-	-	-	-	84.8
Plate 6	83.0	82.6	82.6	-	-	-	-	82.6	82.6	82.6	-	-	-	82.6

Lbs. steam condensate

Weight condensate + bucket	23.75	21.85	17.6	
Weight bucket + water	13.0	12.25	10.75	
Weight condensate	10.75 +	9.60 +	6.85	= 27.20

Lbs. cooling water

Weight water + barrel	309.75
Weight barrel	50.75
Weight water	249.00

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	100.52	0.236
Plate 3	98.12	0.305
Plate 4	95.42	0.387
Plate 5	90.24	0.564
Plate 6	85.27	0.761
Plate 7	82.24	0.893
Reflux	82.34	0.889
Bottoms	104.52	0.137

Barometer = 755 mm.

Run 5B (1) May 31, 1928

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
$P(Lbs./in^2)$	10.0	-	-	-	10.0	-	-	-	10.0	-	-	-	10.0	10.0
t (°F.)	243.0	-	244.0	243.6	-	243.6	-	-	243.6	-	241.0	-	-	243.6
Condenser Data														
t entrance (°C.)	15.58	15.65	-	15.60	-	-	-	-	15.58	15.60	-	-	15.55	15.61
t exit (°C.)	63.58	63.55	63.60	63.55	63.60	-	-	-	63.58	63.60	-	-	-	63.59
Plate temps.														
Plate 1	95.7	-	95.8	-	-	96.0	-	-	-	96.3	-	-	96.9	95.8
Plate 2	92.4	92.6	92.7	-	92.8	-	-	-	93.0	-	-	93.5	93.8	92.9
Plate 3	90.0	-	90.2	-	-	90.3	-	-	90.6	90.3	90.6	90.8	91.5	91.1
Plate 4	87.0	-	-	-	-	-	-	-	-	-	87.3	-	88.0	87.0
Plate 5	84.7	-	-	85.0	-	-	-	84.8	85.0	-	-	85.2	-	84.8
Plate 6	82.8	82.7	-	82.9	-	-	-	83.0	-	-	-	83.2	-	82.5

Lbs. steam condensate

Weight condensate + bucket	22.75	21.85	18.25
Weight bucket	11.0	11.0	9.15
Weight condensate	11.75 +	10,85 +	9.10 = 31.7

Lbs. cooling water

Weight water + barrel	528.75
Weight barrel	61.75
Weight cooling water	468.00

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	90.50	0.563
Plate 3	87.02	0.696
Plate 4	85.02	0.780
Plate 5	83.37	0.853
Plate 6	82.54	0.890
Plate 7	81.70	0.928
Reflux	80.92	0.966
Bottoms	99.22	0.278

Barometer = 760 mm.

Run 5B (2) June 2, 1928 Time of run 50 min.

Time	0	5	10	15	20	25	30	35	40	45	50	Av.
Steam Data												
P(Lbs./in^2)	10.0	-	-	10.0	-	-	10.0	-	-	10.0	-	10.0
t (°F.)	243.6	-	-	244	-	-	244	-	-	244	-	244
Condenser Data												
t entrance (°C.)	16.65	-	-	-	-	-	-	-	16.65	-	16.7	16.65
t exit (°C.)	65.35	-	-	-	-	65.4	-	-	65.4	-	65.4	65.4
Plate temps.												
Plate 1	97.0	-	-	97.5	-	-	98.0	-	-	-	98.7	97.8
Plate 2	94.0	-	-	-	-	-	94.8	-	95.0	-	95.2	94.5
Plate 3	92.0	-	-	-	-	-	-	-	92.3	-	93.0	91.6
Plate 4	88.0	-	-	-	-	-	88.6	-	89.0	-	-	88.6
Plate 5	85.2	-	-	85.3	-	-	85.7	-	86.0	-	86.2	85.9
Plate 6	83.0	-	-	83.2	-	-	83.5	-	83.7	-	84.0	83.9

Lbs. steam condensate

Weight condensate + bucket	20.25	22.5	17.0
Weight bucket	10.5	11.0	12.5
	9.75 +	11.5 +	4.5 = 25.75

Lbs. cooling water

Weight water + barrel	496.5
Weight barrel	57.5
Weight cooling water	439.0

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	92.63	0.987
Plate 3	88.62	0.632
Plate 4	86.17	0.731
Plate 5	84.32	0.811
Plate 6	83.37	0.853
Plate 7	82.42	0.895
Reflux	81.54	0.935
Bottoms	101.45	0.217

Barometer = 760

Run 5B (3) June 7, 1928.

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in^2)	10.0	-	-	10.0	-	-	10.3	-	-	10.0	-	-	10.0	10.0
t (°F.)	244.0	244.0	244.4	244.2	-	-	244.0	244.4	-	244.6	-	-	244.6	244.3
Condenser Data														
t entrance (°C.)	16.65	-	16.70	16.65	-	16.70	16.75	-	16.70	16.75	16.70	-	16.75	16.70
t exit (°C.)	44.2	-	44.4	44.5	-	44.65	44.00	43.85	43.75	44.0	43.25	43.0	43.90	44.00
Plate temps.														
Plate 1	97.6	98.0	-	-	-	-	98.1	-	-	98.5	-	98.8	98.8	98.4
Plate 2	95.4	95.6	-	-	-	95.8	-	-	-	96.1	-	96.2	96.2	95.8
Plate 3	93.0	-	-	-	-	-	93.1	-	-	93.6	-	-	-	92.5
Plate 4	89.2	89.3	-	-	-	89.4	89.3	-	89.5	90.0	-	-	-	89.6
Plate 5	88.6	-	-	86.7	-	86.8	-	-	-	87.0	-	-	-	87.0
Plate 6	84.2	84.3	-	-	-	84.4	-	84.5	-	84.7	-	-	-	84.85

Lbs. steam condensate			
Weight condensate + bucket	22.50	22.20	
Weight bucket	10.40	11.75	
Weight condensate	12.10 +	10.45	= 22.55

Lbs. cooling water	
Weight water + barrel	328.2
Weight barrel	56.0
Weight cooling water	272.0

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	91.84	0.515
Plate 3	89.22	0.610
Plate 4	86.30	0.726
Plate 5	84.60	0.799
Plate 6	83.47	0.849
Plate 7	82.15	0.907
Reflux	81.37	0.944
Bottoms	101.55	0.215

Barometer = 758 mm.

Run 5 C   June 1, 1928.

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in^2)	10.0	-	-	10.0	-	-	10.0	-	-	10.0	-	-	10.0	10.0
t (°F.)	253.6	-	254.0	253.0	-	-	256.1	-	252.4	-	-	-	-	252.4
Condenser Data														
t entrance (°C.)	15.85	-	-	-	-	-	-	-	15.80	-	15.95	-	-	15.87
t exit (°C.)	67.6	67.6	-	67.8	-	68.05	-	-	-	-	-	-	-	67.8
Plate temps.														
Plate 1	96.0	96.3	-	96.0	-	-	96.5	95.5	96.5	-	96.0	96.0	-	95.8
Plate 2	93.3	-	-	93.6	-	-	94.0	-	-	94.5	-	-	-	93.9
Plate 3	91.0	-	-	91.2	91.3	91.5	-	-	91.8	-	-	-	92.0	92.2
Plate 4	87.2	87.3	87.6	-	-	88.0	-	-	-	-	-	-	88.2	87.7
Plate 5	85.0	84.8	-	85.2	-	-	-	-	85.4	-	85.7	85.7	-	85.1
Plate 6	83.2	-	-	-	-	83.4	83.5	-	83.6	-	-	-	83.7	83.0

Lbs. steam condensate			
Weight condensate + bucket	23.50	23.75	
Weight bucket	9.90	10.60	
Total condensate	13.60 +	13.15 =	26.75

Lbs. cooling water	
Weight water + barrel	406.25
Weight barrel	61.25
Weight cooling water	345.00

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	91.24	0.536
Plate 3	87.34	0.684
Plate 4	85.12	0.776
Plate 5	83.60	0.842
Plate 6	82.70	0.083
Plate 7	81.67	0.930
Reflux	81.00	0.963
Bottoms	99.74	0.264

Barometer = 760 mm.

Run6A June 2, 1928.

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P (lbs./in^2)	12.0	-	-	12.0	-	-	12.0	-	-	12.0	-	-	12.0	12.0
t (°F.)	244.6	244.6	-	-	-	25.0	-	-	249.7	-	-	25.0	-	249.6
Condenser data														
t entrance(°C.)	16.08	-	-	-	-	16.0	-	-	-	16.0	-	-	-	16.0
t exit (°C.)	52.5	-	-	52.2	-	-	-	52.0	-	-	52.1	-	-	52.3
Plate temps.(°C.)														
Plate 1	96.8	-	97.0	-	97.1	-	97.0	-	-	97.6	-	-	-	97.3
Plate 2	93.8	-	94.0	-	-	-	-	-	94.3	-	-	-	-	94.05
Plate 3	91.3	91.4	-	-	-	91.7	-	-	-	92.0	-	-	-	90.9
Plate 4	88.0	-	-	-	-	-	-	88.2	-	-	-	-	-	88.2
Plate 5	85.1	85.0	-	85.2	-	-	-	-	-	85.4	-	-	-	85.4
Plate 6	83.0	-	-	-	-	-	-	83.2	-	-	-	-	-	83.5

Lbs. steam condensate

Weight condensate + bucket	22.75	22.5
Weight bucket	10.0	10.5
Total condensate	12.75 +	12.0 = 24.75

Lbs. Cooling water

Weight water + barrel	505.0
Weight barrel	62.0
Total cooling water	443.0

Analysis of Liquids

	B.Pt(°C.)	Comp.
Plate 2	92.86	0.479
Plate 3	88.24	0.648
Plate 4	85.64	0.754
Plate 5	83.80	0.833
Plate 6	83.10	0.865
Plate 7	81.90	0.919
Reflux	81.07	0.959
Bottoms	100.8	0.234

Barometer = 760 mm.

Run 6B June 8, 1928.

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(lbs./in^2)	12.0	-	-	-	-	-	-	-	-	-	12.2	12.4	12.4	12.3
t (°F.)	249.6	250.0	-	-	-	-	-	-	-	-	250.4	250.8	25.1	250.1
Condenser data														
t(entrance °C.)	16.5	16.6	-	16.75	-	-	16.80	-	-	-	-	-	-	16.65
t exit (°C.)	40.6	40.2	40.5	41.4	41.2	41.1	-	41.4	43.7	45.2	46.0	46.5	47.4	42.90
Plate temps.(°C.)														
Plate 1	99.0	99.2	-	-	-	99.3	-	99.6	99.7	99.8	100.0	-	100.2	99.7
Plate 2	95.8	96.0	-	-	-	96.2	-	96.3	-	96.7	96.8	96.9	97.1	96.3
Plate 3	93.0	93.5	93.2	93.5	-	93.7	93.5	93.8	-	94.0	94.5	-	95.0	93.1
Plate 4	89.5	90.0	-	-	-	-	-	-	-	90.4	-	-	91.0	90.2
Plate 5	86.7	86.8	86.9	-	-	87.0	-	-	-	87.2	-	-	87.5	87.2
Plate 6	84.2	84.3	84.5	-	-	84.6	-	-	-	84.8	-	84.9	85.0	85.0

Lbs. steam condensate

Weight condensate + bucket	21.4	21.0	21.95
Weight bucket	11.0	11.75	11.20
Total condensate	10.4+	9.25+	10.75 = 30.40

Lbs. cooling water

Weight water + barrel	520.75
Weight barrel	56.75
Weight water	464.5

Analysis of liquids

	B.Pt(°C.)	Comp.
Plate 2	93.02	0.478
Plate 3	89.95	0.590
Plate 4	86.90	0.707
Plate 5	85.32	0.773
Plate 6	83.80	0.839
Plate 7	81.40	0.902
Reflux	81.62	0.938
Bottoms	102.30	0.200

Barometer = 763 mm.

Run 7 June 8, 1928 Time: 40 minutes

Time	0	5	10	15	20	25	30	35	40	AV.
Steam data										
P(lbs./in^2)	14.0	-	-	14.0	-	-	14.2	-	14.1	14.0
t (°F.)	253.5	25.4	-	253.3	253.8	253.7	253.7	-	254.0	253.8
Condenser data										
t entrance (°C.)	16.8	16.9	-	-	-	-	-	-	-	16.8
t exit (°C.)	38.75	38.30	-	38.40	-	-	-	38.60	38.20	38.45
Plate temps.										
Plate 1	99.2	99.8	-	-	-	100.0	-	-	-	100.0
Plate 2	96.0	96.6	-	-	96.7	-	-	-	-	96.6
Plate 3	93.5	93.8	-	94.0	-	-	-	-	-	93.2
Plate 4	90.0	-	-	-	-	-	-	-	-	90.1
Plate 5	86.8	87.0	-	-	-	-	87.2	-	-	87.2
Plate 6	84.2	84.4	84.5	84.6	-	84.7	-	-	-	84.0

Lbs. steam condensate				
Weight water + bucket	22.75		21.60	
Weight bucket	10.75		11.50	
Total condensate	12.0	+	10.1	= 22.1

Lbs. cooling water	
Weight water + barrel	478.5
Weight barrel	58.0
Weight cooling water	420.0

Analysis of liquids

	B.Pt.(°C.)	Comp.
Plate 2	94.15	0.445
Plate 3	91.20	0.547
Plate 4	87.75	0.678
Plate 5	85.72	0.760
Plate 6	84.50	0.813
Plate 7	87.82	0.887
Reflux	82.00	0.927
Bottoms	103.0	0.187

Barometer = 766 mm.

Run 8A June 19, 1928 Time: 45 Minutes

Time	0	5	10	15	20	25	30	35	40	45	Av.
Steam data											
P(lbs./in^2)	8	8	8	8	8	8	8	8	8	8	8
t (°C.)	113.4	113.3	113.5	113.4	113.4	113.4	113.4	113.4	113.4	113.4	113.4
Condenser data											
t entrance (°C.)	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
t exit (°C.)	25.4	26.1	26.1	25.5	25.4	25.4	25.0	25.1	24.8	25.5	25.5
Plate temps.											
Plate 1	94	94.1	95	94.5	-	-	95.0	95.1	-		94.8
Plate 2	92.4	92.6	92.8	92.8	-	-	-	-	-		92.7
Plate 3	90.0	90.0	90.0	90.0	-	-	90.2	90.1	-		89.7
Plate 4	87.0	87.0	87.0	87.0	-	-	87.0	87.0	-		87.1
Plate 5	84.6	84.6	84.6	84.6	-	-	84.6	84.6	-		84.8
Plate 6	83.0	83.0	82.8	83.0	83.0	83.0	83.0	83.0	83.0		83.4

Lbs. steam condensate

Weight condensate + bucket	15.75	5.75
Weight bucket	2.75	2.75
Total condensate	13.00 +	3.00 = 16.0 in 45 mins.

Lbs. cooling water

Weight water + barrel	457
Weight barrel	61
Weight cooling water	396 in 25 mins.

Analysis of Liquids

	B.Pt.(°C.)	Comp.
Plate 2	88.69	0.630
Plate 3	86.44	0.719
Plate 4	84.07	0.822
Plate 5	82.69	0.884
Plate 6	81.94	0.917
Plate 7	81.19	0.952
Reflux	80.84	0.970
Bottoms	97.76	0.323

Barometer = 760 mm.

Run 8B June 19, 1928 Time: 3:20 to 4:20

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Stean Data														
P(+bs./in²)	8	8	8	8	8	8	8	8	8	8	8	8	8	8
t (°C.)	113.3	113.2	113.1	113.3	113.2	113.3	113.3	113.3	113.3	113.3	113.2	113.2	113.4	113.25
Condenser Data														
t entrance (°C.)	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
t exit (°C.)	32.2	32.25	32.5	32.3	32.1	31.6	31.4	31.0	29.4	27.2	26.9	26.9	27.2	30.25
Plate temps.														
Plate 1	94.8	95.0	95.0	95.0	95.0	95.1	95.1	95.1	95.1	95.5	96.0	95.8	95.8	95.5
Plate 2	92.0	92.0	92.0	92.0	92.2	92.4	92.3	92.5	92.5	92.8	93.0	93.0	93.0	92.4
Plate 3	90.0	90.0	90.0	90.0	90.0	90.1	90.1	90.1	90.1	90.2	90.0	90.6	90.7	89.5
Plate 4	87.0	87.0	87.0	-	87.2	87.2	87.2	87.2	87.2	87.4	88.0	88.0	88.1	87.55
Plate 5	84.6	84.6	84.7	-	85.0	-	85.0	85.0	85.0	85.1	85.2	85.3	85.0	85.2
Plate 6	83.0	83.0	83.0	83.0	83.0	-	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.4

Lbs. steam condensate

Weight condensate + bucket	20.75	10.50
Weight bucket	2.75	2.75
Weight condensate	18.00 +	7.75 =

25.75 lbs. in 50 mins.

Lbs. cooling water

Weight water + barrel	485.75
Weight barrel	57.75
Weight cooling water	328.5 lbs.

Analysis of Liquids

	B.Pt.(°C.)	Comp.
Plate 2	88.54	0.636
Plate 3	86.24	0.728
Plate 4	83.74	0.836
Plate 5	83.14	0.863
Plate 6	82.14	0.907
Plate 7	81.34	0.945
Reflux	80.94	0.964
Bottoms	97.84	0.320

Barometer = 760 mm.

