



The effect of reduced pressure on the efficiency of a packed rectification column
by Daniel O Popovac

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering
Montana State University
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Abstract:

A study is presented of the effect of reduced pressure on the efficiency of a packed rectification column. A rectification column two feet long, one inch diameter and packed with 1/8 inch stainless steel Fenske helices was employed. A test mixture of n-octane - toluene was used. Vapor-liquid equilibrium was determined for this system at pressures of 20, 50, 100, 200, 300, 400, 640.3 and, 760 mm. Hg. absolute.

The column was then tested with the mixture at the same pressures, operating at just "below the flooding point". Calibration was made at total reflux and at reflux ratios of 3.041 and 20*1, in each case it was found that the number of theoretical plates as determined from the corresponding vapor-liquid equilibrium diagram via the McCabe-Thiele method was between 11 and 14. The same column calibrated 14 plates at 760 mm Hg with the standard test mixture n-heptane - toluene. These results indicate that column efficiency is independent of pressure. Design calculations may be based on vapor-liquid equilibrium data determined at the same pressure as that at which the column is to operate, the H.E.T.P. of a given packing remaining constant.

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P. S. Graduate Committee

I SUMMARY

A study is presented of the effect of reduced pressure on the efficiency of a packed rectification column. A rectification column two feet long, one inch diameter and packed with 1/8 inch stainless steel Fenske helices was employed. A test mixture of n-octane - toluene was used. Vapor-liquid equilibrium was determined for this system at pressures of 20, 50, 100, 200, 300, 400, 640, and 760 mm. Hg. absolute. The column was then tested with the mixture at the same pressures, operating at just below the flooding point. Calibration was made at total reflux and at reflux ratios of 30:1 and 20:1. In each case it was found that the number of theoretical plates as determined from the corresponding vapor-liquid equilibrium diagram via the McCabe-Thiele method was between 11 and 14. The same column calibrated 14 plates at 760 mm. Hg. with the standard test mixture n-heptane - toluene. These results indicate that column efficiency is independent of pressure. Design calculations may be based on vapor-liquid equilibrium data determined at the same pressure as that at which the column is to operate, the H.E.P. of a given packing remaining constant.

II INTRODUCTION

The determining factors in the design of fractionating columns are the packing or plate efficiency, the separation desired and the operating conditions. Many methods for calculating the number of theoretical plates or H.E.T.P. necessary for a given separation have been reported. The McCabe-Thiele graphical method and the Fenske equation are well known. (10, 8) Factors influencing column efficiency must therefore play an important role in design calculation.

Efficiency is not a function of any single property or condition and has been investigated with many resulting correlations. Many studies have been reported in the literature on the effect of the physical properties of the material being fractionated. Drickamer and Bradford showed that for commercial hydrocarbon fractionating columns and absorbers, the plate efficiency increased with the decreasing viscosity. (6) This correlation was made on commercial equipment but is suitable only for hydrocarbon separations with low relative volatility of the key components and the average molal liquid viscosity of the column feed, both at the average tower temperature and pressure. (11)

Brown and Lockhart studied the effect of vapor load on plate efficiency in fractionating columns. (3) They report that except for very low velocities, the overall column efficiency is relatively independent of mean vapor velocity,

maximum efficiency being obtained at the maximum allowable velocity from the Souders - Brown equation, (13). Rhodes and Blackburn investigated and correlated the effect of relative amounts of the components in the mixture and the rate of distillation upon efficiency, (16)

No correlation relating column efficiency with operating pressure has appeared in the technical literature to date. Binary mixtures for evaluating low pressure distillation columns have been reported. Williams suggested mixtures of di-n-butyl phthalate and di-n-butyl amolate for this purpose for pressures of about 1 mm. (17) Feldman, Myles and Orchin studied binary mixtures for evaluating rectification columns at pressures from 20 mm. Hg. to 400 mm. Hg. (7) They presented data on two test mixtures; (a) n-dodecane and cyclohexyl cyclopentane and (b) n-tridecane and dicyclohexyl. In this report a plot of average relative volatility versus the pressure showed that for the mixture n-tridecane - dicyclohexyl, the relative volatility approaches a minimum at about 150 mm. then rises again. For n-dodecane + cyclohexyl cyclopentane the relative volatility follows a smooth curve from a high at 20 mm. to a low at 400 mm. The vapor liquid equilibrium diagram for the n-dodecane + cyclohexyl cyclopentane system approaches the 45 degree diagonal from above as the pressure increases from 20 to 400 mm. The diagram for n-tridecane + dicyclohexyl moves from below the 45 degree diagonal through

incidence with it, to above for increasing pressure from 20 mm. to 375 mm. Griswold, Andres and Klein showed the effect of high pressures on the vapor liquid equilibrium diagram of benzene - toluene. (9) Their plots showed that the vapor liquid curve approached the 45 degree diagonal from above as the pressure increased from atmospheric to 500 psi.

The purpose of this work is to determine the effect of reduced pressure on column efficiency. Nowhere in the literature is there information concerning the specific effect on rectification efficiency of changes in operating pressure. The widely diverse views entertained by distillation experts on this subject indicate a need for a correlation of these variables. A test mixture was sought which approached ideality, which was easy to analyze accurately, and would operate over a wide range of pressures. The system n-octane - toluene proved to fulfill these requirements most readily. The vapor liquid equilibrium relationships were determined at a number of different pressures between 20 mm. and 760 mm. Hg. absolute. A standardized packed column was then calibrated at total reflux, at 30:1 reflux ratio and at 20:1 reflux ratio with the test mixture at the same pressures at which the vapor liquid equilibria had been determined. The number of theoretical plates or the H.E.T.P., was determined from the vapor liquid equilibria by the McCabe-Thiele method. Since vapor and liquid throughput

may well be a contributing factor in column efficiency, all determinations were made with the column operating at just below the flooding point, and the rate of liquid take off determined for the runs other than total reflux.

III. EXPERIMENTAL MATERIALS, EQUIPMENT AND PROCEDURE

Normal heptane (Westvaco Chemical Co.) was sufficiently pure for use without further processing. Normal octane (Connecticut Hard Rubber Co.) and toluene (Baker's Analyzed) were subjected to rectification in a laboratory column having approximately thirty theoretical plates, and heart cuts boiling not more than $\pm 0.2^\circ\text{C}$. from the normal boiling points, were separated.

Vapor liquid equilibrium determinations were made in a glass Othmer still, (12) which was connected to the vacuum system. The vacuum system consisted of two five gallon surge tanks, one of which was connected to a Megavac vacuum pump. A Detroit Lubricator Co., No. 683-3, solenoid valve was placed in the line between the surge tanks and the valve was activated by a mercury contact vacuum regulator through a Fisher-Serfass electronic relay, (F.S.Co. 13-991). By disconnecting the vacuum pump, pressurizing one surge tank with nitrogen and reversing the relay, the system could be made to operate at super atmospheric pressure. Operating pressure was read from a mercury manometer connected to the system.

The rectification column employed was made of Pyrex glass, two feet long, one inch in diameter, packed 23 inches high with 1/8 inch Fenske stainless steel helices and equipped with a Corad constant reflux ratio distilling head. The head and

the stillpot were connected through vacuum receivers to the vacuum system so that samples could be withdrawn at the operating pressure. At the start of each run the column was flooded and then the heat input adjusted so that the column operated at just below the flood point.

Vapor liquid equilibrium determinations were obtained by the following procedure. A 75 ml. sample of n-octane, toluene or mixtures of these two were charged to the still. The still was sealed off then slowly pumped to the desired pressure. The heat was adjusted to give a distillation rate of about one drop per second. The mixtures were allowed about two hours to attain equilibrium then the heat was turned off and the vacuum slowly dissipated. Vapor and liquid samples were taken and their composition determined by refractive index in a Valentine Abbe type refractometer, accurate to 0.0001. Refractive indices had previously been obtained on weighed mixtures of the liquids so that the composition of the samples could be read from a refractive index - composition curve. A calibrated precision thermometer was used to determine the vapor temperature in the still.

Calibration of the column was done at the same pressures for which equilibrium data were obtained. A charge of n-octane - toluene was added to the stillpot and vacuum applied. The column was flooded to assure a thoroughly wet packing.

then the heat input adjusted so that the reflux continued just slightly below flooding. All runs were continued at total reflux for about five hours. A vacuum receiver was used to obtain samples to be analyzed while the column remained at the desired pressure. At total reflux, samples were taken until the analysis was constant. At the reflux ratios of 30:1 and 20:1, the head was properly adjusted and the run continued for a half hour before samples were taken. During this time the rate of take off was determined. Then several samples were taken at 15 minute intervals. All analysis was done on the refractometer and composition determined by the refractive index - composition curve. Samples were taken in this manner until distillate and bottoms composition became a constant number of theoretical plates apart.

