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UNIVERSITY OF LOUISVILLE

A GRAPHICAL SOLUTION FOR BATCH STEAM
DISTILLATION OF A BINARY MIXTURE

A Thesis

Submitted to the Faculty

Of the Graduate School of the University of Louisville

In Partial Fulfillment of the

Requirements for the Degree

OF MASTER OF CHEMICAL ENGINEERING

Department of Chemical Engineering

By

Howard D. Carlson

Year

1946

A GRAPHICAL SOLUTION FOR BATCH STEAM
DISTILLATION OF A BINARY MIXTURE

Howard D. Carlson

Approved by the Examining Committee

Chairman Gordon C. Williams

Date June 22, 1946

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LIST OF SYMBOLS

L_1	=	Mols of original charge
L_2	=	Mols of residual charge
p	=	Partial vapor pressure mm. Hg.
P_0	=	Vapor pressure mm. Hg.
T	=	Temperature °C
x	=	Mol fraction of C_6H_6 in liquid
x_1	=	Mol fraction of C_6H_6 in original charge
x_2	=	Mol fraction of C_6H_6 in residual charge
y	=	Mol fraction of C_6H_6 in vapor

A C K N O W L E D G M E N T

The author wishes to acknowledge the kind assistance and helpful guidance of Dr. G. C. Williams, who directed this research.

ABSTRACT

The theory for the graphical solution of batch steam distillation of a binary mixture is presented and illustrated. The results obtained from this graphical procedure are compared with actual experimental results. The comparison showed very close agreement between the graphical results and the experimental results.

Three sets of experimental data are shown for benzene-bromobenzene mixtures and one complete set for benzene-toluene mixtures.

INTRODUCTION

The trend in industry during the past few years has been to replace batch steam distillation equipment with continuous fractionating stills. However, there are many industrial applications which cannot be replaced by continuous fractionating installations. The purification of glycerine and fatty acids are examples of large scale operations of this latter class.

If a mixture of two liquids, each miscible with the other but both immiscible with water, is steam distilled, the composition of the distillate has not been determinable by direct calculations. Such problems in the past have only been solved by actually performing a steam distillation experiment on the specific liquids involved. A graphical method has been suggested which might solve this problem for liquid mixtures which obey Raoult's Law. This graphical procedure would enable one to calculate the composition of the distillate at any given time during a batch steam distillation without actually resorting to experimental procedures. Hence, the purpose of this work was to determine the accuracy of this graphical procedure by comparing calculated results with actual experimental data which was taken under controlled conditions.

HISTORICAL

Batch steam distillation is a very old process which has been developed over a long period of time. In 1904 Rayleigh (1) made a mathematical analysis of simple batch steam distillation and derived the equation which is now known as the Rayleigh Equation. In 1922 E. E. Kohman (2) developed an apparatus for batch steam distillation which was used to determine the amount of hydrogen sulfide evolved by foods when cooked at various temperatures. At about the same time W. K. Lewis and C. S. Robinson (3) integrated the Rayleigh Equation for two liquids which have boiling points very close together. They derived an equation based on the assumption that the ratio of the vapor pressures at one boiling temperature does not differ greatly from that at another boiling temperature. A few years later in 1929 E. M. Baker and E. E. Pettibone (4) developed a graphical method of determining the temperature of a steam distillation at various pressures using saturated steam. A partial pressure chart for steam distillation was developed by C. A. Lee (5) in 1936 assuming that the temperature of the steam was high enough so that no steam condensed in the still pot. Badger and McCabe (6) in 1936 and Walker, Lewis, McAdams and Gilliland (7) in 1937 presented the theory

of batch steam distillation based on the Rayleigh Equation. In 1941 J. H. Perry (8) published the "Chemical Engineers Handbook" which included some unpublished notes of McAdams who derived some equations for steam consumption in batch steam distillations. Up to the present time no attempt has been made to determine the composition of the distillate from the steam distillation of a binary solution when only the original conditions of the mixture and the desired amount of distillate has been fixed.

THEORETICAL

The graphical method presented here was developed by G. C. Williams (9) on the assumption that mixtures of the two liquids may follow Raoult's Law. This Law states that the partial vapor pressure of the solvent in equilibrium with a solution is directly proportional to its mol fraction x , or

$$p = x P_0 \quad (1)$$

where p is the partial vapor pressure of the solvent and P_0 is the vapor pressure of the pure solvent at the same temperature.

Data for the vapor pressure, specific gravity, and index of refraction of benzene-bromobenzene can be found in Tables I, III and V. Conversion of weight percent to mol percent along with the density of benzene-toluene mixtures can be found in Table II. The vapor pressures are used to plot a partial pressure composition diagram shown in Fig. 1. At 100 Mol percent benzene the vapor pressure of pure benzene is plotted along the vertical axis. At 0 Mol percent benzene or 100 Mol percent bromobenzene the vapor pressure of pure bromobenzene is plotted along the vertical axis. A straight line is drawn between the vapor pressure of pure benzene and the vapor pressure of pure bromobenzene each at the same temperature. This line represents the total pressure of benzene and

bromobenzene mixtures at that temperature. Then a straight line is drawn from the vapor pressure of bromobenzene to the origin at 100 Mol percent benzene. This line represents the partial vapor pressure of bromobenzene at that temperature. From this partial pressure composition diagram another partial pressure diagram is plotted as shown in Fig. 3. In this diagram the temperature is plotted along the horizontal axis and the pressure along the vertical axis. From Fig. 1 at a given composition all the pressures at each constant temperature line are recorded. All of these points are plotted on the new pressure temperature diagram and a curve drawn through them. This line represents the constant composition line in the new diagram. This procedure is repeated for various compositions. Besides this original information, the total pressure minus the vapor pressure of water is plotted on the same diagram. By doing this it is possible to find the total partial pressure of the two liquids being steam distilled. Thus at a given temperature the intersection of the total pressure minus the vapor pressure of water line with the temperature will locate the composition and the total pressure of the liquid mixture being distilled. By using the same temperature and composition it is

possible to find the partial pressure of each component of the liquid mixture by using the partial pressure composition diagram with constant temperature lines as shown in Fig. 1. This procedure is repeated for various temperatures as shown in Table IV.

In Table IV the composition of the vapor is calculated by dividing the partial vapor pressure by the total pressure minus the pressure of the water.

Then a plot of Y (composition of the water free vapor) vs. X (composition of the water immiscible liquid) is made as shown in Fig. 5.

The Rayleigh Equation for batch steam distillation is as follows:

$$\ln \frac{L_1}{L_2} = \int_{x_2}^{x_1} \frac{dx}{y-x} \quad (2)$$

where L_1 = mols of original charge

L_2 = mols of residual liquor

x_1 = mol fraction of the more volatile component
in the original charge

x_2 = mol fraction of the more volatile component
in the residual liquor

This same equation may be used with the developed Y vs. X curve in the same manner as for any batch distillation procedure. The value of the integral may be

found by plotting $\frac{1}{y-x}$ vs. X as shown in Fig. 7. The area under this curve represents the value of the integral in the Rayleigh Equation. With this curve it will be possible to solve the Rayleigh Equation for any given set of conditions.