Run 9 June 20, 1928 Time: 10:45 to 11:45

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(lbs./in^2)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
t (°C.)	110.7	110.7	110.8	110.8	110.8	110.9	110.8	110.9	110.8	110.9	110.9	110.9	110.7	110.82
Condenser data														
t entrance (°C.)	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
t exit (°C.)	39.0	39.3	39.0	39.4	38.8	39.0	39.3	39.2	39.4	39.3	39.0	38.6	38.5	39.06
Plate temps.														
Plate 1	95.0	95.0	95.0	95.0	95.1	95.2	95.2	95.6	95.7	95.7	95.6	-	96.0	95.6
Plate 2	92.3	92.2	92.2	92.2	92.4	92.6	92.6	93.0	92.9	92.9	93.0	-	93.0	92.6
Plate 3	90.5	90.3	90.3	90.3	90.4	90.4	90.4	90.5	90.3	90.3	90.5	-	90.7	89.7
Plate 4	87.8	87.8	-	87.8	87.8	87.8	87.8	87.8	87.3	87.4	87.4	-	87.5	87.8
Plate 5	85.0	85.0	-	85.0	85.0	85.0	85.1	85.1	85.0	85.0	85.0	-	85.0	85.2
Plate 6	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	-	83.0	83.4

Lbs. Steam condensate	
Weight condensate + bucket	15.25
Weight bucket	2.75
Weight condensate	12.50
Lbs. cooling water	
Weight water + barrel	212.50
Weight barrel	56.00
Weight cooling water	156.60

Analysis of Liquids

	B.Pt.(°C.)	Comp.
Plate 2	88.99	0.632
Plate 3	86.64	0.726
Plate 4	84.24	0.829
Plate 5	83.24	0.873
Plate 6	82.24	0.920
Plate 7	81.44	0.959
Reflux	81.14	0.973
Bottoms	98.14	0.320

Barometer = 768 mm.

Run 9A June 20, 1928 Time: 3:35 to 4:35

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in^2)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
t (°C.)	110.6	110.8	110.8	110.8	110.7	110.8	110.9	110.9	110.9	110.9	110.9	110.5	110.9	110.8
Condenser Data														
t entrance (°C.)	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.5	17.5	17.5	17.5	17.5	17.56
t exit (°C.)	37.9	38.4	39.4	39.7	39.7	38.9	38.1	36.9	35.6	34.5	33.8	32.8	32.4	36.8
Plate temps.														
Plate 1	95.5	95.5	-	95.8	95.8	95.8	95.8	95.8	95.9	95.8	96.1	96.5	-	96.1
Plate 2	93.0	92.7	-	93.0	93.0	93.0	93.0	93.2	93.3	93.3	93.4	93.8	-	93.15
Plate 3	90.0	90.2	-	90.4	90.3	90.2	90.6	91.0	91.0	91.0	91.1	91.3	-	89.9
Plate 4	87.0	87.0	-	87.1	87.1	87.1	87.2	88.0	88.0	88.0	88.1	88.1	-	87.6
Plate 5	85.0	85.0	-	85.0	85.1	85.1	85.1	85.0	85.0	85.0	85.0	85.0	-	85.2
Plate 6	82.0	82.8	82.8	82.9	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	-	83.35

Lbs. steam condensate	
Weight condensate + bucket	13.50
Weight bucket	2.75
Weight condensate	10.75

Lbs. cooling water	
Weight water + barrell	195.0
Weight barrel	55.5
Weight cooling water	149.5

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	88.94	0.627
Plate 3	86.74	0.714
Plate 4	84.19	0.825
Plate 5	83.24	0.866
Plate 6	82.29	0.909
Plate 7	81.49	0.947
Reflux	80.94	0.974
Bottoms	98.54	0.303

Barometer = 764.0 mm.

Run 10 June 22, 1928 Time: 3:50 to 4:50

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam data														
P(Lbs./in^2)	9	9	9	9	9	9	9	9	9	9	9	9	9	9
t (°C.)	117.4	117.5	117.2	117.1	117.4	117.3	117.4	117.3	117.4	117.3	117.4	117.1	117.3	117.31
Condenser Data														
t entrance (°C.)	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
t exit (°C.)	35.0	32.4	31.2	30.6	30.2	29.8	29.4	29.6	29.3	29.2	29.5	29.2	28.9	30.38
Plate temps.														
Plate 1	95.0	95.0	-	95.0	95.0	95.0	95.0	-	95.0	95.0	95.0	-	95.0	95.2
Plate 2	93.0	93.0	-	93.0	93.0	93.0	93.0	-	94.0	94.0	94.0	-	94.0	93.4
Plate 3	91.0	91.0	-	92.0	92.0	92.0	-	92.0	91.0	92.0	92.0	92.0	92.0	91.0
Plate 4	88.0	88.0	-	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.1
Plate 5	85.0	85.0	-	85.0	85.0	85.0	85.0	85.0	85.0	86.0	86.0	86.0	86.0	85.9
Plate 6	83.0	83.0	-	83.0	83.0	83.0	83.5	83.4	83.5	84.0	84.0	84.0	84.0	83.9

Lbs. steam condensate			
Weight condensate + bucket	19.75	12.00	
Weight bucket	3.00	3.10	
Weight condensate	16.75 +	8.90	= 25.65 lbs.

Lbs. cooling water	
Weight water + barrel	426.0
Weight barrel	58.0
Weight cooling water	368 lbs. in 30 mins.

Analysis of Liquids

	B.Pt (°C.)	Comp.
Plate 2	89.74	0.589
Plate 3	87.24	0.687
Plate 4	85.14	0.774
Plate 5	83.64	0.838
Plate 6	82.44	0.892
Plate 7	81.44	0.938
Reflux	81.04	0.958
Bottoms	98.74	0.291

Barometer = 759 mm.

Run 10A June 25, 1928 Time: 7:00 to 8:00

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in²)	10	10	10	10	10	10	10	10	10	10	10	10	10	10
t (°C.)	116.2	115.7	117.8	116.2	116.1	116.0	116.1	116.2	116.2	116.1	116.0	116.2	116.2	116.0
Condenser Data														
t entrance (°C.)	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2
t exit (°C.)	25.9	25.6	25.6	25.7	25.8	25.6	25.7	25.6	25.5	25.5	25.1	25.0	24.8	25.49
Plate temps.														
Plate 1	96.0	96.0	96.0	96.0	96.0	96.2	96.2	96.2	96.2	96.4	96.4	96.5	96.5	96.6
Plate 2	94.0	94.0	94.0	94.0	94.0	94.5	94.5	94.5	94.5	94.6	94.6	95.0	95.0	94.4
Plate 3	92.0	92.0	92.0	92.0	92.0	92.0	92.2	92.1	92.1	92.2	92.2	93.0	93.0	91.5
Plate 4	88.0	88.0	88.0	88.0	88.0	88.0	88.2	88.2	88.3	88.3	88.3	89.0	89.0	88.35
Plate 5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.6	85.6	85.8	86.2	86.2	85.85
Plate 6	83.5	83.5	83.5	83.5	83.5	84.0	83.8	83.8	83.9	83.9	83.9	84.0	84.0	84.1

Lbs. steam condensate			
Weight condensate + bucket	21.25	6.00	
Weight bucket	3.00	3.00	
Weight condensate	18.25 +	3.00	= 21.25

Lbs. cooling water	
Weight barrel + water	472.0
Weight barrel	58.0
Weight water	414.0 in 30 mins.

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	90.64	0.557
Plate 3	88.34	0.644
Plate 4	85.64	0.754
Plate 5	82.24	0.814
Plate 6	82.94	0.872
Plate 7	83.64	0.912
Reflux	81.24	0.950
Bottoms	100.04	0.255

Barometer = 760

Run 11 June 26, 1928 Time: 3:40 to 4:20

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in^2)	8	7	8	8	8	8	8	8	8					8
t (°C.)	112.0	112.1	112.5	112.5	112.4	112.0	112.1	112.5	111.8					112.19
Condenser Data														
t entrance (°C.)	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.8	16.8					16.88
t exit (°C.)	22.8	22.8	22.9	22.4	22.2	21.9	21.1	20.0	20.9					21.89
Plate temps.														
Plate 1	97.0	97.0	97.0	97.0	97.0	98.0	98.0	98.0	98.0					97.6
Plate 2	95.0	95.0	95.0	95.0	95.0	95.0	95.0	96.0	96.0					95.2
Plate 3	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.5	92.5					91.4
Plate 4	89.0	89.0	89.0	89.0	89.0	89.0	89.0	90.0	90.0					89.3
Plate 5	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0					86.2
Plate 6	83.0	83.0	83.0	83.0	83.0	83.0	83.0	84.0	84.0					83.6

Lbs. steam condensate	
Weight water + bucket	10.0
Weight bucket	3.0
Weight condensate	7.0 in 40 mins.

Lbs. cooling water	
Weight water + barrel	408.0
Weight barrel	58.0
Weight cooling water	350.0 lbs. in 40 mins.

Analysis of Liquids

	B.Pt. (°C.)	Comp.
Plate 2	89.54	0.599
Plate 3	88.14	0.654
Plate 4	85.54	0.760
Plate 5	84.14	0.821
Plate 6	82.74	0.883
Plate 7	82.74	0.883
Reflux	81.34	0.948
Bottoms	100.64	0.290

Barometer = 761 mm.

Run 12 June 27, 1928 Time: 2:25 to 3:25

Time	0	5	10	15	20	25	30	35	40	45	50	55	60	Av.
Steam Data														
P(Lbs./in²)	9	9	9	9	9	9	9	9	9	9	9	9	9	9
t (°C.)	115.8	115.6	115.8	114.9	116.0	116.2	116.1	116.2	115.9	116.0	116.0	116.2	116.8	115.9
Condenser Data														
t entrance (°C.)	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
t exit (°C.)	29.4	29.7	29.4	30.6	29.9	31.1	31.4	31.6	30.3	29.6	29.6	29.7	29.4	30.16
Plate temps.														
Plate 1	98.5	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.2
Plate 2	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0
Plate 3	93.0	93.0	94.0	94.0	94.0	94.0	94.0	94.0	94.0	94.0	94.0	94.0	94.0	94.0
Plate 4	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Plate 5	87.0	87.0	87.5	87.5	87.0	87.0	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.6
Plate 6	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.4

Lbs. steam condensate	
Weight water + bucket	20.25
Weight bucket	3.00
Weight condensate	17.25

Lbs. cooling water	
Weight barrel + water	451
Weight barrel	58
Weight cooling water	393 lbs. in 50 mins.

Analysis of liquids

	B.Pt. (°C.)	Comp.
Plate 2	92.55	0.490
Plate 3	89.70	0.592
Plate 4	86.36	0.723
Plate 5	84.80	0.790
Plate 6	83.63	0.840
Plate 7	82.27	0.903
Reflux	81.54	0.934
Bottoms	101.80	0.290

Barometer = 760 mm.

J - ORIGINAL DATA AND CALCULATED RESULTS, SINGLE PLATE COLUMN

TABLE (29)

Application of Equation 48a to Slot Width and Liquid Depth Data

1	2	3	4	5	6	7	8	9	10
Run No.	E %	100-E	h	i = h - 0.35	$\frac{1}{W}$	$\frac{i}{W}$	$-.0616(\frac{i}{W})$	-0.713 i	(10)= (8) + (9)
12A	89.5	10.5	1.25	0.90	4	3.60	-0.222	-0.641	-0.863
13A	91.5	8.5	1.25	0.90	4	3.60	-0.222	"	-0.863
14A	98.8	1.2	1.25	0.90	16	14.40	-0.888	"	-1.529
15A	99.2	0.8	1.25	0.90	16	14.40	-0.888	"	-1.529
16A	86.2	13.8	1.25	0.90	2	1.80	-0.111	"	-0.752
17A	87.7	12.3	1.25	0.90	2	1.80	-0.111	"	-0.752
18A	95.1	4.9	1.25	0.90	8	7.20	-0.444	"	-1.085
19A	94.6	5.4	1.25	0.90	8	7.20	-0.444	"	-1.085
20A	92.9	7.1	1.75	1.40	2	2.80	-0.173	-0.999	-1.172
21A	95.3	4.7	1.75	1.40	2	2.80	-0.173	"	-1.172
22A	99.5	0.5	1.75	1.40	16	22.40	-1.380	"	-2.379
23A	100.0	0.0	1.75	1.40	16	22.40	-1.380	"	-2.379
24A	96.5	3.5	1.75	1.40	4	5.60	-0.345	"	-1.354
25A	97.1	2.9	1.75	1.40	4	5.60	-0.345	"	-1.354
26A	98.0	2.0	1.75	1.40	8	11.20	-0.690	"	-1.689
27A	98.4	1.6	1.75	1.40	8	11.20	-0.690	"	-1.689
28A	83.2	6.8	1.00	0.65	4	2.60	-0.160	-0.463	-0.623
29A	81.6	8.4	1.00	0.65	4	2.60	-0.160	"	-0.623
30A	93.6	6.4	1.00	0.65	16	10.40	-0.640	"	-1.103

TABLE (29) (Continued)

1 Run No.	2 E %	3 100 - E	4 h	5 i = h - 0.35	6 $\frac{1}{W}$	7 $\frac{i}{W}$	8 $-.0616(\frac{i}{W})$	9 -0.713 i	10 (10) = (8) + (9)
31A	92.9	7.1	1.00	0.65	16	10.40	-0.640	-0.463	-1.103
32A	86.8	13.2	1.00	0.65	8	5.20	-0.320	"	-0.783
33A	88.8	12.0	1.00	0.65	8	5.20	-0.320	"	-0.783
34A	79.8	20.2	1.00	0.65	2	1.30	-0.080	"	-0.543
35A	78.0	22.0	1.00	0.65	2	1.30	-0.080	"	-0.543
36A	70.0	30.0	0.75	0.40	4	1.60	-0.099	-0.285	-0.384
37A	70.3	29.7	0.75	0.40	4	1.60	-0.099	"	-0.384
38A	86.2	13.8	0.75	0.40	16	6.40	-0.394	"	-0.679
39A	88.5	11.5	0.75	0.40	16	6.40	-0.394	"	-0.679
40A	77.0	23.0	0.75	0.40	8	3.20	-0.197	"	-0.482
41A	75.9	24.1	0.75	0.40	8	3.20	-0.197	"	-0.482
42A	68.5	31.5	0.75	0.40	2	0.80	-0.049	"	-0.334
43A	67.0	33.0	0.75	0.40	2	0.80	-0.049	"	-0.334

TABLE 30

Original Data, Determination of Specific Gravity of CCl_4- Toluene Mixtures

1	2	3	4	5	6
Wt. Flask + Toluene gms.	Wt. Flask gms.	Wt. Flask + Sample gms.	Mol. Frac. CCl_4	Westphal Reading	Temp. Sample °C
102.2010	40.2618	113.0090	0.0817	0.9314	20.8
				0.9263	22.2
				0.9251	24.1
88.3150	35.8840	112.7430	0.2181	1.0204	13.7
				1.0084	24.3
				1.0114	21.0
85.1760	42.0690	116.1900	0.3010	1.0691	21.1
				1.0781	14.1
				1.0659	24.3
81.7900	46.2550	118.4340	0.3817	1.1269	21.5
				1.1332	14.1
				1.1234	24.3
67.6320	39.8730	120.1860	0.5313	1.2345	21.9
				1.2461	13.5
				1.2329	24.2
63.5460	42.2580	112.5690	0.5796	1.2703	22.0
				1.2824	14.2
				1.2676	24.3
48.7946	35.0015	106.4866	0.7146	1.3719	22.0
				1.3764	14.0
				1.3675	25.2

TABLE 30 (Continued)

1 Wt. Flask + Toluene gms.	2 Wt. Flask gms.	3 Wt. Flask + Sample gms.	4 Mol. Frac. CCl_4	5 Westphal Reading	6 Temp Sample °C
62.1033	47.8840	124.5736		1.3897	15.0
				1.3704	25.0
56.0724	51.4756	120.8375	0.8940	1.5899	24.5
				1.5952	22.0
				1.5060	24.7
				1.5090	22.2
				1.6053	15.3
102.3864	41.0494	112.0929	0.0867	0.9204	23.0
				0.9183	25.1
92.8806	34.7868	109.7134	0.1478	0.9608	23.4
				0.9592	25.1
57.3425	48.1341	120.4793	0.8041	1.4362	23.9
				1.4328	25.3

TABLE 31

Smoothed Values Used for Plotting Specific Gravity vs. Composition Curves for CCl_4 - Toluene Mixtures

- - - -

Mol Fraction CCl_4	Westphal Reading 20.0°C	Westphal Reading 25.0°C
0	0.8680	0.8615
0.0867	0.9234	0.9180
0.1478	0.9640	0.9590
0.2181	1.0123	1.0078
0.3010	1.0712	1.0653
0.3817	1.1290	1.1225
0.5313	1.2388	1.2318
0.5796	1.2738	1.2668
0.7146	1.3754	1.3679
0.7245	1.3782	1.3705
0.8041	1.4458	1.4335
0.8940	1.5137	1.5056
1.0000	1.5975	1.5891

