AN EXPERIMENTAL STUDY OF
THE SEPARATION OF MULTICOMPONENT MIXTURES
VIA THERMAL PARAMETRIC PUMPING

BY

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ABSTRACT

A thermal continuous parametric pump for separating multicomponent mixtures was experimentally investigated using the model system toluene-aniline-n-heptane on silica gel adsorbent. A simple method for predicting separations is presented and is found to be in good agreement with the experimental results. The method,based on an equilibrium theory, is under the assumption that a multicomponent mixture contains a series of pseudobinary systems, each system consisting of one of the solutes as one component and the common inert solvent as the other component.

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INTRODUCTION

Thermal parametric pumping is a phase-change separation process which depends for its operation on the coupling of periodic changes in temperature affecting the position of interphase equilibrium with synchronous periodic changes in flow direction. In the papers (Chen et al.,(2,3)), separations of binary systems (single solute and its solvent) were experimentally investigated via continuous and semi-continuous parametric pumping. It has been shown that under certain conditions the pumps with feed at the enriched end have the capacity for complete removal of solute from one product stream and, at the same time, give arbitrarily large enrichment of solute in the other product stream.

In this thesis continuous parametric pumping is extended to the separations of multicomponent mixtures. The continuous pump is characterized by a steady flow of both feed and product streams during the hot upflow and cold downflow half-cycles. The system used is toluene-aniline-n-heptane on silica gel. A comparison is made between the experimental data and the calculated results based on the method proposed by Chen and Hill(1) .

THEORY

Figure 1 shows the continuous parametric pump model. Flow is upward during the hot half-cycle and downward during the cold half-cycle. Each half-cycle is $\frac{\pi}{\omega}$ time units in duration and the reservoir displacement volume is $Q(\frac{\pi}{\omega})$, where Q is the reservoir displacement rate. The pump has dead volumes V_T and V_B for the top and bottom reservoirs respectively. The feed is directed to the top of the column at the flow rate $(\phi_T + \phi_B)Q$. The top product flow rate is $\phi_T Q$ and the bottom product flow rate is $\phi_B Q$, and ϕ_T and ϕ_B are the ratios of the top and bottom product rates to the reservoir displacement rate.

For processes inside the column we will assume, as did Pigford et al.$^{(4)}$, that local interphase equilibrium exists with a linear distribution law having a temperature-dependent distribution coefficient. Also, there is negligible axial diffusion, temperature changes between hot and cold cycles are instantaneous, plug flow exists, and the fluid density is constant. We will assume further that the multicomponent mixture may be treated as n pairs of pseudo-binary systems. Each system includes one solute and the common inert solvent, and could be characterized by a dimensionless equilibrium parameter b_i and corresponding values of the penetration distances of the hot and cold cycles, L_{1i} and L_{2i}. L_{1i} and L_{2i}

can be expressed in terms of ϕ_B and the equilibrium parameter b_i (Chen and Hill $^{(1)}$)

$$\frac{L_{1i}}{L_{2i}} = \frac{1 - \phi_B}{1 + \phi_B} \; \frac{1 + b_i}{1 - b_i} \tag{1}$$

$$L_{2i} = \frac{v_o \, (1 + \phi_B)}{(1 + b_i) \left[1 + 0.5(\, m_{1i} + m_{2i} \,)\right]} \left(\frac{\pi}{\omega}\right) \tag{2}$$

where

$$m_i = \frac{\rho_s \, (1 - \varepsilon) \, M_i}{\varepsilon} \tag{3}$$

and M_i $\left(= \frac{x_i}{y_i}\right)$ is the equilibrium distribution coefficient at temperature T. The quantity, b_i, is associated with a given two phase system when operated at two specific temperatures, and may be expressed as

$$b_i = \frac{0.5 \; (\, m_{2i} - m_{1i})}{1 - 0.5 \; (m_{1i} - m_{2i} \;)} \tag{4}$$

The pump performance depends on the relative magnitudes of L_{1i}/L_{2i} and the height of the column, h. There are three possible regions of pump operations (see Figure 2) depending on L_{1i}/L_{2i} and h,

$$\text{Region 1,} \; \frac{L_{1i}}{L_{2i}} \geqslant 1 \quad (\text{or } \phi_B \leqslant b_i) \text{ and } L_{2i} \leqslant h \tag{5}$$

Region 2, $\frac{L_{1i}}{L_{2i}} < 1$ (or $\phi_B > b_i$) and $L_{1i} \leqslant h$

Region 3, L_{1i} and $L_{2i} > h$

By treating the multicomponent mixture as a series of Pseudo-binary systems, the multicomponent separation could be predicted by the mathematical expressions for binary systems developed by Chen and Hill,(1) and Chen et al.(2, 3) It has been found that at steady state ($n \rightarrow \infty$) solute removal from the bottom product stream, $\phi_B Q$, is complete in Region 1 and only partial in Regions 2 and 3.

Considering a mixture containing s solutes, each with its own b_i and

$$b_1 > b_2 > \; ---- \; b_k \geqslant \phi_B > b_k - 1 \; --- > b_s \qquad (6)$$

were subscripts 1, 2, etc., refer to solutes 1, 2, etc.

Furthermore,

$$\begin{aligned} L_{2i} &\leqslant h \quad \text{when } i = 1, 2, --- \; k \\ L_{1i} &\leqslant h \quad \text{when } i = k - 1, --- \; s \end{aligned} \qquad (7)$$

At steady state the components, i = 1, 2, --- k for which the operations are indicated in Region 1, would appear only in the top product stream, and the remaining components (k + 1, --- s) would appear in both the top and bottom Product streams. In the extreme case where k = s the bottom product stream would consist only of pure solvent. By proper adjustment of ϕ_B in Eq. 6 a solute split could be made which is analogous to that obtained by a multicomponent distillation column.

Experimental

(a) Parametric Pumping Experiment

The experimental apparatus is shown schematically in Figure 3. Two dual infusion-withdrawal syringe pumps manufactured by the Harvard Apparatus Co., were used, one for the feed and one for the reservoirs. The jacked column had dimensions length 0.9 m, and inside diameter 0.01 m..Reservoirs at the two opposite ends of the column were two 50 cu. cm. glass syringes.

Prior to each run, a small magnetic stirrer was placed in each syringe to fulfill the required perfect mixing. A micro-switch with stops was wired into the reservoir pump circuit to automatically reserse the action of the syringe plungers at the end of each half cycle. The jacked column was packed with 30 to 60 mesh chromatographic grade silica gel, and filled via the bottom reservoir syringe with the feed mixture of contrations, y_{oi} , at room temperature. The reservoir syringes were set to deliver about 40 cu. cm. per half cycle with a minimum dead volume of approximately in 3 c.c. in each syringe. Hot and cold water baths were connected to the column jacket, and solenoid valves were wired to a dual timer to insure that hot water (333°K) was directed to the column during upflow and cold water (298°K) during downflow. Filled all lines and feed syringe with the feed mixture of contration, y_{oi}. After eleminating all of air from the system, the bottom reservoir held 45 c.c. of the feed mixture and the top reservoir held 5 c.c.. The feed syringe was set to deliver 16 c.c. per half cycle.

To start the run, the feed and reservoir pumps were switched on and the timer was actived. The feed was delivered to the top of the column. The timer switched the solenoids to supply hot water (333°K) to the jacket. Bottom reservoir syringe pushed the fluid into the column, top reservoir received the fluid from the top of the column. Micrometer valves were used to regulate both the top and bottom product flows and impose a small back pressure on the system. The total cycle time was 2,400 sec. (1,200 sec. of up flow followed by 1,200 sec. of down flow). At the end of this half cycle, hot up flow half cycle, the microswitch reversed the reservoir pump movement, and the timer switched the solenoids to supply cold water (298°K) to the jacket. Subsequent to the cold down flow half cycle, the second cycle was started and the procedure was repeated until 14 cycles were completed.

Using the above procedures, twelve experimental runs were carried out. They were a aniline-n-heptane system, a toluene-n-heptane, and ten aniline-toluene-n-heptane systems in different operating conditions. All experimental data are given in Tables 2(A), 2(B), 3(A), 3(B) through 3(J). The experimental parameters for binary systems and ternary systems run 1 & run 2 are shown in Table 1.

(b) Analysis of Product Streams

The product stream samples were taken at the end of each half cycle for analyzing.

To develop the procedure for analyzing ternary system (aniline-toluene-n-heptane) product, three previous experiments were made. First experiment, made a known concentration of aniline-n-heptane solution (aniline conc. $= 2.743 \times 10^{-7}$k gmole/c.c.) diluted it with n-heptane to make different concentration solutions. Each diluted solution concentration was equal to 1/(Dilution Factor) of its original solution. Measuring each diluted solution by ultraviolet spectrometry, the absorbances ,ℓ, at wave length ,λ, of 263 mμ and 289 mμ were acquired. The data is shown on Table 4 and Plotted in Fig. 4 curves 1 and 4. For Second experiment, toluene-n-heptane solution (toluene conc.$= 2.349 \times 10^{-7}$k gmole/c.c.) was made. Other procedures were the same as in experiment 1. The data is shown in Table 5, and Plotted in Fig. 4 curve 3. Made toluene-aniline-n-heptane solution (aniline conc.$= 2.743 \times 10^{-7}$k gmole/c.c., toluene conc.$= 2.349 \times 10^{-7}$k gmole/c.c.) for Third experiment. Same procedures as in First Experiment were carried out. The data is shown in Table 6, and Plotted in Fig. 4 curve 5. Samples for analysis were taken from the product streams at the end of each cycle and analyzed by ultraviolet spectrophotometry using the procedure illustrated in Fig. 4. To prevent the absorbance ,ℓ, from over scale, each sample was diluted with n-heptane before analyzing to decrease its concentration to 1/(Dilution Factor) of that in original solution. For the runs involving binary systems (toluene or aniline in n-heptane) the analysis was straight forward and the concentration of solute was linearly proportional to the absorbance, ℓ, at λ (wavelength) = 263 $m\mu$ for toluene and at $\lambda = 289\ m\mu$ for aniline. This is clearly shown in curves 3 and 1 of Figure 4. In the case of the ternary system, aniline-toluene-n-heptane, the analysis was somewhat complicated. As shown in Fig.4.,, ℓ for aniline at $\lambda = 289\ m\mu$ in toluene-n-heptane coincided with that in n-heptane alone and was found to be independent of the presence of toluene (curves 1 and 2). The ℓ at $\lambda = 263\ m\mu$ in toluene-aniline-n-heptane (curve 5) was the sum of that in toluene-n-heptane (curve 3) and in aniline-n-heptane (curve 4). Therefore, for an unknown ternary mixture the aniline concentration was determined directly from ℓ at $\lambda = 289\ m\mu$ regardless of the toluene concentration. Knowing the aniline concentration, ℓ for aniline at $\lambda = 263\ m\mu$ was determined from curve 4. Subtraction of this ℓ from the total ℓ obtained at $\lambda = 263\ m\mu$ in toluene-aniline-n-heptane gave the contribution of ℓ by toluene alone and hence its concentration from curve 3.

Using above procedures, the product samples of twelve parametric pumping experiments, involving aniline-n-heptane system, toluene-n-heptane system and aniline-toluene-n-heptane in different operating conditions, were analyzed. Analysis results are shown in Tables 7(A), 7(B), and 8(A) through 8(J).

RESULTS AND DISCUSSION

Among twelve experimental runs, the four typical runs — including two binary systems and two ternary systems, are employed in this section. The experimental parameters are shown in Table 1 and the data are plotted in Figures 5 and 6. The equations derived by Chen, et al.(2) were used to calculate the concentration transients and the computed results corresponding to the experimental runs are also presented in Figures 5 and 6. These results compare resonably well with the observed values. In the computations for the ternary system (toluene-aniline-n-heptane), it was assumed that there are no interactions between solutes, and the system contains two pseudo-binaries, each binary consisting of one solute as one component and the common solvent as the other component, i.e., toluene-n-heptane and aniline-n-heptane.

When the pumps are operated in the Region 1, (i.e., $(L_{1i}/L_{2i}) \geqslant 1$ (or $\phi_B \leqslant b_i$) and $L_{2i} \leqslant h$), the bottom concentration transient is (Chen et al.,(2) 1972)

$$\frac{\langle y_{BP2} \rangle_n}{y_{oi}} = \frac{1 - b_i}{1 + b_i} \left[\frac{\frac{1 - b_i}{1 + b_i} + C_2}{1 + C_2} \right]^{n-1} , \qquad n \geqslant 1 \tag{8}$$

and at steady state ($n \rightarrow \infty$),

$$\frac{\langle y_{BP2} \rangle_\infty}{y_{oi}} = 0 \tag{9}$$

Figure 5 illustrates $\langle y_{BP2} \rangle_n / y_{oi}$ v.s. n for both toluene and aniline in both binary and ternary systems. one can see that $\langle y_{BP2} \rangle_n / y_{oi}$ decreases as n increases and, as the theory predicts, approaches zero as n becomes large. The slop, α, (of log $\langle y_{BP2} \rangle_n / y_{oi}$ v.s. n) of the solute i (toluene or aniline) in the binary mixture (toluene-n-heptane or aniline-n-heptane) is coincident with that in the ternary system (toluene-aniline-n-heptane). In other words, for a given C_2, T_1 and T_2, the value of b_i which can be calculated from by Eq. 8 is essentially the same for both the binary and ternary systems. It should be emphasized that the quantity b_i is a measure of the extent of movement of solute i between phases as the result of a change in column temperature. Pump performance is enhanced by a large b_i. The particular b_i values considered here were determined to be 0.15 and 0.31 for toluene and aniline respectively.

Figure 6 shows the effects of L_{1i}, L_{2i} and h on the product concentrations. As long as L_{2i} is less than or equal to L_{1i} and h (Region 1), the separation factor, defined as the quotient of the top and bottom concentrations, approaches infinity as n becomes larger. If, in a pump originally operated in Region 1, L_{2i} is increased until it exceeds h or if L_{1i} becomes less than L_{2i}, switching points are encountered which cause the steady-state behavior of the pump to abruptly switch from a mode in which solute is completely removed from the bottom product stream to one in which solute removal is incomplete. One may visualize crossing the boundary $L_{2i}=h$ as a result of increasing L_{2i} by increasing the reservoir displacement volume, $Q\frac{\pi}{\omega}$. Crossing of the boundary $L_{1i}=L_{2i}$ may be viewed as resulting from an increase of ϕ_B so that $\phi_B > b_i$, or $L_{2i} > L_{1i}$. At $T_1 = 333^\circ K$ and $T_2 = 298^\circ K$ the switching point for toluene corresponds to the condition $\phi_B = b_{toluene} = 0.15$. In the case of aniline, the condition is $\phi_B = b_{aniline} = 0.31$. Thus, when $\phi \leq 0.15$ (curves 3a and 3b), the operation is in region 1 for both toluene and aniline, and solute removal from the bottom product stream may be complete at $n \rightarrow \infty$. If ϕ_B is increased to the interval range, $0.15 < \phi \leq 0.31$ (curves 4a and 4b), the operation switches to region 2 for toluene and, remains in region 1 for aniline, and the bottom product could eventually contain only toluene. If ϕ_B is further increased, $\phi_B > 0.31 = b_{aniline}$, the operation is now in region 2 for both toluene and aniline, and both aniline and toluene would appear in the bottom product stream at $n \rightarrow \infty$. Over the internal $\phi_B \leq b_i$ = switch point of solute i, then $\langle y_{TP2} \rangle_\infty / y_{oi} = 1 + \frac{\phi_B}{\phi_T}$

Beyond the switching points (see curve 4a, Figure 6),

$< y_{BP2} >_\infty / y_{oi}$ and $< y_{TP2} >_\infty / y_{oi}$ can be calculated by the equations (Chen and Hill (1))

$$\frac{< y_{TP2} >_\infty}{y_{oi}} = \frac{(\phi_T + \phi_B)\ (1 - b\,\phi_B)}{\phi_T + \phi_B - b\,(1 + \phi_T\,\phi_B)}$$

$$\frac{< y_{BP2} >_\infty}{y_{oi}} = \frac{(\phi_B - b)\ (\phi_T + \phi_B)}{\phi_B\left[(\phi_T - \phi_B) - b\,(1 - \phi_T\phi_B)\right]}$$

The method presented here is a means of predicting multicomponent separations by assuming that solutes do not interact with one another. In practice, the concentrations of solutes may be quite high and the high solute concentrations may cause competition for the adsorption sites. Therefore the maximum separation factors may never be obtained.

CONCLUSIONS

A simple means of predicting multicomponent separations in the continuous thermal parametric pump is presented. A multicomponent system is treated as a series of pseudo-binary systems, each binary system consisting of one of the solutes as one component and the common inert solvent as the other component. This approach permits the use of transient and steady state equations for binary systems developed by Chen and Hill(1) and Chen et. al.,(2) Experimental data for the concentration transients agree reasonably well with the analytical predictions.

It is shown that the thermal parametric pump is capable of separating components in a multicomponent mixture and, as a theoretical limit, of attaining infinite separation factors. Also, the net movement of concentration fronts through the adsorption column is found to be important in determining the pump performance. Those solutes for which the net movement is upward would, at steady state, appear only in the top product. The remaining solutes would appear in both the top and bottom products. In the limiting case, it is possible for the bottom product to consist solely of pure solvent. This happens when all solutes in a mixture are very strongly adsorbed in a given cycle or when the flow rate of the bottom product is very small.

NOTATION

b = dimensionless equilibrium parameter defined by Equation (4)

C_1 = $\frac{V_T}{Q\frac{\pi}{\omega}}$, dimensionless

C_2 = $\frac{V_B}{Q\frac{\pi}{\omega}}$, dimensionless

h = column height, m

L = penetration distances defined by Equation (1) or (2), m

M = $\frac{x}{y}$, k gmoles/g.

m = dimensionless equilibrium parameter defined by Eq. 3

n = number of cycle of pump operation

Q = reservoir displacement rate, cm^3/s

v_o = interstital velocity based on the reservoir displacement rate, m/s

V_T = top reservoir dead volume, cm^3

V_B = bottom reservoir dead volume, cm^3

x = concentration of solute in the solid phase, k gmole/g of adsorbent

y = concentration of solute in the liquid phase, k gmoles/cm^3 or k gmoles/k gmoles of fluids.