By assuming a given starting composition and the final composition of the distillate, one can calculate the total volume of the distillate. Then keeping the same starting composition and assuming different final compositions, one can calculate the total volume of the distillate at each assumed final composition.

With this information it will be possible to plot a curve of composition of distillate vs. percent volume distilled over as shown in Fig 9. Similar curves can be made by assuming different starting compositions. Thus it would be possible to find any of the usual unknown quantities for a distillation of this type with ease.

TABLE I
VAPOR PRESSURE OF BENZENE, BROMOBENZENE, TOLUENE
AND WATER AT VARIOUS TEMPERATURES (10)

Benzene		Bromobenzene		Toluene		Water		
°C	$P_{C_6H_6}$	°C	$P_{C_6H_5Br}$	°C	$P_{C_7H_8}$	°C	P_{H_2O}	760- P_{H_2O}
20	74.66	60	27.61	15.0	16.77	50	92.51	667.49
30	118.24	70	43.55	25.8	28.75	55	118.04	641.96
40	181.08	80	66.22	30.0	36.70	60	149.38	610.62
50	268.97	90	97.72	40.0	59.10	65	187.54	572.46
60	388.58	100	141.10	50.0	92.60	70	233.70	526.30
70	547.40	110	198.70	60.0	139.50	75	289.10	470.90
80	753.62	120	274.90	70.0	202.40	80	355.10	404.90
90	1016.10	130	372.65	80.0	289.70	85	433.60	326.40
100	1344.30	140	495.80	90.0	404.60	90	525.76	234.24
110	1748.20	150	649.05	100.0	557.20	95	633.90	126.10
120	2238.10	160	846.00	110.7	760.00	100	760.00	0.00

TABLE II
DENSITY OF BENZENE-TOLUENE MIXTURES (II) AND
CALCULATED WEIGHT vs. MOL PERCENT

Benzene-Toluene		Benzene-Bromobenzene		Benzene-Toluene	
Wt. % C_6H_6	$d_4^{25^\circ C}$	Wt. % C_6H_5Br	Mol % C_6H_5Br	Wt. % C_7H_8	Mol % C_7H_8
0.000	0.86054	0.0	0.0	0.0	0.0
10.990	0.86198	10.0	5.2	10.0	8.6
20.200	0.86295	20.0	11.0	20.0	17.5
30.588	0.86400	30.0	17.5	30.0	26.6
40.876	0.86537	40.0	24.8	40.0	36.6
51.920	0.86682	50.0	33.1	50.0	45.9
66.576	0.86906	60.0	42.6	60.0	56.0
72.560	0.86985	70.0	53.5	70.0	66.4
83.250	0.87163	80.0	66.4	80.0	77.2
91.556	0.87288	90.0	81.6	90.0	88.5
100.000	0.87420	100.0	100.0	100.0	100.0

TABLE III
EXPERIMENTAL DATA FOR THE INDEX OF REFRACTION AND
SPECIFIC GRAVITY OF BENZENE-BROMOBENZENE MIXTURES

Wt. of C_6H_6	Wt. of C_6H_5Br	Wt. % C_6H_5Br	Mol % C_6H_5Br	Sp. Gr.	Index of Ref.
43.3948	0.0000	0.00	0.0	0.8746	1.4977
40.6695	4.6748	10.30	5.3	0.9139	1.5017
37.9287	9.3762	19.82	10.9	0.9534	1.5055
34.8438	14.7243	29.71	17.3	0.9990	1.5098
31.4091	20.5845	39.59	24.5	1.0479	1.5143
27.6732	26.9830	49.37	32.6	1.1016	1.5194
23.4584	34.1310	59.27	42.0	1.1607	1.5252
18.1865	43.1663	70.36	54.2	1.2366	1.5326
12.7100	52.5538	80.70	67.7	1.3120	1.5400
6.9367	62.4179	90.00	81.5	1.3950	1.5480
0.0000	74.3213	100.00	100.0	1.4950	1.5573

TABLE IV
DERIVED DATA FROM CONSTRUCTED TEMPERATURE PRESSURE
CURVE FOR BENZENE, BROMOBENZENE AND WATER

X	°C	$P_{C_6H_6}$ & $P_{C_6H_5Br}$	P_o of C_6H_5Br
100.0	69.0	535.0	0.0
90.0	71.0	516.0	5.0
80.0	73.0	495.0	8.0
70.0	75.0	496.0	16.0
60.0	77.5	441.0	25.0
50.0	80.0	406.0	34.0
40.0	82.5	369.0	44.0
30.0	85.0	322.0	55.0
25.0	87.0	295.0	65.0
20.0	88.0	267.0	73.0
15.0	90.0	235.0	84.0
10.0	92.0	200.0	95.1
5.0	93.5	160.0	105.0
2.0	94.5	140.0	110.0
0.0	95.0	120.0	120.0

TABLE IV (CONTINUED)

DERIVED DATA FROM CONSTRUCTED TEMPERATURE PRESSURE
CURVE FOR BENZENE, BROMOBENZENE AND WATER

P_o of C_6H_6	Y	Y-X	$\frac{1}{Y-X}$
535.0	100.0	0.000	∞
511.0	90.0	0.090	11.10
487.0	98.5	0.185	5.55
453.0	96.5	0.265	3.77
416.0	94.5	0.345	2.90
374.0	91.7	0.417	2.39
325.0	88.1	0.481	2.08
267.0	83.0	0.530	1.89
230.0	78.0	0.530	1.89
194.0	73.0	0.530	1.89
151.0	64.5	0.495	2.02
105.0	52.5	0.425	2.35
55.0	35.0	0.300	3.33
30.0	21.0	0.190	5.26
0.0	0.0	0.000	∞

TABLE V
EXPERIMENTAL DATA FOR INDEX OF REFRACTION vs.
COMPOSITION OF BENZENE-TOLUENE MIXTURES

Wt. C_6H_6	Wt. C_7H_8	Mols C_6H_6	Mols C_7H_8	Mols Total	Mol % C_6H_6	Index Ref.
----	----	-----	-----	-----	0.0	1.4935
1.3850	7.1199	0.017720	0.07720	0.09492	18.7	1.4938
3.0498	5.4715	0.039000	0.05946	0.09846	39.8	1.4942
4.7469	3.8077	0.060600	0.04130	0.10190	59.6	1.4950
6.6493	2.0025	0.085000	0.02175	0.10675	79.6	1.4962
----	----	-----	-----	-----	100.0	1.4979

FIGURE 3
VAPOR PRESSURE OF BENZENE AND BROMOBENZENE VS.
TEMPERATURE AT CONSTANT MOL PERCENT LINES

FIGURE 4

VAPOR PRESSURE OF BENZENE AND TOLUENE VS.
TEMPERATURE AT CONSTANT MOL PERCENT LINES

FIGURE 5

DERIVED Y - X CURVE FOR STEAM DISTILLATION
OF BENZENE - BROMOBENZENE MIXTURES

FIGURE 6

DERIVED Y-X CURVE FOR STEAM DISTILLATION
OF BENZENE - TOLUENE MIXTURES

FIGURE 7
AUXILIARY PLOT FOR GRAPHICAL EVALUATION OF $\int \frac{dx}{y-x}$ FOR BENZENE — BROMOBENZENE MIXTURES

$\frac{1}{Y-X}$

0.370

0.283

0.246

0.229

0.219

0.217

0.219

0.221

0.230

0.244

0.265

0.294

0.338

0.405

X (MOL PERCENT C_6H_6 IN LIQUID)

EXPERIMENTAL

The results of the graphical procedure could be checked only by comparison with results from steam distillation experiments. In order to perform the experiment, an accurate method to determine the composition of the distillate had to be devised. Since the index of refraction varies with the composition of a distillate, it is sometimes possible to use the index of refraction for determinations of compositions.

