LIQUID CHANNELING IN SMALL PACKED TOWERS

by

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1944

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Department of Chemical Engineering, February 28, 1944

Signature of Professor in
Charge of Research Signature redacted

Signature of Head of
Department Signature redacted

✓

149 Highland Avenue
Buffalo, New York
February 21, 1944

Professor W. K. Lewis
Department of Chemical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

Submitted herewith is our thesis on the subject "Liquid Channeling in Small Packed Towers" in partial fulfillment of the requirements of the degree of Bachelor of Science in Chemical Engineering Practice.

Respectfully yours,

Signature redacted

Gonzalo C. Docal, '44 X-B

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Page S. Ufford, '44 X-B

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I. SUMMARY

The problem of channeling in small packed towers was undertaken with the intent to throw some light in a field in which existing data are both meager and conflicting.

Channeling was studied on three, four, six, and eight-inch towers for liquor rates between 2500 and 5000 lbs./hr.-ft^2. and for two kinds of packing - one-inch stoneware and one-half-inch carbon Raschig rings. The liquid used was water, and no countercurrent flow of gas was attempted.

The method of procedure consisted in collecting two portions of water at two different cross sections of tower - the outer quarter of the area and the inner three quarters.

The data compiled are presented graphically in curves of percent of liquid distributed over the outer area versus height of packing for different ratios of tower diameter to size of packing and at constant liquid rates. Similar curves for each tower, but at varying rates of feed show the negligible effect of feed rate of flow on distribution.

Results show that for towers packed with one-inch rings uniform, constant distribution is reached

after five feet of packing are traversed, provided that the ratio of tower diameter to size of packing be eight to one. For one-half-inch packing this critical ratio seems to be much higher, at any rate larger than sixteen to one.

It has also been concluded that one-inch rings give a better distribution of liquid than one-half-inch rings. Material out of which packing is made affects channeling, porous substances showing more tendency to channel. Carbon rings seem to be more desirable than stoneware.

The best tower for pilot plant work is the eight-inch tower, packed with one-inch rings; one foot of packing being necessary for multiple feed or at least five feet for central distribution.

Further work should be continued in the field covering other kinds of packing and different rates, in an attempt to confirm the conclusions reached here.

II. INTRODUCTION

The uniform distribution of the liquid feed is a determining factor in the efficient operation of packed towers; consequently, any tendency for this liquid to channel through the packing is of the utmost importance. The general concensus of opinion, based on little experimental work, is that once the liquid has reached the walls of the tower there is little chance for it to return to the packing. The conclusions arrived at by various investigators seem contradictory, with the result that recommendations for distribution control in industrial towers are conflicting.

Baker, Chilton, and Vernon[1] have shown that in towers where there is a ratio of tower diameter to size of packing of approximately eight to one or greater, fairly uniform distribution of the liquor feed is eventually reached after four or five tower diameters have been traversed, and after that height "there is no marked tendency for the liquor to channel either toward the wall or in any other way."

Tour and Lerman have approached the problem from the point of view of mathematics and have applied to it the laws of frequency distribution.[5] They have shown that for unconfined liquid distribution, where the tower diameter is large enough so as to make wall effects negligible, the Normal Law of Probability applies. Lerman in the discussion of his work[5] has stated that "the variable of liquid distribution may be best treated by keeping it constant, that is, by operating packed towers at liquid distributions approaching uniformity using simple redistribution devices down the column."

Thus the need of a clear conception of the problem of channeling is seen to be imperative. Of extreme importance is the extrapolation of results for small towers to those of industrial size.

In this problem investigations have been undertaken to determine the extent of channeling through the outer quarter of the cross section of the columns most commonly used in pilot work, at different rates of liquor flow and for two different kinds of packing.

III. PROCEDURE

The method used to study the problem of channeling consisted simply in introducing water at the top of a column and collecting at its bottom two different portions - one coming from the inner three quarters of the cross section of the tower and the other from the outer narrow quarter.

Water was chosen as the most convenient liquid, since channeling does not seem to depend on the characteristics of the liquid, but rather on the dimensions of the tower and the size of packing.[1] Likewise no countercurrent flow of gas was attempted since previous investigators[1] have shown that it has no effect on liquid distribution except at gas velocities near the loading point of the tower.

Towers.

The columns used were ordinary cylindrical stove pipes with inside diameters of three, four, six and eight inches, these sizes having been chosen because of their frequent use in pilot plant work. Each tower was approximately five and a half feet long, and liquid distribution was studied at every foot of packing from one to five feet. The columns were kept vertical during all runs by alignment with two plumb lines located ninety degrees apart around the periphery of the column.

Packing.

The kinds of packing studied were one-inch stoneware and one-half-inch carbon Raschig rings. The rings were supported by a 7/16-inch wire screen cut the shape of the tower and resting on six 1-3/8-inch screws piercing the walls of the tower (Figure 1). In the three-inch tower only three $\frac{3}{4}$-inch screws were used as support to the wire screen (3/8-inch holes). In all towers the supporting screen was placed at one and a half inches from the bottom in order to allow free drop of liquid after it left the packing.

Liquid Feed.

The rate of flow of water into the top of the tower was controlled by a valve and indicated by a manometer installed across a calibrated orifice (Figure 12). In all investigations made the water was fed exactly at the surface of the packing and at the center of the column. No attempt was made to use a multiple point distribution. For the three-inch tower a $\frac{1}{4}$-inch feed pipe was used and for all others a $\frac{1}{2}$-inch pipe.

To assure accurate central distribution an arrangement was constructed consisting of two boards, one of circular shape that fitted tightly inside the column and the other with a circular groove of the exact circumference of the tower. Both boards were pierced with holes at their exact centers to accomodate the feed pipe. The circular board was placed inside the tower close to the top of the packing, while the second board was placed with the top edge of the tower fitting in the groove in the manner of a cover. The feed pipe was introduced exactly to the surface of the packing through the central hole in the boards (Figure 1).

In order to determine the effect of varying liquor rates on channeling, investigations in the four- and eight-inch towers were done at five different water rates. These were 4800 ± 300, 4300 ± 300, 3800 ± 300, 3200 ± 240, 2500 ± 350 lbs./hr.-ft.^{2} Such high values were chosen because they fall more within the range of industrial rates[4] than the lower ones (500 to 1700 lbs./hr.-ft.^{2}) used by other experimenters.[1]

For the six-inch tower only the highest and lowest rates were used, while for the three-inch tower only the lowest rate was examined.

Collecting Device.

Instead of using an elaborate method of collection of the portions of water through the different cross sections of the tower, it was decided to consider only the outer quarter of area. Such a procedure was justified since it is through this outer portion and down the walls of the tower that channeling is more critical.

Thus the collecting device consisted simply of a funnel of the proper diameter so as to cover the inner three-quarters of the tower cross section. The water falling inside the funnel was led to a container, and that falling between its edge and the walls of the tower into another (Figure 1).

The funnel was centered at the middle of the tower by eye. This method was found satisfactory, since it was observed that water left the packing in the form of little streams concentrated either at the walls or towards the center. Thus a small deviation of the funnel from the exact position affected little the amount of water caught.

Method.

Once the tower was packed, the liquid rate was adjusted to the desired manometer reading, and water was allowed to run for several minutes to assure complete wettness of the packing. Then simultaneously the outlet hoses from each of the two portions collected were run into respective containers and a stopwatch started. The run was stopped when the smaller of the two portions of water was large enough, at least 20 pounds, to minimize holdup and starting errors.

Knowing the time of the run and the average rate of flow during the interval, the total amount of water used for the run could be calculated and checked against the sum of the portions collected. These two values did not completely check on all cases because the water rate was only approximately constant. However, this fact did not affect the results obtained since the percentages were found from direct weights. In the plots these average rates of flow have been used, since as shown below channeling is not affected by varying feed.

