ENGINEERING CALCULATIONS FOR THE DISTILLATION OF THE FURFURAL-WATER SYSTEM

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ENGINEERING CALCULATIONS FOR THE DISTILLATION OF THE FURFURAL-WATER SYSTEM

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Introduction

Process design calculations being carried out at the U. S. Forest Products Laboratory to obtain optimum operating conditions for a pilot-plant furfural reactor required data on high-pressure, vapor-liquid equilibrium for the furfural-water system. While the literature yielded some data for pressures up to 9.5 atmospheres, the processing investigations involved pressures up to about 20 atmospheres. Part 1 of this report outlines how the existing data were extrapolated and gives the results of this extrapolation.

The important results of the calculations concerning the recovery of furfural by distillation at atmospheric pressure are presented in Part 2. Also included in Part 2 is a calculation procedure for selecting equipment of optimum size. The procedure is elucidated with an example calculation.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

PART 1: EXTRAPOLATION OF VAPOR-LIQUID EQUILIBRIUM DATA

Nomenclature

The nomenclature used in the extrapolation of vapor-liquid equilibrium data is as follows:

- p - partial pressure - atmospheres
- π - total pressure - atmospheres
- n - gram - mols
- R - Universal Gas Constant = 1.987 $\frac{\text{cals}}{\text{gm. mol - °K}}$
- T - temperature - °K
- γ - liquid activity coefficient
- x - mol fraction in the liquid
- y - mol fraction in the vapor
- P - vapor pressure of pure component - atmospheres
- ΔH - heat of mixing - $\frac{\text{cals}}{\text{gm. - mol}}$
- A, B - Van-Laar coefficients

Subscripts

- w - water
- F - furfural
- a - azeotrope
- T_{ws} - boiling point of water

Basic Equations

$$p_F + p_w = \pi \tag{1}$$

$$p_F = n_F \frac{RT}{V} \tag{2}$$

$$p_w = n_w \frac{RT}{V} \tag{3}$$

$$\gamma_F x_F P_F = y_F \pi = p_F \tag{4}$$

$$\gamma_w x_w P_w = y_w \pi = p_w \tag{5}$$

$$\left(\frac{\delta \ \ln \gamma_F}{\delta T}\right)_{x_F} = - \frac{\Delta H}{RT^2} \qquad (6)$$

$$\log \gamma_F = \frac{B x_w^2}{\left[x_w + \left(\frac{B}{A}\right) x_F\right]^2} \qquad (7)$$

$$\log \gamma_w = \frac{A x_w^2}{\left[\left(\frac{A}{B}\right) x_w + x_F\right]^2} \qquad (8)$$

Data--Values and Sources

Vapor pressure data for water in the range 100° to 300° C., taken from the International Critical Tables,[2] was fitted to the functional form, $\ln P_w = \frac{a}{T} + b$, by the method of least squares to obtain the constants in equation (9).

$$\ln P_w = \frac{4731.6}{T} + 12.7172 \qquad (9)$$

The following vapor pressure equation for furfural was taken from a publication by Dunlop and Peters.[3]

$$\ln P_F = \frac{5086.4}{T} + 11.6926 \qquad (10)$$

Vapor-Liquid Equilibrium

When this work was begun, only one source of data for the homogeneous system was known to be available.[4] Subsequently, some Russian

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[2] International Critical Tables, III, 233 (1928).

[3] Dunlop, A. P. and Peters, F. N. "The Furans" p. 315. Reinhold, New York, 1953.

[4] Curtis, R. G., and Hatt, H. H. Australian Journal of Science Research, A, 1, 213 (1948).

data[5] became available but were not used in the extrapolation. The extrapolation was based on experimental data for pressures of 5.97, 7.60, and 9.51 atmospheres. At each of these pressures the system exhibits a homogeneous azeotrope. Data taken at these pressures are included in table 3.

Method of Extrapolation

Correlation of Experimental Data

Using the experimental data of Curtis and Hatt[4] and equations (1), (2), (3), (4), and (5), values of γ_F and γ_w were calculated in the concentration range of interest, 0-10 mol percent. The results of these calculations are listed in table 3. Correlations of γ_F as a function of x_F at the three pressures are shown in figures 1, 2, and 3. These curves were obtained in the following manner:

The Van-Laar equations, (7) and (8), show that

$$B = [\ln \gamma_F]_{x_F = 0}$$

and

$$A = [\ln \gamma_w]_{x_w = 0}$$

According to (6), both A and B should plot as straightline functions of $\frac{1}{T}$ if ΔH is considered constant.

Therefore, correlation was done by fitting the Van-Laar functional form to the data, with the restriction that the constants A and B had to be straightline functions of $\frac{1}{T}$. The values of B were calculated from the intercept values, and values of A from the value of γ_F at $\gamma_F = 0.09$, Best fit of the curves was judged by visual inspection. The final values selected for A and B are given in table 1.

[5] Mel'nikov, N. P., and Tsirlin, Yu. Zhur Priklad Khim. 29 (9) 1456 (1956).

Extrapolation Procedure

A preliminary estimate, using the method of Carlson and Coburn,[6] indicated that only a small temperature difference between the boiling point of the azeotrope and the boiling point of water at the same pressure would be expected; thus A and B could be considered constant over the concentration range of interest, varying only with the temperature (pressure) level.

The values of A and B used at each pressure were obtained from the equations:

$$A = \frac{-0.20505}{T} \times 10^3 + 0.9017 \qquad (11)$$

$$B = \frac{0.9091}{T} \times 10^3 - 0.60886 \qquad (12)$$

The value of T to be used with these equations is the saturation temperature of water at the particular pressure involved. The constants used in equations (11) and (12) were evaluated by fitting the experimental values of A and B to the functional form, using the least mean squares method. Calculated values used for each pressure are listed in table 1.

The calculation procedure for obtaining x-y points was as follows:

1. At a chosen π and x_F, the values of A and B were available from table 1.

2. Assuming a T, the vapor pressures P_F and P_w were calculated from equations (9) and (10).

3. Values of γ_F and γ_w were calculated from equations (7) and (8).

4. The partial pressures p_w and p_F were calculated from equations (4) and (5).

5. The values of p_w and p_F must satisfy equation (1); if not, a new temperature must be assumed in step (2) and the calculation reiterated until equation (1) is satisfied.

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[6] Hougen, O. A., and Watson, K. M. Chemical Process Principles, Vol II, Chapter XV. John Wiley and Sons, New York (1947).

6. The correct values of p_w and p_F from step (5) were used in equations (2) and (3) to obtain the values of y_F.

Results

The numerical work was set up for processing on an electronic computer. Results are listed in table 2 and presented graphically in figure 4. Figures 5, 6, and 7 show a comparison of the calculated values with the original experimental data used to make the extrapolation.

Comparison of the calculated values with the more recent Russian data listed in table 9 reveals large differences. This is to be expected, as the Russian data vary considerably from the data of Curtis and Hatt used to make the calculation. Unfortunately, no equilibrium temperature measurements were included in the Russian work. Thus, it was not possible to extrapolate it over the concentration range of interest.

PART 2: DISTILLATION AT ATMOSPHERIC PRESSURE

Nomenclature

Nomenclature used in the following distillation calculations is as follows:

- H - enthalpy of vapor - B.t.u. per lb.
- h - enthalpy of liquid - B.t.u. per lb.
- w - reflux - lb. per hr.
- D - distillate - lb. per hr.
- s - bottoms - lb. per hr.
- V - vapor - lb. per hr.
- r - recovery - percent
- F - feed - lb. per hr.
- G - mass velocity - lb. per $ft.^2$-hr.
- L - tower diameter - inches
- q - heat load - B.t.u.
- C - tower cost - $ per plate
- a - cross-sectional tower area - $ft.^2$
- B - vertical coordinate of operating point for rectifying section on the Ponchon-Savarit Diagram - B.t.u.

λ - vertical coordinate of operating point for stripping section on the Ponchon-Savarit Diagram - B.t.u.

α - relative volatility

Subscripts

c - condenser
s - bottoms
n - n^{th} plate
1 - top plate
D - distillate
w - water

Plate and Energy Calculations

Although the fractionation of aqueous furfural solutions is complicated by the formation of an azeotrope at a 35 percent furfural content, it nevertheless is possible to separate pure furfural by distillation at atmospheric pressure. This is due to the partially miscible liquid system formed by condensing vapors that contain more than 18.1 percent furfural and the accompanying enrichment that takes place in the denser phase. Solutions containing less than 18.1 percent of furfural can be rectified to give an 84.1 percent furfural product and a bottom with practically zero furfural content. The product of rectification, which has passed the azeotrope composition (35 percent of furfural) because of enrichment on condensing, is then suitable for further processing in a stripper where essentially pure furfural is obtained.

Determination of the plate and energy requirements for this two-tower distillation system was made by the Ponchon-Savarit method. The problem was divided into two parts corresponding to the azeotrope column (where the dilute solution is concentrated to yield a two-phase liquid product) and the dehydrating column (where pure furfural is stripped from the 84.1 percent furfural feed).

Azeotrope Column

In the derivation of furfural solutions from pentose-containing materials, the reaction kinetics and processing conditions limit the possible feed concentrations to the azeotrope column to less than 7 percent of furfural. In rectifying such feeds, the condensed overhead vapors yield a two-phase liquid containing 84.1 percent of furfural in the denser phase and 18.1 percent in the lighter phase. The lighter phase is refluxed to the azeotrope tower, while the heavy phase is sent to the dehydrator. It is possible to describe the operation of the azeotrope tower if the vapor-liquid equilibrium relationship is known and the following four variables are specified: Feed composition, enthalpy of the feed, reflux ratio, and recovery. In the analysis of the azeotrope tower, the range of these variables was:

H_F = 100, 125, 150, 175, 200, 225 B.t.u. per lb.
x_F = 1, 1.5, 2, 2.5, 3, 5, 6.45 percent furfural
$\frac{w}{D}$ = [1, 1.05, 1.10, 1.15, 1.2, 1.5, 2, 2.5, 3, 4] $(\frac{w}{D})$ min.

r = 99, 97, 95, 90 percent

The values for the enthalpy of the feed correspond to feed conditions from below saturation to slightly above saturation. In the solution of the azeotrope problem to find the plate and energy requirements for the variables listed above, the following equations were used:

$$\alpha = \frac{(100 - x)\ y}{(100 - y)\ x}$$

$$H = -7.48\ y + 1155$$

$$h = -.7\ x + 180$$

$$\frac{h - h_F}{x - x_F} = \frac{H - h}{y - x}$$

$$\frac{x_D - y_1}{y_1 - x_w} = \frac{B - H_1}{H_1 - h_w}$$

$$\frac{w}{D} = \frac{x_D - y_1}{y_1 - x_w}$$

$$y_{n+1} = \frac{81,997.5 + x_n [B - 1096.13]}{- 6.78 x_n + B + 449.1}$$

$$x_{n+1} = \frac{975 x_s - y_n (\lambda - 180 + 7.48 x_s)}{- 6.78 y_n - .7 x_s - \lambda + 1155}$$

$$r = \frac{x_D D}{x_F F} [100]$$

Calculation was carried out by the following procedure:

1. Determination of the tie line through a given $\underline{x_F}$ and $\underline{H_F}$.

A. Assume $\underline{x}$ lies on the tie line and find the equilibrium $\underline{y}$ value from:

$$\alpha = \frac{(100 - x) y}{(100 - y) x}$$

B. Compute the corresponding $\underline{h}$, $\underline{H}$, $\underline{h_F}$, and $\underline{H_F}$ by:

$$h = - 0.7 x + 180$$

$$H = - 7.48 y + 1155$$

C. Check the computed values

$$\frac{h - h_F}{x - x_F} = \frac{H - h}{y - x}$$

D. (a) If the assumed $\underline{x}$ satisfied the equation, then it lies on the tie line that passes through (x_F, H_F).

(b) If the equation is not satisfied, a new $\underline{x}$ must be assumed and the calculation repeated.

2. Minimum reflux ratio

A. Extrapolate the tie line determined in step 1 through $\underline{x_D}$ to obtain the operating point (X_D, B).

B. Solve the following two equations for $\underline{y_1}$ and $\underline{H_1}$:

$$\frac{x_D - y_1}{y_1 - x_w} = \frac{(\frac{q_c}{D} + h_D) - H_1}{H_1 - h_w}$$

$$H = -7.48\ y + 1155$$

and
$$\frac{W}{D} = \frac{x_D - y_1}{y_1 - x_w}$$

3. Determine theoretical plates and heat loads at various reflux ratios.

A. For a given reflux ratio, determine $\underline{y_1}$ and $\underline{H_1}$ from the equations given in 2 B.

B. Determine the operating point (x_D, B)

$$B = (H_1 - h_w)\left[\frac{x_D - y_1}{y_1 - x_w}\right] + H_1$$

C. Find $\frac{q_c}{x_F F}$; condenser heat load per pound of furfural fed to the column.

$$B = \frac{q_c}{D} + h_D$$

$$x_s = \frac{x_D\ x_F\ [1 - R]}{x_D - R\ x_F}$$

$$\frac{q_c}{x_F F} = \left[\frac{B - h_D}{x_F}\right]\left[\frac{x_F - x_s}{x_D - x_s}\right]$$

4. Extrapolate the line through ($\underline{x_D}$, $\underline{B}$) and ($\underline{x_F}$, $\underline{H_F}$) to get the operating point ($\underline{x_s}$, $\underline{\lambda}$).

5. Calculate $\frac{q_s}{x_F F}$; reboiler heat load per pound of furfural fed to the column.

$$\lambda = h_s - \frac{q_s}{s}$$

$$\frac{q_s}{x_F F} = \left[\frac{h_s - \lambda}{x_F}\right]\left[\frac{x_F - x_D}{x_s - x_D}\right]$$

6. Determine the theoretical number of plates in the rectifying section.

A. Using the $\underline{y_1}$ determined in step 3A, find the corresponding $\underline{x_1}$.

$$\alpha = \left[\frac{100 - x}{100 - y}\right]\left[\frac{y}{x}\right]$$

B. Calculate y_{n+1} by:

$$y_{n+1} = \frac{81,997.5 + x_n [B - 1096.13]}{-6.78\ x_n + B + 449.1}$$

C. If $\underline{x_n}$ is greater than the $\underline{x}$ determined in step 1, then steps A and B must be repeated using the previously calculated $\underline{y_{n+1}}$.

7. Determine the theoretical number of plates in the stripping section.

A. From the relative volatility relationship, get the $\underline{y}$ associated with $\underline{x_s}$.

B. Calculate $\underline{x_{n+1}}$ by:

$$x_{n+1} = \frac{975\ x_s - y_n (\lambda - 180 + 7.48\ x_s)}{-6.78\ y_n - .7\ x_s - \lambda + 1155}$$

C. If $\underline{x_{n+1}}$ is greater than the $\underline{x}$ determined in step 1, steps A and B must be repeated, using the calculated $\underline{x_{n+1}}$.

The above computations were programed and carried out on an electronic computer for the entire grid of variables listed on page 6. Results of these computations are listed in tables 4, 5, and 6, and illustrated in figures 10, 11, and 13.

Dehydrating Column

The 84.1 percent furfural product of the azeotrope column is fed to the dehydrator, where pure furfural is withdrawn as bottoms and a vapor of the azeotrope composition is produced overhead. The calculations for this tower can be treated similarly to those for the azeotrope tower by using concentrations in terms of water rather than furfural and by reversing the enthalpy lines on the Ponchon-Savarit diagram. The feed may be considered as two parts--a feed resulting from refluxing part of the overhead vapors, and the furfural-rich layer from the azeotrope column. With the following changes, the dehydrating column can be solved, using the same program as for the azeotrope column.

(1) The feed to the dehydrating tower contains 15.9 percent of water and is fed at saturation temperature.

(2) This feed falls on a known equilibrium tie line, so the minimum reflux ratio is also known without calculation. This part of the computation can therefore be skipped.

(3) It is not necessary to use the rectifying plate calculation.

(4) Change the constants in the $\underline{x_{n+1}}$ and enthalpy equations.