$\langle\ \rangle$ = average value

Greek Letters

ϕ = product volumetric flow rate/reservoir

$\frac{\pi}{\omega}$ = displacement rate, dimensionless

duration of half cycle,s

ε = void fraction in packing, dimensionless

ρ_f = density of fluids k gmoles/cm^3

ρ_s = density of adsorbent, kg./cm^3

Subscripts

0 = initial condition

1 = upflow

2 = downflow

B = stream from or to bottom of the column

i = solute i

P = product stream

T = stream from or to top of the column

BP = bottom product

TP = top product

Figure 1

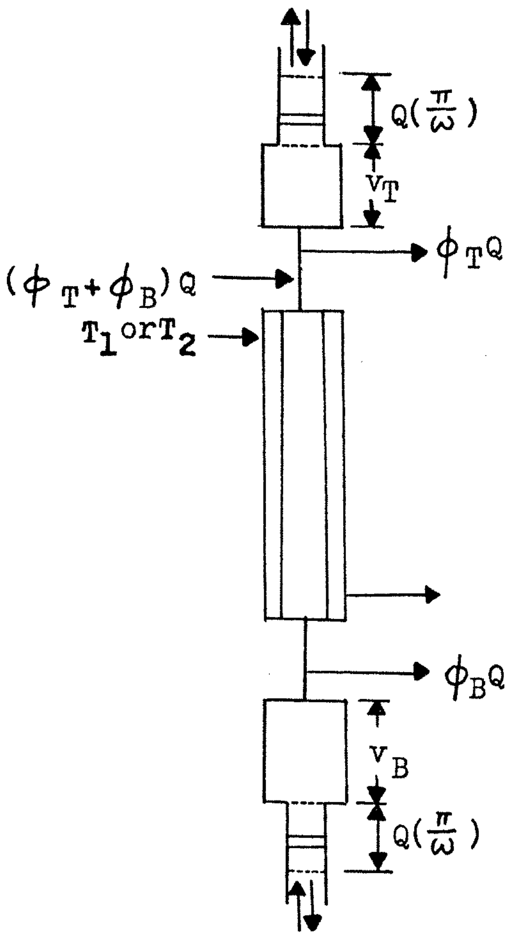

$Q(\frac{\pi}{\omega})$
v_T
$\phi_T Q$
$(\phi_T+\phi_B)Q$
T_1 or T_2
$\phi_B Q$
v_B
$Q(\frac{\pi}{\omega})$

Figure 2

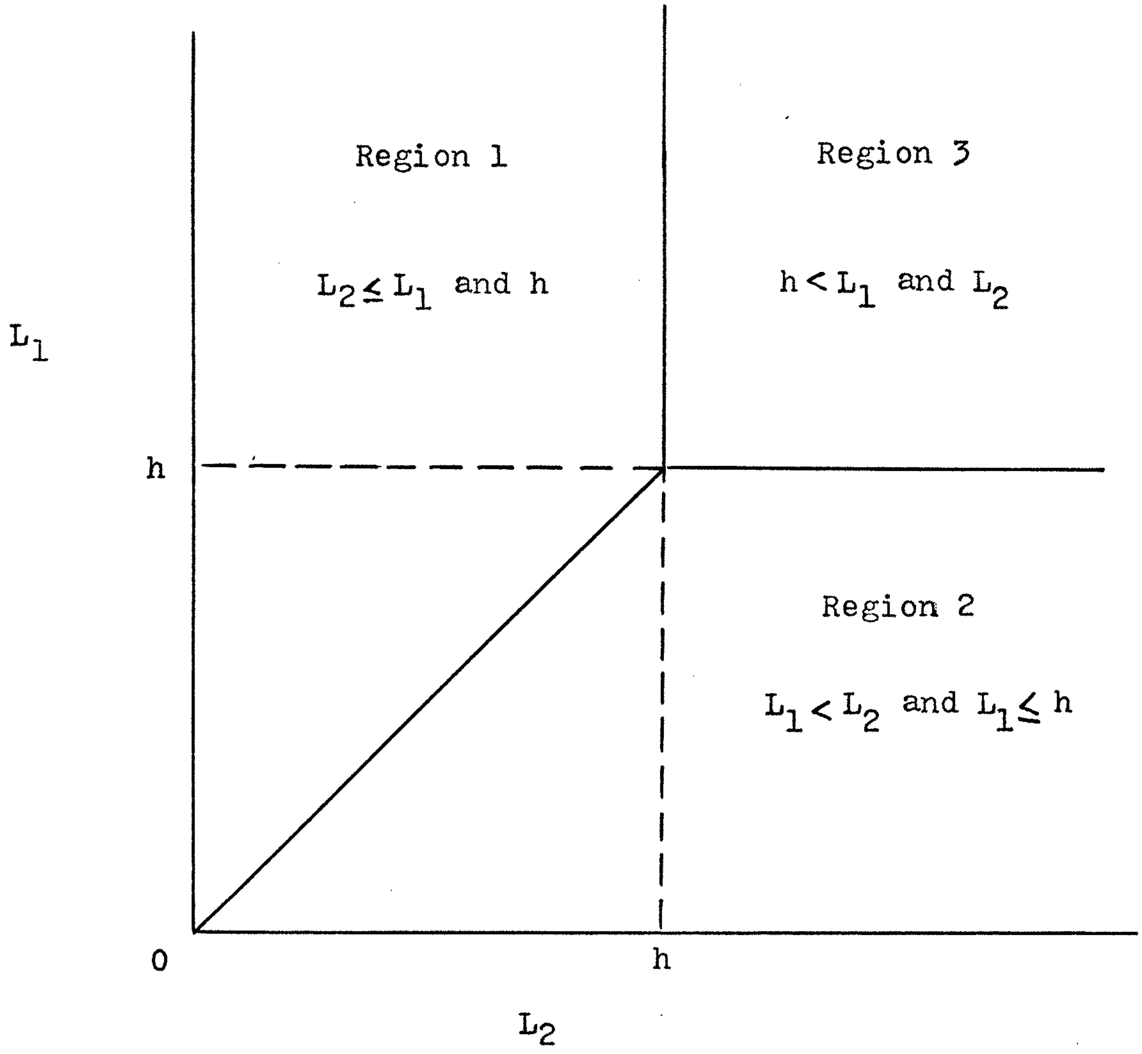
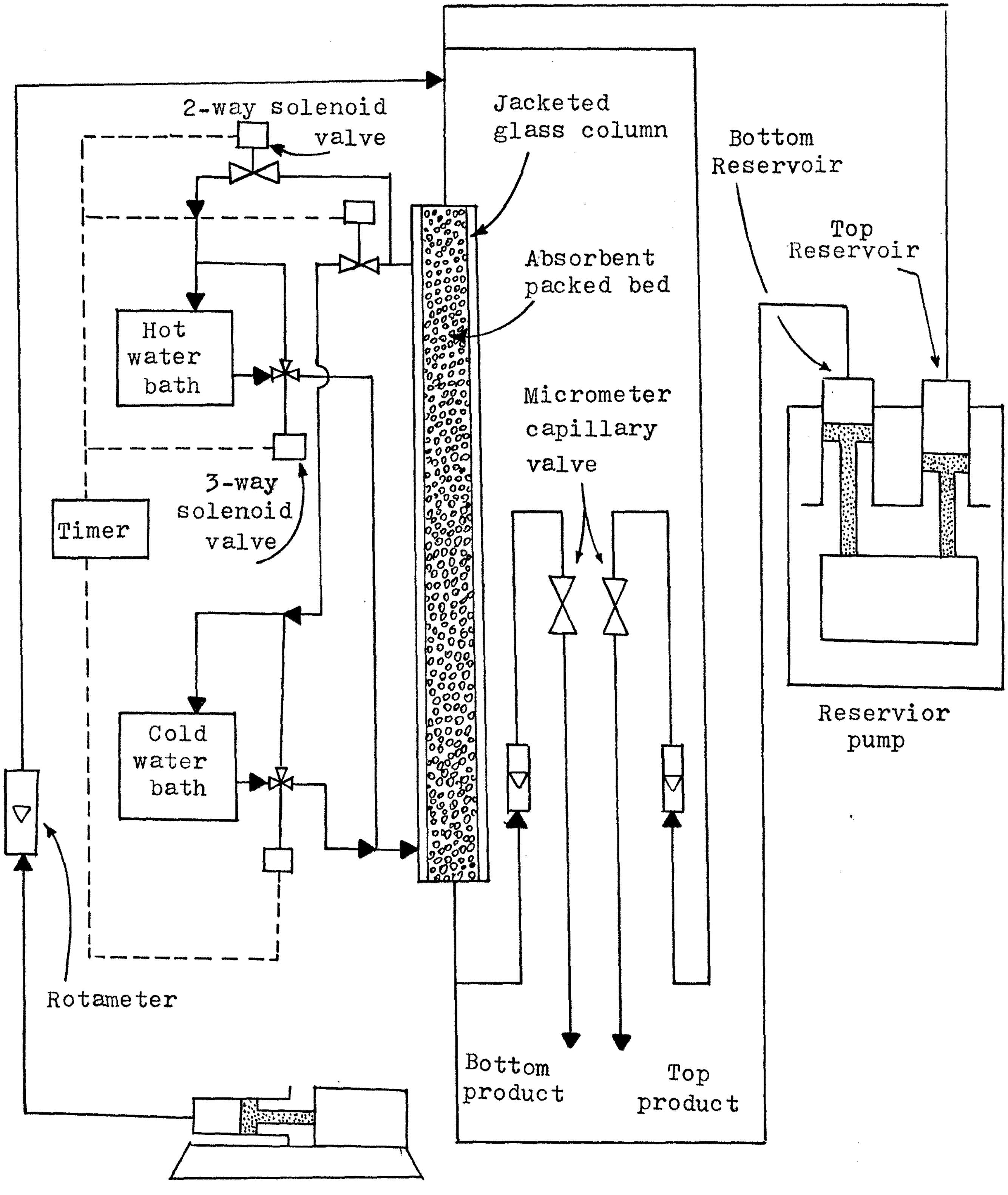

Region 1
$L_2 \leq L_1$ and h
Region 3
$h < L_1$ and L_2
L_1
h
Region 2
$L_1 < L_2$ and $L_1 \leq h$
0
h
L_2

Fig. 3


2-way solenoid valve
Jacketed glass column
Bottom Reservoir
Top Reservoir
Absorbent packed bed
Hot water bath
Micrometer capillary valve
3-way solenoid valve
Timer
Cold water bath
Reservior pump
Rotameter
Bottom product
Top product
Feed pump

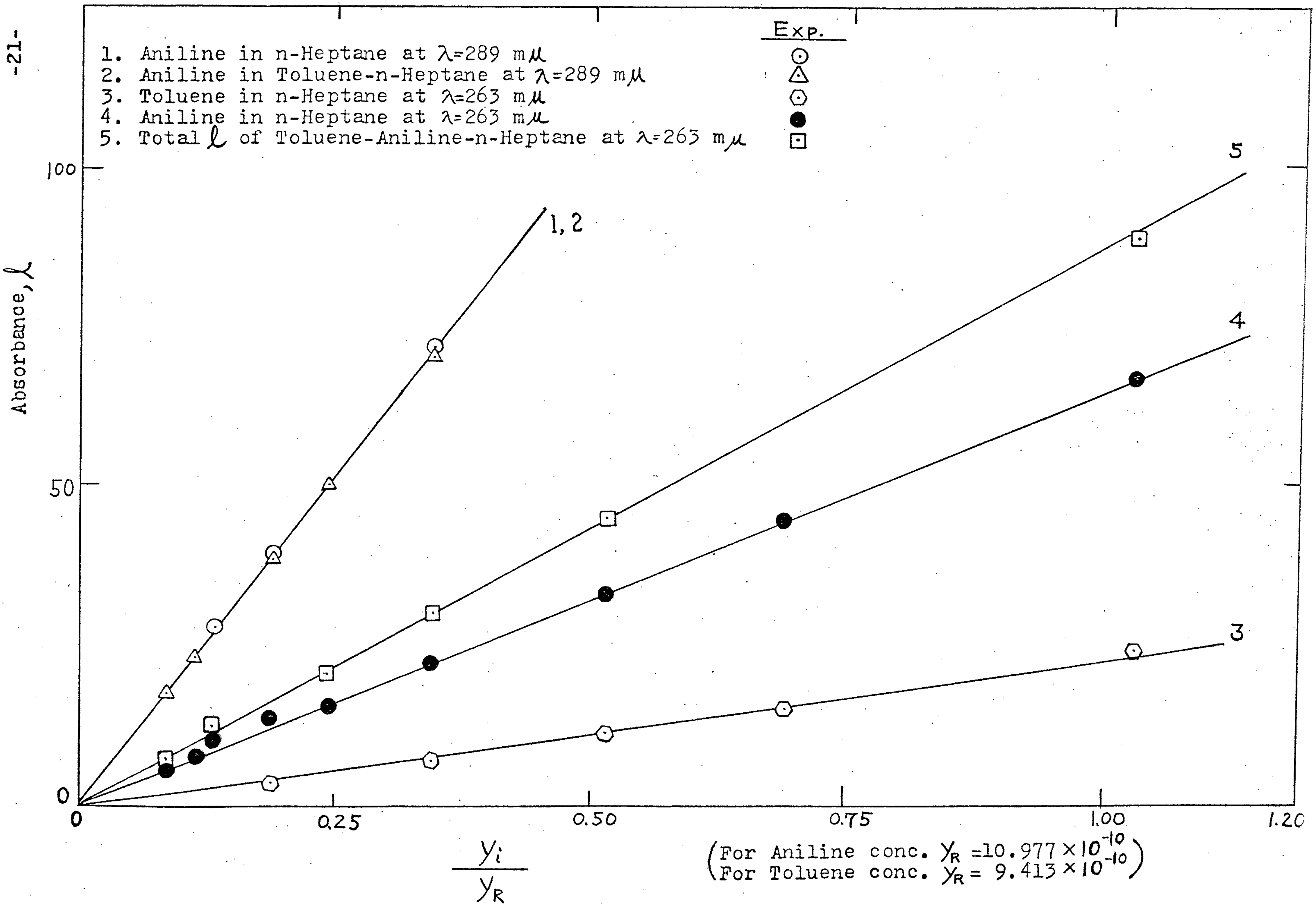

Exp.
1. Aniline in n-Heptane at λ=289 mμ ⊙
2. Aniline in Toluene-n-Heptane at λ=289 mμ △
3. Toluene in n-Heptane at λ=263 mμ ⬡
4. Aniline in n-Heptane at λ=263 mμ ●
5. Total ℓ of Toluene-Aniline-n-Heptane at λ=263 mμ ⊡
1, 2
5
4
3
Absorbance, ℓ
100
50
0
0
0.25
0.50
0.75
1.00
1.20
$\frac{y_i}{y_R}$
(For Aniline conc. y_R =10.977 × 10^{-10}
For Toluene conc. y_R = 9.413 × 10^{-10})

Figure 5

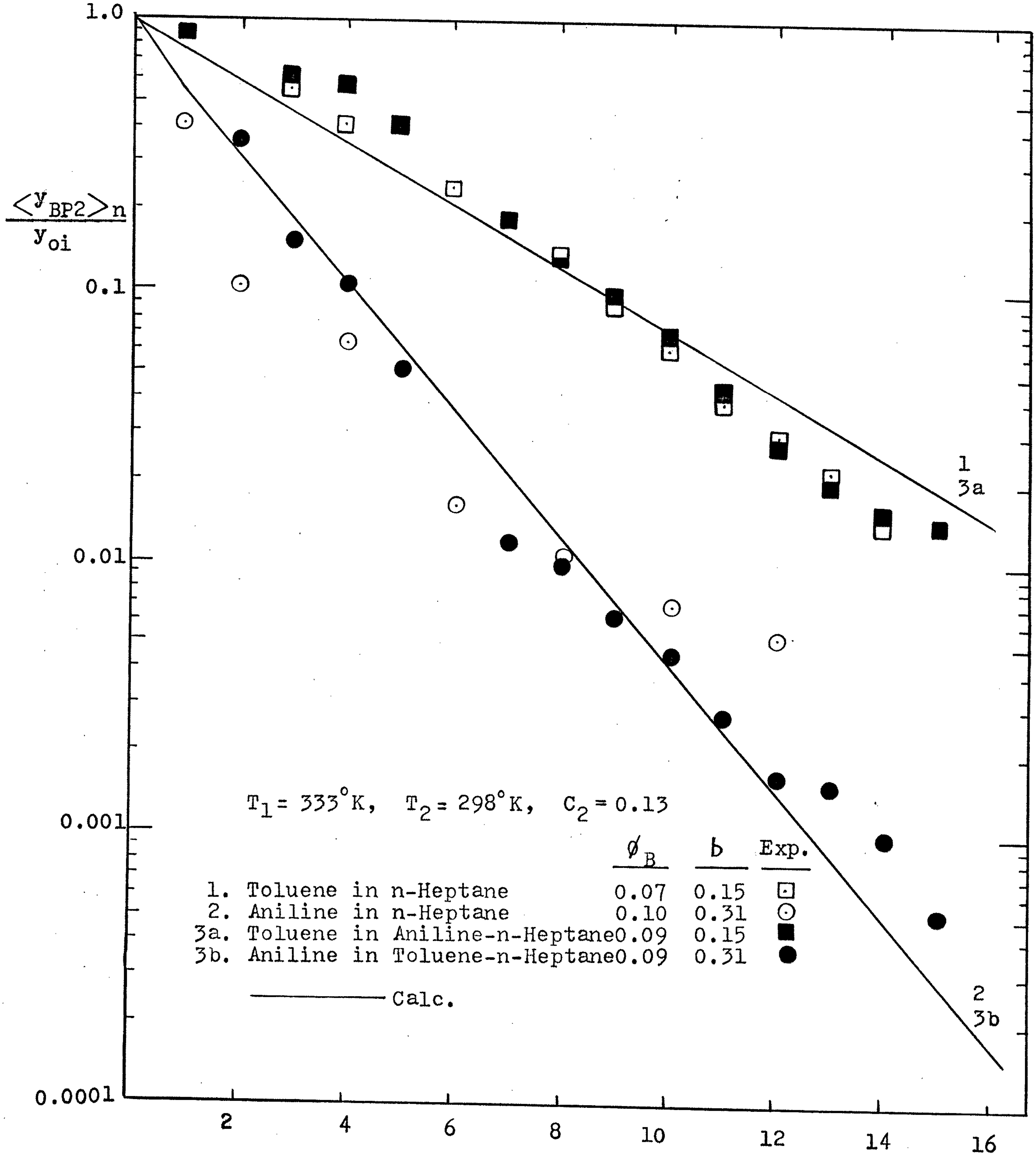

1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$
2
4
6
8
10
12
14
16
1
3a
2
3b
$T_1 = 333°K$, $T_2 = 298°K$, $C_2 = 0.13$
ϕ_B b Exp.
1. Toluene in n-Heptane 0.07 0.15 ⊡
2. Aniline in n-Heptane 0.10 0.31 ⊙
3a. Toluene in Aniline-n-Heptane 0.09 0.15 ■
3b. Aniline in Toluene-n-Heptane 0.09 0.31 ●
Calc.