M.I.T. STATION
BETHLEHEM STEEL C.O.
REPORT NO.F15-1B43 FIGURE 1
FEBRUARY 19, 1944 G.C.D.-P.S.U

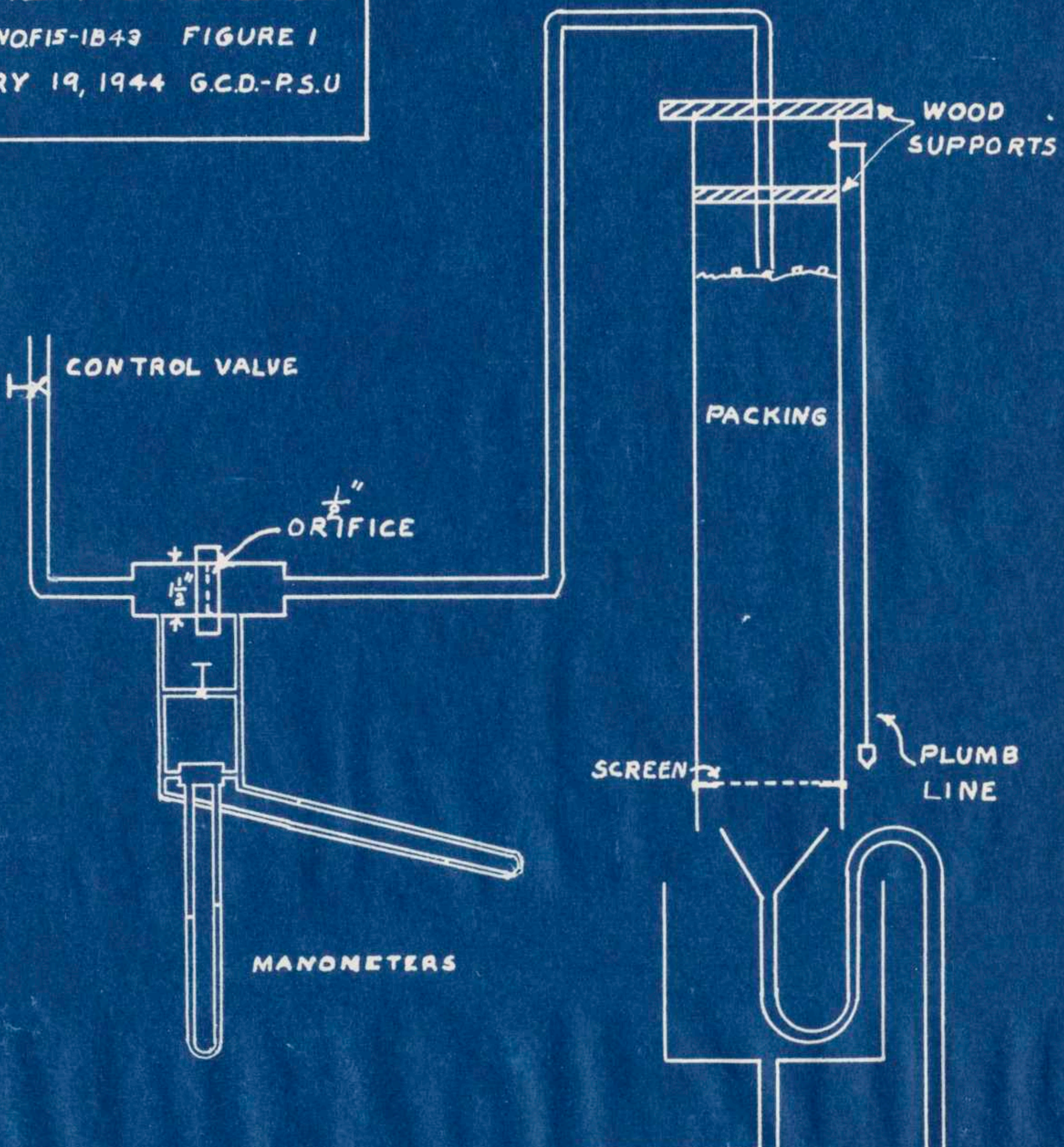


DIAGRAM OF APPARATUS

IV. RESULTS

The results of the investigation are best shown by a series of graphs (Figures 2 to 6) in which the percent of total liquid distributed in the outer quarter of the cross section of the tower is plotted versus feet of packing. Each of these graphs is drawn for one rate of feed flow, and each curve on the graph corresponds to a different ratio of tower diameter to size of packing.

Figure 7 shows a similar plot of the data obtained by Baker, Chilton, and Vernon[1] for stoneware rings and glass rings at the same ratio of column diameter to size of packing as some of the cases investigated in this report.

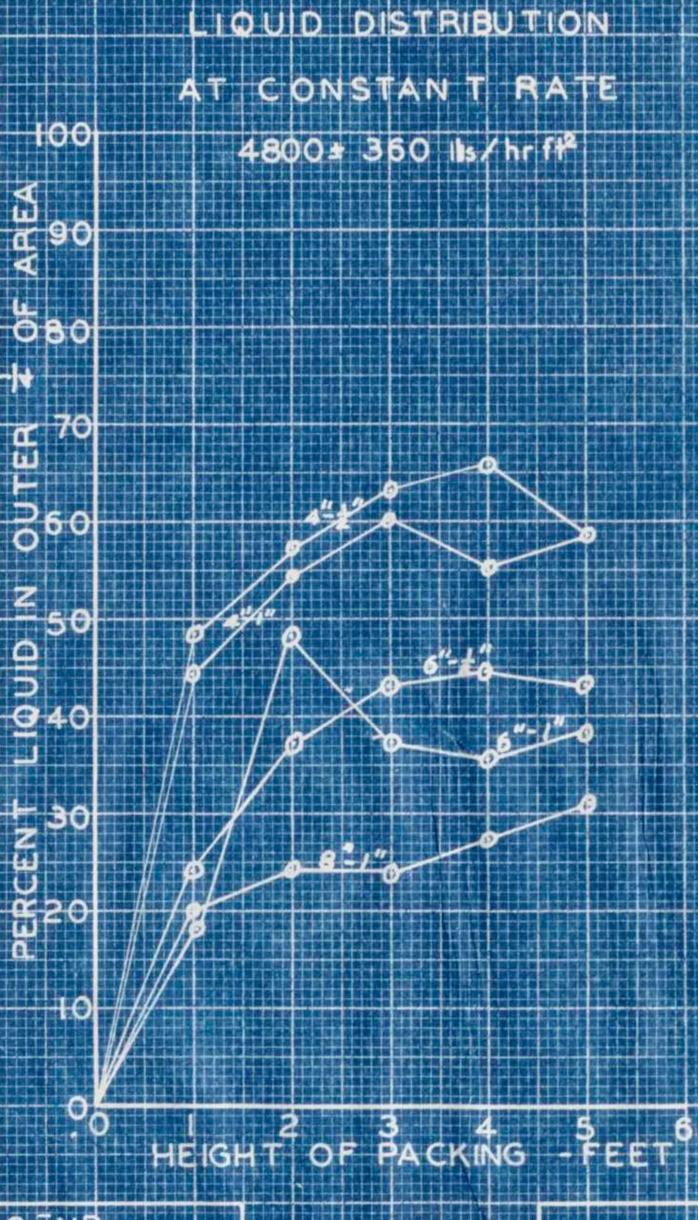
The effect of different rates of flow of liquid is shown in Figures 8 to 11. Each of these graphs refers to a tower with a kind of packing. In each case the percent of total feed distributed in the outer cross section of the column is plotted versus height of packing in feet. Each curve represents a different rate. In Figures 10 and 11 data found by Baker, Chilton and Vernon[1] at 500 lbs./hr.-ft.^{2} have been superimposed for the sake of comparison. It can be seen that these curves follow the same trend as the others.

Qualitative Observations.

During the course of the experiment several visual observations were made which are worthwhile mentioning under results.

When one-inch rings were used, water dropped from the packing in a relatively small number of thick streams; however, when one-half-inch rings were tried, the number of streams was much greater and each carried less volume of water.

From certain spots of the bottom of the tower it was noticed that liquid never dripped. The feed was then placed directly over these spots and again no liquid ran through them. It was concluded that the formation of such "dead spots" was due to accidental tighter packing of the rings at these places. Packing the tower under water was found to reduce "dead spots" to a certain extent.



LEGEND

First Figure Indicates

Tower Dia.