IV RESULTS

A mixture was necessary which approached ideality, could be utilized over a wide range of pressures, and whose refractive indices were different enough to permit accurate analysis. The first mixture chosen was ethylbenzene - n-octane. These liquids satisfied the requirements above but the data obtained on the system was unsuitable. A smooth equilibrium curve could not be obtained at lower pressures. This made column calibration with this mixture impractical. The system toluene-methylcyclohexane was then tested but was found to have too low a boiling point at 20 mm. and was therefore unsuitable for this study.

N-octane - toluene proved satisfactory and fulfilled all the requirements.

The boiling points of the pure components determined in the equilibrium still compared favorably with the vapor pressure data found in the literature. (5, 14, 18) These were plotted on a Cox chart and this curve used to calculate activity coefficients. Unreliable temperature measurements at 20 mm. Hg. made calibrations of vapor pressures and activity coefficients impossible at this pressure. The experimental equilibrium data and the calculated data are shown in Tables I to VIII, inclusive. An example of the equilibrium diagram at 400 mm. Hg. is illustrated in Figures 1, 2 and 3. These

were plotted on graph paper 20" x 20" to give sufficient accuracy. The consistency of the data is shown to be satisfactory upon inspection of the activity coefficient curves of Figures 4 and 5 as suggested by Carlson and Colburn. (4) Their study shows that deviations in these curves indicate inaccuracies in the data. Slopes of the lines must always be of opposite sign at a given value of x ; if the slope of one of the curves is equal to zero, the other must have a zero slope at the same value of x except at the terminal points. The approach to the value of 1.0 with a horizontal tangent indicates that Raoult's law applies to the component whose mol fraction approaches 1.0 and Henry's law demands that the other end of each curve reach a finite value with a finite slope. Figures 6 to 9, inclusive, are plots of the relative volatility as calculated from the data. A plot of average relative volatility versus pressure is shown in Figure 10. The average relative volatility of this system has a maximum at about 400 mm. Hg. as shown in Figure 10. Othmer reported that the mixture acetone-water forms an azeotrope at high pressures and with decreasing pressure the relative volatility increased. (13) Berg, Harrison and Montgomery showed that the azeotrope composition of isobutanol-ethylbenzene decreases with increased pressure. (1) This illustrates decreasing relative volatility with decreasing pressure. Comparison of these reported data

with that of this paper indicates that the effect of pressure on the relative volatility varies with the mixture used.

Table II contains the data obtained from the calibration runs. These data were used to make McCabe-Thiele diagrams at the various pressures. (Figures 1, 2 and 3) From these diagrams the number of theoretical plates in the column was determined. The H.E.T.P. was calculated upon the 23 inches of packing in the column. The H.E.T.P. data are shown in Table X. The number of theoretical plates obtained at the various pressures were consistently between 11 and 14. The slightly higher values obtained at the lower pressures might be justified by the fact that operation closer to flooding was easier to obtain at these pressures giving a higher efficiency. The fact that the number of theoretical plates are consistently between the limits of 11 and 14 shows that the efficiency remains relatively the same with changes in operating pressure. It is interesting to note that the results do not get steadily lower or higher but that the slight discrepancies in the number of plates obtained are scattered enough to indicate no definite trend.

In order to verify the results obtained with the system n-octane - toluene, the column was calibrated at the three reflux ratios with another test mixture, n-heptane - toluene. These results were plotted using the equilibrium data of Bromley and Quiggle. (2) The number of theoretical plates

obtained was 14 which compares favorably with that of the system n-octane - toluene. These data are included in Tables IX and X.

V CONCLUSIONS

The following conclusions may be drawn from this study:

1. Packed column efficiency is relatively independent of changes in operating pressure and factors normally associated with pressure change.
2. The increase or decrease in the degree of separation of a mixture in a given column accompanying pressure change is due primarily to change in the average relative volatility with pressure.
3. Design calculations for rectification should be based upon the vapor liquid equilibrium relation at the operating pressure.

VI REFERENCES

- (1) Berg, L., Harrison, J. M., and Montgomery, G. W., Ind. Eng. Chem., 38, 1149 (1946)
- (2) Bromiley, E. C. and Quiggle, D., Ind. Eng. Chem., 25, 1136 (1933)
- (3) Brown, C. G. and Lockhart, F. J., Trans. A.I.Ch.E., 39, 63 (1943)
- (4) Carlson, H. C. and Colburn, A. P., Ind. Eng. Chem., 34, 581 (1942)
- (5) Doss, M. P., Physical Constants of the Principal Hydrocarbons, 4th Ed. The Texas Co., 1943
- (6) Brickamer, H. G. and Bradford, J. R., Trans. A.I.Ch.E., 32, 319 (1943)
- (7) Feldman, J., Myles, H., and Orchin, J., Paper presented before the Petroleum Division of the American Chemical Society, April, 1948
- (8) Fenske, M. R., Ind. Eng. Chem., 24, 482 (1932)
- (9) Griswold, J., Andres, D., and Klein, B. A., Trans. A.I.Ch.E., 32, 223 (1943)
- (10) McCabe, W. L. and Thiele, E. W., Trans. A.I.Ch.E., 17, 605 (1925)
- (11) O'Connell, H. E., Trans. A.I.Ch.E., 42, 741 (1946)
- (12) Othmer, D. F., Ind. Eng. Chem. Anal. Ed., 4, 232 (1932)
- (13) Othmer, D. F., and Morley, F. R., Paper presented before the 108th meeting of the American Chemical Society, September, 1944
- (14) Perry, J. H., "Handbook for Chemical Engineers", p. 365, 2nd Ed., McGraw-Hill Book Co., New York (1941)
- (15) Souders, M. Jr., and Brown, C. G., Ind. Eng. Chem., 26, 98 (1934)
- (16) Rhodes, F. H. and Blackburn, P. G., Ind. Eng. Chem., 29, 51 (1937)

- (17) Williams, F. E.; Ind. Eng. Chem., 39, 779 (1947)
- (18) "Handbook of Chemistry and Physics", pp. 1752-53,
26th Ed., Chemical Rubber Publishing Co., (1942-3)

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TABLE I

Equilibrium Data for n-Octane - Toluene at 20 mm.

Weight % in Liquid		Weight % in Vapor		Relative Volatility
n-Octane	Toluene	n-Octane	Toluene	
100	0	100	0	
98.1	1.9	95.8	4.2	2.265
94.4	5.6	88.0	12.0	2.30
91.3	8.7	82.3	17.7	2.26
87.7	12.3	77.1	22.9	2.12
83.0	17.0	69.8	30.2	2.11
82.6	17.4	69.4	30.6	2.10
79.5	20.5	65.4	34.6	1.99
72.5	27.5	57.3	42.7	1.963
64.5	33.5	47.5	52.5	2.0
56.0	44.0	40.8	59.2	1.85
47.7	52.3	34.4	63.6	1.74
38.9	61.1	27.6	72.4	1.67
31.8	68.2	22.0	78.0	1.65
26.2	73.8	18.4	81.6	1.57
20.7	79.3	14.9	85.1	1.49
16.0	84.0	11.9	88.1	1.41
11.2	88.8	8.7	91.3	1.32
8.0	92.0	6.4	93.6	1.27
0	100.0	0	100.0	

TABLE II

Equilibrium Data for System n-Octane - Toluene at 50 mm.

Temp. °C.	Weight % in Liquid		Weight % in Vapor		Vapor Pressure mm. Hg.		Activity Coefficient		Relative Volatility
	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	
50.7	100.0	0.0	100.0	0.0	50.0				
50.4	99.9	0.1	98.9	1.1	49.8	92.5			
49.8	99.1	0.9	95.5	4.5	49.2	90.0	0.981	2.780	5.2
48.8	96.9	3.1	90.0	10.0	46.3	86.0	1.003	1.880	3.47
48.3	94.5	4.5	87.0	13.0	45.5	85.0	1.012	1.700	3.17
47.5	92.7	7.3	82.1	17.9	43.7	83.0	1.012	1.480	2.77
46.7	88.5	11.5	75.5	24.5	42.0	78.0	1.016	1.370	2.49
45.8	85.7	14.2	70.7	29.3	40.5	76.0	1.019	1.360	2.50
45.0	82.8	17.2	65.5	34.5	38.5	73.0	1.028	1.370	2.53
44.2	77.4	22.6	58.2	41.8	37.0	70.5	1.013	1.310	2.46
43.4	71.9	28.1	52.8	47.2	36.0	68.0	1.021	1.240	2.28
42.8	68.7	31.3	50.0	50.0	35.0	67.0	1.040	1.190	2.19
41.7	61.0	39.0	43.2	56.8	33.2	64.0	1.072	1.140	2.06
41.2	60.0	40.0	42.5	57.5	33.0	62.0	1.068	1.160	2.03
40.5	52.0	48.0	35.4	64.6	31.2	60.5	1.091	1.110	1.98
40.2	44.2	55.8	29.2	70.7	30.6	59.6	1.078	1.060	1.91
39.3	37.6	62.4	24.5	75.5	29.4	57.0	1.108	1.060	1.86
38.9	29.7	70.3	20.0	80.0	28.8	55.8	1.170	1.020	1.69
38.5	23.3	76.7	16.3	83.7	28.2	54.8	1.240	0.996	1.56
38.2	18.5	81.5	13.4	86.6	27.7	54.0	1.305	0.984	1.47
37.9	15.0	85.0	11.2	88.8	27.4	53.2	1.365	0.981	1.40
37.6	11.3	88.7	8.5	91.5	26.7	52.5	1.408	0.983	1.37
37.4	8.0	92.0	6.2	93.8	26.5	51.8	1.460	0.982	1.31
37.0	5.7	94.3	4.3	95.7	26.0	51.0	1.450	0.995	1.34
36.9	0.0	100.0	0.0	100.0	50.0				

TABLE III

Equilibrium Data for System n-Octane - Toluene at 100 mm.

