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EFFECT OF COLUMN DIAMETER ON

THE FREQUENCY RESPONSE OF

WATER FLUIDIZED BEDS

ΒY

EDWARD C. MAIURO

A THESIS

PRESENTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE

OF

MASTER OF SCIENCE IN CHEMICAL ENGINEERING

ΑT

NEWARK COLLEGE OF ENGINEERING

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> Newark, New Jersey 1968

APPROVAL OF THESIS

FOR

DEPARTMENT OF CHEMICAL ENGINEERING NEWARK COLLEGE OF ENGINEERING

ΒY

FACULTY COMMITTEE

APPROVED:

NEWARK, NEW JERSEY

JUNE, 1968

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ABSTRACT

The effect of column diameter on the frequency response of water fluidized beds was investigated.

Studies were made on four columns ranging from four to ten inches in diameter. Water was used to fluidize the beds which consisted of spherical glass beads .0185 inches in diameter. A trace solution of sodium chloride was sinusoidally introduced into the beds. Inlet and outlet concentrations were continuously measured by an electrical conductivity recorder. Separate frequency response tests were conducted on the inlet calmning section in an attempt to obtain the frequency response of this region alone. Results of the tests were expressed as Bode plots.

As the bed diameter was increased, the system became more backmixed in nature. In an attempt to quantify this data, theoretical frequency response curves were calculated based on the mixing cell model. However, over the range of frequencies tested, poor correlation was obtained between this theoretical model and the empirical data.

ACKNOWLEDGMENTS

The author wishes to express his indebtedness to Dr. Deran Hanesian for his guidance during the course of this study; and to his wife, Agnes Maiuro, for her encouragement and patient endurance, as well as her aid in typing the manuscript.

TABLE OF CONTENTS

	Page	No.
TITLE PAGE	i	
APPROVAL PAGE	11	
ABSTRACT	111	
ACKNOWLEDGEMENTS	iv	
TABLE OF CONTENTS	v	
LIST OF FIGURES	vii	
LIST OF TABLES	viii	
INTRODUCTION	1	
APPROACH TO THE PROBLEM	4	
EXPERIMENTAL APPARATUS AND EQUIPMENT	6	
THEORETICAL ANALYSIS	11	
General Theory	11	
Application of General Theory	14	
RESULTS AND DISCUSSION	18	
CONCLUSIONS	28	
RECOMMENDATIONS	29	
FOOTNOTES	30	
BIBLIOGRAPHICAL ENTRIES	31	•-*
APPENDIX	33	
Instrument List	34	
Rotameter Calibration Curve	35	

TABLE OF CONTENTS (cont.)

	Page No.
Experimental Data	36
Numerical Computations	38
Computer Program Statement for Determination of N	42
Theoretical Computations of Total System Gain (AR) at Values of N from 1-10 for the Four Columns (4 Time Constants)	46
Computer Program Statement for Determination of N2	56
Computer Data for Determination of N ₂	60

LIST OF FIGURES

Figure No.		Page No.
1	Experimental Equipment Layout	9
2	Column Assembly	10
3	Block Diagram of System	16
4	Typical Frequency Response Test (High Frequency)	19
5	Typical Frequency Response Test (Low Frequency)	20
6	Experimental Amplitude Ratio Curves	22
7	Amplitude Ratio Curves (3.75 inch Column)	23
8	Amplitude Ratio Curves (5.75 inch Column	24
9	Amplitude Ratio Curves (7.75 inch Column)	25
10	Amplitude Ratio Curves (9.75 inch Column)	26
11	Rotameter Calibration Curve	_ 35

LIST OF TABLES

		1
Table No.		Page No.
1	Experimentally Determined Overall System Amplitude Ratio (3.75 inch Column)	36
2	Experimentally Determined Overall System Amplitude Ratio (5.75 inch Column)	36
3	Experimentally Determined Overall System Amplitude Ratio (7.75 inch Column)	37
4	Experimentally Determined Overall System Amplitude Ratio (9.75 inch Column)	37
5	Calculated Data	41
6	Computer Data for Determination of N ₂ (3.75 inch Column)	60
7	Computer Data for Determination of N_2 (5.75 inch Column)	61
8	Computer Data for Determination of N_2 (7.75 inch Column)	62
9	Computer Data for Determination of N_2 (9.75 inch Column)	63

viii

INTRODUCTION

Scaling up results from small to large size fluidized beds is an important and difficult problem. It has been recognized that large units generally give results differing from small scale laboratory units. A basic problem facing the designer of a fluidized system is that the flow behavior of large beds differs substantially from small units.(1)

The purpose of this study was to investigate the effect of column diameter on the frequency response of the fluidized bed.

The dynamic characteristics of tubular flow systems, including fluidized systems, may be conveniently expressed in terms of frequency response data. The frequency response method yields results which are reproducible and relatively easy to compare with those obtained from theoretical models.

In frequency response testing a sine wave of a given amplitude and frequency is used as the input signal to the system being studied. The output signal should also be a sine wave with the same frequency; but the amplitude and angular displacement of the wave will be altered in accordance with the dynamics of the system. The ratio of the output wave amplitude to the input wave amplitude, coupled with the angular displacement between the two waves constitute the data of frequency response.

-1-

In reality, the flow in a fluidized bed, as well as most other physical processes, is extremely complex and non-linear in nature. However, a system will respond linearly for a given amplitude and range of frequencies. A linear system is one that may be described by linear differential equations. In frequency response terms, a system is linear if the frequency of the output wave equals the frequency of the input wave. Therefore, to employ the frequency response technique readily, it is imperative to remain within the linear bounds of the system.

The purpose of this study was to investigate the effect of bed diameter on the frequency response of fluidized beds, not to develop a rigorous fluid bed model. In an attempt to quantify the empirical data obtained, a rather simplified model was used, the mixing cell model. In this model, one attempts to account for the longitudinal mixing by assuming that the bed acts as a series of noninteracting perfect mixers.⁽²⁾ Theoretical frequency response curves were calculated based on the mixing cell flow model. These theoretical curves were then compared to the experimental curves to arrive at the number of perfect mixers for each column.

Much work has been performed on the dynamic analysis of fluid bed systems by step, pulse and frequency response techniques. However, an exhaustive search of the literature has revealed that the bulk of this work has been performed on small size columns, 4 inch diameter and less. There is a lack

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of data for a broad range of column diameters. It is for this reason that the 4 to 10 inch beds were evaluated.

A listing and summarization of previous work on longitudinal dispersion of liquid in fixed and fluidized beds is presented in AIChE Preprint 33E, November 26-30, 1967.

APPROACH TO THE PROBLEM

Theoretical responses were calculated for each column over the range of frequencies tested by use of the mixing cell model. A computer was employed in the calculation of the theoretical responses for N perfect mixing cells. Bode plot data was obtained for values of N ranging from 1 to 200.

A frequency response analysis was performed on each column and the results plotted on Bode diagrams. These experimental results were then compared to the theoretical frequency responses.

Each column consisted of two sections, the packed calmning section and the fluidized section. As it was the intent of this work to develop a scale-up correlation for fluidized beds, only the response of the fluidized section was desired. Therefore, the inlet conductivity cell was placed as close as possible to the base of the fluidized bed. (See Fig. 2) However, due to the construction of the cell, the signal measured was not the conductivity directly at the base of the fluidized bed. But rather, it was the conductivity 3-3/4 inches below the fluidbed base. It was therefore necessary to determine the response of this section alone. The response of the fluidized section could then be obtained by subtracting the packed calmning section response from the overall system response.

To obtain the response of the calmning section alone, one must run frequency response tests on each column with the fluidized section emptied. This was attempted. However, when the

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glass beads were removed from the columns, air bubbles formed on the conductivity electrodes. This resulted in completely meaningless conductivity readings and prevented experimental determination of the calmning section response. This difficulty necessitated a different approach to the problem. As experimental determination of the calmning section response was impossible, a theoretical response based on the mixing cell model was calculated for this region.

EXPERIMENTAL APPARATUS AND EQUIPMENT

The experimental equipment included a low frequency sine wave generator which applied a 3-15 psig. air signal to a Mason Neilon control valve. This control valve was placed in the tracer inlet line. The control valve's opening and closing varied the amount of salt solution feed into the fluidized bed, thus causing the electrical conductivity of the bed to rise and fall.

The apparatus used for the experimentation is shown in Figures 1 and 2. The range of column diameters studied required the construction of an apparatus which was adaptable to all four columns.