An examination of the systems which fulfilled the initial requirements of miscibility for the two components, immiscibility with water, and at the same time having a wide boiling point range, high differences in refractive index and densities, and all the while holding close to the characteristics of ideal solutions lead to the choice of a benzene-bromobenzene system.

Mixtures of these two components were prepared and the indices of refraction measured with an Abbe refractometer. From this data the index of refraction vs. the composition of the liquids curve was plotted as shown in Fig. 11. From the known compositions of this series of liquids the specific gravity likewise was measured and a curve of specific gravity vs. index of refraction was plotted as shown in Fig. 13. Also a curve of composition of the liquids vs. the specific gravity was plotted as shown in Fig. 15.

After this preliminary experimental work the actual steam distillation experiment was set up. A three-neck liter flask was used as the still pot. This three-neck flask was placed in a container, well insulated with asbestos. A thermometer was placed in one neck and a glass steam nozzle that went to the bottom of the flask was placed in another neck. This glass steam nozzle distributed the steam evenly throughout the bottom of the flask. The steam was generated by using a Meker burner under a liter flask half full of water. The third and middle neck of the flask is connected through a three way stop cock to a vertical water condenser. From the other side of this three way stop cock a large glass goose neck was connected to a water condenser inclined so that the condensate would run through an adapter into 15 ml. centrifuge tubes. The goose neck of the three way stop cock was wrapped with about four feet of resistance wire which was connected to an electrical circuit. This resistance wire heated the goose neck and kept the vapors from condensing. A sketch of the apparatus may be seen in Fig. 17. Numerous trial runs were made before this experimental set-up was finally assembled.

The experiment was performed in the following manner. A solution of the two liquids was made up

and its' index of refraction determined. The volume of the solution was measured and then the solution was poured into the three-neck liter flask. A Meker burner was lighted and placed under the liter flask which was half full of water. The two way stop cock was placed in such a position that the vapors coming from the three-neck flask would rise up in the vertical condenser. The water was turned on both water condensers and the circuit which contained the heat resistance wire, was closed so that the goose neck would heat up. When the water in the flask started to boil, steam entered the three-neck flask and was evenly dispersed throughout the liquid in the bottom of the flask. The steam gradually heated up the liquid mixture until vapors started to come up in the vertical water condenser. This condenser was very efficient and returned essentially all the vapors as liquid to the flask. The amount of the vapor being condensed could be controlled by controlling the amount of gas to the Meker burner. The solution was allowed to steam distill under total reflux for about ten minutes. This gave the equipment sufficient time to heat up so that heat losses would be kept at a minimum during the experiment. At the end of ten minutes the rate of distillation was reduced so that practically no vapors

were going to the vertical water condenser. Then the two way stop cock was changed so that the vapors from the flask would go up into the goose neck and then into the inclined condenser. After the stop cock was turned the rate of steam to the flask was increased again so that the distillation rate would be increased. The heat resistance wire around the goose neck kept the vapors in the goose neck from condensing. As the vapors condensed in the inclined water condenser, the liquid ran down through an adapter into a small receiving chamber which had a stop cock in its outlet. The outlet of this chamber was placed in a 15 ml. centrifuge tube. When this centrifuge tube was half full of distillate, the temperature of the vapor in the three-neck flask was recorded. As this 15 ml. centrifuge tube was filled up, the stop cock in the outlet of the small chamber was turned off. Another centrifuge tube was placed under the outlet of the small chamber and the stop cock in the outlet of the chamber was opened. Then the previous sample was stoppered and the total volume of the sample recorded. This procedure was repeated until the temperature of the vapor in the flask started to go above 95°C . Then the Meker burner was turned off and the equipment was allowed to set a few minutes until all of the distillate

had drained into the centrifuge tube. All of the samples collected during the experiment contained water plus a mixture of the two liquids. These samples were all centrifuged in order to obtain a good separation of the water from the mixture of the two liquids. Then the amount of water in each sample was recorded. The liquid mixture layer composition was found by determining the index of refraction of the liquid mixture layer in each sample. The liquid remaining in the three-neck flask was poured into a graduate and the volume of the liquid mixture measured and recorded. The liquid mixture composition was found by determining the index of refraction of the mixture. This experimental procedure provided sufficient data for calculation of the desired curves.

After the experimental data was obtained, a curve of the true vapor temperature vs. temperature calculated from the composition of each sample collected, was plotted as shown in Fig. 18. A curve of weight percent of liquid composition vs. mol percent of liquid composition was plotted as shown in Fig. 20 in order to calculate the curve of composition vs. percent volume distilled over. Experimental data was obtained for three different starting compositions using benzene, bromobenzene mixtures. The graphical procedure was

calculated using the same starting compositions and the results are compared in Fig. 9. A similar procedure was followed for benzene-toluene mixtures and the series of curves, Figs. 2, 4, 6, 8, 12, 14, 16, 19, and 21 culminate in the final comparison curves in Fig. 10.

FIGURE 9

RELATIONSHIP BETWEEN COMPOSITION AND VOLUME OF
DISTILLATE FOR STEAM DISTILLATION OF BENZENE —
BROMOBENZENE MIXTURES

FIGURE 10

RELATIONSHIP BETWEEN COMPOSITION AND VOLUME OF DISTILLATE FOR STEAM DISTILLATION OF BENZENE — TOLUENE MIXTURES

FIGURE 11

INDEX OF REFRACTION VS. MOL PERCENT BROMOBENZENE
FOR BENZENE — BROMOBENZENE MIXTURES

INDEX OF REFRACTION AT 25° C

FIGURE 13

SPECIFIC GRAVITY VS. INDEX OF REFRACTION
FOR BENZENE - BROMOBENZENE MIXTURES

FIGURE 14
SPECIFIC GRAVITY VS. INDEX OF REFRACTION
FOR BENZENE-TOLUENE MIXTURES

FIGURE 15

SPECIFIC GRAVITY VS. MOL PERCENT BROMOBENZENE
FOR BENZENE — BROMOBENZENE MIXTURES

FIGURE 16

SPECIFIC GRAVITY - MOL RELATIONSHIP
FOR BENZENE - TOLUENE MIXTURES

FIGURE 17
SKETCH OF EXPERIMENTAL APPARATUS

FIGURE 18
TEMPERATURE CORRELATION FOR BENZENE —
BROMOBENZENE MIXTURES

FIGURE 19

TEMPERATURE CORRELATION FOR BENZENE -
TOLUENE MIXTURES

FIGURE 20
CONVERSION GRAPH FOR BENZENE - BROMOBENZENE MIXTURES

FIGURE 21
CONVERSION GRAPH FOR BENZENE — TOLUENE MIXTURES

DISCUSSION

The initial condition of each experimental run was used as a starting point for each graphical solution corresponding to that run. The results obtained by the graphical procedure were then compared with the experimental results in order to check the graphical procedure for validity. This comparison was made by plotting the results as composition of the distillate vs. percent volume of the original charge distilled over. If these two curves did not coincide there were three possible simple explanations. First, there may be some experimental error due to faulty procedure or equipment arrangement. Secondly, the two miscible liquids used in the distillation may not obey Raoult's Law. If this is the case there will be a deviation between the two curves because the graphical procedure is based on the assumption that the two liquids used do obey Raoult's Law. The third possible explanation is that the graphical procedure itself is not correct.