Second Figure Indicates

Packing Size

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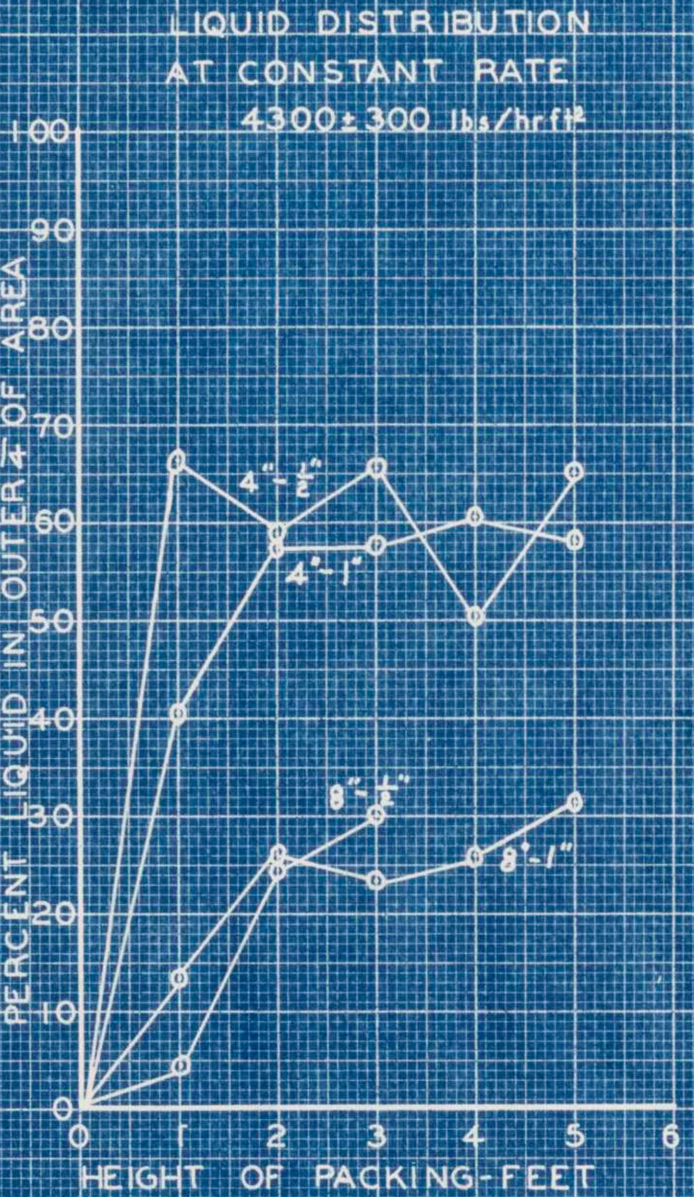
REPORT NO F15-1B44	FIGURE 2
2-19-44	G.C.D. - P.S.U.



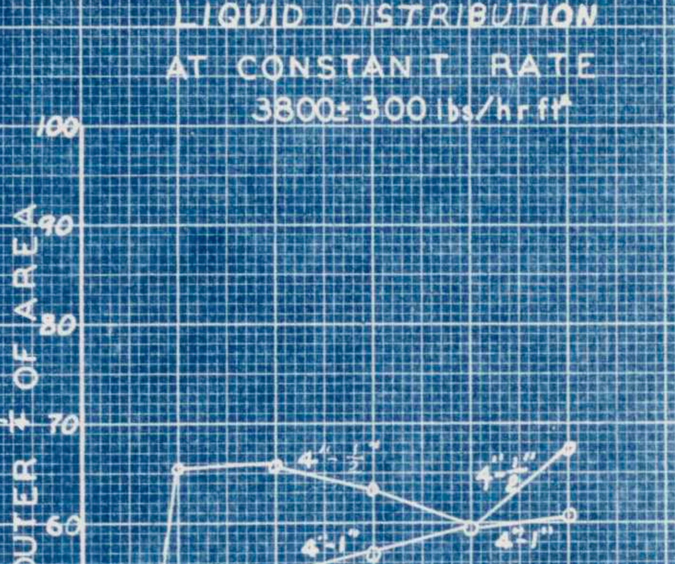
LIQUID DISTRIBUTION
AT CONSTANT RATE
4300 ± 300 lbs/hr ft^2

M. I. T. STATION

BETHLEHEM STEEL CO

REPORT NO F15-1B43	FIGURE 3
2-19-44	G.C.D.-P.S.U.

LIQUID DISTRIBUTION
AT CONSTANT RATE
3800± 300 lbs/hr ft²



M.I.T. STATION

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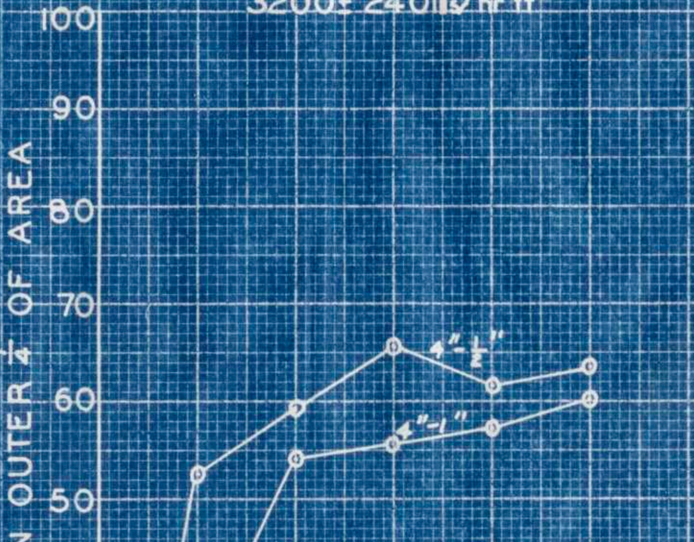
REPORT NO. F15-1843	FIGURE 4
2-19-44	G.C.D. - P.S.U.



LIQUID DISTRIBUTION
AT CONSTANT RATE
3200 ± 240 lbs/hr ft²

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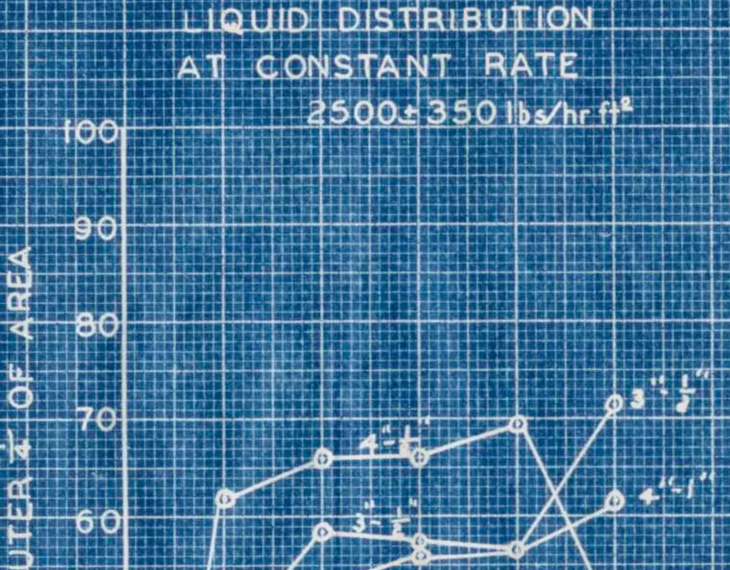
BETHLEHEM STEEL CO.	
REPORT F15 – 1843	FIGURE 5
2-19-44	G.C.D. - P.S.U.