Two 14 inch square steel plates were drilled and tapped at the centers to afford an entrance and exit for the liquid. Also, each plate was covered with soft rubber. This rubber functioned as a gasket at the plate and column interfaces. Each column consisted of two sections, the 8 inch calmning section and the 4.5 foot fluidizing section. In assembling each column, the calmning section was set down on the plate and filled with Raching Rings. A gasket and bed support screen were then placed over this first section. Another gasket followed and next the fluidizing section was bolted and clamped

to the calmning section. The entire column was then clamped between the two steel plates. Dow Hi-Vac grease was applied between the gaskets, column and plates to insure a water-tight seal. The glass beads for the fluidizing section were added after the column was assembled, through the fitting in the top plate. To change columns with this system, only loosening the clamps and a replacement of the column was required. All four columns were made of Lucite with a wall thickness of 1/8 inch.

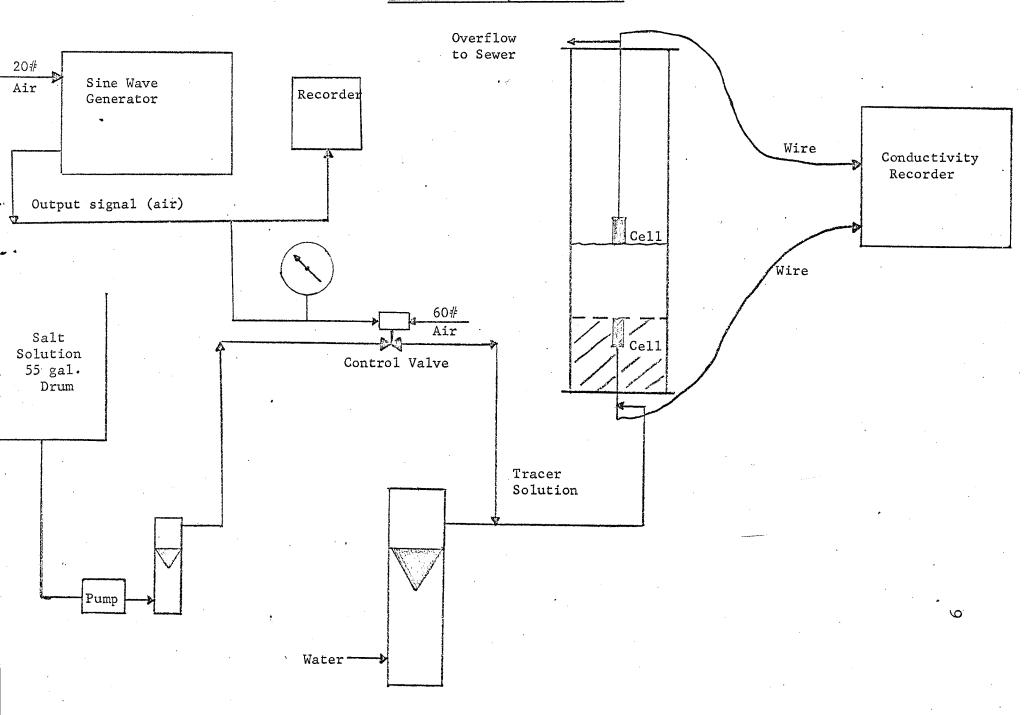
The apparatus was constructed so that one conductivity cell was placed within the calmning section, and measured the conductivity at the base of the fluidized bed. The second conductivity cell was lowered through the top plate and positioned at the upper edge of the fluidized bed. These two cells transmitted the signals to a Beckmann Honeywell two pen electrolytic conductivity indicator recorder. The recorder range was O-10,000 micromhos, with a linear O-10 scale.

A pneumatic recorder was positioned in parallel with the control valve as a check on the air signal being supplied to the valve by the sine wave generator.

A saturated solution of sodium chloride was used for the trace signal. The salt solution was stored in a 55 gallon polyethylene drum. This solution was delivered to the bed by means of a centrifugal pump which provided a nearly constant head of 22 psig.

The fluidizing water for the system was checked for variations in static pressure, only slight fluctuations were noted. The water was fed into the columns by a 3/4 inch pipe through a rotameter. The overflow was carried to the sewer by a one inch rubber hose. The rotameters used for the fluidizing liquid were two Fischer-Porter rotameters. These meters were rated at 2.7 and 8.8 gallons per minute at 100% flow. The meters were calibrated and found to be linear.

FIGURE 1 EXPERIMENTAL EQUIPMENT LAYOUT



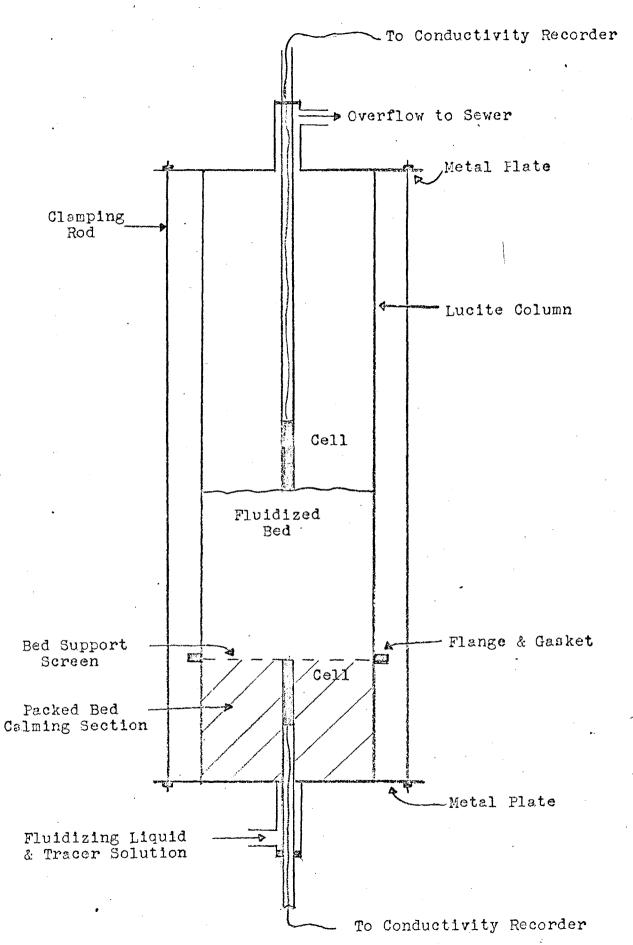


Figure 2 COLUMN ASSEMBLY

THEORETICAL ANALYSIS

General Theory

In the mixing cell model the system is represented as a series of finite, perfectly mixed cells. By definition the concentration in a perfect mixer has a value at every point equal to the concentration at the outlet C_0 . For continuous flow through the mixer we have the material balance:

 $C_{1} = C_{0} + T dC_{0}$ \overline{dT}

where T is the average time of residence (volume of the mixer divided by the constant volumetric flow rate). If C_1 is varied sinusoidally, then the value of the signal at any place in the system is given by:

 $C = X e^{jwt}$

(2)

(1)

X is a complex number which can be represented by a radius vector in the complex plane, having a certain length (magnitude) and a phase angle with respect to the positive real axis. In the frequency response analysis, the relationship between two signals C and their vectors X is of interest. It can be expressed by the ratio of their respective magnitudes (amplitude ratio) and the difference between their respective phase angle (phase lag). If the concentrations for the two signals are recorded, the complex ratio between X_0 and X_1 is called the harmonic response

function of the entire system (transfer function). This function depends on the frequency w of the applied signal in a way which is characteristic of the system.

