STUDY OF PACKING METHODS AND THEIR EFFECT UPON LIQUID DISTRIBUTION IN DUMPED PACKED TOWERS

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THESIS

This is to certify that the

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ABSTRACT

STUDY OF PACKING METHODS AND THEIR EFFECT UPON LIQUID DISTRIBUTION IN DUMPED PACKED TOWERS

by John F. Knoop

The liquid distribution using water with two packed towers having inside diameters of 2.5 and 5.0 inches were measured for glass spheres and glass Raschig rings dumped by various methods. No gas flow was used and the liquid distribution was found by dividing the liquid flow into four parts, each from twenty-five per cent of the cross sectional area.

In most cases, a multipoint feed distributor was employed. It was found that a packed depth equivalent to four tower diameters with this distributor was sufficient to give results that were reproducible for greater packed depths.

For glass spheres, no relationship could be found to indicate that the liquid distribution was altered by the packing method. Large "wall effects" (liquid concentration near the wall) were noted for column to packing ratios of 5 to 1. The effect was suppressed but not eliminated by increasing the ratio to 10 to 1.

For glass Raschig rings, one condition was found where it appeared that the liquid distribution was affected to a small extent by the packing method employed.

In that case, random dumping methods resulted in liquid flow to the center of a column. When the column was packed from both the center to the wall and wall to center, the distribution became more uniform. This was for a column to packing ratio of 20 to 1. For a ratio of 10 to 1, large "wall effects" again resulted.

A comparison was also made between gas distribution data reported in the literature and the liquid distributions which were found experimentally. From this data, it appeared that the flow rates were proportional in the center of the tower and inversely proportional near the wall.

For all the packings and towers, the liquid distribution varied with the flow rate. However, no trend was noted.

Approved by Randall W Ludt

STUDY OF PACKING METHODS AND THEIR EFFECT UPON LIQUID DISTRIBUTION IN DUMPED PACKED TOWERS

By

John F. Knoop

A THESIS

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I would like to thank Dr. Randall Ludt for his many suggestions and dedicated help without which I would not have been able to complete this thesis. Similarly, I would like to extend thanks to Mr. William Clippinger who so capably and expertly aided in the construction of the experimental towers.

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Introduction

Packed towers have been employed throughout the chemical process industry for a long period of time in a great many operations as a means of contacting liquids and vapors, as a medium for chemical reactions, as a facility for liquid-liquid extraction, and as a mode of mixing. However, the scale-up and sizing of these operations is carried out with little confidence. Even for columns of the same dimension containing identical packing there is a lack of agreement. A possible explanation might be found if the packing arrangement were studied because of the effect that the packing can have on the liquid and gas flow patterns within a tower.

Therefore, since packing arrangement could be a primary factor in determining the tower's operating efficiency, it was proposed to determine if the packing arrangement could be varied by changing the method by which a column was packed. The liquid distribution from four equal and concentric area sections at the bottom of a tower was used as a parameter to indicate any change in packing arrangement.

Historical Background

The design of packed towers is still largely a matter of experience partly because proven empirical relationships have not been developed through experimental work. Leva[1] has pointed out that a large amount of the data that has been collected is contradictory and thus might add to the difficulty of defining variables that are important to the design of packed towers.

Of the design tools that are available, many have been based upon theoretical derivations which may very well be valid if controlling assumptions are correct. In most cases, it is assumed that both liquid and gas flows are uniform over the column's cross sectional area. Thus, since the flows are not uniform, and this has been proven,[4,5] the relative gas-liquid rates (reflux for distillation) will vary considerably within the column and will be reflected in the operating efficiency of a column.

Specifically, Norman[2] found a large difference in the operating efficiency of two packed columns under identical conditions. He concluded that maldistribution (non-uniformity) of liquid was the cause of the difference. Other experimenters such as Morales, Spinn, and Smith[3] have studied the distribution of gas in a 2 inch diameter tower packed with Raschig rings. With no liquid flow, the gas velocity too varied considerably over the cross sectional area with a low velocity occurring in the center and at the walls. They also found that the gas distribution varied with depth of packing.

Baker, Chilton, and Vernon[4] studied the liquid distribution of various packings at various depths. They found that the liquid concentrated at the walls of small towers and not with large towers. This led them to conclude that the liquid would concentrate on the wall unless the column diameter was greater than 8 times the packing diameter. They also found that the liquid distribution remained unchanged once it had traversed a depth equivalent to 10 column diameters for a single center point feed. These men also concluded that the vapor velocity had little effect upon liquid distribution except near flooding conditions and that moderate changes in liquid rate had little effect upon liquid distribution.

Another experimenter, J. W. Mullins[5], worked on the same problem of liquid distribution and substantiated the fact that the liquid tends to concentrate at the wall unless the proper sized packing is used. However, he concluded that the "wall effect" could be eliminated if the column diameter were 12 or more times the packing diameter.

Equipment

The experimental work was carried out in two packed columns. One of the columns as shown in Figure 1 was 48 inches long and had an inside diameter of 2.5 inches. The tower was cut from a piece of transparent plastic pipe. The pipe was held firmly between the bottom packing support plate and an upper plate with four steel rods. The rods were threaded and equipped with wing nuts for easy dismantling. The packing support as shown in Figure 2 was constructed from brass bar stock and tubing in such a manner that the cross sectional area between each of the four concentric cylinders would trap the liquid flow from 25 per cent of the column cross sectional area. The drains from each of the column cross sections were connected to tubing so that the flow from each could be collected in 4000 ml flasks.

A rotameter on the water feed line was used as a flow indicator. A stop watch was used to measure the length of time for each run.

The second column was identical to the first except that the inside diameter was 5.0 inches. The column was supported with a similar plate and all auxiliary equipment was the same.

The columns were packed with 1/4 inch diameter glass spheres, 1/2 inch glass spheres, 1/4 inch glass Raschig rings, and 1/2 inch glass Raschig rings.

Figure 1. Experimental Packed Column.

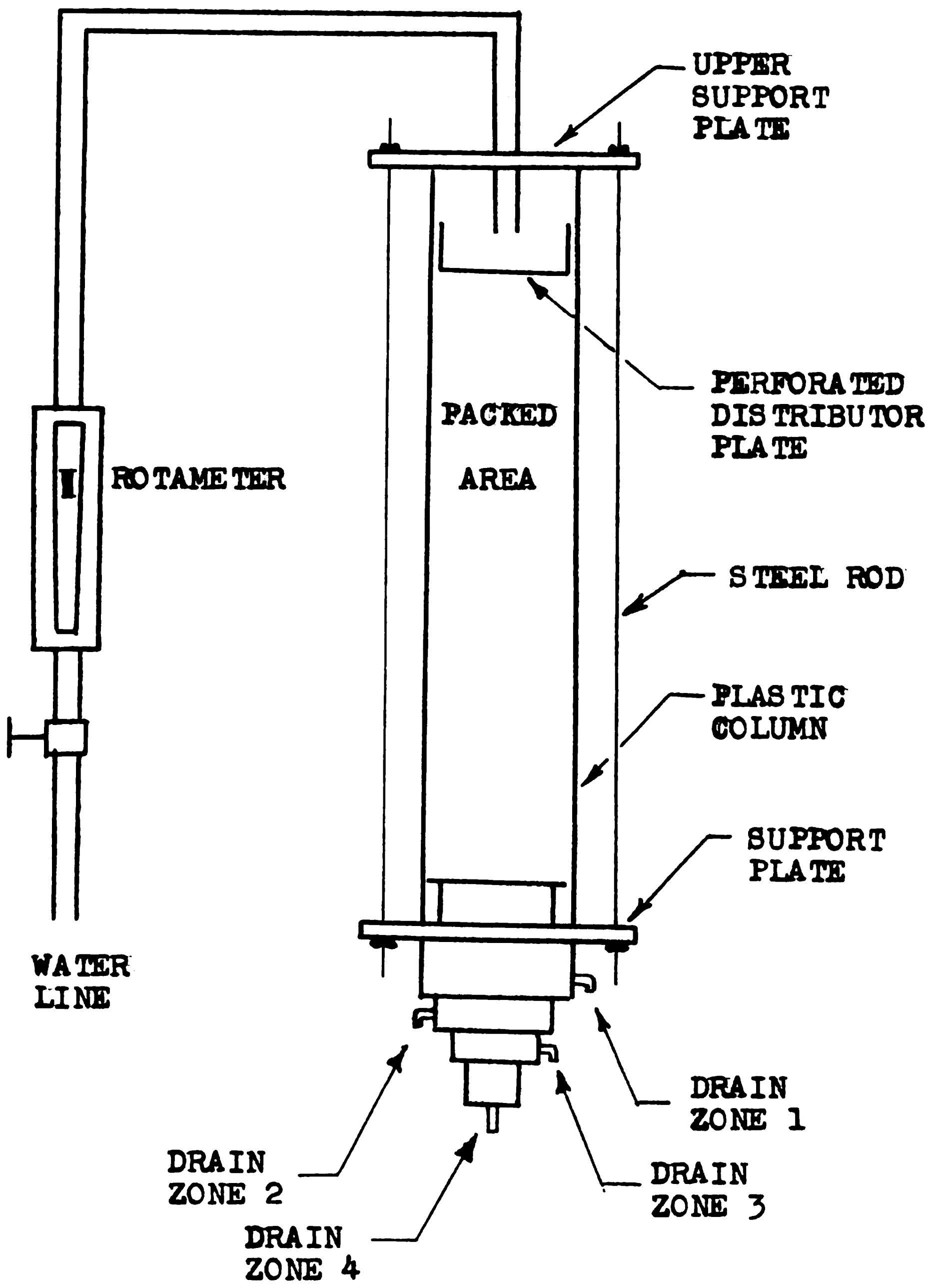
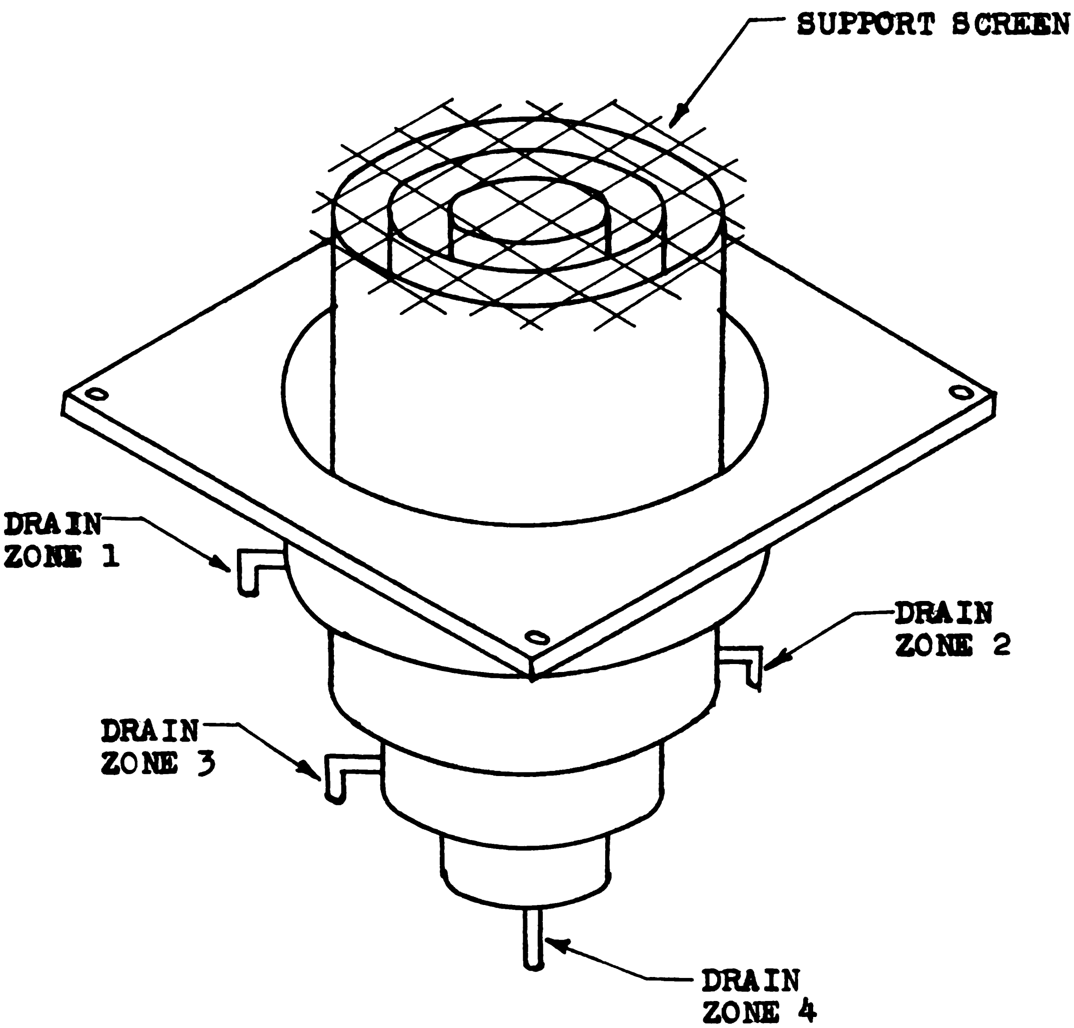