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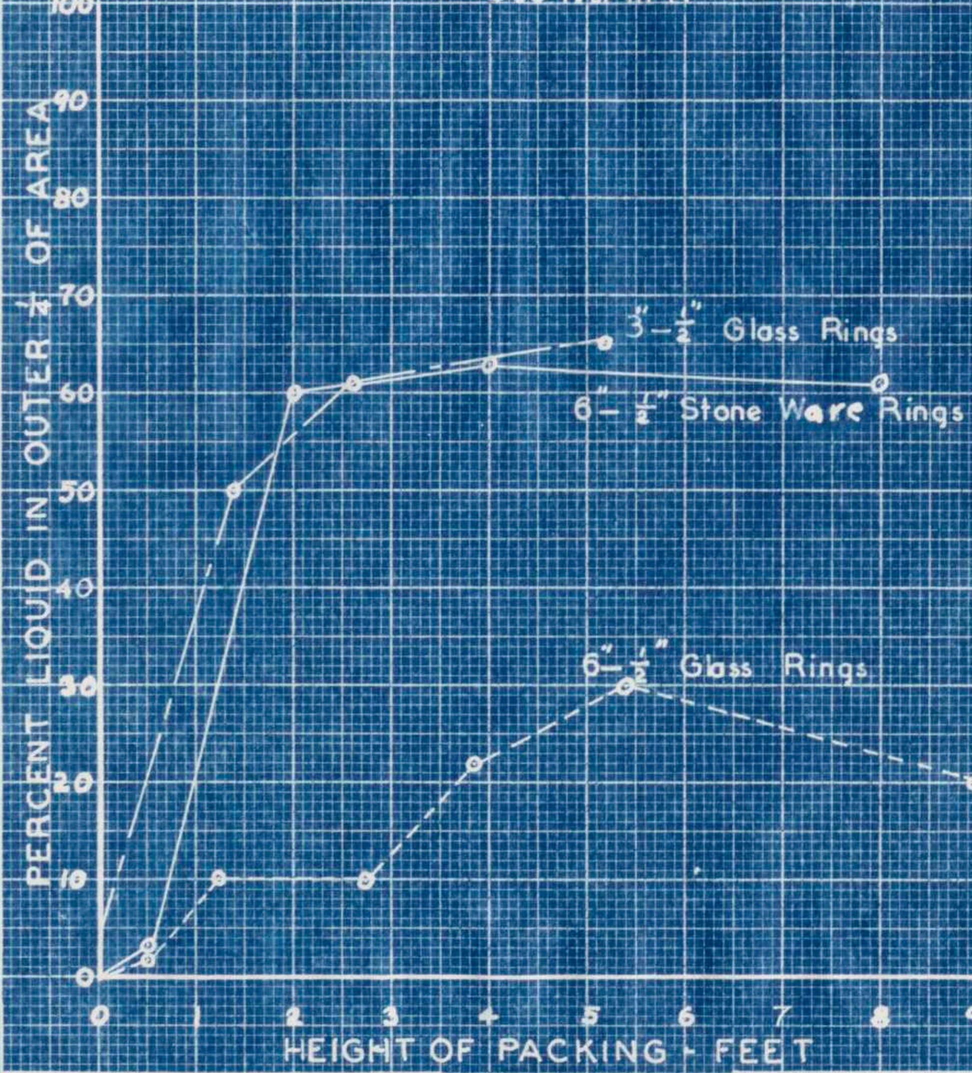
REPORT NO. F15-1843	FIGURE 6
2-19-44	G.C.D. - P.S.U.

LIQUID DISTRIBUTION
AT CONSTANT RATE

500 lbs/hr ft^2



DATA FROM

BAKER, CHILTON
And VERNON

REFERENCE I

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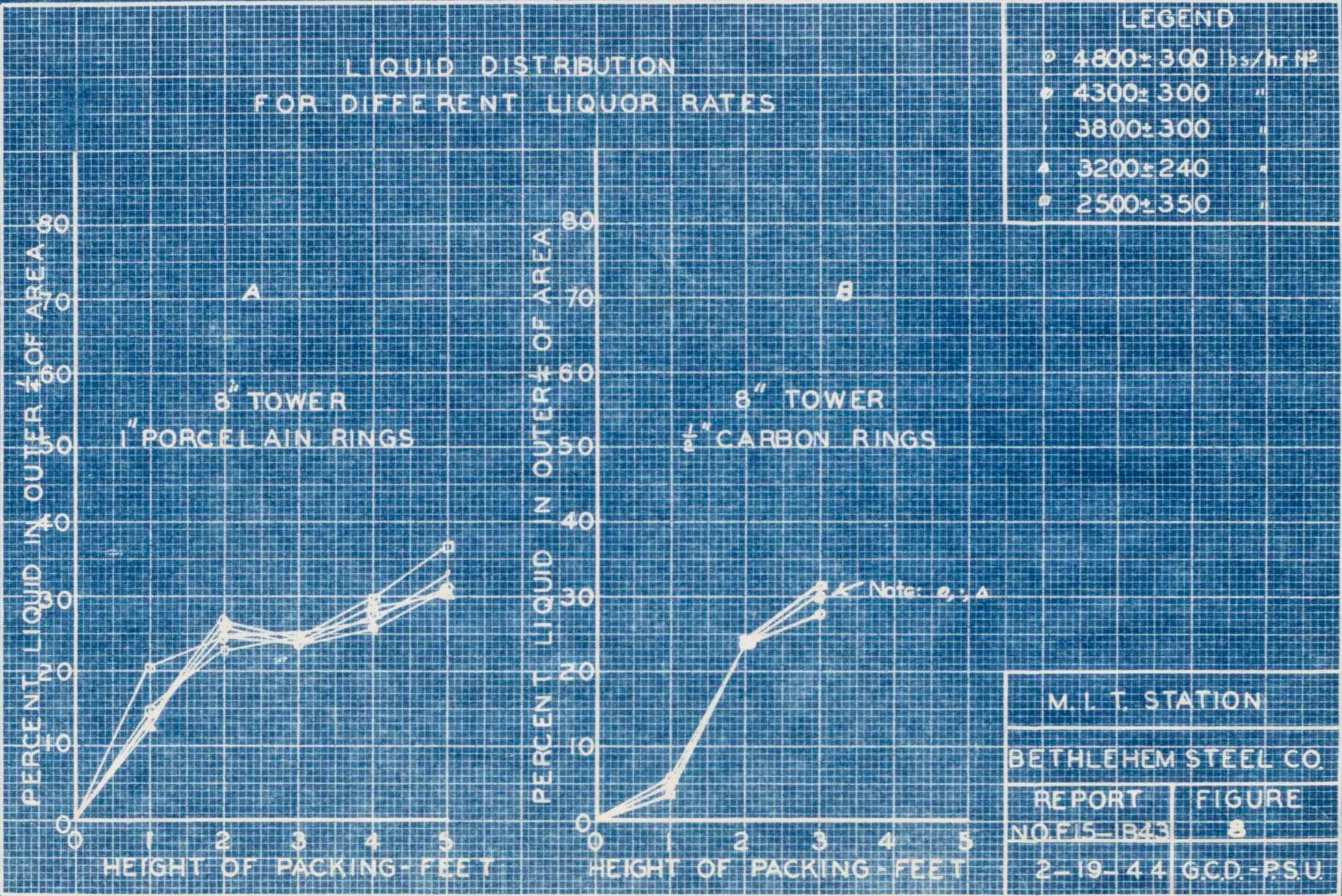
REPORT
NO.F15-1843

FIGURE
I

2-19-44

G.C.D.-P.S.U.

LIQUID DISTRIBUTION FOR DIFFERENT LIQUOR RATES



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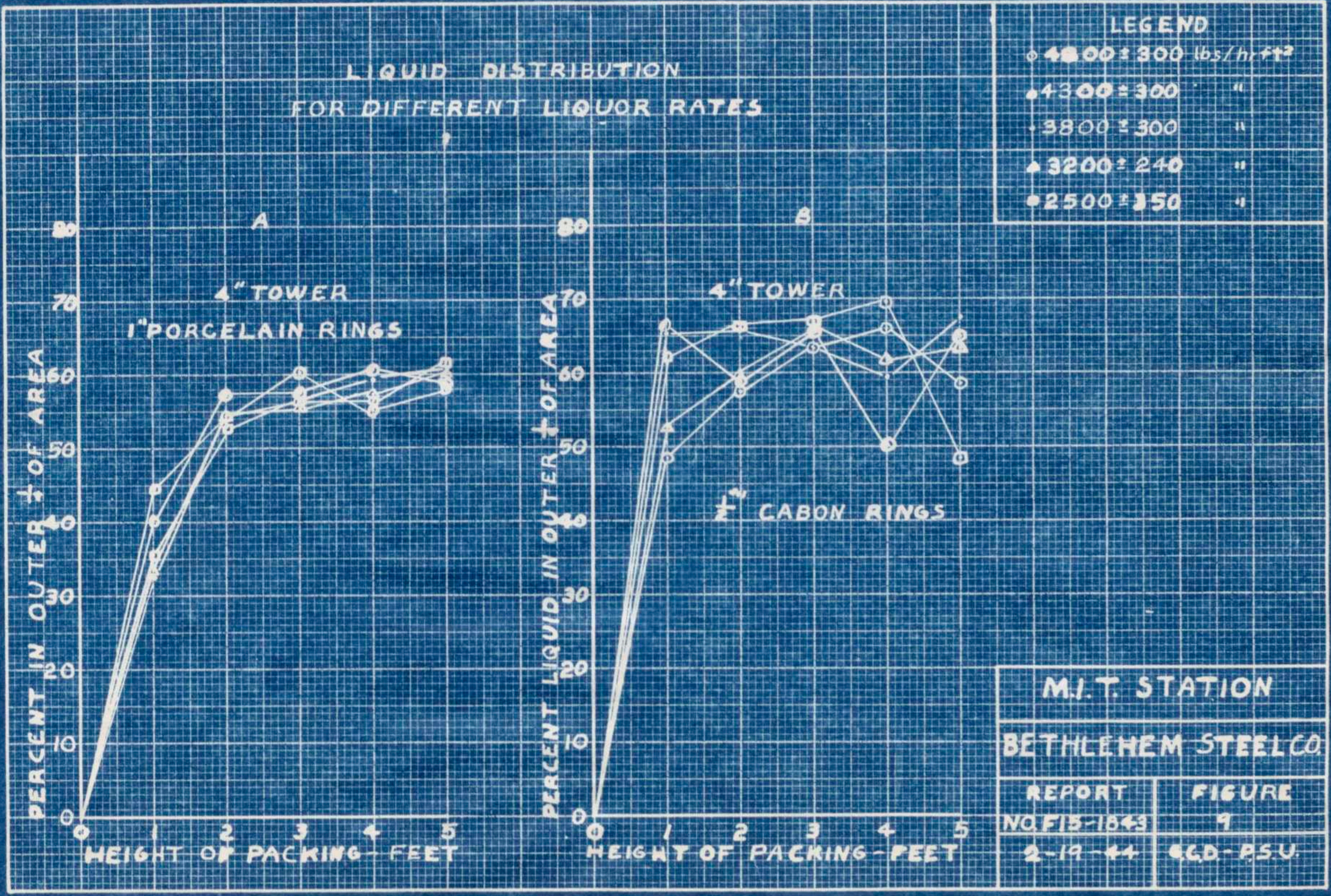
REPORT	FIGURE
NO. F15-1843	8
2-19-44	G.C.D.-P.S.U.