Substitution of equation 2 into equation 1 yields:

$$X_{i} = X_{o} + j w T X_{o}$$
 (3)

and for the transfer function of one perfect mixer

$$\frac{X_0}{X_1} = \frac{1}{1 + jwT}$$
(4)

The value of the amplitude ratio (AR) and phase angle (ϕ) are:

 $AR = (1 + w^2 T^2)^{-\frac{1}{2}}$

 ϕ = -arc tan (wT)

Applying the result of equation 4 to a system containing N perfect mixers in cascade having equal times of residence (T/N), the transfer function is:

$$G(s) = \begin{bmatrix} 1 \\ \frac{T}{N}s + 1 \end{bmatrix}^{N}$$
(5)

$$G(jw) = \begin{bmatrix} 1 \\ \frac{T}{N}jw + 1 \end{bmatrix} N$$

where

or

T = Time Constant (min.) =
$$V/q$$

V = Total volume of N mixers (ft³)
q = Flow rate (ft³/min.)
N = Number of perfect mixing cells

From the transfer function, the amplitude ratio and phase angle may be obtained.

$$G(jw) = \begin{bmatrix} 1 \\ \sqrt{1 + (wT/N)^2} \end{bmatrix}^N$$
(6)

$$G(jw) = -N \operatorname{arc} \operatorname{tan} (wT/N)$$
 (7)

where

G(jw) = amplitude ratio = AR $G(jw) = phase angle = \emptyset$ w = frequency (cycles/min)

When a sinusoidal disturbance is introduced into a flow system, the outgoing signal is smaller in amplitude and exhibits a phase lag with respect to the entering signal. In general, the amplitude ratio is ≤ 1 and the phase angle ≤ 0.3

Application of General Theory

The system studied consisted of two regions, the packed calmning section and the fluidized section, each with its own transfer function. The mixing cell model assumes that the response of each element is independent of conditions in the other elements. The elements are considered non-interacting and the total system transfer function is the product of the individual transfer functions.

$$G = G_1 \cdot G_2 \tag{8}$$

where

G = total system transfer function

 G_1 = packed calmning section transfer function

 G_2 = fluidized bed transfer function

Also,

 $AR = AR_1 + M_2$ $\emptyset = \emptyset_1 + \emptyset_2$

Amplitude ratios will be utilized throughout this discussion, to obtain the number of mixing cells in each section. Values for N can be obtained from the phase angle curves of Bode plots, since a system with N mixing cells exhibits a phase lag of

14.

 $N \pi/2$ as the frequency approaches ∞ . However as real systems exhibit dead time, which effects the phase angle but not the amplitude ratio, the experimental determination of N from phase angle diagrams was not attempted.

$$AR = AR_1 \cdot AR_2$$

$$\left[1 + \left(\frac{wT}{N}\right)^{2}\right]^{-N/2} = \left[1 + \left(\frac{wT_{1}}{N_{1}}\right)^{2}\right]^{-N_{1}/2} \cdot \left[1 + \left(\frac{wT_{2}}{N_{2}}\right)^{2}\right]^{-N_{2}/2}$$
(9)

where

- N = number of mixing cells in total system. This value is determined from the experimental frequency response curve of the total system.
- N₁ = number of mixing cells in section 1 (packed calmning section)

 N_2 = number of mixing cells in section 2 (fluidized bed)

= are known quantities.

N, N₂

= unknown quantities

but

$$N = N_1 + N_2$$

therefore

$$N_2 = N - N_1$$

(11)

(10)

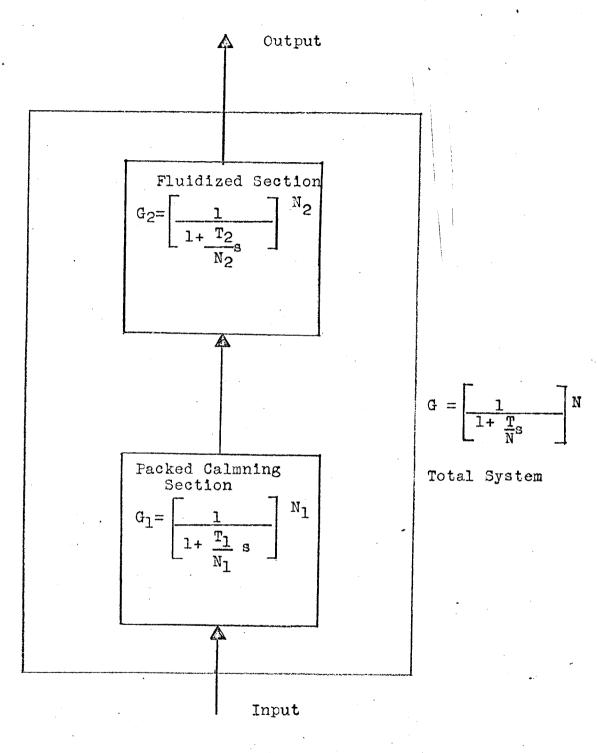


Figure 3 BLOCK DIAGRAM OF SYSTEM

16

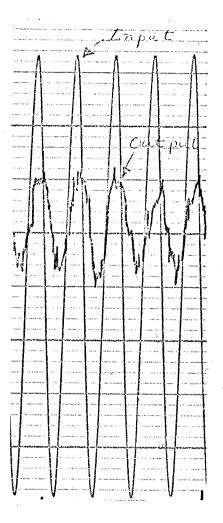
Equations 9 and 10 comprise two equations in two unknowns which were solved for N_2 , the number of mixing cells in the fluidized region. The solution was performed by a trial and error technique on a computer. This calculation yielded the amplitude ratio of the fluidized bed and in turn the number of perfect mixing cells.

RESULTS AND DISCUSSION

The frequency response tests were conducted to obtain the total system amplitude ratio curve, from which by a comparison with the theoretical model N could be obtained.

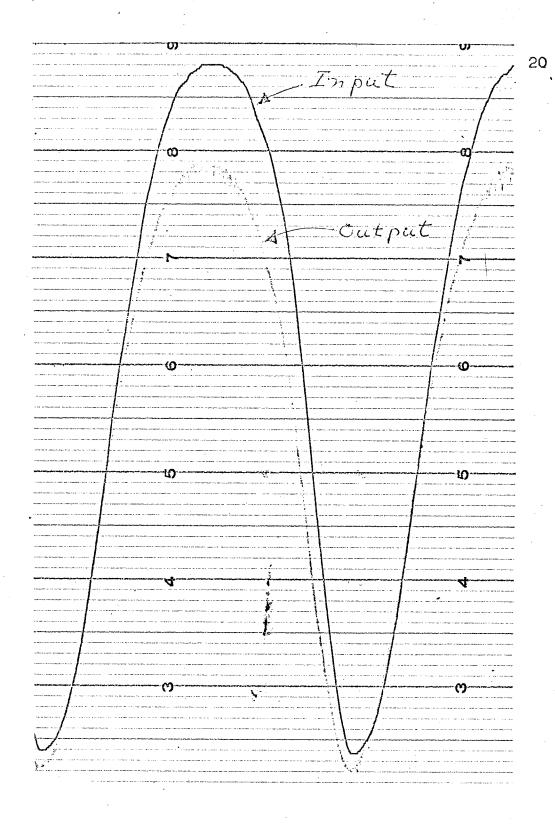
These tests were run on each column over a range of frequencies ranging from 7.50 cycles/min to 0.12 cycles/min. The input signal to the bed was sinusoidal in shape, while the outlet wave was less sinusoidal, in appearance it was more triangular. This effect was more noticeable at the lower frequencies. Typical experimental frequency response tests are presented in Figures 4 and 5. The system responded linearly over the range of frequencies tested. Figures 7, 8, 9, 10 are amplitude ratio plots obtained from the experimental data superimposed over the theoretical amplitude ratio plot for the N value which best fit the experimental data. Figure 6 contains the experimental amplitude ratio curves for all four bed diameters, computed from curves similar to those in Figures 4 and 5. It can be seen from Figure 6 that for a given frequency as bed diameter increases the amplitude ratio decreases.

Ferfect plug flow is postulated for a system where no amplitude attenuation of the incoming sinusoidal occurs. A plug flow system can be thought of as consisting of an infinite number of infinitesmally small perfect mixing cells, which would result in



TYPICAL FREQUENCY RESPONSE TEST (HIGH FREQUENCY)

Figure 4



TYPICAL FREQUENCY RESPONSE TEST (LCW FREQUENCY)

Figure 5

an amplitude ratio equivalent to unity. For a given frequency as the amplitude ratio decreases, more attenuation of the input sinusoidal, the system becomes less plug flow in nature, i.e., exhibits more backmixing. Hence, the experimental data tabulated in Figure 6 indicates that an increase in bed diameter results in increased backmixing. Kramer and Alberda⁴ have demonstrated that the frequency response diagrams of real systems generally lie between those for one perfect mixer and for perfect plug flow. However, it is not at all necessary that the diagram for a real system coincides with one for a certain number of perfect mixers.

A theoretical model, the mixing cell model, was employed in an attempt to quantify the empirical data obtained. However, attempts to represent the mixing phenomena of the total system by the mixing cell model proved unfruitful. The model yielded amplitude ratio curves whose shapes did not agree with the plots of the experimental values. It is perhaps significant however, that the curves did approach each other at the highest test frequency, 7.5 cycles/min. It seems logical to test at still higher frequencies to see if this trend is continued. This was attempted. A sinusoidal input of 15 cycles/min was introduced into the system. However, the noise inherent in the system obscurred the outlet sine wave making a computation of the amplitude for this higher frequency impossible.