Figure 2. Packing Support and Liquid Separator.



Procedure

a) Operating

Since it was desired to measure the effect of random packing methods on liquid flow patterns, it was necessary to pack each column several times. To start, the plastic column was fitted between the upper and lower brass support plates with rubber gaskets. The steel guide wires were put in place and tightened to hold the plates and column in place. Next, the column was clamped to a laboratory support rack and leveled. A one-quarter inch screen was placed over the packing support so that small packing would not wedge in the separator. The column was then packed by dumping the packing into the column using one of the methods listed on the following page. In most cases, the column was packed to a depth of 40 inches.

Next, a liquid distributor was placed on top of the packing and the liquid flow started. No gas flow was used. The liquid flow was increased until the packing became flooded. This rate was observed on the rotameter. The flow was reduced by approximately half and the column was allowed to attain a state of equilibrium. In the meantime, four 4000 ml flasks were placed in a rack so that they could be placed under the drains at the same time. A stop watch was started as the flasks in the rack were placed beneath the drains. After a large quantity of water had been collected, the rack and flasks were

removed as the watch was stopped. The run time was recorded along with the volume of water collected at each drain.

This procedure was followed for three different water flow rates on each packing. After obtaining this data, the column was dismantled and the packing removed. After reassembling the column, packing was again dumped into the tower by another method. This procedure was repeated for all of the packings.

The following methods were followed in packing the two columns:

(1) Dry random pack (DRP)

Packing was dumped into a dry column evenly over the cross sectional area.

(2) Packed from center (PCF)

Packing was dumped into the center of a dry column.

(3) Packed from wall (OSD)

Packing was dumped into annular area near the wall of a dry column.

(4) Wet random pack (RPW)

Packing was dumped into a water-filled column evenly over the cross-sectional area.

(5) Moving water pack (MCW)

Packing was dumped into water-filled tower with the water being moved down the column at a superficial velocity of 0.16 feet per second or

0.43 feet per second.

(6) Rotating water pack (ROD)

Packing was dumped into water-filled tower with water being rotated with a stirrer so that the packing was thrown to wall of column.

(7) Moving rotating water pack (RMW)

Packing was dumped into water-filled tower with water being rotated and being moved down at a velocity of 0.43 feet per second.

(8) Packed from wall in water (OSW)

Packing was dumped into annular space near the wall of a water-filled column.

(9) Packed with tube in center (PTC)

Packing was dumped into water-filled tower that had a 7/16 inch diameter tube in the center of the tower. Tube was removed after tower was packed.

(10) Packed with a tube being raised in center (RTC)

Packing was dumped into a water-filled tower that had a 7/16 inch diameter tube being raised in the center of column. Tube extended into packing 1/2 inch.

(11) Packed in tube (PIT)

Packing was placed in 1 inch diameter tube. Tube was placed in dry tower and slowly raised. Packing was replaced in tube as packing drained into the tower.

b) Correlation of Data

The experimental results were used to calculate the percentage of total liquid flow that was collected from each of the four equal and concentric areas of the column cross section. Graphically, these data were correlated to the over-all liquid mass flow rate which was expressed in pounds per hour per square foot of empty cross sectional area. In each case, the data were plotted as an accumulative percentage of the flow collected from successive annular zones, starting with the annular area adjacent to the wall and ending with the flow from the center section. For example, the percentage shown in Figure 4 for a mass flow rate of 15,000 pounds per hour per square foot indicate that the area near the wall (Zone 1) collected 34% of the flow; the area adjacent to Zone 1 (Zone 2) collected 58-34 or 24%; the next area (Zone 3) collected 77-58 or 19%; and the center area (Zone 4) collected 100-77 or 23%. Had the percentages all been 25, the flow distribution would have been perfectly uniform and the three points on the graph would have been at 25, 50, and 75 instead of 34, 58, and 77. Therefore, if as in the example the curves are displaced to the right, the flow is concentrated at the wall. Similarly, a shift to the left would indicate a concentration in the center.

Table 1. Tabulated Results from 2.5 Inch Diameter Column Packed with 0.5 Inch Glass Spheres to a Depth of 36 Inches.

Run No.	Method of Packing	Mass Flow Lbs./Hr.-Sq.Ft.	Percent of Flow Zone 1	Zone 2	Zone 3	Zone 4
1	1 DRP	42,500	52.0	18.4	16.0	13.6
2	1 DRP	42,200	49.5	20.9	15.6	14.0
3	1 DRP	42,200	48.8	21.7	15.3	14.2
4	1 DRP	41,900	50.6	20.4	15.0	14.0
5	1 DRP	54,100	37.9	23.4	23.5	15.2
6	1 DRP	56,800	42.2	20.5	22.8	14.6
7	1 DRP	57,000	41.7	22.3	21.5	14.5
8	1 DRP	81,000	35.1	21.6	24.4	18.9
9	1 DRP	81,900	35.3	21.9	25.8	17.0
10	2 DRP	41,000	51.7	22.5	11.9	13.9
11	2 DRP	42,000	51.1	23.2	11.9	13.8
12	2 DRP	56,400	42.2	22.8	19.1	13.9
13	2 DRP	56,200	43.4	23.8	19.2	13.6
14*	2 DRP	81,500	37.9	23.0	23.5	15.6
15*	2 DRP	41,600	52.0	24.0	10.0	14.0
16*	2 DRP	57,600	43.6	24.0	19.2	13.2
17	2 DRP	80,500	38.1	23.0	24.0	14.9
18	1 PCF	42,000	51.2	19.8	15.7	13.3
19	1 PCF	56,000	48.1	19.1	19.3	13.5
20	1 PCF	81,300	40.7	20.6	26.3	12.6
21	1 OSD	42,500	50.3	19.1	18.2	12.4
22	1 OSD	58,200	46.4	20.6	20.6	12.4
23	1 OSD	85,000	39.8	22.1	26.8	11.3

*These runs were with center point distribution, all others were multipoint.

Table 2. Tabulated Results from 2.5 Inch Diameter Column Packed with 0.25 Inch Glass Spheres to a Depth of 20 Inches.

Run No.	Method of Packing	Mass Flow Lbs./Hr.-Sq.Ft.	Percent of Flow Zone 1	Zone 2	Zone 3	Zone 4
24	3 DRP	52,000	27.4	27.1	30.6	14.9
25	4 DRP	49,800	27.1	27.0	22.1	23.8
26	4 DRP	32,300	34.1	28.2	25.6	12.1
27	4 DRP	41,500	34.6	25.1	19.3	21.0
28	4 DRP	55,900	33.0	19.7	26.9	20.4
29	5 DRP	46,300	20.8	34.2	21.0	24.0
30	5 DRP	31,200	33.6	28.8	20.9	15.7
31	5 DRP	38,400	29.8	25.2	23.7	21.3
32	5 DRP	47,100	34.2	22.4	22.2	21.2

Table 3. Tabulated Results from 2.5 Inch Diameter Column Packed with 0.25 Inch Glass Raschig Rings to a Depth of 42 Inches.

