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A STUDY OF THE FLOW OF WATER
IN THE SETTLING BASINS OF THE
DETROIT WATER WORKS.
ITS EFFICIENCY AND IMPROVEMENT

Thesis for the Degree of B. S.

Harry S. Aten

1927

27
THESIS

**A STUDY OF THE FLOW OF WATER IN THE SETTLING BASINS
OF THE DETROIT WATER WORKS. ITS EFFICIENCY AND
IMPROVEMENT.**

A THESIS

**Submitted to the faculty of
the Michigan State College of
Agriculture and Applied Science.**

By

Harry S. Aten

Candidate

**for the degree of
Bachelor of Science**

June 1927

THESIS

cop. 1

I wish to take this opportunity to express my great appreciation and to thank the members of the Engineering Department of the [~]Detroit Water Works for their generous assistance and hearty cooperation given me while collecting the data for this thesis.

I also wish to thank professor C. L. Allon and professor H. C. Woods for their part in assisting me in this work.

A STUDY OF THE FLOW OF WATER IN THE SETTLING BASINS
OF THE DETROIT WATER WORKS. ITS EFFICIENCY AND
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PROBLEM

It has been found from experiments on the settling basins of the Detroit water works that the "detention time" is a very poor measure of the actual conditions in the tanks. It has been found, for example, that with a theoretical detention time of a little over three hours some of the particles of any certain charge of water find their way through in less than fifty minutes while others take six hours or more to get through, with the larger portion of the charge passing through in from one to three hours.

Theoretically every particle of water should pass through in the same length of time as every other particle, that is, suppose that a certain quantity of water be charged into the inlet of the basin in a mass, That quantity should pass through the basin and out of it in the same mass with each particle in the same general relation to its fellows as at the beginning. A basin with this condition of flow would be an ideal basin. Obviously, however, this condition cannot be fully attained but it can be quite closely approximated.

If it were possible to attain a complete lack of

FLOW OF WATER IN THE SETTLING BASINS
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dispersion in a tank the ideal or perfect flow in the tank would be accomplished. With a straight rectangular tank open at both ends, the ideal flow would mean that the velocity at any point would be the same as at any other point and that the water entering in a vertical plane at one end would pass out at the other as the same vertical plane. However, with the water flowing in a curved path, as it does at the Detroit plant, it will be necessary that the velocities at some points be greater than at others to cause the water to flow in and out in the same relation. A numerical measure of this dispersion in the tanks would be a fair indication of the efficiency of the basin. The smaller the dispersion the higher the efficiency.

The problem, then, is to find a measure for this dispersion and then put such an arrangement of baffles, screens, or vanes in the basin as will make this dispersion as small as possible.

MEANING OF DISPERSION

In this discussion dispersion is taken to mean what is commonly termed short circuiting. It is believed by some that this is a better term for it. The word dispersion, however, would include not only short circuiting but also long circuiting and so would indicate the whole action of the water in the tank and not just a part of it. Short circuiting is where a portion of the water takes a more direct route from the inlet to the outlet at a much

higher velocity than the theoretical. Long circuiting, then, must be taken to mean just the opposite, or where a portion of the water stays in an eddy for some time or flows in a circuituous route at a low velocity.

EFFECT OF DISPERSION

Experiments conducted by Imhoff on sewage settling basins show that the effect of the detention time on the clearness of the effluent diminishes progressively with the time. That is, the first unit of time is more effective than the second and the second is more effective than the third and so on. Now if the dispersion in the tank is great it is apparent that the water that passes through in a short while has less settled parts per million than that which is retained a longer time but as all the water flows out of the same outlet the water of less clearness is mixed with that of greater clearness and the effluent has a quality of an effluent from a tank where there is no dispersion and a detention time somewhat less than the theoretical period of the tank with the greater dispersion. Therefore, a tank devoid of dispersion would give a much clearer effluent than one having the same detention time and great dispersion.