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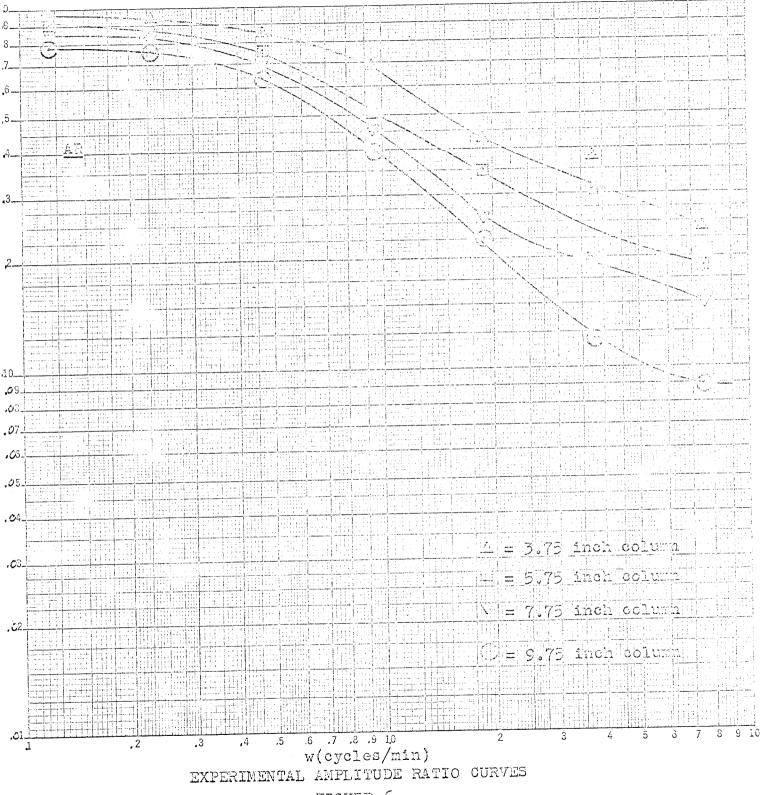
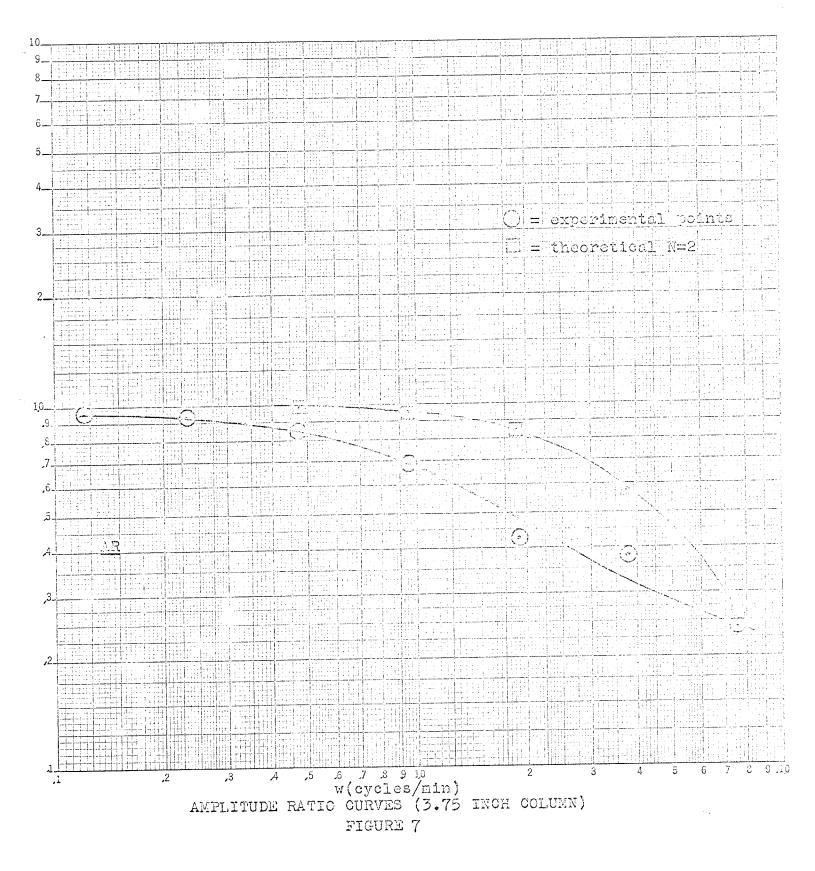


FIGURE 6

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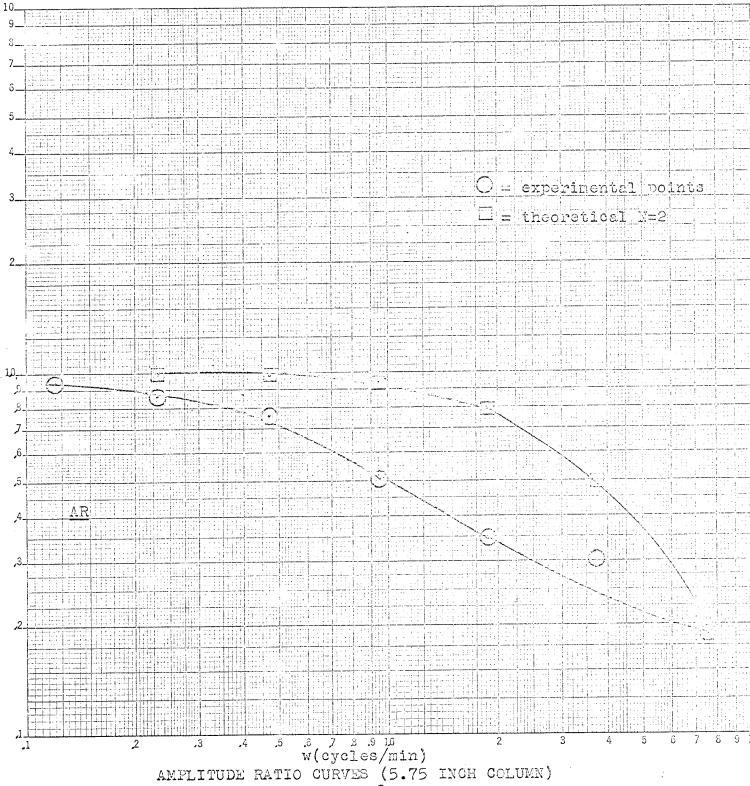


FIGURE 8

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Hence, the theoretical values of N which yielded the best fit to the experimental data were chosen for the number of mixing cells for the total system, fluidized section and packed calmning section.

It is felt that better correlation between model and experimental data could have been obtained, if the response of the empty column could be obtained. It appears that at the low flow velocity utilized, a correction to the amplitude is required for interaction with the bed support and column wall. As was mentioned previously, this was attempted. The low flows had to be maintained due to the fact that the small beads chosen, .0185 in. diameter, were easily driven from the column. At these low flows. air bubbles entering the system dissolved in the water would accumulate on the conductivity electrode. This was not too severe a problem when beads were in the column, as they would circulate through the cell and displace the air bubbles. But when attempts were made at running the column empty, to measure entrance, column wall and bed support responses, bubbles accumulated on the electrodes and made conductivity measurement impossible.

The interaction with the bed support and column wall undoubtedly contributed to the disagreement between empirical results and theoretical predictions.

The values of N for the total system are listed in tables 6-9 As the N values were extremely low, computation of meaningful N_1 and N_2 values was impractical.

CONCLUSIONS

For the flow rate employed in this study, as bed diameter increased the flow pattern in the bed became less plug flow in nature and exhibited increased backmixing.

The fluidized and packed bed systems used in this study were linear.

It is believed that the poor correlation between experimental data and the theoretical mixing cell model, is in part due to the interaction of the wall and bed support.

The theoretical model used did not accurately describe the mixing phenomena in the fluidized beds studied. It is obvious that a different model, perhaps more sophisticated than the mixing cell model is required to describe the system.

RECOMMENDATIONS

1--

This study may be performed using a considerably larger bead size. This will allow the use of higher flow rates, without the fear of displacing beads from the column. At higher flow rates air bubbles do not accumulate on the conductivity cells, which tend to introduce noise into the system. Also, the higher flows and the resulting lower noise level will allow testing at higher frequencies. At the higher flow rate it will also be possible to test the effect of the empty column response, the wall response and bed support response, without having air bubbles hindering the measurement.