Run No.	Method of Packing	Mass Flow Lbs./Hr.-Sq.Ft.	Percent of Flow Zone 1	Zone 2	Zone 3	Zone 4
33	1 RPW	35,400	37.4	25.6	18.7	18.2
34	1 RPW	52,000	43.5	24.2	17.4	14.9
35	1 RPW	79,300	41.0	24.4	18.1	16.5
36	2 RPW	34,300	37.2	21.6	21.2	20.0
37	2 RPW	53,000	48.4	16.4	19.7	15.5
38	2 RPW	78,300	45.8	16.8	19.8	17.6
39	3 RPW	36,700	36.6	27.8	19.7	16.4
40	3 RPW	53,500	37.8	26.2	23.1	12.9
41	3 RPW	76,100	43.2	22.1	22.1	12.6
42	4 RPW	34,800	28.7	27.3	28.1	15.9
43	4 RPW	52,000	36.3	28.0	21.8	13.9
44	4 RPW	76,600	37.7	23.5	19.4	19.4
45	1 MCW	35,000	34.6	23.7	21.2	20.4
46	1 MCW	52,500	44.0	21.2	18.3	16.7
47	1 MCW	79,700	38.5	23.0	19.4	19.1
48	2 MCW	36,300	28.3	26.2	25.0	20.5
49	2 MCW	52,800	38.0	25.8	22.1	14.1
50	2 MCW	79,000	41.6	23.8	21.8	12.8
51	3 MCW	34,800	32.6	23.3	23.7	20.4
52	3 MCW	53,000	41.4	23.6	24.0	11.0
53	3 MCW	73,400	43.3	24.9	22.6	9.2
54	1 ROD	35,700	34.3	24.5	25.3	15.9
55	1 ROD	50,500	39.6	18.0	28.6	13.8
56	1 ROD	71,200	40.0	23.1	22.0	14.9
57	1 RMW	36,000	33.9	21.8	28.5	15.8
58	1 RMW	52,800	42.7	19.8	27.2	10.3
59	1 RMW	73,200	44.5	19.9	24.6	11.0
60	1 OSW	38,200	39.0	27.7	16.0	17.3
61	1 OSW	54,000	40.2	27.3	17.7	14.8
62	1 OSW	76,900	40.4	23.0	19.6	17.0
63	1 PTC	39,800	42.0	25.7	17.7	14.0
64	1 PTC	53,200	42.1	25.3	20.1	12.5
65	1 PTC	76,600	40.2	22.8	22.6	14.4
66	1 RTC	37,500	36.0	25.4	22.7	15.9
67	1 RTC	52,700	37.5	26.6	19.7	16.2
68	1 RTC	74,600	35.9	24.5	22.0	16.6

Table 4. Tabulated Results from 5.0 Inch Diameter Column Packed with 0.5 Inch Glass Spheres by Method DRP.

Run No.	Depth of Packing	Mass Flow Lbs./Hr.-Sq.Ft.	Percent of Flow Zone 1	Zone 2	Zone 3	Zone 4
69	40"	25,900	23.7	26.0	21.8	28.5
70	40"	24,200	27.4	26.3	22.8	23.5
71	40"	33,400	20.8	23.7	25.7	29.8
72	20"	15,900	35.3	21.2	21.2	22.3
73	20"	24,900	25.7	27.0	23.1	24.2
74	20"	34,100	22.4	21.6	24.9	31.2
75	30"	14,500	28.4	19.8	21.4	20.4
76	30"	24,200	25.7	26.3	24.3	23.7
77	30"	33,900	21.5	22.7	24.0	31.8
78	40"	14,900	37.4	18.4	27.0	23.5
79	40"	26,100	25.7	25.7	20.7	27.9
80	40"	33,100	23.5	22.3	22.3	31.9
By Method PCF						
81	40"	15,700	38.8	24.4	13.3	23.5
82	40"	24,900	26.5	26.1	23.2	24.2
83	40"	33,600	22.8	24.7	24.7	27.8
By Method OSW						
84	40"	15,700	37.0	20.3	20.3	22.4
85	40"	25,600	26.4	25.2	26.4	23.0
86	40"	32,400	23.8	22.5	23.4	30.3

Table 5. Tabulated Results from 5.0 Inch Diameter Column Packed with 0.25 Inch Glass Raschig Rings to a Depth of 40 Inches.

Run No.	Method of Packing	Mass Flow Lbs./Hr.-Sq.Ft.	Percent of Flow Zone 1	Zone 2	Zone 3	Zone 4
87	1 RPW	14,100	20.8	23.8	24.0	31.4
88	1 RPW	23,400	23.2	23.2	24.7	28.9
89	1 RPW	34,000	21.5	21.5	22.5	34.5
90	2 RPW	15,150	19.5	22.0	22.4	36.1
91	2 RPW	23,600	22.8	22.5	23.7	31.0
92	2 RPW	30,900	23.1	22.7	24.0	30.2
93	3 RPW	14,900	18.5	24.4	24.4	32.7
94	3 RPW	25,000	22.4	24.8	23.6	28.7
95	3 RPW	31,800	21.9	23.1	23.1	31.9
96	1 MCW	14,200	21.2	26.1	22.1	29.6
97	1 MCW	25,800	24.8	23.4	24.8	27.0
98	1 MCW	28,500	24.4	21.4	21.2	33.0
99	1 ROD	13,900	27.8	25.8	19.8	26.6
100	1 ROD	20,300	24.4	26.2	24.7	24.7
101	1 ROD	33,800	25.9	24.2	23.1	26.8
102	2 ROD	15,100	22.2	29.9	16.9	31.0
103	2 ROD	21,600	22.5	26.0	24.4	27.1
104	2 ROD	32,400	24.4	29.4	23.8	28.0
105	1 RMW	16,800	21.8	33.0	19.8	25.4
106	1 RMW	24,800	26.1	26.7	22.5	24.7
107	1 RMW	33,100	24.1	24.9	24.2	26.7
108	2 RMW	19,400	25.4	39.0	20.8	23.4
109	2 RMW	25,300	21.9	23.0	21.9	33.2
110	2 RMW	30,000	24.0	24.8	21.0	30.2
111	1 PIT	17,500	22.6	30.4	19.4	27.6
112	1 PIT	23,600	23.5	23.8	26.3	26.3
113	1 PIT	28,500	23.7	24.5	23.7	28.1

Table 6. Tabulated Results from 5.0 Inch Diameter Column Packed with 0.5 Inch Glass Raschig Rings to a Depth of 40 Inches.

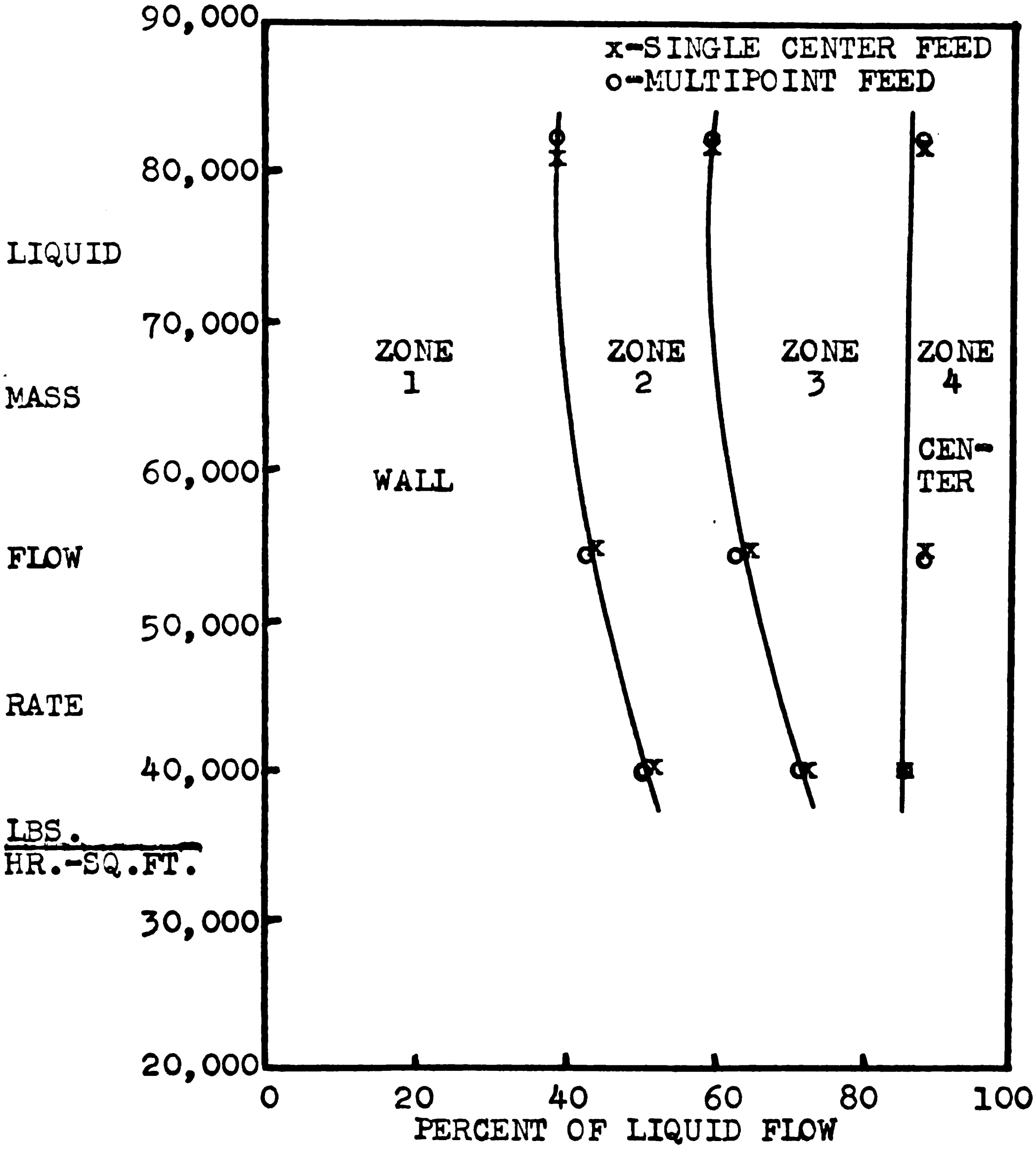
Run No.	Method of Packing	Mass Flow Lbs./Hr.-Sq.Ft.	Percent of Flow Zone 1	Zone 2	Zone 3	Zone 4
114	1 RPW	18,600	27.0	23.6	23.9	25.5
115	1 RPW	23,800	29.5	25.1	22.5	22.9
116	1 RPW	34,300	33.6	21.3	21.7	23.4
117	2 RPW	18,800	28.6	20.2	18.6	32.6
118	2 RPW	24,400	30.1	17.8	19.1	33.0
119	2 RPW	31,800	32.3	15.3	21.2	31.2

Discussion of Results

Primarily, the purpose of this study was to determine if the packing arrangement of dumped beds could be altered enough by employing various dumping methods to change the liquid distribution. Because there are several other variables which could affect the liquid distribution, it was desired to define these variables experimentally so that their effect could be minimized. Three variables which were considered to be important were feed distribution, bed depth, and liquid rate.