NEED OF A MEASURE OF DISPERSION

It would appear then that dispersion lowers the efficiency of a settling basin. If this is true, then a

measure of this dispersion would be important in indicating the action or characteristics of the basin. In the words of Mr. Morrill of the Detroit Water Works, a measure of the dispersion in a settling basin is a dimension, nearly, if not quite as important as the actual volume of the basin. To give the nominal time of a settling basin without giving a measure of its dispersion is like giving the effective size of a filter sand without giving its uniformity coefficient.

FLOATS

Floats were at first used to determine the dispersion in the tanks. These floats were of two types, namely, surface floats and subsurface floats. By placing these floats at various points and watching their respective courses, a good general idea of the currents and eddies in the tanks was obtained. However, floats started at the same point but at different times behaved entirely different from each other. This showed that the eddies were ever changing and no representative indications could be obtained. Some floats would pass from inlet to outlet in a fairly direct path while others would get into a large slow eddy and at times would one and at times would move in the opposite directions, still others would get in a corner or along the wall and remain there. Sometimes the paths would cross each other thus indicating that the water flowed now in one direction and then in

another.

When the floats' paths were plotted up they proved to be merely a maze of lines from which no definite conclusions of value could be drawn. Other than showing that there was dispersion and that the flow in the tanks was very poor, the floats proved useless.

COLORED WATER

Coloring matter was next used as an indicator. The water was dosed with the colored liquid at the inlet and the color front of the flow was carefully plotted at one minute intervals. A model basin similar to the one shown in fig. 1 was used for these and succeeding experiments. Wires were stretched across the basin parallel to all four sides at one foot intervals. A man standing above this model with a chart could easily draw in the contours. A sample of these contours is shown in fig. 2. Mud was at first used as a coloring matter but it settled out too quickly and it also necessitated cleaning the basin after each run. Uranine was then tried with much better success. This is of such a nature that it will diffuse quite thoroughly with the water. A small quantity poured in to the water at the inlet would color it sufficiently to enable the observer to follow the course of the water around the tank with ease. However, where there was a reversal of flow the colored water flowing backward would