TABLE 32

ANALYTICAL DATA AND CALCULATED RESULTS

Runs 12A to 43A

1	2	3	4	5	6	7	8	9	10
Run No.	Specific Samples Plate Liquid	Gravity t/15°C Reflux Liquid	Temperatures Samples °C Plate Liquid	Reflux Liquid	Mol Fractions Ethanol Plate Liquid	Reflux Liquid	Theo. Vapor	E %	Super-ficial Vap.Vel. F.P.S.
12A	0.8984	0.8512	20.4	21.2	0.3422	0.5635	0.5895	89.5	0.209
13A	0.8975	0.8492	22.3	22.7	0.3395	0.5675	0.5885	91.5	0.209
14A	0.9000	0.8473	23.2	22.4	0.3265	0.5805	0.5835	98.8	0.209
15A	0.9035	0.8499	22.9	22.3	0.3145	0.5765	0.5785	99.2	0.209
16A	0.9101	0.8562	22.4	22.2	0.2910	0.5315	0.5695	86.2	0.209
17A	0.9106	0.8557	22.8	22.3	0.2880	0.5335	0.6580	87.7	0.209
18A	0.9008	0.8491	22.2	22.0	0.3270	0.5712	0.5835	95.1	0.209
19A	0.9012	0.8497	22.0	21.8	0.3260	0.5695	0.5835	94.6	0.209
20A	0.9020	0.8503	22.1	22.2	0.3225	0.5636	0.5820	92.9	0.209
21A	0.9021	0.8494	23.2	22.4	0.3185	0.5680	0.5800	95.3	0.209
22A	0.9042	0.8480	22.1	22.1	0.3140	0.5770	0.5780	99.5	0.209
23A	0.9063	0.8482	22.6	22.3	0.3055	0.5750	0.5750	100.0	0.209
24A	0.9117	0.8521	20.7	21.0	0.2900	0.5595	0.5690	96.5	0.209
25A	0.9114	0.8514	21.1	21.4	0.2895	0.5610	0.5640	97.1	0.209
26A	0.9101	0.8497	23.0	23.0	0.2890	0.5630	0.5685	98.0	0.209
27A	0.9110	0.8502	22.0	22.2	0.2885	0.5640	0.5685	98.4	0.209
28A	0.9045	0.8558	22.2	22.2	0.3125	0.5335	0.5780	83.2	0.209
29A	0.9056	0.8570	22.4	22.3	0.3080	0.5265	0.5760	81.6	0.209
30A	0.9102	0.8524	22.3	22.3	0.2908	0.5518	0.5695	93.6	0.209
31A	0.9112	0.8528	22.7	22.7	0.2860	0.5475	0.5675	92.9	0.209
32A	0.9123	0.8561	23.6	23.1	0.2800	0.5275	0.5650	86.8	0.209

Table 32 (Continued)

1	2	3	4	5	6	7	8	9	10
Run No.	Specific Gravity Samples t/15°C		Temperature Samples °C		Mol Fractions Ethanol			E %	Superficial Vap. Vel. F.P.S.
	Plate Liquid	Reflux Liquid	Plate Liquid	Reflux Liquid	Plate Liquid	Reflux Liquid	Theo Vapor		
33A	0.9122	0.8553	23.0	23.1	0.2815	0.5315	0.5655	88.0	0.209
34A	0.9075	0.8575	22.1	23.2	0.3015	0.5190	0.5735	79.8	0.209
35A	0.9062	0.8584	23.4	23.4	0.3025	0.5140	0.5740	78.0	0.209
36A	0.9102	0.8648	22.5	22.4	0.2905	0.4855	0.5690	70.0	0.209
37A	0.9117	0.8652	22.3	22.4	0.2855	0.4835	0.5670	70.3	0.209
38A	0.9122	0.8573	21.2	21.4	0.2865	0.5290	0.5680	86.2	0.209
39A	0.9142	0.8565	22.8	22.9	0.2750	0.5305	0.5635	88.5	0.209
40A	0.9094	0.8605	22.8	22.8	0.2923	0.5058	0.5700	77.0	0.209
41A	0.9092	0.8609	22.5	22.8	0.2940	0.5040	0.5705	75.9	0.209
42A	0.9066	0.8635	23.0	23.2	0.3025	0.4885	0.5740	68.5	0.209
43A	0.9066	0.8627	22.7	22.7	0.3035	0.4950	0.5745	67.0	0.209

TABLE 33

Original Data, Runs 12A to 43A

Ethanol-Water Mixtures, Slot Width and Liquid Depth Studies

1 Run	2 Date	3 Height Overflow Pipe Inches	4 Cap Slot Width Inches	5 Room Temp. °C	6 Barometer m.m.Hg.	7 Barometer corr. m.m.Hg.	8 Barometer corr. to °C m.m.Hg.	9 Time	10 Temperatures °C	11	12	13 Heat Input Watts	14
									Plate Liquid	Plate Vapor	Lagging	Still	Jacket
12A	5/31/29	1.25	1/4	25.0	756.0	3.1	752.9	4:30	81.20	81.80	81.0	1600	120
								5:00	81.20	81.80	82.0	1600	120
								5:20	81.20	81.80	82.0	1600	120
								5:30	81.20	81.80	82.0	1600	120
13A	5/31/29	1.25	1/4	--	--	--	752.9	5:50	--	--	--	1600	120
								6:30	81.20	81.75	80.0	1600	120
								7:35	81.20	81.80	79.5	1600	120
								7:45	81.20	81.75	79.5	1600	120
14A	5/31/29	1.25	1/16	24.0	756.4	2.9	753.5	9:00	81.50	81.50	79.0	1600	120
								9:30	81.50	81.50	79.0	1600	120
								9:55	81.50	81.50	79.0	1600	120
15A	6/1/29	1.25	1/16	26.0	755.2	3.2	752.0	9:00	81.60	81.60	75.0	1600	150
								9:50	81.60	81.60	79.0	1600	120
								10:05	81.60	81.60	82.0	1600	120

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run	Date	Height Overflow Pipe Inches	Cap Slot Width Inches	Room Temp. °C.	Barometer m.m.Hg.	Barometer corr. m.m.Hg.	Barometer corr. to °C m.m.Hg.	Time	Temperatures °C			Heat Input Watts	
									Plate Liquid	Plate Vapor	Lagging	Still	Jacket
16A	6/1/29	1.25	1/2	26.0	755.5	3.2	752.3	11:30	--	--	--	1600	120
								11:50	81.80	82.70	72.0	1600	120
								12:50	81.80	82.70	80.5	1600	120
								12:55	81.80	82.70	80.5	1600	120
17A	6/1/29	1.25	1/2	26.5	755.5	3.2	752.3	1:15	--	--	--	1600	120
								1:30	81.85	82.80	82.0	1600	120
								1:50	81.85	82.75	81.8	1600	120
								2:00	81.90	82.85	81.8	1600	120
18A	6/1/29	1.25	1/8	25.5	755.8	3.2	752.6	4:20	--	--	--	1600	120
								4:45	81.45	81.60	77.0	1600	120
								4:55	81.45	81.65	77.0	1600	120
								5:00	81.50	81.65	77.0	1600	120
								5:05	81.50	81.65	78.5	1600	120
19A	6/1/29	1.25	1/8	25.0	755.8	3.2	752.6	5:45	--	81.60	79.0	1600	120
								5:55	--	81.65	78.0	1600	120
								6:05	--	81.70	78.0	1600	130
								6:15	--	81.70	78.5	1600	130
								6:30	--	81.70	79.0	1600	130
								6:45	--	81.70	79.0	1600	13o

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run	Date	Height Overflow Pipe Inches	Cap Slot Width Inches	Room Temp. °C.	Barometer m.m.Hg.	Barometer corr. m.m.Hg.	Barometer corr. to °C mm.Hg.	Time	Temperatures °C Plate Liquid	Plate Vapor	Lagging	Heat Input Watts Still	Jacket
20A	6/2/29	1.75	1/2	22.0	759.0	2.7	756.3	12:00	81.60	81.80	50.0	1600	165
								12:30	81.60	81.80	70.0	1600	165
								12:50	81.60	81.80	80.0	1600	115
								1:00	81.60	81.85	80.0	1600	115
21A	6/2/29	1.75	1/2	24.0	758.3	2.9	755.4	1:20	81.60	81.80	78.5	1600	115
								2:15	81.60	81.80	78.5	1600	115
								2:25	81.65	81.85	78.5	1600	115
								2:30	81.60	81.90	78.5	1600	115
22A	6/2/29	1.75	1/16	23.0	758.3	2.8	755.5	3:30	81.55	81.65	77.5	1600	120
								3:55	81.60	81.70	80.0	1600	120
								4:15	81.60	81.70	80.0	1600	120
								4:25	81.60	81.70	80.0	1600	120
								4:30	81.60	81.70	80.0	1600	120
23A	6/2/29	1.75	1/16	23.0	857.4	2.8	755.6	5:00	--	--	80.0	1600	120
								5:30	81.80	81.80	80.0	1600	120
								6:00	81.80	81.80	80.0	1600	120
24A	6/2/29	1.75	1/4	22.0	759.5	2.7	756.8	6:45	81.90	82.30	78.0	1600	120
								7:15	81.90	82.30	78.0	1600	150
								7:35	81.90	82.30	79.0	1600	150

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run	Date	Height Overflow Pipe Inches	Cap Slot Width Inches	Room Temp. °C.	Barometer m.m.Hg.	Barometer corr. m.m.Hg.	Barometer corr. to °C m.m.Hg.	Time	Temperatures °C			Heat Input Watts	
									Plate Liquid	Plate Vapor	Lagging	Still	Jacket
25A	6/2/29	1.75	1/4	23.0	759.5	2.7	756.8	8:00	--	82.40	79.0	1600	160
								8:15	--	82.45	79.0	1600	160
								8:30	--	82.45	80.0	1600	160
								8:45	--	82.45	80.5	1600	160
								9:00	--	82.45	80.5	1600	160
26A	6/2/29	1.75	1/8	23.0	759.5	2.7	756.8	9:25	--	--	--	1600	155
								9:40	--	82.30	80.0	1600	155
								9:55	--	82.30	80.0	1600	155
								10:10	--	82.30	80.0	1600	155
								10:25	--	82.30	80.0	1600	155
27A	6/2/29	1.75	1/8	23.0	759.5	2.7	756.8	10:45	--	82.35	81.0	1600	160
								11:00	--	82.40	81.0	1600	160
								11:15	--	82.40	81.0	1600	160
								11:30	--	82.40	81.0	1600	160
								11:45	--	82.40	81.0	1600	160
28A	6/3/29	1.00	1/4	23.5	761.3	2.8	758.5	11:5o	81.60	82.90	52.0	1600	150
								12:55	81.60	83.10	80.0	1600	120
								1:05	81.60	83.10	80.0	1600	120
29A	6/3/29	1.00	1/4	24.0	761.4	2.9	758.5	1:20	81.70	83.10	76.0	1600	120
								2:35	81.70	83.10	78.0	1600	140
								2:45	81.70	83.10	78.0	1600	140

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run	Date	Height Overflow Pipe Inches	Cap Slot Width Inches	Room Temp. °C.	Barometer m.m.Hg.	Barometer corr. m.m.Hg.	Barometer corr. to °C m.m.Hg.	Time	Temperatures °C			Heat Input Watts	
									Plate Liquid	Plate Vapor	Lagging	Still	Jacket
30A	6/3/29	1.00	1/16	23.5	761.4	2.8	758.6	4:00	--	--	--	1600	150
								4:25	82.10	82.40	75.0	1600	150
								4:45	82.10	82.50	77.0	1600	150
								4:50	82.10	82.50	78.0	1600	150
								5:00	82.10	82.60	78.0	1600	150
31A	6/3/29	1.00	1/16	23.0	761.4	2.8	758.6	5:25	--	--	--	1600	120
								6:00	82.20	82.70	80.0	1600	120
								6:45	82.20	82.75	78.0	1600	120
								7:00	82.20	82.75	78.0	1600	120
								7:05	82.30	82.80	78.0	1600	120
32A	6/4/29	1.00	1/8	24.5	763.7	3.1	760.6	9:00	--	--	--	1600	160
								9:30	82.40	83.50	62.0	1600	160
								9:40	82.45	83.60	72.0	1600	160
								9:50	82.40	83.60	77.0	1600	160
33A	6/4/29	1.00	1/8	24.5	763.7	3.1	760.6	10:15	--	83.60	77.0	1600	170
								10:30	--	83.70	78.0	1600	170
								10:45	--	83.65	79.0	1600	170
								11:00	--	83.65	81.0	1600	160
								11:15	--	83.65	81.0	1600	160

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run	Date	Height Overflow Pipe Inches	Cap Slot Width Inches	Room Temp. °C	Barometer m.m.Hg.	Barometer corr. m.m.Hg.	Barometer corr. to °C m.m.Hg.	Time	Temperatures °C			Heat Input Watts	
									Plate Liquid	Plate Vapor	Lagging	Still	Jacket
34A	6/4/29	1.00	1/2	25.0	--	--	760.6	11:45	--	83.80	80.0	1600	160
								12:00	--	83.90	81.0	1600	160
								12:15	--	83.90	81.5	1600	160
								12:30	--	83.90	81.5	1600	160
								12:45	--	83.90	82.0	1600	160
35A	6/4/29	1.00	1/2	25.0	--	--	760.6	1:10	--	83.95	82.0	1600	160
								1:25	--	84.00	82.5	1600	160
								1:40	--	84.00	83.0	1600	150
								1:55	--	84.00	83.0	1600	150
								2:10	--	84.00	82.5	1600	150
36A	6/4/29	0.75	1/4	25.0	763.7	3.1	760.6	2:30	--	--	--	1600	165
								2:45	82.10	84.60	64.0	1600	165
								2:50	82.20	84.70	74.0	1600	165
								3:05	82.20	84.70	78.0	1600	145
								3:20	82.20	84.70	79.0	1600	145
37A	6/4/29	0.75	1/4	--	--	--	760.6	3:40	82.30	84.80	80.0	1600	135
								3:55	82.30	84.80	80.0	1600	135
								4:30	82.30	84.80	80.0	1600	135
								4:40	82.30	84.80	80.0	1600	135
38A	6/4/29	0.75	1/16	25.0	763.9	3.1	760.8	5:00	82.50	83.50	78.0	1600	150
								6:00	82.50	83.50	79.5	1600	150

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run	Date	Height Overflow Pipe Inches	Cap Slot Width Inches	Room Temp. °C	Barometer m.m.Hg.	Barometer corr. m.m.Hg.	Barometer corr. to °C m.m.Hg.	Time	Temperatures °C			Heat Input Watts	
									Plate Liquid	Plate Vapor	Lagging	Still	Jacket
39A	6/5/29	0.75	1/16	25.0	766.0	3.1	762.9	9:00	--	--	--	1600	170
								9:20	--	83.70	70.0	1600	170
								9:30	--	83.75	74.0	1600	170
								9:45	--	83.80	76.0	1600	170
								10:00	--	83.80	76.0	1600	170
								10:15	--	83.80	79.0	1600	170
40A	6/5/29	0.75	1/8	25.0	--	--	762.9	10:45	--	85.20	80.0	1600	160
								11:00	--	85.20	81.0	1600	160
								11:15	--	85.25	81.0	1600	160
								11:30	--	85.25	82.0	1600	160
								11:45	--	85.25	82.0	1600	160
41A	6/5/29	0.75	1/8	25.0	--	--	762.9	12:15	--	85.30	82.0	1600	160
								12:30	--	85.35	83.0	1600	160
								12:45	--	85.35	83.0	1600	160
								1:00	--	85.35	83.0	1600	160
								1:15	--	85.35	83.0	1600	160
42A	6/5/29	0.75	1/2	25.0	--	--	762.9	1:40	--	87.10	83.0	1600	155
								1:55	--	87.15	83.0	1600	155
								2:10	--	87.15	82.0	1600	155
								2:25	--	87.15	82.0	1600	155
								2:40	--	87.15	82.0	1600	155
43A	6/5/29	0.75	1/2	25.0	--	--	762.9	3:10	--	87.25	81.0	1600	165
								3:25	--	87.30	82.0	1600	165
								3:40	--	87.30	82.0	1600	165
								3:55	--	87.30	82.0	1600	165
								4:10	--	87.30	82.0	1600	165

TABLE (34)

Analytical Data and Calculated Results, Runs 1 B to 47B

1	2	3	4	5	6	7	8	9	10
Run No.	Specific Gravity Samples t/15°C		Temp. Samples °C.		Mol Fractions Ethanol			E_M %	Sup. Vap. Vel. F. P. S.
	Plate Liq.	Reflux	Plate Liq.	Reflux	Plate Liq.	Reflux	Theo. Vapor		
1B	0.8993	0.8526	21.5	21.2	0.3355	0.5555	0.5865	87.6	0.29
2B	.8980	.8523	22.2	21.4	.3380	.5565	.5880	87.3	.29
3B	.9061	.8563	23.2	22.7	.3035	.5285	.5740	83.3	.49
4B	.9090	.8573	22.4	22.2	.2950	.5255	.5710	83.6	.49
5B	.9163	.8600	21.2	22.2	.2690	.5150	.5605	84.3	.56
6B	.9177	.8618	21.2	21.2	.2665	.5055	.5600	81.5	.56
7B	.9094	.8568	21.3	21.3	.2965	.5320	.5715	85.5	.21
8B	.9106	.8574	20.3	20.3	.2950	.5330	.5710	86.2	.21
9B	.9074	.8560	21.0	20.4	.3050	.5405	.5745	87.3	.14
10B	.9064	.8550	21.4	21.2	.3080	.5420	.5760	87.3	.11
11B	.9171	.8611	23.4	22.9	.2655	.5025	.5590	80.9	.41
12B	.9198	.8621	22.0	22.0	.2575	.5010	.5570	81.3	.42
13B	.9151	.8603	22.5	23.0	.2730	.5055	.5620	80.5	.35
14B	.9209	.8636	22.8	22.2	.2515	.4925	.5535	79.9	.35
15B	.9182	.8597	23.0	23.0	.2600	.5085	.5570	83.7	.28
16B	.9137	.8580	22.8	22.9	.2770	.5185	.5640	84.2	.21
17B	.9207	.8693	23.1	22.3	.2510	.4635	.5535	70.2	.26
18B	.9238	.8735	23.0	22.0	.2410	.4446	.5490	66.0	.40
19B	.9075	.8653	22.7	21.3	.3000	.4880	.5730	68.8	.26
20B	.9118	.8673	22.9	22.1	.2835	.4745	.5660	67.6	.40
21B	.9127	.8698	23.1	23.0	.2790	.4580	.5645	62.7	.53
22B	.9473	.8911	22.4	24.0	.1635	.3595	.5060	57.2	.57
23B	.9518	.8945	23.8	23.8	.1455	.3470	.4925	58.0	.58