·2--

A study similar to the one performed over a range of flow rates may be of value.

3---

Utilization of a different model perhaps the axial diffusion model in arriving at a scale-up factor for fluidized beds.

FOOTNOTES

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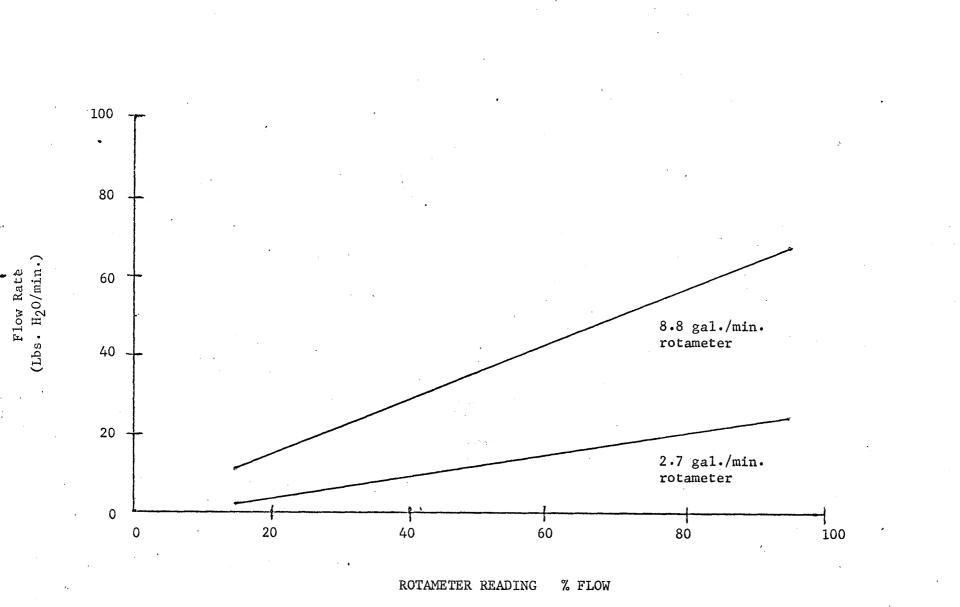
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APPENDIX

	Page
Instrument List	34
Rotameter Calibration Curve	35
Experimental Data	36
Numerical Computations	38
Computer Program Statement for Determination of N	42
Theoretical Computations of Total System Gain (AR) at Values of N from 1-10 for the Four Columns (4 Time Constants)	46
Computer Program Statement for Determination of N ₂ for the Four Columns (4 Time Constants)	56
Computer Data for Determination of N2	60

INSTRUMENT LIST

- 1. Conductivity Cells, Type Cel-VH2OKFT and Cel-VH2OKFT-Y-15 Beckman Instruments
- 2. Ultra Low Frequency Sinusoidal Signal Generator, Model SG-101P, Procedyne Associates Inc., New Brunswick, New Jersey
- 3. Consotrol Controller, Mode 58, Foxboro Co., Foxboro, Massachusetts
- 4. Control Valve, Model #37-24681, Mason Neilon Inc., Norwood, Massachusetts
- 5. Electrolytic Conductivity Recorder, Model Y15302816-02-99 Beckman/Honeywell
- 6. Rotameters -- Three -- .68 gpm,, 2.7 gpm., 8.8 gpm., Fischer-Porter, Warminster, Fennsylvania





ROTAMETER CALIBRATION CURVES

TABLE 1

EXPERIMENTALLY DETERMINED OVERALL SYSTEM AMPLITUDE RATIO

3.75 INCH COLUMN

w (Cycles/min)	Amplitude Ratio (AR)
7.50	.24
3.75	• 38
1.88	.43
0.94	.69
0.47	.86
0,23	•94
0.12	.96

TABLE 2

EXPERIMENTALLY DETERMINED OVERALL SYSTEM AMPLITUDE RATIO

5.75 INCH COLUMN

w (Cycles/min)	Amplitude Ratio (AR)
7.50	.19
3.75	.31
1.88	•35
0.94	.51
0.47	.76
0.23	.86
0.12	.92

TABLE 3

EXPERIMENTALLY DETERMINED CVERALL SYSTEM AMPLITUDE RATIO

7.75 INCH COLUMN

w (Cycles/min)	Amplitude Ratio (AR)
7.50	.15
3.75	.20
1.88	.26
0.94	.46
0.47	.69
0.23	.82
0.12	.85

TABLE 4

EXPERIMENTALLY DETERMINED OVERALL SYSTEM AMPLITUDE RATIO

9.75 INCH COLUMN

w (Cycles/min)	Amplitude Ratio (AR)
7.50	.09
3.75	.12
1.88	,23
0.94	.40
0.47	.64
0.23	.76
0.12	.79

NUMERICAL COMPUTATIONS

Time Constant Calculation

Danckwerts⁵ has shown that if a volume V is fed with a flow rate q, regardless of the transfer function of the region, the average time of travel through the region is V/q. This is the time constant (T) for a mixing process.

The time constant of the overall system studied is equal to the sum of the time constants of two sections.

 $T = T_1 + T_2$ T = V/q

q = constant to each section.

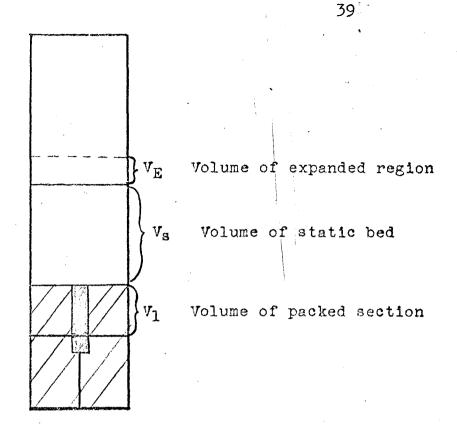
Hence, in order to calculate the time constants for each section it is necessary to compute the void volume in each section.

Fluidized Section

 $v_2 = v_s \cdot (E_2) + v_E$

where

 V_2 = void volume of fluidized region V_8 = volume of static bed E_2 = calculated voidage factor (.44) V_E = expanded volume



Packed Section

 $V_1 = V_p(E_1)$ where

The voidage factor (E) for the static bed was experimentally determined by filling a cylinder with a known volume of water. To this the beads were added up to a given volume. The total volume of beads and water was then read, from this data the voidage factor was easily calculated. In a similar fashion, the voidage factor (E_1) for the packed calmning section was obtained.

Minimum Fluidization Mass Velocity Calculation

The mass flow rate (G_{mf}) at minimum fluidization⁶ is given by:

$$G_{mf} = \frac{688 \ D_p^{1.82} \left(ff \left[fs - ff \right] \right)}{u^{.88}} \cdot 94$$

where

$$G_{mf} = \text{mass flow rate (lb/hr-ft}^{2})$$

$$D_{p} = \text{diameter of beads (in)}$$

$$f = \text{density of fluidizing medium (lb/ft}^{3})$$

$$s = \text{density of beads (lb/ft}^{3})$$

$$u = \text{viscosity of fluidizing medium (lb/hr-sec)}$$

$$G_{mf} = \frac{688 (.0185)^{1.8} [62.3 (155.7-62.3)]}{(1.3)^{.88}}$$

 $G_{mf} = 1,310 \ lb/hr-ft^2$

The four columns were operated at approximately three times (2.96)this value. The study was limited to low flows because beads were driven out of the smaller columns at flows higher than three times the minimum fluidization velocity.