Subject MODEL BASIN

Gallons per Minute 58

Theor.
Velocity 1.65'/M

Adjusted for Currents

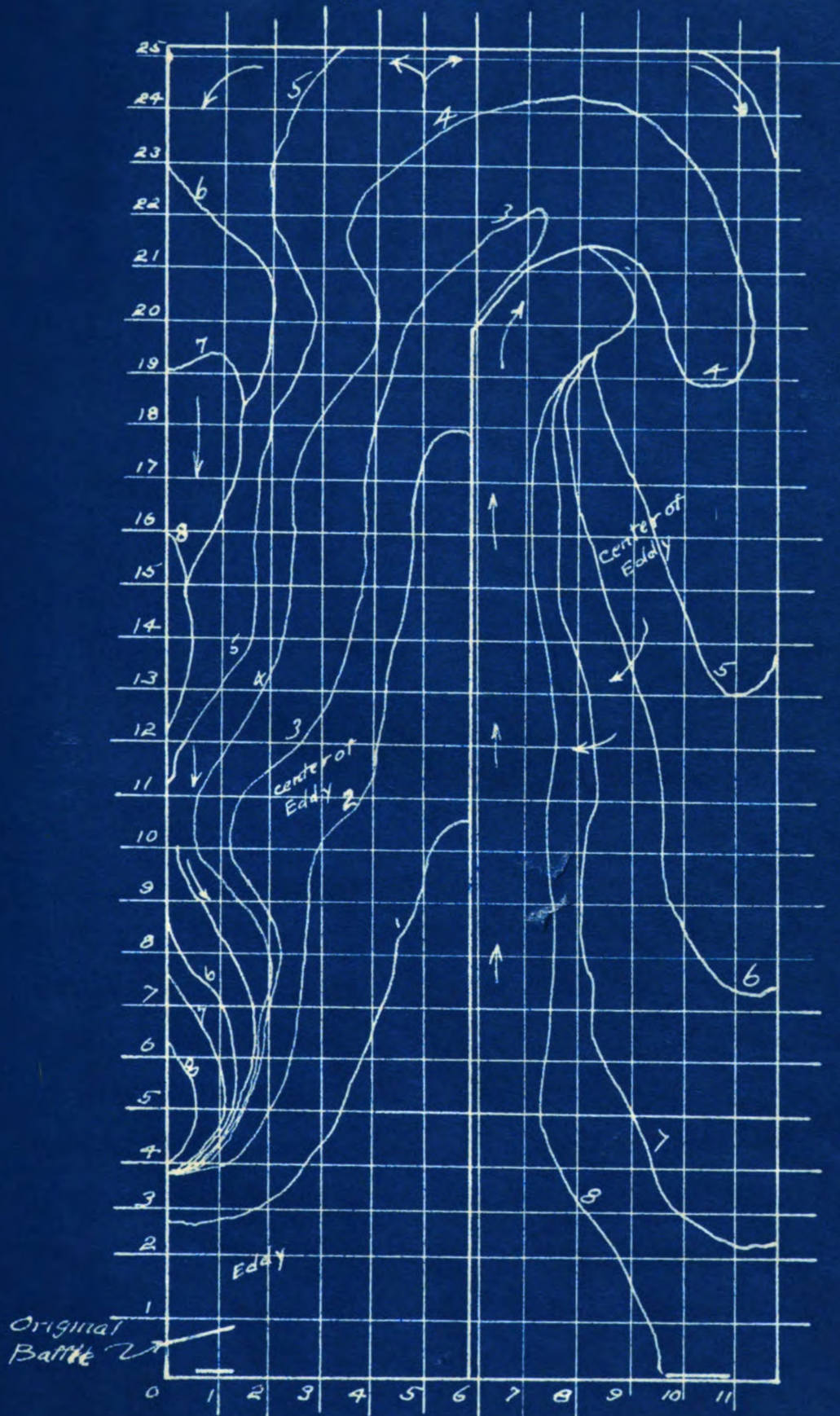


Fig. 1

mix with the other and no indications could be obtained.

This method gave sufficient indications of the flow to allow experiments to be carried on using different arrangements of screens, vanes, and baffles. No numerical data could be obtained from this method that would in any way give a measure of the dispersion or of the efficiency of the basin. Quite a number of experiments were carried on by this method using different arrangements in the tank but as a better method of indicating the dispersion was later devised the results of these experiments will not be given. This method did prove valuable, however, in adjusting the flow in the model basin to make the conditions of flow in it to that in the large basin.

THE SALT TEST

The salt test is the same in principle as the color test with this exception, it lends itself quite readily to chemical and mathematical analysis. To make this test a mixing chamber is required in which to mix up the salt solution and some means is necessary whereby the solution may be dosed into the water in as short a time as possible. Accordingly a tank was constructed large enough to hold a quantity of water sufficient to dissolve about $\frac{1}{2}$ pound of salt for use with the model basin. An outlet was provided that would empty the tank in approximately one minute. By taking quantitative analyses of the effluent

at one minute intervals from the time of dosing to the time when no more excess salt appears and plotting these results on ordinary graph paper, a curve will be obtained that closely resembles a normal distribution curve. The data thus obtained will be in parts per million per minute of salt.

The method used to make the quantitative analysis of the effluent was to measure the resistances at the outlet by means of an Ohmmeter. This consisted essentially of a wheatstone bridge and a cell containing two platinized electrodes. This instrument measures the resistance of the liquid in ohms. To use this data it must be changed into p.p.m. of salt which necessitated calibrating the instrument to read in p.p.m. In calibrating the instrument it was found that temperature change effected the readings materially. A change of one tenth of a degree centegrade being sufficient to change the resistance of the solution about 7 ohms. With the temperature constant, a change of one ohm indicates a change of about .2 p.p.m. of salt. Accordingly it is necessary from the point of accuracy to read temperatures to the hundredth of a degree. The cell should be placed in such a place in the outlet as to secure the most representative readings.