(5) Bottoms composition is known to be 99.5 percent furfural.

Table 7 summarizes the results of this computation.

Costs and Design Factors for the Distillation Columns

The design of the distillation unit was based on a production of 15,000,000 pounds of furfural per year. Using the results of the plate and energy calculation, distillation costs were determined from the following relations:

1. $$F = D\left[\frac{x_D - x_s}{x_F - x_s}\right]$$

2. $$V_1 = D \left[\frac{x_D - x_w}{y_1 - x_w} \right]$$

3. $$a = \frac{V_1}{G}$$

$$G = 904 \text{ lb. per hr.-ft.}^2$$

where G is the allowable vapor velocity. This was based on using the properties of water as the properties of the fluid being distilled and assuming a plate spacing of 24 inches.[7] The area based on the vapor velocity is sufficient to accomodate the liquid flow if the liquid down-spouts comprise 10 percent of the plate area and if the velocity in them is at least 4 feet per second.

4. Overall plate efficiency = 43 percent.[8]

5. $$\ln C = 0.1187 (\ln L)^2 + 4.95769$$

This relation was determined from the data presented in Newton and Aries,[9] and was scaled to current costs with the Marshall Stevens index. The final tower cost was amortized over a 3-year period after maintenance costs of 10 percent were included.

6. Steam cost = $1.00 per million B.t.u's

The above relations were applied to the engineering results of the previous sections to obtain the data shown in table 8 and figures 8, 9, 12, and 13. Comparison of figures 8 and 9 indicates there is negligible variation in the cost of the azeotrope distillation with a change in feed enthalpy. In going from 100 to 225 B.t.u. per pound of feed, the distillation cost for a feed solution with 2 percent of furfural is decreased by less than 0.03 cent per pound of furfural produced. This represents about a 3 percent change in the cost.

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[7] Sanders, M., and Brown, G. G. Ind. Eng. Chem., 26, 98 (1934).

[8] O'Connell, H. E. Trans. Inst. Chem. Engrs., 42, 741 (1946).

[9] Aries, R. S., and Newton, R. D. Chemical Engineering Cost Estimation, p. 70. McGraw-Hill Book Company, Inc., New York (1955).

Figures 8 and 9 also demonstrate that the optimum ratio of actual reflux to minimum reflux is very nearly constant and is in the region of 1.10 to 1.15. The major portion of the cost for distillation in the azeotrope tower can be attributed to the cost of steam. According to the values in table 8, the steam cost accounts for approximately 80 percent of the total cost and, in general, amounts to less than a cent per pound of furfural. From figure 10, the steam requirement range from 17 to less than 5 pounds per pound of furfural at feed concentrations of 1 and 6.45 percent of furfural. This corresponds to an annual steam cost of about $50,000 to $160,000, whereas the total azeotrope tower costs are in the order of $50,000.

In contrast to the distillation in the azeotrope column, the requirements for the recovery of furfural in the dehydrator are exceedingly small. Steam consumption in the dehydrating tower is approximately one-tenth of that for the azeotrope column; while, in addition, the tower diameter and the number of plates necessary for separation in the dehydrator are smaller by a factor of about seven or eight. Accordingly, the economics of the entire distillation operation are predominately influenced by the mode of operation in the azeotrope column.

Table 1.--Extrapolated values of Van-Laar constants at various pressures based upon experimental data at 5.97, 7.60, and 9.51 atmospheres

Line No.	Pressure π	Equilibrium temperature T	Van-Laar constant A	Van-Laar constant B
	Atm.	°K		
1	1.000	372.1	0.3507	1.834
2	2.000	393.5	.3807	1.701
3	4.000	407.3	.3983	1.623
4	5.970	432.9	.4280	1.491
5	7.600	442.7	.4385	1.445
6	9.5100	452.1	.4481	1.402
7	10.00	454.3	.4504	1.392
8	12.00	462.4	.4582	1.357
9	14.00	469.5	.4649	1.327
10	16.00	475.8	.4707	1.302
11	18.00	481.5	.4758	1.279
12	20.00	486.7	.4803	1.259

Table 2.--Calculated values of equilibrium boiling points and vapor and liquid compositions at various pressures

Line No.	Pressure π	Equilibrium temperature T	Furfural in the liquid x_F	Furfural in the vapor y_F
	Atmospheres	°K	Mol percent	Mol percent
1	1.000	371.1	0.5	3.679
2		370.5	1	5.900
3		370.0	2	8.053
4		369.8	3	8.733
5		369.3	4	8.800
6		369.9	5	8.555
7		369.9	6	8.225
8		369.9	7	7.867
9		369.9	8	7.519
10		369.9	8.5	7.355
11	2.000	392.3	0.5	3.002
12		392.1	1	5.019
13		391.5	2	7.315
14		391.2	3	8.340
15		391.2	4	8.726
16		391.2	5	8.782
17		391.2	6	8.667
18		391.2	7	8.468
19		391.2	8	8.233
20		391.2	8.5	8.112
21	4.000	416.7	0.5	2.709
22		416.2	1	4.625
23		415.5	2	6.975
24		415.2	3	8.170
25		415.0	4	8.739
26		415.0	5	8.957
27		415.0	6	8.975
28		415.0	7	8.882
29		415.0	8	8.728
30		415.0	8.5	8.639
31	5.970	432.2	0.5	2.139
32		431.7	1	3.773
33		431.1	2	6.001
34		430.7	3	7.338
35		430.5	4	8.132
36		430.4	5	8.586
37		430.4	6	8.824
38		430.4	7	8.921
39		430.4	8	8.929
40		430.4	8.5	8.910

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Table 2.--Calculated values of equilibrium boiling points and vapor and liquid compositions at various pressures--Continued

Line No.	Pressure π	Equilibrium temperature T	Furfural in the liquid x_F	Furfural in the vapor y_F
	Atmospheres	°K	Mol percent	Mol percent
41	7.600	442.0	0.5	1.982
42		441.5	1	3.530
43		440.9	2	5.711
44		440.5	3	7.080
45		440.3	4	7.938
46		440.2	5	8.465
47		440.2	6	8.775
48		440.1	7	8.939
49		440.1	8	9.006
50		440.1	8.5	9.013
51	9.510	451.5	0.5	1.844
52		451.1	1	3.313
53		450.4	2	5.440
54		450.1	3	6.829
55		449.8	4	7.738
56		449.7	5	8.327
57		449.7	6	8.700
58		449.6	7	8.924
59		449.6	8	9.044
60		449.6	8.5	9.076
61	10.00	453.7	0.5	1.813
62		453.3	1	3.263
63		452.6	2	5.377
64		452.3	3	6.769
65		452.0	4	7.689
66		451.9	5	8.292
67		451.8	6	8.679
68		451.8	7	8.916
69		451.8	8	9.050
70		451.8	8.5	9.088
71	12.00	461.9	0.5	1.708
72		461.4	1	3.095
73		460.8	2	5.160
74		460.4	3	6.559
75		460.2	4	7.512
76		460.0	5	8.160
77		460.0	6	8.595
78		459.9	7	8.879
79		459.9	8	9.057
80		459.9	8.5	9.115

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Table 2.--Calculated values of equilibrium boiling points and vapor and liquid compositions at various pressures--Continued

Line No.	Pressure π	Equilibrium temperature T	Furfural in the liquid x_F	Furfural in the vapor y_F
	Atmospheres	°K	Mol percent	Mol percent
81	14.00	469.0	0.5	1.622
82		468.5	1	2.957
83		467.9	2	4.976
84		467.5	3	6.376
85		467.3	4	7.354
86		467.1	5	8.037
87		467.1	6	8.511
88		467.0	7	8.834
89		467.0	8	9.048
90		467.0	8.5	9.123
91	16.00	475.3	0.5	1.555
92		474.9	1	2.846
93		474.3	2	4.827
94		473.9	3	6.226
95		473.6	4	7.223
96		473.5	5	7.933
97		473.4	6	8.438
98		473.3	7	8.792
99		473.3	8	9.037
100		473.3	8.5	9.127
101	18.00	481.0	0.5	1.494
102		480.6	1	2.746
103		480.0	2	4.689
104		479.6	3	6.085
105		479.4	4	7.094
106		479.2	5	7.827
107		479.1	6	8.359
108		479.1	7	8.741
109		479.0	8	9.012
110		479.0	8.5	9.116
111	20.00	486.2	0.5	1.443
112		485.8	1	2.661
113		485.2	2	4.572
114		484.9	3	5.963
115		484.6	4	6.983
116		484.5	5	7.734
117		484.4	6	8.288
118		484.3	7	8.694
119		484.3	8	8.988
120		484.3	8.5	9.103

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Table 3.--Values of γ_F and γ_W--calculated from data of Curtis and Hatt[1]

Line No.	Pressure π	Equilibrium temperature F	Furfural content of liquid x_F	Furfural content of vapor y_F	Vapor pressure of furfural P_F	Vapor pressure of water P_W	Activity coefficient of furfural γ_F	Activity coefficient of water γ_W
	Atmospheres	°K	Mol fraction	Mol fraction	Atmospheres	Atmospheres		
1	5.971	432.1	0	0	.9243	5.853	....	1.020
2		431.9	.0017	.0070	.9192	5.824	26.75	1.020
3		431.8	.0017	.0088	.9167	5.812	33.72	1.020
4		431.2	.0086	.0316	.9020	5.721	24.32	1.019
5		431.1	.0094	.0370	.8994	5.707	26.13	1.017
6		430.6	.0154	.0598	.8871	5.634	26.14	1.012
7		430.4	.0231	.0668	.8823	5.606	19.57	1.017
8		430.1	.0470	.0808	.8750	5.562	11.73	1.035
9		430.05	.0731	.0889	.8738	5.555	8.31	1.057
10		430.0	.0903	.0903	.8726	5.548	6.84	1.076
11		430.2	.1550	.0974	.8775	5.572	4.28	1.145
12	7.597	442.0	0	0	1.2031	7.480	....	1.016
13		441.75	.0019	.0080	1.1954	7.435	26.76	1.016
14		441.7	.0025	.0090	1.1937	7.425	22.91	1.017
15		441.0	.0084	.0323	1.1721	7.300	24.92	1.016
16		440.9	.0094	.0340	1.1690	7.283	23.51	1.017
17		440.5	.0167	.0508	1.1569	7.212	19.98	1.017
18		440.4	.0178	.0586	1.1539	7.194	21.67	1.012
19		440.35	.0236	.0610	1.1523	7.186	17.04	1.017
20		440.3	.0247	.0607	1.1508	7.177	16.22	1.020
21		439.9	.0517	.0832	1.1388	7.107	10.73	1.033
22		439.85	.0699	.0889	1.1373	7.100	8.50	1.048
23		439.8	.0910	.0910	1.1358	7.090	6.69	1.072
24	9.513	451.4	0	0	1.5289	9.348	....	1.018
25		451.3	.0015	.0068	1.5251	9.327	28.28	1.015
26		451.2	.0019	.0074	1.5213	9.305	24.36	1.017
27		450.9	.0052	.0193	1.5109	9.240	23.37	1.015
28		450.8	.0058	.0204	1.5061	9.218	22.21	1.017
29		450.7	.0070	.0254	1.5024	9.197	22.98	1.015
30		450.6	.0088	.0284	1.4987	9.175	20.48	1.016
31		450.3	.0146	.0414	1.4874	9.111	18.14	1.016
32		449.9	.0222	.0622	1.4724	9.027	18.10	1.011
33		449.8	.0268	.0631	1.4692	9.005	15.24	1.016
34		449.6	.0398	.0778	1.4616	8.964	12.73	1.019
35		449.5	.0459	.0798	1.4579	8.943	11.35	1.026
36		449.4	.0674	.0878	1.4541	8.921	8.52	1.043
37		449.3	.0874	.0903	1.4505	8.901	6.78	1.064
38		449.4	.0910	.0910	1.4541	8.921	6.54	1.066

[1]Curtis, R. G. and Hatt, H. H. Australian Journal of Science Research A, 1, 213 (1948).

Table 4.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (99 percent of furfural in feed recovered overhead)

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
1	1.000	100.0	[2]7.870	25.81	8,355	16,290	....	....
2			8.264	25.49	8,749	16,680	4	37
3			8.657	25.20	9,143	17,070	3	30
4			9.051	24.94	9,537	17,470	3	26
5			9.444	24.69	9,931	17,860	3	24
6			11.81	23.53	12,290	20,220	2	16
7			15.74	22.32	16,230	24,160	2	11
8			19.68	21.58	20,170	28,100	2	9
9			23.61	21.07	24,110	32,040	2	8
10			31.48	20.42	31,990	39,920	2	7
11	1.000	175.0	[2]14.23	22.71	14,720	15,160	....	....
12			14.95	22.52	15,440	15,870	4	35
13			15.66	22.34	16,150	16,580	3	25
14			16.37	22.18	16,860	17,290	3	21
15			17.08	22.03	17,570	18,000	3	18
16			21.35	21.34	21,850	22,280	3	11
17			28.47	20.63	28,970	29,400	2	7
18			35.58	20.20	36,100	36,530	2	6
19			42.70	19.90	43,220	43,650	2	5
20			56.93	19.53	57,470	57,900	2	5
21	1.000	225.0	[2]18.97	21.69	19,470	14,900	....	....
22			19.92	21.54	20,420	15,850	4	29
23			20.87	21.40	21,370	16,800	3	21
24			21.82	21.28	22,320	17,750	3	17
25			22.77	21.16	23,270	18,700	3	14
26			28.46	20.63	28,960	24,390	3	8
27			37.94	20.09	38,460	33,890	3	6
28			47.43	19.76	47,950	43,380	3	5
29			56.91	19.53	57,450	52,880	2	5
30			75.89	19.25	76,440	71,870	2	4
31	1.500	100.0	[2]5.829	28.02	6,312	11,580	....	....
32			6.121	27.63	6,604	11,870	4	27
33			6.412	27.26	6,900	12,160	3	23
34			6.704	26.93	7,187	12,450	3	21
35			7.000	26.62	7,479	12,740	3	19
36			8.744	25.14	9,230	14,490	2	13
37			11.66	23.59	12,150	17,410	2	10
38			14.57	22.62	15,070	20,330	2	8
39			17.49	21.95	17,980	23,250	2	7
40			23.32	21.10	23,820	29,080	2	6

(Sheet 1 of 6)

Table 4.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (99 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
41	1.500	175.0	[2]9.668	24.56	10,150	10,420	....	....
42			10.15	24.29	10,640	10,900	4	30
43			10.63	24.05	11,120	11,390	3	23
44			11.11	23.82	11,610	11,870	3	19
45			11.60	23.61	12,090	12,350	3	16
46			14.50	22.64	14,990	15,260	3	10
47			19.34	21.63	19,830	20,100	3	10
48			24.17	21.01	24,670	24,930	2	7
49			29.00	20.59	29,510	29,770	2	6
50			38.67	20.06	39,190	39,450	2	5
51	1.500	225.0	[2]12.70	23.20	13,190	10,120	....	....
52			13.33	22.98	13,830	10,760	4	27
53			13.97	22.79	14,460	11,390	3	19
54			14.60	22.61	15,100	12,030	3	16
55			15.24	22.45	15,730	12,660	3	14
56			19.05	21.68	19,550	16,480	3	8
57			25.40	20.89	25,900	22,830	3	8
58			31.75	20.41	32,260	29,190	2	6
59			38.10	20.08	38,620	35,550	2	5
60			50.80	19.67	51,330	48,260	2	4
61	2.000	100.0	[2]4.813	29.70	5,295	9,225	....	....
62			5.054	29.25	5,535	9,466	4	22
63			5.294	28.84	5,776	9,707	3	19
64			5.535	28.45	6,017	9,948	3	18
65			5.776	28.10	6,258	10,190	3	16
66			7.219	26.39	7,703	11,630	3	16
67			9.626	24.58	10,110	14,040	2	12
68			12.03	23.44	12,520	16,450	2	9
69			14.44	22.66	14,930	18,860	2	8
70			19.25	21.64	19,750	23,680	2	7
71	2.000	175.0	[2]7.400	26.22	7,884	8,064	....	....
72			7.770	25.89	8,254	8,435	4	26
73			8.139	25.59	8,625	8,805	3	20
74			8.510	25.31	8,995	9,175	3	17
75			8.800	25.05	9,365	9,546	3	15
76			11.10	23.83	11,590	11,770	3	15
77			14.80	22.56	15,290	15,470	2	10
78			18.50	21.77	18,990	19,180	2	7
79			22.20	21.23	22,700	22,880	2	6
80			29.60	20.55	30,110	30,290	2	5