Temp. °C.	Weight % in Liquid		Weight % in Vapor		Vapor Pressure mm. Hg.		Activity Coefficient		Relative Volatility
	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	
65.5	100.0	0.0	100.0	0.0	100.0				
65.1	99.9	0.1	98.9	1.1	96.4	168	1.030	6.55	11.1
64.6	97.8	2.2	94.0	6.0	91.8	165	1.052	1.65	2.78
64.2	97.6	2.4	93.5	6.5	91.5	162	1.042	1.67	2.79
63.4	91.9	8.1	81.4	18.6	88.5	157	1.000	1.46	2.59
64.0	96.9	3.1	90.7	9.3	90.5	161	1.040	1.86	3.21
62.5	89.0	11.0	76.2	23.8	85.5	152	1.002	1.42	2.53
61.2	85.5	14.5	70.2	29.8	81.5	145	1.008	1.42	2.50
59.6	78.6	21.4	60.5	39.5	76.0	137	1.013	1.35	2.40
58.4	70.8	29.2	50.2	49.8	71.0	130	1.000	1.31	2.40
57.0	62.8	37.2	43.1	56.9	67.5	123	1.018	1.25	2.23
55.6	54.2	45.8	37.4	62.6	63.0	116	1.095	1.18	1.94
55.2	42.3	57.7	28.5	71.5	62.0	114	1.088	1.09	1.84
54.4	32.1	67.9	22.2	77.8	60.0	110	1.150	1.04	1.66
53.8	25.6	74.4	18.2	81.8	58.0	107	1.225	1.025	1.55
53.3	17.5	82.5	13.1	86.9	57.0	105	1.310	1.003	1.41
53.0	13.3	86.7	10.5	89.5	56.5	103	1.400	1.002	1.31
52.6	9.0	91.0	7.0	93.0	55.0	102	1.410	1.002	1.31
52.2	6.9	93.1	5.5	94.5	54.5	100.5	1.460	1.010	1.27
52.0	0.0	100.0	0.0	100.0	100				

TABLE IV

Equilibrium Data for System n-Octane - Toluene at 200 mm.

Temp. °C.	Weight % in Liquid		Weight % in Vapor		Vapor Pressure mm. Hg.		Activity Coefficient		Relative Volatility
	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	
83.4	100.0	0.0	100.0	0.0	200				
82.0	99.0	1.0	93.0	7.0	190	306	0.990	4.560	7.53
81.0	95.0	5.0	87.1	12.9	183	298	1.002	1.730	2.81
79.4	90.7	9.3	78.8	21.2	173	285	1.003	1.600	2.59
78.0	84.6	15.4	68.7	31.3	162	268	1.003	1.515	2.50
76.2	76.0	24.0	57.9	42.1	152	252	1.003	1.390	2.30
74.8	67.3	32.7	48.3	51.7	143	239	1.004	1.320	2.20
73.8	57.0	43.0	39.7	60.3	138	230	1.010	1.220	2.01
72.8	49.5	50.5	33.5	66.5	132	223	1.025	1.180	1.89
71.0	37.3	62.7	24.4	75.6	123	210	1.063	1.155	1.84
70.0	27.8	72.2	18.9	81.1	119	204	1.142	1.110	1.66
69.7	20.3	79.7	14.9	85.1	117	202	1.255	1.060	1.45
69.6	13.6	86.4	10.0	90.0	116.2	201	1.263	1.040	1.42
69.5	7.2	92.8	5.4	94.6	116	200.2	1.293	1.022	1.36
69.4	0.0	100.0	0.0	100.0		200			

TABLE V

Equilibrium Data for System n-Octane - Toluene at 300 mm.

Temp. °C.	Weight % in Liquid		Weight % in Vapor		Vapor Pressure mm. Hg.		Activity Coefficient		Relative Volatility
	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	
94.4	100.0	0.0	100.0	0.0	300				
93.1	98.4	1.6	93.6	6.4	280	442	1.020	2.720	4.20
92.3	96.7	3.3	88.3	11.7	273	434	1.005	2.450	3.89
91.4	92.3	7.7	83.0	17.0	265	420	1.020	1.580	2.46
90.7	88.6	11.4	76.7	23.3	256	412	1.015	1.485	2.36
88.8	82.5	17.5	66.1	33.9	239	390	1.005	1.490	2.42
87.3	73.8	26.2	56.2	43.8	230	368	1.008	1.365	2.20
85.7	64.7	35.3	46.4	53.6	215	350	1.002	1.300	2.12
83.1	52.0	48.0	36.8	63.2	198	321	1.072	1.230	1.86
82.0	43.7	56.3	30.4	69.6	190	310	1.100	1.200	1.78
81.3	34.8	65.2	23.8	76.2	185	307	1.110	1.150	1.71
80.8	29.0	71.0	19.7	80.3	182	304	1.115	1.120	1.67
80.6	18.9	81.1	13.2	86.8	179	302	1.165	1.067	1.53
80.4	11.8	88.2	8.5	91.5	178	301	1.215	1.040	1.44
80.2	8.2	91.8	6.5	93.5	177	300.2	1.345	1.020	1.29
80.1	0.0	100.0	0.0	100.0		300.0			

TABLE VI

Equilibrium Data for System n-Octane - Toluene at 1,00 mm.

Temp. °C.	Weight % in Liquid		Weight % in Vapor		Vapor Pressure mm. Hg.		Activity Coefficient		Relative Volatility
	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	
103.0	100.0	0.0	100.0	0.0	4.00				
101.6	98.5	1.5	94.3	5.7	370	573	1.035	2.650	3.97
100.0	95.5	4.5	87.7	12.3	350	560	1.050	1.950	2.97
98.5	91.9	8.1	78.3	21.7	334	530	1.020	2.030	3.14
97.0	86.0	14.0	67.5	32.5	314	512	1.000	1.840	2.96
95.4	80.9	19.1	61.0	39.0	302	480	1.010	1.700	2.71
94.5	73.5	26.5	53.5	46.5	290	470	1.005	1.490	2.41
93.5	56.9	43.1	41.0	59.0	281	450	1.025	1.220	1.90
94.4	71.9	28.1	52.1	47.9	288	467	1.005	1.460	2.35
93.7	64.0	36.0	46.1	53.9	282	454	1.020	1.320	2.08
92.5	53.8	46.2	36.4	63.6	270	437	1.005	1.265	2.04
92.0	50.5	49.5	34.3	65.7	268	432	1.015	1.240	1.95
91.5	46.3	53.7	32.0	68.0	264	424	1.045	1.200	1.83
91.2	36.6	63.4	24.9	75.1	261	420	1.040	1.130	1.74
90.7	27.7	72.3	19.8	80.2	258	415	1.110	1.075	1.55
90.3	22.7	77.3	16.1	83.9	255	411	1.115	1.058	1.53
89.6	18.4	81.6	12.8	87.2	248	404	1.125	1.062	1.53
89.2	13.4	86.6	9.7	90.3	246	402	1.185	1.042	1.44
88.9	8.5	91.5	6.5	93.5	240	401	1.275	1.020	1.34
88.8	4.2	95.8	3.7	96.3	239	400.5	1.475	1.010	1.14
88.7	0.0	100.0	0.0	100.0		4.00			

TABLE VII

Equilibrium Data for System n-Octane - Toluene at 640 mm.