A comparison of the experimental results using benzene-bromobenzene mixtures with the graphical calculated results is shown in Fig. 9. For a starting composition of 70 mol percent the agreement between the two curves is very good. At 51 mol percent starting composition both curves have similar shapes al-

though one curve appears to have a slightly different slope than the other one. The 30 mol percent starting composition curves have exactly the same shape and slope even though there is a small deviation between them. It should be noted that at 70 mol percent the calculated curve lies below the experimental curve and crosses it at one end. At 51 mol percent about three-quarters of the calculated curve lies below the experimental curve and the rest is above. While at 30 mol percent the calculated curve is completely above the experimental curve. Thus going from a higher mol percent benzene starting composition to a lower mol percent benzene starting composition, the calculated curve changes from below to above the experimental curve. The point at which both curves cross, moves from right to left as the mol percent benzene starting composition decreases. At 30 mol percent the point has apparently moved beyond the left end of the curve, leaving the calculated curve completely above the experimental curve. By comparing the left side of the curves it is noticed that at 70 mol percent both curves practically coincide while at 51 mol percent there is a large deviation between the curves. At 30 mol percent there is a constant deviation throughout the total length of the

curves.

A comparison of the experimental results using benzene-toluene mixtures with the graphical calculated results is shown in Fig. 10. With a starting composition of 49 mol percent the agreement between the two curves is very good with the calculated curve completely above the experimental curve. This deviation of measured from calculated points is not serious. It represents a real difference, but the values on an overall basis are well within necessary predictions for engineering calculations.

During the experimental run when each centrifuge tube was exactly half full the temperature of the vapor above the boiling liquid was recorded as the observed temperature. The composition of each sample was used in Fig. 3 or 4 to determine the temperature at which the composition of the vapor above the boiling mixture corresponds to the composition of the sample collected. A plot of the observed temperature vs. the calculated temperature is shown in Fig. 18 and 19. It is very significant that all three temperature curves for mixtures of benzene and bromobenzene fall together. This result indicates that there was very little experimental error.

CONCLUSIONS

The results obtained in the experimental work of this thesis show substantial agreement with the postulated curves obtained by graphically combining the procedures for batch steam distillation and a Raoult law approximation of equilibrium curves. The benzene-bromobenzene system was checked at three different concentrations, and the benzene-toluene system at one. The latter, which follows Raoult's law somewhat closer than the former, gave a somewhat closer correlation, but both systems are sufficiently close for general calculation purposes. Examination of temperature readings, observed and calculated, showed a relatively constant disagreement which indicated a deviation of each experimental and calculated result but likewise showed the accuracy of the experimental technique.

The general conclusion is that the procedure may be used as a close approximation for predicting distillates produced by batch steam distillation of binary mixtures, when the mixtures approximate Raoult's law. The degree of error is dependent upon the degree of deviation from Raoult's law, but exact correlations have not been established.

A P P E N D I X

SAMPLE CALCULATIONS

After the experimental data for run no. 4 was obtained the following calculations were made for each sample taken.

For sample number one the volume of the C_6H_6 layer = 12.7 cc. and has a composition of 6.0 mol percent C_6H_5Br . From Fig. 20 one can find that 6.0 mol percent C_6H_5Br = 11.3 wt. percent C_6H_5Br . From Fig. 15 the specific gravity = 0.920

$$\text{Wt. of sample} = 12.7 \times 0.920 = 11.68 \text{ gms.}$$

$$\begin{aligned} \text{Wt. of } C_6H_5Br \text{ in sample} &= 11.3 \times 11.68 = \\ &1.230 \text{ gms.} \end{aligned}$$

Accumulative weight percent of bromobenzene

$$\begin{aligned} &= \frac{\text{Total wt. of } C_6H_5Br \text{ distilled over}}{\text{Total wt. of } C_6H_6 \text{ \& } C_6H_5Br \text{ distilled over}} \\ &= \frac{1.320}{11.68} = 11.30 \end{aligned}$$

Accumulative weight percent of benzene

$$= 100 - 11.3 = 88.7$$

Accumulative volume of samples = total volume of C_6H_6 & C_6H_5Br distilled over = 12.7

Percent total volume distilled over

$$\begin{aligned} &= \frac{\text{Accumulative volume of samples}}{\text{Total volume of original charge to pot}} \\ &= \frac{12.7}{188} = 6.76 \end{aligned}$$

SAMPLE CALCULATIONS (CONTINUED)

This procedure is repeated for each sample collected and then the percent volume is plotted against the composition of each sample.

After this the graphical results are calculated.

The original charge consisted of 188 cc. of 49 mol percent of C_6H_5Br .

From Fig. 15 the specific gravity = 1.205

$188 \times 1.205 = 226.5$ gms. of original chg.

$$\frac{226.5 \times 0.66}{157.02} = 0.954 \text{ mols } C_6H_5Br$$

$$\frac{226.5 \times 0.34}{78.11} = 0.986 \text{ mols } C_6H_6$$

$$L_1 = 1.940 \text{ mols total}$$

$$x_1 = 0.51 = \text{mol fraction of } C_6H_6$$

$$\text{Assume } x_2 = 0.45$$

$$\text{Rayleigh Equation} = \ln \frac{L_1}{L_2} = \int_{x_2}^{x_1} \frac{dx}{y-x}$$