(Sheet 2 of 6)

Table 4.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (99 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
81	2.000	225.0	[2]9.590	24.60	10,080	7,757	....	....
82			10.07	24.34	10,560	8,237	4	25
83			10.55	24.09	11,040	8,717	3	18
84			11.03	23.86	11,520	9,197	3	15
85			11.51	23.65	12,000	9,677	3	13
86			14.39	22.67	14,880	12,560	3	8
87			19.18	21.66	19,680	17,360	2	6
88			23.98	21.03	24,480	22,160	2	5
89			28.77	20.61	29,280	26,960	2	4
90			38.36	20.07	38,880	36,560	2	4
91	2.500	100.0	[2]4.173	31.10	4,654	7,785	....	....
92			4.381	30.61	4,863	7,993	4	20
93			4.590	30.15	5,072	8,202	3	17
94			4.800	29.73	5,281	8,411	3	16
95			5.007	29.34	5,490	8,620	3	14
96			6.260	27.45	6,743	9,873	2	11
97			8.346	25.43	8,831	11,960	2	8
98			10.43	24.15	10,920	14,050	2	7
99			12.52	23.26	13,010	16,140	2	6
100			16.69	22.11	17,190	20,320	2	5
101	2.500	175.0	[2]6.112	27.64	6,595	6,725	....	....
102			6.417	27.26	6,901	7,031	4	22
103			6.723	26.91	7,207	7,337	3	18
104			7.029	26.58	7,513	7,643	3	16
105			7.334	26.28	7,818	7,949	3	14
106			9.168	24.86	9,654	9,784	2	9
107			12.22	23.37	12,710	12,840	2	7
108			15.27	22.44	15,770	15,900	2	6
109			18.34	21.80	18,830	18,960	2	5
110			24.45	20.98	24,950	25,080	2	4
111	2.500	225.0	[2]7.715	25.94	8,199	6,330	....	....
112			8.100	25.62	8,585	6,716	4	23
113			8.486	25.33	8,971	7,102	3	17
114			8.872	25.06	9,358	7,488	3	15
115			9.258	24.81	9,744	7,874	3	13
116			11.57	23.63	12,060	10,190	2	8
117			15.43	22.40	15,920	14,050	2	6
118			19.29	21.64	19,780	17,910	2	5
119			23.14	21.12	23,640	21,770	2	4
120			30.86	20.46	31,370	29,500	2	4

(Sheet 3 of 6)

Table 4.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (99 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
121	3.000	100.0	[2]3.750	32.23	4,230	6,827	....	....
122			3.936	31.71	4,417	7,014	4	17
123			4.124	31.22	4,605	7,202	3	15
124			4.311	30.77	4,792	7,390	3	14
125			4.500	30.35	4,980	7,577	3	13
126			5.624	28.32	6,106	8,703	2	10
127			7.500	26.13	7,982	10,580	2	8
128			9.373	24.73	9,859	12,460	2	7
129			11.25	23.76	11,740	14,330	2	6
130			15.00	22.51	15,490	18,090	1	5
131	3.000	175.0	[2]5.264	28.89	5,746	5,843	....	....
132			5.527	28.47	6,009	6,107	4	20
133			5.790	28.08	6,273	6,370	3	16
134			6.054	27.71	6,536	6,634	3	14
135			6.317	27.38	6,800	6,897	3	13
136			7.896	25.79	8,381	8,477	2	9
137			10.53	24.10	11,020	11,110	2	7
138			13.16	23.04	13,650	13,750	2	6
139			15.79	22.31	16,280	16,380	2	5
140			21.06	21.38	21,550	21,650	2	4
141	3.000	225.0	[2]6.533	27.12	7,016	5,447	....	....
142			6.859	26.76	7,343	5,774	4	20
143			7.186	26.43	7,670	6,101	3	16
144			7.513	26.12	7,997	6,428	3	14
145			7.839	25.83	8,324	6,755	3	12
146			9.799	24.48	10,290	8,716	2	8
147			13.06	23.07	13,560	11,990	2	6
148			16.33	22.19	16,830	15,260	2	5
149			19.60	21.59	20,100	18,530	2	4
150			26.13	20.82	26,630	25,070	2	4
151	5.000	100.0	[2]2.972	34.94	3,452	4,982	....	....
152			3.121	34.34	3,600	5,131	4	12
153			3.270	33.79	3,749	5,280	3	11
154			3.418	33.27	3,898	5,428	3	10
155			3.566	32.79	4,047	5,577	3	10
156			4.458	30.44	4,939	6,470	2	8
157			5.943	27.86	6,427	7,957	2	6
158			7.430	26.19	7,914	9,445	1	6
159			8.916	25.03	9,402	10,930	1	5
160			11.89	23.50	12,380	13,910	1	5

(Sheet 4 of 6)

Table 4.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (99 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
161	5.000	175.0	[2]3.584	32.73	4,064	4,095	....	....
162			3.763	32.19	4,244	4,274	4	14
163			3.942	31.69	4,423	4,453	3	12
164			4.121	31.23	4,602	4,633	3	11
165			4.301	30.79	4,782	4,812	3	10
166			5.376	28.70	5,858	5,888	2	8
167			7.168	26.44	7,652	7,682	2	6
168			8.960	25.00	9,445	9,476	2	5
169			10.75	24.00	11,240	11,270	2	5
170			14.34	22.68	14,830	14,860	1	4
171	5.000	225.0	[2]4.214	31.00	4,695	3,726	....	....
172			4.425	30.51	4,906	3,937	4	15
173			4.636	30.06	5,117	4,148	3	12
174			4.847	29.64	5,328	4,359	3	11
175			5.057	29.25	5,539	4,570	3	10
176			6.322	27.37	6,805	5,835	2	7
177			8.429	25.37	8,914	7,945	2	5
178			10.54	24.10	11,020	10,050	2	5
179			12.64	23.22	13,130	12,160	2	4
180			16.86	22.08	17,350	16,380	2	4
181	6.450	100.0	[2]2.729	36.02	3,208	4,379	....	....
182			2.865	35.40	3,345	4,516	4	11
183			3.002	34.82	3,481	4,652	4	10
184			3.138	34.28	3,618	4,789	3	9
185			3.274	33.77	3,754	4,925	3	8
186			4.093	31.30	4,574	5,745	2	7
187			5.457	28.57	5,940	7,110	1	6
188			6.822	26.80	7,305	8,476	1	5
189			8.186	25.55	8,671	9,842	1	5
190			10.91	23.91	11,400	12,570	1	4
191	6.450	175.0	[2]3.099	34.43	3,578	3,586	....	....
192			3.253	33.85	3,733	3,742	4	12
193			3.408	33.30	3,889	3,897	3	10
194			3.563	32.80	4,044	4,052	3	9
195			3.718	32.32	4,199	4,207	3	9
196			4.648	30.03	5,129	5,137	2	7
197			6.197	27.52	6,680	6,688	2	5
198			7.746	25.91	8,231	8,239	1	5
199			9.300	24.78	9,782	9,790	1	4
200			12.39	23.30	12,880	12,890	1	4

(Sheet 5 of 6)

Table 4.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (99 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
201	6.450	225.0	[2]3.475	33.08	3,956	3,189	....	....
202			3.649	32.53	4,130	3,362	4	13
203			3.823	32.02	4,304	3,536	3	11
204			3.997	31.55	4,478	3,710	3	10
205			4.171	31.11	4,651	3,884	3	9
206			5.213	28.97	5,695	4,928	2	7
207			6.951	26.66	7,435	6,668	2	5
208			8.689	25.18	9,174	8,407	2	5
209			10.43	24.15	10,910	10,150	1	4
210			13.90	22.81	14,390	13,630	1	4

[1]Based on weight of furfural charged.

[2]Indicates minimum reflux ratio.

(Sheet 6 of 6)

Table 5.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (97 percent of furfural in feed recovered overhead)

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
1	1.000	100.0	[2]7.853	25.82	8,170	16,100	....	....
2			8.246	25.51	8,555	16,490	4	29
3			8.639	25.22	8,940	16,870	3	23
4			9.031	24.95	9,325	17,260	3	20
5			9.424	24.70	9,710	17,640	3	18
6			11.78	23.54	12,020	19,950	2	12
7			15.71	22.33	15,870	23,800	2	9
8			19.63	21.58	19,720	27,660	2	7
9			23.56	21.08	23,580	31,510	2	6
10			31.41	20.43	31,280	39,210	2	5
11	1.000	175.0	[2]14.24	22.71	14,430	14,860	....	....
12			14.95	22.52	15,130	15,560	4	24
13			15.66	22.34	15,830	16,260	3	18
14			16.37	22.18	16,520	16,960	3	15
15			17.08	22.03	17,220	17,650	3	13
16			21.35	21.34	21,410	21,840	3	8
17			28.47	20.63	28,390	28,820	2	6
18			35.59	20.20	35,370	35,810	2	5
19			42.71	19.90	42,350	42,790	2	4
20			56.94	19.53	56,320	56,750	2	4
21	1.000	225.0	[2]18.98	21.69	19,080	14,520	....	....
22			19.93	21.54	20,010	15,450	4	19
23			20.88	21.40	20,940	16,380	3	14
24			21.83	21.28	21,880	17,310	3	11
25			22.78	21.16	22,800	18,240	3	10
26			28.47	20.62	28,390	23,820	3	6
27			37.96	20.09	37,700	33,130	3	5
28			47.45	19.76	47,010	42,440	3	4
29			56.94	19.53	56,320	51,750	2	3
30			75.92	19.25	74,930	70,360	2	3
31	1.500	100.0	[2]5.829	28.02	6,185	11,450	....	....
32			6.121	27.63	6,470	11,740	4	22
33			6.412	27.26	6,756	12,020	3	18
34			6.704	26.93	7,042	12,310	3	16
35			7.000	26.62	7,328	12,590	3	15
36			8.744	25.14	9,043	14,310	2	10
37			11.66	23.59	11,900	17,170	2	8
38			14.57	22.62	14,760	20,030	2	6
39			17.49	21.95	17,620	22,880	2	6
40			23.32	21.10	23,340	28,600	2	5

(Sheet 1 of 6)

Table 5.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (97 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
41	1.500	175.0	[2]9.668	24.56	9,949	10,210	....	....
42			10.15	24.29	10,420	10,690	4	21
43			10.63	24.05	10,900	11,160	3	16
44			11.12	23.82	11,370	11,640	3	14
45			11.60	23.61	11,840	12,110	3	12
46			14.50	22.64	14,690	14,960	3	8
47			19.34	21.63	19,430	19,700	2	5
48			24.17	21.01	24,170	24,440	2	5
49			29.00	20.59	28,910	29,180	2	4
50			38.67	20.06	38,400	38,660	2	4
51	1.500	225.0	[2]12.70	23.20	12,920	9,855	....	....
52			13.33	22.98	13,550	10,480	4	18
53			13.97	22.79	14,170	11,100	3	14
54			14.60	22.61	14,790	11,720	3	11
55			15.24	22.45	15,410	12,350	3	10
56			19.05	21.68	19,150	16,080	3	6
57			25.40	20.89	25,380	22,310	2	4
58			31.75	20.41	31,610	28,540	2	4
59			38.10	20.08	37,840	34,770	2	3
60			50.80	19.67	50,290	47,220	2	3
61	2.000	100.0	[2]4.813	29.70	5,188	9,120	....	....
62			5.054	29.25	5,424	9,356	4	18
63			5.294	28.84	5,660	9,592	3	15
64			5.535	28.45	5,896	9,828	3	14
65			5.776	28.10	6,132	10,060	3	13
66			7.219	26.39	7,548	11,480	2	9
67			9.626	24.58	9,908	13,840	2	7
68			12.03	23.44	12,270	16,200	2	6
69			14.44	22.66	14,630	18,560	2	5
70			19.25	21.64	19,350	23,280	2	5
71	2.000	175.0	[2]7.400	26.22	7,725	7,906	....	....
72			7.770	25.89	8,087	8,269	4	19
73			8.139	25.59	8,450	8,632	3	15
74			8.509	25.31	8,813	9,000	3	13
75			8.880	25.05	9,176	9,358	3	11
76			11.10	23.83	11,350	11,540	2	7
77			14.80	22.56	14,980	15,160	2	5
78			18.50	21.77	18,610	18,790	2	5
79			21.20	21.23	22,240	22,420	2	4
80			29.60	20.55	29,500	29,680	2	4

(Sheet 2 of 6)

Table 5.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (97 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
81	2.000	225.0	[2]9.590	24.60	9,870	7,555	....	....
82			10.07	24.34	10,340	8,025	4	17
83			10.55	24.09	10,810	8,496	3	13
84			11.03	23.86	11,280	8,966	3	11
85			11.51	23.65	11,750	9,436	3	9
86			14.39	22.67	14,580	12,260	3	6
87			19.18	21.66	19,280	16,960	2	4
88			23.98	21.03	23,980	21,660	2	4
89			28.77	20.61	28,690	26,370	2	3
90			38.36	20.07	38,090	35,770	2	3
91	2.500	100.0	[2]4.173	31.10	4,560	7,692	....	....
92			4.382	30.61	4,765	7,897	4	16
93			4.590	30.15	4,969	8,101	3	14
94			4.799	29.73	5,174	8,306	3	12
95			5.008	29.34	5,379	8,501	3	11
96			6.260	27.45	6,607	9,739	2	9
97			8.346	25.43	8,653	11,790	2	7
98			10.43	24.15	10,700	13,830	2	6
99			12.52	23.26	12,750	15,880	2	5
100			16.69	22.11	16,840	19,970	2	4
101	2.500	175.0	[2]6.112	27.64	6,462	6,594	....	....
102			6.417	27.26	6,761	6,893	4	17
103			6.723	26.91	7,061	7,193	3	13
104			7.029	26.58	7,361	7,493	3	12
105			7.334	26.28	7,661	7,792	3	10
106			9.168	24.86	9,459	9,591	2	7
107			12.22	23.37	12,460	12,590	2	5
108			15.28	22.44	15,450	15,590	2	4
109			18.34	21.80	18,450	18,580	2	4
110			24.45	20.98	24,450	24,580	2	3
111	2.500	225.0	[2]7.715	25.94	8,034	6,166	....	....
112			8.100	25.62	8,412	6,544	4	16
113			8.486	25.33	8,790	6,922	3	12
114			8.872	25.06	9,169	7,300	3	10
115			9.258	24.81	9,547	7,679	3	9
116			11.57	23.63	11,820	9,949	2	6
117			15.43	22.40	15,600	13,730	2	4
118			19.29	21.64	19,380	17,520	2	4
119			23.14	21.12	23,170	21,300	2	3
120			30.86	20.46	30,730	28,870	2	3

(Sheet 3 of 6)