If each p.p.m. of salt be considered as an individual phenomenon with a certain number occurring or passing out in each unit of time, it will be seen that they truly represent a frequency distribution . When plotted as a

frequency series the curve will conform more or less closely to the curve of normal distribution, depending on the efficiency of the basin. If the data be considered as a grouped frequency series, it will be seen that a certain number of molecules of salt will appear a certain number of minutes after the dosing, a certain number in the next minute, and a certain number in each minute thereafter until the completion of the run when no more excess salt appears. The high point of the curve, which is the point where the molecules of salt appear most frequently, should be somewhere near the nominal time of the basin. It should be evident that the closer the high point of the curve is to the nominal time, the more efficient the basin would be. Fig. 2a shows a curve plotted from data obtained from a salt run on the original basin. Fig. 2b shows a curve obtained from the model basin with the curved vanes in place, giving a much better flow. This indicates the same thing that the color did, namely, that there is dispersion and eddying in the basin. With great dispersion the curve is irregular, rather flat and drawn out, and the center of gravity does not coincide very closely with the nominal time of the basin. At the time of writing this thesis the curved vanes had not yet been installed in the original basin so that no check on the results could be obtained. If the basin had a complete lack of dispersion, the entire

quantity of salt would come out of the outlet at or very close to the nominal time of the basin and the curve would rise from zero a minute or two before this time to a considerable height at the time and return to zero $\frac{1}{2}$ immediately after it. The center of gravity of this curve would coincide with the nominal time of the basin.

COEFFICIENT OF DISPERSION

Now if a numerical value could be obtained to indicate the difference between the center of gravity of the curve obtained from plotting the data collected from a salt run and the center of gravity of the ideal curve, or, in other words, the line through the theoretical time of the basin, it would be a fair measure of the dispersion in the basin. If dispersion be defined as that property of a series by which the several variates tend to differ in value from the average, it will be found that two series with identical means may have entirely different dispersions. There are several methods used in statistical work to measure this dispersion. Of these the average deviation is probably the best adapted to the present needs.

The average deviation is the mean of the absolute (without regard to plus and minus signs) deviations of the several variates from the median. In the following work it will be assumed sufficiently accurate to measure the deviations from the mean rather than from the median because of the somewhat greater facility of measuring the deviations from the mean. If the frequency be denoted by (f) and the

time by x , then $\sum fx = \sum f = M$, the mean time. Now let r = percent excess of salt, then $\sum r$ will be the total percent of excess salt. Let t = the theoretical time and t_0 = time in minutes from the beginning of the run. Then $(t - t_0)$ = the deviation from the mean for that minute. The average deviation, then, will be the summation of the product of each percentage and its deviation divided by the total percentage, or, expressed as a formula, A.D. = $\frac{\sum r(t - t_0)}{\sum r}$.

The coefficient of dispersion may now be defined as $100 - K$, where K is taken as the average deviation divided by the average mean time and expressed in percent. On the following page will be found an example illustrating this principle.

EXPERIMENTS

Following this discussion is a summary of the experiments that have been conducted in the attempt to improve the conditions of flow in the sedimentation basins at Detroit. The poor arrangements are given as well as the good with the idea of showing the effect of the various devices used. Many experiments were run with floats and others with coloring but the results thus obtained did not yield much information and they will not be discussed.

Design of Vanes

The arrangement shown in fig. 21 is the one that

was chosen to be used in the large basin. The vanes as designed are to be made of two sheets of iron bolted to channel irons thus forming a double wall. At the upstream end of the vanes are placed moveable wings so that adjustment can be easily made for varying rates of flow. The exact position of these vanes in the large basin will be determined largely by experiment. It is unfortunate that time does not permit of the actual results being given in this thesis.

EXAMPLE

The following is an example of the method of computing the coefficient of dispersion.