Figure 6

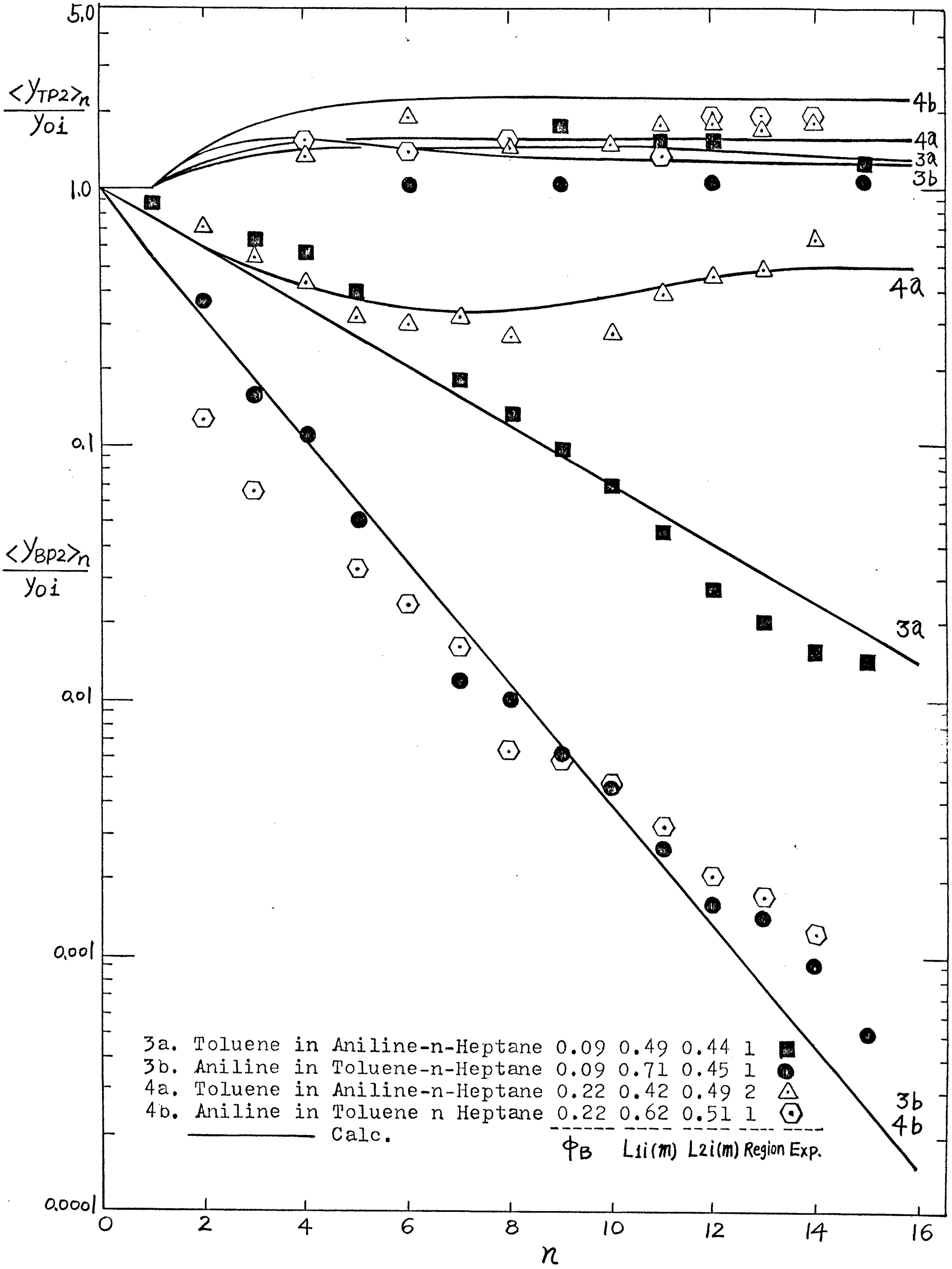

5.0
1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{TP2}\rangle_n}{y_{oi}}$
$\frac{\langle y_{BP2}\rangle_n}{y_{oi}}$
0
2
4
6
8
10
12
14
16
n
4b
4a
3a
3b
4a
3a
3b
4b
3a. Toluene in Aniline-n-Heptane 0.09 0.49 0.44 1 ■
3b. Aniline in Toluene-n-Heptane 0.09 0.71 0.45 1 ●
4a. Toluene in Aniline-n-Heptane 0.22 0.42 0.49 2 △
4b. Aniline in Toluene n Heptane 0.22 0.62 0.51 1 ⊙
——— Calc.
ϕ_B $L_{1i}(m)$ $L_{2i}(m)$ Region Exp.

Fig. 7

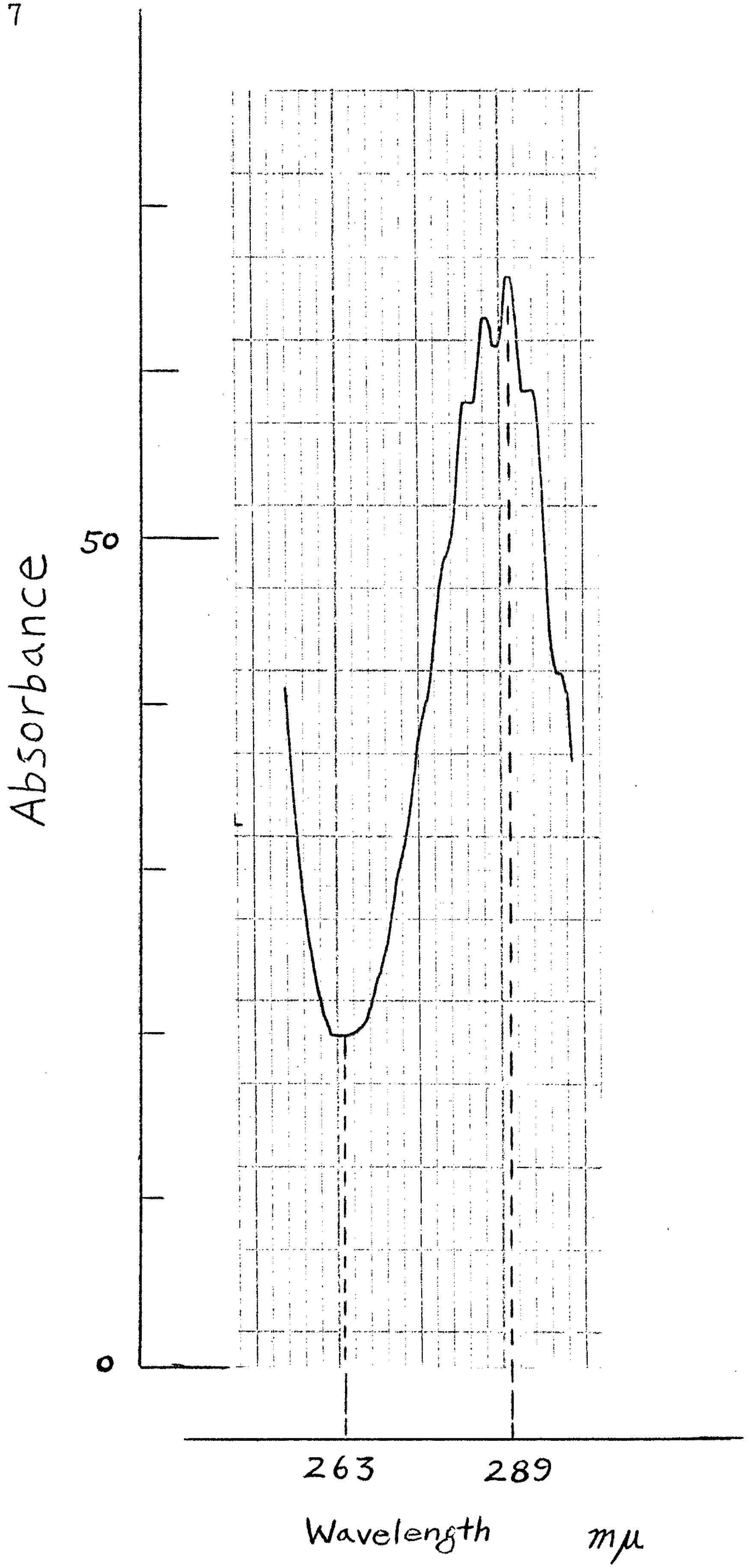


Fig. 8

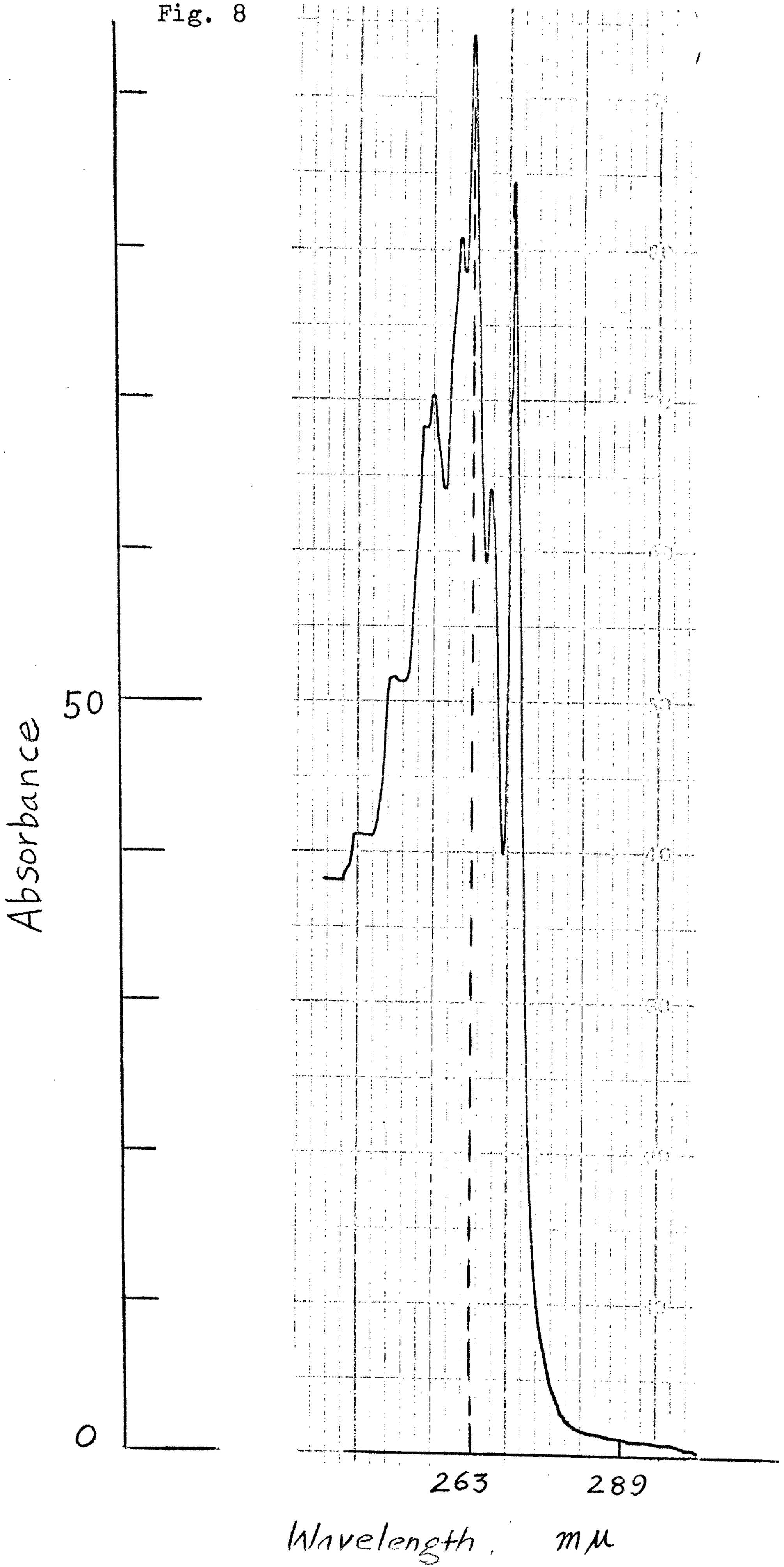


Fig. 9

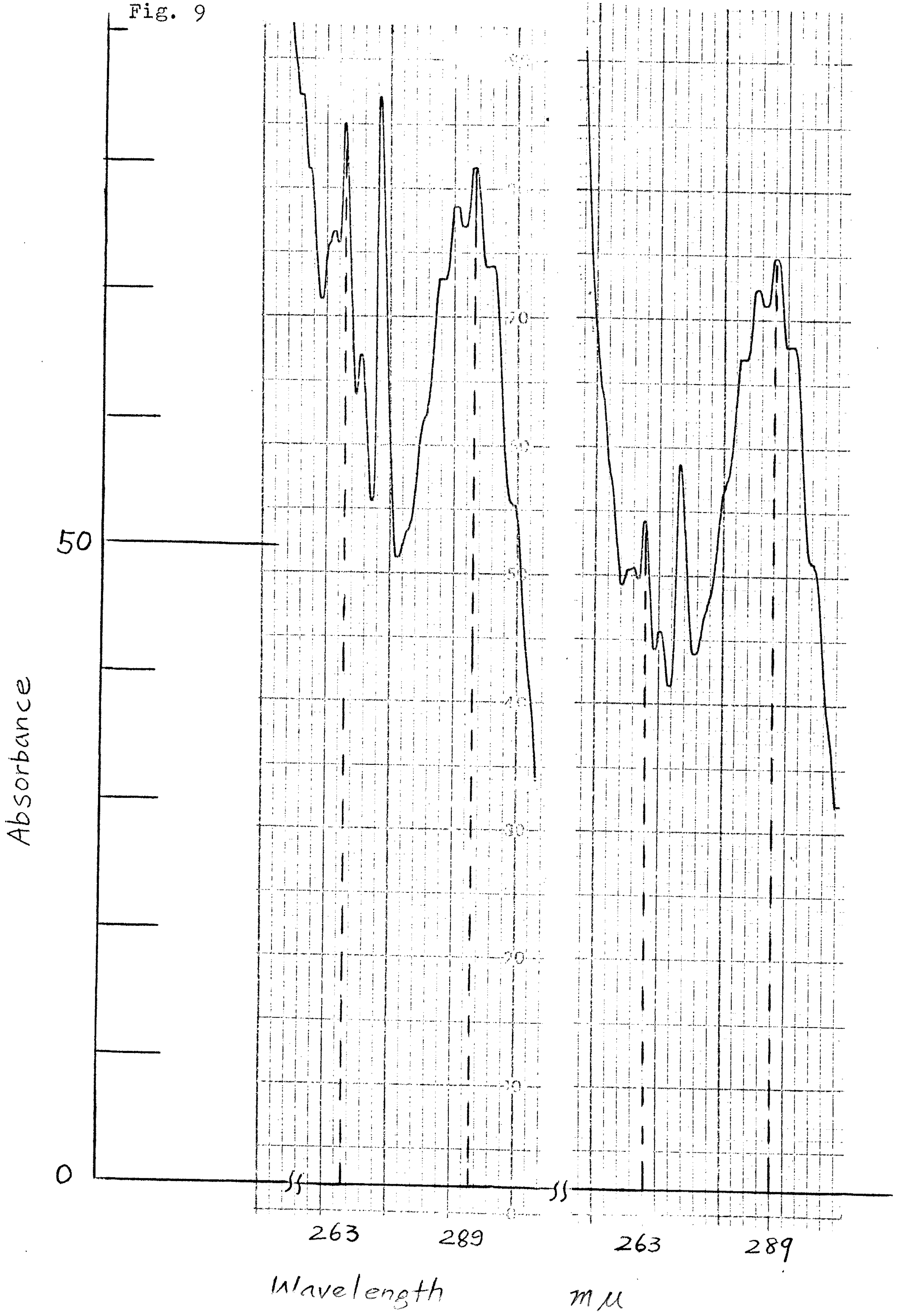


TABLE 1 Experimental and Model Parameter

$\frac{\pi}{\omega}$ =1200 Sec., $T1 = 333^{o}K$, $T_2 = 298^{o}K$, $h = 0.9m$, $\phi_T + \phi_B = 0.4$

	Conc., Vol.%		ϕ_B	C_1	C_2	b_i	L_{1i}(m)	L_{2i}(m)	Region
	Toluene	Aniline							
A.	2.5	0	0.07	0.12	0.13	0.15	0.51	0.43	1
B.	0	2.5	0.10	0.11	0.13	0.31	0.70	0.45	1
C.	2.5	2.5	0.09	0.12	0.13				
C-1						0.15	0.49	0.44	1
C-2						0.31	0.71	0.45	1
D.	2.5	2.5	0.22	0.12	0.13				
D-1						0.15	0.42	0.49	2
D-2						0.31	0.62	0.51	1

A. Toluene-n-heptane system

B. Aniline-n-heptane system

C. *Aniline-toluene-n-heptane system experiment, Run 1

C-1 Toluene-n-heptane system

C-2 Aniline-n-heptane system

D. *Aniline-toluene-n-heptane system experiment, Run 2

D-1 Toluene-n-heptane system

D-2 Aniline-n-heptane system

* Assume that a ternary system contains two pseudo-binaries

TABLE 2(A)

System: Aniline—n-Heptane

Feed: Aniline Conc.= 2.743×10^{-7} k gmole/c.c. 2.5 Vol.%

Operating Condition:

$T_1 = 333^\circ K$ $T_2 = 298^\circ K$

$\frac{\pi}{\omega} = 1200$ Sec. $\phi_T + \phi_B = 0.40$

$Q\frac{\pi}{\omega} = 40$ c.c. $\phi_B = 0.1$

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Bottom (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Bottom (c.c.)	Reservoir Displacement Top (c.c.)	Product Bottom (c.c.)	Product Top (c.c.)
--	42	--	46.0	5.0	--	--	--	--
1 Up	26	16.0	5.0	45.0	41.0	40.0	4.0	11.0
1 Down	10	16.0	46.0	4.0	41.0	40.0	3.7	8.0
--	43	Feed syringe was refilled with feed						
2 Up	27	16.0	4.0	46.0	42.0	42.0	4.0	11.6
2 Down	11	16.0	46.0	4.0	42.0	42.0	3.6	9.0
--	45	Feed syringe was refilled with feed						
3 Up	28	17.0	5.0	48.0	41.0	44.0	3.8	11.8
3 Down	12	16.0	46.0	4.0	41.0	44.0	3.9	10.2
--	47	Feed syringe was refilled with feed						
4 Up	33	14.0	4.0	46.0	42.0	42.0	4.0	11.0
4 Down	17	16.0	42.0	7.0	38.0	39.0	3.6	11.6
5 Up	3	14.0	4.0	43.0	38.0	36.0	3.8	10.7
--	47	Feed syringe was refilled with feed						
5 Down	31	16.0	42.0	4.0	38.0	39.0	3.8	9.3

TABLE 2(A) (Continued)

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)
6 Up	17	16.0	5.0	41.0	37.0	37.0	3.8	11.0
6 Down	1	16.0	42.0	4.0	37.0	37.0	3.8	10.9
--	47	Feed syringe was refilled with feed						
7 Up	32.5	15.5	4.0	41.0	38.0	37.0	3.9	12.0
7 Down	17	15.5	41.0	3.5	37.0	37.5	3.7	10.2
8 Up	3	14.0	5.0	41.0	36.0	37.5	3.9	11.0
--	46	Feed syringe was refilled with feed						
8 Down	29	17.0	42.0	5.0	37.0	36.0	3.6	12.2
9 Up	13	16.0	5.0	42.0	37.0	37.0	4.0	12.8
--	47	Feed syringe was refilled with feed						
9 Down	32	15.0	44.0	3.0	39.0	39.0	3.4	11.2
10 Up	17	15.0	5.0	42.0	39.0	39.0	3.7	13.0
10 Down	2	15.0	42.0	3.0	37.0	39.0	3.7	11.0
--	47	Feed syringe was refilled with feed						
11 Up	31	16.0	4.0	42.0	38.0	39.0	4.0	12.2
11 Down	14	17.0	45.0	3.0	41.0	39.0	3.8	11.8
--	47	Feed syringe was refilled with feed						
12 Up	31	16.0	6.0	43.0	39.0	40.0	4.0	12.8
12 Down	14	17.0	46.0	2.0	40.0	41.0	3.8	13.0
--	45	Feed syringe was refilled with feed						
13 Up	30	15.0	4.0	47.0	42.0	45.0	3.7	11.8
13 Down	13	17.0	47.0	5.0	43.0	42.0	3.5	12.6

TABLE 2(A) (Continued)

Cycle No. n	Feed		Reservoir Reading		Reservoir Displacement		Product	
	Syringe Reading (c.c.)	Volume Fed (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)
--	46	Feed syringe was refilled with feed						
14 Up	30	16	6.0	47.0	41.0	42.0	3.8	11.6
14 Down	4	16	47.0	5.0	41.0	42.0	3.8	11.0

TABLE 2(B)

System: Tolnene - n-Heptane

Feed: Toluene Conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

Operating Condition:

$T_1 = 333^\circ K$ $\phi_B + \phi_T = 0.4$

$T_2 = 298^\circ K$ $\phi_B = 0.05$ (Experimental)

$\frac{\pi}{\omega} = 1200$ Sec. $Q\frac{\pi}{\omega} = 40$ c.c.

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)
--	47	--	46.0	6.0	--	--	--	--
1 Up	31	16	5.0	43.0	41.0	37.0	2.0	12.0
1 Down	15	16	42.0	5.0	37.0	38.0	1.9	12.0
--	48	Feed syringe was refilled with feed						
2 Up	34	14	4.0	43.0	36.0	38.0	2.0	14.0
2 Down	18	16	42.0	5.0	38.0	38.0	1.8	7.0
3 Up	2	16	5.0	40.0	37.0	35.0	2.2	15.6
--	49	Feed syringe was refilled with feed						
3 Down	33	16	45.0	5.0	40.0	35.0	1.9	12.0
4 Up	17	16	5.0	43.0	40.0	38.0	2.4	15.0
--	48	Feed syringe was refilled with feed						
4 Down	32	16	46.0	5.0	41.0	38.0	1.9	12.4
5 Up	16	16	5.0	46.0	41.0	41.0	2.0	16.0
5 Down	1	15	45.0	5.0	40.0	41.0	2.0	12.0
--	48	Feed syringe was refilled with feed						
6 Up	32	16	5.0	46.0	40.0	41.0	2.0	16.0

TABLE 2(B) (Continued)

Cycle No. n	Feed		Reservoir Reading		Reservoir Displacement		Product	
	Syringe Reading (c.c.)	Volume Fed (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)	Bottom (c.c.)	Top (c.c.)
6 Down	16	16	45.0	5.0	40.0	41.0	1.8	12.6
7 Up	0	16	5.0	46.0	40.0	41.0	2.0	17.0
--	49	Feed syringe was refilled with feed						
7 Down	32	17	46.0	6.0	41.0	40.0	1.9	12.6
8 Up	16	16	5.0	48.0	41.0	42.0	2.0	15.0
8 Down	0	16	45.0	5.0	40.0	43.0	2.0	13.4
--	49	Feed syringe was refilled with feed						
9 Up	33	16	5.0	47.0	40.0	42.0	2.0	12.8
9 Down	17	16	45.0	5.0	40.0	42.0	2.0	14.2
10 Up	1	16	5.0	46.0	40.0	41.0	2.0	15.0
--	49	Feed syringe was refilled with feed						
10 Down	33	16	45.0	5.0	40.0	41.0	2.0	12.4
11 Up	17	16	5.0	45.0	40.0	40.0	2.0	15.2
11 Down	1	16	45.0	5.0	40.0	40.0	2.0	13.2
--	48	Feed syringe was refilled with feed						
12 Up	32	16	5.0	45.0	40.0	40.0	2.0	14.7
12 Down	16	16	45.0	5.0	40.0	40.0	2.0	14.5
13 Up	0	16	5.0	45.0	40.0	40.0	2.2	15.0
--	48	Feed syringe was refilled with feed						
13 Down	32	16	45.0	5.0	40.0	40.0	2.0	12.0
14 Up	16	16	5.0	45.0	40.0	40.0	2.0	16.0
14 Down	0	16	45.0	5.0	40.0	40.0	2.0	12.8

TABLE 3(A) Parametric Pumping Experiment Run 1

System : Aniline - Toluene - n-Heptane

Feed ; Aniline Conc. = 2.743×10^{-7} k gmole/c.c. = 2.5 Vol.%

Toluene Conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

Operating Condition :

$T_1 = 333$ K $\qquad \phi_B + \phi_T = 0.4$

$T_2 = 298$ K $\qquad \phi_B = 0.05$ (Experimental)

$\frac{\pi}{\omega} = 1200$ Sec. $\qquad Q\frac{\pi}{\omega} = 40$ c.c.

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
--	32	--	47	7	--	--	--	--
1 Up	16	16	7	47	40	40	2.0	13.0
2 Dn.	0	16	47	7	40	40	2.3	11.0
--	48	Feed syringe was refilled with feed						
2 Up	32	16	7	47	40	40	2.3	17.0
2 Dn.	16	16	47	7	40	40	2.0	17.0
3 Up	0	16	7	47	40	40	2.3	16.0
--	48	Feed syringe was refilled with feed						
3 Dn.	32	16	47	7	40	40	2.0	12.5
4 Up	16	16	7	47	40	40	2.3	16.0
4 Dn.	0	16	47	7	40	40	2.1	11.0
--	50	Feed syringe was refilled with feed						
5 Up	34	16	7	47	40	40	2.4	15.0
5 Dn.	18	16	47	7	40	40	2.2	12.0
6 Up	2	16	7	47	40	40	2.3	17.0

TABLE 3(A). (Continued)

Cycle No. n	Feed		Reservoir Reading		Reservoir Displacement		Product	
	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
--	50	Feed syringe was refilled with feed						
6 Dn.	37	13	47	7	40	40	2.0	10.0
7 Up	21	16	7	47	40	40	2.3	16.0
7 Dn.	5	16	47	7	40	40	2.2	13.0
--	51	Feed syringe was refilled with feed						
8 Up	36	15	7	47	40	40	2.2	15.2
8 Dn.	20	16	47	7	40	40	2.2	12.0
9 Up	4	16	7	47	40	40	2.2	16.0
--	50	Feed syringe was refilled with feed						
9 Dn.	34	16	47	7	40	40	2.3	12.0
10 Up	18	16	7	47	40	40	2.2	15.5
10 Dn.	2	16	47	7	40	40	2.5	13.0
--	50	Feed syringe was refilled with feed						
11 Up	34	16	7	47	40	40	2.2	15.0
11 Dn.	18	16	47	7	40	40	2.5	11.0
12 Up	2	16	7	47	40	40	2.3	15.0
--	50	Feed syringe was refilled with feed						
12 Dn.	33	17	47	7	40	40	2.8	15.0
13 Up	17	16	7	47	40	40	2.0	15.0
13 Dn.	1	16	47	7	40	40	2.3	13.0
--	50	Feed syringe was refilled with feed						
14 Up	34	16	7	47	40	40	2.2	15.0
14 Dn.	18	16	47	7	40	40	2.3	16.0

TABLE 3(A). (Continued)

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
15 Up	28	16	7	47	40	40	2.2	15.0
15 Dn.	12	16	47	7	40	40	2.0	13.0

TABLE 3(B). Parametric Pumping Experiment Run 2

System : Aniline – Toluene – n Heptane

Feed : Aniline 18c.c.+ Toluene 18c.c. + n-Heptane 684c.c.

Aniline Conc. = 2.743×10^{-7} k gmole/c.c. = 2.5 Vol.%

Toluene Conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

Operating Condition :

$T_1 = 333^\circ K$ $\qquad \phi_B + \phi_T = 0.4$

$T_2 = 298^\circ K$ $\qquad \phi_B = 0.218$ (Experimental)

$\frac{\pi}{\omega} = 1200$ Sec. $\qquad Q\frac{\pi}{\omega} = 40$c.c.

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	50	--	48	7	--	--	--	--
1 Up	35	15	8	47	40	40	8.7	7.6
1 Dn.	20	15	48	7	40	40	8.7	5.3
2 Up	4	16	7	47	41	40	8.7	11.0
--	49	Feed syringe was refilled with feed						
2 Dn.	32	17	47	7	40	40	8.6	5.6
3 Up	16	16	7	47	40	40	8.6	9.4
--	50	Feed syringe was refilled with feed						
3 Dn.	34	16	47	7	40	40	8.6	6.0
4 Up	17	17	7	47	40	40	8.6	10.6
4 Dn.	1	16	47	7	40	40	8.6	5.6
--	50	Feed syringe was refilled with feed						
5 Up	34	16	7	47	40	40	8.6	8.6

TABLE 3(B) (Continued)

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
5 Dn.	18	16	47	7	40	40	8.7	6.6
6 Up	2	16	7	47	40	40	8.6	8.8
	51	Feed syringe was refilled with feed						
6 Dn.	35	16	47	7	40	40	8.7	5.8
7 Up	19	16	7	47	40	40	8.6	9.2
7 Dn.	3	16	47	7	40	40	8.7	7.4
--	53	Feed syringe was refilled with feed						
8 Up	37	16	7	47	40	40	8.7	7.8
8 Dn.	21	16	47	7	40	40	8.7	5.8
9 Up	5	16	7	47	40	40	8.7	8.8
--	50	Feed syringe was refilled with feed						
9 Dn.	34	16	47	7	40	40	8.8	5.9
10 Up	18	16	7	47	40	40	8.7	8.2
10 Dn.	2	16	47	7	40	40	8.7	6.6
--	51	Feed syringe was refilled with feed						
11 Up	35	16	7	47	40	40	8.8	8.4
11 Dn.	19	16	47	7	40	40	8.7	6.2
12 Up	3	16	7	47	40	40	8.7	8.6
--	49	Feed syringe was refilled with feed						
12 Dn.	33	16	47	7	40	40	8.7	6.2
13 Up	17	16	7	47	40	40	8.7	9.0
13 Dn.	1	16	47	7	40	40	8.7	5.8

TABLE 3(B) (Continued)

Cycle No. n	Feed: Syringe Reading (c.c.)	Feed: Volume Fed (c.c.)	Reservoir Reading: Botm. (c.c.)	Reservoir Reading: Top (c.c.)	Reservoir Displacement: Botm. (c.c.)	Reservoir Displacement: Top (c.c.)	Product: Botm. (c.c.)	Product: Top (c.c.)
--	40	Feed syringe was Refilled with feed						
14 Up	24	16	7	47	40	40	8.7	9.4
14 Dn.	8	16	47	7	40	40	8.7	6.0

TABLE 4. Absorbance of Aniline Solution

Solution : Aniline 2.5c.c. + n-Heptane 97.5c.c.

Conc. of Aniline = 2.743×10^{-7} k gmole/c.c.

No.	$\left(\text{Dilution Factor}\right)^{-1}$	Toluene Conc. $\times 10^{10}$ k gmole/c.c.	$\frac{y_i}{y_R}$	Absorbance, ℓ at 263 $m\mu$	Absorbance, ℓ at 289 $m\mu$
1.	242	11.33	1.031	67.2	--
2.	363	7.56	0.689	44.0	--
3.	484	5.67	0.516	33.6	--
4.	726	3.78	0.344	22.8	72.0
5.	1029	2.67	0.243	16.0	--
6.	1331	2.06	0.188	13.5	40.5
7.	1815	1.51	0.138	11.0	28.5
8.	2178	1.26	0.115	7.5	--
9.	2904	0.95	0.086	5.5	--

Where $y_R = 10.977 \times 10^{-10}$

TABLE 5. Absorbance of Toluene Solution

Solution : Toluene 2.5c.c. + n-Heptane 97.5c.c.

Conc. of Toluene = 2.349×10^{-7} k gmole/c.c.

No.	$\begin{pmatrix}\text{Dilution}\\ \text{Factor}\end{pmatrix}^{-1}$	Toluene conc. $\times 10^{10}$ k gmole/c.c.	$\frac{y_i}{y_R}$	Absorbance, ℓ at 263 $m\mu$	Absorbance, ℓ at 289 $m\mu$
1.	242	9.71	1.031	23.6	0
2.	363	6.47	0.688	15.5	0
3.	484	4.85	0.516	11.0	0
4.	726	3.24	0.344	7.2	0
5.	1331	1.76	0.188	4.0	0

Where $y_R = 9.413 \times 10^{-10}$

TABLE 6. Absorbance of Aniline and Toluene Solution

Solution : Aniline 2.5 c.c. + Toluene + n-Heptane 95.0 c.c.

Conc. of Aniline = 2.743×10^{-7}k gmole/c.c.

Conc. of Toluene = 2.349×10^{-7}k gmole/c.c.

No.	$\left(\text{Dilution Factor}\right)^{-1}$	Aniline Conc. $\times 10^{10}$ k gmole/c.c.	Toluene Conc. $\times 10^{10}$ k gmole/c.c.	$\frac{y_i}{y_R}$	Asorb., ℓ at 289 mμ	Asorb., ℓ at 263 mμ
1.	242	11.33	9.71	1.031	--	89.0
2.	484	5.67	4.85	0.516	--	43.8
3.	726	3.78	3.24	0.344	71.0	30.0
4.	1029	2.67	2.29	0.243	51.0	21.0
5.	1331	2.06	1.76	0.188	39.4	--
6.	1815	1.51	1.29	0.138	--	12.0
7.	2178	1.26	1.08	0.115	23.5	--
8.	2904	0.95	0.81	0.086	17.5	7.4

Where $y_R = 9.413 \times 10^{-10}$ for Toluene conc.

$y_R = 10.977 \times 10^{-10}$ for Aniline conc.