Table 5.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (97 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
121	3.000	100.0	[2]3.749	32.23	4,144	6,743	....	....
122			3.936	31.71	4,328	6,927	4	14
123			4.124	31.22	4,512	7,110	3	12
124			4.311	30.77	4,696	7,294	3	11
125			4.500	30.35	4,880	7,478	3	11
126			5.624	28.32	5,983	8,581	2	8
127			7.498	26.13	7,821	10,420	2	6
128			9.373	24.73	9,660	12,260	2	5
129			11.25	23.76	11,500	14,100	2	5
130			15.00	22.51	15,180	17,770	1	4
131	3.000	175.0	[2]5.264	28.89	5,630	5,729	....	....
132			5.527	28.47	5,888	5,987	4	15
133			5.790	28.07	6,146	6,245	3	12
134			6.054	27.71	6,404	6,503	3	11
135			6.317	27.38	6,663	6,761	3	10
136			7.896	25.79	8,211	8,310	2	7
137			10.53	24.10	10,790	10,890	2	5
138			13.16	23.04	13,370	13,470	2	4
139			15.79	22.31	15,960	16,050	2	4
140			21.06	21.38	21,120	21,220	2	3
141	3.000	225.0	[2]6.533	27.12	6,874	5,306	....	....
142			6.859	26.76	7,195	5,627	4	15
143			7.186	26.43	7,515	5,947	3	12
144			7.513	26.12	7,835	6,267	3	10
145			7.839	25.83	8,186	6,588	3	9
146			9.799	24.48	10,080	8,510	2	6
147			13.07	23.07	13,280	11,710	2	4
148			16.33	22.19	16,490	14,920	2	4
149			19.60	21.59	19,690	18,120	2	3
150			26.13	20.82	26,100	24,530	2	3
151	5.000	100.0	[2]2.972	34.94	3,382	4,914	....	....
152			3.121	34.34	3,528	5,060	4	10
153			3.269	33.79	3,673	5,205	3	9
154			3.418	33.27	3,819	5,351	3	8
155			3.566	32.79	3,965	5,497	3	8
156			4.458	30.44	4,839	6,371	2	6
157			5.944	27.86	6,297	7,229	2	5
158			7.430	26.19	7,754	9,286	1	5
159			8.916	25.03	9,212	10,740	1	4
160			11.89	23.50	12,130	13,660	1	4

(Sheet 4 of 6)

Table 5.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (97 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
161	5.000	175.0	[2]3.584	32.73	3,982	4,014	....	....
162			3.763	32.19	4,158	4,190	4	11
163			3.942	31.69	4,334	4,366	3	10
164			4.121	31.23	4,509	4,541	3	9
165			4.301	30.79	4,685	4,717	3	8
166			5.376	28.70	5,740	5,772	2	6
167			7.168	26.44	7,497	7,529	2	5
168			8.960	25.00	9,255	9,287	2	4
169			10.75	23.99	11,010	11,040	2	4
170			14.34	22.68	14,530	14,560	1	3
171	5.000	225.0	[2]4.214	31.00	4,601	3,632	....	....
172			4.425	30.51	4,807	3,839	4	11
173			4.636	30.06	5,014	4,046	3	9
174			4.847	29.64	5,221	4,253	3	8
175			5.057	29.25	5,427	4,459	3	7
176			6.322	27.37	6,667	5,699	2	5
177			8.429	25.37	8,734	7,766	2	4
178			10.54	24.10	10,800	9,833	2	4
179			12.64	23.22	12,870	11,900	2	3
180			16.86	22.08	17,000	16,030	2	3
181	6.450	100.0	[2]2.729	36.02	3,143	4,316	....	....
182			2.865	35.40	3,277	4,449	4	9
183			3.002	34.82	3,411	4,583	3	8
184			3.138	34.28	3,545	4,717	3	7
185			3.274	33.77	3,679	4,851	2	7
186			4.093	31.30	4,481	5,654	1	6
187			5.457	28.57	5,820	6,992	1	5
188			6.822	26.80	7,158	8,330	1	4
189			8.186	25.55	8,496	9,668	1	4
190			10.91	23.91	11,170	12,340	1	3
191	6.450	175.0	[2]3.099	34.43	3,506	3,516	....	....
192			3.253	33.85	3,658	3,667	4	9
193			3.408	33.30	3,810	3,819	3	8
194			3.563	32.80	3,962	3,971	3	7
195			3.718	32.32	4,114	4,123	3	7
196			4.648	30.03	5,026	5,035	2	5
197			6.197	27.53	6,545	6,555	2	4
198			7.746	25.91	8,065	8,074	1	4
199			9.296	24.78	9,584	9,594	1	4
200			12.39	23.31	12,620	12,630	1	3

(Sheet 5 of 6)

Table 5.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (97 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
201	6.450	225.0	[2]3.475	33.08	3,876	3,110	....	....
202			3.649	32.53	4,046	3,280	4	10
203			3.823	32.02	4,217	3,451	3	8
204			3.997	31.55	4,387	3,621	3	7
205			4.171	31.10	4,558	3,792	3	7
206			5.213	28.97	5,580	4,814	2	5
207			6.951	26.66	7,284	6,519	2	4
208			8.689	25.18	8,989	8,223	2	4
209			10.43	24.15	10,690	9,927	1	3
210			13.90	22.81	14,100	13,340	1	3

[1]Based on weight of furfural changed.

[2]Indicates minimum reflux ratio.

(Sheet 6 of 6)

Table 6.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (95 percent of furfural in feed recovered overhead)

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
1	1.000	100.0	[2]7.853	25.82	8,001	15,930		
2			8.246	25.51	8,378	16,310	4	25
3			8.369	25.22	8,756	16,690	3	20
4			9.031	24.95	9,133	17,070	3	17
5			9.424	24.70	9,510	17,440	3	16
6			11.78	23.54	11,770	19,710	2	11
7			15.71	22.33	15,550	23,480	2	8
8			19.63	21.58	19,320	27,250	2	6
9			23.56	21.08	23,090	31,020	2	6
10			31.41	20.43	30,630	38,570	2	5
11	1.000	175.0	[2]14.24	22.71	14,132	14,570		
12			14.95	22.52	14,820	15,250	4	20
13			15.66	22.34	15,500	15,930	3	15
14			16.37	22.18	16,180	16,620	3	12
15			17.08	22.03	16,870	17,300	3	11
16			21.35	21.34	20,970	21,400	3	7
17			28.47	20.63	27,810	28,240	2	5
18			35.59	20.20	34,640	35,080	2	4
19			42.71	19.90	41,480	41,910	2	4
20			56.94	19.53	55,160	55,590	2	3
21	1.000	225.0	[2]18.98	21.69	18,690	14,120		
22			19.93	21.54	19,600	15,030	4	15
23			20.88	21.40	20,510	15,950	3	11
24			21.83	21.28	21,420	16,860	3	9
25			22.78	21.16	22,340	17,770	3	8
26			28.47	20.63	27,810	23,240	3	5
27			37.96	20.09	36,920	32,360	3	4
28			47.45	19.76	46,040	41,470	3	3
29			56.94	19.53	55,150	50,590	2	3
30			75.92	19.25	73,390	68,820	2	3
31	1.500	100.0	[2]5.829	28.02	6,057	11,320		
32			6.121	27.63	6,337	11,600	4	19
33			6.412	27.26	6,617	11,880	3	16
34			6.704	26.93	6,897	12,160	3	14
35			6.995	26.62	7,177	12,440	3	13
36			8.744	25.14	8,857	14,120	2	9
37			11.66	23.59	11,660	16,920	2	7
38			14.57	22.62	14,460	19,720	2	6
39			17.49	21.95	17,260	22,520	2	5
40			23.32	21.10	22,860	28,120	2	4

(Sheet 1 of 6)

Table 6.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (95 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
41	1.500	175.0	[2]9.668	24.56	9,744	10,010	....	....
42			10.15	24.29	10,210	10,470	4	18
43			10.63	24.05	10,670	10,940	3	14
44			11.12	23.82	11,140	11,400	3	11
45			11.60	23.61	11,600	11,870	3	10
46			14.50	22.64	14,390	14,650	3	6
47			19.34	21.63	19,030	19,300	2	5
48			24.17	21.01	23,670	23,940	2	4
49			29.00	20.59	28,320	28,580	2	4
50			38.67	20.06	37,600	37,870	2	3
51	1.500	225.0	[2]12.70	23.20	12,660	9,590	....	....
52			13.33	22.98	13,270	10,190	4	15
53			13.97	22.79	13,880	10,810	3	11
54			14.60	22.61	14,490	11,420	3	9
55			15.24	22.45	15,100	12,030	3	8
56			19.05	21.68	18,760	15,690	3	5
57			25.40	20.89	24,860	21,790	2	4
58			31.75	20.41	30,960	27,890	2	3
59			38.10	20.08	37,050	33,990	2	3
60			50.80	19.67	49,250	46,190	2	3
61	2.000	100.0	[2]4.813	29.70	5,081	9,014	....	....
62			5.054	29.25	5,312	9,245	4	16
63			5.294	28.24	5,543	9,476	3	14
64			5.535	28.45	5,774	9,707	3	12
65			5.776	28.10	6,005	9,939	3	11
66			7.219	26.39	7,392	11,330	2	8
67			9.626	24.58	9,704	13,640	2	6
68			12.03	23.44	12,020	15,950	2	5
69			14.44	22.66	14,330	18,260	2	5
70			19.25	21.64	18,950	22,880	2	4
71	2.000	175.0	[2]7.400	26.22	7,565	7,749	....	....
72			7.769	25.89	7,921	8,104	4	16
73			8.139	25.59	8,276	8,459	3	13
74			8.509	25.31	8,631	8,815	3	11
75			8.879	25.05	8,987	9,170	3	9
76			11.10	23.83	11,120	11,300	2	6
77			14.80	22.56	14,670	14,860	2	5
78			18.50	21.77	18,230	18,410	2	4
79			22.20	21.23	21,780	21,960	2	4
80			29.60	20.55	28,890	29,070	2	3

(Sheet 2 of 6)

Table 6.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (95 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
81	2.000	225.0	[2]9.590	24.60	9,670	7,353	...	...
82			10.07	24.34	10,130	7,814	4	14
83			10.55	24.09	10,590	8,274	3	11
84			11.03	23.86	11,050	8,735	3	9
85			11.51	23.65	11,510	9,195	3	8
86			14.39	22.67	14,280	11,960	3	5
87			19.18	21.66	18,880	16,570	2	4
88			23.98	21.03	23,490	21,170	2	3
89			28.77	20.61	28,090	25,780	2	3
90			38.36	20.07	27,300	34,990	2	3
91	2.500	100.0	[2]4.173	31.10	4,466	7,599	...	...
92			4.382	30.61	4,666	7,800	4	14
93			4.590	30.15	4,867	8,000	3	12
94			4.800	29.73	5,067	8,201	3	11
95			5.008	29.34	5,268	8,401	3	10
96			6.260	27.45	6,470	9,604	2	8
97			8.346	25.43	8,475	11,610	2	6
98			10.43	24.15	10,480	13,610	2	5
99			12.52	23.26	12,480	15,620	2	4
100			16.69	22.11	16,490	19,630	2	4
101	2.500	175.0	[2]6.112	27.64	6,328	6,462	...	...
102			6.417	27.26	6,622	6,755	4	14
103			6.723	26.91	6,915	7,049	3	11
104			7.029	26.58	7,209	7,342	3	10
105			7.334	26.28	7,503	7,636	3	9
106			9.168	24.86	9,264	9,397	2	6
107			12.22	23.37	12,200	12,330	2	5
108			15.28	22.44	15,130	15,270	2	4
109			18.34	21.80	18,070	18,200	2	3
110			24.45	20.98	23,940	24,070	2	3
111	2.500	225.0	[2]7.715	25.94	7,868	6,001	...	...
112			8.100	25.62	8,238	6,372	4	14
113			8.486	25.33	8,609	6,742	3	10
114			8.872	25.06	8,979	7,113	3	9
115			9.258	24.81	9,350	7,483	3	8
116			11.57	23.63	11,570	9,707	2	5
117			15.43	22.40	15,280	13,410	2	4
118			19.29	21.64	18,980	17,120	2	3
119			23.14	21.12	22,690	20,820	2	3
120			30.85	20.46	30,100	28,230	2	3

(Sheet 3 of 6)

Table 6.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (95 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
121	3.000	100.0	[2]3.749	32.23	4,059	6,659	....	....
122			3.936	31.71	4,239	6,839	4	13
123			4.124	31.22	4,419	7,019	3	11
124			4.311	30.77	4,599	7,199	3	10
125			4.499	30.35	4,779	7,379	3	9
126			5.624	28.32	5,859	8,459	2	7
127			7.498	26.13	7,660	10,260	2	5
128			9.373	24.73	9,461	12,060	2	5
129			11.25	23.76	11,260	13,860	2	4
130			15.00	22.51	14,860	17,460	1	4
131	3.000	175.0	[2]5.264	28.89	5,514	5,614	....	....
132			5.527	28.47	5,767	5,867	4	13
133			5.790	28.08	6,019	6,120	3	11
134			6.054	27.71	6,272	6,372	3	9
135			6.317	27.38	6,525	6,625	3	8
136			7.896	25.79	8,042	8,142	2	6
137			10.53	24.10	10,570	10,670	2	4
138			13.16	23.04	13,100	13,200	2	4
139			15.79	22.31	15,630	15,730	2	3
140			21.06	21.38	20,680	20,780	2	3
141	3.000	225.0	[2]6.533	27.12	6,733	5,166	....	....
142			6.859	26.76	7,046	5,480	4	12
143			7.186	26.43	7,360	5,794	3	10
144			7.513	26.12	7,674	6,107	3	8
145			7.839	25.83	7,988	6,421	3	7
146			9.799	24.48	9,870	8,304	2	5
147			13.07	23.07	13,010	11,440	2	4
148			16.33	22.19	16,150	14,580	2	3
149			19.60	21.59	19,280	17,720	2	3
150			26.13	20.82	25,560	23,990	2	3
151	5.000	100.0	[2]2.972	34.94	3,312	4,846	....	....
152			3.121	34.34	3,455	4,988	4	9
153			3.269	33.79	3,598	5,131	3	8
154			3.418	33.27	3,740	5,274	3	8
155			3.566	32.79	3,883	5,417	3	7
156			4.458	30.44	4,740	6,273	2	6
157			5.944	27.86	6,167	7,700	2	5
158			7.430	26.19	7,594	9,128	1	4
159			8.916	25.03	9,022	10,560	1	4
160			11.89	23.50	11,880	13,410	1	3

(Sheet 4 of 6)

Table 6.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (95 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
161	5.000	175.0	[2]3.584	32.73	3,900	3,933	....	....
162			3.763	32.19	4,072	4,105	4	10
163			3.942	31.69	4,244	4,278	3	8
164			4.121	31.23	4,416	4,450	3	8
165			4.301	30.79	4,588	4,622	3	7
166			5.376	28.70	5,621	5,655	2	5
167			7.168	26.44	7,343	7,376	2	4
168			8.960	25.00	9,064	9,097	2	4
169			10.75	24.00	10,790	10,820	2	3
170			14.33	22.68	14,230	14,260	1	3
171	5.000	225.0	[2]4.214	31.00	4,506	3,539	....	....
172			4.245	30.51	4,708	3,741	4	10
173			4.636	30.06	4,911	3,944	3	8
174			4.847	29.64	5,113	4,146	3	7
175			5.057	29.25	5,315	4,349	3	6
176			6.332	27.37	6,530	5,563	2	5
177			8.429	25.37	8,553	7,587	2	4
178			10.54	24.10	10,580	9,611	2	3
179			12.64	23.22	12,600	11,640	2	3
180			16.86	22.08	16,650	15,680	2	3
181	6.450	100.0	[2]2.729	36.02	3,079	4,252	....	....
182			2.865	35.40	3,210	4,383	4	8
183			3.002	34.82	3,341	4,514	4	7
184			3.138	34.28	3,472	4,645	3	7
185			3.274	33.77	3,603	4,776	3	6
186			4.093	31.30	4,389	5,563	2	5
187			5.457	28.57	5,700	6,873	1	4
188			6.822	26.80	7,010	8,184	1	4
189			8.186	25.55	8,320	9,494	1	3
190			10.91	23.91	10,940	12,120	1	3
191	6.450	175.0	[2]3.099	34.43	3,434	3,445	....	....
192			3.253	33.85	3,583	3,593	4	8
193			3.408	33.30	3,731	3,742	3	7
194			3.563	32.80	3,880	3,891	3	7
195			3.718	32.32	4,029	4,040	3	6
196			4.648	30.03	4,922	4,933	2	5
197			6.197	27.53	6,410	6,421	2	4
198			7.746	25.91	7,898	7,909	1	3
199			9.296	24.78	9,387	9,397	1	3
200			12.39	23.31	12,360	12,370	1	3

(Sheet 5 of 6)

Table 6.--Plate and energy requirements for producing a furfural-water azeotrope in a tower operating at atmospheric pressure (95 percent of furfural in feed recovered overhead)--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Reflux ratio W/D	Furfural content of overhead vapor	Condenser duty[1] $\frac{q_c}{x_F F}$	Reboiler duty[1] $\frac{q_s}{x_F F}$	Number of theoretical plates in rectifying section	Number of theoretical plates in stripping section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.	Lb. per lb.	Percent	B.t.u. per lb.	B.t.u. per lb.		
201	6.450	225.0	[2]3.475	33.08	3,796	3,032	....	....
202			3.649	32.53	3,963	3,198	4	9
203			3.823	32.02	4,130	3,365	3	7
204			3.997	31.55	4,297	3,532	3	6
205			4.171	31.11	4,464	3,699	3	6
206			5.213	28.97	5,465	4,701	2	4
207			6.951	26.66	7,134	6,370	2	3
208			8.689	25.18	8,803	8,039	2	3
209			10.43	24.15	10,470	9,708	1	3
210			13.90	22.81	13,810	13,050	1	3

[1]Based on weight of furfural charged.