Temp. °C.	Weight % in Liquid		Weight % in Vapor		Vapor Pressure mm. Hg.		Activity Coefficient		Relative Volatility
	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	
118.4	100.0	0.0	100.0	0.0	640				
116.6	99.0	1.0	95.5	4.5	595	920	1.040	3.130	4.66
115.8	97.6	2.4	91.8	8.2	580	875	1.040	2.490	3.64
115.3	96.4	3.6	89.0	11.0	568	870	1.040	2.240	3.27
114.8	93.8	6.2	84.0	16.0	557	865	1.030	1.910	2.88
114.0	90.4	9.6	76.9	23.1	540	845	1.010	1.820	2.83
112.8	86.1	13.9	70.6	29.4	520	820	1.010	1.650	2.58
111.5	79.3	20.7	63.2	36.8	510	780	1.000	1.460	2.23
109.4	72.5	27.5	54.0	46.0	475	740	1.005	1.450	2.25
108.8	68.7	31.3	50.0	50.0	464	720	1.005	1.420	2.19
107.8	62.3	37.7	44.3	55.7	448	705	1.015	1.340	2.08
107.2	56.7	43.3	39.1	60.9	442	697	1.000	1.290	2.04
106.5	49.9	50.1	34.8	65.2	435	677	1.025	1.230	1.87
105.8	44.7	55.3	30.8	69.2	424	668	1.040	1.200	1.81
105.6	38.1	61.9	26.8	73.2	420	660	1.070	1.150	1.68
105.0	32.7	67.3	22.2	77.8	410	655	1.060	1.130	1.70
104.6	28.3	71.7	19.8	80.2	407	649	1.100	1.105	1.60
104.2	23.8	76.2	17.1	82.9	404	646	1.140	1.082	1.51
104.0	20.0	80.0	14.6	85.4	403	644	1.160	1.065	1.46
103.8	17.1	82.9	12.7	87.3	402	643	1.190	1.050	1.42
103.6	14.4	85.6	10.8	89.2	401	642	1.210	1.040	1.39
103.4	11.4	88.6	8.8	91.2	400	641	1.240	1.030	1.34
103.3	8.1	91.9	6.3	93.7	400	640	1.260	1.022	1.31
103.2	0.0	100.0	0.0	100.0		640			

TABLE VIII

Equilibrium Data for System n-Octane - Toluene at 760 mm.

Temp. °C	Weight % in Liquid		Weight % in Vapor		Vapor Pressure mm. Hg.		Activity Coefficient		Relative Volatility
	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	n-Octane	Toluene	
125.2	100.0	0.0	100.0	0.0	760				
124.0	99.3	0.7	97.1	2.9	720	1200	1.035	2.630	4.24
123.0	97.7	2.3	93.5	6.5	700	1150	1.040	1.870	2.95
122.2	94.9	5.1	87.7	12.3	680	1080	1.035	1.700	2.61
120.7	90.7	9.3	80.4	19.6	660	1050	1.020	1.560	2.38
119.0	83.6	16.4	69.3	30.7	645	975	0.990	1.460	2.26
117.4	77.4	22.6	61.8	38.2	598	930	1.015	1.380	2.12
116.2	69.8	30.2	55.6	44.4	579	900	1.045	1.240	1.85
115.0	64.5	35.5	46.9	53.1	558	866	0.990	1.310	2.06
113.8	54.5	45.5	38.1	61.9	527	840	1.010	1.230	1.95
113.0	46.2	53.8	32.7	67.3	522	822	1.025	1.160	1.77
112.3	36.2	63.8	25.2	74.8	518	810	1.020	1.100	1.64
111.6	26.8	73.2	19.3	80.7	511	790	1.075	1.060	1.53
111.0	19.2	80.8	14.2	85.8	498	775	1.130	1.040	1.43
110.5	10.5	89.5	8.2	91.8	486	766	1.220	1.020	1.32
110.2	5.2	94.8	4.1	95.9	478	762	1.250	1.010	1.28
110.1	0.0	100.0	0.0	100.0		760			

TABLE IX

Column Calibration Data for System n-Octane - Toluene

Pressure mm. Hg.	Weight % Toluene in Stillpot			Weight % Toluene in Distillate			Through- put ml./min.
	Total Reflux	30:1 Reflux Ratio	20:1 Reflux Ratio	Total Reflux	30:1 Reflux Ratio	20:1 Reflux Ratio	
20	17.6	11.0	8.1	96.6	96.5	96.2	1.80
50	5.5	7.3	16.0	96.9	96.9	96.2	9.3
100	4.4	7.3	8.4	96.7	96.2	96.5	12.7
200	3.9	8.0	10.5	96.7	96.5	96.5	18.7
300	9.9	12.0	9.9	97.0	96.6	96.1	20.8
400	10.6	13.0	15.8	96.4	96.1	95.9	25.8
640	8.1	14.0	17.4	96.0	95.5	94.4	26.9
760	7.6	12.8	18.1	95.4	95.6	95.3	28.6

Column Standardization with System n-Heptane - Toluene

760	20.5	18.0	28.0	92.5	88.9	90.0	28.0
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TABLE X

Column Calibration Data for System n-Octane - Toluene

Pressure mm. Hg.	Number of Theoretical Plates			H.E.T.P.		
	Total Reflux	30:1 Reflux Ratio	20:1 Reflux Ratio	Total Reflux	30:1 Reflux Ratio	20:1 Reflux Ratio
20	13	14	15	1.77	1.64	1.53
50	13	14	12	1.77	1.64	1.92
100	13.5	13.5	13.75	1.70	1.70	1.67
200	12.5	12.5	12.5	1.84	1.84	1.84
300	11.5	11.75	11.5	2.0	1.96	2.0
400	11	11	11	2.09	2.09	2.09
640	11.5	11.5	11.5	2.0	2.0	2.0
760	11.75	12	11.75	1.96	1.92	1.96

Column Standardization with System n-Heptane - Toluene

760	14	14	14	1.64	1.64	1.64
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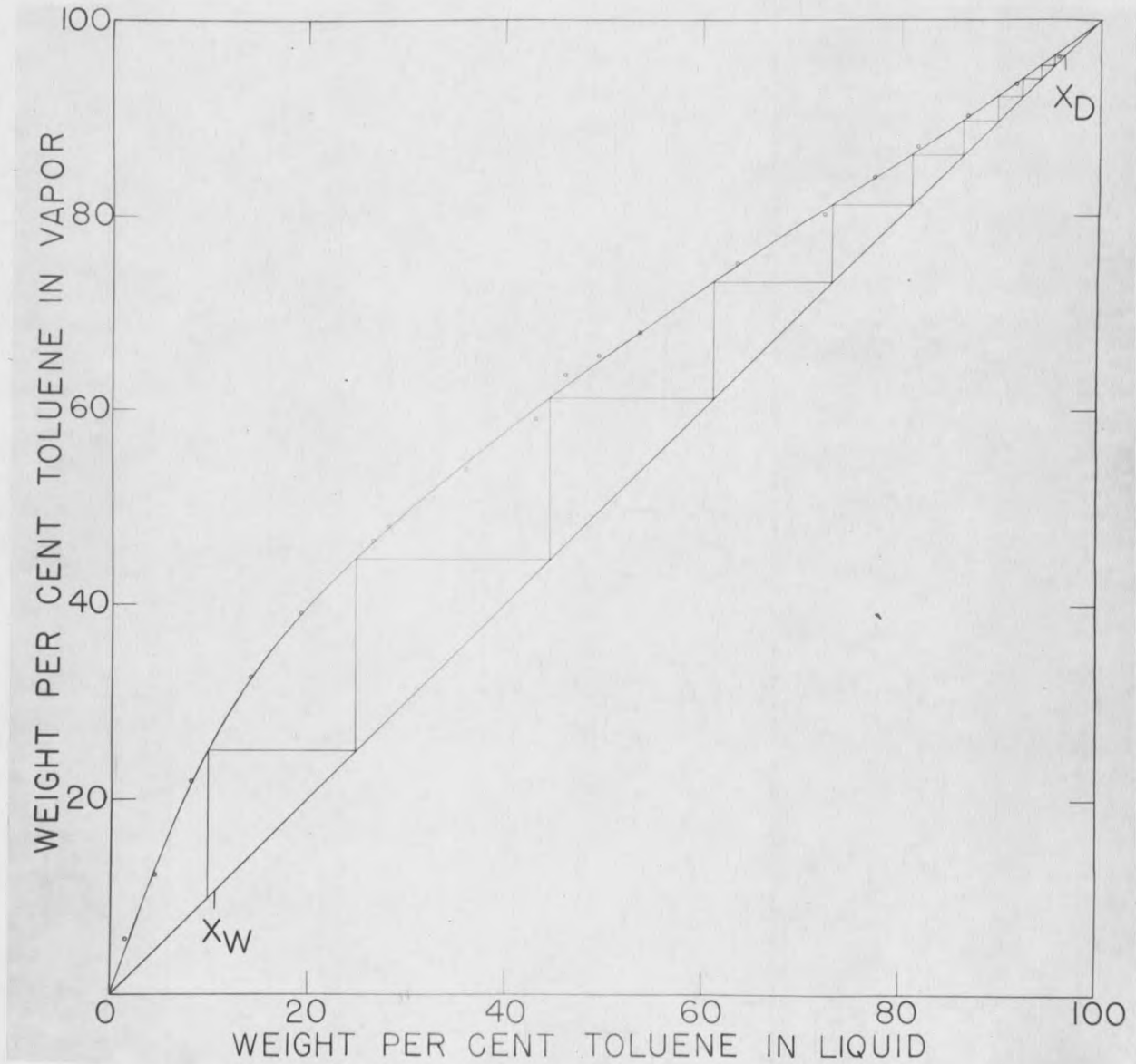


Figure 1

Equilibrium Curve and Theoretical Plates at Total Reflux
at 400 mm. Hg.