LIQUID DISTRIBUTION FOR DIFFERENT LIQUOR RATES



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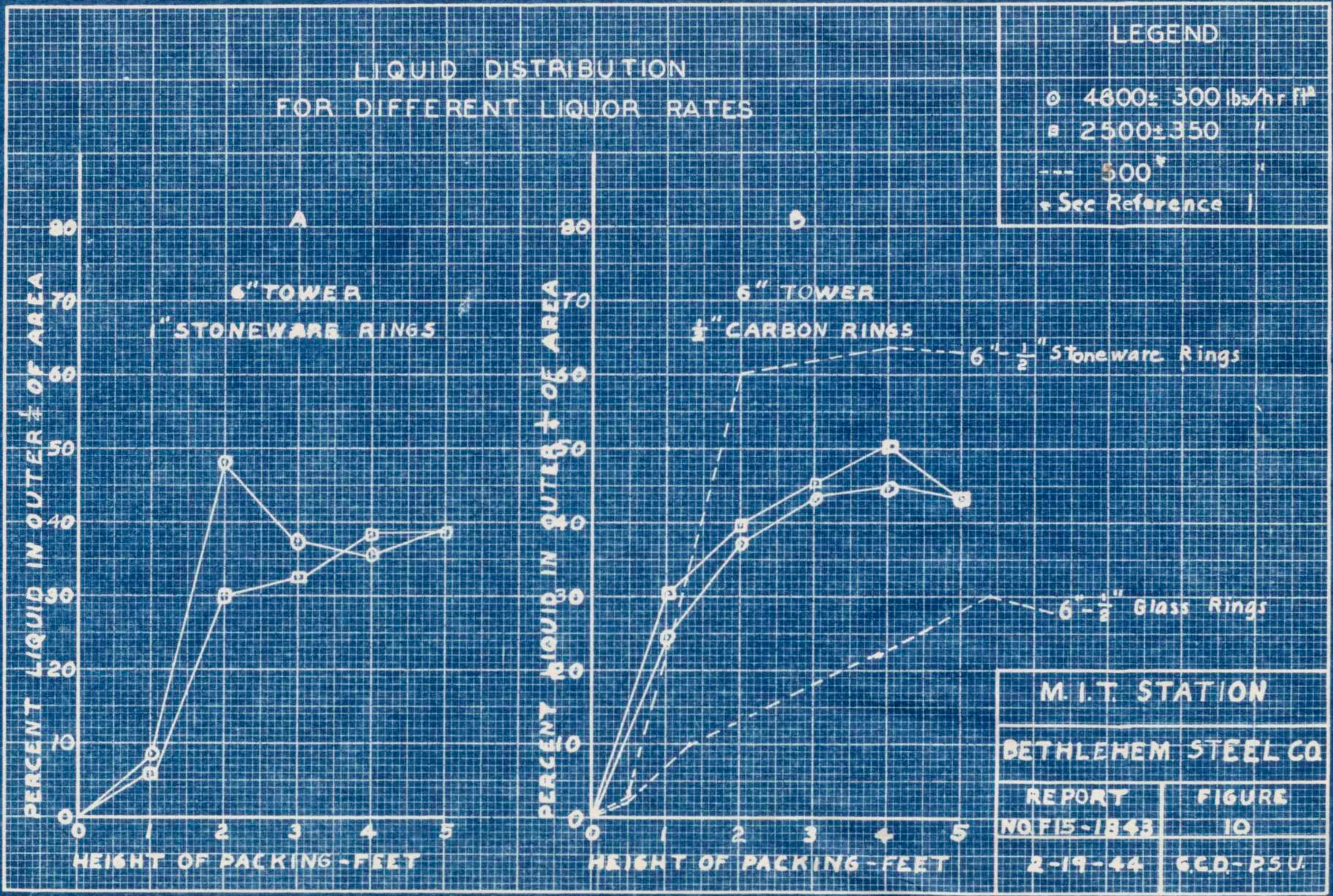
REPORT	FIGURE
NO. F15-1843	9
2-19-44	G.G.D.-P.S.U.



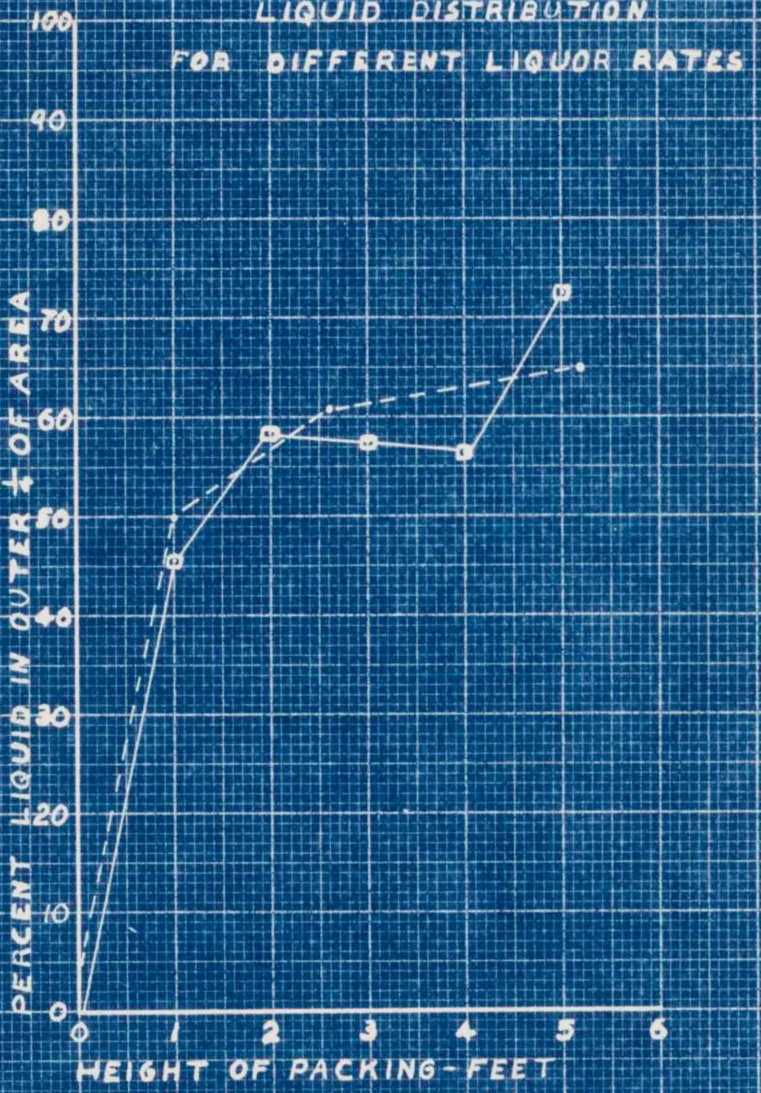
LIQUID DISTRIBUTION
FOR DIFFERENT LIQUOR RATES

M. I. T. STATION

BETHLEHEM STEEL CO.