			L		
	Inside Diameter				
Columns	In	3.75"	5.75"	7.75"	9.75 ⁿ
V	ft ³	.0404	.1097	.2300	.4235
٧٦	ft ³	.0155	.0366	.0664	.1050
V2	ft3	.0249	.0731	.1636	.3189
q	ft ³ /min	.09	.20	.36	.57
<u> </u>	min	.45	.54	.64	.75
Tl	min	.17	.18	.19	.19
T ₂	min	.28	.36	.45	.56
Height of Static Bed	in	4 ¹¹	6"	81	10"
Height of Fluidized Bed (Section 2)	in	6"	8.25"	10.5"	11"
Height of Packed Bed (Section 1)	in	3.75"	3.75"	3.75"	3.75"

	PR/	ROGRAM STATEMENT FOR DET	CERMINATION OF N	42
HASE	ANGLE_C	CALCULATIONS, ED M	FOBTRAN SOURCE	LIST
	ISN	SOURCE STATEMENT		•
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	11	DIMENSION TO%5C		·
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	6	XXI#1000 •		
	7	PRINT 102		
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-	12	W#15.		
	13	XI#I XI#XI/XXI	<u>.</u>	
	14	DD 15 IW#1,9		
	16	DO 10 IT#1,4		
-	17	G#%1.0/SQRT%1.08%h	W*T0%IT[/XI[**2[[**XI	an a
	20	WTX#W*TO%IT[/XI		
	21	<u>A# - X I + ATAN % WTX [</u>		
	22	A#A*57.29578	·	
	23	PRINT 101,XI,W,T02 IWT#IWT81	LIT[,G,A	
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00250	1025	125,217
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00226	2005	254
00160	205	
00202	255	252
00211	305	242
00215	355	247
00016	55	261,265,274
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00404	TO	21, 158, 178, 199
00400	W	136,156,176,197,225,227
00400	WTX	179,183
00377	XI	144,145,147,157,172,177,186,195
00403	XXT	122,146,238,262,264,273
00232	D.0000	140,143,159,160,161,163,167,168,170,171,173,184,185
00140	P.0026	211
00130	P.0042	240,241
00175	P.0045	246
00201	P.0050	251
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1.0000	1.8750	0.5400	0,702
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1.0000	0,9375	0.4500	0,921
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2.0000	1.8750	0,7500	0,669	
2.0000	0,9375	0.4500	0,957	
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3.0000	7.5000	0.6400	0.148
3.0000	7,5000	0.7500	0,10
3,0000	3,7500	0.4500	0,662
3.0000	3,7500	0.5400	0,56
3.0000	3,7500	0.6400	0.470
3.0000	3,7500	0.7500	0.386
3,0000	1.8750	0.4500	0.89
3.0000	1.8750	0.5400	0,85
3.0000	1.8750	0.6400	0,80
3.0000	1,8750	0.7500	0.742
3.0000	0,9375	0.4500	0.97
3,0000	0,9375	0,5400	0,95
3.0000	0,9375	0.6400	0,94
3,0000	0.9375	0.7500	0,92
3.0000	0.4688	0.4500	0,99
3.0000	0.4688	0.5400	0,98
3.0000	0.4688	0.6400	0,98
3.0000	0.4688	0.7500	0.97
3.0000	0.2344	0.4500	0.99
. 3.0000	0.2344	0,5400	0,99
3.0000	0,2344	0.6400	0.99
3.0000	0.2344	0,7500	0.99
3.0000	0.1172	0.4500	0.99
3.0000	0.1172	0.5400	0.99
3.0000	0,1172	0,6400	0.99
3.0000	0.1172	0.7500	0.99
3,0000	0.0586	0,4500	0,99
3.0000	0.0586	0.5400	0,99
3,0000	0.0586	0.6400	0,99
3.0000	0.0586	0.7500	0,99
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	a miningener (1,2,4,4,4), and an analysis of the manifest first of second second second second second second s	n an a sharaya ya waxa a saya kasara kasar kasara sharaya kasara kasara kasara kasara kasara kasara kasara kas N	n i sana ay ana ang ang ang ang ang ang ang ang ang
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NO, REACTORS	CYCLES/MIN.	TIME%MIN.C	GAIN
60.50 (m) 50 ML 60 50 ML 63 ML 63 ML 60	999 (99 KC) 496 FB 997 KC 179 (898 FC) 796	and	مود بنك وي الم
. 4.0000	15,0000	0,4500	0,067
4,0000	15,0000	0.5400	0,038
4.0000	15.0000	0.6400	0,021
4.0000	15,0000	0.7500	0.012
4.0000	7,5000	0.4500	0.341
4.0000	7,5000	0.5400	0,243
4,0000	7,5000	0.6400	0,168
4.0000	7.5000	0.7500	0.112
4.0000	3.7500	0.4500	0,720
4.0000	3,7500	0.5400	0,633
4.0000	3,7500	0.6400	0,540
4.0000	3,7500	0,7500	0,447
• 4.0000	1.8750	0,4500	0.916
4.0000	1.8750	0,5400	0,883
4.0000	1.8750		
		0.6400	0.841
4.0000	1,8750	0.7500	0.792
4.0000	0,9375	0.4500	. 0,978
4.0000	.0,9375	0.5400	0,968
4.0000	0,9375	0.6400	0,956
4.0000	0.9375	0,7500	0,941
4.0000	0,4688	0,4500	0,994
4.0000	0.4688	0.5400	0,992
4,0000	0.4688	0.6400	0,988
4.0000	0,4688	0.7500	0,984
- 4.0000	0,2344	0.4500	0,998
4.0000	0.2344	0,5400	0,998
4.0000	0,2344	0,6400	0,997
4.0000	0.2344	0,7500	0,996
4.0000	0.1172	0,4500	0,999
4.0000	0,1172	0.5400	0,999
4.0000	0,1172	0,6400	0,999
4.0000	0.1172	0,7500	0,999
4.0000	0,0586	0,4500	0,999
4,0000	0.0586	0.5400	0.999
4.0000	0,0586	0.6400	0,999
4.0000	0.0586	0,7500	0,999
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n an fair a bhaing ann an saith Mar Barla a saith an ann dhullachtair ann an ann an ann an ann an ann an ann an	· · ·		a (*) přestava a dre a ale v drava, stanov v proslavní ka (*) v stanov P pr
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1911 - 1912 - 1919 - 1919 - 1919 - 1919 - 1919	NOREACTORS	CYCLES/MIN.	TIME%MIN.C	GAIN
	5.0000	15,0000	0,4500	0,074
	- 5.0000	15.0000	0,5400	0,040
	5.0000	15,0000	0.6400	0,021
	5.0000	15,0000	0,7500	0,011
	5,0000	7,5000	0,4500	0,391
	5.0000	7.5000	0,5400	0.283
	5.0000	7,5000	0,6400	0,195
	5.0000	7,5000	0.7500	0,129
	and the second second of the second s	3,7500		
	5.0000	•	0,4500	0.763
	5.0000	3,7500	0,5400	0.684
	5.0000	3,7500	0,6400	0,595
	5.0000	3,7500	0.7500	0,503
	5.0000	1.8750	0.4500	0,932
	5.0000.	1,8750	0,5400	0.904
	5.0000	1.8750	0.6400	0.869
	5.0000	1,8750	0,7500	0,826
	5.0000	0.9375	0,4500	0,982
	5,0000	0,9375	0,5400	0,974
	5,0000	0.9375	0.6400	0,964
	5.0000	0.9375	0.7500	0,952
	5.0000	0.4688	0.4500	0,995
	5.0000	0.4688	0.5400	0,993
	5.0000	0.4688	0,6400	0,991
	5,0000	0,4688	0,7500	0,987
	5.0000	0:2344	0,4500	0,998
	5.0000	0.2344	0,5400	0,998
	5,0000	0.2344	0.6400	0,997
	5.0000	0.2344	0,7500	0,996
	5,0000	0,1172	0.4500	0.999
	5.0000 .	0,1172	0,5400	0,999
	5,0000	0,1172	0.6400	0,999
	5.0000	0.1172	0.7500	0.999
	5.0000	0.0586	0,4500	0,999
	5.0000	0.0586	0.5400	0,999
	5.0000	0,0586	0.6400 -	0,999
	5.0000	0,0586	0.7500	0,999
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		a Malina Manana Manana ang kang kang kang kang kang kang		
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NO, REACTORS	CYCLES/MIN.	TIME %MIN. [GAIN
the list has no by the first the day of the set	907 1909 FAB 000 990 FC FAB 900 990 990		
6.0000	15,0000	0,4500	0.0860
- 6.0000	15.0000	0,5400	0,0445
6.0000	15,0000	0,6400	0,0222
6.0000	15,0000	0,7500	0,0109
6.0000	7,5000	0,4500	0,4384
6.0000	7,5000	0,5400	0,3242
6.0000	7,5000	0,6400	0,2267
6,0000	7,5000	0,7500	0,1508
6.0000	3,7500	0.4500	0,7958
6.0000	3,7500	0,5400	0,723
6.0000	3,7500	0,6400	0,6407
6.0000	3,7500	0,7500	0,5511
6.0000	1,8750	0,4500	0,9429
6,0000	1,8750	0,5400	
6.0000	1,8750	0,6400	0,9192
6.0000	1,8750	0,7500	
6.0000	0,9375	0,4500	0,8518
6.0000	0.9375	0,5400	0,9853
6.0000	0,9375	0,6400	0.9789
6.0000	0,9375	0,7500	0,9706
6.0000	0,4688	0,4500	0,9599
6.0000	0,4688	0,5400	0.9963
6.0000	0,4088		0,9947
6.0000	0,4088	0,6400	0.9925