The area under the curve in Fig. 7 between the limits of 0.51 and 0.45 = 0.140

$$\ln \frac{1.940}{L_2} = \int_{x_2}^{x_1} \frac{dx}{y-x} = 0.140$$

Solving, $L_2 = 1.687$ mols of residue

$$L_1 - L_2 = 1.940 - 1.687 = 0.253 \text{ mols of distillate}$$

SAMPLE CALCULATIONS (CONTINUED)

$$\text{Mols } \text{C}_6\text{H}_6 \text{ in residue} = 1.687 \times 0.45 = 0.759$$

$$\text{Mols } \text{C}_6\text{H}_5\text{Br in residue} = 1.687 \times 0.55 = 0.928$$

$$\begin{aligned} \text{Mols } \text{C}_6\text{H}_6 \text{ in distillate} &= 0.986 - 0.759 \\ &= 0.227 \end{aligned}$$

$$\begin{aligned} \text{Mols } \text{C}_6\text{H}_5\text{Br in distillate} &= 0.954 - 0.928 \\ &= 0.026 \end{aligned}$$

$$\text{Mol percent } \text{C}_6\text{H}_5\text{Br} = \frac{0.026}{0.253} = 10.28$$

$$\text{From Fig. 15 } 10.28 \text{ mol } \% = 0.951 \text{ sp. gr.}$$

$$0.227 \times 78.11 = 17.72 \text{ gms. of } \text{C}_6\text{H}_6$$

$$0.026 \times 157.02 = 4.08 \text{ gms. of } \text{C}_6\text{H}_5\text{Br}$$

$$\text{Total} = 21.80 \text{ gms. of distillate}$$

$$\frac{21.80}{0.951} = 22.9 \text{ cc. of distillate}$$

$$\text{Percent total volume over} = \frac{22.9}{188} = 12.2$$

This procedure is repeated for various assumed values of x_2 . From these values the curve in Fig. 9 for 51 mol percent starting composition is plotted.

TABLE VI

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES - RUN NO. 4

Sample No.	Sample Volume - cc.			T °C Of Vapor	Index Of Refraction	Mol Percent C ₆ H ₅ Br
	Total	Water	C ₆ H ₆ & C ₆ H ₅ Br			
1	14.0	1.4	12.7	80.3	1.5020	6.0
2	14.1	1.8	12.3	81.2	1.5035	8.0
3	14.0	2.3	11.7	82.4	1.5044	9.4
4	14.2	2.6	11.6	83.6	1.5058	11.8
5	14.2	2.5	11.7	85.0	1.5077	14.0
6	13.9	3.2	10.7	86.6	1.5102	18.1
7	14.1	3.5	10.6	88.6	1.5141	24.2
8	14.1	4.3	9.8	90.7	1.5208	34.6
9	14.2	5.0	9.2	92.5	1.5291	48.3
10	14.4	5.8	8.6	93.9	1.5378	63.3
11	14.4	6.2	8.2	94.8	1.5462	78.4
Residue	156.0	89.0	67.0	--	1.5568	98.9
Original Chg.	188.0	--	188.0	--	1.5295	49.0

TABLE VI (CONTINUED)

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES - RUN NO. 4

Sample No.	Wt. Percent C_6H_5Br	Density	Wt. Of Sample	Wt. Of C_6H_5Br	Wt. Percent C_6H_5Br Accum.
1	11.3	0.920	11.68	1.320	11.30
2	15.0	0.935	11.50	1.725	13.17
3	17.3	0.945	11.05	1.914	14.50
4	20.5	0.959	11.11	2.280	15.95
5	24.7	0.978	11.43	2.822	17.71
6	30.8	1.005	10.77	3.320	19.77
7	39.0	1.046	11.09	4.315	22.45
8	51.5	1.114	10.90	5.610	26.00
9	65.5	1.201	11.05	7.245	30.40
10	77.5	1.291	11.10	8.610	35.05
11	87.9	1.378	11.28	9.910	39.95

TABLE VI (CONTINUED)

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES - RUN NO. 4

Wt. Percent C_6H_6 Accum.	Volume Of Samples Accum.	Percent Total Volume Over	Obs. Temp.	Y (Mol % C_6H_6)	X (Mol % C_6H_6)	Calculated Temperature
88.70	12.7	6.76	80.3	94.0	59.0	77.5
86.83	25.0	13.30	81.2	92.0	52.0	79.0
85.50	36.7	19.50	82.4	90.6	48.0	80.2
84.05	48.3	25.40	83.6	88.8	43.0	81.5
82.29	60.0	31.90	85.0	86.0	36.0	83.5
80.23	70.7	37.80	86.6	81.9	30.0	85.0
77.55	81.3	43.30	88.6	75.8	23.8	86.7
74.00	91.1	48.50	90.7	65.4	16.4	89.3
69.60	100.3	53.40	92.5	51.7	10.7	91.0
64.95	108.9	57.80	93.9	36.7	6.5	92.7
60.05	117.1	62.40	94.8	21.6	3.6	93.7

TABLE VII
CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE
WITH A STARTING COMPOSITION OF 51 MOL PERCENT

x_2	x	x_1	L_1	$\int_{x_2}^{x_1} \frac{dx}{y-x}$	L_2	$L_1 - L_2$	(A) $L_2 \times x_2$	(B) $L_2(100-x_2)$
45	90.0	51	1.940	0.140	1.687	0.253	0.759	0.928
40	88.1	51	1.940	0.247	1.518	0.422	0.606	0.912
35	86.0	51	1.940	0.347	1.370	0.570	0.480	0.890
30	83.0	51	1.940	0.442	1.246	0.694	0.374	0.872
25	78.5	51	1.940	0.537	1.132	0.808	0.283	0.849
20	73.0	51	1.940	0.631	1.030	0.910	0.206	0.824
15	65.7	51	1.940	0.726	0.938	1.002	0.141	0.797
10	57.0	51	1.940	0.828	0.846	1.094	0.085	0.761
5	38.8	51	1.940	0.958	0.745	1.195	0.037	0.708
2	21.0	51	1.940	1.083	0.655	1.285	0.013	0.642

TABLE VII (CONTINUED)

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE

WITH A STARTING COMPOSITION OF 51 MOL PERCENT

(C) 0.986-A	(D) 0.954-B	$\frac{D}{L_1-L_2}$	(E) C(78.11)	(F) D(157.02)	(G) E & F	(H) Sp. Gr.	$\frac{G}{H}$
0.227	0.026	10.28	17.73	4.08	21.81	0.951	22.95
0.380	0.042	9.95	29.70	6.60	36.30	0.949	38.30
0.506	0.064	11.21	39.60	10.05	49.65	0.959	51.85
0.612	0.082	11.81	47.90	12.90	60.80	0.961	63.80
0.703	0.105	13.00	54.90	16.50	71.40	0.969	73.60
0.780	0.130	14.30	60.90	20.40	81.30	0.979	83.00
0.845	0.157	15.60	66.00	24.60	90.60	0.988	91.80
0.901	0.193	17.60	70.50	30.30	100.80	1.001	100.70
0.949	0.246	20.60	74.10	38.60	112.70	1.022	110.00
0.973	0.312	24.20	76.00	49.00	125.00	1.047	119.50

TABLE VII (CONTINUED)

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE
WITH A STARTING COMPOSITION OF 51 MOL PERCENT

Wt. Percent C_6H_6 Accum.	Volume Of Samples Accum.	Percent Volume Over
81.3	22.95	12.20
81.8	38.30	20.35
79.7	51.85	27.60
78.8	63.20	33.60
77.0	73.60	39.20
75.0	83.00	44.10
72.8	91.80	48.80
70.0	100.70	53.60
65.9	110.00	58.50
60.7	119.50	63.60