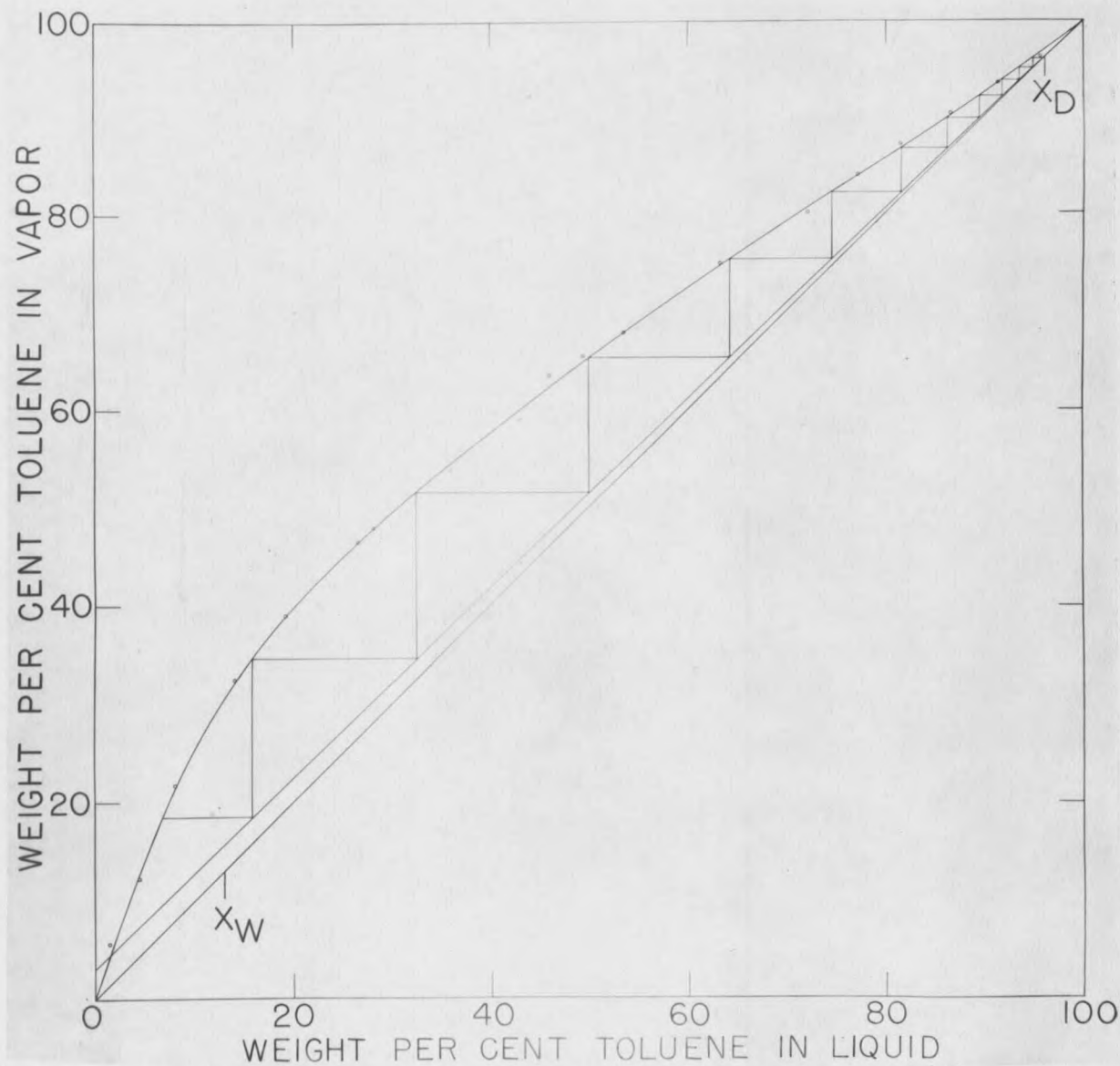


Figure 2

Equilibrium Curve and Theoretical Plates at 30:1 Reflux Ratio at 400 mm. Hg.

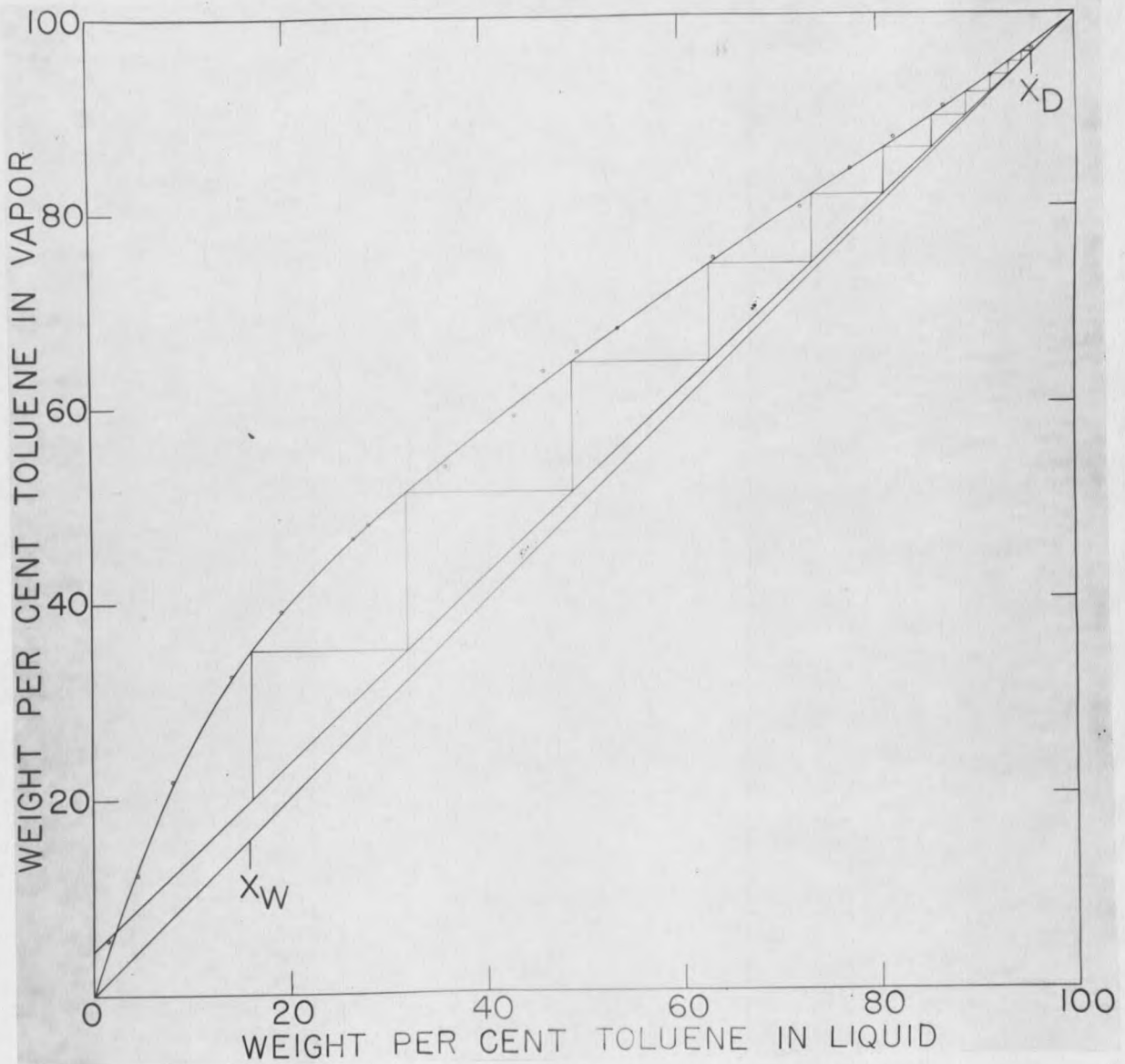


Figure 3

Equilibrium Curve and Theoretical Plates at 20:1 Reflux Ratio at 400 mm. Hg.