Table (34) (Continued)

1	2	3	4	5	6	7	8	9	10
Run No.	Specific Gravity Sample t/15°C.		Temp. Samples °C.		Mol Fractions Ethanol			E_M %	Sup. Vap. Vel. F. P. S.
	Plate Liq.	Reflux	Plate Liq.	Reflux	Plate Liq.	Reflux	Theo. Vapor		
24B	.9199	.8722	22.9	23.2	.2545	.4460	.5550	63.7	.51
25B	.9127	.8687	23.2	22.0	.2790	.4680	.5645	66.2	.39
26B	.9128	.8672	22.0	22.2	.2840	.4740	.5665	67.3	.26
27B	.9114	.8664	23.8	23.5	.2825	.4730	.5660	67.1	.26
28B	.9122	.8665	22.5	22.2	.2832	.4775	.5660	68.7	.26
29B	.9148	.8709	23.3	24.0	.2715	.4485	.5615	61.1	.39
30B	.9149	.8705	24.0	23.9	.2695	.4510	.5610	62.3	.39
31B	.9188	.8761	22.4	22.2	.2600	.4320	.5570	57.8	.51
32B	.9200	.8749	24.1	24.0	.2505	.4300	.5530	59.3	.51
33B	.9463	.8912	23.3	23.9	.1645	.3600	.5070	57.0	.57
34B	.9113	.8658	23.1	23.2	.2845	.4775	.5670	68.2	.19
35B	.9083	.8633	23.5	23.6	.2950	.4880	.5710	69.9	.13
36B	.9161	.8700	22.8	23.0	.2685	.4570	.5605	64.5	.25
37B	.9140	.8688	23.0	23.0	.2750	.4635	.5630	65.4	.19
38B	.9080	.8637	23.1	23.0	.2968	.4885	.5720	69.7	.12
39B	.9256	.8765	22.5	22.4	.2362	.4290	.5465	59.0	.56
40B	.9231	.8733	23.1	23.0	.2430	.4420	.5500	64.9	.46
41B	.9193	.8704	22.2	22.5	.2585	.4575	.5565	66.7	.40
42B	.9105	.8621	22.7	22.8	.2885	.4975	.5685	74,6	.20
43B	.9139	.8651	22.8	22.2	.2760	.4850	.5635	72.8	.27
44B	.9170	.8684	22.1	22.2	.2670	.4685	.5600	68.7	.40
45B	.9226	.8719	23.0	22.0	.2450	.4515	.5505	67.7	.53
46B	.9141	.8523	22.0	22.0	.2778	.5535	.5640	96.2	.26
47B	.9161	.8548	22.1	22.2	.2700	.5390	.5610	92.5	.25

TABLE (35)

Original Data, Runs 1B to 47B

1	2	3	4	5	6	7	8	9	10	11	12	13	14
									Temperatures °C.			Heat Input	
Run No.	Date	Height Overflow Pipe In.	Slot Width Inches	Room Temp. °C.	Bar. m.m. Hg.	Bar. corr. m.m.Hg.	Bar. corr. to °C m.m.Hg.	Time	Plate Liq.	Plate Vapor	Lagg-ing	Watts Still	Jacket
1B	8/12/29	1.19	1/4	27.0	758.2	3.3	754.9	5:20	81.20	82.10	85	2200	160
2B	"	"	"	27.0	758.4	3.3	755.1	7:00	81.30	82.10	83	2180	"
3B	"	"	"	---	---	---	755.1	8:05	82.00	83.30	84	3180	"
4B	"	"	"	---	---	---	755.1	9:25	82.10	83.40	80	3780	"
5B	8/13/29	"	"	24.0	762.8	2.9	759.9	12:20	82.40	83.90	79	4260	"
6B	"	"	"	---	---	---	759.9	2:00	82.40	84.00	88	4260	"
7B	"	"	"	---	---	---	759.9	4:25	81.80	82.80	78	1600	"
8B	"	"	"	---	---	---	759.9	6:50	81.90	82.90	85	1600	"
9B	"	"	"	---	---	---	759.9	8:10	81.80	82.50	84	1100	"
10B	8/14/29	"	"	23.0	762.5	2.8	759.7	12:25	81.80	82.50	78	1080	"
11B	"	"	"	---	---	---	759.7	2:55	82.20	83.60	75	3160	"
12B	"	"	"	---	---	---	759.7	5:45	82.20	83.70	78	3200	"
13B	"	"	"	---	---	---	759.7	7:05	82.20	83.40	78	2680	"
14B	8/16/29	"	"	26.0	765.9	3.2	762.7	3:00	82.50	83.90	85	2640	"
15B	"	"	"	---	---	---	762.7	4:15	82.40	83.60	79	2120	"
16B	"	"	"	---	---	---	762.7	5:30	82.30	83.30	83	1640	"
17B	8/20/29	0.75	"	24.0	769.2	3.0	766.2	3:00	82.60	85.40	78	2020	"
18B	"	"	"	24.0	768.6	3.0	765.6	4:35	82.90	86.00	82	3040	"
19B	8/21/29	"	"	25.0	771.2	3.1	768.1	2:50	82.20	84.70	81	2000	"
20B	"	"	"	---	---	---	768.1	4:15	82.40	85.00	82	3040	"
21B	"	"	"	---	---	---	768.1	5:00	82.60	85.50	82	4040	"
22B	8/22/29	"	"	---	---	---	765.0	2:35	84.50	89.30	81	4360	"

Table (35) (Continued

Run No.	Date	Height Overflow Pipe In.	Slot Width Inches	Room Temp °C	Bar. m.m. Hg.	Bar. Corr. m.m.Hg.	Bar. corr.to °C m.m.Hg.	Time	Temperatures °C. Plate Liq.	Plate Vapor	Lagging °C	Heat Input Watts Still	Jacket
23B(1)	8/23/29	0.75	1/4	27.0	762.8		3.3	1:45	84.80	89.30	84	4400	160
24B(1)	"	"	"	---	---	---	759.5	2:55	82.40	85.50	80	3900	"
25B(1)	"	"	"	---	---	---	759.5	4:15	82.20	85.00	82	2960	"
26B(1)	"	"	"	---	---	---	759.5	5:05	---	84.70	82	2000	"
27B(2)	8/26/29	"	"	---	---	---	763.2	11:10	82.20	84.90	92	1980	"
28B(2)	"	"	"	28.0	766.6	3.4	763.2	12:10	82.20	84.90	82	2000	"
29B(2)	"	"	"	---	---	--	763.2	1:15	82.40	85.70	83	2980	"
30B(2)	"	"	"	---	---	--	763.2	2:10	82.40	85.80	84	2960	"
31B(2)	"	"	"	---	---	--	763.2	3:10	82.60	86.40	83	3900	"
32B(2)	"	"	"	---	---	--	763.2	4:00	82.60	86.40	84	3900	"
33B(2)	"	"	"	---	---	--	763.2	4:40	84.30	88.70	85	4340	"
34B(2)	8/27/29	"	"	29.0	760.2	3.6	756.6	2:40	84.30	---	74	1480	"
35B(2)	"	"	"	---	---	--	756.6	4:20	83.80	---	82	960	"
36B(3)	8/28/29	"	"	---	---	--	756.0	1:20	82.30	84.90	73	1940	"
37B(3)	"	"	"	---	---	--	759.0	2:45	82.20	84.70	81	1480	"
38B(3)	"	"	"	27.0	762.3	3.3	759.0	4:10	81.90	83.90	81	950	"
39B(3)	"	"	"	---	---	--	759.0	4:05	82.90	86.50	82	4300	"
40B(3)	"	"	"	---	---	--	759.0	5:55	82.60	85.90	82	3480	"
41B(3)	"	"	"	25.0	763.2	3.1	760.1	7:15	82.60	85.30	78	2960	"
42B(4)	9/6/29	"	"	24.0	764.0	2.9	761.1	1:40	82.40	83.80	87	1520	"
43B(4)	"	"	"	---	---	--	761.1	2:45	82.50	84.30	80	2060	"
44B(4)	"	"	"	---	---	--	761.1	3:35	82.50	84.80	78	3080	"
45B(4)	"	"	"	---	---	--	761.1	4:35	82.60	85.60	73	4080	"
46B	9/16/29	1.75	1/16	24.0	772.2	3.0	769.2	12:55	82.30	82.45	76	1980	"
47	"	"	"	---	---	--	769.2	1:5o	82.30	82.50	79	1940	"

(1) Baffle in front of take off
(2) 12 slots per cap
(3) 16 slots per cap
(4) 8 triangular slots per cap

TABULATION OF ORIGINAL DATA

BENZENE-TOLUENE RUNS (1-54) SINGLE PLATE COLUMN

LIQUID DEPTH 13/16", WIDTH CAP SLOTS ¼"

Table 36

Run No.	Temperatures °C Plate Vapor	Jacket	Heat Input Watts Still	Jacket	True Boiling Pt. of Samples °C Plate	Reflux	Barometer m.m. Hg. corr.	Mol. Fractions Benzene Plate Liquid	Reflux Liquid	Theo. Vapor	Superficial Vap.Vel. F.P.S.	Efficiency o/o
1.	92.90	71	1770	170	93.18	89.75	766.4	0.475	0.600	0.692	0.294	57.5
2.	93.40	79.5	1800	185	93.59	90.24	765.5	0.461	0.581	0.680	0.300	54.8
3.	93.80	84.5	1010	175	93.39	90.12	764.4	0.466	0.584	0.684	0.169	54.1
4.	94.30	86.0	980	180	94.02	90.62	764.4	0.446	0.565	0.666	0.165	53.9
5.	94.15	94.0	550	165	93.95	90.32	760.6	0.442	0.570	0.662	0.093	58.1
6.	94.90	81.1	520	190	94.73	90.88	761.0	0.417	0.550	0.639	0.087	59.5
7.	96.40	89.0	1400		96.27	92.52	760.9	0.370	0.490	0.590	0.235	54.7
8.	102.50	95.8	1000	185	102.40	99.50	759.9	0.194	0.271	0.366	0.168	44.8
9.	102.55	93.8	500	175	102.56	99.17	758.7	0.188	0.279	0.356	0.084	54.5
10.	102.80	92.5	1800	185	103.30	100.08	758.1	0.168	0.252	0.326	0.302	53.3
11.	103.10	94.5	1450	190	103.48	100.30	758.0	0.164	0.245	0.320	0.243	52.0
12.	104.80	86.0	1880	190	104.09	101.00	755.8	0.146	0.225	0.290	0.315	54.9
13.	101.20	87.0	1820	180	99.85	96.27	745.7	0.245	0.349	0.440	0.305	53.2
14.	101.50	89.3	1820	180	100.28	96.79	745.7	0.234	0.331	0.421	0.305	52.4
15.	101.50	93.0	1540	190	100.18	96.77	744.40	0.235	0.332	0.426	0.259	50.8

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	True Boiling Pt. of Samples °C Plate	True Boiling Pt. of Samples °C Reflux	Barometer m.m.Hg. corr.	Mol. Fractions Benzene Plate Liquid	Mol. Fractions Benzene Reflux Liquid	Mol. Fractions Benzene Theo. Vapor	Superficial Vap.Vel. F.P.S.	Efficiency o/o
16.	101.80	95.5	1540		100.77	96.89	743.2	0.216	0.326	0.399	0.259	60.3
17.	102.00	92.5	1540		100.52	96.68	742.1	0.222	0.332	0.407	0.259	59.4
18.	102.00		1540		100.82	97.30	742.0	0.215	0.310	0.397	0.259	52.2
19.	102.10	93.0	1820		101.30	97.92	741.1	0.202	0.294	0.378	0.305	50.7
20.	103.10	89.0	1540	185	102.05	98.65	752.9	0.194	0.287	0.365	0.259	54.2
21.	103.60	94.5	1740		103.10	99.68	754.2	0.169	0.259	0.328	0.293	56.7
22.	103.20	94.5	940		102.20	99.04	755.7	0.194	0.279	0.365	0.158	49.9
23.	103.60	94.5	940		102.35	99.15	755.7	0.190	0.276	0.359	0.158	51.0
24.	91.50	81.0	1800	185	89.61	86.60	762.0	0.599	0.718	0.790	0.302	62.3
25.	91.50		1800		89.61	86.88	764.3	0.599	0.707	0.790	0.302	56.9
26.	91.70	88.5	1800		89.69	86.85	764.5	0.597	0.708	0.789	0.302	57.8
27.	91.50	81.0	990		89.45	86.77	761.8	0.606	0.712	0.795	0.166	56.2
28.	91.20	80.0	500		89.30	86.30	761.8	0.611	0.730	0.799	0.084	63.2
29.	91.80	84.5	1400		89.73	86.93	762.7	0.596	0.706	0.788	0.235	57.5
30.	91.20	86.0	400		89.27	86.32	762.7	0.614	0.731	0.801	0.067	62.7
31.			410		89.43	86.47	764.5	0.610	0.729	0.798	0.069	63.5
32.	92.20	88.0	1260		90.17	87.28	764.5	0.583	0.696	0.778	0.211	57.3
33.	92.30	87.0	1400		90.19	87.28	764.5	0.582	0.696	0.779	0.235	57.8
34.	92.50		1800		90.40	87.59	765.2	0.575	0.685	0.774	0.302	55.5
35.	92.20	87.5	1000		90.07	87.48	765.2	0.587	0.689	0.782	0.168	52.5

Run No.	Temperatures °C Plate Vapor		Heat Input Watts		True Boiling Pt. of Samples °C		Barometer m.m. Hg. corr.	Mol. Fractions Benzene			Superficial Vap. Vel. F.P.S.	Efficiency o/o
	Plate Vapor	Jacket	Still	Jacket	Plate	Reflux		Plate Liquid	Reflux Liquid	Theo. Vapor		
36.	89.50	77.0	960	180	87.18	85.17	762.7	0.697	0.779	0.853	0.161	52.8
37.	89.50	87.0	1800		87.60	85.09	761.1	0.677	0.779	0.841	0.302	62.4
38.	89.50	85.6	1400		84.48	85.05	761.1	0.682	0.781	0.844	0.235	61.1
39.	89.00	86.3	400		87.08	84.66	760.4	0.696	0.797	0.853	0.067	64.5
40.	89.00	86.5	400		87.08	84.66	760.4	0.696	0.797	0.853	0.067	64.5
41.	89.20	86.0	700		87.30	84.98	760.3	0.687	0.783	0.847	0.118	60.0
42.	89.50	89.0	1000		87.38	85.20	760.3	0.685	0.773	0.846	0.168	54.5
43.	89.50	83.0	1000		87.56	85.25	760.3	0.677	0.771	0.842	0.168	57.1
44.	89.70	85.5	1400		87.65	85.30	760.3	0.673	0.769	0.840	0.235	57.5
45.	89.90	86.0	1800		87.89	85.57	760.3	0.664	0.758	0.834	0.302	55.5
46.	88.50	87.0	200		87.21	84.38	753.8	0.679	0.795	0.842	0.034	71.1
47.	87.00	85.5	1800		85.34	83.47	753.8	0.755	0.835	0.889	0.302	60.3
48.	87.30		1800		85.45	83.65	756.0	0.754	0.832	0.886	0.302	58.9
49.	98.30	85.2	1800		96.58	92.76	764.6	0.362	0.489	0.581	0.302	58.0
50.	98.30	89.4	1800		96.58	92.90	764.6	0.362	0.484	0.581	0.302	55.5
51.	98.50	90.0	1800		96.58	92.81	762.6	0.362	0.483	0.581	0.302	55.1
52.	101.60	91.8	1800		100.18	96.76	762.6	0.256	0.356	0.454	0.302	50.6
53.	101.80		1800		100.18	96.48	761.1	0.254	0.363	0.452	0.302	55.2
54.	101.80		1800		100.38	96.79	760.6	0.248	0.353	0.443	0.302	54.1

RUNS WITH ETHANOL-WATER MIXTURES

OBSERVED DATA AND CALCULATED VALUES

Note: See pages   for additional notes on Runs 67 to 229

Runs 67 to 123: Height Overflow Pipe above Plate: 13/16", Bubble cap, 8 slots ¼" wide ½" high

Run No.	Temperatures °C		Heat Input Watts		Spec. Gravity of Samples t/15°C		Temp. Samples °C		Mol. Fractions Alcohol			Barometer m.m.Hg. corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
	Plate Vapor	Jacket	Still	Jacket	Plate	Reflux	Plate	Ref.	Plate Liq.	Reflux Liq.	Theo. Vapor			
67	82.80		1800		0.9366	0.8640	22.2	19.7	0.2010	0.5015	0.5290		0.235	91.6
68	83.80		1800		0.9452	0.8690	20.2	19.2	0.1765	0.4785	0.5155		0.235	89.0
69	82.20		1800		0.9180	0.8600	20.2	19.0	0.2685	0.5250	0.5605		0.235	87.9
70	82.20		1800		0.9284	0.8772	20.5	20.4	0.2300	0.4335	0.5440		0.235	64.8
71	83.20		1800		0.8995	0.8652	20.7	20.9	0.3375	0.4900	0.5875		0.235	61.0
72	83.50		1800	150	0.8984	0.8588	22.0	21.2	0.3375	0.5220	0.5875		0.235	73.8
73	83.50		1800		0.8991	0.8589	22.0	21.2	0.3345	0.5220	0.5865		0.235	74.4
74	83.50		1800		0.8990	0.8574	21.1	21.2	0.3380	0.5295	0.5880		0.235	76.6
75	83.00		980		0.8937	0.8578	22.2	21.2	0.3555	0.5270	0.5950		0.128	71.6
76	83.00		980		0.8949	0.8590	21.7	21.2	0.3525	0.5205	0.5940		0.128	69.6
77	82.20		960		0.8914	0.8565	22.4	21.4	0.3640	0.5335	0.5980		0.125	72.4
78	81.90		500		0.8878	0.8525	21.1	21.1	0.3830	0.5565	0.6060		0.065	77.8
79	81.00		200		0.8770	0.8461	20.2	20.3	0.4350	0.5973	0.6265		0.026	84.8
80	81.00		200		0.8809	0.8499	21.2	20.0	0.4137	0.5765	0.6180		0.026	79.7
81	83.00		1400		0.9004	0.8600	20.3	20.8	0.3325	0.5170	0.5860		0.183	72.8

RUNS WITH ETHANOL-WATER MIXTURES, Continued.