TABLE VIII

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES - RUN NO. 5

Sample No.	Sample volume - cc.			T °C Of Vapor	Index Of Refraction	Mol Percent C_6H_5Br
	Total	Water	C_6H_6 & C_6H_5Br			
1	14.0	2.5	11.5	86.0	1.5097	17.4
2	14.4	3.8	10.6	87.8	1.5187	22.0
3	13.9	3.8	10.1	89.0	1.5158	26.8
4	14.2	4.0	10.2	90.2	1.5192	32.3
5	13.9	4.6	9.3	91.5	1.5240	40.0
6	14.0	5.0	9.0	92.8	1.5303	50.2
7	14.2	5.7	8.5	93.8	1.5365	61.2
8	13.8	6.0	7.8	94.8	1.5431	73.0
9	14.3	6.4	7.9	95.0	1.5477	81.0
10	14.0	6.6	7.4	95.2	1.5517	88.7
11	15.0	7.4	7.6	95.6	1.5540	93.2
Residue	165.0	79.0	86.0	--	1.5571	99.7
Original Chg.	190.0	--	190.0	--	1.5413	70.0

TABLE VIII

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES - RUN NO. 5

Sample No.	Wt. Percent C_6H_5Br	Density	Wt. Of Sample	Wt. Of C_6H_5Br	Wt. Percent C_6H_5Br Accum.
1	29.8	0.999	11.48	3.420	29.8
2	36.0	1.030	10.91	3.930	32.8
3	42.2	1.063	10.47	4.545	35.9
4	49.0	1.098	11.20	5.490	39.2
5	57.3	1.148	10.66	6.110	43.1
6	67.1	1.213	10.91	7.340	46.9
7	76.0	1.278	10.48	8.140	50.8
8	84.2	1.348	10.48	8.820	54.8
9	89.5	1.394	11.00	9.850	58.7
10	94.0	1.436	10.60	9.960	62.3
11	96.7	1.460	11.08	10.700	65.5

TABLE VIII (CONTINUED)

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES - RUN NO. 5

Volume Of Samples Accum.	Wt. Percent C_6H_6 Accum.	Percent Total Volume Over	Obs. Temp.	Y (Mol % C_6H_6)	X (Mol % C_6H_6)	Calculated Temperature
11.5	70.2	6.05	86.0	82.6	31.0	84.6
22.1	67.2	11.62	87.8	78.0	26.0	86.3
32.2	64.1	16.95	89.0	73.2	21.4	87.3
42.4	60.8	22.30	90.2	67.7	17.7	88.7
51.7	56.9	27.20	91.5	60.0	13.8	90.0
60.7	53.1	32.00	92.8	49.8	10.0	91.2
69.2	49.2	36.40	93.8	38.8	7.0	92.5
77.0	45.2	40.50	94.5	27.0	4.5	93.3
84.9	41.3	44.60	95.0	19.0	3.2	93.7
92.3	37.7	48.50	95.2	11.3	2.0	94.5
99.9	34.5	52.50	95.6	6.8	1.3	94.8

TABLE IX

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE
WITH A STARTING COMPOSITION OF 30 MOL PERCENT

x_2	x	x_1	L_1	$x_1 \frac{dx}{y-x}$ x_2	L_2	$L_1 - L_2$	$\frac{(A)}{L_2 \times x_2}$	$\frac{(B)}{L_2(100-x_2)}$
25	78.5	30	1.894	0.095	1.727	0.167	0.4320	1.295
20	73.0	30	1.894	0.189	1.568	0.326	0.3135	1.255
15	65.7	30	1.894	0.285	1.425	0.469	0.2140	1.811
10	57.0	30	1.894	0.387	1.287	0.607	0.1237	1.158
5	38.8	30	1.894	0.517	1.130	0.764	0.0565	1.074
2	21.0	30	1.894	0.642	0.998	0.896	0.0199	0.978

TABLE IX (CONTINUED)

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE

WITH A STARTING COMPOSITION OF 30 MOL PERCENT

(C) 0.574-A	(D) 1.320-B	$\frac{D}{L_1-L_2}$	(E) C(78.11)	(F) D(157.02)	E & F	Sp. Gr.	$\frac{G}{H}$
0.142	0.025	14.95	11.10	3.95	15.03	0.982	15.05
0.261	0.065	19.93	20.40	10.20	30.60	1.016	30.10
0.360	0.109	23.25	28.15	17.10	45.25	1.040	43.50
0.445	0.162	26.70	34.80	25.40	60.20	1.072	56.10
0.518	0.246	32.40	40.50	38.60	79.10	1.098	72.20
0.654	0.342	38.10	43.20	53.60	96.80	1.138	85.10

TABLE IX (CONTINUED)

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE
WITH A STARTING COMPOSITION OF 30 MOL PERCENT

Volume Of Samples Accum.	Wt. Percent C_6H_6 Accum.	Percent Volume Over
15.05	73.9	7.93
30.10	66.7	15.84
43.50	62.2	22.90
56.10	57.7	29.50
72.20	51.2	38.00
85.10	44.7	44.80

TABLE X
EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES
RUN NO. 6

Sample No.	Sample Volume - cc.			T °C	Index Of	Mol %
	Total	Water	C ₆ H ₆ & C ₆ H ₅ Br	Vapor	Refraction	C ₆ H ₅ Br
1	13.9	0.9	13.0	75.8	1.4995	2.4
2	13.9	1.2	12.7	76.3	1.5001	3.3
3	13.5	1.4	12.1	76.8	1.5007	4.0
4	13.6	1.6	12.0	77.5	1.5009	4.3
5	15.0	1.8	13.2	78.2	1.5011	4.8
6	14.1	1.9	12.2	79.1	1.5019	5.7
7	14.4	2.2	12.2	80.3	1.5029	7.0
8	14.8	2.5	12.3	81.8	1.5040	8.8
9	13.7	2.2	11.5	83.7	1.5060	11.5
10	14.0	2.8	11.2	85.8	1.5084	15.3
11	14.0	3.8	10.2	88.7	1.5137	23.4
12	14.1	4.5	9.6	91.3	1.5232	38.8
13	14.5	5.7	8.8	94.0	1.5370	62.1
14	14.8	7.0	7.8	95.3	1.5510	87.4
Residue	141.0	105.0	36.0	--	1.5573	99.9
Original Chg.	198.0	---	198.0	--	1.5178	30.0

TABLE X (CONTINUED)

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES

RUN NO. 6

Sample No.	Wt. % C_6H_5Br	Density	Wt. Of Sample	Wt. Of C_6H_5Br	Wt. % C_6H_5Br Accum.
1	5.0	0.894	11.6	0.580	5.0
2	6.8	0.900	11.4	0.775	5.9
3	7.9	0.906	11.0	0.870	6.5
4	8.6	0.909	10.9	0.937	7.1
5	9.3	0.919	12.0	1.115	7.5
6	10.9	0.918	11.2	1.221	8.1
7	13.2	0.927	11.3	1.492	8.8
8	16.3	0.940	11.5	1.875	9.8
9	20.9	0.959	11.0	2.300	11.0
10	26.8	0.985	11.0	2.946	12.5
11	38.0	1.041	10.6	4.030	14.7
12	56.0	1.141	10.9	6.100	18.0
13	76.8	1.283	11.3	8.680	22.6
14	93.4	1.429	11.1	10.350	27.6