[2]Indicates minimum reflux ratio.

(Sheet 6 of 6)

Table 7.--Plate and energy requirements for the dehydrating column

Line No.	Water content of overhead vapor y_1	Reflux ratio $\frac{w}{D}$	Condenser duty[1] $\frac{q_c}{x_w W}$	Reboiler duty[1] $\frac{q_s}{x_w W}$	Number of theoretical plates
	Percent		B.t.u. per lb.	B.t.u. per lb.	
1	65.16	0.336	1162	1163	4
2	64.59	.3495	1170	1170	3
3	64.02	.3654	1177	1178	3
4	63.47	.3813	1185	1185	3
5	60.39	.4766	1231	1231	3
6	56.07	.6354	1307	1307	3
7	52.52	.7943	1383	1383	3
8	49.54	.9532	1459	1459	3
9	44.83	1.2710	1611	1611	3

[1] B.t.u. per lb. of water fed.

Table 8.--Economic factors for the azeotrope tower at optimum reflux

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Actual reflux ratio / Minimum reflux ratio f	Reflux ratio W/D	Tower diameter L	Annual steam cost C_S	Annual tower cost C_T	Cost of tower and steam[1] C_D
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.			In.	Dollars	Dollars	Cents per lb.
				RECOVERY--99 PERCENT				
1	1.000	100.0	1.150	9.051	67.06	185,300	39,230	1.497
2		175.0	1.100	15.66	86.32	175,800	49,110	1.500
3		225.0	1.100	20.87	98.91	178,200	48,730	1.513
4	1.500	100.0	1.100	6.412	57.59	129,000	30,300	1.062
5		175.0	1.150	11.11	73.63	125,900	32,710	1.057
6		225.0	1.100	13.97	81.84	120,800	36,480	1.049
7	2.000	100.0	1.100	5.294	53.06	103,000	23,710	.8444
8		175.0	1.100	8.139	63.94	93,390	29,680	.8205
9		225.0	1.100	10.55	71.88	92,460	30,470	.8195
10	2.500	100.0	1.100	4.590	50.01	86,990	20,400	.7159
11		175.0	1.100	6.723	58.78	77,820	24,960	.6852
12		225.0	1.100	8.486	65.14	75,320	26,290	.6774
13	3.000	100.0	1.100	4.124	47.88	76,390	17,630	.6268
14		175.0	1.100	5.790	55.12	67,560	21,230	.5920
15		225.0	1.100	7.186	60.52	64,700	23,230	.5862
16	5.000	100.0	1.050	3.121	42.93	54,420	14,200	.4575
17		175.0	1.100	3.942	47.02	47,230	14,450	.4112
18		225.0	1.100	4.636	50.21	43,990	15,350	.3956
19	6.450	100.0	1.050	2.865	41.58	47,890	10,350	.3883
20		175.0	1.100	3.408	44.41	41,330	11,890	.3548
21		225.0	1.100	3.823	46.45	37,510	13,340	.3390
				RECOVERY--97 PERCENT				
22	1.000	100.0	1.100	8.639	65.67	182,600	34,450	1.447
23		175.0	1.100	15.66	86.33	176,000	36,840	1.419
24		225.0	1.100	20.88	98.93	177,300	34,520	1.412
25	1.500	100.0	1.100	6.412	57.59	130,100	24,470	1.031
26		175.0	1.100	10.63	72.15	120,800	27,670	.990
27		225.0	1.100	13.97	81.84	120,200	28,190	.989
28	2.000	100.0	1.100	5.294	53.06	103,800	19,400	.8215
29		175.0	1.100	8.139	63.94	93,440	23,230	.7778
30		225.0	1.100	10.55	71.88	91,960	23,210	.7678
31	2.500	100.0	1.100	4.590	50.01	87,690	17,240	.7000
32		175.0	1.100	6.723	58.78	77,860	19,020	.6459
33		225.0	1.100	8.486	65.14	74,930	19,720	.6310

(Sheet 1 of 2)

Table 8.--Economic factors for the azeotrope tower at optimum reflux--Con.

Line No.	Furfural content of feed by weight x_F	Feed enthalpy H_F	Actual reflux ratio / Minimum reflux ratio f	Reflux ratio W/D	Tower diameter L	Annual steam cost C_S	Annual tower cost C_T	Cost of tower and steam[1] C_D
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent	B.t.u. per lb.			In.	Dollars	Dollars	Cents per lb.
			RECOVERY--97 PERCENT (Con.)					
34	3.000	100.0	1.100	4.124	47.88	76,970	14,690	0.6111
35		175.0	1.100	5.790	55.12	67,600	16,760	.5624
36		225.0	1.100	7.186	60.52	64,380	18,340	.5514
37	5.000	100.0	1.100	3.269	43.70	56,350	10,820	.4478
38		175.0	1.100	3.763	46.16	45,350	14,210	.3971
39		225.0	1.100	4.636	50.21	43,800	12,280	.3739
40	6.450	100.0	1.050	2.865	41.58	48,160	8,626	.3786
41		175.0	1.050	3.253	43.62	39,700	11,700	.3427
42		225.0	1.100	3.823	46.45	37,350	10,480	.3189
			RECOVERY--95 PERCENT					
43	1.000	100.0	1.100	8.639	65.67	184,500	30,470	1.433
44		175.0	1.100	15.66	86.33	176,100	31,580	1.385
45		225.0	1.050	19.93	96.76	166,200	37,670	1.359
46	1.500	100.0	1.100	6.412	57.59	131,300	22,140	1.023
47		175.0	1.100	10.63	72.15	120,900	24,760	.9711
48		225.0	1.100	13.97	81.84	119,500	23,220	.9513
49	2.000	100.0	1.100	5.294	53.06	104,700	18,330	.8204
50		175.0	1.100	8.139	63.94	93,500	20,650	.7610
51		225.0	1.100	10.55	71.88	91,450	20,310	.7451
52	2.500	100.0	1.100	4.590	50.01	88,420	15,300	.6915
53		175.0	1.100	6.723	58.78	77,910	16,640	.6303
54		225.0	1.100	8.486	65.14	74,520	17,090	.6107
55	3.000	100.0	1.100	4.124	47.88	77,580	13,710	.6806
56		175.0	1.100	5.790	55.12	67,640	15,640	.5552
57		225.0	1.050	6.859	59.30	60,570	19,180	.5316
58	5.000	100.0	1.100	3.269	43.70	56,710	9,919	.4442
59		175.0	1.100	3.942	47.02	47,280	10,600	.3858
60		225.0	1.100	4.636	50.21	43,590	11,260	.3657
61	6.450	100.0	1.050	2.865	41.58	48,450	7,764	.3747
62		175.0	1.100	3.408	44.41	41,360	9,148	.3367
63		225.0	1.100	3.823	46.45	37,200	9,528	.3115

[1] Based on weight of furfural produced.

(Sheet 2 of 2)

Table 9.--Furfural-water vapor-liquid equilibrium data from Mel'nikov and Tsirlin[1]

Line No.	Pressure π	Furfural in liquid x_F	Furfural in vapor y_F
	Atmospheres	Mol percent	Mol percent
1	3.0	0.09416	0.5000
2		.1891	.9874
3		.5767	2.716
4		.9775	3.851
5		2.041	6.425
6		3.204	7.052
7	5.75	.09416	.4327
8		.1891	.8275
9		.5767	2.275
10		.9775	3.364
11		2.041	5.824
12		3.204	6.579
13	7.00	.09416	.4075
14		.1891	.7553
15		.5767	2.069
16		.9775	3.240
17		2.041	4.914
18		3.204	6.257
19	9.00	.09416	.3871
20		.1891	.7025
21		.5767	1.890
22		.9775	2.997
23		2.041	4.914
24		3.204	6.122
25	14.0	.09416	.3467
26		.1891	.6320
27		.5767	1.652
28		.9775	2.609
29		2.041	4.319
30		3.204	5.678
31	18.0	.09416	.3367
32		.1891	.6024
33		.5767	1.552
34		.9775	2.425
35		2.041	4.239
36		3.204	5.461

[1]Mel'nikov, N. P. and Tsirlin, Yu. A. Zur Priklad Khim 29, (9) 1456 (1956).

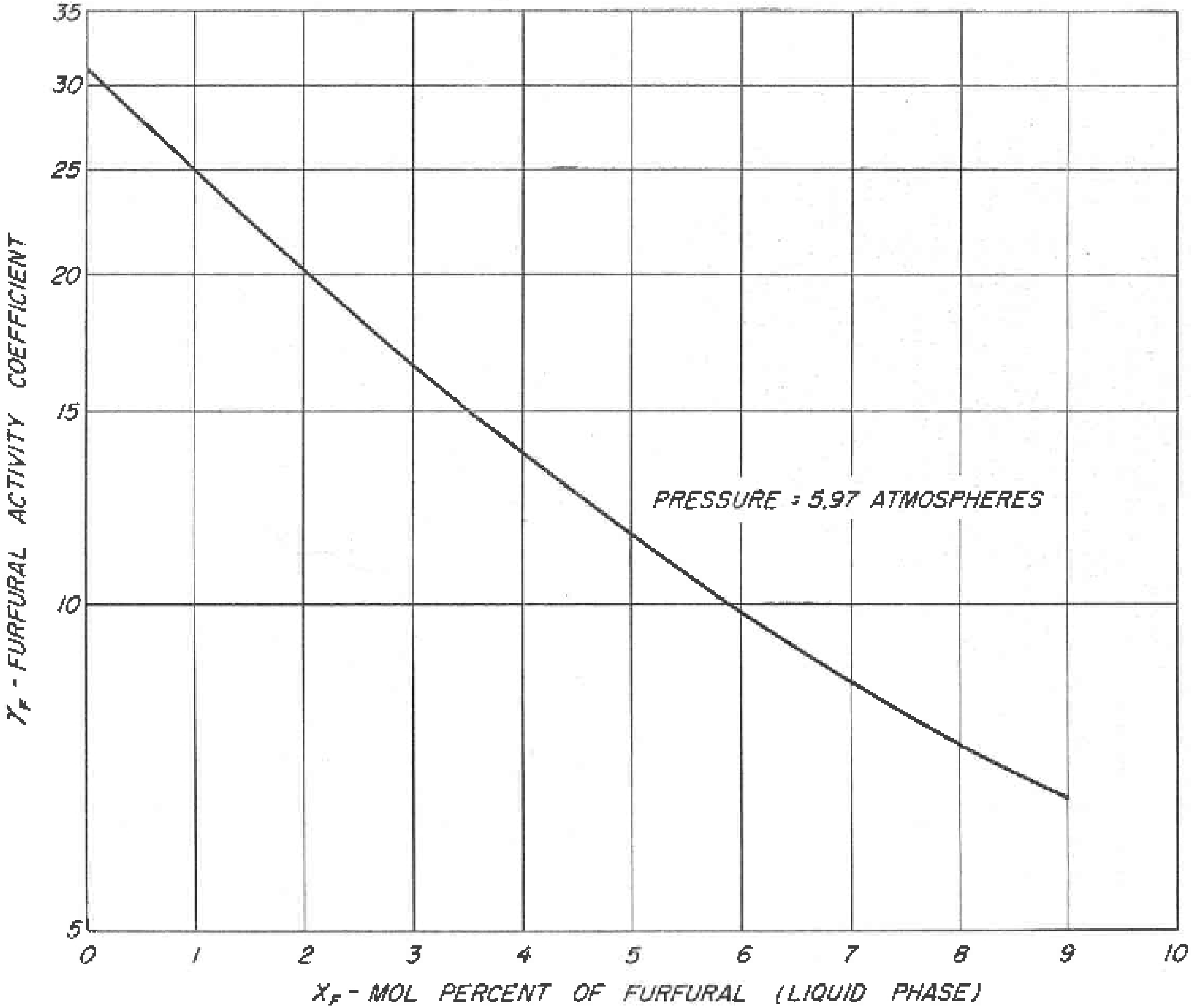

Figure 1.--Activity coefficient of furfural as a function of composition at a pressure of 5.97 atmospheres.

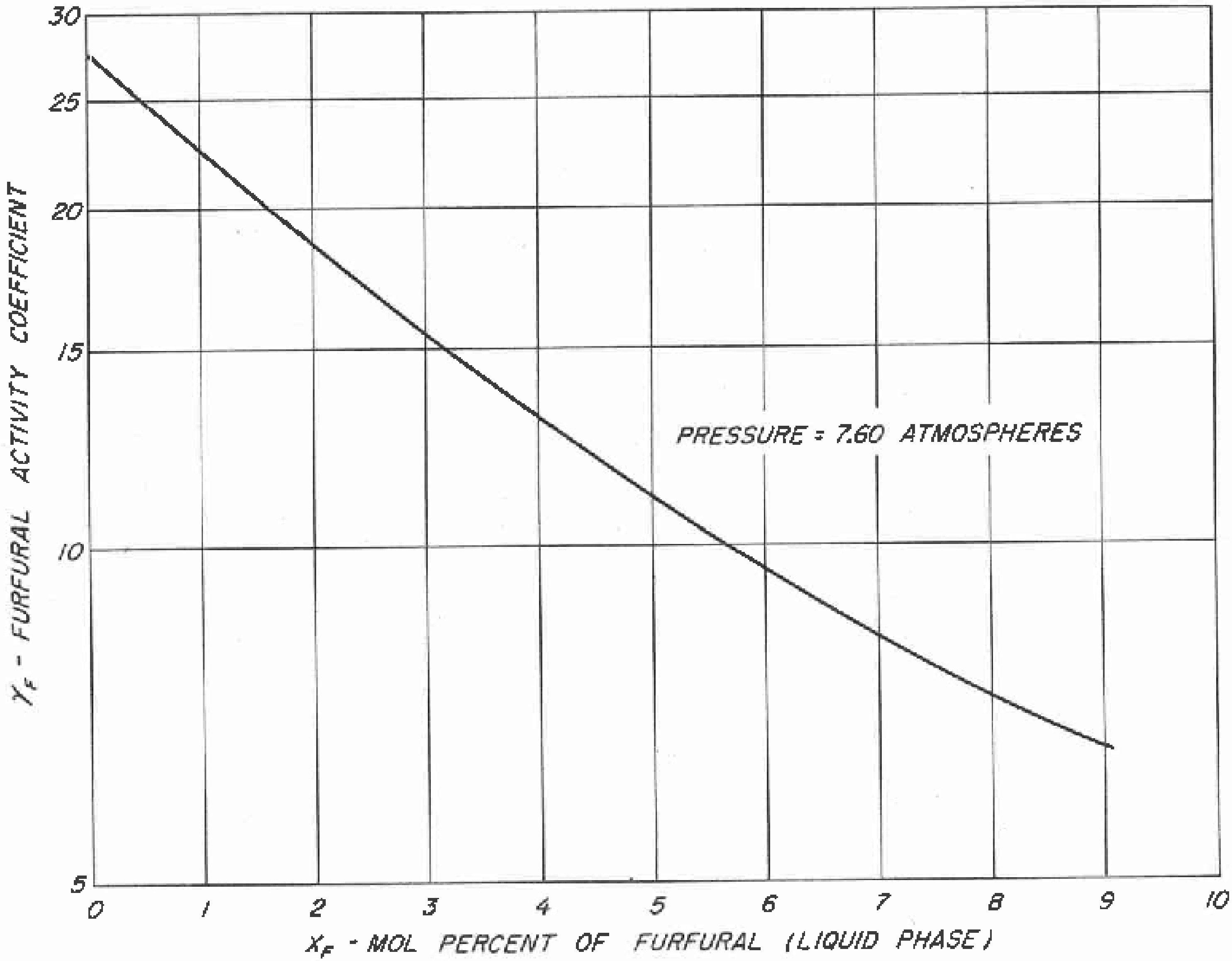

Figure 2.--Activity coefficient of furfural as a function of composition at a pressure of 7.60 atmospheres.