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer M.m.Hg. corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
82	83.00		1400		0.9012	0.8604	20.0	20.2	0.3322	0.5170	0.5860		0.183	72.8
83	80.00		1700		0.8650	0.8424	21.2	20.7	0.4897	0.6175	0.6420		0.222	83.8
84	80.00		1700		0.8600	0.8420	21.0	20.2	0.5160	0.6225	0.6580		0.222	75.0
85	80.60		1700		0.8600	0.8426	22.2	21.6	0.5110	0.6145	0.6585		0.222	70.2
86	80.70		1400		0.8574	0.8415	22.8	21.0	0.5220	0.6215	0.6610		0.183	71.6
87	80.60		990		0.8571	0.8395	21.4	20.9	0.5305	0.6340	0.6650		0.129	77.0
88	80.50		1000		0.8565	0.8394	21.1	20.9	0.5350	0.6350	0.6665		0.133	76.0
89	80.20		520	180	0.8560	0.8383	20.8	21.1	0.5387	0.6405	0.6685		0.068	78.4
90	80.10		510	180	0.8556	0.8382	21.1	21.0	0.5396	0.6417	0.6685		0.067	79.3
91	79.80		200		0.8513	0.8370	20.9	21.2	0.5645	0.6480	0.6800		0.026	72.2
92	79.80		200		0.8506	0.8370	21.1	20.7	0.5675	0.6509	0.6810		0.026	73.4
93	80.90		1600	✓	0.8600	0.8423	21.3	20.7	0.5148	0.6170	0.6580		0.209	71.5
94	81.20		1790		0.8690	0.8439	20.2	21.6	0.4745	0.6045	0.6420		0.234	77.6
95	80.90		1600	✓	0.8634	0.8434	19.5	19.2	0.5051	0.6180	0.6540		0.209	75.8
96	80.00		190	180	0.8542	0.8358	20.1	19.4	0.5515	0.6525	0.6740		0.025	82.5
97	80.00		200	180	0.8500	0.8337	20.1	20.2	0.5755	0.6740	0.6845		0.026	90.3
98	81.00		1600		0.8628	0.8433	20.2	20.2	0.5045	0.6140	0.6540		0.209	73.3

RUNS WITH ETHANOL-WATER MIXTURE, Continued

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
99	81.00		1600		0.8630	0.8434	20.2	20.2	0.5042	0.6135	0.6540		0.209	73.0
100	80.80		1000		0.8613	0.8418	19.8	19.9	0.5148	0.6245	0.6580		0.133	76.5
101	80.90		750		0.8597	0.8414	20.0	20.2	0.5220	0.6260	0.6610		0.098	74.8
102	80.90		750		0.8600	0.8410	20.2	20.2	0.5195	0.6285	0.6600		0.098	77.6
103	80.90		1000		0.8614	0.8418	20.2	20.4	0.5120	0.6225	0.6570		0.133	76.2
104	81.00		1400		0.8622	0.8432	20.4	20.7	0.5075	0.6130	0.6545		0.183	71.8
105	81.10		1700		0.8638	0.8440	20.8	20.7	0.4980	0.6080	0.6510		0.222	71.9
106	80.90		1800		0.8612	0.8417	21.7	21.3	0.5070	0.6185	0.6550		0.235	75.3
107	80.90		1800		0.8632	0.8424	21.2	21.4	0.4985	0.6140	0.6515		0.235	75.5
108	80.80		1800		0.8578	0.8400	22.3	22.2	0.5230	0.6240	0.6615		0.235	72.9
109	80.70		1800	180	0.8591	0.8403	22.6	23.1	0.5145	0.6170	0.6580		0.235	71.5
110	80.80		1800	180	0.8597	0.8408	22.4	23.1	0.5115	0.6145	0.6565		0.235	71.0
111	80.70		1800	180	0.8592	0.8409	21.9	22.4	0.5170	0.6170	0.6590		0.235	70.4
112	80.70		1800		0.8590	0.8404	22.2	22.3	0.5160	0.6205	0.6585		0.235	73.3
113	80.20		1800		0.8540	0.8387	22.5	22.6	0.5420	0.6310	0.6700		0.235	69.5
114	80.50		1600		0.8540	0.8409	23.0	22.6	0.5392	0.6170	0.6685		0.209	60.1
115	80.50		1600		0.8540	0.8385	22.2	22.2	0.5430	0.6330	0.6700		0.209	70.9

RUNS WITH ETHANOL-WATER MIXTURE, Continued

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
116	81.70		1610	180	0.8807	0.8569	22.3	21.2	0.4105	0.5320	0.6165	765.0	0.210	59.0
117	81.50		1600	180	0.8727	0.8492	20.4	21.0	0.4510	0.5760	0.6330	765.0	0.209	68.7
118	81.50		1630	185	0.8725	0.8481	21.5	21.2	0.4515	0.5810	0.6330	765.0	0.213	71.3
119	81.50		1600	180	0.8738	0.8485	21.2	21.1	0.4470	0.5790	0.6315	765.0	0.209	71.5
120	81.50		1600		0.8732	0.8485	21.2	21.2	0.4490	0.5790	0.6320	765.0	0.209	71.1
121	84.30		1600		0.9110	0.8638	22.2	22.2	0.2875	0.4955	0.5680	765.0	0.209	74.1
122	84.50		1600		0.9128	0.8642	22.7	22.4	0.2805	0.4885	0.5650	765.0	0.209	73.1
123	84.20		1600	190	0.9127	0.8645	21.4	21.3	0.2845	0.4918	0.5665		0.209	73.5
Runs 124 to 133: Height overflow pipe above plate = 13/16"; Bubble Cap, 4 slots ½" wide ½" high														
124	86.10		1590	185	0.9205	0.8727	21.3	21.4	0.2570	0.4510	0.5560		0.209	64.9
125	86.20		1620	180	0.9213	0.8742	21.6	21.1	0.2533	0.4450	0.5540		0.209	63.7
126	86.20 88.40		1600	190	0.9438	0.8881	22.2	22.2	0.1760	0.5290	0.5330		0.209	98.9
127	85.10		1600	180	0.9108	0.8680	23.2	22.2	0.2860	0.4705	0.5675		0.209	65.5
128	84.50		990	180	0.9030	0.8642	22.9	22.6	0.3163	0.4880	0.5790		0.129	65.3
129	84.50		990	180	0.9065	0.8645	23.0	23.1	0.3030	0.4808	0.5740		0.129	65.6
130	83.00		500	180	0.8998	0.8598	21.3	22.0	0.3340	0.5130	0.5860		0.065	71.0
131	81.00		200	180	0.8711	0.8458	23.8	24.3	0.4488	0.5825	0.6320		0.026	72.9
132	85.30		1600	170	0.9140	0.8678	22.7	24.0	0.2759	0.4640	0.5635		0.209	65.5

RUNS WITH ETHANOL-WATER MIXTURE, Continued.

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. Corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
133	85.30		1600	170	0.9142	0.8693	24.4	24.8	0.2710	0.4530	0.5615		0.209	62.6
Runs 134 to 137: Height overflow pipe above plate 13/16"; Bubble cap, 16 slots, 1/8" wide, ½" high.														
134	85.50	81.5	1600	210	0.9367	0.8708	20.5	20.5	0.2040	0.4635	0.5305		0.209	79.5
135	85.30	82.7	1600	140	0.9276	0.8662	20.1	20.2	0.2348	0.4853	0.5455		0.209	80.7
136	85.30	78.0	1600	130	0.9263	0.8668	20.7	20.6	0.2385	0.4830	0.5480		0.209	79.1
137	85.30	80.8	1600	150	0.9283	0.8671	20.4	20.5	0.2322	0.4825	0.5445		0.209	80.0
Runs 145 to 155: Height overflow pipe above plate 1"; Bubble cap: 8 slots, ¼" wide, ½" high.														
145	83.50	83.0	1600	160	0.9137	0.8554	21.4	21.2	0.2805	0.5400	0.5650		0.209	91.2
146	83.60	80.0	1600	150	0.9149	0.8585	21.0	21.0	0.2772	0.5240	0.5640		0.209	86.2
147	83.70	80.0	1600	150	0.9158	0.8593	20.0	19.8	0.2765	0.5250	0.5640		0.209	86.6
148	83.70	80.0	1600	150	0.9180	0.8600	19.9	19.9	0.2690	0.5210	0.5605		0.209	86.5
149	82.20	81.0	500	150	0.9041	0.8519	19.7	19.9	0.3220	0.5655	0.5815		0.065	93.7
150	82.20	80.0	500	150	0.9007	0.8508	21.2	19.7	0.3310	0.5725	0.5850		0.065	94.8
151	81.90	77.0	200	190	0.9103	0.8591	21.2	21.2	0.2935	0.5200	0.5700		0.026	81.9
152	81.80	71.0	200	195	0.9118	0.8532	21.4	21.2	0.2875	0.5502	0.5680		0.026	93.6
153	81.80	79.0	200	190	0.9061	0.8605	20.6	21.0	0.3120	0.5135	0.5780		0.026	75.6
154	84.00	80.0	950	150	0.9236	0.8630	20.0	19.9	0.2495	0.5055	0.5525		0.124	84.5
155	83.90	80.0	950	150	0.9243	0.8600	21.4	22.2	0.2435	0.5010	0.5500		0.124	83.9

RUNS WITH ETHANOL-WATER MIXTURE, Continued

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. Corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
Runs 156 to 158: Height overflow pipe above plate 1"; Bubble cap: 32 slots, 1/16" wide, ½" high														
156	82.20	88	1600	150	0.9133	0.8535	20.2	20.2	0.2850	0.5550	0.5670		0.209	95.7
157	82.20	81.5	1600	120	0.9128	0.8538	20.4	21.0	0.2840	0.5500	0.5665		0.209	94.1
158	82.30	81.8	1600	120	0.9147	0.8541	21.2	21.2	0.2770	0.5470	0.5640		0.209	94.1
Runs 159 to 162: Height overflow pipe above plate 1"; Bubble cap: 16 slots, 1/8" wide ½" high														
159	82.90		1600	165	0.9181	0.8550	20.4	20.2	0.2675	0.5470	0.5600		0.209	95.4
160	83.10	84.0	1600	165	0.9229	0.8591	20.2	20.2	0.2501	0.5245	0.5530		0.209	90.6
161	83.10	80.0	1600	165	0.9228	0.8596	20.2	20.4	0.2515	0.5210	0.5535		0.209	89.2
162	83.10	80.0	1600	150	0.9230	0.8593	20.2	20.1	0.2510	0.5240	0.5535		0.209	90.2
Runs 163 to 166: Height overflow pipe above plate 1"; Bubble cap, 4 slots, ½" wide, ½" high														
163	84.50	79.0	1600	150	0.9335	0.8671	18.2	18.2	0.2180	0.4915	0.5380		0.209	85.4
164	84.70	79.6	1600	150	0.9328	0.8663	21.3	21.4	0.2154	0.4825	0.5365		0.209	83.2
165	84.80	80.1	1600	150	0.9345	0.8670	20.7	21.1	0.2105	0.4800	0.5395		0.209	81.9
166	85.00	83.0	1600	150	0.9353	0.8676	20.4	20.8	0.2085	0.4775	0.5330		0.209	82.9
Runs 167 to 170: Height overflow pipe above plate 1¾"; Bubble cap, 4 slots, ½" wide, ½" high														
167	81.50	76.1	1600	170	0.8995	0.8498	23.2	22.4	0.3290	0.5668	0.5840		0.209	92.8
168	81.50	77.2	1600	140	0.9010	0.8510	21.2	21.1	0.3295	0.5625	0.5840		0.209	91.6
169	81.50	77.2	1600	140	0.9033	0.8512	20.4	20.2	0.3229	0.5682	0.5820		0.209	94.6
170	81.70	80.0	1600	145	0.9050	0.8529	20.2	20.6	0.3165	0.5570	0.5795		0.209	91.5

RUNS WITH ETHANOL-WATER MIXTURE, Continued

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. Corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
Runs 171 to 180: Height overflow pipe above plate 1¾"; Bubble cap 32 slots, 1/16" wide, ½" high														
171	81.00	85.0	1600	185	0.9059	0.8489	20.2	20.7	0.3130	0.5795	0.5780		0.209	100.5
172	81.00	83.0	1600	140	0.9054	0.8479	21.0	22.6	0.3130	0.5760	0.5780		0.209	99.3
173	81.00		1600	140	0.9058	0.8467	24.0	24.0	0.3025	0.5750	0.5740		0.209	100.5
174	81.50	77.0	200	120	0.9052	0.8527	23.6	24.2	0.3060	0.5405	0.5750		0.026	87.2
175	81.90	77.0	200	130	0.9100	0.8544	23.4	23.2	0.2985	0.5360	0.5720		0.026	87.2
176	81.80	78.0	500	130	0.9024	0.8477	24.2	24.0	0.3150	0.5690	0.5790		0.065	96.2
177	82.20	78.0	500	130	0.9121	0.8520	23.2	23.0	0.2815	0.5505	0.5655		0.065	94.7
178	82.00	80.0	500	130	0.9074	0.8502	22.2	22.0	0.3015	0.5650	0.5735		0.065	96.9
179	82.20	82.0	990	120	0.9116	0.8508	25.8	22.0	0.2765	0.5620	0.5640		0.129	99.2
180	82.20	65.0	990	130	0.9146	0.8510	23.0	22.2	0.2730	0.5600	0.5620		0.129	99.2
Runs 182 to 184: Height owerflow pipe above plate 1¾"; Bubble cap 8 slots, ¼" wide, ½" high														
182	83.60	69.0	1600	135	0.9308	0.8602	21.4	21.4	0.2215	0.5135	0.5395		0.209	91.8
183	83.60	80.0	1600	135	0.9323	0.8591	22.2	21.4	0.2145	0.5190	0.5365		0.209	94.5
184	82.40	66.0	1600	185	0.9171	0.8551	21.7	21.2	0.2678	0.5420	0.5640		0.209	92.5
Runs 185 to 187: Height overflow pipe above plate 1¾"; Bubble cap 16 slots, 1/8" wide, ½" high														
185	82.50	75.8	1600	160	0.9176	0.8550	21.2	21.2	0.2671	0.5424	0.5600		0.209	93.8
186	82.50	78.8	1600	160	0.9177	0.8556	22.1	21.2	0.2647	0.5482	0.5590		0.209	96.2
187	82.50	78.2	1600	160	0.9210	0.8558	21.0	21.4	0.2560	0.5472	0.5555		0.209	97.1

RUNS WITH ETHANOL-WATER MIXTURE, Continued

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. Corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
Runs 188 to 190: Height overflow pipe above plate 7/8" Bubble Cap, 32 slots, 1/16" wide, ½" high														
188	83.00	79.0	1600	160	0.9126	0.8534	23.0	23.2	0.2800	0.5417	0.5650		0.209	91.7
189	83.00	79.8	1600	160	0.9122	0.8548	23.0	23.2	0.2813	0.5341	0.5655		0.209	89.0
190	83.00	81.5	1600	120	0.9141	0.8546	23.0	22.3	0.2746	0.5395	0.5630		0.209	91.9
Runs 191 to 194: Height overflow pipe above plate 2 5/8"; Bubble cap 8 slots, ¼" wide ½" high														
191	82.00	75.0	1600	150	0.9052	0.8484	23.2	22.7	0.3070	0.5725	0.5755		0.209	98.9
192	82.00	77.5	1600	155	0.9060	0.8503	22.1	23.0	0.3075	0.5597	0.5755		0.209	94.2
193	82.00	77.8	1600	155	0.9059	0.8495	24.2	24.0	0.3015	0.5590	0.5735		0.209	94.5
194	82.00	78.0	1600	155	0.9062	0.8494	24.3	24.6	0.3000	0.5568	0.5730		0.209	93.8
Runs 195 to 197: Height overflow pipe above plate 2 5/8"; Bubble cap 4 slots, ½" wide, ½" high														
195	82.00	78.5	1600	160	0.9074	0.8482	22.6	22.5	0.3010	0.5740	0.5735		0.209	100.1
196	81.90	76.5	1600	155	0.9068	0.8505	23.3	23.2	0.3000	0.5575	0.5730		0.209	94.2
197	81.90	78.0	1600	160	0.9077	0.8508	24.0	23.3	0.2955	0.5555	0.5710		0.209	94.3
Runs 198 to 202: Height overflow pipe above plate 2 5/8"; Bubble cap 16 slots 1/8" wide ½" high														
198			1600		0.9216	0.8580	22.0	21.2	0.2511	0.5262	0.5535		0.209	90.9
199	82.30	78.0	1600	151	0.9226	0.8567	22.2	22.7	0.2471	0.5271	0.5515		0.209	91.9
200	82.30	79.0	1600	151	0.9209	0.8521	24.4	23.9	0.2470	0.5455	0.5515		0.209	98.1
201	82.40	80.0	1600	[illegible]	0.9232	0.8547	23.0	22.6	0.2428	0.5375	0.5500		0.209	96.1