TABLE X (CONTINUED)

EXPERIMENTAL DATA FOR BENZENE-BROMOBENZENE MIXTURES

RUN NO. 6

Volume Of Samples Accum.	Wt. % C_6H_6 Accum.	% Total Volume Over	Obs. Temp.	Y (Mol % C_6H_6)	X (Mol % C_6H_6)	Calcul- ated Temp.
13.0	95.0	6.56	75.8	97.6	78.0	73.3
25.7	94.1	12.98	76.3	96.7	71.0	74.7
37.8	93.5	19.09	76.8	96.0	67.0	75.5
49.8	92.9	25.10	77.5	95.7	65.8	75.8
63.0	92.5	31.80	78.2	95.2	63.5	76.2
75.2	91.9	38.00	79.1	94.3	60.5	76.9
87.4	91.2	44.10	80.3	93.0	55.5	78.3
99.7	90.2	50.40	81.8	91.2	50.0	79.5
111.2	89.0	56.10	83.7	88.5	42.4	81.5
122.4	87.5	61.80	85.8	84.7	33.9	83.8
132.6	85.3	67.00	88.7	76.6	24.4	86.7
142.2	82.0	71.90	91.3	61.2	14.4	90.0
151.0	77.4	76.30	94.0	37.9	6.8	93.3
158.8	72.4	80.20	95.3	12.6	2.2	94.5

TABLE XI

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE

MIXTURES WITH A STARTING COMPOSITION OF 70 MOL PERCENT

x_2	x	x_1	L_1	$\int_{x_2}^{x_1} \frac{dx}{y-x}$	L_2	$L_1 - L_2$	$\frac{(A)}{L_2 \times x_2}$	$\frac{(B)}{L_2(100-x_2)}$
65	95.6	70	2.110	0.174	1.772	0.338	1.150	0.622
60	94.5	70	2.110	0.327	1.520	0.590	0.912	0.608
50	91.7	70	2.110	0.590	1.160	0.950	0.530	0.580
40	88.2	70	2.110	0.812	0.936	1.174	0.375	0.561
30	83.0	70	2.110	1.007	0.724	1.386	0.217	0.507
25	78.5	70	2.110	1.202	0.633	1.477	0.158	0.475
20	73.0	70	2.110	1.296	0.576	1.534	0.115	0.461
15	65.7	70	2.110	1.392	0.523	1.587	0.078	0.445
10	57.0	70	2.110	1.494	0.473	1.673	0.047	0.426
5	38.9	70	2.110	1.623	0.415	1.695	0.021	0.394
2	21.0	70	2.110	1.724	0.368	1.742	0.007	0.361

TABLE XI (CONTINUED)

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE

MIXTURES WITH A STARTING COMPOSITION OF 70 MOL PERCENT

(C) 0.574-A	(D) 1.320-B	$\frac{D}{L_1-L_2}$	(E) C(78.11)	(F) D(157.02)	(G) E & F	(H) Sp. Gr.	$\frac{G}{H}$
0.328	0.010	2.9	25.6	1.6	27.2	0.897	30.0
0.566	0.024	4.1	44.3	3.8	48.1	0.906	53.1
0.898	0.052	5.5	70.1	8.2	78.3	0.917	85.4
1.103	0.071	6.0	86.3	11.1	97.4	0.920	105.7
1.261	0.125	9.0	98.6	19.6	118.2	0.941	125.8
1.320	0.157	10.6	103.1	24.7	127.8	0.953	134.1
1.363	0.171	11.1	106.5	26.9	133.4	0.958	139.3
1.400	0.187	11.8	109.3	29.4	138.7	0.961	144.1
1.431	0.206	12.6	112.0	32.4	144.4	0.967	149.5
1.457	0.238	14.0	113.8	37.4	151.2	0.977	155.0
1.471	0.271	15.5	115.0	42.6	157.6	0.988	159.8

TABLE XI (CONTINUED)

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-BROMOBENZENE
MIXTURES WITH A STARTING COMPOSITION OF 70 MOL PERCENT

Volume Of Samples Accum.	Wt. Percent C_6H_6 Accum.	Percent Volume Over
30.3	94.1	15.3
53.1	92.0	26.8
85.4	89.6	43.1
105.7	88.6	53.4
125.8	83.5	63.5
134.1	80.7	67.9
139.3	79.8	70.4
144.1	78.9	72.9
149.5	77.6	75.5
155.0	75.1	78.3
159.8	73.0	80.6

TABLE XII
DERIVED DATA FROM THE CONSTRUCTED TEMPERATURE PRESSURE
CURVE FOR BENZENE, TOLUENE, AND WATER

X	T °C	$P_{C_6H_6}$ & $P_{C_6H_5Br}$	P_o of C_6H_5Br
100	69.2	532	0
90	70.4	521	22
80	71.7	508	45
70	73.0	492	70
60	74.5	478	97
50	76.0	459	128
45	76.8	449	145
40	77.6	439	162
35	78.4	429	181
30	79.0	419	199
25	79.9	406	218
20	80.7	393	238
15	81.6	379	262
10	82.5	366	288
5	83.5	350	308
2	84.1	341	329
0	84.4	337	337

TABLE XII (CONTINUED)

DERIVED DATA FROM THE CONSTRUCTED TEMPERATURE PRESSURE
CURVE FOR BENZENE, TOLUENE, AND WATER

P_0 of C_6H_6	Y	Y-X	$\frac{1}{Y-X}$
532	100.0	0.000	∞
499	95.6	0.056	17.85
463	91.2	0.112	8.44
422	85.8	0.158	6.33
381	79.8	0.198	5.05
331	72.2	0.222	4.50
304	67.8	0.228	4.39
277	63.1	0.231	4.34
248	57.9	0.229	4.39
220	52.6	0.226	4.43
188	46.2	0.212	4.72
155	39.4	0.194	5.15
117	30.8	0.158	6.34
78	21.3	0.113	8.85
42	12.0	0.070	14.30
12	3.5	0.015	66.60
0	0.0	0.000	∞

TABLE XIII
EXPERIMENTAL DATA FOR BENZENE-TOLUENE MIXTURES
RUN NO. 7

Sample No.	Sample Volume - cc.			Vapor	Index Of	Mol %
	Total	Water	C_6H_6 & C_7H_8	T °C	Refraction	C_6H_6
1	14.0	1.0	13.0	76.3	1.4956	70.0
2	14.3	1.4	12.9	76.9	1.4955	68.3
3	14.0	1.7	12.3	77.2	1.4954	66.6
4	14.0	1.6	12.4	77.8	1.4953	65.0
5	14.1	1.6	12.5	78.0	1.4950	59.5
6	14.5	2.0	12.5	78.4	1.4950	59.5
7	14.7	1.7	13.0	79.0	1.4949	57.9
8	14.6	2.0	12.6	79.5	1.4947	53.6
9	14.4	2.0	12.4	80.1	1.4946	51.2
10	14.2	2.2	12.0	80.3	1.4945	48.8
11	14.2	2.2	12.0	80.9	1.4943	42.9
12	14.2	2.5	11.7	82.5	1.4941	35.0
13	14.4	2.5	11.9	83.0	1.4939	24.5
14	14.3	2.2	12.1	83.3	1.4937	12.5
15	14.1	2.6	11.5	84.3	1.4935	0.0
16	14.2	11.0	3.2	100.0	1.4935	0.0
Orig. Chg.	197.0	--	197.0	---	1.4945	48.8