The first variable that was studied was liquid feed distribution. Baker, Chilton, and Vernon had presented conclusive evidence that the liquid distribution does not change once the liquid has traversed about 10 column diameters of depth when a single center point feed was employed. The 2.5 inch column was packed to a depth of 36 inches or 14 column diameters and, therefore, should have been in a range where the liquid distribution would be unaffected. Data was collected and correlated to flow rate for a center point feed and a multipoint feed. From the plot of this data in Figure 3, it can be seen that the liquid distribution was unaffected by the initial distribution at that depth. When the single center point feed was used, it was observed visually that the liquid had not spread to the wall until a depth of 15 inches was reached. With 21 inches of the wall wetted,

FIGURE 3. EFFECT OF INITIAL DISTRIBUTION ON FINAL LIQUID DISTRIBUTION. 2.5 INCH TOWER WITH 0.5 INCH SPHERES.

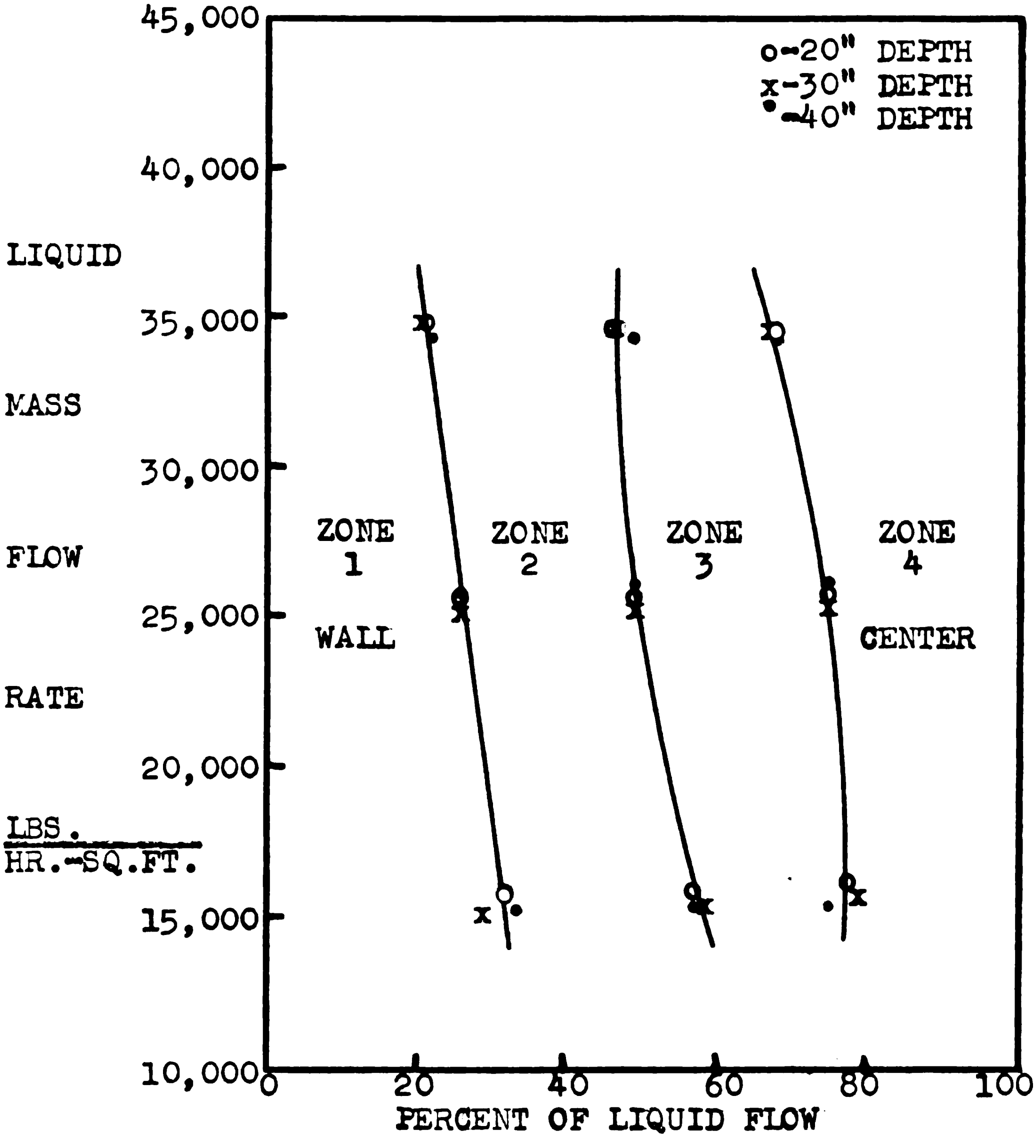


it would appear that a depth less than 9 column diameters would be required when a multipoint distributor was used.

To prove that this would be the case, data were obtained from the 5 inch column equipped with a multipoint distributor and packed to depths of 20, 30, and 40 inches with 0.5 inch glass spheres. This data is shown in Figure 4 and it can be seen that the distribution was almost identical for all three depths. Therefore, it was concluded that a packed depth equivalent to 4 column diameters for a column equipped with a multipoint liquid feed distributor would be more than sufficient to insure that the initial distribution was not affecting the final liquid distribution.

In all of the above cases, the liquid distribution was plotted against the liquid rate so that this affect could be shown. As can be seen in each case, the liquid distribution varied considerably with rate. It should also be noted that this rate is of such a high value that its significance is not fully understood. Theoretically, the flow should become more uniform as the rate increases and in most cases it was found that it does. However, on one or two packings this was not the case. Possibly, the liquid rates in these columns were not as close to a loading point as the rate might indicate.

FIGURE 4. EFFECT OF PACKING DEPTH ON LIQUID DISTRIBUTION. 5.0 INCH TOWER WITH 0.5 INCH SPHERES.



a) Spherical Packing

Having concluded that the use of a multipoint feed distribution above a packed bed of at least 20 inches would be sufficient, work was directed to determine the effect of packing methods on the liquid distribution. Both towers were packed with glass spheres. In the case of the 2.5 inch tower packed with 0.5 inch spheres, the column was packed seven times using three different methods. The first method which was a random dumping in a dry tower was repeated four times. The other two methods were similar, except in one case the column was packed by dumping in the center and the other by dumping near the wall. The liquid distribution was found for each dumping and is shown in Figure 5 as a plot of distribution versus mass flow rate. In no case could any variation in distribution be contributed to the method by which the column was packed.

The same 0.5 inch glass spheres were packed in the 5.0 inch tower using three methods. Again, the tower was packed by random dumping and dumping in the center of a dry tower. The third method to be employed was that of dumping near the wall of a water-filled column. The liquid distribution for these methods are shown in Figure 6. Again, no change in distribution was found.

The 2.5 inch tower was also packed with 0.25 inch glass spheres. In all cases, the column was packed by

FIGURE 5. LIQUID DISTRIBUTION FOR THREE DIFFERENT METHODS OF PACKING A 2.5 INCH TOWER WITH 0.5 INCH GLASS SPHERES.