6.0000	0.2344	0,7500	0,9898
6.0000	0 * 2344	0.4500	0,9991
6.0000	0.2344	0.5400	0,9987
6.0000	0.2344	0,6400 0,7500	0.9981 0.9974
6.0000	0,1172		
6,0000	0,1172	0,4500 0,5400	0,9998 0,9997
6,0000	0,1172	0,6400	0,9995
6.0000	0,1172	0,7500	0.9994
6.0000	0.0586	0,4500	0.9999
6.0000	0.0586	0,5400	
6.0000	0.0586		0,9999
6.0000	0.0586	0.6400	0,9999
	0:0200		0,9990
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			52	
NO, REACTORS	CYCLES/MIN.	TIME%MIN.C	GAIN	
925 936 146 947 947 947 947 947 947 948 948 948 948	40 50 50 50 50 50 50 50 50 50 50 50 50 50	· (19) (12) (12) (12) (12) (12) (12) (12) (12	1, yan Can ban Ann	
7.0000	15,0000	0.4500	0,100	
7.0000	15,0000	0.5400	0,051	
7.0000	15,0000	0.6400	0,024	
7.0000	15.0000	0.7500	0.011	
7.0000	7.5000	0.4500	0.481	
7.0000	7.5000	0.5400	0.364	
7.0000	7.5000	0.6400	0,259	
7.0000	7.5000	0.7500	0.174	
7.0000	3,7500	0,4500	0,820	
7.0000	3,7500	0.5400	0.754	
7.0000	3,7500	0.6400	0.677	
7.0000	3.7500	0.7500	0,592	
7.0000	1,8750	0,4500	0.950	
7.0000	1,8750	0.5400	0,930	
7.0000	1,8750	0.6400	0,903	
7.0000	1.8750	0.7500	0,870	
7.0000	0,9375	0.4500	0,987	
7.0000	0,9375	0.5400	0,981	
7.0000	0,9375	0,6400	0.974	
7.0000	0,9375	0.7500	0.965	
7.0000	0.4688	0.4500	0,996	
7.0000	0,4688	0.5400	0,995	
7.0000	0,4688	0,6400	0,993	
7.0000	0,4688	0,7500	0,991	
7.0000	0,2344	0,4500	0,999	
- 7.0000	0.2344	0.5400	0,998	
7.0000	0.2344.	0.6400	0,998	
7.0000	0.2344	0.7500	0,997	
7.0000	0,1172	0.4500	0,999	
7.0000	0,1172	0,5400	0,999	
7.0000	0,1172	0.6490	0,999	
7.0000	0.1172	0,7500	0,999	
7,0000	0:0586	0.4500	1,000	
7.0000	0.0586	0.5400	0.999	
7.0000	0,0586	0.6400	0,999	
7.0000	0,0586	0.7500	0,999	
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			د. محمد المحمد العربي المحمد ا	
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NO. REACTORS 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000	CYCLES/MIN. 15.0000 15.0000 15.0000 7.5000 7.5000 7.5000 7.5000 3.7500 3.7500 3.7500 3.7500 1.8750 1.8750 1.8750	TIME%MIN.C 0.4500 0.5400 0.6400 0.7500 0.4500 0.5400 0.6400 0.7500 0.4500 0.6400 0.7500 0.4500 0.6400	GAIN 0,116 0,059 0,028 0,012 0,519 0,401 0,292 0,200 0,840 0,780
8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000	15.0000 15.0000 7.5000 7.5000 7.5000 7.5000 3.7500 3.7500 3.7500 3.7500 1.8750 1.8750	0.5400` 0.6400 0.7500 0.4500 0.5400 0.6400 0.7500 0.4500 0.4500 0.5400	0,059 0.028 0.012 0.519 0.401 0,292 0.200 0.840 0.780
8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000	15.0000 15.0000 7.5000 7.5000 7.5000 7.5000 3.7500 3.7500 3.7500 3.7500 1.8750 1.8750	0.5400` 0.6400 0.7500 0.4500 0.5400 0.6400 0.7500 0.4500 0.4500 0.5400	0,059 0.028 0.012 0.519 0.401 0,292 0.200 0.840 0.780
8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000	15,0000 15,0000 7,5000 7,5000 7,5000 7,5000 3,7500 3,7500 3,7500 3,7500 3,7500 1,8750 1,8750	0.6400 0.7500 0.4500 0.5400 0.6400 0.7500 0.4500 0.5400	0.028 0.012 0.519 0.401 0.292 0.200 0.840 0.780
8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000	15,0000 7,5000 7,5000 7,5000 7,5000 3,7500 3,7500 3,7500 3,7500 1,8750 1,8750	0.7500 0.4500 0.5400 0.6400 0.7500 0.4500 0.5400	0.012 0.519 0.401 0.292 0.200 0.840 0.780
8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000	7,5000 7,5000 7,5000 7,5000 3,7500 3,7500 3,7500 3,7500 3,7500 1,8750 1,8750	0.4500 0.5400 0.6400 0.7500 0.4500 0.5400	0.519 0.401 0.292 0.200 0.840 0.840
8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000 8,0000	7,5000 7,5000 7,5000 3,7500 3,7500 3,7500 3,7500 3,7500 1,8750 1,8750	0.5400 0.6400 0.7500 0.4500 0.5400	0,401 0,292 0,200 0,840 0,780
8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000	7,5000 7,5000 3,7500 3,7500 3,7500 3,7500 3,7500 1,8750 1,8750	0.6400 0.7500 0.4500 0.5400	0,292 0,200 0,840 0,780
8.0000 8.0000 8.0000 8.0000 8.0000 8.0000 8.0000	7,5000 3,7500 3,7500 3,7500 3,7500 1,8750 1,8750 1,8750	0.7500 0.4500 0.5400	0,200 0,840 0,780
8.0000 8.0000 8.0000 8.0000 8.0000 8.0000	3,7500 3,7500 3,7500 3,7500 1,8750 1,8750 1,8750	0.4500 0.5400	0.840 0.780
8,0000 8,0000 8,0000 8,0000	3,7500 3,7500 3,7500 1,8750 1,8750 1,8750	0,5400	0.780
8.0000 8.0000 8.0000	3,7500 3,7500 1,8750 1,8750 1,8750		
<u> </u>	3.7500 1.8750 1.8750	0,0100	0.708
8.0000	1,8750 1,8750	0,7500	0,627
	1.8750	0,4500	0,956
		0,5400	0.938
8.0000	1,8750	0,6400	0.914
8.0000	1.8750	0.7500	0.885
8.0000	0,9375	0.4500	0,989
8.0000	0,9375	0,5400	0.984
8.0000	0.9375	0.6400	0,977
8.0000	0,9375	0,7500	0,969
8.0000	0,4688	0,4500	0,997
8.0000	0.4688	0,5400	0,996
8.0000	0,4688	0,6400	0.994
8.0000	0.4688	0.7500	0,992
. 8.0000	0.2344	0,4500	0,999
8.0000	0.2344	0,5400	0,999
8,0000	0.2344	0.6400	0,998
8.0000	0.2344	0.7500	0,998
8.0000	0,1172	0,4500	0,999
8.0000	0,1172	0,5400	0,999
8.0000	0.1172	0,6400	0.999
8.0000	0.1172	0,7500	0,999
8.0000	0+0586	0,4500	1.000
8.0000	0,0586	0.5400	0,999
8.0000	0,0586	0.6400	0,999
8.0000	0.0586	0,7500	0,999
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ND, REACTORS	CYCLES/MIN.	TIME%MIN, [GAIN
-000 cậm Cân sự của qua của đặc lận _{biế} t đặc đặc 100			ago 63 ago 300
9.0000	15,0000	0,4500	0,1342
9,0000	15.0000	0,5400	0.069
9,0000	15,0000	0.6400	0.0327
9.0000	15,0000	0.7500	0,0145
9.0000	7,5000	0,4500	0,5532
9.0000	7,5000	0.5400	0,436
9.0000	7.5000	0.6400	0.324
9.0000	7.5000	0.7500	0,226
9,0000	3,7500	0.4500	0.856
9.0000	3.7500	0.5400	0,800
9.0000	3.7500	0.6400	0,734
9.0000	3,7500	0,7500	0,657
9.0000	1,8750	0.4500	0.961
9.0000	1.8750	0,5400	0,945
9.0000	1,8750	0,6400	0,923
9.0000	1.8750	0.7500	0,897
9.0000	0,9375	0,4500	0.990
9.0000	0,9375	0,5400	0,985
9.0000	0,9375	0,6400	0,980
9.0000	0.9375	0,7500	
9.0000	0,4688	0,4500	0,973 0,997 0,996
9.0000	0.4688	0,5400	
9.0000	0,4688	Annual management of a second seco	0.995
9.0000	0,4688	0.6400 0.7500	0,993
9.0000	0.2344	0,4500	
9.0000	0.2344	0,5400	0.999 0.999
9.0000	0,2344	0,6400	0,998
9.0000	0,2344	0,7500	0.998
9.0000	0,1172	A REAL PROPERTY OF A REAL PROPERTY AND A REAL PROPERTY OF A REAL PROPERTY AND A	and a second
9.0000		0.4500	0.999
	0,1172	0.5400	0.999
9.0000	0,1172	0,6400	0,999
9.0000	0,1172	0,7500	0,999
9.0000	0,0586	0.4500	1,000
. 9.0000	0.0586	0,5400	0,999
°.0000	0+0586	0.6400	0,999
9.0000	0.0586	0.7500	0.999
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	na mana ang kanana mana na dia pana na manana y sa na pangkana na kanang na sanana mananana di kanandinan na na A	а толарын жан таритту ан саларында у жанар таруала картар улар и кардарынарын тарар жан антарардан андарын аула а	namen van de senere an en
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	and a second second 		999.000 (1999) - (1979) - (1979) - (1979) - (1979) - (1979) - (1979) - (1979) - (1979) - (1979) - (1979) - (1979)