REPORT	FIGURE
NO F15-1843	10
2-19-44	G.C.D.-P.S.U.

LIQUID DISTRIBUTION FOR DIFFERENT LIQUOR RATES



LEGEND

——— 3" TOWER
½" CARBON RINGS
RATE - 2500±350 $\frac{lbs}{hr\,ft^2}$

* - - - 3" TOWER
½" GLASS RINGS
RATE - 500 $\frac{lbs}{hr\,ft^2}$

* See Reference 1

M. I. T. STATION

BETHLEHEM STEEL CO

REPORT	FIGURE
NO. F15-1843	11
2-19-44	G.C.D.- P.S.U.

V. DISCUSSION OF RESULTS

In the study of channeling in packed towers there are a number of variables which may affect the degree of channeling - gas and liquid rate, ring material, ring size, tower size, and liquid surface tension and viscosity. Studies were made with different liquor rates, different ring materials, different ring sizes, and different tower sizes. No gas flow was used because according to Baker, Chilton, and Vernon[1] channeling is independent of counter-current flow of gas. The effect of surface tension and viscosity was not studied.

In packed columns the matter of uniform distribution (25 percent of liquid in the outer quarter of area) is very important because only in this way can the maximum amount of liquid wet the packing and bring about better absorption. It is seen from the graphs (Figure 2 to 6) that the percent of liquid in the outer cross section of area increases from the point of feed to four or five feet of packing, at which point distribution reaches a constant value. During the discussion care must be taken not to confuse these two terms - uniform distribution and constant distribution.

Liquid Rates.

Figures 8 to 11 show that variation of liquor rate from approximately 2500 to 5000 lbs./hr.-ft^2. affects the distribution of the liquid through the packing to a negligible extent, provided that the liquid has traversed at least one foot of packing. It can thus be seen that the deviations of some of the points in graphs 2 to 11 can not be blamed on the 10 to 15 percent variation of the liquor rates.

Ring Material.

From Figure 10 B it can be concluded that large differences in channeling are caused by different materials of packing. Thus it is seen that at 500 lbs./hr.-ft^2. for porous stoneware rings channeling is quite bad, 63 percent, while with glass rings of the same size, for the same tower and at the same rate of feed channeling is much less, 30 percent. The porous stoneware rings are of such a nature that they permit a low surface tension and thus hold a thin film of liquid. On the other hand the glass rings allow a high surface tension and hold a thick film of liquid. Thus if a drop of liquid should come in contact with the stoneware rings, it will follow the film on the ring and be drawn into channels. However, for glass rings the drop would have more of a tendency to fall off freely. This may be the reason for the above phenomenon.

Not enough data have been taken to conclude definitely how carbon rings fit into this correlation. However, from a visual comparison of carbon rings with stoneware and glass, the carbon rings seem to be smoother and less porous than stoneware, but less smooth and more porous than glass. It seems that carbon rings should fit between the other two, and when constancy of distribution is reached, they would give a smaller percent of liquid in the outer area than stoneware rings and larger percentages than glass rings.

Figure 10 B seems to prove this fact further. From these curves it is seen that the carbon curves lie midway between the upper stoneware curves and the lower glass curves. The two carbon rings curves are for approximately 5000 and 2500 lbs./hr.-ft^2. while the glass and stoneware curves are both for 500 lbs./hr.-ft^2. The small change in distribution shown in the 5000 to 2500 range of rate of feed seems to indicate that this change would be small also for the 500 to 2500 lbs./hr.-ft^2. range.[1] Therefore the variation in the distribution shown can be blamed mostly on the different ring materials.

It can be concluded that if one-inch carbon rings had been used their curve of distribution versus feet of packing would have fallen below that for the one-inch stoneware rings. Since curves for the one-half-inch carbon rings are higher than those for one-inch stoneware rings, they will be also higher than those for one-inch carbon rings. Therefore, one-half-inch rings cause more channeling than one-inch rings, regardless of ring material.

Ring Size.

Packing rings perform a double function. During the first few feet of packing, before constancy of distribution is reached, rings spread the liquid out to the walls of the tower. Further down by contact with the walls they tend to redistribute the liquid back to the packing, thus bringing about constant distribution. The one-inch rings seem to perform this function better than the one-half-inch rings, especially in the case of the eight-inch tower, where the point of constant distribution coincides with that of uniform distribution, thus giving maximum wetting conditions in the packing.

Two different ring sizes of one-inch and one-half-inch were used. The results of the investigation (Figures 2 to 6) show that in all cases except for the eight-inch tower, at any height of packing the percent liquor in the outer quarter of area of the tower was larger for one-half-inch carbon rings than for one-inch stoneware rings. For the eight-inch tower conditions were reversed during the first two feet of packing.

The fact that one-half-inch rings are consistently worse (See discussion above) can be explained as follows. It is believed that there is some relation between channeling and liquid holdup. Holdup is due to liquid held by surface tension around the points of contact of a piece of packing with another or with the walls of the tower. Liquid builds up around these contacts in the form of "doughnuts". Now smaller rings are packed more compactly than large ones and give rise to more points of contact, especially between the walls and the packing. If these "doughnut" shaped accumulations of liquid are so close that they touch each other, they provide an easy way for the liquid to flow through. Therefore, liquid will take this short cut path down the tower walls rather than tend to be distributed evenly over the entire cross section.

From the qualitative results it is seen that for the larger packing, the water dropped from the tower in a few thick streams, while for the smaller packing the streams seemed greater in number and carried less volume of water. With the large packing the amount of open spaces between rings is much larger than for smaller packing, thus the liquor would tend to form fewer but larger streams.

Tower Size.

From Figures 2 to 6 it is noted that tower size has a great effect on channeling. For towers with diameters of three or four inches the constancy of distribution attained at five feet of packing is when between 50 and 70 percent of the liquid flows in the outer quarter of area a figure well above the desired value for uniform distribution, 25 percent. On the other hand, for the eight-inch tower, packed with the same rings and at the same rates of feed, these percentages are between 20 and 30 percent. In most of the higher curves, ratios of tower diameter to size of packing are small (6, 4) while in the low curves similar ratios are large numbers (8, 16).

These results seem to indicate that towers with too large a packing for a narrow diameter show extreme concentration of liquid in the outer sections. They have per foot of length less pieces of packing in contact with the walls to divert the liquid running down the walls back to the rest of the packing. However, according to this reasoning if such a tower were packed with smaller rings, distribution should be more uniform. The data show that this is not the case, and an explanation of the phenomenon has been presented in the preceding section.

The results obtained do not agree completely with the general rule stated by Baker, Chilton, and Vernon that uniform distribution (25 percent) is eventually attained and kept in all towers, provided that the ratio of tower diameter to packing size be larger than eight to one.

Such a figure seems to hold for towers packed with one-inch stoneware rings; however, for columns packed with one-half inch carbon rings the eight to one ratio is not true by any means, a larger figure seeming more adequate. The best distribution with one-half-inch carbon rings is obtained for the eight-inch tower (ratio 16); however, data are not sufficient to indicate constancy of distribution. Larger ratios than sixteen to one will probably give a constant distribution at 25 percent.

Effect of Feed Distribution.

In this experiment only one method of feed distribution was used, single point distribution. From an observation of Figures 2 to 11 it is noted that constancy of distribution is never attained before four or five feet of packing. The effect of multiple point distribution is to shorten this five feet distance necessary to obtain a steady state[1]. Thus with a four point distributor, constancy of liquid distribution can be reached with one foot of packing. Chilton and colleagues[1] have shown that distributors with more than four points are not more efficient in producing this effect.

Discussion of Eight-Inch Tower.