TABLE 7(A).Analyses of Product Stream Samples

For the Parametric Pumping Experiment :

System : Aniline – n-Heptane

Feed : Aniline Conc. = 2.743 x 10^{-7}k gmole/c.c.= 2.5 Vol.%

$\phi_B = 0.1$

Sample No. (Cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorbance, at289 $m\mu$	Sample Conc. k gmole/c.c. x 10	$\frac{\langle y_{BPz}\rangle_n}{y_{oi}}$
Feed	726	70.6	2.743	1.00
1 Bot.,Down	242	84.2	1.089	0.0397
2 Bot.,Down	121	42.8	0.277	0.101
4 Bot.,Down	63	50.4	0.170	0.0619
6 Bot.,Down	16	52.5	0.045	0.0164
8 Bot.,Down	10	52.8	0.0283	0.0103
10 Bot.,Down	11	31.2	0.0184	0.0067
12 Bot.,Down	6	43.6	0.0140	0.0051

				$\frac{\langle y_{TBz}\rangle_n}{y_{oi}}$
4 Top,Down	1331	38.9	2.773	1.01
5 Top,Down	1331	41.9	2.990	1.09
6 Top,Down	1331	44.3	3.155	1.15
7 Top,Down	1331	44.3	3.155	1.15
8 Top,Down	1331	39.3	2.806	1.02
10 Top,Down	1331	42.4	3.023	1.10

TABLE 7(B). Analyses of Product Stream Samples

For the Parametric Pumping Experiment:

System: Toluene -n-Heptane

Feed: Toluene conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.05$

Sample No. (Cycle No.) n	$\left(\text{Dilution Factor}\right)^{-1}$	Absorb. at 263 mμ	Sample Conc. x 10^7 k gmole/c.c.	$\frac{\langle y_{BP2}\rangle_n}{y_{oi}}$
Feed	66	84.0	2.349	1.00
3 Botm. Down	48	62.1	1.264	0.54
4 Botm. Down	40	55.5	0.939	0.40
6 Botm. Down	24	55.4	0.564	0.24
8 Botm. Down	11	57.0	0.312	0.133
9 Botm. Down	8	62.5	0.212	0.09
10 Botm. Down	6	54.5	0.139	0.059
11 Botm. Down	6	36.6	0.093	0.0397
12 Botm. Down	4	41.2	0.070	0.0297
13 Botm. Down	3	38.9	0.049	0.021
14 Botm. Down	2	39.5	0.033	0.014
				$\frac{\langle y_{TP2}\rangle_n}{y_{oi}}$
4 Top, Down	121	50.0	2.56	1.09
6 Top, Down	121	53.5	2.75	1.17
8 Top, Down	121	58.2	2.98	1.27
10 Top, Down	121	60.8	3.12	1.33
12 Top, Down	121	57.2	2.94	1.25
14 Top, Down	121	59.0	3.03	1.29

TABLE 8(A). Analyses of Product Stream Samples

For the Parametric Pumping Experiment : Run 1

System: Aniline – Toluene – n-Heptane

Feed : Aniline Conc. = 2.743×10^{-7}k gmole/c.c. = 2.5 Vol.%

Toluene Conc. = 2.349×10^{-7}k gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.05$ (Experimental Value)

Sample No. (Cycle No.) n	$\left(\text{Dilution Factor}\right)^{-1}$	Absorbance at 289 mμ	Absorbance at 263 mμ	$\frac{\langle y_{BP2}\rangle_n}{y_{oi}}$	
				Aniline	Toluene
1 Bot., Down	363	49.1	27.3	--	0.845
2 Bot., Down	363	49.1	--	0.348	--
3 Bot., Down	242	31.3	22.8	0.148	0.606
4 Bot., Down	88	58.7	51.5	0.101	0.560
5 Bot., Down	40	63.5	71.0	0.0496	0.390
7 Bot., Down	36	16.4	31.5	0.0115	0.180
8 Bot., Down	20	24.8	42.0	0.0097	0.130
9 Bot., Down	11	28.8	53.2	0.0062	0.092
10 Bot., Down	7	32.9	60.0	0.0045	0.066
11 Bot., Down	6	22.2	45.5	0.0026	0.044
12 Bot., Down	6	13.6	28.0	0.0016	0.027
13 Bot., Down	4	19.2	23.8	0.0015	0.021
14 Bot., Down	4	12.0	23.5	0.00094	0.015
15 Bot., Down	3	8.5	27.5	0.00049	0.014
Feed	726	70.5	28.8	1.00	1.00

TABLE 8(A). (continued)

Sample No. (Cycle No.) n	$\left(\text{Dilution Factor}\right)^{-1}$	Absorbance, at 289 mμ	Absorbance, at 263 mμ	$\frac{\langle y_{TP2} \rangle}{y_{oi}}$	
				Aniline	Toluene
Feed	1331	38.5	15.8	1.00	1.00
9 Top, Down	1331	38.5	18.8	1.00	1.75
11 Top, Down	1331	38.5	17.7	1.00	1.50
12 Top, Down	1331	38.5	17.8	1.00	1.52
15 Top, Down	1331	40.4	17.2	1.051	1.22

TABLE 8(B). Analyses of Product Stream Samples

For the Parametric Pumping Experiment : Run 2

System : Aniline - Toluene - n-Heptane

Feed : Aniline Conc. = $2.743 \times 10^{-7}k$ gmole/c.c. = 2.5 Vol.%

Toluene Conc. = $2.349 \times 10^{-7}k$ gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.218$

Sample No. (Cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorbance at 289 mμ	$\frac{\langle y_{BPz}\rangle_n}{y_{oi}}$ Aniline
Feed	605	84.8	1.00
2 Botm.,Down	121	53.0	0.125
3 Botm.,Down	121	27.5	0.065
5 Botm.,Down	44	37.5	0.032
6 Botm.,Down	20	60.5	0.0236
7 Botm.,Down	10	82.0	0.016
8 Botm.,Down	10	32.8	0.0064
9 Botm.,Down	6	55.5	0.0065
10 Botm.,Down	6	40.2	0.0047
11 Botm.,Down	$\frac{8}{3}$	63.5	0.0033
12 Botm.,Down	$\frac{5}{3}$	63.4	0.00206
13 Botm.,Down	$\frac{5}{3}$	53.5	0.00174
14 Botm.,Down	1	64.5	0.00126

(continued on next page)

TABLE 8(B). (Continued)

Sample No. (Cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorbance at 289 mμ	Absorbance at 263 mμ	$\frac{\langle y_{BP2}\rangle_n}{y_{oi}}$ Toluene
Feed	616	84.0	34.6	1.00
2 Botm., Down	88	74.0	67.0	0.71
3 Botm., Down	66	51.0	60.5	0.54
4 Botm., Down	44	44.0	67.0	0.43
5 Botm., Down	44	38.5	51.5	0.32
6 Botm., Down	44	28.0	45.0	0.29
7 Botm., Down	33	25.2	60.0	0.31
8 Botm., Down	22	15.0	71.5	0.267
10 Botm., Down	22	10.5	70.5	0.27
11 Botm., Down	33	5.0	66.5	0.39
12 Botm., Down	33	3.2	77.5	0.46
13 Botm., Down	33	1.0	80.0	0.48
14 Botm., Down	44	0.5	80.0	0.64

Top product stream samples were analyzed by gas chromatograph

Cycle No. n	$\frac{\langle y_{TB2}\rangle_n}{y_{oi}}$ Aniline	Toluene
14	1.860	1.806
13	1.866	1.741
12	1.833	1.806
11	1.333	1.774
10	1.400	1.483

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APPENDIX

Among 10 ternary system experimental runs, 8 runs (run 3 through run 10) are attached in the appendix here. Their experimental data, product streams analysis, and plotted figures are following:

Run No.	Experimental Data**	Product Analysis**	Plotted Figures**
3	Table 3(C)	Table 8(C)	Fig. 10
4	3(D)	8(D)	11
5	3(E)	8(E)	12
6	3(F)	8(F)	13
7	3(G)	8(G)	14
8	3(H)	8(H)	15
9	3(I)	8(I)	16
10	3(J)	8(J)	17

**Note:
Refer to Pages 16 and 17 for notations and Greek letters shown on Tables and Figures.

TABLE 3(C). Parametric Pumping Experiment, Run 3

System : Aniline — Toluene — n-Heptane

Feed : Aniline conc. = $2.743 \times 10^{-7}k$ gmole/c.c. = 2.5 Vol.%

Toluene conc. = $2.349 \times 10^{-7}k$ gmole/c.c. = 2.5 Vol.%

Operating condition :

$T_1 = 333^\circ K$ $\phi_T + \phi_B = 0.4$

$T_2 = 298^\circ K$ $\phi_B = 0.088$

$\frac{\pi}{\omega} = 1200$ Sec. $Q\frac{\pi}{\omega} = 40$ c.c.

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (C.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	43	--	47	7	--	--	--	--
1 Up	27	16	7	47	40	40	3.5	13.0
1 Dn.	11	16	47	7	40	40	3.5	9.0
--	48	Feed syringe was refilled with feed						
2 Up	32	16	7	47	40	40	3.5	14.0
2 Dn.	16	16	47	7	40	40	3.5	10.4
3 Up	0	16	7	47	40	40	3.5	14.5
--	50	Feed syringe was refilled with feed						
3 Dn.	34	16	47	7	40	40	3.5	10.0
4 Up	18	16	9	47	38	40	3.5	13.5
4 Dn.	2	16	48	7	39	40	3.4	12.0
--	50	Feed syringe was refilled with feed						
5 Up	33	17	7	47	41	40	3.5	17.0
5 Dn.	17	16	47	7	40	40	3.5	10.6

TABLE 3(C). (continued)

Cycle No. n	Feed		Reservoir Reading		Reservoir Displacement		Product	
	Syringe Reading (c.c.)	volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
6 Up	1	16	7	47	40	40	3.5	16.2
--	51	Feed syringe was refilled with feed						
6 Dn.	36	15	46	7	39	40	3.5	9.0
7 Up	22	14	7	47	41	40	3.5	13.5
7 Dn.	6	16	47	7	40	40	3.5	9.8
--	50	Feed syringe was refilled with feed						
8 Up	34	16	7	47	40	40	3.7	13.0
8 Dn.	18	16	46	7	39	40	3.5	10.5
9 Up	2	16	7	7	39	40	3.5	14.0
--	50	Feed syringe was refilled with feed						
9 Dn.	34	16	47	7	40	40	3.5	10.4
10 Up	18	16	7	47	40	40	3.5	15.2
10 Dn.	3	15	47	7	40	40	3.5	9.0
--	50	Feed syringe was refilled with feed						
11 Up	34	16	7	47	40	40	3.5	15.8
11 Dn.	18	16	47	7	40	40	3.5	9.0
--	50	Feed syringe was refilled with feed						
12 Up	34	16	7	47	40	40	3.5	13.0
12 Dn.	18	16	47	7	40	40	3.5	11.2
--	46	Feed syringe was refilled with feed						
13 Up	30	16	7	47	40	40	3.5	15.0
13 Dn.	14	16	47	7	40	40	3.5	10.2

TABLE 3(C). (Continued)

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	47	Feed syringe was refilled with feed						
14 Up	31	16	7	47	40	40	3.5	14.6
14 Dn.	15	16	47	7	40	40	3.5	10.4
--	50	Feed syringe was refilled with feed						
15 Up	34	16	47	7	40	40	3.5	14.6
15 Dn.	18	16	7	47	40	40	3.5	10.0

TABLE 3(D). Parametric Pumping Experiment <u>Run 4</u>

System : Aniline – Toluene – n-Heptane

Feed : Aniline Conc. = 0.6585 x 10^{-7} k gmole/c.c. = 0.6 Vol.%

Toluene Conc. = 2,349 x 10^{-7} k gmole/c.c. = 2.5 Vol.%

Operating Conditions :

$T_1 = 333^\circ K$ $\phi_B + \phi_T = 0.4$

$T_2 = 298^\circ K$ $\phi_B = 0.05$

$\frac{\pi}{\omega} = 1200$ Sec. $Q\frac{\pi}{\omega} = 40$ c.c.

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
--	40	--	47	7	--	--	--	--
1 up	24	16	7	47	40	40	2.0	17.0
1 Dn.	8	16	47	7	40	40	2.0	12.0
--	50	Feed syringe was refilled with feed						
2 Up	34	16	9	47	38	40	2.2	14.2
2 Dn.	17	17	47	7	38	40	2.2	13.0
3 Up	1	16	6	47	41	40	2.3	17.2
--	50	Feed syringe was refilled with feed						
3 Dn.	34	16	47	7	41	40	2.2	12.0
4 Up	18	16	7	47	40	40	2.1	16.8
4 Dn.	2	16	47	7	40	40	1.8	11.2
--	50	Feed syringe was refilled with feed						
5 Up	34	16	7	47	40	40	2.0	17.8
5 Dn.	18	16	47	7	40	40	2.1	10.0

TABLE 3(D). (Continued)

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
6 Up	2	16	7	47	40	40	2.4	17.4
--	50	Feed syringe was refilled with feed						
6 Dn.	34	16	47	7	40	40	2.0	11.0
7 Up	18	16	7	47	40	40	2.4	16.6
7 Dn.	2	16	47	7	40	40	2.2	12.0
--	50	Feed syringe was refilled with feed						
8 Up	34	16	7	47	40	40	2.1	17.0
8 Dn.	18	16	47	7	40	40	2.0	15.0
9 Up	2	16	7	47	40	40	2.2	16.2
--	50	Feed syringe was refilled with feed						
9 Dn.	34	16	47	7	40	40	2.2	12.0
10 Up	18	16	7	47	40	40	2.3	16.2
10 Dn.	2	16	47	7	40	40	2.1	12.6
--	50	Feed syringe was refilled with feed						
11 Up	34	16	7	47	40	40	2.2	16.0
11 Dn.	18	16	47	7	40	40	2.0	13.8
12 Up	2	16	7	47	40	40	2.2	16.0
--	50	Feed syringe was refilled with feed						
12 Dn.	34	16	47	7	40	40	2.0	13.0
13 Up	18	16	7	47	40	40	2.4	16.0
13 Dn.	2	16	47	7	40	40	2.0	12.0

TABLE 3(D). (Continued)

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	50	Feed syringe was refilled with feed						
14 Up	34	16	7	47	40	40	2.2	15.8
14 Dn.	18	16	47	7	40	40	2.0	13.0

TABLE 3(E). Parametric Pumping Experiment Run 5

System : Aniline — Toluene — n-Heptane

Feed : Aniline conc. = 0.5486×10^{-7}k gmole/c.c. = 0.5 Vol.%

Toluene conc. = 2.349×10^{-7}k gmole/c.c. = 2.5 Vol.%

Operating condition :

$T_1 = 333^\circ K$

$T_2 = 298^\circ K$

$\frac{\pi}{\omega} = 1200$ Sec.

$\phi_T + \phi_B = 0.4$

$\phi_B = 0.05$

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	50	--	47	8	--	--	--	--
1 Up	34	16	9	47	38	38	2.0	12.0
1 Dn.	18	16	47	8	38	39	2.2	10.0
2 Up	2	16	8	48	39	40	2.0	14.0
--	50	Feed syringe was refilled with feed						
2 Dn.	34	16	47	8	39	40	2.0	12.0
3 Up	18	16	9	47	38	39	2.2	16.0
3 Dn.	1	17	48	8	39	39	2.0	11.0
--	32	Feed syringe was refilled with feed						
4 Up	15	17	9	45	39	37	2.3	16.0
--	49	Feed syringe was refilled with feed						
4 Dn.	33	16	47	7	38	38	2.0	11.0
5 UP	17	16	7	45	40	38	2.3	17.0
5 Dn.	1	16	47	5	40	40	2.0	10.0
--	50	Feed syringe was refilled with feed						

TABLE 3(E). (Continued)

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
6 Up	33	17	7	45	40	40	2.0	17.0
6 Dn.	17	16	44	7	37	38	2.0	12.0
7 Up	1	16	7	46	37	39	2.2	15.0
--	50	Feed syringe was refilled with feed						
7 Dn.	34	16	44	7	37	39	2.2	12.0
8 Up	17	17	8	45	36	38	2.2	16.0
8 Dn.	2	15	44	8	36	37	2.0	12.0
--	50	Feed syringe was refilled With feed						
9 Up	34	16	8	45	36	37	2.2	16.0
9 Dn.	18	16	46	6	38	39	2.0	13.0
10 Up	2	16	9	45	37	39	2.2	15.4
--	50	Feed syringe was refilled with feed						
10 Dn.	34	16	45	9	36	36	2.0	12.0
11 Up	18	16	9	45	36	36	2.3	15.4
11 Dn.	2	16	45	9	36	36	2.0	12.0
--	49	Feed syringe was refilled with feed						
12 Up	33	16	9	45	36	36	2.2	16.0
12 Dn.	17	16	45	9	36	36	2.2	12.2
13 Up	1	16	9	45	36	36	2.3	15.6
--	50	Feed syringe was refilled with feed						
13 Dn.	34	16	45	9	36	36	2.2	11.2
14 Up	18	16	9	45	36	36	2.2	16.0
14 Dn.	2	16	47	8	38	37	2.2	12.0

TABLE 3(F). Parametric Pumping Experiment Run 6

System : Aniline — Toluene — n-Heptane

Feed; Aniline conc. = $0.329 \times 10^{-7}k$ gmole/c.c. = 0.3 Vol.%

Toluene conc. = $2.349 \times 10^{-7}k$ gmole/c.c. = 2.5 Vol.%

Operating condition :

$T_1 = 333$ K

$T_2 = 298$ K

$\frac{\pi}{\omega} = 1200$ Sec.

$\phi_T + \phi_B = 0.4$

$\phi_B = 0.05$

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
--	49	--	47	10	--	--	--	--
1 Up	38	11	9	43	38	33	2.4	6.4
1 Dn.	27	11	44	8	35	35	2.2	3.0
2 Up	17	10	10	47	34	39	2.2	8.0
2 Dn.	7	10	46	10	36	37	2.0	3.5
--	50	Feed syringe was refilled with feed						
3 Up	40	10	10	48	36	38	2.2	10.0
3 Dn.	30	10	47	12	37	36	2.0	4.0
4 Up	20	10	9	48	38	36	2.2	12.5
4 Dn.	10	10	46	10	37	38	2.2	6.7
5 Up	0	10	7	48	39	38	2.0	13.0
--	50	Feed syringe was refilled with feed						
5 Dn.	40	10	46	9	39	39	2.2	3.1
6 Up	30	10	9	46	37	37	2.0	10.4
6 Dn.	20	10	46	9	37	37	2.2	5.0

TABLE 3(F). (Continued)

Cycle No. n	Feed		Reservoir Reading		Reservoir Displacement		Product	
	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
7 Up	10	10	9	46	37	37	2.1	12.2
7 Dn.	0	10	46	9	37	37	2.0	4.0
--	50	Feed syringe was refilled with feed						
8 Up	40	10	8	47	38	38	2.1	13.0
8 Dn.	30	10	47	9	39	38	2.0	4.5
9 Up	20	10	9	47	38	38	2.2	12.5
9 Dn.	10	10	47	9	38	38	2.0	4.0
10 Up	0	10	9	47	38	38	2.2	13.0
--	51	Feed syringe was refilled with feed						
10 Dn.	40	11	47	9	38	38	2.1	4.0
11 Up	30	10	9	47	38	38	2.0	12.0
11 Dn.	20	10	47	9	38	38	2.1	4.0
12 Up	10	10	9	47	38	38	2.0	11.5
12 Dn.	0	10	47	9	38	38	2.0	5.0
--	50	Feed syringe was refilled with feed						
13 Up	40	10	9	47	38	38	2.0	12.0
13 Dn.	30	10	47	9	38	38	2.0	4.5
14 Up	20	10	9	47	38	38	2.0	12.5
14 Dn.	10	10	47	9	38	38	2.0	3.5

TABLE 3(G). Parametric Pumping Experiment Run 7

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = $0.329 \times 10^{-7}k$ gmole/c.c. = 0.3 Vol.%

Toluene conc. = $2.349 \times 10^{-7}k$ gmole/c.c. = 2.5 Vol.%

Operating condition :

$T_1 = 333^{\circ}K$

$T_2 = 298^{\circ}K$

$\frac{\pi}{\omega} = 1200$ Sec.