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NO, REACTORS	CYCLES/MIN,	TIME%MIN,[GAIN
10,0000	15.0000	0,4500	0,1530
10.0000	15,0000	0,5400	0.080
10.0000	15,0000	0,6400	0.0382
10,0000	15.0000	0.7500	0.0168
10.0000	7,5000	0.4500	0,583
10.0000	7,5000	0.5400	0,467
10.0000	7.5000	0.6400	0.3540
10.0000	7,5000	0,7500	0.253
10.0000	3,7500	0.4500	0,869
10.0000	3,7500	0,5400	0.818
10.0000	3.7500	0.6400	0,755
10.0000	3.7500	0,7500	0,683
10.0000	1.8750	0.4500	0,9652
10.0000	1.8750	0,5400	0,950
10.0000	1.8750	0.6400	0,931
10.0000	1.8750	0.7500	0,906
10.0000	0,9375	0.4500	0.991
10.0000	0,9375	0,5400	0,987
10.0000	0.9375	0.6400	0,9822
10.0000	0.4688	0.4500	0.9978
10.0000	0.4688	0,5400	0.9968
10.0000	0,4688	0.6400	0,995
10.0000	0.4688	0,7500	0.9938
10.0000	0,2344	0,4500	0.9994
10.0000	0.2344	0.5400	0,9992
10.0000	0.2344	0.6400	0,9989
10.0000	0.2344	0.7500	0,9985
10.0000	0,1172	0,4500	0,9999
10.0000 .	0.1172	0,5400	0,9998
10.0000	0.1172	0,6400	0,9997
10.0000	0.1172	0,7500	0,9990
10.0000	0.0586	0.4500	1,0000
10,0000	0,0586	0,5400	0,9999
10.0000	0,0586	0.6400	0,9999
10.0000	0,0586	0,7500	0,9999
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	PROGRAM STATEMENT FOR DETERMINATION OF N2	56
PHASE ANGLE	CALCULATIONS, ED M FORTRAN SOURCE LIS	s <u>T</u>
· ~ · · · · · · · · · · · · · · · · · ·	\$IBFTC DELTA NOLIST, NODECK, REF	
1	REAL N, N1, N2, NN	
2	DIMENSION N%10[,T0%10[,T1%10[,T2%10[, DATA N/2+,2,3+,3+, 6+0,/	
4	DATA TO/0.45,0,54,0.64,0.75,6+0./	n na na manana ang kananana na na manana na n
5	DATA T1/0.17,0.18,0.19,0.19,6*0./ W#7.50	Lan hanna har year an
' 7 10	DO 30 IN#1.4	
- 10 - 11		
12 13	PRINT 100	naka (in a su in an ann an ann an an an an an ann an an
14	PRINT 102	n an bara a sasaran magana magana a sa sanan ang na mananan manan manana mandala a sasara sa sasara sa
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17	DO 10 IM#1.M	an maana sa sa waxaa ka yaya ka ya ka ya kababa ya kababa ka kababa ka kababa ka ka kababa kababa kababa ka kab
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35 ~ 36		1X,5HOMEGA,/C
37	101 FORMAT%5%2X,F13.2[,/[
- 41	103 FORMAT%2%2X,F13,2[,3%F12,3,3X[,E15,8[SX ING ISX SHULLIAS
42	END	
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00300	1025	193
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00453	IT	164,165
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00405	TO	22,109,100,255
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TABLE 6

COMPUTER DATA FOR DETERMINATION OF N2 (NUMBER OF PERFECT MIXERS IN FLUIDIZED SECTION)

Nl	N2	AR1	AR ₂	AR	Delta (AR-AR _l ·AR ₂)
.2	1.8	.819	.499	.372	.0362
.4	1.6	.751	.511	.372	.0119
.6	1.4	.710	.527	.372	.002 0
.8	1.2	.683	.545	.372	.0001
1.0	<u> </u>	.663	.568	.372	.0044
1.2	0.8	.648	.597	.372	.0148
1.4	0.6	.636	.637	.372	.0326
1.6	0.4	.626	.693	.372	.0616
1.8	0.2	.618	.783	.372	.1116

3.75 INCH COLUMN N=2

TA	BL	E	7

COMPUTER DATA FOR DETERMINATION OF N2 (NUMBER OF PERFECT MIXERS IN FLUIDIZED SECTION)

	·····	·			·
Nl	N ₂	AR1	AR ₂	AR	Delta (AR-AR ₁ •AR ₂)
0.2	1.8	.815	.438	.331	.0266
0.4	1.6	•744	.453	.331	.0069
0.6	1.4	.702	.471	.331	.0003
0.8	1.2	.673	.493	.331	.0014
1.0	. 1.0	.652	.520	.331	.0085
1.2	0.8	.636	.554	.331	.0219
1.4	0.6	.623	.600	.331	.0432
1.6	0.4	.613	.664	.331	.0764
1.8	0.2	.604	.765	.331	.1319

5.75 INCH COLUMN N=2

PABLE 8

COMPUTER DATA FOR DETERMINATION OF N2 (NUMBER OF FERFECT MIXERS IN FLUIDIZED SECTION)

		I ● I → 1	N=3	<u>MIN</u>	
Nl	N ₂	ARl	^{AR} 2	AR	Delta (AR-AR ₁ •AR ₂)
0.3	2.7	<u>.</u> 769	.335	.239	.0188
0.6	2.4	.694	.349	.239	.0035
0.9	2.1	.652	.366	.239	.000003
1.2	1.8	.625	.387	.239	.0031
1.5	1.5	.606	.413	.239	.0118
1.8	1.2	.592	.448	.239	.0265
2.1	0.9	· .581	.496	.239	.0494
2.4	0.6	.572	.567	,239	.0856
2.7	0.3	.564	.687	.239	.1489

7.75 INCH COLUMN N=3

TABLE 9

COMPUTER DATA FOR DETERMINATION OF N2 (NUMBER OF PERFECT MIXERS IN FLUIDIZED SECTION)

Nl	N2	AR1	AR ₂	AR	Delta (AR-AR ₁ ·AR ₂)
0.3	2.7	.769	.282	.205	.0116
0.6	2.4	.694	.297	.205	.0010
0.9	2.1	.652	.316	.205	.0007
1.2	1.8	.625	.338	.205	.0064
1.5	<u> </u>	.606	.367	.205	.0175
1.8	1.2	.592	.406	.205	.0348
2.1	0.9	.581	.458	.205	.0608
2.4	0.6	.572	.536	.205	.1011
2.7	0.3	.564	.666	.205	.170 7

9.75 INCH COLUMN N=3