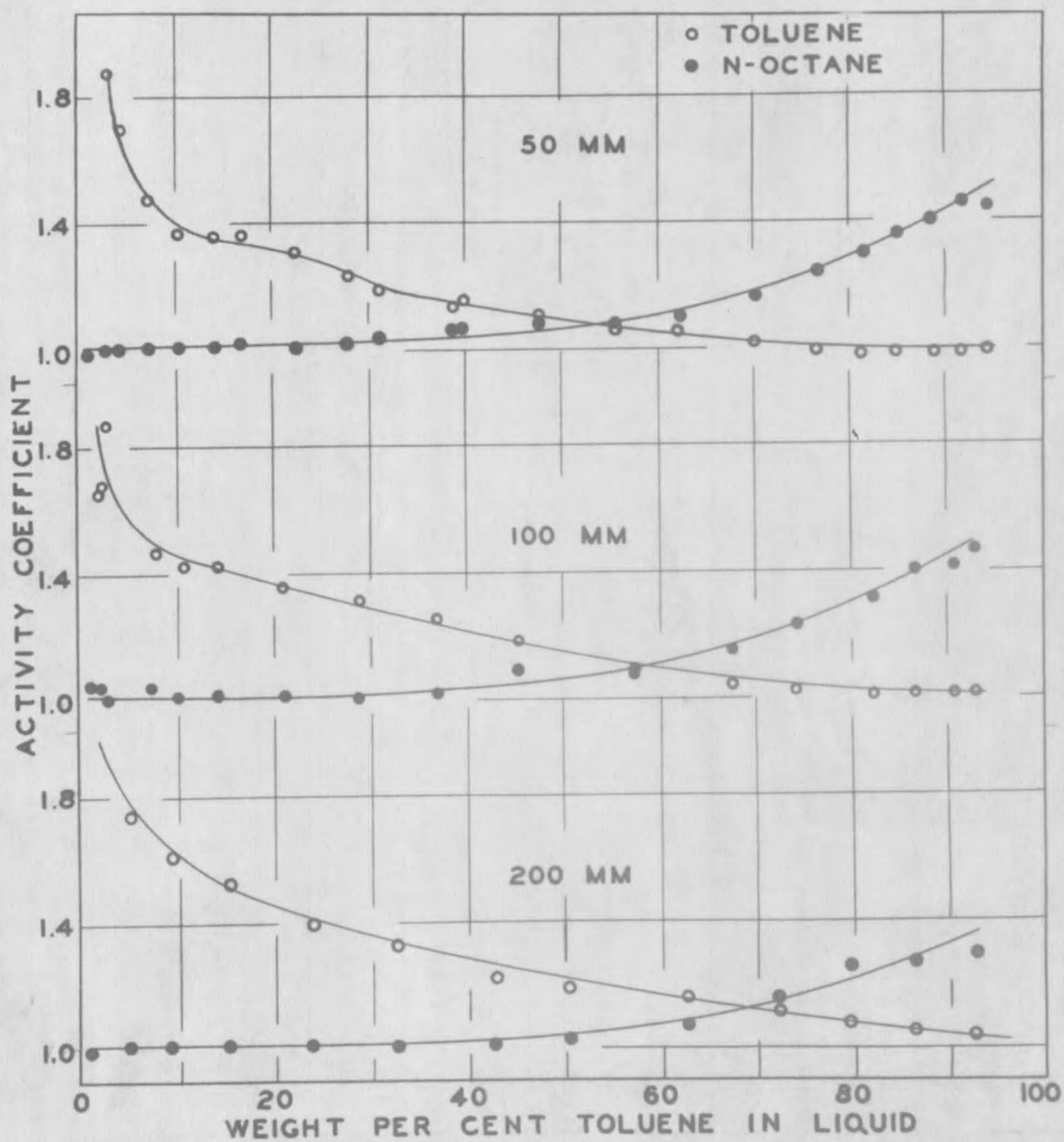


Figure 4
Activity Coefficients at Various Pressures

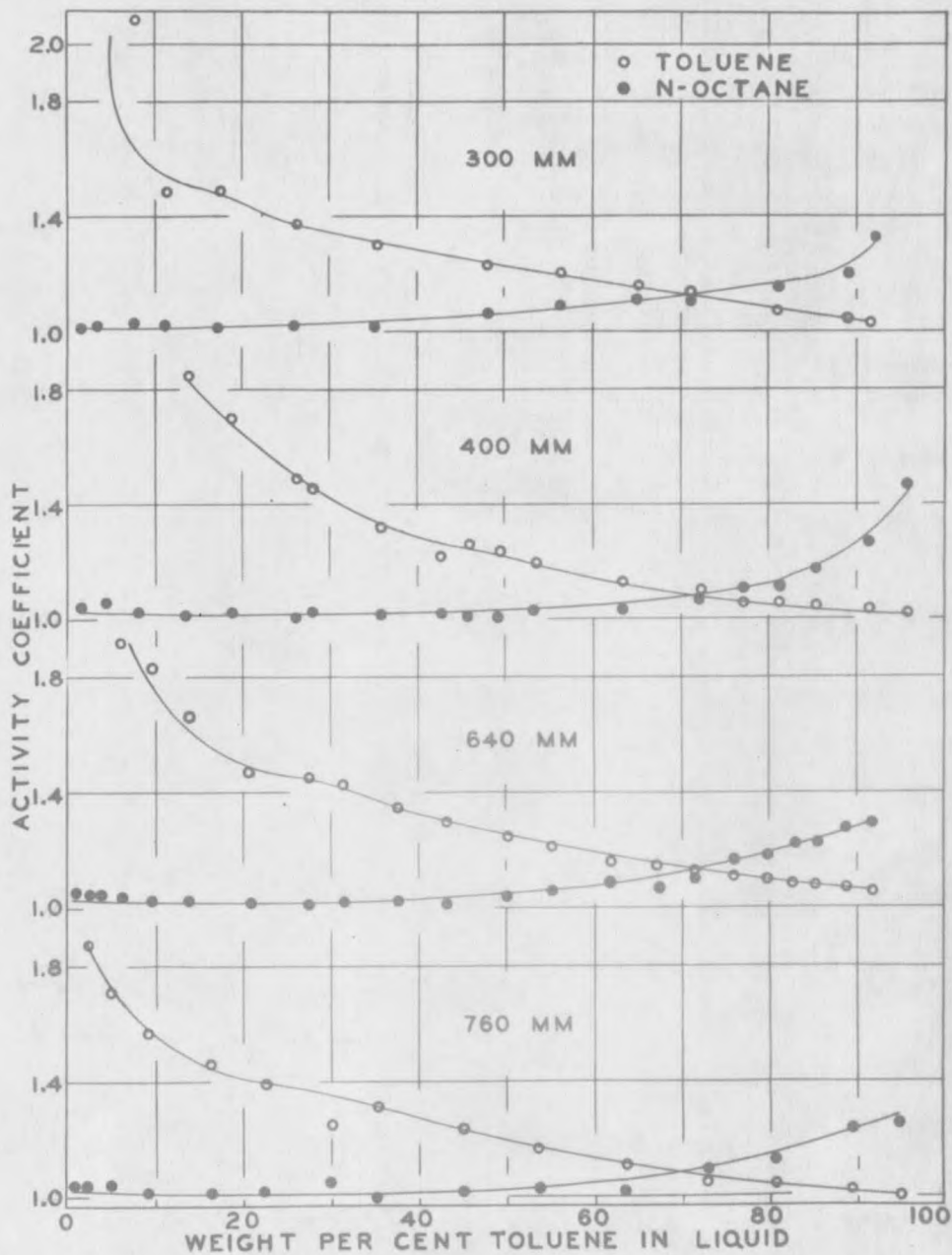


Figure 5
Activity Coefficients at Various Pressures