TABLE XIII (CONTINUED)
EXPERIMENTAL DATA FOR BENZENE-TOLUENE MIXTURES

RUN NO. 7

Sample No.	Wt. % C_7H_8	Density	Wt. of Sample	Wt. of C_7H_8	Wt. % C_7H_8 Accum.
1	33.5	0.8690	11.30	3.782	33.5
2	35.2	0.8687	11.20	3.940	34.3
3	37.3	0.8685	10.68	3.985	35.3
4	38.8	0.8682	10.75	4.175	36.2
5	44.5	0.8673	10.82	4.815	37.8
6	44.5	0.8673	10.82	4.815	38.9
7	46.2	0.8671	11.28	5.210	40.0
8	50.3	0.8664	10.92	5.500	41.3
9	52.8	0.8661	10.75	5.680	42.5
10	55.5	0.8658	10.40	5.775	43.8
11	61.0	0.8650	10.58	6.330	45.2
12	68.5	0.8641	10.10	6.910	47.0
13	78.5	0.8629	10.26	8.050	49.4
14	89.4	0.8617	10.42	9.310	52.1
15	100.0	0.8605	9.90	9.900	55.1
16	100.0	0.8605	2.75	2.750	55.8

TABLE XIII (CONTINUED)
EXPERIMENTAL DATA FOR BENZENE-TOLUENE MIXTURES

RUN NO. 7

Volume Of Samples Accum.	Wt. % Volume Accum.	% Total Volume Over	Obs. Temp. °C	Y (Mol % C ₆ H ₆)	X (Mol % C ₆ H ₆)	Cal. Temp. °C
13.0	66.5	6.6	76.3	70.0	47.4	76.5
25.9	65.7	13.1	76.9	68.3	45.2	76.7
38.2	64.7	19.4	77.2	66.6	43.3	77.2
50.6	63.8	25.7	77.8	65.0	41.8	77.4
63.1	62.2	32.1	78.0	59.5	36.0	78.3
75.6	61.1	38.4	78.4	59.5	36.0	78.3
88.6	60.0	45.0	79.0	57.9	34.4	78.5
101.2	58.7	51.4	79.5	53.6	30.5	79.0
113.6	57.5	57.6	80.1	51.2	28.7	79.4
125.6	56.2	63.8	80.4	48.8	26.5	79.6
137.6	54.8	69.9	80.9	42.9	22.1	80.3
149.3	53.0	75.9	82.5	35.0	17.1	81.3
161.2	50.6	82.7	83.0	24.5	11.2	82.2
173.3	47.9	88.1	83.3	12.5	5.0	83.5
184.8	44.9	93.8	84.3	0.0	0.0	84.4
188.0	44.2	95.5	100.0	0.0	0.0	84.4

TABLE XIV

CALCULATIONS FOR THE GRAPHICAL PROCEDURE USING BENZENE-TOLUENE MIXTURES
WITH A STARTING COMPOSITION OF 48.8 MOL PERCENT

x_2	x	x_1	L_1	$\int_{x_2}^{x_1} \frac{dx}{y-x}$	L_2	$L_1 - L_2$	$L_2^{(A)} \times x_2$	$L_2^{(B)} (100 - x_2)$
45	67.8	49	1.996	0.176	1.671	0.325	0.753	0.918
40	63.1	49	1.996	0.395	1.343	0.653	0.537	0.806
35	57.9	49	1.996	0.612	1.080	0.916	0.378	0.702
30	52.6	49	1.996	0.831	0.869	1.127	0.260	0.609
25	46.2	49	1.996	1.061	0.690	1.306	0.172	0.518
20	39.4	49	1.996	1.306	0.540	1.456	0.108	0.432
15	30.8	49	1.996	1.589	0.406	1.590	0.061	0.345
10	21.3	49	1.996	1.959	0.281	1.715	0.028	0.253

TABLE XIV (CONTINUED)

CALCULATIONS OF THE GRAPHICAL PROCEDURE USING BENZENE-TOLUENE MIXTURES
WITH A STARTING COMPOSITION OF 48.8 MOL PERCENT

(C) 0.987-A	(D) 1.018-B	$\frac{D}{L_1-L_2}$	(E) C(78.11)	(F) D(157.02)	(G) E & F	(H) Sp. Gr.	$\frac{G}{H}$
0.225	0.100	30.8	17.60	9.21	26.81	0.8636	31.1
0.441	0.212	32.5	34.55	19.54	54.09	0.8638	62.6
0.600	0.316	34.5	46.95	29.15	76.10	0.8641	88.1
0.718	0.409	36.3	56.10	37.65	93.75	0.8643	108.5
0.806	0.500	38.3	63.00	46.10	109.10	0.8645	126.5
0.870	0.586	40.3	68.00	54.05	122.50	0.8647	142.0
0.917	0.673	42.3	71.70	62.00	133.70	0.8649	154.9
0.950	0.765	44.5	74.30	70.50	144.80	0.8652	167.1

TABLE XIV (CONTINUED)
 CALCULATIONS OF THE GRAPHICAL PROCEDURE USING BENZENE-TOLUENE MIXTURES
 WITH A STARTING COMPOSITION OF 48.8 MOL PERCENT

Volume Of Samples Accum.	Wt. Percent C_6H_6 Accum.	Percent Volume Over
31.1	65.6	15.87
62.6	63.7	31.80
88.1	61.5	44.70
108.5	59.9	55.00
126.5	57.6	64.20
142.0	55.5	72.10
154.9	53.6	78.60
167.1	51.3	85.00

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V I T A

Howard D. Carlson, son of Mr. Harry D. Carlson and Mrs. Gertrude Foose Carlson, was born June 13, 1921 in the Town of Colonie, Albany County, New York.

He attended elementary schools in the Town of Colonie and graduated from Cohoes High School at Cohoes, N. Y. with a College Entrance Diploma.

He attended Rensselaer Polytechnic Institute at Troy, N. Y. and received a Bachelor of Chemical Engineering Degree on May 18th, 1942. His thesis, "An Investigation of Film Coefficients For Condensing Mixed Vapors In The System: Ethanol - Water," was performed under the direction of Dr. L. S. Coonley.

Attending the University of Louisville, he obtained the degree of Master of Chemical Engineering in 1946. His thesis, "A Graphical Solution for Batch Steam Distillation of a Binary Mixture," was performed under the direction of Dr. G. C. Williams.

In May 1942 he was employed by E. I. Du Pont de Nemours and Company as a Chemical Engineer and assigned to the production of Neoprene (a synthetic rubber). In April 1945 he was transferred as a supervisor to a Rocket Powder Plant in Charlestown, Indiana. At the end of the war he was transferred to the Planning Division of the Engineering Department as a Process Engineer, and is now employed in that section.