RUNS WITH ETHANOL-WATER MIXTURE, Continued

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec.Gravity of Samples t/15°C Plate	Spec.Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Ref.	Mol.Fractions Alcohol Plate Liq.	Mol.Fractions Alcohol Reflux Liq.	Mol.Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. Corr.	Superficial Vap.Vel. F.P.S.	Efficiency o/o
202	82.40	79.0	1600	160	0.9242	0.8546	23.2	23.2	0.2390	0.5355	0.5480		0.209	96.0
Runs 203 to 206: Height overflow pipe above plate 2 5/8"; Bubble cup 32 slots, 1/16" wide, ½" high														
203	83.70	79.0	1600		0.9383	0.8588	20.2	20.0	0.1985	0.5270	0.5280		0.209	99.8
204	82.10	76.0	1600	150	0.9194	0.8535	23.0	22.9	0.2559	0.5425	0.5505		0.209	97.3
205	82.10	76.0	1600	150	0.9179	0.8528	22.9	22.5	0.2617	0.5485	0.5580		0.209	96.8
206	82.10	75.7	1600	150	0.9189	0.8537	22.9	22.6	0.2580	0.5432	0.5560		0.209	95.6
Runs 207 to 210: Height overflow pipe above plate ½"; Bubble cap 4 slots ½" wide, ½" high														
207	84.8	61.0	1600	150	0.8866	0.8641	22.5	22.0	0.3844	0.4913	0.5980		0.209	50.1
208	84.9	79.0	1600	150	0.8888	0.8658	23.7	22.9	0.3704	0.4796	0.6005		0.209	47.5
209	83.0	77.0	500	150	0.8784	0.8538	23.2	23.2	0.4172	0.5394	0.6195		0.065	60.4
210			500	150	0.8786	0.8532	23.2	23.2	0.4165	0.5422	0.6190		0.065	62.0
Runs 211 to 216: Height overflow pipe above plate ½"; Bubble cap, 8 slots, ¼" wide, ¾" high allowing ¼" free space above liquid surface														
211	85.30		1600	155	0.8917	0.8651	20.2	20.3	0.3710	0.4930	0.6005		0.209	53.1
212	85.30		1600	150	0.9061	0.8660	21.6	20.9	0.3090	0.4860	0.5765		0.209	66.2
213	85.40		1600	150	0.8938	0.8664	19.8	22.0	0.3630	0.4795	0.5980		0.209	49.6
214	85.00		1600	150	0.9059	0.8713	23.4	23.8	0.3040	0.4480	0.5740		0.209	53.3
215	83.80		500	150	0.8950	0.8603	21.2	21.4	0.3500	0.5260	0.5925		0.065	72.5
216	84.30		500	150	0.8976	0.8588	22.2	22.2	0.3395	0.5175	0.5880		6.065	71.5

RUNS WITH ETHANOL-WATER MIXTURE, Continued

Run No.	Temperatures °C Plate Vapor	Temperatures °C Jacket	Heat Input Watts Still	Heat Input Watts Jacket	Spec. Gravity of Samples t/15°C Plate	Spec. Gravity of Samples t/15°C Reflux	Temp. Samples °C Plate	Temp. Samples °C Reflux	Mol. Fractions Alcohol Plate Liq.	Mol. Fractions Alcohol Reflux Liq.	Mol. Fractions Alcohol Theo. Vapor	Barometer m.m.Hg. Corr.	Superficial Vap. Vel. F.P.S.	Efficiency o/o
Runs 217 to 222: Height overflow Pipe above Plate 9/16"; No bubble cap used														
217	90.50	88.0	1600	165	0.9178	0.9126	22.2	22.4	0.2635	0.2820	0.5585		0.209	6.3
218	90.80	89.0	1600	160	0.9184	0.9134	21.2	22.2	0.2640	0.2795	0.5590		0.209	5.1
219	88.30	89.0	500	150	0.9088	0.9000	21.4	22.2	0.2985	0.3300	0.5720		0.065	11.5
220	88.50	88.0	500	145	0.9085	0.8997	22.2	22.4	0.2975	0.3310	0.5720		0.065	12.2
221	84.80	86.0	200	120	0.8970	0.8746	23.0	23.2	0.3395	0.4350	0.5885		0.026	38.3
222	84.50	80.0	200	120	0.8933	0.8710	22.7	22.4	0.3555	0.4550	0.5955		0.026	41.9
Runs 223 to 229: Height overflow pipe above Plate 1¼"; Bubble cap, 8 slots, ¼" wide, ½" high 3/16" Layer of Paraffin on Surface of Liquid														
223	85.10	80.0	420		0.9570	0.8687	20.4	21.7	0.1322	0.4695	0.5010		0.055	91.4
224	85.70	80.0	200	150	0.9620	0.8776	20.8	21.5	0.1165	0.4280	0.4850		0.026	84.5
225	86.80	86.0	205	150	0.9676	0.8842	21.3	21.2	0.0941	0.3990	0.4560		0.027	84.5
226	87.30	85.0	400	150	0.9688	0.8795	21.2	22.2	0.0909	0.4160	0.4520		0.052	90.0
227	82.90	76.0	500	140	0.9110	0.8523	22.2	22.2	0.2884	0.5527	0.5790		0.065	91.0
228	82.30	77.0	500	140	0.9028	0.8485	22.2	22.2	0.3168	0.5740	0.5875		0.065	94.5
229	80.90	80.0	200	140	0.8740	0.8378	22.4	23.2	0.4410	0.6328	0.6292		0.065	101.8

K. MISCELLANEOUS DATA FROM THE LITERATURE.

LATENT HEAT DATA, ALCOHOL AND WATER

+ °C	(a) r alc. gm. cal/ gm.	(b) M_r Alc. gm. cal/ gm. mol	r H_2O gm. cal/ gm.	M r H_2O gm. cal/ gm. mol.	$\frac{Mr\ Alc.}{Mr\ H_2O}$
78	206.9	9520	551	9946	0.959
80	206.1	9490	550	9923	.956
82	205.3	9430	550	9899	.953
84	204.5	9400	549	9881	.952
86	203.6	9360	548	9857	.950
88	202.8	9330	546	9839	.950
90	201.9	9280	545	9815	.946
92	201.0	9250	544	9791	.945
94	200.1	9200	542	9772	.941
96	199.1	9160	541	9747	.941
98	198.1	9110	540	9729	.936
100	197.1	9070	539	9704	.935

(a) From smooth curve drawn through points from literature.

(b) From Marks & Davis Steam Tables.

LATENT HEAT DATA, BENZENE AND TOLUENE

+ °C	(a) r Benz. gm. cal/ gm.	(b) r Tol. gm. cal/ gm.	Mr Benzene gm. cal/ gm. mol	Mr Toluene gm. cal/ gm. mol	$\frac{Mr_B}{Mr_T}$
80	94.2	91.9	7350	8450	0.870
82	93.9	91.6	7320	8430	.869
84	93.5	91.3	7290	8400	.868
86	93.2	90.9	7270	8360	.870
88	92.8	90.5	7240	8330	.869
90	92.5	90.2	7210	8300	.869
92	92.1	89.9	7180	8260	.869
94	91.8	89.5	7160	8230	.870
96	91.4	89.1	7130	8200	.870
98	91.1	88.8	7110	8170	.870
100	90.7	88.5	7080	8140	.871
102	90.3	88.1	7040	8100	.870
104	89.9	87.7	7010	8060	.870
106	89.5	87.3	6980	8030	.870
108	89.1	86.9	6950	7990	.871
110	88.8	86.5	6930	7960	.870

(a) Read from smooth curve drawn through points from literature.

(b) Based on 3 values around 110°C. and a value at 80° estimated using the Clapeyron equation.

LATENT HEAT DATA - (LANDOLT-BORNSTEIN 1923 EDITION)

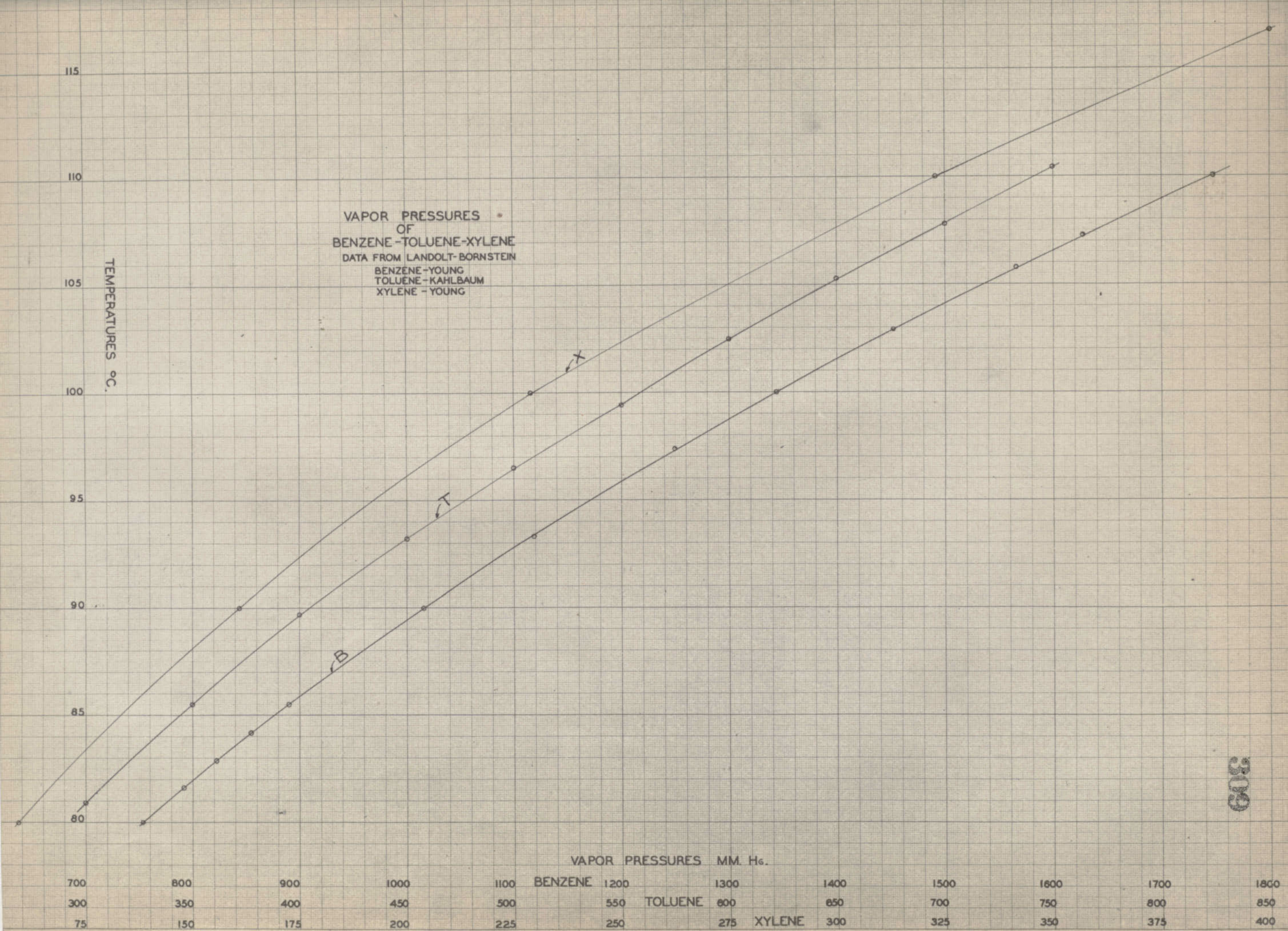
Benzol		Toluol		Alcohol		CCl_4	
+ °C	Latent Heat gm. cal/gm.	+ °C.	Latent Heat gm. cal/gm.	+ °C	Latent Heat gm. cal/gm.	+ °C	Latent Heat gm. cal/gm. mol
0	136.7	110.2	86.2	0	229	76.75	7150
0	106.1	110.8	86.8	0	220.9	80.0	7100
0	109.0	110.8	87.4	0	236.5	100	6830
19.95	103.82			0	239.1	120	6500
30.07	102.30			9.9	243.1		
40.05	100.71			20	252.0		
50.01	99.14			40	218.7		
80.20	94.37			60	213.4		
80.00	95.45			70	209.9		
80.1	92.9			77.9	202.4		
80.2	94.9			78	206.4		
80.35	93.45			78.1	254.7		
80.35	94.35			78.2	201.5		
90	93.6			78.2	216.5		
100	91.4			80.0	206.4		
				100	197.1		
				120	184.2		

VAPOR PRESSURE DATA (LANDOLT-BORNSTEIN, 1923 ED.)

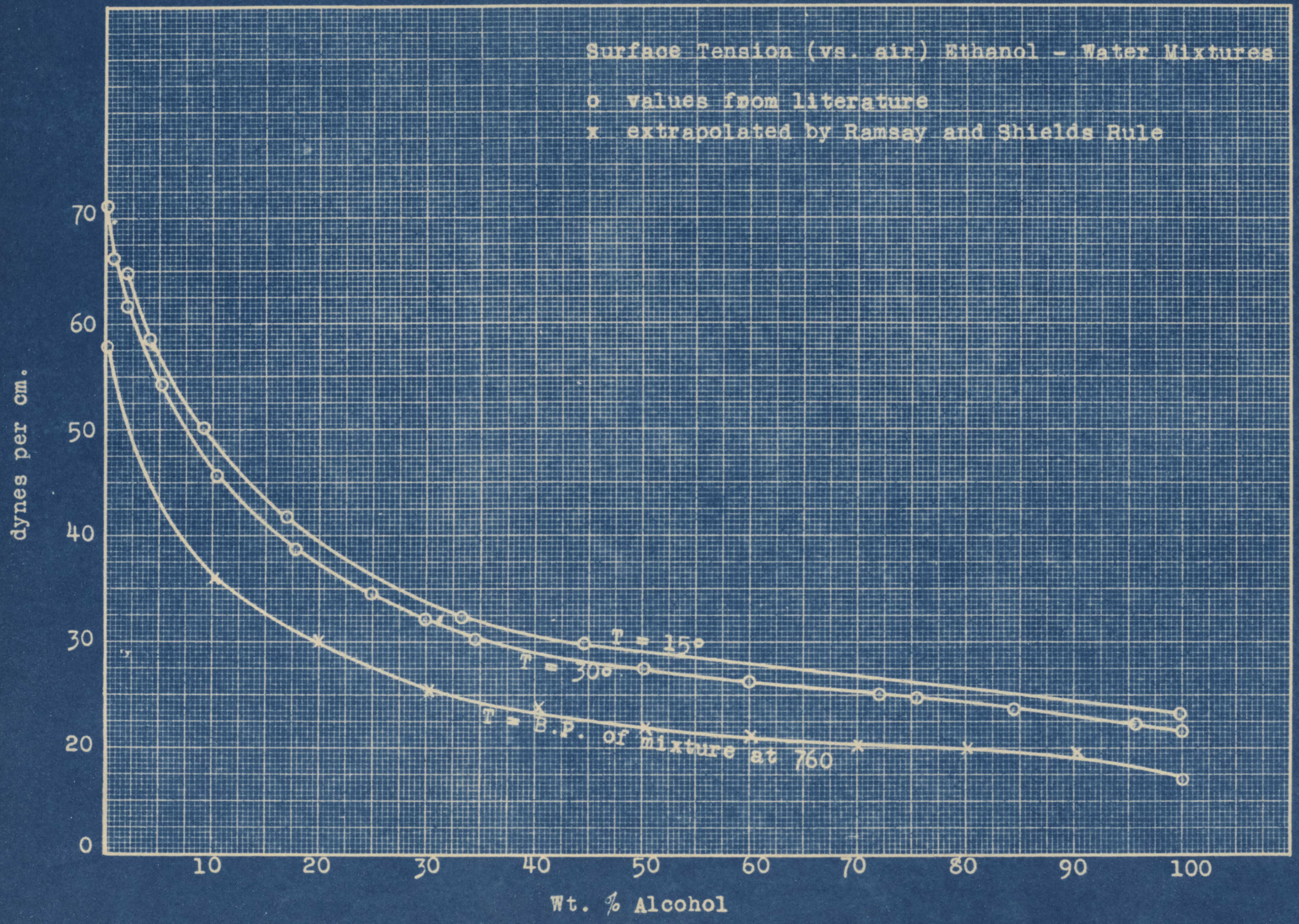
Benzol (a)		Toluol(b)		Carbon Tetrachloride	
+ °C	Vap. Press. m.m. Hg.	+ °C	Vap. Press. m.m. Hg.	+ °C	Vap. Press. M.m. Hg.
-10	14.83	28.8	35	70	617.5
0	26.54	31.6	40	80	838.8
10	45.43	34.0	45	90	1117.2
20	74.66	36.3	50	100	1462.0
30	118.24	45.2	75	110	1883.7
40	181.08	51.8	100		
50	268.97	62.0	150		
60	388.58	69.6	200		
70	547.40	75.9	250		
80	753.62	80.9	300		
90	1016.1	85.5	350		
100	1344.3	89.7	400		
110	1748.2	93.2	450		
120	2238.1	96.5	500		
130	2824.9	99.4	550		
140	3520.0	102.5	600		
150	4334.8	105.3	650		
		107.8	700		
		110.4	760		