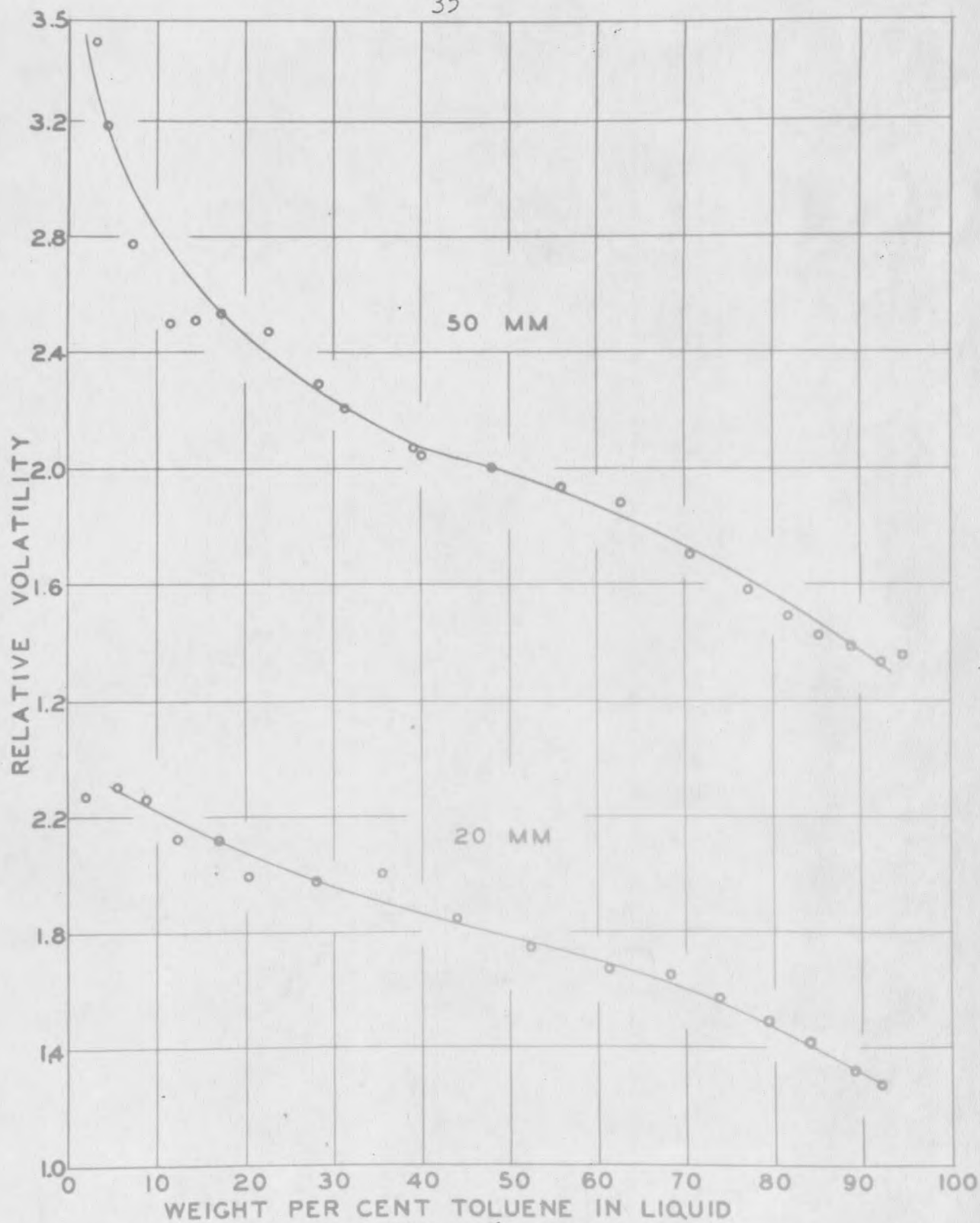


Figure 6
Relative Volatilities at 20 mm. and 50 mm. Hg.

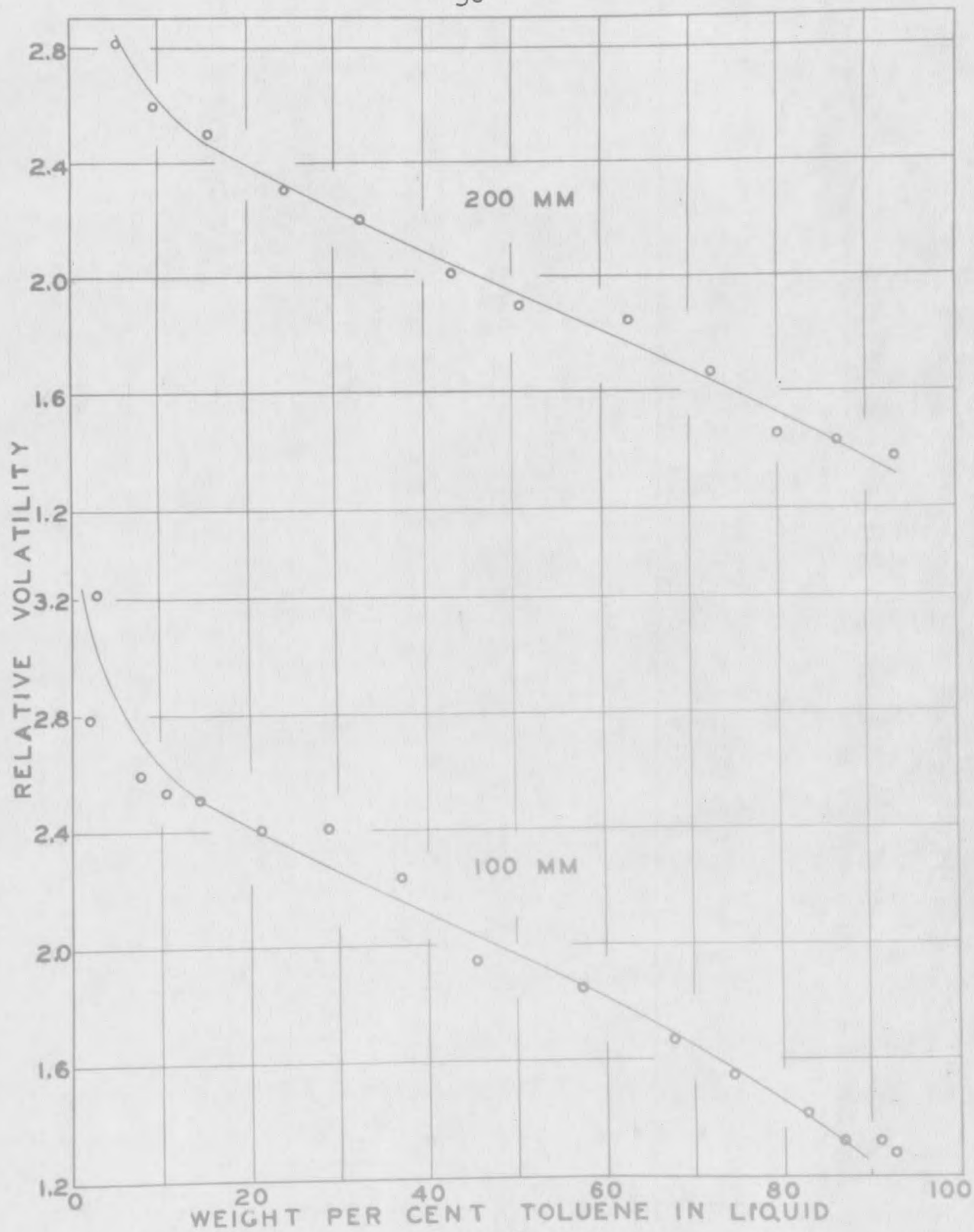


Figure 7
Relative Volatilities at 100 mm. and 200 mm. Hg.