x	f	r	Σ r	(t - t ₀)	r(t - t ₀)	fx
Time in min.	p.p.m. Excess NaCl					
1	70.8	0.0				
3	71.8	1.0	1.10	1.10	5.8	3.0
4	73.5	2.7	3.00	4.10	4.8	10.8
5	76.0	5.2	5.77	9.87	3.8	26.0
6	79.5	8.7	9.66	19.53	2.8	52.2
7	82.8	12.0	13.34	32.87	1.8	84.0
8	86.6	15.8	17.57	50.44	0.8	126.4
9	83.4	12.6	14.00	64.44	0.2	113.4
10	80.8	10.0	11.00	75.44	1.2	100.0
11	78.5	7.7	8.56	84.00	2.2	84.7
12	75.9	5.1	5.66	89.66	3.2	61.2
13	74.3	3.5	3.89	93.55	4.2	45.5
14	73.1	2.3	2.56	96.11	5.2	32.2
15	72.7	1.9	2.11	98.22	6.2	28.5
16	72.0	1.2	1.33	99.55	7.2	19.2
17	71.1	0.3	0.33	99.88	8.2	5.1
18	70.9	0.1	0.11	99.99	9.2	1.8
19	70.8	0.0	----	----	10.2	----
20	70.8	0.0	----	----	11.2	----
		90.0		100.00%		216.33
						794.0

$$\text{Mean} = \frac{\sum fx}{\sum f} = \frac{794.0}{90.0} = 8.8 \text{ minutes.}$$

$$\text{A.D.} = \frac{\sum [r(t - t_0)]}{r} = \frac{216.23}{100} = 2.1623$$

$$K = \frac{\text{A.D.}}{\text{Mean}} = \frac{2.1623}{8.8} = \frac{m}{\text{min}} .246$$

$$\text{Coefficient of dispersion} = 100 - (0.246 \times 100) = 75.4\%$$

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Salt Run on West Basin
Data Not Corrected For Temperature