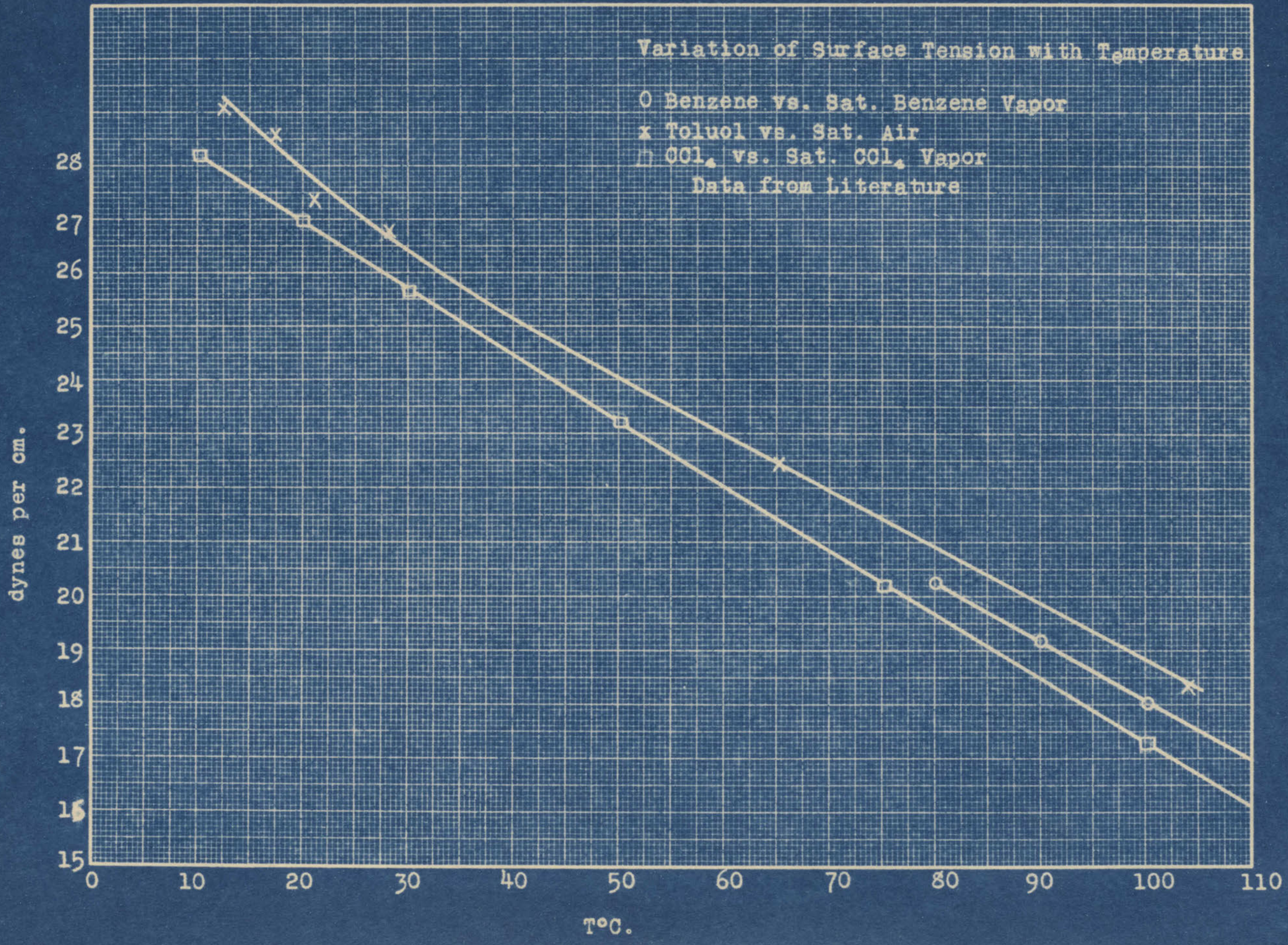
(a) Orig. Ref. Young; J.Chem.Soc. 55, 486 (1889)

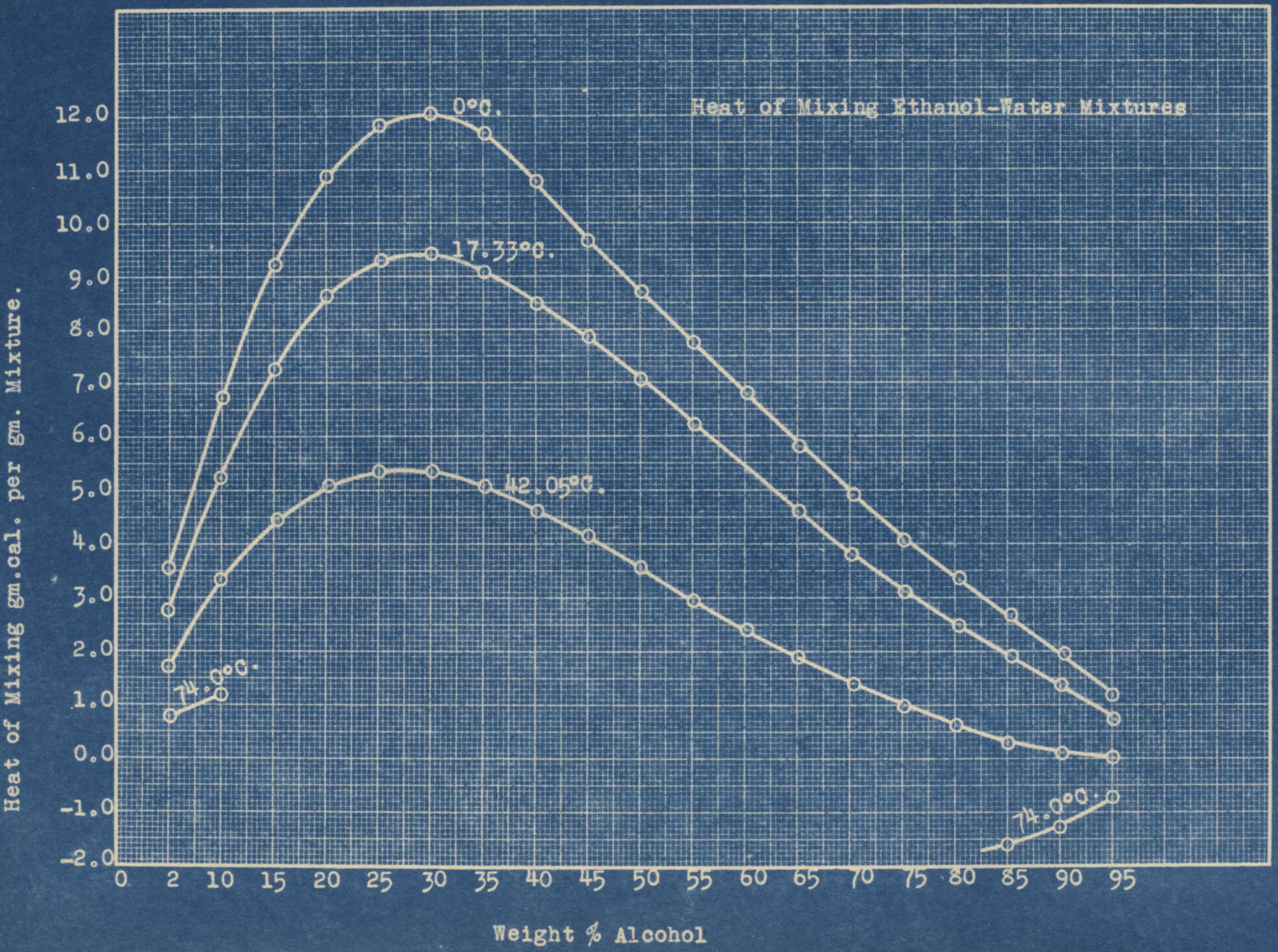
(b) " " Kablbaum, Z.S. ph. Chem. 26, 603, (1918)

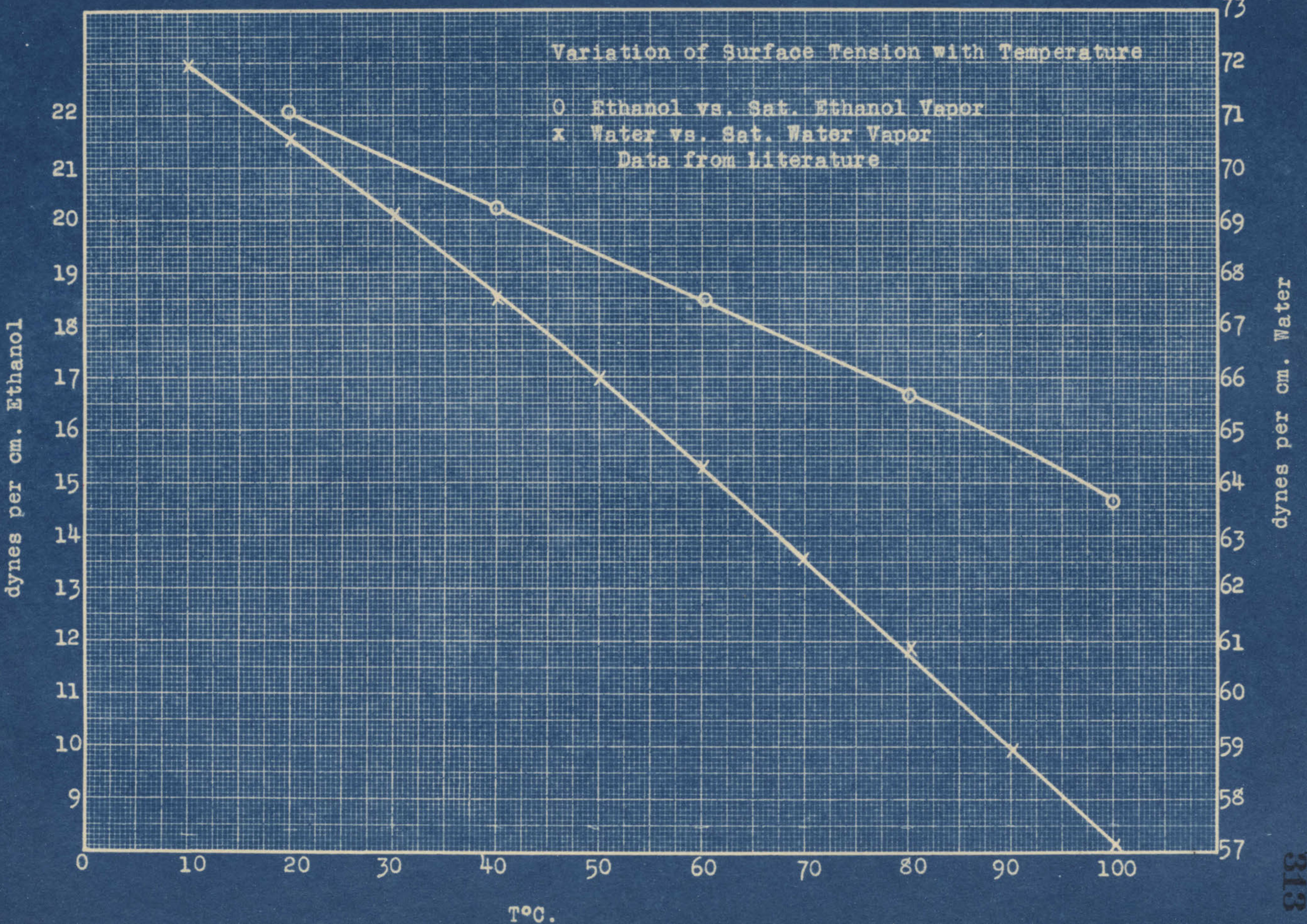


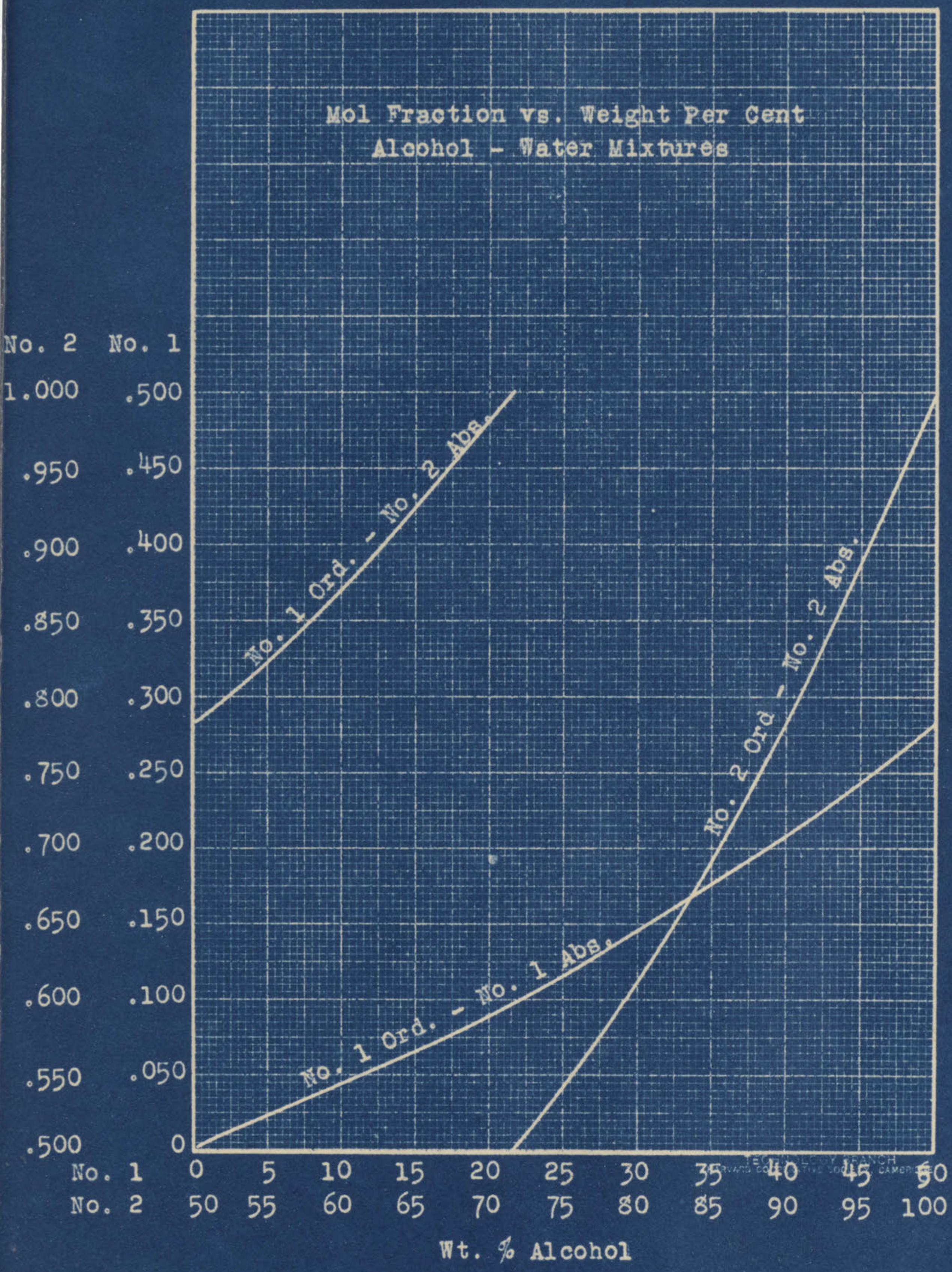
VAPOR PRESSURES
OF
BENZENE-TOLUENE-XYLENE
DATA FROM LANDOLT-BORNSTEIN
BENZENE-YOUNG
TOLUENE-KAHLBAUM
XYLENE - YOUNG


Surface Tension (vs. air) Ethanol - Water Mixtures
o values from literature
x extrapolated by Ramsay and Shields Rule
T = 15°
T = 30°
T = B.P. of mixture at 760
dynes per cm.
70
60
50
40
30
20
0
10
20
30
40
50
60
70
80
90
100
Wt. % Alcohol


Variation of Surface Tension with Temperature
O Benzene vs. Sat. Benzene Vapor
x Toluol vs. Sat. Air
□ CCl_4 vs. Sat. CCl_4 Vapor
Data from Literature
dynes per cm.
15
16
17
18
19
20
21
22
23
24
25
26
27
28
0
10
20
30
40
50
60
70
80
90
100
110
T°C.


Heat of Mixing Ethanol-Water Mixtures
0°C.
17.33°C.
42.05°C.
74.0°C.
74.0°C.
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
0
2
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Heat of Mixing gm.cal. per gm. Mixture.
Weight % Alcohol


Variation of Surface Tension with Temperature
O Ethanol vs. Sat. Ethanol Vapor
x Water vs. Sat. Water Vapor
Data from Literature
dynes per cm. Ethanol
22
21
20
19
18
17
16
15
14
13
12
11
10
9
dynes per cm. Water
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
58
57
0
10
20
30
40
50
60
70
80
90
100
T°C.


Mol Fraction vs. Weight Per Cent
Alcohol - Water Mixtures
No. 2
No. 1
1.000
.500
.950
.450
.900
.400
.850
.350
.800
.300
.750
.250
.700
.200
.650
.150
.600
.100
.550
.050
.500
0
No. 1 Ord. - No. 2 Abs.
No. 2 Ord - No. 2 Abs.
No. 1 Ord. - No. 1 Abs.
No. 1
0
5
10
15
20
25
30
35
40
45
50
No. 2
50
55
60
65
70
75
80
85
90
95
100
Wt. % Alcohol

L - CALCULATION OF REFLUX RATIO IN THE RECTIFICATION OF HYDROCARBONS

It is often desired to calculate the reflux ratio at the top of a plate column handling a complex mixture of hydrocarbons. In general, operating data include temperature and pressure at the top of the column, and the temperature of the reflux liquid returning to the top of the column. The purpose of the following discussion is to show how this information can be used to compute the reflux ratio at the top of the column, providing one will determine the analysis of the overhead product.