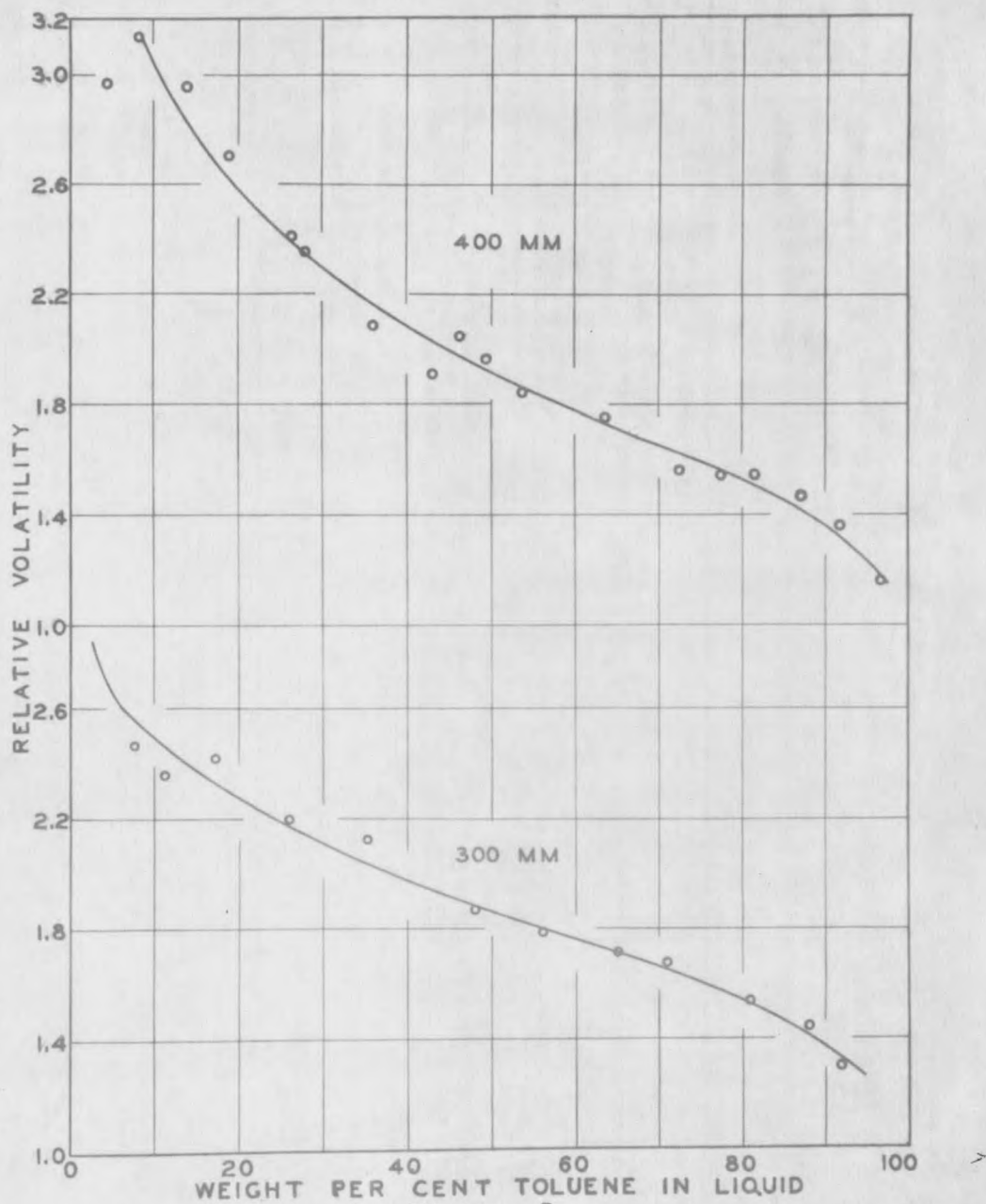


Figure 8
Relative Volatilities at 300 mm. and 400 mm. Hg.

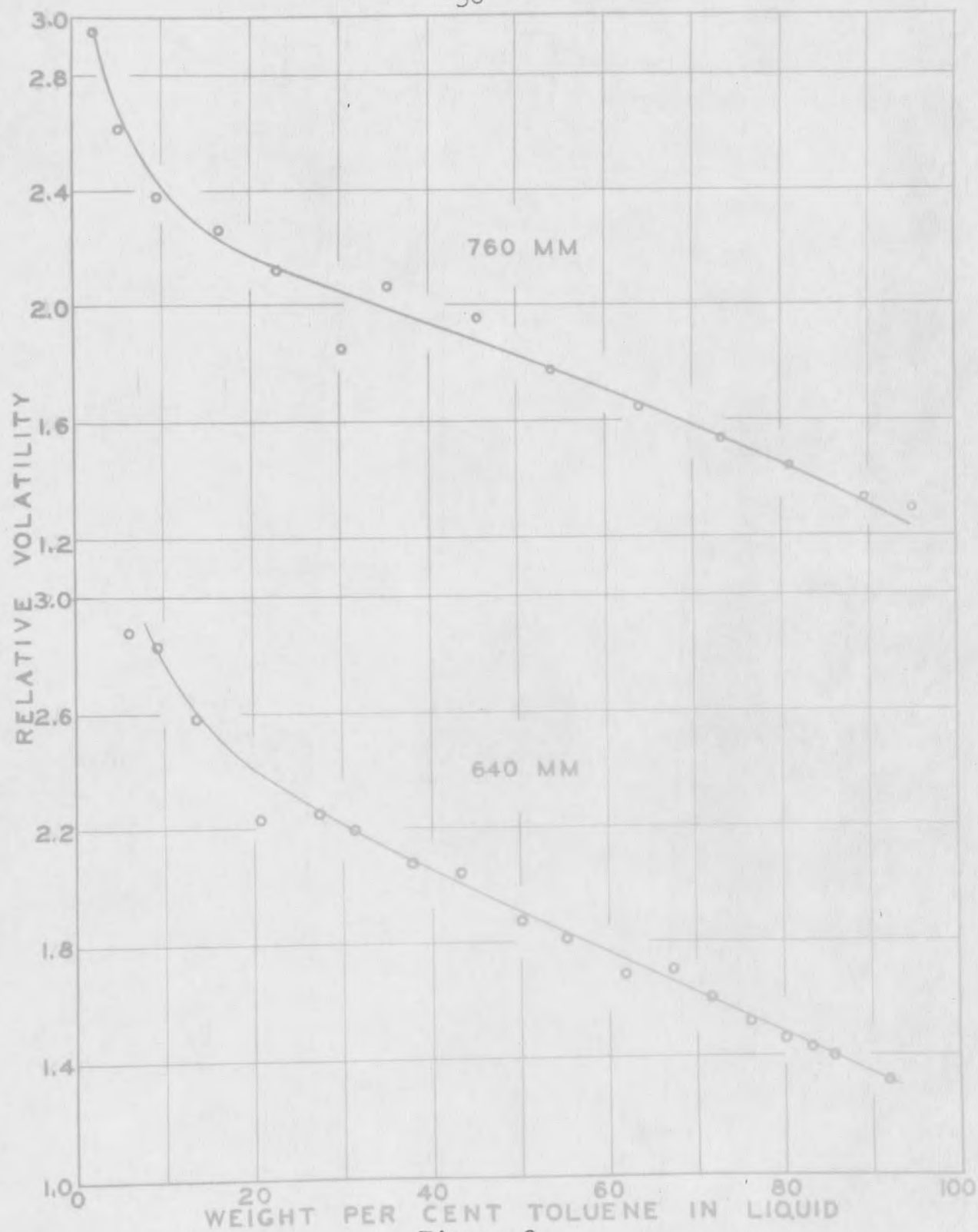


Figure 9

Relative Volatilities at 640 mm. and 760 mm. Hg.

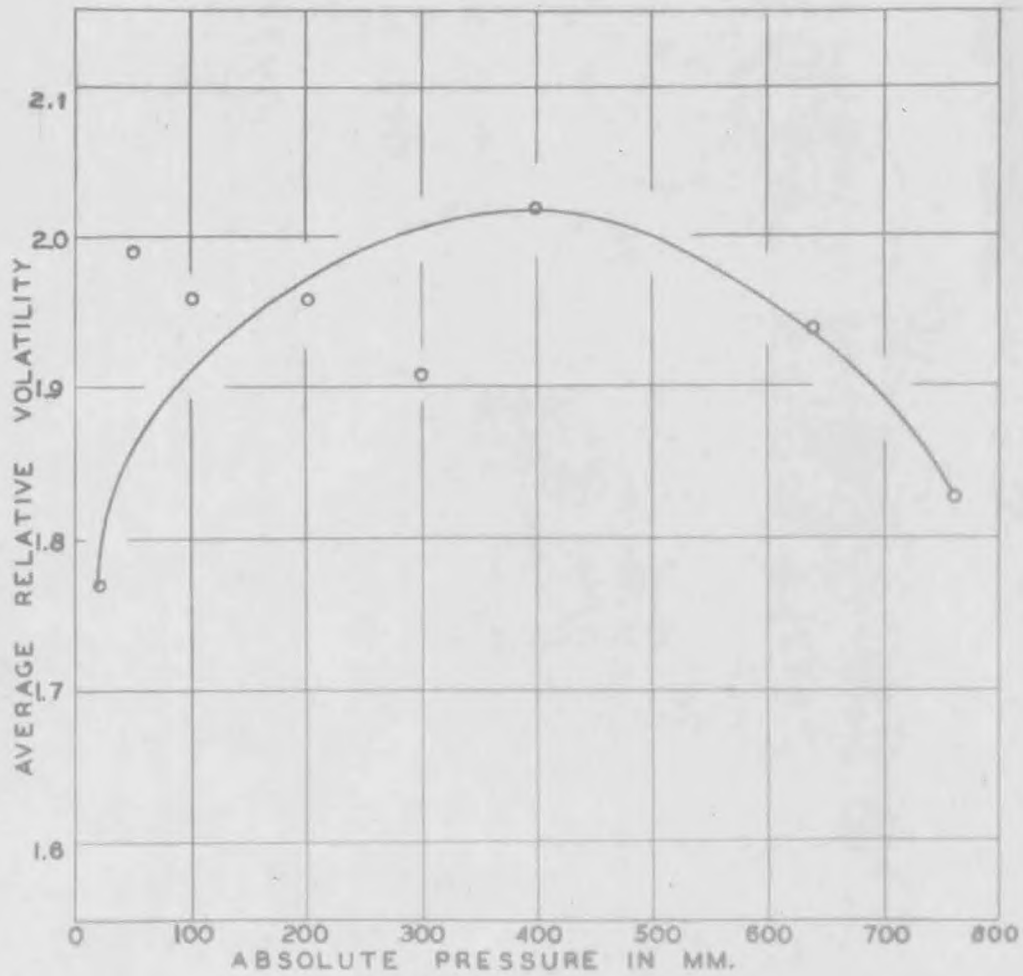
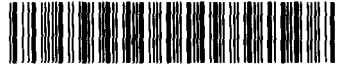


Figure 10

Average Relative Volatility versus Pressure in
mm. Hg.



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The effect of reduced pressure on the efficiency of a packed rectification column

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