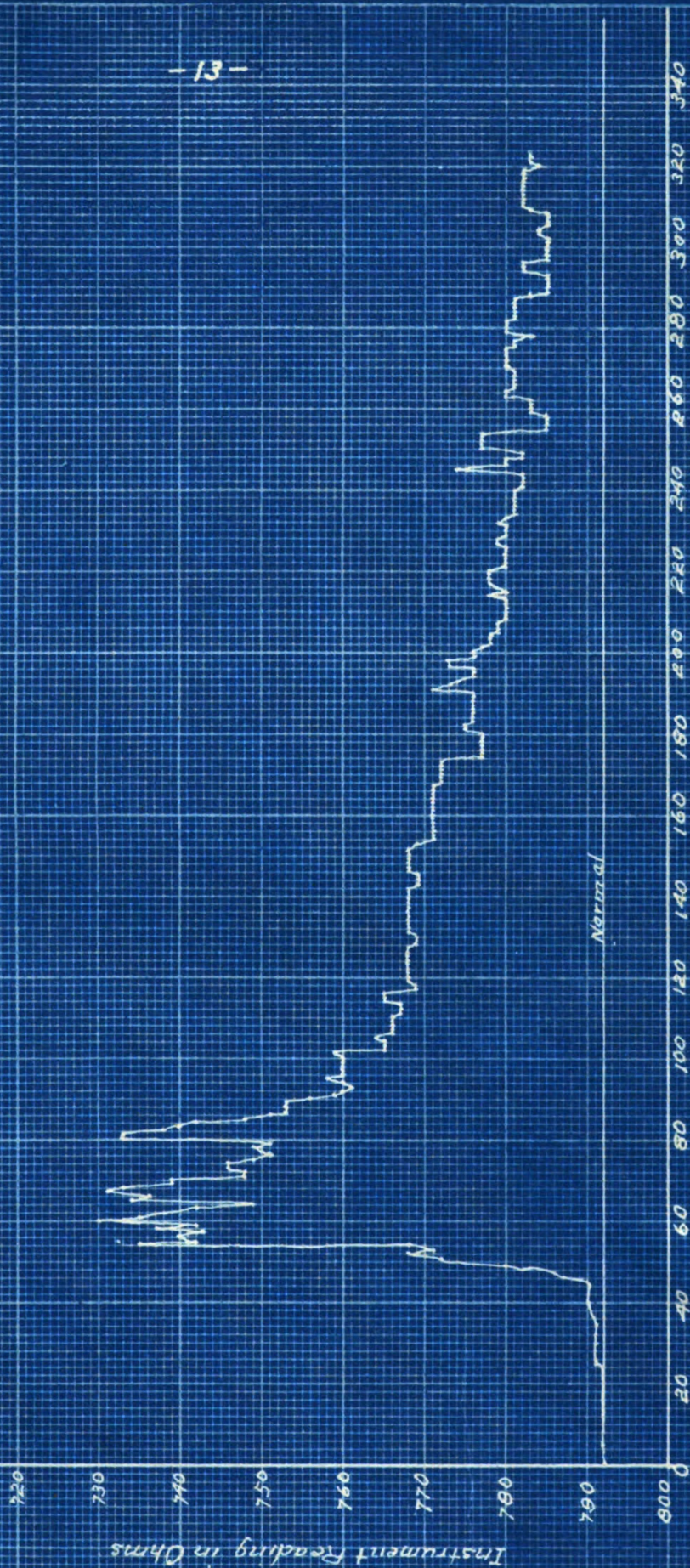
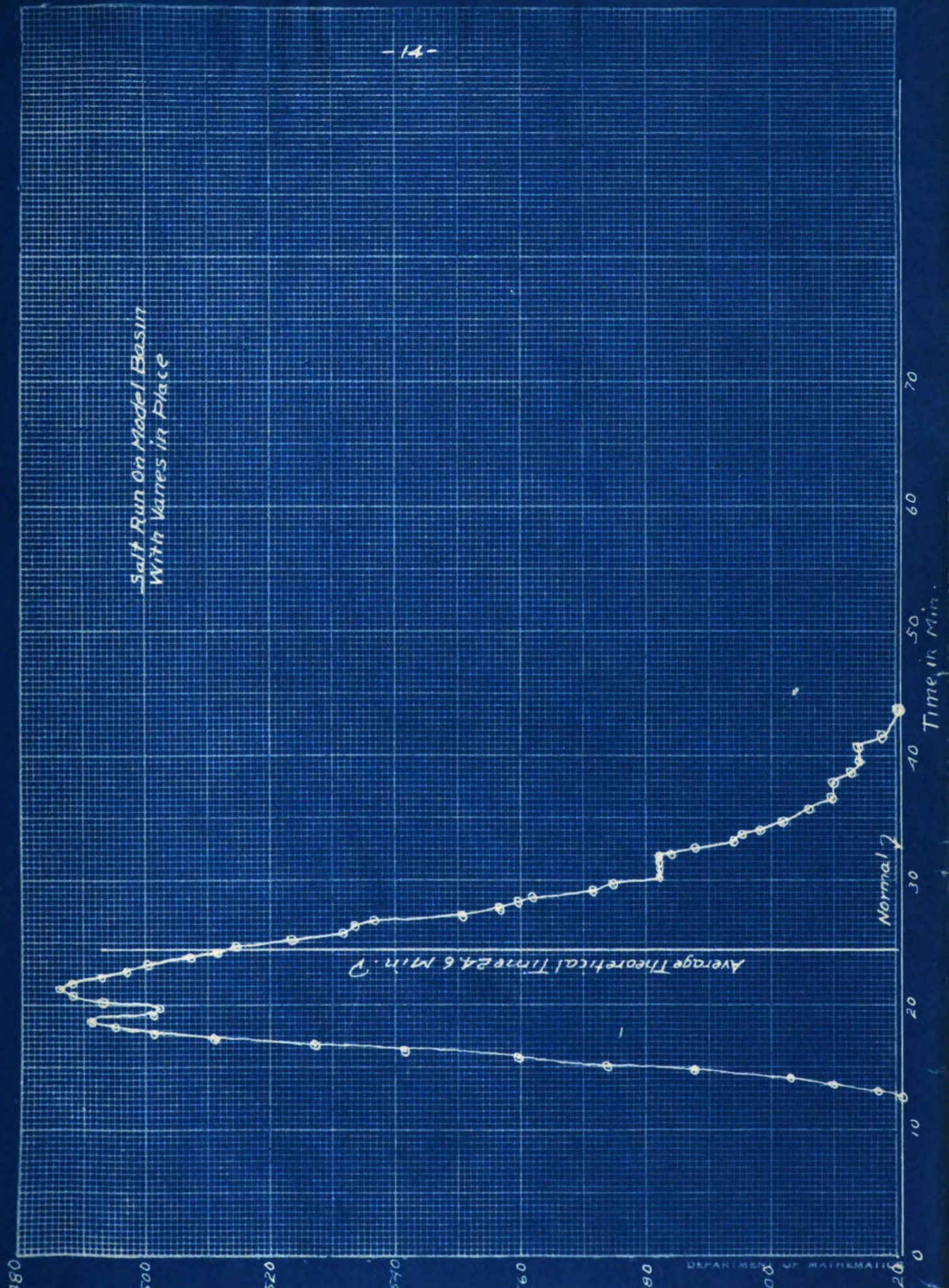