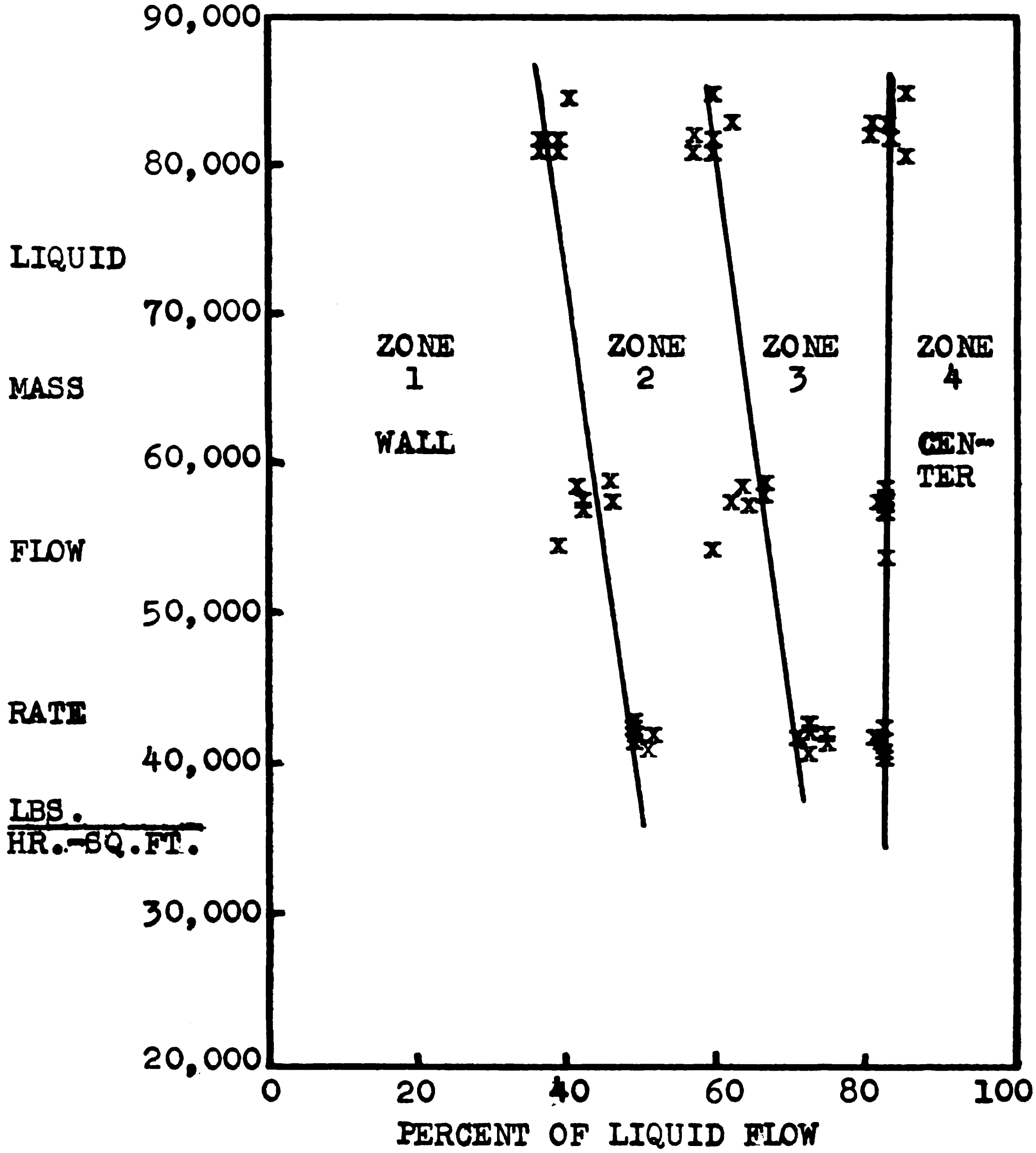
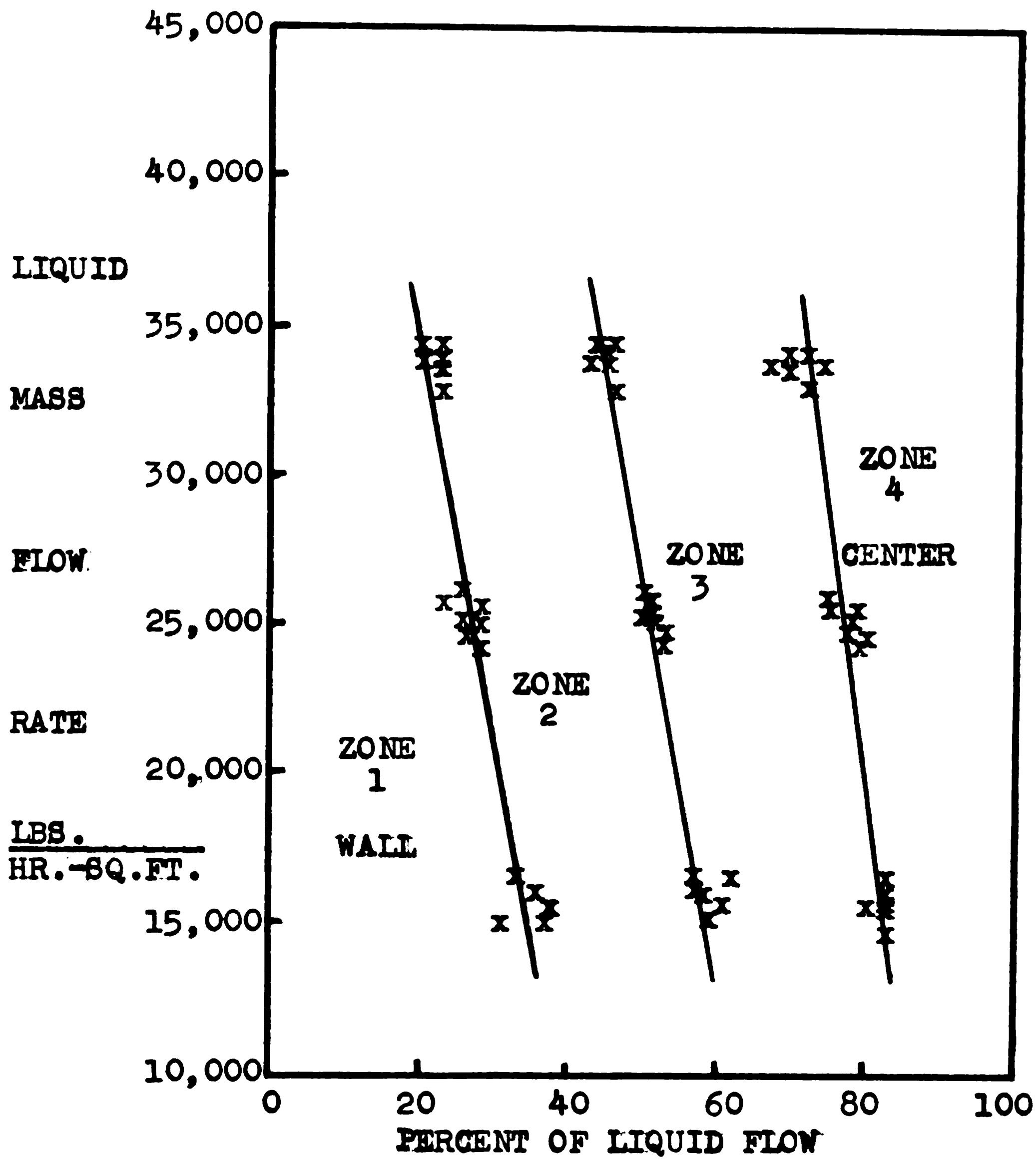


FIGURE 6. LIQUID DISTRIBUTION FOR THREE DIFFERENT METHODS OF PACKING A 5.0 INCH TOWER WITH 0.5 INCH GLASS SPHERES.



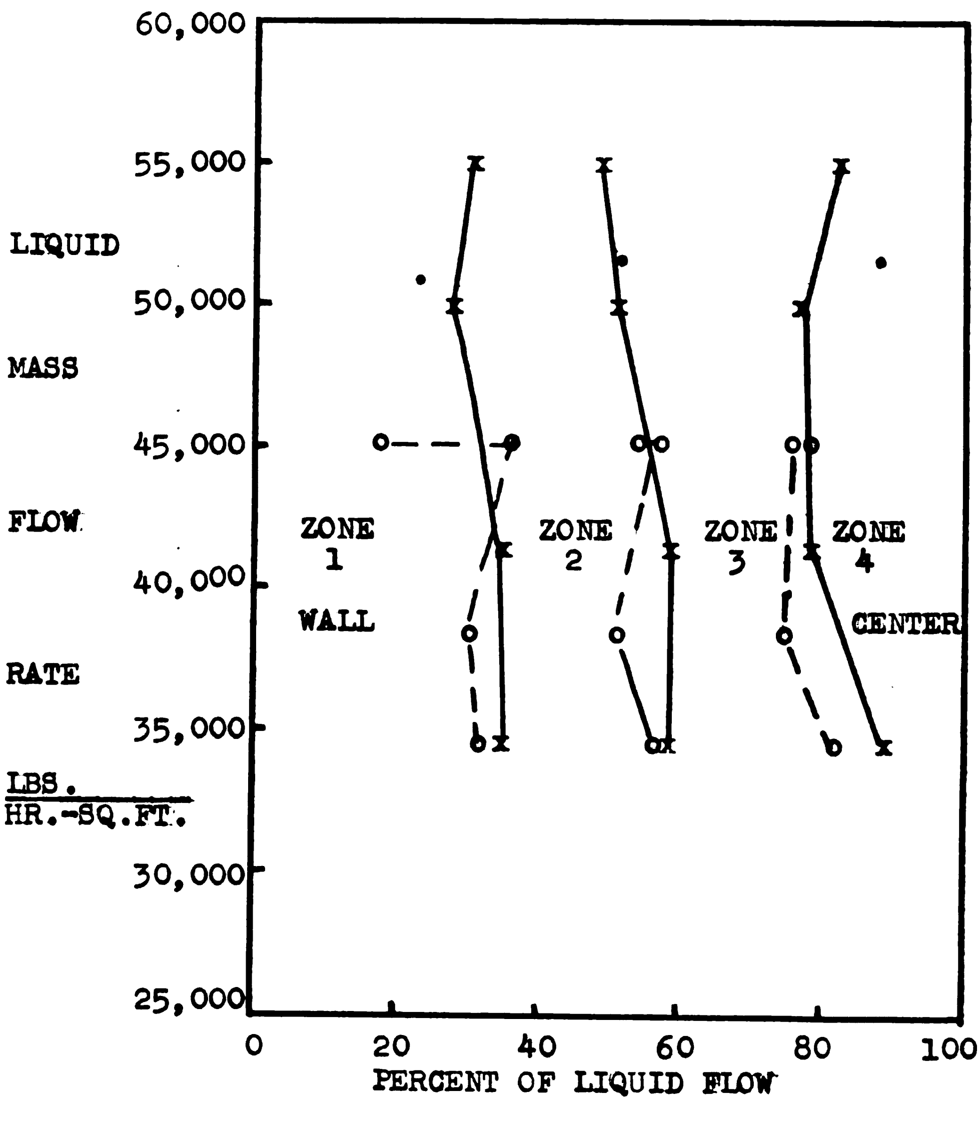
random dumping into a dry column. No other methods were used since the distribution could not be reproduced for the same packing. It was noted that the liquid flow from some of the zones fluctuated when the column was being fed at a constant rate. Since there was a possibility that the packing support screen might be producing the fluctuations, the screen was removed. However, the fluctuation did not cease as illustrated in Figure 7. Therefore, the average liquid distribution of each packing was found and is shown in the following table.