From Figures 2 to 6 it is noted that for the eight-inch tower the one-inch and one-half-inch curves intersect at three pipe diameters and 25 percent of liquor in the outer quarter of area. It is also noted that from the origin to this intersection the curve for the one-inch rings is concave downward while that for the one-half-inch rings is concave upward. If the ordinates are expressed by y, liquid distributed over the outer quarter of area, and the abscissae, x, express feet of packing, these two curves may be represented by a general equation such as $x = ky^n$, k and n being functions of packing size and material. For the one-inch curve n seems to be two while for the one-half-inch rings n is one half. It must be remembered that here there are two variables involved, ring size and ring material. The relative effects of each on this general equation can not be predicted from the data obtained.

This correlation shows that with one-inch rings the initial two feet of packing are wetted much more than for the one-half-inch rings. Thus with single point distribution, even for the first two feet of packing, the one-inch rings are more efficient than the one-half-inch rings.

Best Towers for Pilot Plants.

From study of the results it can be inferred that the best tower size for ordinary pilot work is the eight-inch tower with one-inch rings. Such a tower is the only one studied that reaches a constant distribution between 20 and 30 percent, which represents uniform liquid distribution. The only inconvenience of this tower is that at least five feet of packing are needed with central feed to reach this constant uniform distribution. However, this distance can be shortened considerably by the use of multiple point distributors. Then a uniform distribution (25 percent) may probably be reached and kept with as little as a foot of packing.

A word of warning may be included about the use of one-half-inch rings in three, four and six-inch towers. It is seen that in them constancy of distribution is reached when high percentages of liquid flow through the outer quarter of area. Multiple distributors would make the effect worse for they help to reach this steady state sooner.

VI. CONCLUSIONS

1. One-inch stoneware rings seem to give in all cases studied a more uniform distribution than one-half-inch carbon rings, not because of the difference in material but because of the difference in size.
2. In small towers with central feed the percent of liquid distributed over the outer quarter of cross section increases with height of packing until approximately five feet are reached. Beyond this height a constant value is attained.
3. Towers packed with one-inch stoneware rings seem to reach uniform constant distribution of liquid through their cross sections if the ratio of their diameter to size of packing is greater than eight to one.
4. Towers packed with one-half inch rings seem to reach uniform constant distribution of liquid through their cross section for much larger ratios of tower diameter to size of packing, at any rate larger than sixteen to one.
5. Material out of which packing is made seems to affect channeling, porous material showing more tendency to channel. Carbon rings give better distribution than stoneware rings.

6. Changes of liquor rate from 2500 to 5000 lbs./hr.-ft.^{2} have negligible effect on channeling.
7. The best tower size for pilot plant work is the eight-inch tower packed with one-inch rings.

VII. RECOMMENDATIONS

In order to test the proposed theories about channeling it is recommended that:

1. The relation between channeling and hold-up be investigated.
2. Further data be obtained with more varied sizes and materials of packing, in an attempt to check the conclusions arrived at.

In order to make valid the extrapolation of pilot plant data to industrial scale equipment it is recommended that:

1. Eight-inch diameter of wider towers be used with one-inch packing.
2. With one-half-inch packing towers be used with much larger ratios of diameter to size of packing, at any rate ratios larger than sixteen to one.
3. Towers above six inches in diameter be more than five feet high if central distribution is used and about one foot if multiple distributors are employed.

VIII. APPENDIX

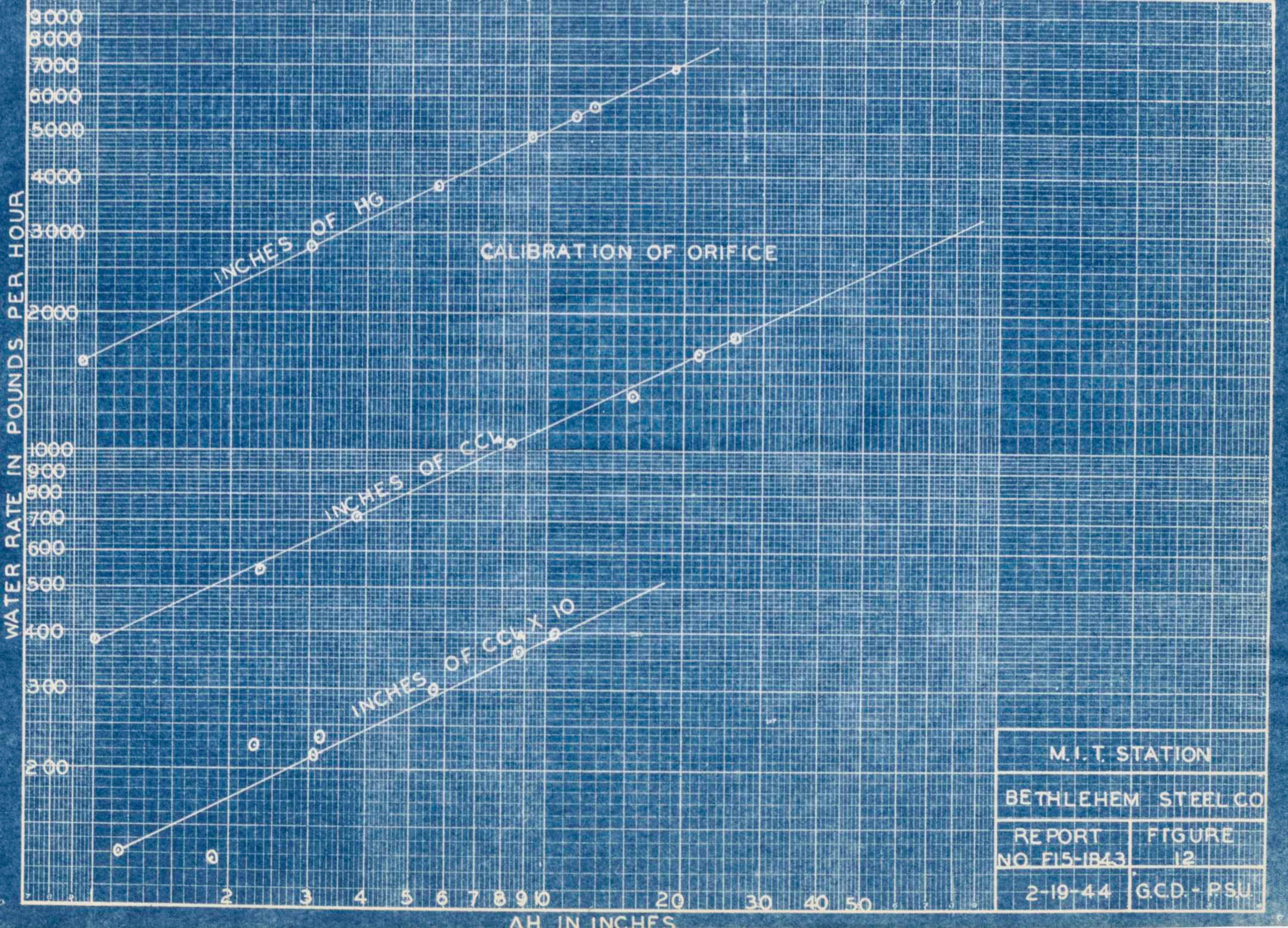
A. DETAILS OF PROCEDURE

Calibration of Orifice.

The orifice used in measuring the feed rates was calibrated in the usual manner. A measured amount of water was allowed to flow through the orifice during a measured interval of time. Readings of the manometer installed across the pressure taps were taken during this time. The readings remained constant at small rates of flow, but at high rates they varied from one to one and a half inches. When this was the case the representative change of head for the run was the calculated as the square of the arithmetic averages of the square roots of the observed changes in head, since in ideal orifices flow rate is proportional to the square root of the change in head.

Each run made gave a rate of flow with a corresponding change of head. All points thus obtained were plotted in the calibration graph shown in Figure 12.

For high rates of flow, above 1500 lbs./hr. a vertical mercury manometer was used; between 1500 and 400 lbs./hr. carbon tetrachloride was substituted as manometer fluid. Finally, below 400 lbs./hr. an inclined carbon tetrachloride manometer was employed.



CALIBRATION OF ORIFICE

M.I.T. STATION

BETHLEHEM STEEL CO

REPORT NO F15-1843	FIGURE 12
2-19-44	G.C.D. - P.S.U.