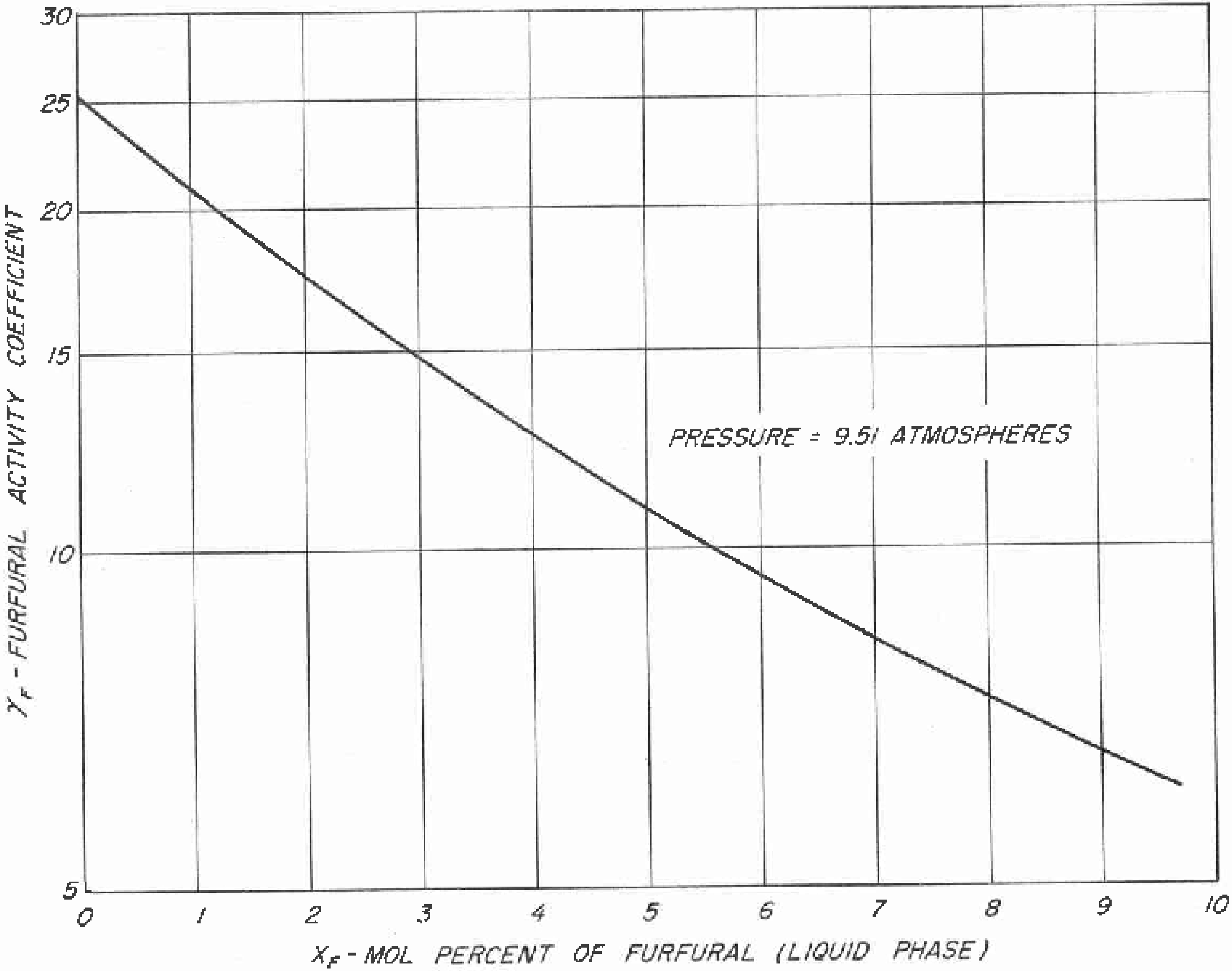

Figure 3. --Activity coefficient of furfural as a function of composition at a pressure of 9.51 atmospheres.

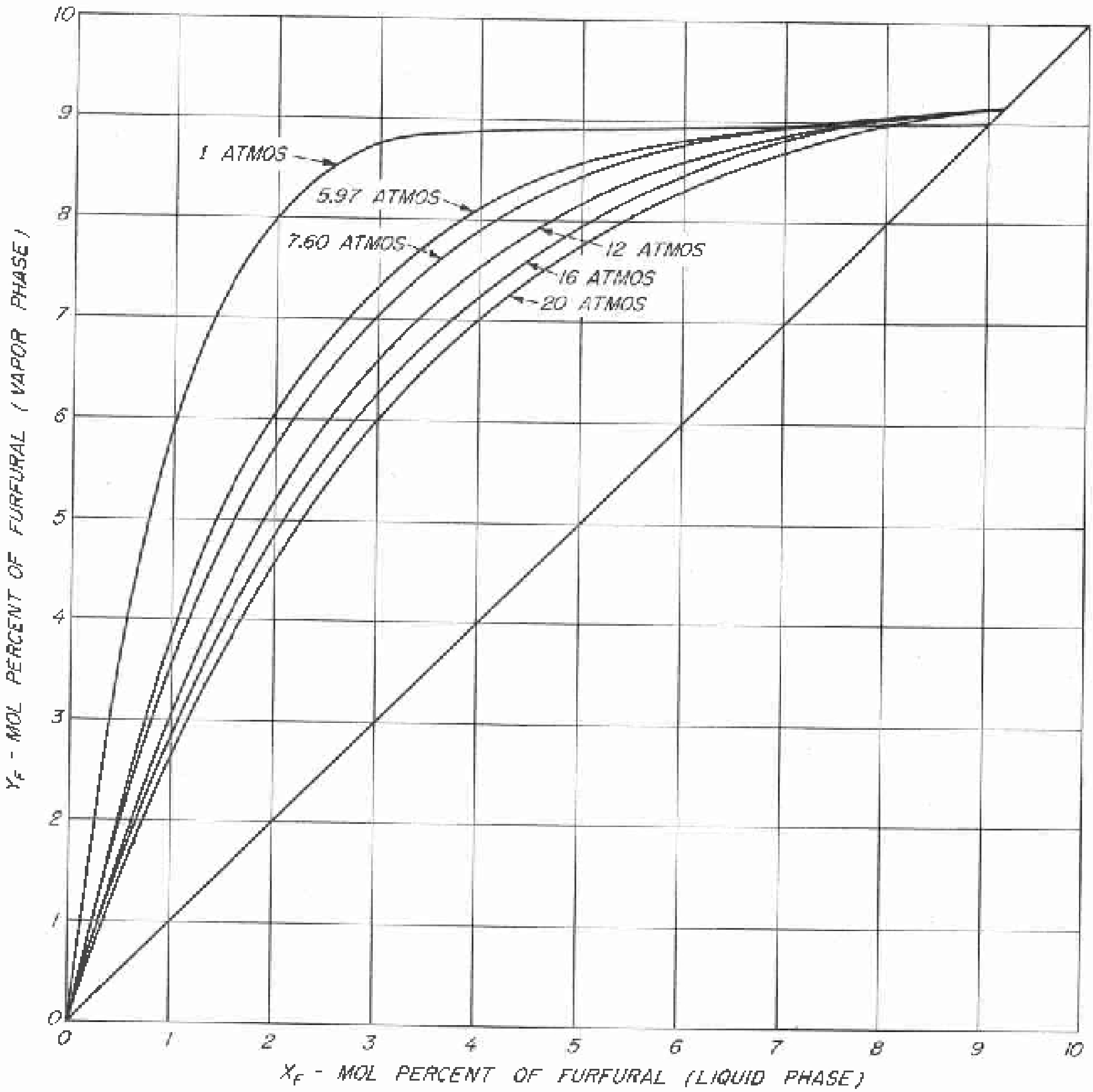

Figure 4. --Calculated values of equilibrium vapor-liquid compositions at various system pressures.

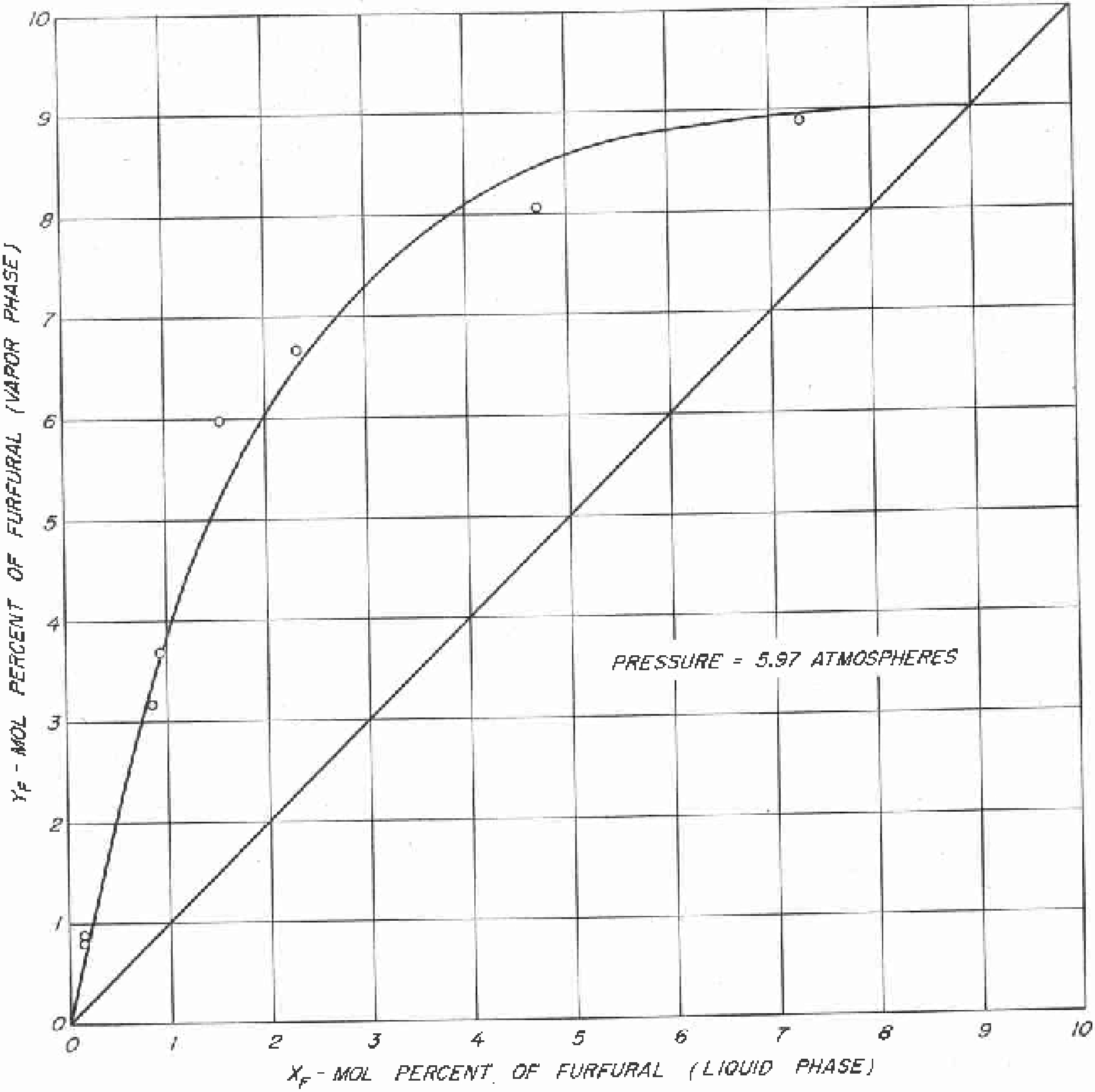

Figure 5. --Comparison of calculated vapor-liquid compositions to experimental values at a pressure of 5.97 atmospheres. Note: Solid curve was calculated, and circles represent experimental data.

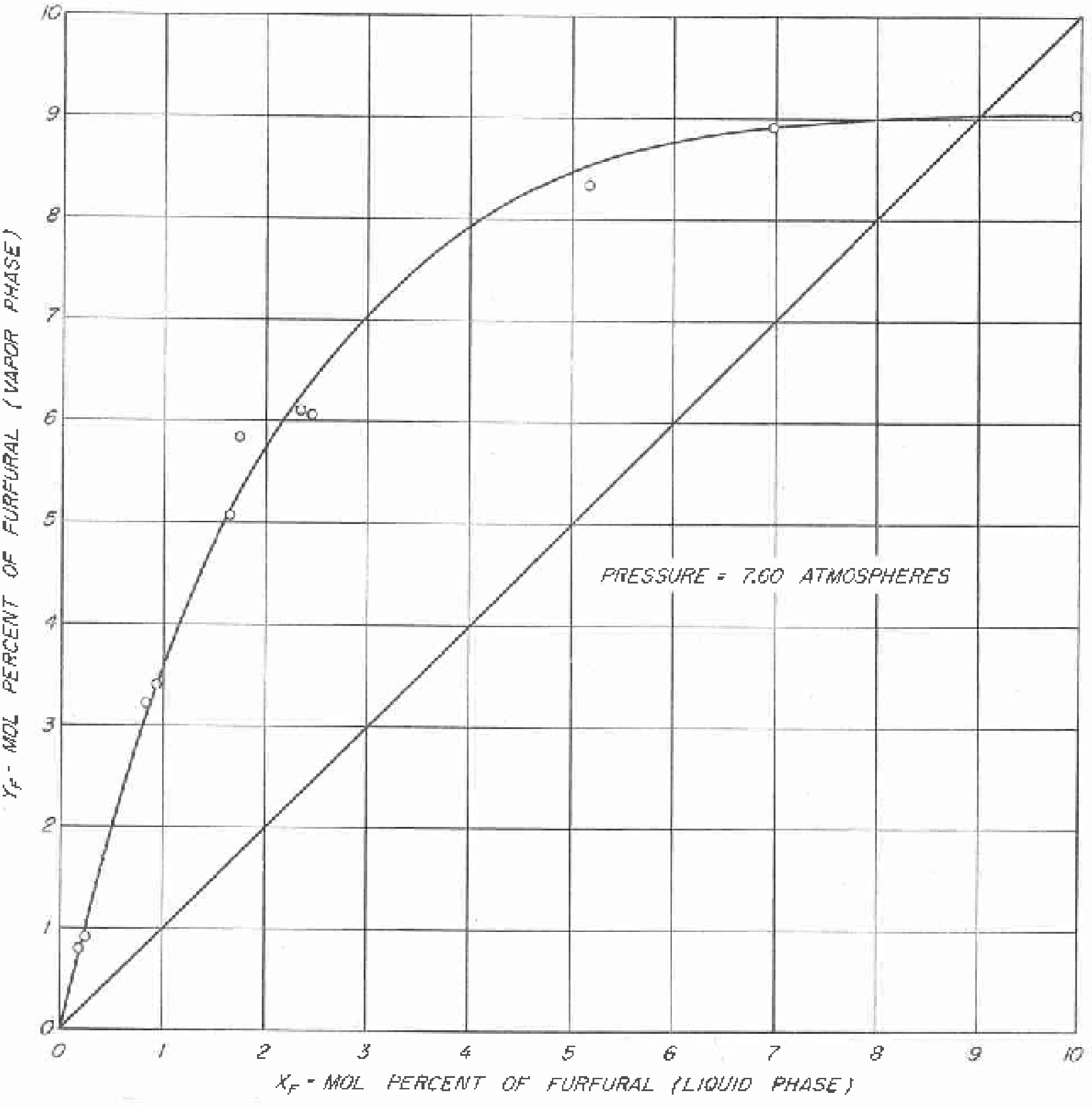

Figure 6.--Comparison of calculated vapor-liquid compositions to experimental values at a pressure of 7.60 atmospheres. Note: Solid curve was calculated, and circles represent experimental data.