Table 7. Average Liquid Distribution for Spherical Packing. Packing Diameter - d, Column Diameter - D.

d (Inches)	D (Inches)	D/d	Method	Zones (Wall) 1	2	3	(Center) 4
1/2	2.5	5	DRP	43.9	22.2	19.3	14.6
1/2	2.5	5	PCF	46.7	19.8	20.4	13.1
1/2	2.5	5	OSD	45.5	20.6	21.8	12.0
1/4	2.5	10	DRP	30.5	26.5	23.6	19.4
1/2	5.0	10	DRP	27.3	23.4	23.6	19.4
1/2	5.0	10	PCF	29.4	25.1	20.4	25.2
1/2	5.0	10	OSD	29.1	22.7	23.4	25.2

Here, as with the plotted data, no effect of packing method on liquid distribution could be found. With this data it can be seen that a large "wall effect" occurred at this low ratio of column to packing diameter. Essentially, this is the same conclusion that was drawn by Baker, Chilton, and Vernon. From their studies, it was concluded that the "wall effect" could be eliminated

FIGURE 7. LIQUID DISTRIBUTION FOR THREE PACKINGS OF THE SAME METHOD IN A 2.5 INCH TOWER WITH 0.25 INCH SPHERES.



by keeping the diameter ratio equal to or above 10. However, as shown by this data the "wall effect" was only suppressed, not eliminated by using a diameter ratio of 10. Since a higher ratio was not used,it cannot be said what the minimum ratio would be; however, Norman indicated that the minimum ratio should be 12. Therefore, it appears that this data would be comparable to his 12 to 1 ratio.

b) Raschig Ring Packing

Theoretically, it should be much more difficult to obtain similar packing arrangements for dumped beds of irregularly shaped packing such as Raschig rings. However, on the other hand, it should be easier to shift the arrangement by employing a specific dumping method. As a result, the 2.5 inch column was packed with 0.25 inch Raschig rings by seven methods. These methods included a random dumping into a water-filled tower; random dumping into a water-filled tower that was being drained to give the packing a faster fall velocity; dumping into a water-filled tower with water being rotated so that packing would be driven to and settle near the wall; dumping into a centered tube extending to the packing in a water-filled tower so that the packing would slide from center to wall during dumping; and dumping in annular area between the wall and a tube extending to the packing so that the packing would slide from wall to center in dumping. The liquid distribution for each case was plotted in Figure 8. In no case could any variation in distribution be contributed to the dumping method.

Similarly, the 5.0 inch column was packed with 0.5 inch Raschig rings using five of the above packing methods. The liquid distribution for each case is shown in Figure 9. From this plot it was shown that random

FIGURE 8. LIQUID DISTRIBUTION FOR SEVEN METHODS OF PACKING A 2.5 INCH TOWER WITH 0.25 INCH RASCHIG RINGS.

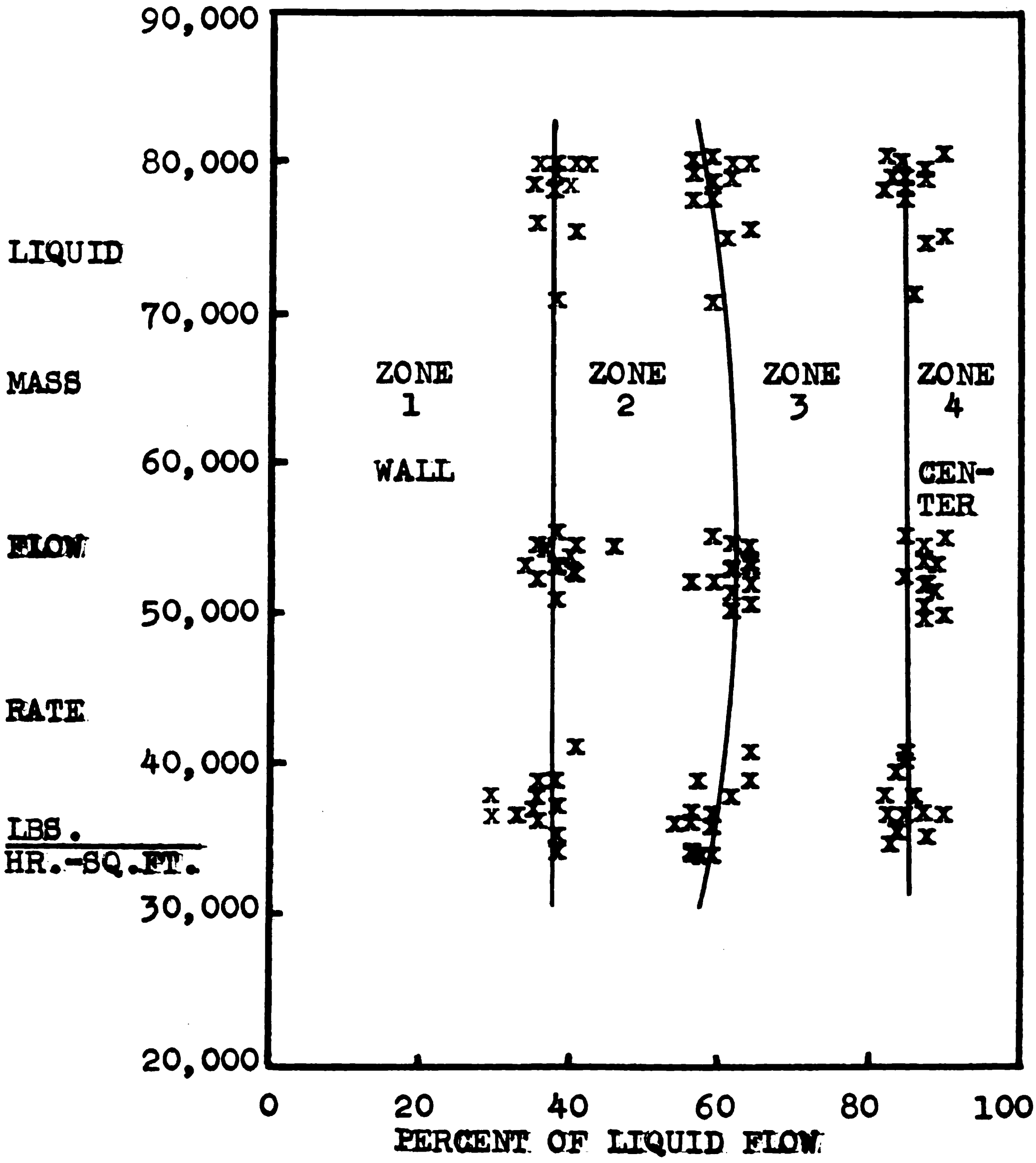
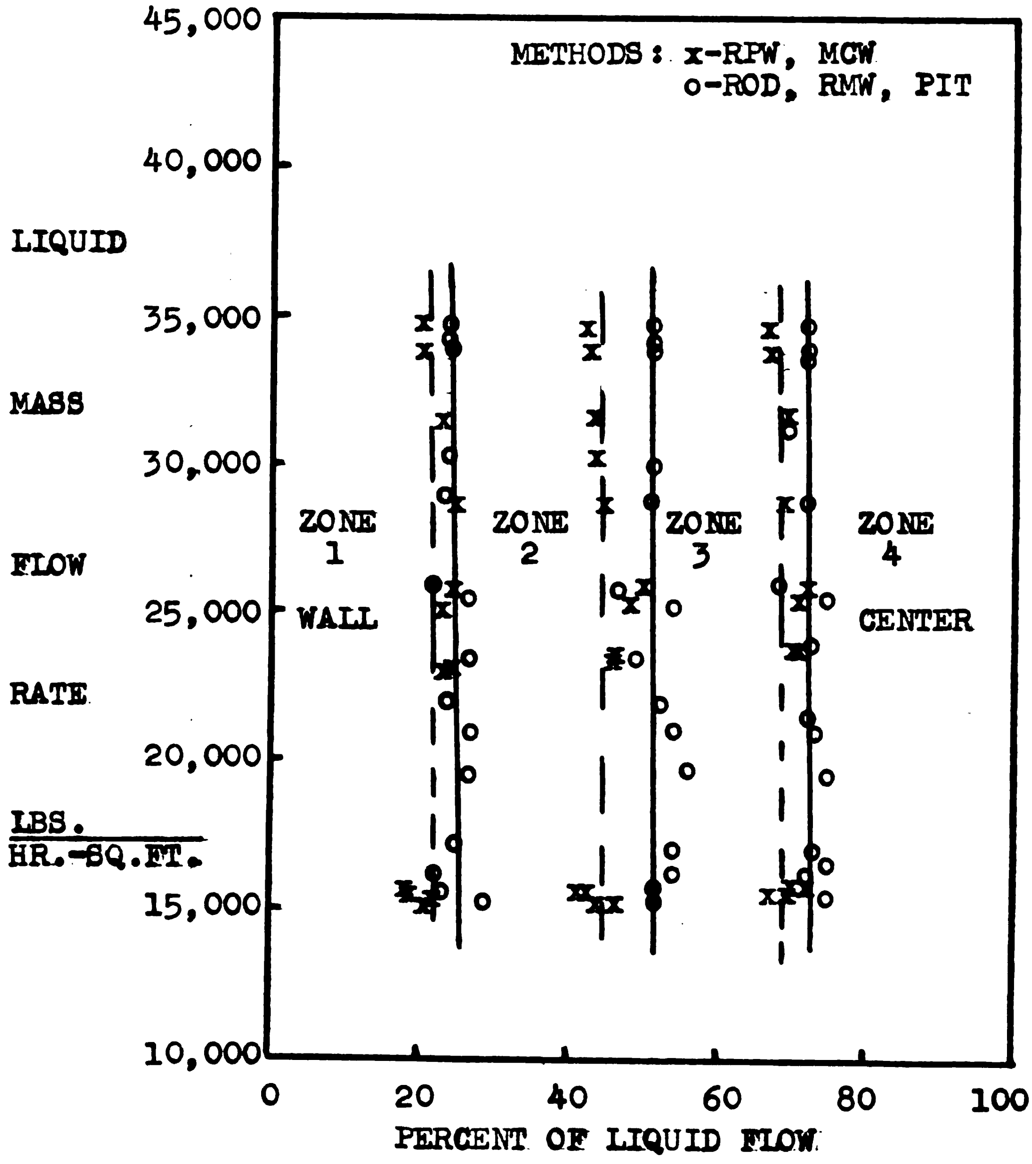


FIGURE 9. LIQUID DISTRIBUTION FOR SEVERAL METHODS OF PACKING A 5.0 INCH TOWER WITH 0.25 INCH RASCHIG RINGS.