For illustration consider the following data applying to a continuous rectifying column used for the stabilization of a casing-head gasoline. The vapors from the top plate, at a temperature of 100°F. and an absolute pressure of 220 lbs. per square inch (15 atmospheres), flow to the top of a condenser coil, and the reflux condensate and residue gas from the bottom of the condenser pass to a trap. The reflux liquid flows by gravity to the top plate while the residue gas is withdrawn through a valve. Analysis of the residue gas by volume: 11.6% air, 23.1% CH_4, 17.0% C_2H_6, 43.9% C_3H_8, 4.3% C_4H_{10} and 0.1% C_5H_{12}.

NOMENCLATURE

π = total pressure, atmospheres absolute.

P = vapor pressure, atmospheres.

p = partial pressure, atmospheres.

y = mol fraction of a component in vapor.

y* = mol fraction of a component in vapor in equilibrium with a given liquid.

x = mol fraction of a component in liquid.

f = correction factor in Raoult's law,

$$f = \frac{\pi y}{P x}$$

V = mols vapor per mol of overhead product.

O = mols liquid overflow per mol of overhead product.

D = mols overhead product (The basis of the following calculations is D = 1).

Subscripts 1 and T refer to the top plate and trap conditions respectively.

E = Efficiency factor in Murphree equation.

In making the calculation the following assumptions are made:

1. The correction factor, f, in Raoult's law is the same for all components, i.e.,

   $f_a = p_a/P_a\ x_a = f_b = p_b/P_b\ x\ b$, etc.

2. No appreciable error is involved in applying Dalton's Law, i.e., the total pressure equals the sum of the partial pressures. = .

   It will be recalled that the Murphree equation gives the quantitative relationship between the actual composition of the vapor entering any plate and that leaving it, y_{n-1} and y_n, in terms of the composition, y_n^* of the vapor which would be in equilibrium with the liquid actually on a given plate, i.e.,

   $y_n = Ey_n^* + (1-E)\ y_{n-1}$ . . . . (1)

3. In applying this equation the plate efficiency, E, is taken as 0.6, a value which is reasonable for plant columns handling the mixture involved.

Since the reflux liquid and residual vapor, or overhead product, have been in intimate contact in the condenser coil, it is allowable to assume equilibrium between reflux liquid and overhead vapor.

Due to small friction drop through the condenser, the absolute pressure in the reflux trap may be taken as that at the top of the column. From an analysis of the vapors leaving the trap, the partial pressure of each of these components (Item 2, Table I) is obtained by multiplying the known vapor composition (Item I, Table I) by the absolute pressure. = 15 atmospheres. Since the trap temperature is known, the vapor pressure of each of the individual components is read from the Cox vapor-pressure chart[1] and tabulated as Item 3, Table 1. According to Raoult's Law, the term fx is equal to the partial pressure of any component divided by the vapor pressure of that component, giving Item 4, Table I. The sum of the values tabulated as Item 4 equals f (Σ x). Since x must equal unity, the values of f is thus determined. For the data given, f equals 1.00, i.e., these data check Raoult's Law.[2] The values of x are then tabulated as Item 5.

---

1. E.R. Cox, Ind. Eng. Chem., 15 (June,1923),592; Calingaert and Davis, Ibid., 17 (Dec. 1925),1287.

2. If the temperature of the trap had not been known it would have been necessary to assume a value of f and, by trial and error, to find the temperature required to make the calculated value of x equal unity. However, by measuring the temperature of the trap, one can determine the value of f for use in subsequent calculations, as done above.

The reflux ratio is defined as the mols of reflux liquid returned to the column from the trap per mol of overhead product. One then assumes a numerical value for this ratio and by material balances around the partial condenser, employing Items 6 and 7, Table II, calculates the composition of vapors leaving the top plate, Item 8. These values are then substituted in the Murphree equation using the following form:

$$y_n = \left(\frac{f\ P_1 x_1}{\pi}\right)E + (1-E)\left(\frac{O_1\ x_1}{V_2} + \frac{D\ x_1}{V_2}\right)$$

which equation is obtained by combining Equation 1 with Raoult's Law and a material balance. The sum of the values of the mol fractions of the components in the liquid on the top plate must equal unity, and if one has assumed the proper value of O/D the value of x will equal 1. The values tabulated as Item 10 show the results of the calculation based on O/D equal to 0.40 mols of the reflux liquid per mol of product, since this value was the proper one to satisfy the stipulated conditions. Obviously, the reflux ratio obtained in such a calculation will depend upon the assumed value of the efficiency term of the Murphree equation, the numerical value of the correction factor in Raoult's Law and any deviations from Dalton's Law which may develop. Now that reflux ratio is known at the top of the column, if the temperatures of the various plates are measured, one can compute the reflux ratio, and liquor and gas compositions for lower plates. If reflux ratios and plate temperatures are available, Lewis and Wilde(14a) show how these data may be used to determine the plate efficiency.

(14a) Lewis and Wilde, Trans. Amer. Inst. Chem. Engr., 21, (1928), 99

TABLE I

Calculation of Reflux Liquid Composition (Basis: 1 mol of Residue Gas = D)

Item	(1)	(2)	(3)	(4)	(5)
Component	Mol Fraction in overhead y_T	Partial Pressure $p_T=15.0\ y_T$ (Atm.)	Vapor Press (atm.) at temp. of trap $P_{75\,°F}$.	$f_{xT} = p_T/P_T$	x_T = Item (4)/f
Methane + air	.347	5.20	----	----	----
Ethane	.170	2.55	40.8	0.063	.063
Propane	.439	6.59	10.27	.641	.641
Butane	.043	.645	2.37	.272	.272
Pentane	.001	.015	.62	.024	.024
	1.000	15.000	$\sum f x_T$=	1.000	$\sum x$=1.000

TABLE II

Calculation of 0/D using the Murphree equation; 0/D assumed to be 0.37 (trial and error)

Item	(6)	(7)	(8)	(9)	(10)
Component	Mols component in reflux $(0/D)x_T$	Mols component in vapor (1)+(6)	Vapor component above top plate, y_1	Vapor press. (atm.) at temp. at top plate $P_{100°F}$	Liquid Comp. on Top Plate, x_1
Methane+Air	----	.347	.248	----	----
Ethane	.025	.195	.139	55.2	.039
Propane	.257	.695	.497	14.5	.537
Butane	.109	.152	.108	3.69	.368
Pentane	.009	.010	.008	1.05	.053
	0.400	1.400	1.000		Σx_1 = .997

It is sometimes assumed that the vapor leaving the top plate is in equilibrium with the liquid on the top plate, i.e., $y_1 = y_1$*, which demands a plate efficiency of 100%.

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*The small solubility of both air and methane in the reflux are neglected.

Table 3 shows the results of making such assumption, and on this basis the calculated value of the reflux ratio is found to be .27, a discrepancy of 32%.

TABLE III

Reflux Ratio, O/D, Obtained by Assuming Equilibrium on Top Plate; O/D assumed to be 0.27 (trial and error).

Item

Component	Mols component in reflux $(O/D)x_T$	Mols component in vapor (1)+(11)	Vapor composition above plate y_1	Liquid composition on top plate $x_1 = \frac{y_1}{f\,P_1}$
Methane+Air	----	.347	.273	.040
Ethane	.017	.187	.147	.494
Propane	.173	.612	.482	.374
Butane	.074	.117	.092	.086
Pentane	.006	.607	.006	
	0.270	1.270	1.000	.999

M. INTEGRATION OF HANK'S RIGOROUS GAS FILM EQUATION FOR DEHUMIDIFICATION IN WETTED WALL TOWER.

For point conditions the general film diffusion equation when one component is stationary may be written as:

$$W_A = \frac{k\ w}{x} \ln \frac{p_{Bi}}{p_{Bg}} = f\ g' \ln \frac{p_{Bi}}{p_{Bg}} \quad - - - (A)$$

This applies at any section of a tower of differential length. When applied to the tower as a whole the usual practice has been to employ average (arithmetic or log mean, preferably the latter) values of the partial pressure, based on entering and exit conditions. It is the present purpose to show that the rigorous equation may be integrated over the tower, the integral being evaluated by use of the "Ei" function of Jahnke and Emde.(23)

Let m_A = total grams of water condensed in time θ_c, θ_c being the time of contact of any given portion of mixture in the tower.

$$\frac{dm_A}{d\theta_c} = f'g\ A' \ln \frac{p_{Bi}}{p_{Bg}} \quad - - - - - - (B)$$

Let G' = grams of bone dry air passing through tower in time θ_c

Then $m_A = G'\ (H_1' - H_2')$

Or in differential form:

$$dm_A = G' \, d \, H' \qquad - - - (C)$$

$$H' = \frac{18 \, p_{Ag}}{(\pi - p_{Ag})29} \qquad - - - (D)$$

To get in terms of p_B, by Dalton's law $p_{Ag} = - p_{Bg}$

Therefore $H' = \frac{18(\pi - p_{Bg})}{29 \, p_{Bg}}$ - - - (E)

Differentiating:

$$dH' = \frac{18}{29} \left[\frac{- p_{Bg} \, dp_{Bg} - (\pi - p_{Bg}) \, dp_{Bg}}{p_{Bg}^2} \right] \quad -- (F)$$

$$dH' = \frac{18}{29} \left[\frac{- p_{Bg} - (\pi - p_{Bg})}{p_{Bg}^2} \right] dp_{Bg} \quad -- (G)$$

$$dH' = - \frac{18}{29} (\pi) \frac{dp_{Bg}}{p_{Bg}^2} \quad - - - - - - - - (H)$$

From B and C

$$G' dH' = f' g A' \ln \ln \frac{p_{Bi}}{p_{Bg}} \, d\theta_c \quad - - - - - - - - (I)$$

From H and I

$$G' \left(\frac{-18 \pi}{29} \right) \frac{dp_{Bg}}{p_{Bg}^2 \ln \frac{p_{Bi}}{p_{Bg}}} = f' g \, A \, d \, \theta_c \quad - - - - (J)$$

Integrating over tower:

$$\int_{p_{Bg_1}}^{p_{Bg_2}} \frac{d \, p_{Bg}}{p_{Bg}^2 \ln \frac{p_{Bi}}{p_{Bg}}} = \frac{f' g \, A'}{G' \left(\frac{-18\pi}{29} \right)} \int_0^{\theta_c} d\theta_c \quad - -(K)$$

The left hand side of K may be evaluated as follows:

Let $\ln \frac{p_{Bi}}{p_{Bg}} = -Z$

Then $dZ = \frac{1}{\frac{p_{Bi}}{p_{Bg}}} \frac{p_{Bi}\, dp_{Bg}}{p_{Bg_2}} = \frac{dp_{Bg}}{p_{Bg}}$

$$\frac{p_{Bi}}{p_{Bg}} = e^{-Z}$$

$$p_{Bg} = \frac{p_{Bi}}{e^{-Z}}$$

$$dp_{Bg} = \frac{p_{Bi}}{e-Z}\, d\,Z$$

Therefore $\frac{dp_{Bg}}{p_{Bg}^{2} \ln \frac{p_{Bi}}{p_{Bg}}} = \frac{1}{p_{Bi}} \quad \frac{e^{-Z} dZ}{Z}$

Limits of p_{Bg} = (limits Z)

The new limits are

$$Z_1 = -\ln \frac{p_{Bi}}{p_{Bg_1}}$$

$$Z_2 = -\ln \frac{p_{Bi}}{p_{Bg_2}}$$

Therefore the left-hand side of Equation K may be evaluated as:

$$\int_{p_{Bg_1}}^{p_{Bg_2}} \frac{dp_{Bg}}{p_{Bg_2} \ln \frac{p_{Bi}}{p_{Bg}}} = \frac{1}{p_{Bi}} \left[Ei\left(-\ln \frac{p_{Bi}}{p_{Bg_1}}\right) - Ei\left(-\ln \frac{p_{Bi}}{p_{Bg_2}}\right) \right]$$

Or

$$\frac{A'f'g\theta_c}{G'\frac{(18)}{(29)}} = \frac{1}{p_{Bi}} \quad Ei\left(-\ln\frac{p_{Bi}}{p_{Bg_1}}\right) - Ei\left(-\ln\frac{p_{Bi}}{p_{Bg_2}}\right) \quad - - - - (L)$$

The values of the Ei terms may be looked up in Jahnke and Emde (23) for the corresponding values of the terms $-\ln\frac{p_{Bi}}{p_{Bg}}$ and $-\ln \frac{p_{Bi}}{p_{Bg}}$.

Nomenclature:

W_A = $\frac{\text{gms. } H_2O}{\text{hr.- cm.}^2}$

k_w = diffusion coefficient as

$\frac{(gm)\ (cm)}{(hr)\ (cm)^2}$ and = $\frac{M_A\ 3600\ (k_{vo})}{22400}\frac{T}{T_o}$

k_{vo} = Specific diffusion coefficient at 0°C and 1 atm.
π = Total pressure, m.m. Hg.
p_A = Partial pressure of water vapor, m.m. Hg.

p_B = partial pressure of air, m.m. Hg. Subscripts i and g represent interfacial and main body conditions respectively.

A' = area of tower, sq. cm.

x = gas film thickness, cm.

$f'g = \frac{k_w}{x} = \frac{gms}{(hr)(cm)^2}$

m_A = gms. H_2O condensed in time θ_c.

θ_c = time of contact of air-water vapor mixture in tower, hours.

G' = grams b.d. air passing through tower in time θ_c

H' = Grosvenor humidity, gms. of water per gram cf. bone dry air.

Subscripts 1 and 2 refer to entrance and exit conditions respectively.

N. NOMENCLATURE

V = Mols of vapor passing through a column per unit time.

O = Mols of liquid overflow per unit time.

P = Mols of distillate withdrawn as product per unit time.

W = Mols residue from still per unit time

x = Mol fraction of more volatile component in liquid

y = Mol fraction of more volatile component in vapor.

y^*= Mol fraction of more volatile component in vapor which would represent equilibrium with a liquid in which the mol fraction of this same component is x.

n, $n-1$ = The numbers of the plates under consideration counting from feed plate up.

m, $m-1$ = The numbers of the plates under consideration, below the feed plate, counting up from the still.

c As subscript refers to condensate stream.

w As subscript refers to waste stream.

Y = Total mols of a given component in the vapor passing through a column per unit time.

Π = Total pressure on a system. (Atmospheres or millimeters of Mercury, depending upon context).

Πo= Standard barometric pressure, 1 atmosphere or 760 millimeters.

p = Partial pressure of a given component in a vapor mixture.

A, As subscript denotes the more volatile constituents of a binary mixture of A and B.

B, As subscript denotes the less volatile constituent of a binary mixture of A and B.

g, As subscript refers to conditions in the main body of the vapor in a system containing both a liquid and a vapor phase.

i, As subscript refers to conditions at a liquid-vapor interface.

α = Specific resistance coefficient in Lewis-Chang equation: $\alpha = \frac{R\ T}{k_m\ M_A M_B}$

ρ = Partial density of a component under its own partial pressure in a vapor mixture, grams per c.c.

u = Linear velocity of gaseous diffusion, cm. per sec.

N = Molal rate of diffusion, gram - mols per hour per sq. cm.

M = Molecular weight in vapor phase, when accompanied by subscripts A or B.

T = Absolute temperature,

T_o = Standard absolute temperature, 273°K.

k_m = Specific diffusion coefficient,

$$\frac{(\text{gram mols})(\text{cm.film thickness})}{(\text{second})(\text{s}\underset{q}{\text{t}}\text{.cm. of interface})}$$

k_v = Specific diffusion coefficient,

$$\frac{(\text{c.c.})(\text{cm.film thickness})}{(\text{second})(\text{sq.cm.interface})}$$

k_{vo}= Value of k_v at standard conditions, $T = T_o$, $\pi = \pi_o$ (N.B. k_v and k_{vo} are the values of specific diffusion (coefficients reported in the literature).

R = Gas constant in Lewis-Chang equation, c.c.-atmospheres per degree C.

δ = Partial density of a vapor component under standard conditions, grams per c.c.

D = Linear dimension of apparatus in gas film thickness relation.

Z = Gas viscosity, 10^{-7} poises.

d = Partial density of a component in a liquid mixture, grams per c.c.

v = Volume fraction of a component in a liquid mixture.

X = Gas film thickness, cm.

X' = Liquid film thickness, cm.

m = Molecular weight in liquid phase.

V' = Gram mols of vapor containedin a bubble.

θ = Time of contact, seconds.

S = Interfacial area of a bubble, sq. cm.

M_r = Molal latent heat of vaporization, gram cal. per gram mol or B.t.u. per lb. mol depending upon context.

M_c = Molal heat capacity of liquid, cal. per gram mol per degree C, or B.t.u. per lb. mol per degree F.

H = Overall coefficient of heat transfer.

t_1 = Temperature of vapor entering a plate section, °C.

t_2 = Temperature of vapor leaving a plate section, °C.

t_L = Temperature of liquid on a plate of a column.

E_s = Plate efficiency defined as the ratio ,

$$\frac{\text{actual No. Plates}}{\text{No. of Theo. Plates}}$$

E_L = Plate efficiency used in Lewis differential enrichment equation.

E_M = Murphree plate efficiency,

$$E_M = \frac{y_n - y_{n-1}}{y_n{*} - y_{n-1}}$$

E_{L-W} = Lewis-Wilde plate efficiency,

$$E_{L-W} = \frac{Y_n - Y_{n-1}}{Y_n{*} - Y_{n-1}}$$

E_v = Vaporization efficiency in steam distillation,

$$E_v = \frac{p}{p{*}}$$

M = Efficiency factor used by Murphree,

$$M = 1 - E_M$$

E_T = Temperature efficiency,

$$E_T = \frac{t_1 - t_2}{t_1 - t_L}$$

O. BIBLIOGRAPHY

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