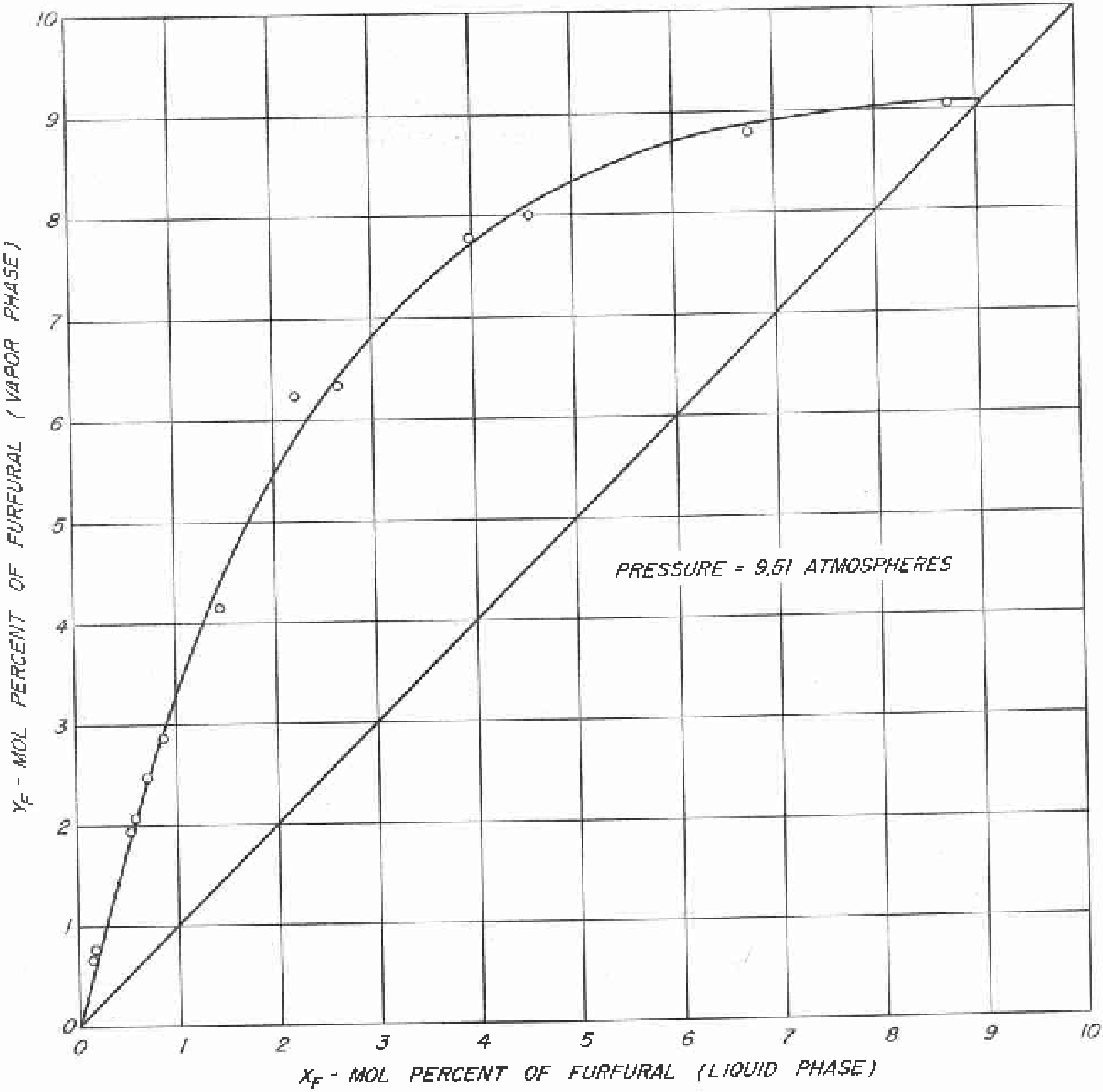

Figure 7.--Comparison of calculated vapor-liquid compositions to experimental values at a pressure of 9.51 atmospheres. Note: Solid curve was calculated, and circles represent experimental data.

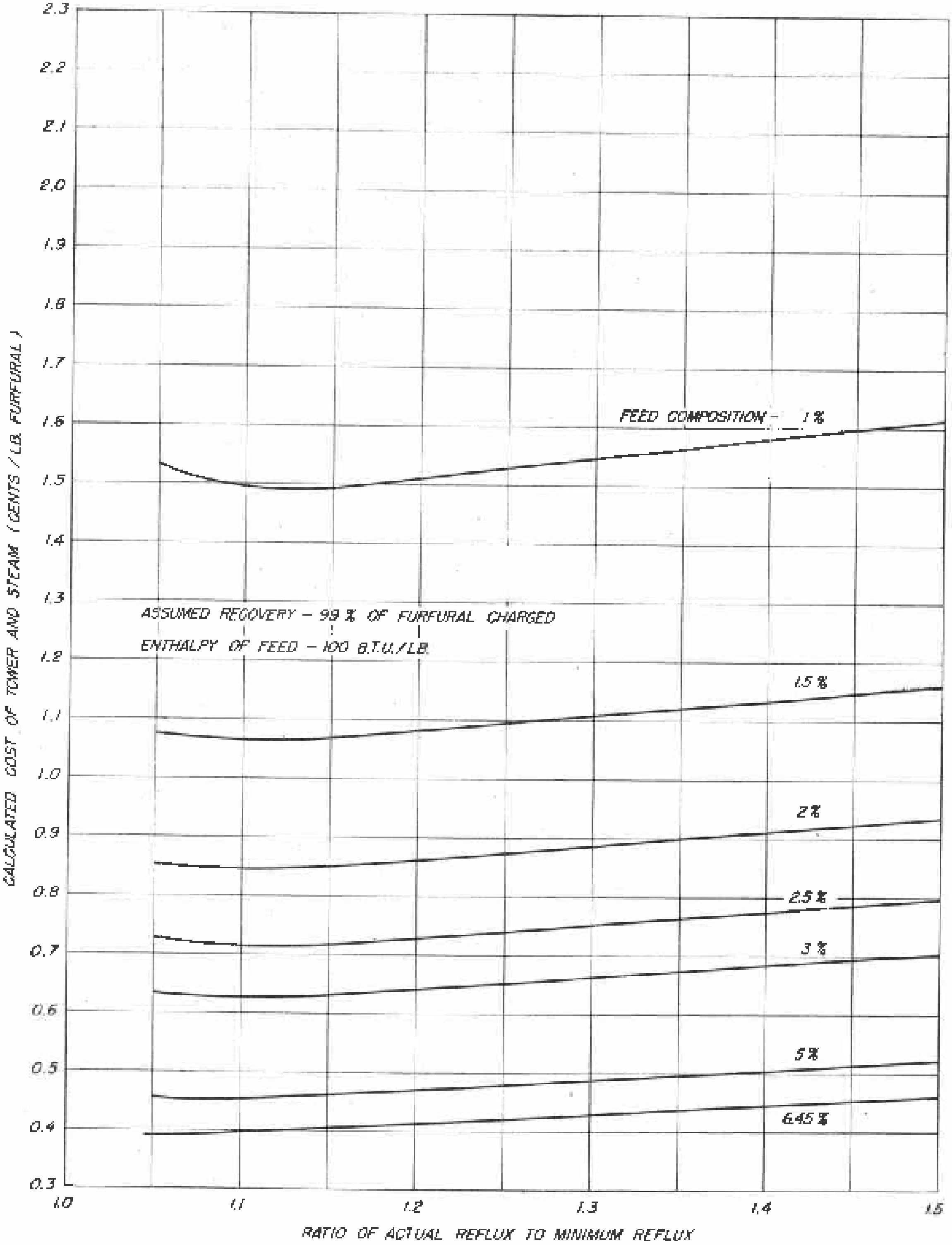

Figure 8.--Effect of reflux ratio on total cost of the azeotrope tower for a feed enthalpy of 100 B.t.u. per pound and a 99 percent recovery of the furfural charged.

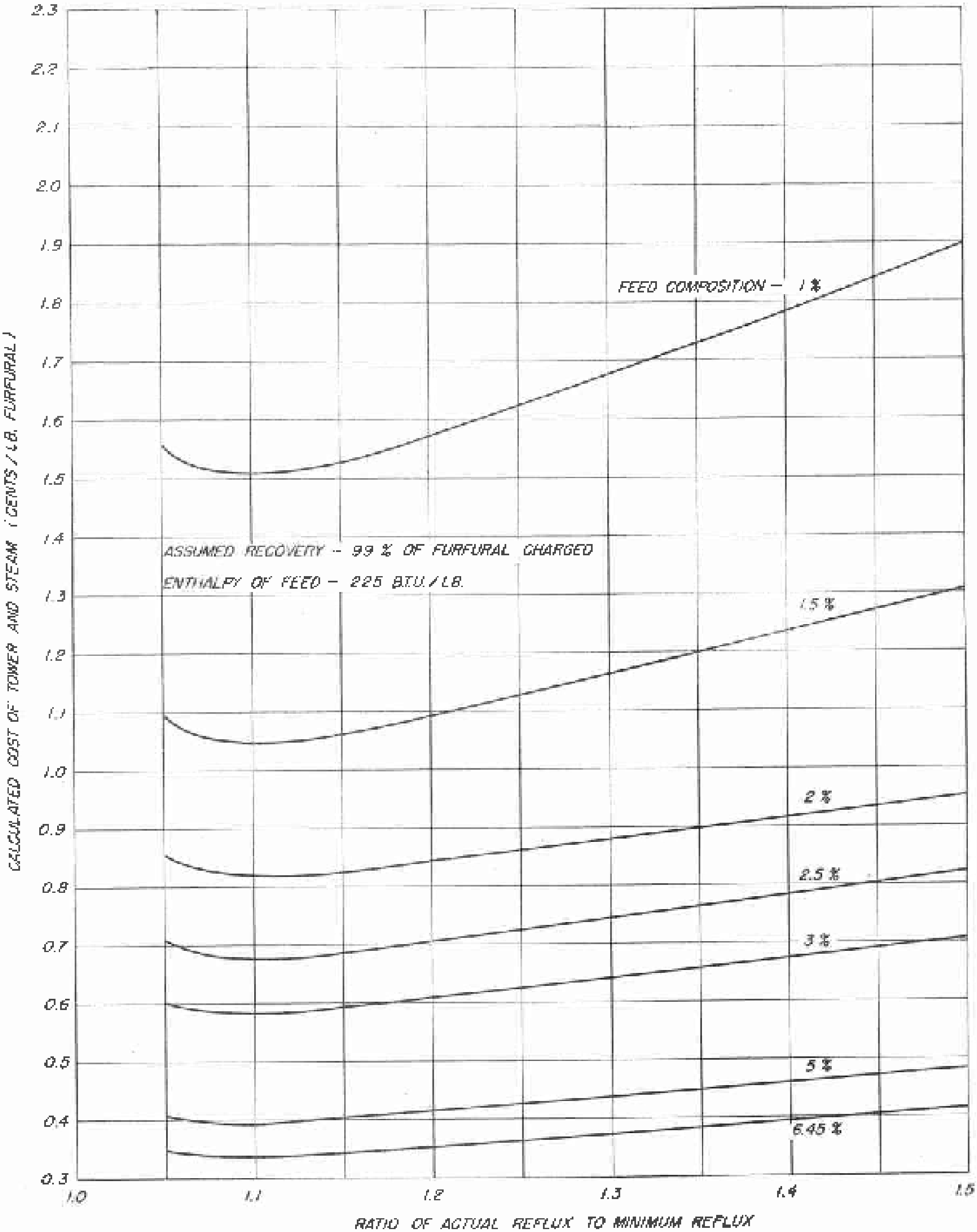

Figure 9.--Effect of reflux ratio on total cost of the azeotrope tower for a feed enthalpy of 225 B.t.u. per pound and a 99 percent recovery of the furfural charged.

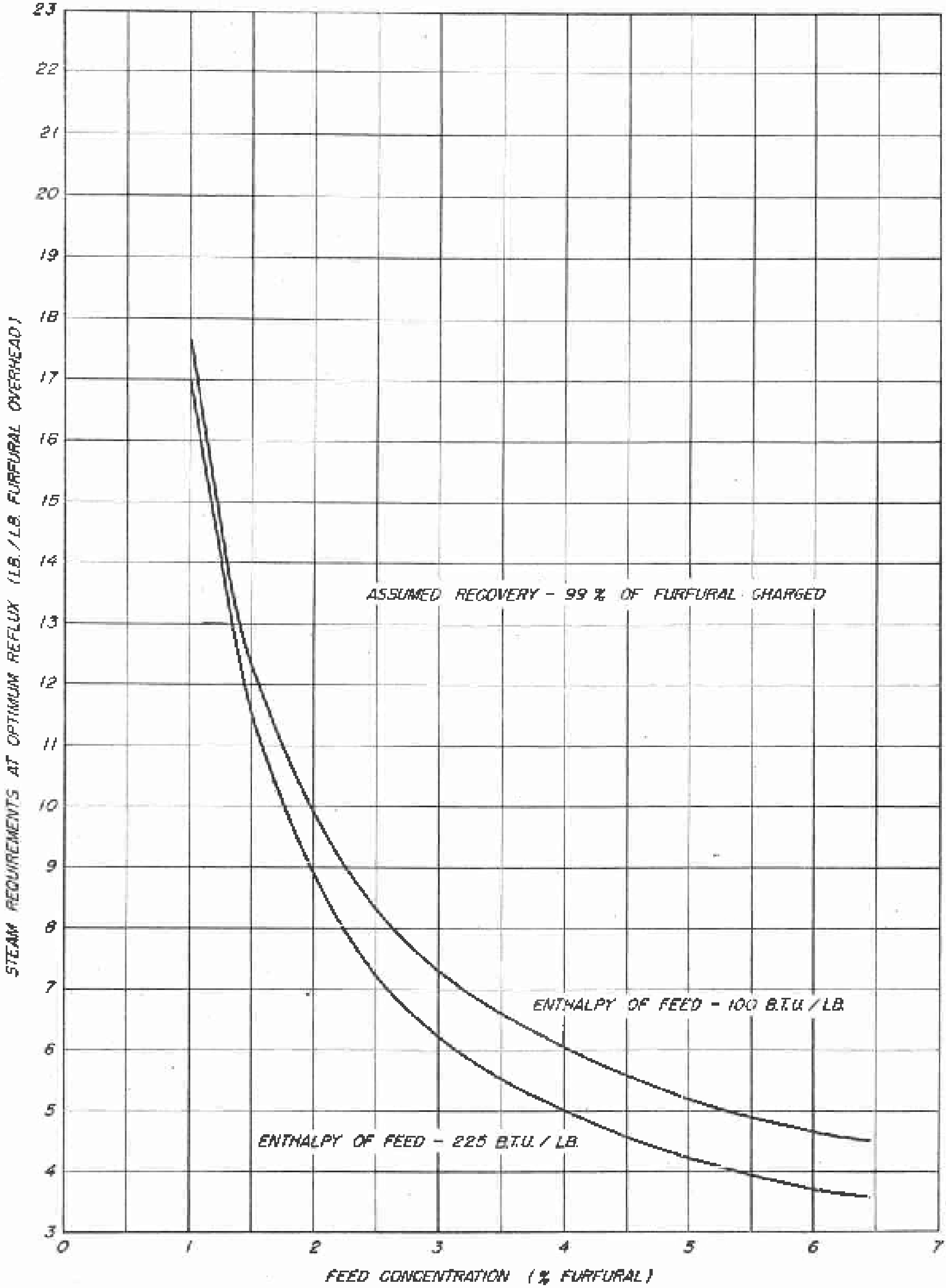

Figure 10. --Steam requirements for the azeotrope tower at optimum reflux at various feed concentrations for 99 percent recovery of the furfural charged.