$\phi_T + \phi_B = 0.4$

$\phi_B = 0.05$

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	41	--	45	10	--	--	--	--
1 Up	25	16	9	47	36	37	1.8	15.4
1 Dn.	9	16	48	9	39	38	1.0	10.0
--	51	Feed syringe was refilled with feed						
2 Up	35	16	11	47	37	38	2.0	13.8
2 Dn.	19	16	46	7	35	40	2.0	14.0
3 Up	3	16	7	46	39	39	2.0	15.0
--	51	Feed syringe was refilled with feed						
3 Dn.	35	16	46	8	39	38	2.0	11.2
4 Up	19	16	8	46	38	38	2.2	16.0
4 Dn.	3	16	46	8	38	38	2.0	12.0
--	50	Feed syringe was refilled with feed						
5 Up	34	16	8	46	38	38	2.0	15.6
5 Dn.	18	16	46	9	38	37	1.8	12.5
6 Up	2	16	9	47	37	38	2.0	14.6

TABLE 3(G).(Continued)

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c)	Top (c.c.)
--	50	Feed syringe was refilled with feed						
6 Dn.	34	16	46	9	37	38	2.2	12.0
7 Up	18	16	10	46	36	37	1.8	16.2
7 Dn.	2	16	46	9	36	37	2.0	12.8
--	51	Feed syringe was refilled with feed						
8 Up	35	16	10	46	36	37	1.8	15.2
8 Dn.	19	16	46	10	36	36	1.9	12.4
9 Up	3	16	10	46	36	36	1.8	16.0
--	50	Feed syringe was refilled with feed						
9 Dn.	34	16	46	9	36	37	2.0	12.5
10 Up	18	16	9	47	37	38	1.8	16.0
10 Dn.	2	16	46	10	37	37	1.9	12.6
--	50	Feed syringe was refilled with feed						
11 Up	34	16	10	46	36	36	1.8	15.0
11 Dn.	18	16	46	9	36	37	1.8	14.0
12 Up	2	16	10	47	36	38	2.2	15.0
--	50	Feed syringe was refilled with feed						
12 Dn.	34	16	46	10	36	37	1.8	12.0
13 Up	18	16	9	45	37	35	2.0	17.0
13 Dn.	2	16	45	9	36	36	2.0	12.0

TABLE 3(G).(Continued)

Cycle No. n	Feed Syringe Reading (c.c)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	51	Feed syringe was refilled with feed						
14 Up	35	16	9	45	36	36	2.0	16.0
14 Dn.	19	16	45	9	36	36	2.0	9.0
15 Up	3	16	9	45	36	36	2.0	16.0
--	50	Feed syringe was refilled with feed						
15 Dn.	34	16	45	9	36	36	2.0	10.0

TABLE 3(H). Parametric Pumping Experiment Run 8

System : Aniline — Toluene — n-Heptane

Feed : Aniline conc. = 2.743×10^{-7} k gmole/c.c. = 2.5 Vol.%

Toluene conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

Operating condition :

$T_1 = 333^\circ K$

$T_2 = 298^\circ K$ $\phi_T + \phi_B = 0.4$

$\frac{\pi}{\omega} = 1200$ Sec. $\phi_B = 0.1$

	Feed		Reservoir Reading		Reservoir Displacement		Product	
Cycle No. n	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
--	48	--	46	5	--	--	--	--
1 Up	32	16	5	44	41	39	2.2	9.6
1 Dn.	16	16	45	5	40	39	1.7	5.0
2 Up	0	16	5	45	40	40	4.0	13.0
-	49	Feed syringe was refilled with feed						
2 Dn.	33	16	45	5	40	40	3.2	9.0
3 Up	17	16	5	45	40	40	4.0	14.0
3 Dn.	1	16	45	5	40	40	3.6	11.0
-	49	Feed syringe was refilled with feed						
4 Up	33	16	5	45	40	40	4.0	13.4
4 Dn.	17	16	45	5	40	40	3.5	9.4
5 Up	1	16	5	46	40	41	4.0	13.6
--	49.5	Feed syringe was refilled with feed						
5 Dn.	33.5	16	46	5	41	41	2.8	9.6
6 Up	17.5	16	5	46	41	41	4.0	13.2

TABLE 3(H). (Continued)

Cycle No. n	Feed		Reservoir Reading		Reservoir Displacement		Product	
	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
6 Dn.	2.5	16	45	5	40	41	4.0	10.4
--	49	Feed syringe was refilled with feed						
7 Up	33	16	5	46	40	41	4.0	12.6
7 Dn.	17	16	45	5	40	41	4.0	10.6
8 Up	1	16	5	46	40	41	4.0	11.6
--	50	Feed syringe was refilled with feed						
8 Dn.	34	16	45	5	40	41	4.0	8.0
9 Up	18	16	5	46	40	41	4.0	13.7
9 Dn.	2	16	45	5	40	41	4.0	12.0
--	49	Feed syringe was refilled with feed						
10 Up	33	16	5	45	40	40	4.0	14.0
10 Dn.	17	16	45	5	40	40	4.0	11.0
11 UP	1	16	5	45	40	40	4.0	13.4
--	49	Feed syringe was refilled with feed						
11 Dn.	33	16	45	5	40	40	3.5	10.0
12 Up	17	16	5	45	40	40	4.0	13.0
12 Dn.	1	16	45	5	40	40	4.0	10.0
--	49	Feed syringe was refilled with feed						
13 Up	33	16	5	45	40	40	4.0	13.5
13 Dn.	17	16	45	5	40	40	4.0	10.0
14 Up	1	16	5	45	40	40	4.0	9.8
--	26	Feed syringe was refilled with feed						
14 Dn.	10	16	45	5	40	40	4.0	9.8

TABLE3(I). Parametric Pumping Experiment Run 9

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = 2.743×10^{-7} k gmole/c.c. = 2.5 Vol.%

Toluene conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

Operating Condition :

$T_1 = 333^\circ K$

$T_2 = 298^\circ K$ $\phi_T + \phi_B = 0.4$

$\frac{\pi}{\omega} = 1200$ Sec. $\phi_B = 0.05$

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	48	--	48	8	--	--	--	--
1 Up	32	16	5	46	43	38	2.0	3.8
1 Dn.	16	16	45	5	40	41	2.2	3.7
2 Up	0	16	5	45	40	40	2.0	12.0
--	50	Feed syringe was refilled with feed						
2 Dn.	34	16	48	7	43	38	2.0	5.0
3 Up	18	16	8	48	40	41	2.0	13.5
3 Dn.	2	16	47	6	39	42	1.8	15.0
--	50	Feed syringe was refilled with feed						
4 Up	34	16	8	47	39	41	1.8	13.2
4 Dn.	18	16	48	7	40	40	1.8	12.0
5 Up	2	16	8	47	40	40	1.8	18.0
--	50	Feed syringe was refilled with feed						
5 Dn.	34	16	47	7	39	40	1.9	11.2
6 Up	18	16	9	47	38	40	1.9	14.2

TABLE 3(I). (Continued)

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
6 Dn.	2	16	48	8	39	39	1.8	12.0
--	50	Feed syringe was refilled with feed						
7 Up	34	16	8	48	40	40	1.8	17.0
7 Dn.	18	16	47	9	39	39	2.0	10.5
8 Up	2	16	9	48	38	39	2.0	16.0
--	50	Feed syringe was refilled with feed						
8 Dn.	34	16	47	9.5	38	38.5	1.8	11.2
9 Up	18	16	10	47	37	37.5	2.0	17.0
9 Dn.	2	16	47	7	37	40	1.9	13.5
--	50	Feed syringe was refilled with feed						
10 Up	34	16	7	47	40	40	2.0	18.0
10 Dn.	18	16	47	7	40	40	1.8	10.6
11 Up	2	16	6	48	41	41	2.0	17.4
--	50	Feed syringe was refilled with feed						
11 Dn.	34	16	47	7	41	41	1.8	10.6
12 Up	17	17	7	47	40	40	2.0	17.4
12 Dn.	1	16	47	7	40	40	2.0	11.0
--	50	Feed syringe was refilled with feed						
13 Up	34	16	7	47	40	40	2.0	17.0
13 Dn.	18	16	47	7	40	40	1.7	10.0
14 Up	2	16	7	49	40	42	1.8	13.4
--	25	Feed syringe was refilled with feed						
14 Dn.	9	16	48	7.5	41	41.5	1.8	12.0

TABLE 3(J) Parametric Pumping Experiment <u>Run 10</u>

System : Aniline — Toluene — n-Heptane

Feed : Aniline Conc. = 0.914 x 10^{-7}k gmole/c.c. = 0.8 Vol.%

Toluene conc. = 2.349 x 10^{-7}k gmole/c.c. = 2.5 Vol.%

Operating condition :

$T_1 = 333^\circ K$

$T_2 = 298^\circ K$ $\phi_B + \phi_T = 0.4$

$\frac{\pi}{\omega}$ = 1200 Sec. $\phi_B = 0.05$

Cycle No. n	Feed Syringe Reading (c.c.)	Feed Volume Fed (c.c.)	Reservoir Reading Botm. (c.c.)	Reservoir Reading Top (c.c.)	Reservoir Displacement Botm. (c.c.)	Reservoir Displacement Top (c.c.)	Product Botm. (c.c.)	Product Top (c.c.)
--	48	--	48	7	--	--	--	--
1 Up	32	16	8	47	40	40	1.8	11.5
1 Dn.	16	16	48	7	40	40	2.0	10.2
2 Up	0	16	7	47	41	40	2.0	15.6
--	48	Feed syringe was refilled with feed						
2 Dn.	32	16	47	8	40	39	1.8	6.8
3 Up	16	16	8	47	39	39	2.2	13.5
3 Dn.	0	16	48	7	40	40	1.8	12.0
--	48	Feed syringe was refilled with feed						
4 Up	32	16	8	47	40	40	1.8	16.5
4 Dn.	16	16	47	7	39	40	1.6	11.2
5 Up	0	16	8	47	39	40	1.8	15.4
--	47	Feed syringe was refilled with feed						
5 Dn.	31	16	47	7	39	40	1.3	11.2

TABLE 3(J).(Continued)

Cycle No. n	Feed		Reservoir Reading		Reservoir Displacement		Product	
	Syringe Reading (c.c.)	Volume Fed (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)	Botm. (c.c.)	Top (c.c.)
6 Up	15	16	8	47	39	40	1.9	15.4
--	48	Feed syringe was refilled with feed						
6 Dn.	32	16	47	7	39	40	1.5	11.5
7 Up	16	16	8	47	39	40	1.6	15.0
7 Dn.	0	16	47	8	39	40	2.0	10.0
--	48	Feed syringe was refilled with feed						
8 Up	32	16	8	47	39	40	2.0	15.2
8 Dn.	16	16	48	7	40	40	2.0	11.8
9 Up	0	16	8	47	40	40	2.0	14.6
--	48	Feed syringe was refilled with feed						
9 Dn.	32	16	48	7	40	40	2.0	11.2
10 Up	16	16	8	47	40	40	2.2	15.0
10 Dn.	0	16	48	7	40	40	1.6	12.0
--	49	Feed syringe was refilled with feed						
11 Up	33	16	8	47	40	40	2.2	16.0
11 Dn.	17	16	48	7	40	40	1.9	8.0
12 Up	1	16	8	47	40	40	2.1	15.1
--	48	Feed syringe was refilled with feed						
12 Dn.	32	16	47	8	39	39	2.2	10.5
13 Up	17	15	7	48	40	40	2.5	13.2
13 Dn.	1	16	47	8	40	40	2.2	11.0

TABLE 8(C). Analyses of Product Stream Samples

For The Parametric Pumping Experiment : Run 3

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = 2.743×10^{-7} k gmole/c.c. = 2.5 Vol.%

Toluene conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.088$

Sample No. (Cycle No.) n	$\left(\text{Dilution Factor}\right)^{-1}$	Absorb. at289 $m\mu$	Absorb. at263 $m\mu$	$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$ Aniline	$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$ Toluene
Feed	605	86.0	35.4	1.00	1.00
1 Botm.Down	121	81.0	57.0	0.188	0.710
2 Botm.Down	55	78.5	72.2	0.083	0.482
3 Botm.Down	36	84.0	82.0	0.058	0.369
4 Botm.Down	24	65.0	70.0	0.0299	0.214
5 Botm.Down	24	43.0	49.5	0.0198	0.159
6 Botm.Down	20	37.0	39.5	0.0142	0.103
7 Botm.Down	11	62.8	65.8	0.0132	0.0932
8 Botm.Down	8	59.5	76.7	0.0091	0.0851
9 Botm.Down	5	63.0	73.2	0.0061	0.049
10 Botm.Down	4	58.0	58.3	0.0045	0.0295
11 Botm.Down	3	60.0	55.0	0.0035	0.0201
12 Botm.Down	3	46.0	43.4	0.0027	0.0160
13 Botm.Down	3	36.5	35.5	0.0021	0.0132
14 Botm.Down	1	68.0	51.0	0.0013	0.0055
15 Botm.Down	1	58.0	43.6	0.0011	0.0047

TABLE8(D). Analyses of Product Stream Samples of Run 4

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = 0.6585 x 10^{-7} k gmole/c.c. = 0.6 Vol.%

Toluene conc. = 2.349 x 10^{-7} k gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.05$

Sample No. (Cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorbance at 289 mμ	Absorbance at 263 mμ	$\frac{\langle Y_{BP2}\rangle_n}{Y_{oi}}$	
				Aniline	Toluene
Feed	242	54.0	40.0	1.00	1.00
1	88	46.0	61.4	0.03095	0.724
2	88	24.2	42.4	0.1630	0.542
3	55	23.8	55.0	0.100	0.461
4	40	19.5	43.0	0.0597	0.261
6	11	33.2	82.5	0.0279	0.140
7	11	21.5	60.0	0.0181	0.086
8	4	44.5	96.0	0.0137	0.058
9	3	34.2	82.5	0.00785	0.038
10	3	28.0	60.0	0.00642	0.027
11	3	20.0	42.0	0.0046	0.019
12	3	11.8	23.5	0.00271	0.0102
13	3	7.5	12.0	0.00172	0.0051
14	3	5.0	9.5	0.00115	0.0042

TABLE 8(E). Analyses of Product Stream Samples

For the Parametric Pumping Experiment : Run 5

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = $0.5486 \times 10^{-7}k$ gmole/c.c. = 0.5 Vol.%

Toluene conc. = $2.349 \times 10^{-7}k$ gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.05$

Sample No. (Cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorb. at 289mμ	Absorb. at 263mμ	$\frac{\langle y_{BP2}\rangle}{y_{oi}}$	
				Aniline	Toluene
Feed	121	85.6	71.8	1.00	1.00
2 Botm.Down	100	33.8	53.6	0.326	0.79
3 Botm.Down	66	38.5	72.4	0.245	0.73
4 Botm.Down	44	43.3	91.7	0.184	0.63
6 Botm.Down	33	16.4	73.0	0.0684	0.41
8 Botm.Down	16	21.5	92.2	0.037	0.25
9 Botm.Down	11	22.0	98.0	0.0233	0.185
10 Botm.Down	11	22.4	83.8	0.0237	0.155
11 Botm.Down	7	19.0	94.0	0.0128	0.113
12 Botm.Down	6	17.6	90.2	0.0102	0.093
13 Botm.Down	4	18.4	95.8	0.0071	0.066
14 Botm.Down	3	20.0	95.4	0.0058	0.049

TABLE 8(F). Analyses of Product Stream Samples of Exp. Run 6

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = 0.329 x 10^{-7}k gmole/c.c. = 0.3 Vol.%

Toluene conc. = 0.349 x 10^{-7}k gmole/c.c. = 2.5 Vol.%

ϕ_B=0.05

Sample No. (Cycle No.) n	(Dilution Factor)$^{-1}$	Absorb. at 289mμ	Absorb. at 263mμ	$\frac{\langle y_{Bp2}\rangle_n}{y_{oi}}$	
				Aniline	Toluene
Feed	121	51.6	61	1.00	1.00
2	36	31	92	0.180	0.54
4	36	13	39.5	0.075	0.234
5	30	24.0	56.0	0.12	0.267
6	16	37.8	90.0	0.096	0.23
7	10	38.0	79.0	0.060	0.123
8	10	28.5	45.0	0.046	0.066
9	10	18.5	30.8	0.030	0.046
10	9	27.0	22.5	0.039	0.0234
11	4	74.0	52.5	0.047	0.022
12	4	30.0	23.2	0.0192	0.0103
13	4	36.0	23.0	0.023	0.0088
14	4	24.5	21.8	0.0157	0.011

TABLE 8(G). Analyses of Product Stream Samples

For the Parametric Pumping Experiment Run 7

System : Aniline - Toluene - n-Heptane

Feed : Aniline conc. = 0.329×10^{-7} k gmole/c.c. = 0.3 Vol.%

Toluene conc. = 2.349×10^{-7} k gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.05$

Sample No. (cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorb. at 289mμ	Absorb. at 263mμ	$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$ Aniline	$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$ Toluene
Feed	121	50	62	1.00	1.00
2	54	44.6	86.0	0.40	0.69
3	30	27.0	76.0	0.134	0.36
4	30	12.2	42.0	0.061	0.203
5	16	18.8	56.2	0.050	0.143
6	11	26.2	60.5	0.047	0.102
7	6	33.5	68.5	0.033	0.062
8	4	43.0	60.0	0.028	0.033
9	4	40.0	42.2	0.026	0.021
10	4	27.5	30.5	0.018	0.016
11	4	26.8	22.5	0.018	0.010
13	5	25.5	18.5	0.021	0.0095
14	3	32.5	23.5	0.016	0.0072
15	3	22.5	17.0	0.011	0.0054

TABLE8(H).Analyses of Product Stream Sample
For The Parametric Pumping Experiment Run 8

System : Aniline - Toluene - n-Heptane

Feed : Aniline conc. = 2.743×10^{-7} k gmole/c.c.= 2.5 Vol.%

Toluene conc. = 2.349×10^{-7} k gmole/c.c.= 2.5 Vol.%

$\phi_B = 0.1$

Sample No. (Cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorb. at 289mμ	Absorb. at 263mμ	$\frac{\langle y_{BP2}\rangle_n}{y_{0i}}$	
				Aniline	Toluene
Feed	726	72.0	30.0	1.00	1.00
2 Botm.Down	242	71.0	38.4	0.33	0.735
3 Botm.Down	264	60.0	34.0	0.304	0.75
6 Botm.Down	44	63.0	86.8	0.052	0.54
8 Botm.Down	32	38.2	74.2	0.0232	0.36
10 Botm.Down	18	29.0	92.5	0.0098	0.27
12 Botm.Down	14	22.2	83.0	0.006	0.19
14 Botm.Down	9	21.0	93.5	0.0035	0.142