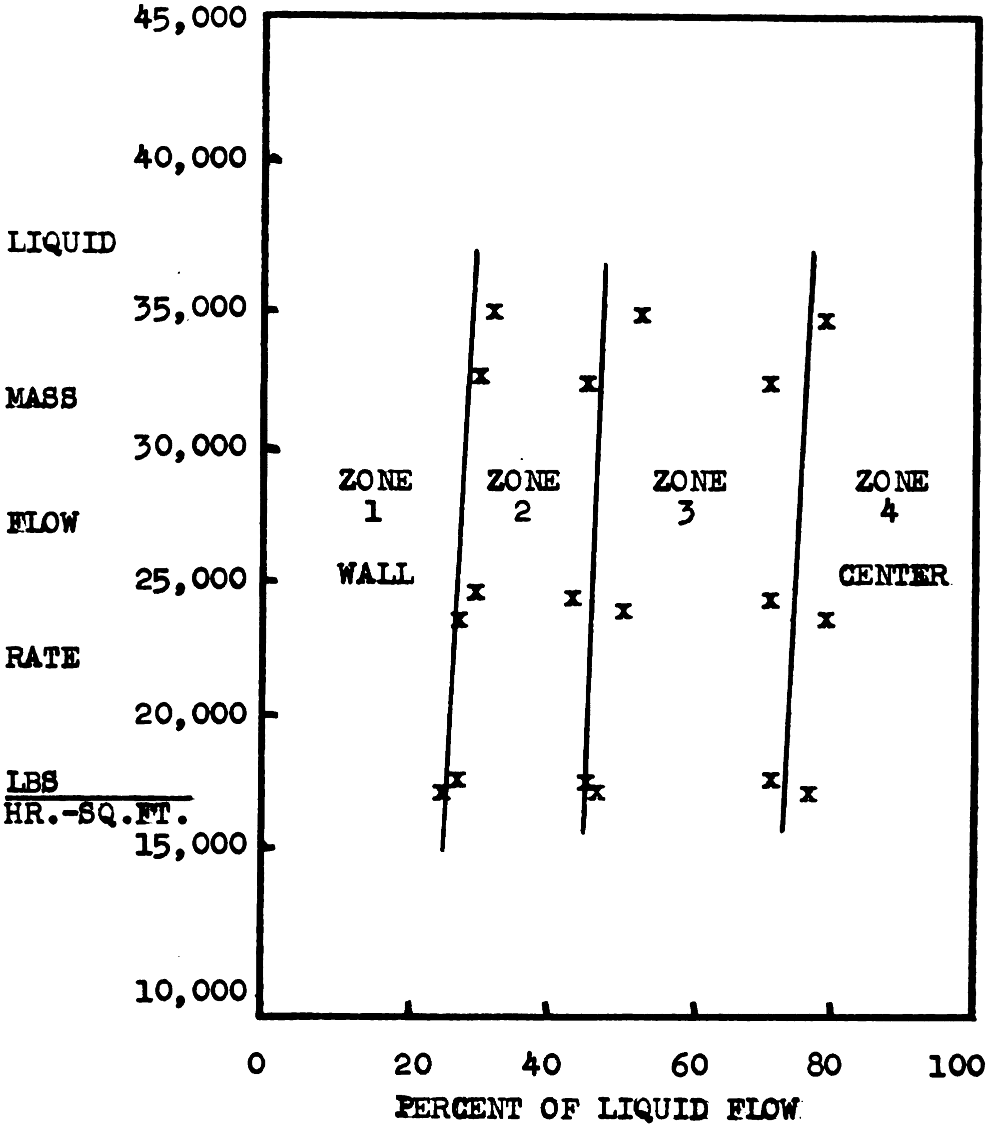
packing methods resulted in liquid flow concentrating in the center. Using methods that allowed the packing to build up on the wall or in the center resulted in a fairly uniform distribution.

The 5.0 inch column was also packed with 0.5 inch glass Raschig rings. However, only two packings were made since poor agreement was found even though the same method was used. This data is shown in Figure 10. Since there was some variation, an average liquid distribution was found and listed in the following table.

Table 8. Average Liquid Distribution for Raschig Rings. Packing Diameter - d, Column Diameter - D.

d (Inches)	D (Inches)	D/d	Method	(Wall) 1	Zones 2	3	(Center) 4
1/4	2.5	10	RPW	39.4	23.6	20.8	16.2
1/4	2.5	10	MCW	37.5	23.6	22.0	16.9
1/4	2.5	10	ROD	39.2	22.6	24.6	13.5
1/4	2.5	10	RMW	40.4	20.5	26.8	12.4
1/4	2.5	10	OSW	39.9	26.2	17.8	16.4
1/4	2.5	10	PTC	41.4	24.6	20.1	13.6
1/4	2.5	10	PIT	36.5	25.5	21.5	16.2
1/2	5.0	10	RPW	30.2	20.5	21.2	28.1
1/4	5.0	20	RPW	21.5	23.1	23.7	31.7
1/4	5.0	20	MCW	23.5	23.6	22.7	29.9
1/4	5.0	20	ROD	24.5	26.9	22.1	27.3
1/4	5.0	20	RMW	24.0	28.9	21.6	27.2
1/4	5.0	20	PIT	23.2	26.2	23.1	27.3

FIGURE 10. LIQUID DISTRIBUTION FOR 0.5 INCH RASCHIG RINGS IN A 5.0 INCH TOWER.

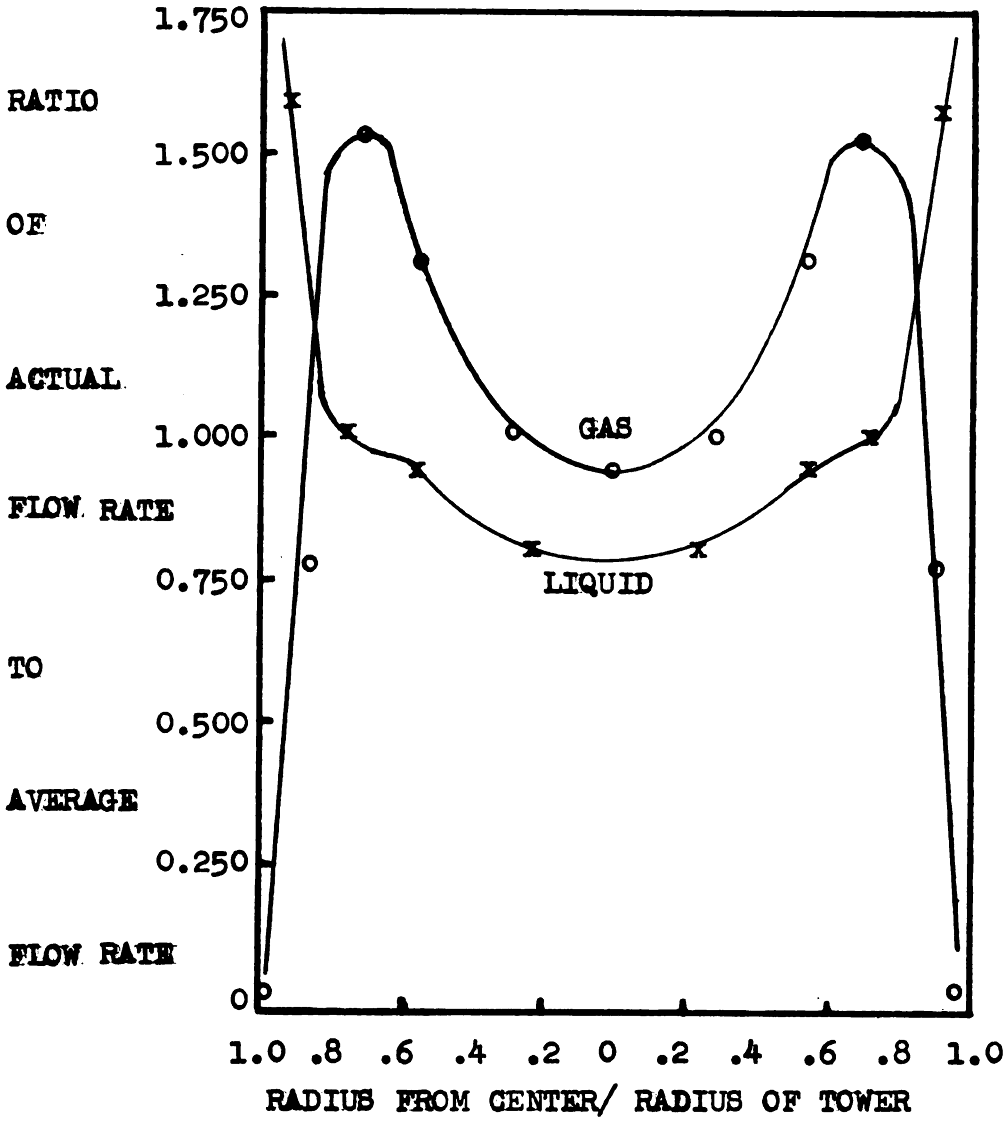


Here, it can be seen that a diameter ratio of 10 - 1 resulted in a "wall effect" or wall flow. When the ratio was increased to 20 - 1, the liquid flowed to the center for random dumping methods. Again, the averaged data indicates that the center flow could be decreased slightly by employing a method that allowed the packing to build up on the wall or in the center of the tower. Thus, it was concluded that the wall effect could be eliminated with a diameter ratio (D/d) of 20 - 1. However, at this condition, a "center flow effect" occurred which might be suppressed by using the proper packing method. Since the variation in liquid distribution due to packing method was small, it would be recommended that these packing methods be checked on larger diameter towers employing larger packing.

c) Comparison of Liquid and Gas Distributions

Morales, Spinn, and Smith have found the gas distribution for a 2 inch tower for 1/8, 1/4, and 1/2 inch Raschig rings at various depths of packing. They observed that low velocities occurred in the center and near the wall of the tower as well as finding that the distribution varied with depth of packing. Since their 1/4 inch packing in the 2 inch tower should be comparable to 1/4 inch rings in this 2.5 inch tower, an attempt was made to correlate the distributions. This was done by determining the relative flow rate at a point in reference to the column radius (r_o) for both the gas and liquid. The relative gas rate was found by dividing the point velocity by the average velocity (V/V avg.). The relative liquid rate was found by dividing the actual liquid mass rate for a section (G) by the average mass rate (G avg.) for the whole section. These adjusted rates were plotted and shown in Figure 11. The gas and liquid rates appeared to be proportional in the center of the tower and inversely proportional near the walls. Since this was based on only one comparison, it is recommended that the gas distribution be found for larger towers before any firm conclusions are drawn about the relation of gas to liquid distribution.