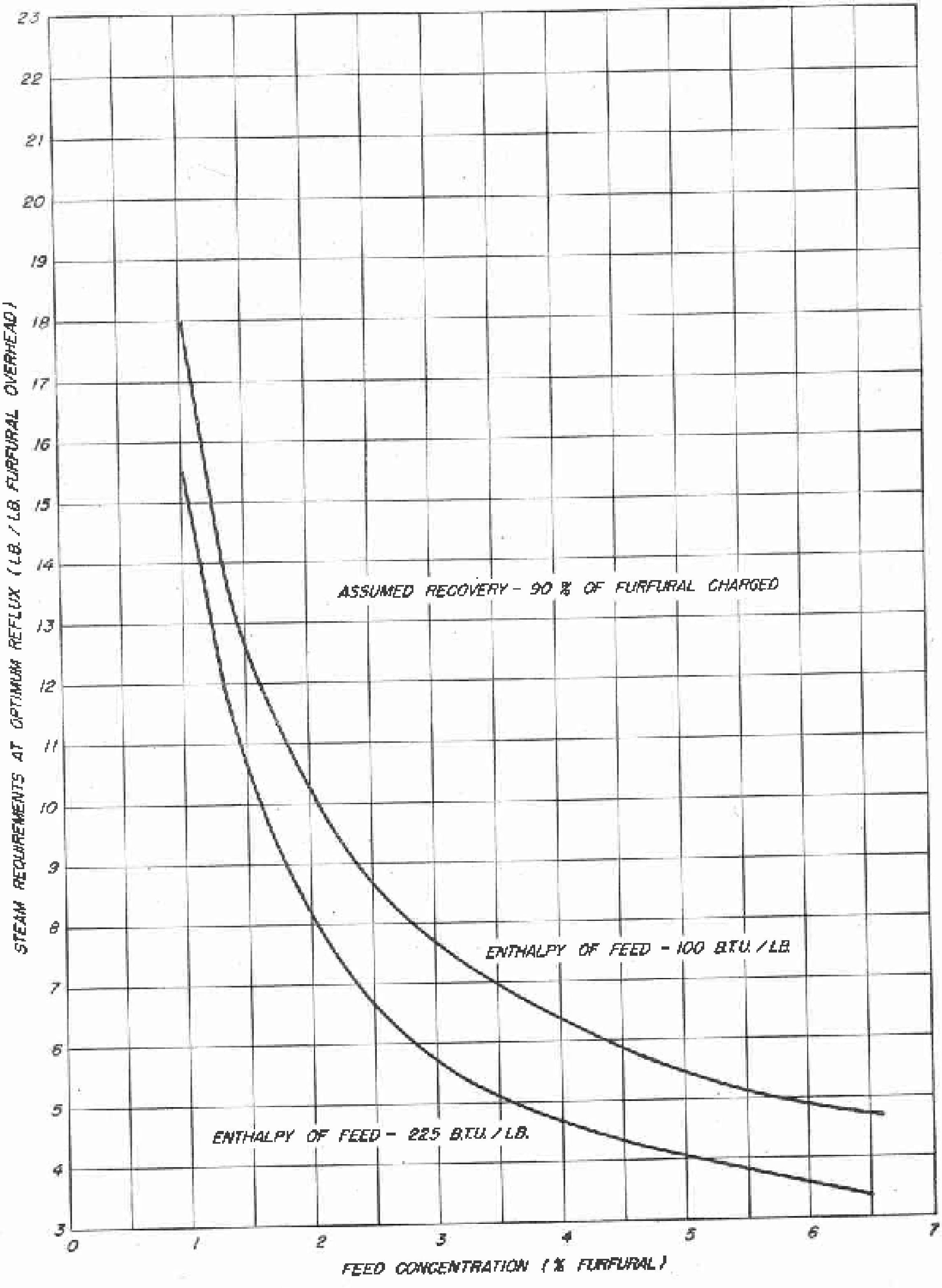

Figure 11.--Steam requirements for the azeotrope tower at optimum reflux at various feed concentrations for 90 percent recovery of the furfural charged.

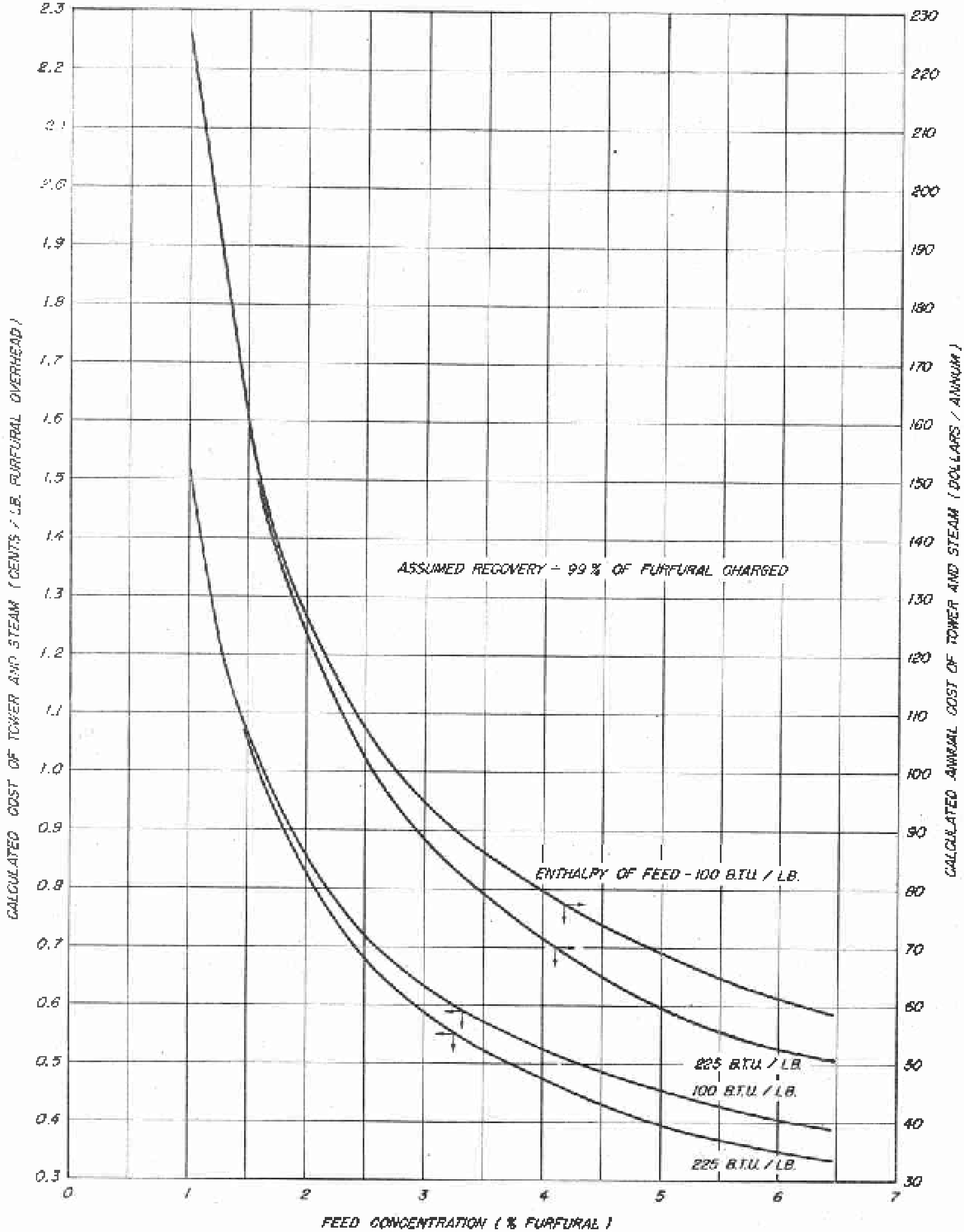

Figure 12. --Total cost of the azeotrope distillation as a function of feed concentration at 99 percent recovery of the furfural charged.

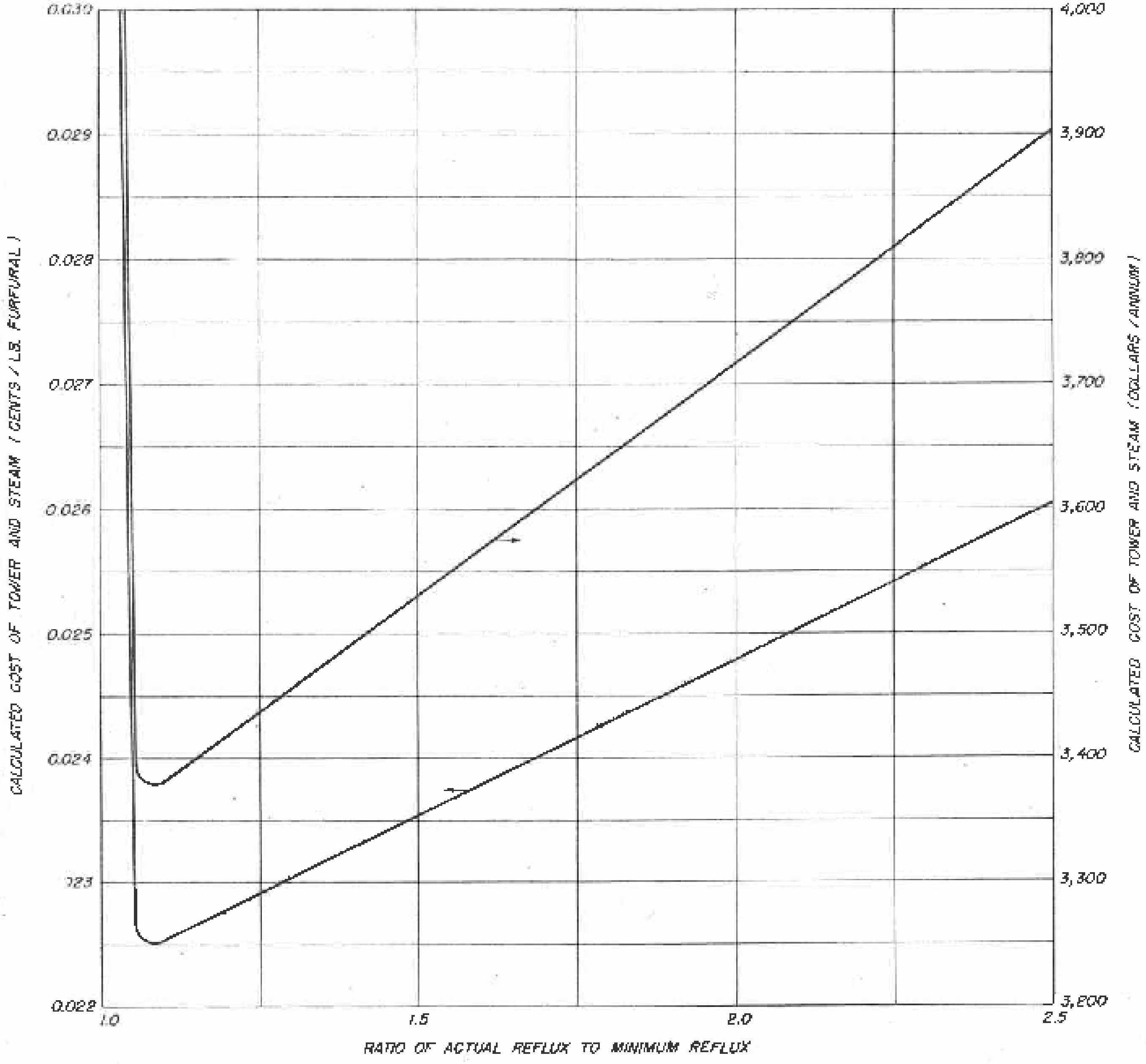

Figure 13. --Effect of reflux ratio on total cost of the dehydrating tower.

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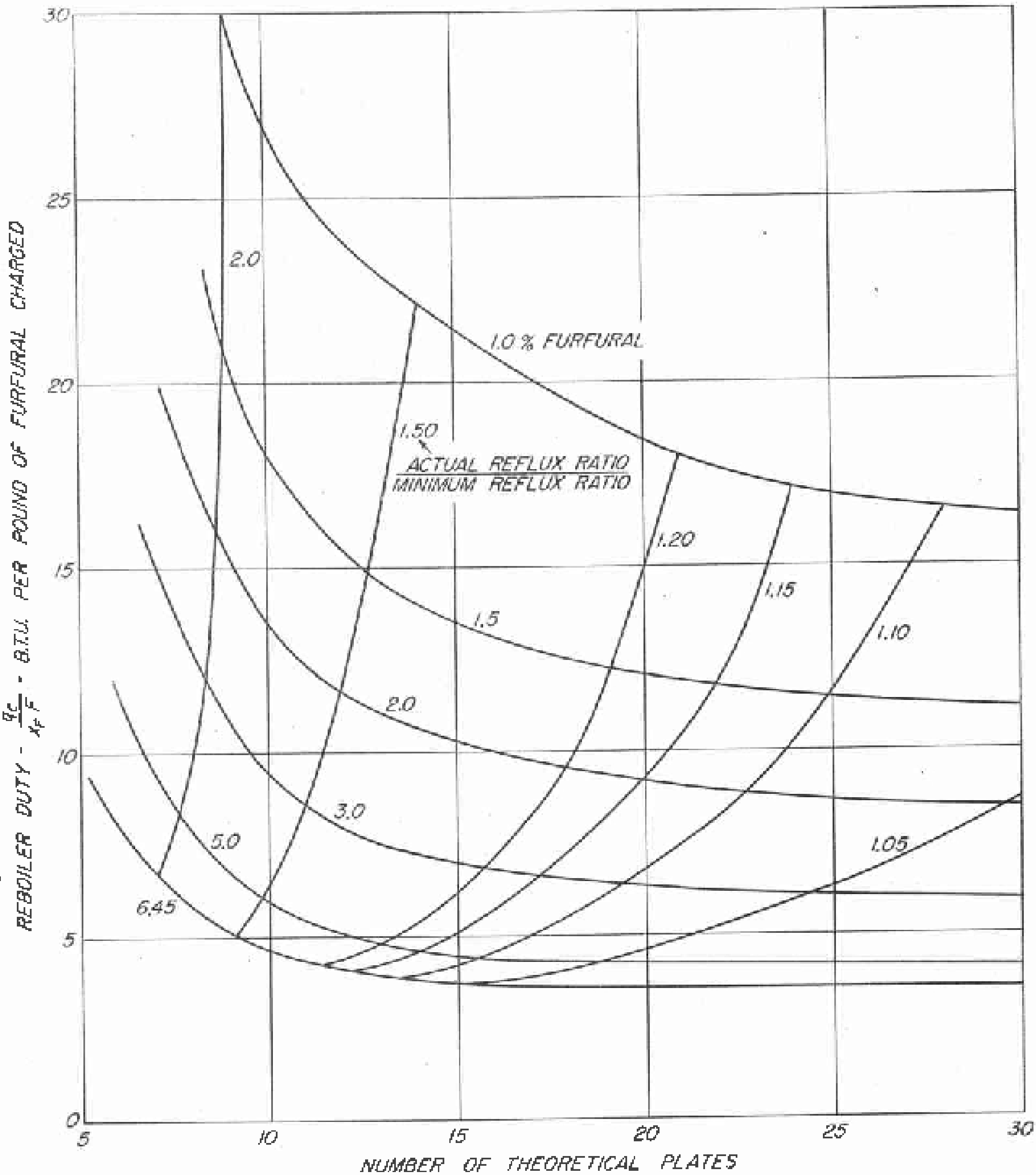

Figure 14. --Relation of heat requirements to theoretical plate requirements of the azeotrope tower for 99 percent recovery of the furfural charged.

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