TABLE 8(I). Analyses of Product Stream Samples

For The Parametric Pumping Experiment : Run 9

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = 2.743 x 10^{-7}k gmole/c.c. = 2.5 Vol.%

Toluene conc. = 2.349 x 10^{-7}k gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.05$

Sample No. (Cycle No.) n	$(\text{Dilution Factor})^{-1}$	Absorb. at 289mμ	Absorb. at 263mμ	$\frac{\langle Y_{BPz}\rangle_n}{Y_{oi}}$	
				Aniline	Toluene
Feed	605	86.5	35.5	1.00	1.00
2	242	47.5	24.2	0.22	0.43
4	121	70.0	42.2	0.16	0.46
6	55	76.0	68.2	0.08	0.45
8	40	56.2	66.2	0.043	0.356
10	27	38.8	67.8	0.02	0.275
11	22	35.6	69.4	0.015	0.234
12	18	34.8	74.2	0.012	0.208
13	15	29.0	74.0	0.0083	0.178
14	12	33.2	81.2	0.0076	0.155

TABLE 8(J). Analyses of Product Stream Samples

For The Parametric Pumping Experiment : Run 10

System : Aniline – Toluene – n-Heptane

Feed : Aniline conc. = 0.914 x 10^{-7}k gmole/c.c. = 0.8 Vol.%

Toluene conc. = 2.349 x 10^{-7}k gmole/c.c. = 2.5 Vol.%

$\phi_B = 0.05$

Sample No. (Cycle No.) n	(Dilution Factor)$^{-1}$	Absorb. at 289mμ	Absorb. at 263mμ	$\frac{\langle y_{BP2}\rangle_n}{y_{oi}}$	
				Aniline	Toluene
Feed	242	72.0	44.6	1.00	1.00
2	66	91.4	91.4	0.346	0.76
3	55	58.3	83.8	0.184	0.66
4	36	51.4	96.6	0.106	0.530
5	36	36.8	77.2	0.076	0.432
6	25	30.6	83.0	0.044	0.334
7	24	22.5	67.8	0.031	0.266
8	20	21.0	68.8	0.024	0.227
9	18	17.5	58.8	0.018	0.175
11	11	15.8	60.0	0.010	0.11
12	7	17.4	77.5	0.007	0.092
13	5	17.4	84.5	0.005	0.072

TABLE 8(J). (Continued)

Cycle No. n	$\frac{\langle y_{TB2} \rangle_n}{y_{o1}}$	
	Aniline	Toluene
8	1.466	1.451
6	1.333	1.870
4	1.500	1.354

Figure 10

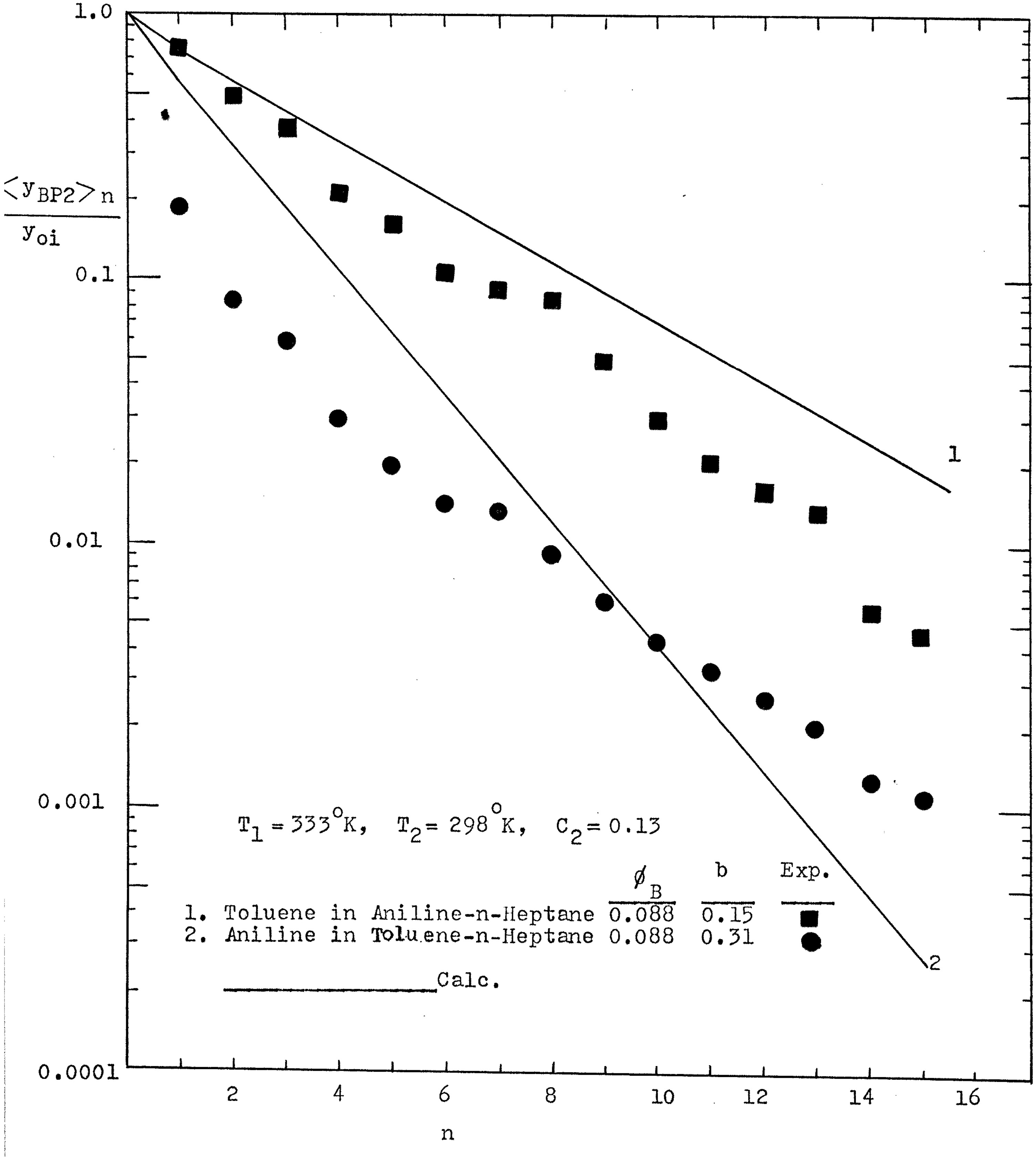
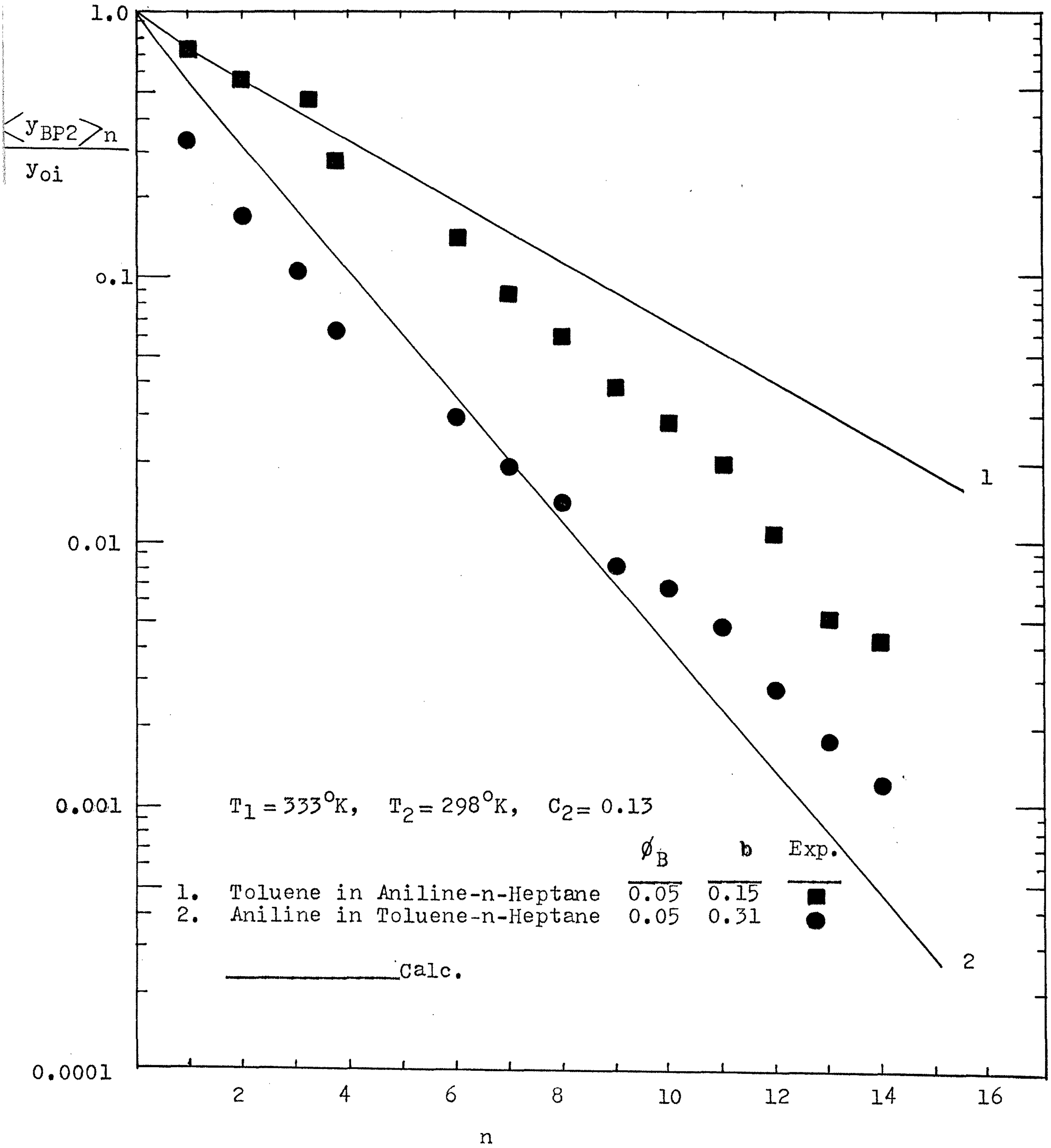

1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$
2
4
6
8
10
12
14
16
n
1
2
$T_1 = 333^\circ K$, $T_2 = 298^\circ K$, $C_2 = 0.13$
ϕ_B
b
Exp.
1. Toluene in Aniline-n-Heptane 0.088 0.15 ■
2. Aniline in Toluene-n-Heptane 0.088 0.31 ●
Calc.

Figure 11



$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$
1.0
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
16
n
1
2
$T_1 = 333^{\circ}K$, $T_2 = 298^{\circ}K$, $C_2 = 0.13$
ϕ_B b Exp.
1. Toluene in Aniline-n-Heptane 0.05 0.15 ■
2. Aniline in Toluene-n-Heptane 0.05 0.31 ●
Calc.

Figure 12

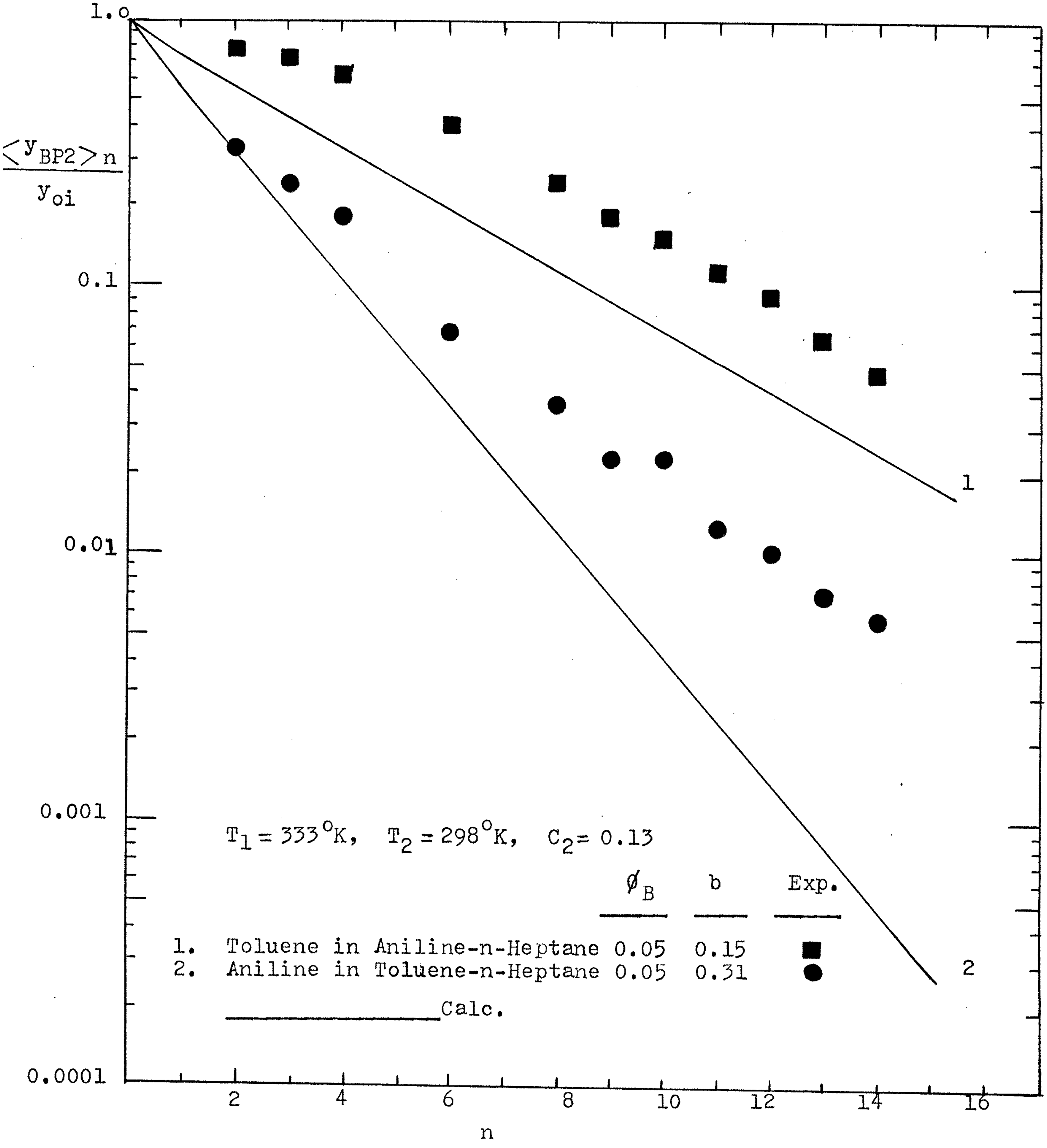

1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{BP2} \rangle n}{y_{oi}}$
2
4
6
8
10
12
14
16
n
1
2
$T_1 = 333^{\circ}K$, $T_2 = 298^{\circ}K$, $C_2 = 0.13$
ϕ_B b Exp.
1. Toluene in Aniline-n-Heptane 0.05 0.15 ■
2. Aniline in Toluene-n-Heptane 0.05 0.31 ●
Calc.

Figure 13

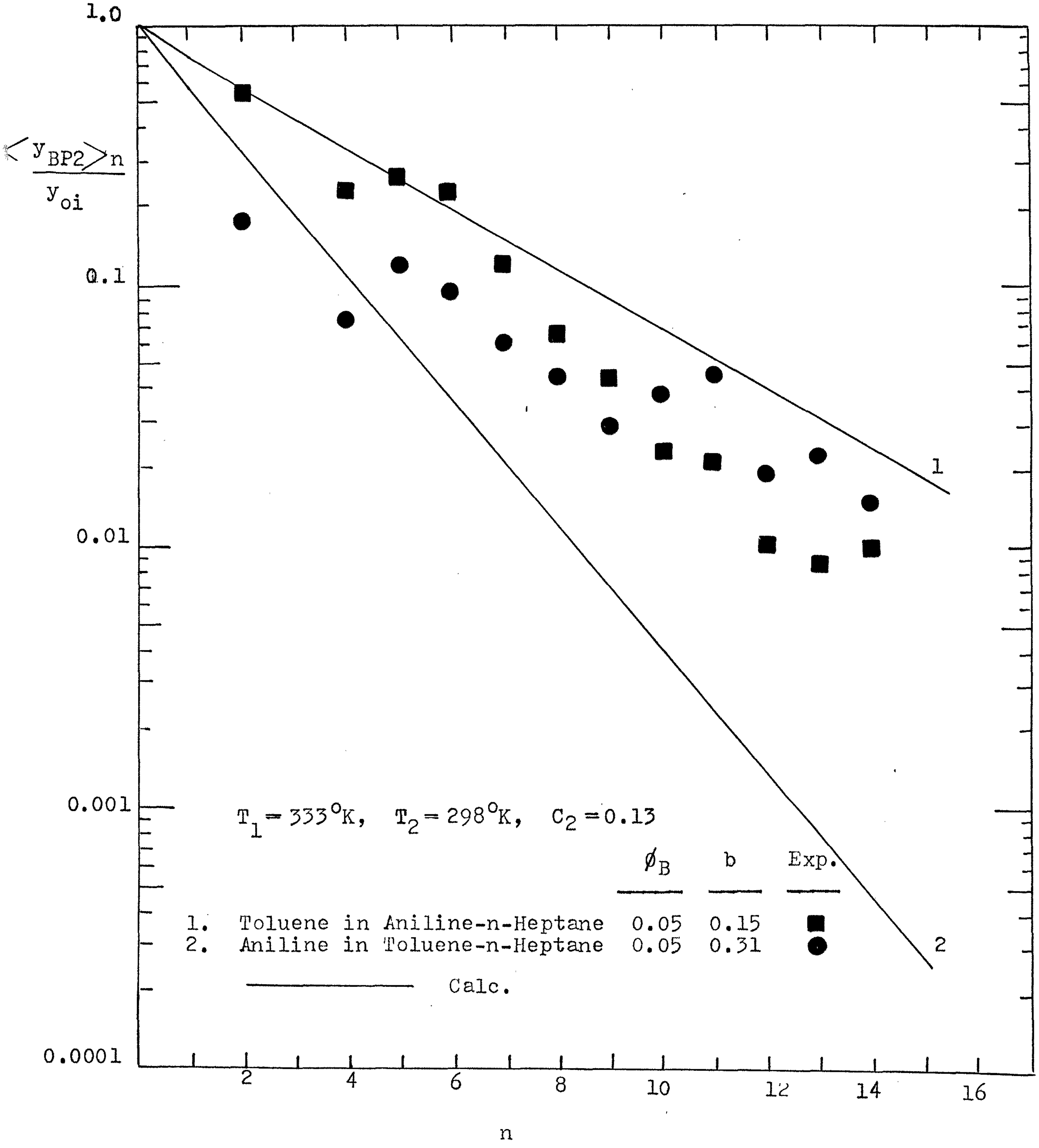

1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{BP2} \rangle n}{y_{oi}}$
2
4
6
8
10
12
14
16
n
1
2
$T_1 = 333^{\circ}K$, $T_2 = 298^{\circ}K$, $C_2 = 0.13$
ϕ_B b Exp.
1. Toluene in Aniline-n-Heptane 0.05 0.15 ■
2. Aniline in Toluene-n-Heptane 0.05 0.31 ●
Calc.