FIGURE 11. COMPARISON OF GAS AND LIQUID DISTRIBUTIONS FROM SEPARATE TOWERS PACKED WITH 0.25 INCH RASCHIG RINGS. GAS DISTRIBUTION WAS FROM DATA BY MORALES, SPINN, AND SMITH FOR A SUPERFICIAL GAS VELOCITY OF 1.21 FT./SEC. AND NO LIQUID FLOW IN A 2 INCH TOWER. LIQUID DISTRIBUTION WAS FOR A LIQUID MASS FLOW RATE OF 15,000 LBS./HR.-SQ.FT. AND NO GAS FLOW IN THE 2.5 INCH TOWER.



Conclusions

The following conclusions were reached as a result of the preceding experimental work:

1) For the packing methods employed, it was not possible to change the liquid distribution by any large amount.

2) Liquid concentrates near the wall of towers having a ratio of column to packing diameters of 10 - 1.

3) Flow rate affects the liquid distribution; however, no trend was observed.

4) Liquid flow reaches a fixed distribution within a depth equivalent to 4 column diameters below a multipoint feed distributor.

5) Liquid distribution did not change as long as liquid rate was constant for most packings; however, 0.25 inch spheres produced a distribution that fluctuated.

6) Data from two independent columns, one for measuring gas distribution with no liquid flow and another for measuring liquid distribution with no gas flow, the gas and liquid rates appeared to be proportional in the center and inversely proportional near the wall.

Table A. Experimental Data from 2.5 Inch Diameter Column Packed with 0.5 Inch Glass Spheres to a Depth of 36 Inches.

Run No.	Method of Packing	Run Time (Seconds)	Water Collected (Milliliters) Zone 1	Zone 2	Zone 3	Zone 4
1	1 DRP	43.0	4070	1440	1250	1080
2	1 DRP	43.5	3900	1650	1230	1100
3	1 DRP	43.4	3840	1710	1200	1120
4	1 DRP	41.8	3800	1530	1140	1045
5	1 DRP	40.0	3520	2170	2180	1410
6	1 DRP	36.0	3700	1800	2000	1280
7	1 DRP	36.7	3740	2000	1930	1300
8	1 DRP	30.0	3670	2260	2550	1960
9	1 DRP	29.0	3600	2230	2630	1730
10	2 DRP	41.0	3730	1620	870	1000
11	2 DRP	40.0	3700	1680	865	1000
12	2 DRP	37.0	3960	2040	1710	1240
13	2 DRP	36.5	3820	2090	1690	1200
14	2 DRP	27.3	3610	2190	2240	1500
15	2 DRP	41.5	3860	1780	740	1040
16	2 DRP	34.0	3660	2020	1610	1110
17	2 DRP	31.0	4100	2480	2580	1600
18	1 PCF	41.8	3850	1490	1180	1000
19	1 PCF	32.2	3730	1480	1500	1040
20	1 PCF	27.0	3830	1940	2460	1180
21	1 OSD	36.3	3330	1260	1200	820
22	1 OSD	35.0	4050	1800	1800	1090
23	1 OSD	27.5	4000	2220	2690	1120

Table B. Experimental Data from 2.5 Inch Diameter Column Packed with 0.25 Inch Glass Spheres to a Depth of 20 Inches.

Run No.	Method of Packing	Run Time (Seconds)	Water Collected (Milliliters) Zone 1	Zone 2	Zone 3	Zone 4
24	3 DRP	42.5	2600	2570	2910	1400
25	4 DRP	46.7	2700	2690	2200	2380
26	4 DRP	35.8	1680	1400	1270	610
27	4 DRP	35.8	2200	1600	1230	1340
28	4 DRP	27.6	2180	1300	1780	1350
29	5 DRP	28.0	1160	1900	1170	1330
30	5 DRP	30.0	1350	1190	840	630
31	5 DRP	31.0	1530	1290	1210	1080
32	5 DRP	31.9	2200	1440	1430	1370

Table C. Experimental Data from 2.5 Inch Diameter Column Packed with 0.25 Inch Glass Raschig Rings to a Depth of 42 Inches.

Run No.	Method of Packing	Run Time (Seconds)	Water Collected (Milliliters) Zone 1	Zone 2	Zone 3	Zone 4
33	1 RPW	34.2	1940	1330	970	950
34	1 RPW	36.2	3510	1950	1400	1200
35	1 RPW	26.5	3700	2200	1630	1480
36	2 RPW	35.6	1950	1130	1110	1050
37	2 RPW	32.2	3540	1200	1440	1140
38	2 RPW	26.5	4080	1500	1760	1560
39	3 RPW	34.2	1940	1500	1060	880
40	3 RPW	34.0	2940	2040	1800	1000
41	3 RPW	28.3	4000	2040	2040	1170
42	4 RPW	33.6	1440	1370	1410	800
43	4 RPW	34.3	2780	2140	1670	1060
44	4 RPW	27.0	3350	2080	1730	1730
45	1 MCW	34.2	1780	1220	1090	1050
46	1 MCW	35.4	3510	1690	1460	1330
47	1 MCW	25.4	3340	1790	1680	1660
48	2 MCW	38.0	1670	1550	1480	1210
49	2 MCW	32.5	2800	1900	1630	1040
50	2 MCW	30.2	4260	2440	2230	1320
51	3 MCW	31.7	1540	1100	1120	960
52	3 MCW	28.0	2640	1500	1530	700
53	3 MCW	25.6	3490	2000	1820	740
54	1 ROD	32.0	1680	1200	1240	780
55	1 ROD	30.8	2640	1200	1900	920
56	1 ROD	22.0	2680	1550	1480	1000
57	1 RMW	30.0	1570	1010	1320	730
58	1 RMW	18.2	1760	820	1120	420
59	1 RMW	15.0	2100	940	1150	520
60	1 OSW	30.2	1930	1370	790	860
61	1 OSW	21.0	1960	1330	860	720
62	1 OSW	20.0	2660	1520	1290	1120
63	1 PTC	30.0	2160	1320	910	740
64	1 PTC	24.6	2360	1420	1130	700
65	1 PTC	16.3	2130	1220	1210	770
66	1 RTC	34.5	2000	1410	1260	880
67	1 RTC	34.6	2930	2080	1540	1260
68	1 RTC	16.6	1960	1300	1170	880

Table D. Experimental Data from 5.0 Inch Diameter Column Packed with 0.5 Inch Glass Spheres by Method DRP.

Run No.	Depth of Packing	Run Time (Seconds)	Water Collected (Milliliters) Zone 1	Zone 2	Zone 3	Zone 4
69	40"	19.2	2020	2220	1860	2440
70	40"	21.1	2400	2300	2000	2060
71	40"	17.6	2100	2400	2600	3000
72	20"	20.8	2000	1200	1200	1270
73	20"	19.6	2150	2260	1930	2030
74	20"	17.5	2300	2220	2550	3180
75	30"	24.4	2330	1200	1300	1240
76	30"	17.2	1840	1880	1740	1700
77	30"	17.2	2150	2270	2400	3180
78	40"	23.4	2240	1100	1240	1400
79	40"	17.9	2060	2060	1660	2240
80	40"	15.0	2000	1900	1900	2720

By Method PCF

81	40"	22.0	2360	1450	800	1400
82	40"	21.0	2380	2340	2080	2180
83	40"	14.0	1840	2000	2000	2250

By Method OSW

84	40"	21.0	2100	1160	1160	1260
85	40"	19.8	2300	2100	2300	2000
86	40"	14.0	1850	1750	1820	2360

Table E. Experimental Data from 5.0 Inch Diameter Column Packed with 0.25 Inch Glass Raschig Rings to a Depth of 40 Inches.

Run No.	Method of Packing	Run Time (Seconds)	Water Collected (Milliliters) Zone 1	Zone 2	Zone 3	Zone 4
87	1 RPW	21.0	1060	1210	1220	1600
88	1 RPW	21.0	1960	1960	2080	2440
89	1 RPW	12.8	1600	1600	1680	2570
90	2 RPW	20.0	1010	1140	1160	1880
91	2 RPW	18.2	1680	1660	1750	2300
92	2 RPW	15.6	1910	1880	1980	2500
93	3 RPW	21.5	1020	1350	1350	1800
94	3 RPW	20.7	2030	2200	2100	2550
95	3 RPW	14.3	1700	1800	1880	2480
96	1 MCW	23.0	1200	1480	1250	1680
97	1 MCW	15.5	1700	1600	1700	1860
98	1 MCW	15.4	1840	1620	1600	2500
99	1 ROD	21.1	1400	1300	1000	1340
100	1 ROD	19.8	1680	1800	1700	1700
101	1 ROD	15.4	2310	2160	2060	2400
102	2 ROD	20.2	1160	1560	880	1620
103	2 ROD	22.2	1850	2130	2000	2230
104	2 ROD	20.3	2750	2750	2620	3180
105	1 RMW	19.8	1250	1900	1140	1460
106	1 RMW	16.9	1880	1920	1620	1780
107	1 RMW	15.6	2140	2200	2140	2360
108	2 RMW	20.0	1540	1840	1260	1420
109	2 RMW	18.9	1800	1890	1800	2730
110	2 RMW	20.3	2520	2600	2200	3160
111	1 PIT	20.5	1400	1880	1200	1700
112	1 PIT	17.2	1640	1660	1840	1840
113	1 PIT	16.0	1860	1920	1860	2200

Table F. Experimental Data from 5.0 Inch Diameter Column Packed with 0.5 Inch Glass Raschig Rings to a Depth of 40 Inches.

Run No.	Method of Packing	Run Time (Seconds)	Water Collected (Milliliters) Zone 1	Zone 2	Zone 3	Zone 4
114	1 RFW	23.1	2000	1750	1770	1880
115	1 RPW	17.4	2100	1780	1600	1630
116	1 RPW	16.0	3160	2000	2040	2200
117	2 RPW	20.0	1840	1300	1200	2100
118	2 RFW	17.0	2140	1260	1360	2340
119	2 RPW	15.6	2740	1300	1800	2640

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