B. SUMMARY OF DATA AND CALCULATIONS

3" Diameter Tower

½" Carbon Rings Packing

Height of Packing	Liquor Rate	Liquid in inner ¾ of cross section	Liquid in outer ¼ of cross sect.
feet	lbs./hr.-Ft.^{2}	%	%
1	4730	53.7	46.3
1	2550	54.3	45.7
2	2380	41.5	58.5
3	2180	42.3	57.7
4	3360	43.4	56.6
5	2380	27.2	72.8

6" Diameter Tower

½" Carbon Rings Packing

1	4720	75.9	24.1
1	2540	68.8	31.2
2	5000	62.8	37.2
2	2540	60.2	39.8
3	4600	56.8	43.2
3	2600	54.7	45.3
4	4570	55.4	44.6
4	2670	49.8	50.2
5	4780	56.9	43.1
5	2400	56.9	43.1

6" Diameter Tower

1" Stoneware Rings Packing

Height of Packing feet	Liquor Rate lbs./hr.-ft.^{2}	Liquid in inner $\frac{3}{4}$ of cross sect. %	Liquid in outer $\frac{1}{4}$ of cross sect. %
1	4600	81.7	18.3
1	2370	84.1	15.9
2	4790	51.8	48.2
2	2530	69.2	30.8
3	5130	62.6	37.4
3	2490	67.3	32.7
4	4600	64.3	35.7
4	2340	61.7	38.3
5	4780	61.3	38.7
5	2540	61.7	38.3

8" Diameter Tower

$\frac{1}{2}$" Carbon Rings Packing

1	4300	95.1	4.9
1	3670	95.3	4.7
1	3240	94.4	5.6
1	2480	96.2	3.8
2	4240	75.8	24.2
2	3900	75.2	24.8
2	3300	75.3	24.7
2	2440	75.3	24.7
3	4860	72.2	27.8
3	4330	70.0	30.0
3	3790	70.4	29.6
3	3230	70.0	30.0
3	2390	68.6	31.4

8" Diameter Tower

1" Stoneware Rings Packing

Height of Packing feet	Liquor Rate lbs./hr.-ft.^{2}	Liquid in inner $\frac{3}{4}$ of cross sect. %	Liquid in outer $\frac{1}{4}$ of cross sect. %
1	5130	79.7	20.3
1	5130	81.2	18.8
1	4820	79.7	20.3
1	3920	86.1	13.9
1	3440	87.6	12.4
1	2280	85.6	14.4
1	2290	85.7	14.3
2	4930	75.4	24.6
2	4440	74.0	26.0
2	4180	75.7	24.3
2	3380	73.6	26.4
2	2580	77.1	22.9
3	4870	76.1	23.9
3	4300	76.3	23.7
3	3930	74.9	25.1
3	3230	75.9	24.1
3	2420	75.3	24.7
4	4720	72.4	27.6
4	4300	73.8	26.2
4	3750	73.0	27.0
4	3320	71.6	28.4
4	2430	70.4	29.6
5	4820	68.9	31.1
5	4150	68.6	31.4
5	3810	66.8	33.2
5	3770	68.4	31.6
5	3140	69.6	30.4
5	2560	63.6	36.4

4" Diameter Tower

½" Carbon Rings Packing

Height of Packing	Liquor Rate	Liquid in inner ¾ of cross sect.	Liquid in outer ¼ of cross sect.
feet	$lbs./hr.-ft.^2$	%	%
1	4830	51.7	48.3
1	4280	33.6	66.4
1	3740	34.2	65.8
1	3270	47.3	52.7
1	2550	37.7	62.3
2	4890	42.7	57.3
2	4440	41.3	58.7
2	3680	34.1	65.9
2	3020	40.5	59.5
2	2525	34.0	66.0
3	4800	36.8	63.2
3	4350	34.5	65.5
3	3790	36.7	63.3
3	2970	34.3	65.7
3	2540	33.5	66.5
4	4860	34.0	66.0
4	4420	49.9	50.1
4	3790	40.6	59.4
4	2960	38.1	61.9
4	2230	30.5	69.5
5	4930	41.5	58.5
5	4340	35.0	65.0
5	3690	32.5	67.5
5	3050	36.5	63.5
5	2640	51.8	48.2

4" Diameter Tower

1" Stoneware Rings Packing

Height of Packing feet	Liquor Rate lbs./hr.-ft.^{2}	Liquid in inner $\frac{3}{4}$ of cross sect. %	Liquid in outer $\frac{1}{4}$ of cross sect. %
1	4940	55.6	44.4
1	4640	59.6	40.4
1	3580	67.4	32.6
1	3350	66.6	33.4
1	2550	64.5	35.5
2	4950	45.6	54.4
2	4470	42.8	57.2
2	3640	45.5	54.5
2	3190	45.8	54.2
2	2640	47.0	53.0
3	4840	39.8	60.2
3	4330	42.4	57.6
3	4290	43.3	56.7
3	3260	44.3	55.7
3	2320	43.5	56.5
4	5160	44.8	55.2
4	4460	39.3	60.7
4	3620	40.7	59.3
4	3180	42.6	57.4
4	2580	43.2	56.8
5	4940	41.9	58.1
5	4370	41.4	58.6
5	3640	39.3	60.7
5	3350	39.8	60.2
5	2145	38.7	61.3

C. SAMPLE CALCULATIONS

Calibration of Orifice.

Water was allowed to flow through the orifice for an interval of time, readings of the manometer being taken. The water run through was collected and weighed.

Time interval : 5 min. 21.8 ± 0.2 sec. = 5.363 ± 0.004 min.		
Weight of full container	189.63 ± 0.06	lbs.
Weight of empty container	44.06 ± 0.06	lbs.
Weight of water	145.6 ± 0.1	lbs.
Rate of flow $\frac{145.6}{5.363} \times 60$ =	1630 ± 20	lbs./hr.

Change of head during interv. inches CCl_4	$\sqrt{H}$	Deviation of $\sqrt{H}$ from mean
21.4	4.62	0.013
21.8	4.67	0.037
21.7	4.65	0.017
21.1	4.59	0.043
	18.53	0.110

Mean $\sqrt{H}$ = 4.633 or 4.63 ± 0.03

H = 21.5 ± 0.3

These calculations give rise to point 21.5 ± 0.3, 1630 ± 20 in the graph of common logarithm of rate in pounds per hour versus common logarithm of change of height of the manometer fluid in inches. (Figure 12). Other points were found in like manner.

Liquid Distribution.

8" Diameter Tower

4 feet of packing of 1" stoneware rings

Weight of full container	73.87±0.06 lbs.	
Weight of empty container	27.19±0.06 lbs.	
Water in outer quarter section of tower		46.7±0.1 lbs.
Weight of full container	175.50±0.06 lbs.	
Weight of empty container	43.94±0.06 lbs.	
Water in inner three quarters section of tower		131.6±0.1 lbs.
Total water		178.3±0.2 lbs.

Percent of water in outer quarter $\frac{46.7}{178.3} \times 100 = 26.2 \pm 0.2\ \%$

Percent of water in inner three quarters $\frac{131.6}{178.3} \times 100 = 73.8 \pm 0.2\ \%$

Check of Water Balance.

Change of height during interval	Rates from graph
inches CCl_4	lbs. per hour
18.1 0.1	1510 ± 20
17.8 0.1	1490 ± 20

Average rate for interval 1500 ± 10

Interval of run 7 min. 12.6 sec. = 7.210 ± 0.003 min.

Total water $\frac{1500}{60} \times 7.210 = 180 \pm 2$ lbs.

D. LOCATION OF ORIGINAL DATA

Book Number	Description of Data	Pages
71	Calibration of orifice	127-128 136-137
71	Channeling on eight inch diameter tower	129-134
71	Channeling on four inch diameter tower	135 138-146
81	Channeling on six inch diameter tower	12-14
81	Channeling on three inch diameter tower	15

Data books are on file at the M. I. T. Station of Chemical Engineering Practice, Bethlehem Steel Company, Lackawanna, New York.

E. LITERATURE CITATIONS

1. Baker, J. C., Chilton, J. H., and Vernon, H. C.; Trans. Am. Inst. Chem. Eng., 31, 296-315 (1935).
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3. Jesser, B. W., and Elgin, J. C.; Trans. Am. Inst. Chem. Eng. 39, 277-298 (1943).
4. Sherwood, T. K.; "Absorption and Extraction", lst. ed. Mc Graw-Hill Book Company, New York (1937).
5. Tour, R. S., and Lerman, F.; Trans. Am. Inst. Chem. Eng. 35, 709-718, 719-742 (1939); 36, 177-179 (1940).