Figure 14

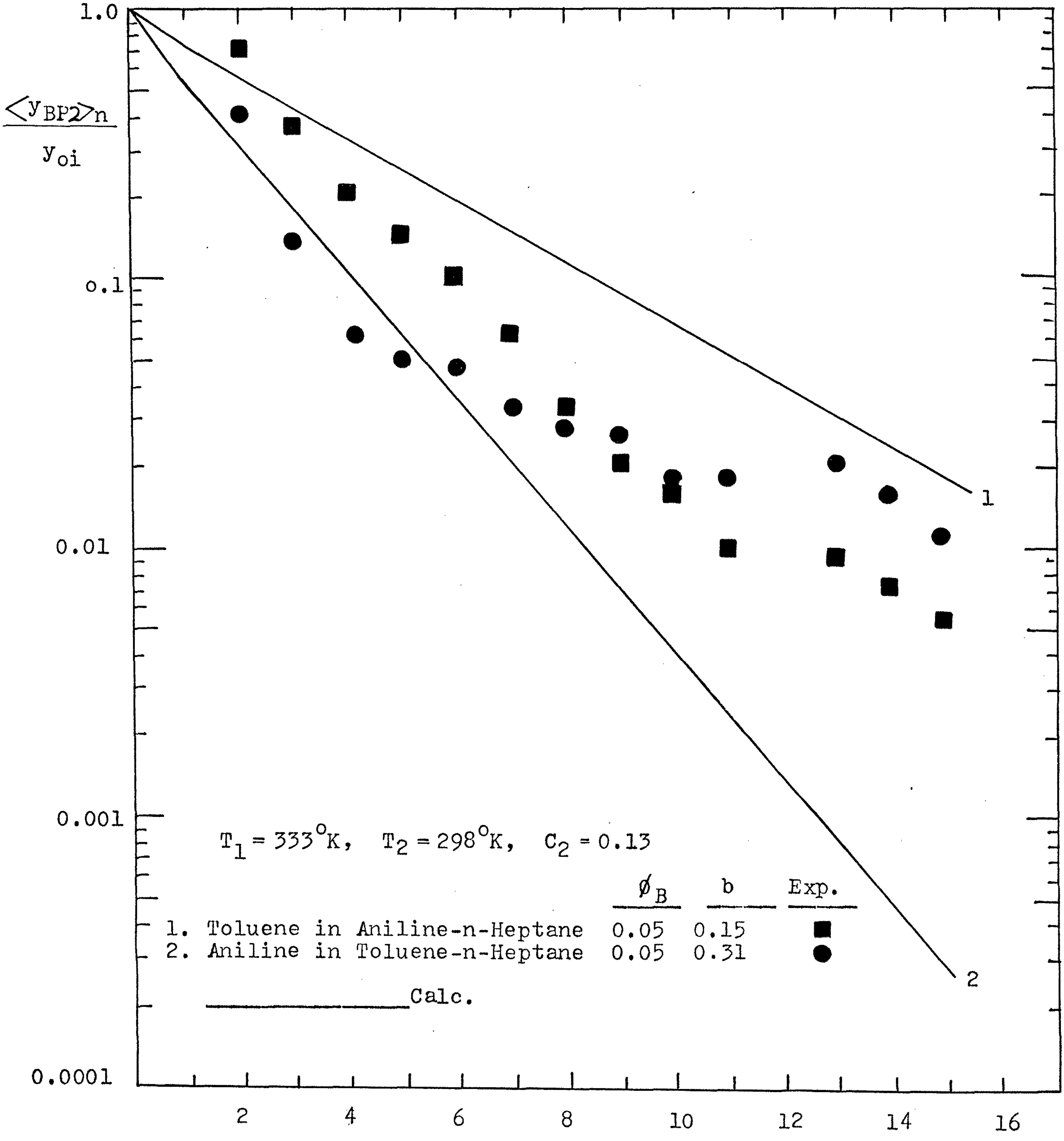

1.0
0.1
0.01
0.001
0.0001
<yBP2>n
yoi
2
4
6
8
10
12
14
16
1
2
T1 = 333°K, T2 = 298°K, C2 = 0.13
ØB b Exp.
1. Toluene in Aniline-n-Heptane 0.05 0.15 ■
2. Aniline in Toluene-n-Heptane 0.05 0.31 ●
Calc.

Figure 15

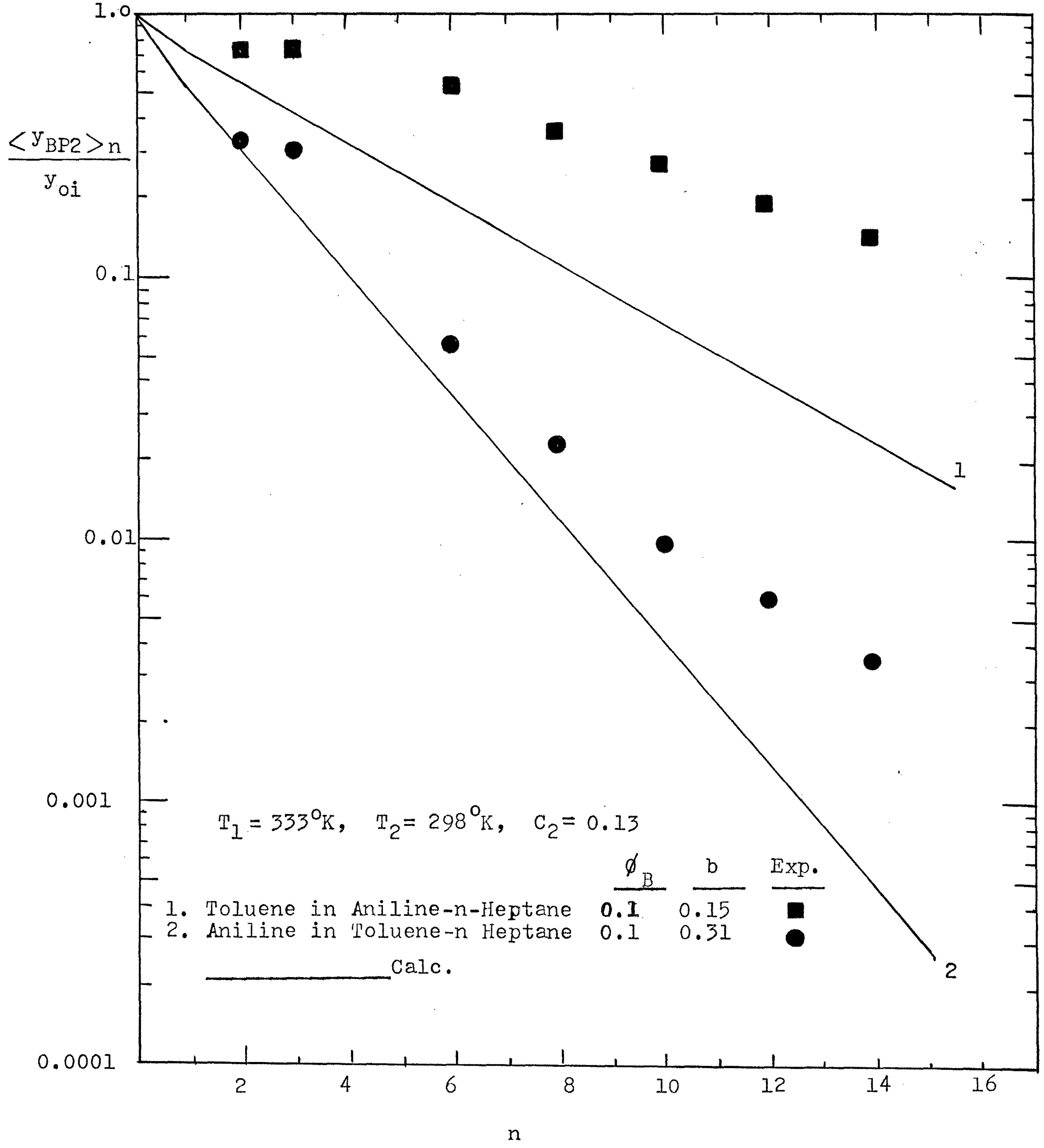

1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{BP2} \rangle n}{y_{oi}}$
2
4
6
8
10
12
14
16
n
1
2
T1 = 333°K, T2 = 298°K, C2 = 0.13
ØB b Exp.
1. Toluene in Aniline-n-Heptane 0.1 0.15 ■
2. Aniline in Toluene-n Heptane 0.1 0.31 ●
———— Calc.

Figure 16

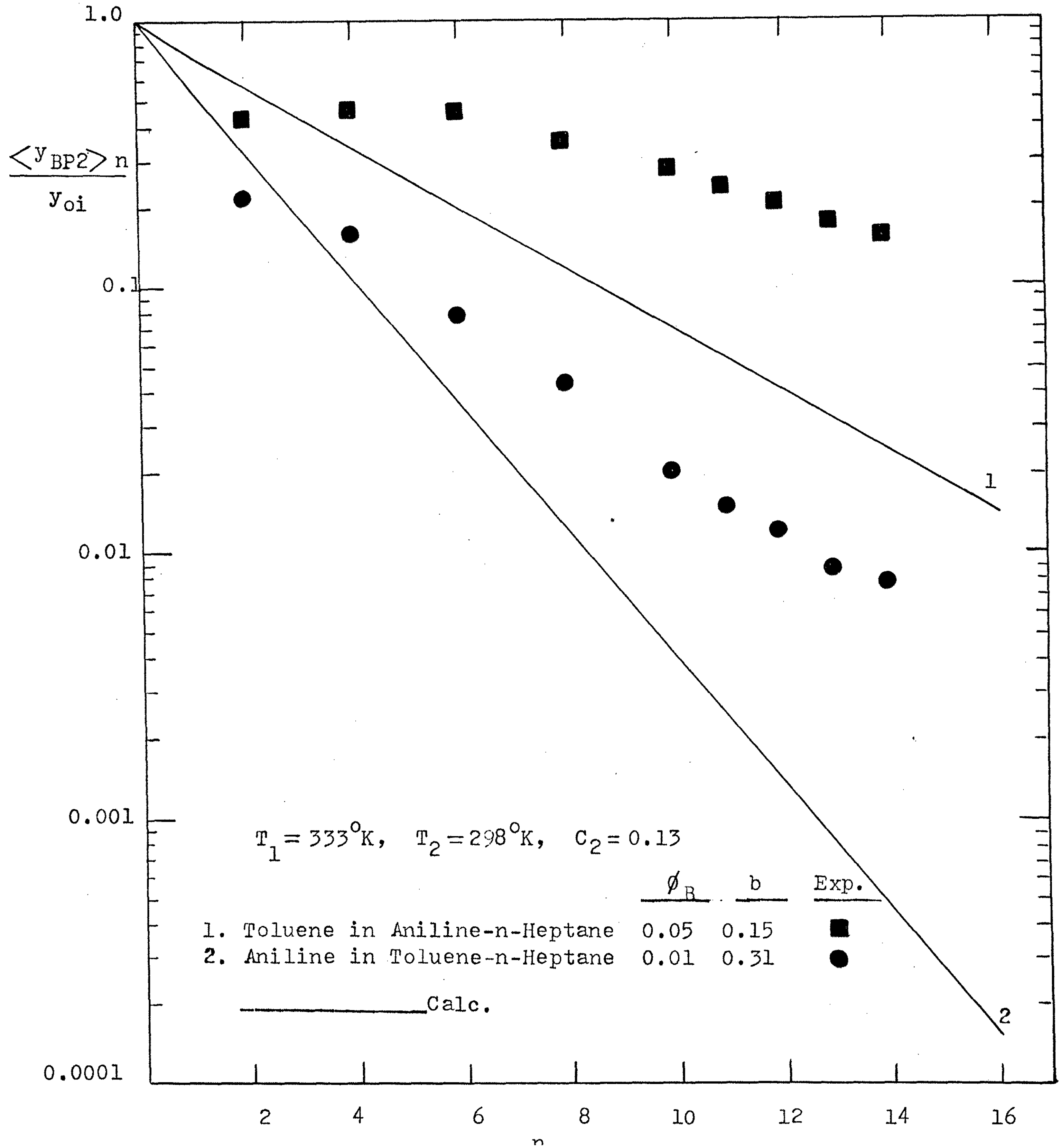
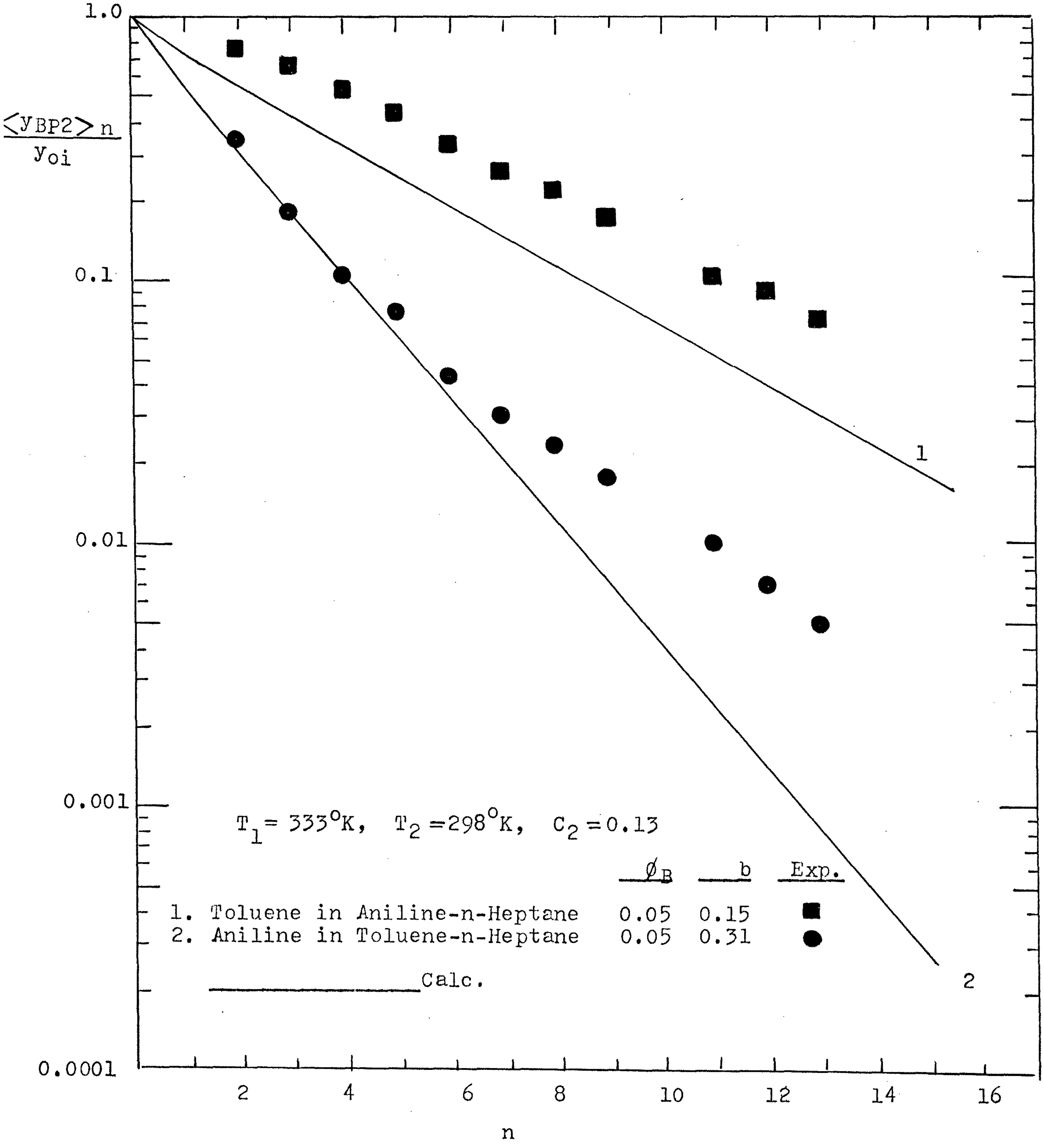

1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{BP2} \rangle n}{y_{oi}}$
2
4
6
8
10
12
14
16
n
1
2
$T_1 = 333^\circ K$, $T_2 = 298^\circ K$, $C_2 = 0.13$
ϕ_B
b
Exp.
1. Toluene in Aniline-n-Heptane 0.05 0.15 ■
2. Aniline in Toluene-n-Heptane 0.01 0.31 ●
Calc.

Figure 17


1.0
0.1
0.01
0.001
0.0001
$\frac{\langle y_{BP2} \rangle_n}{y_{oi}}$
2
4
6
8
10
12
14
16
n
1
2
$T_1 = 333^{\circ}K$, $T_2 = 298^{\circ}K$, $C_2 = 0.13$
ϕ_B
b
Exp.
1. Toluene in Aniline-n-Heptane 0.05 0.15 ■
2. Aniline in Toluene-n-Heptane 0.05 0.31 ●
Calc.