Fig. 2a.

-14-

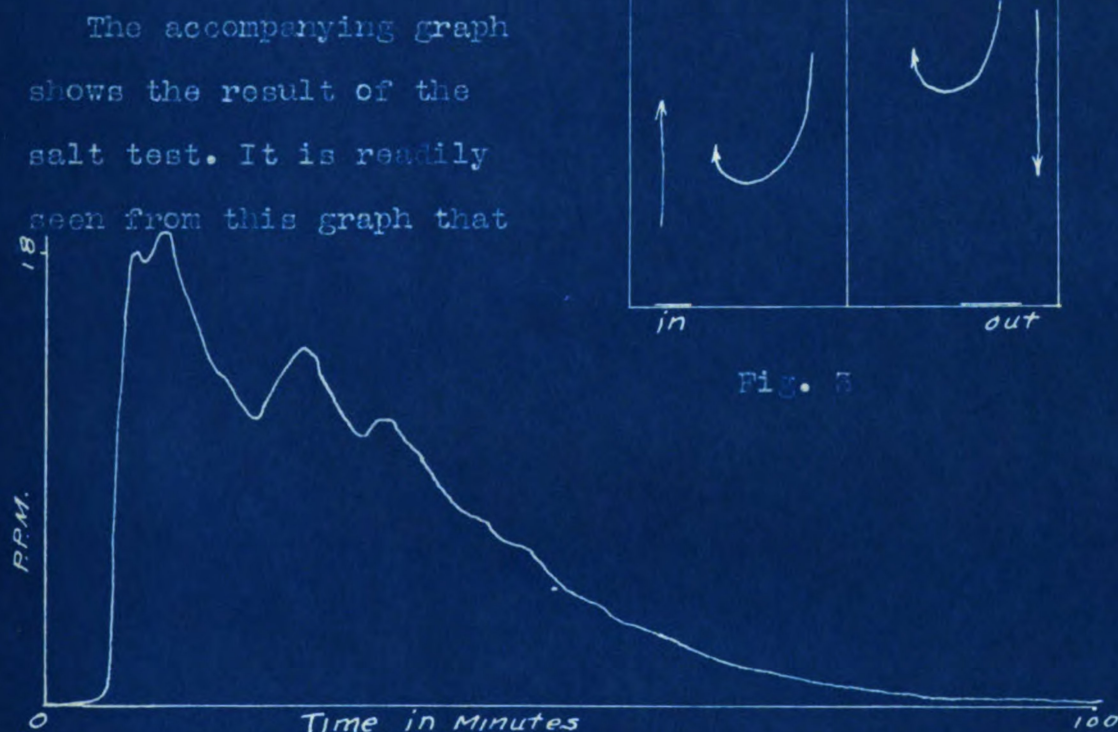
Salt Run On Model Basin
With Varies in Place



In figure 3 is shown the basin with no impediment except the corner baffles. The arrows indicate the direction of flow and the eddies.



Fig. 3



this arrangement of the basin is a very poor one. The peak of the curve occurs much too soon and the long time that it takes the curve to come back to normal indicates that there is considerable dispersion in the basin. The coefficient of efficiency was not figured for this run because the graph alone is sufficient to show that the arrangement is undesirable.

In fig. 4 is shown the actual arrangement of the large basin with the perforated baffle at the entrance. As the graph shows this baffle has a tendency to lessen the dispersion but does not have a great effect upon it.

The total flow in this run was 128 GPM.

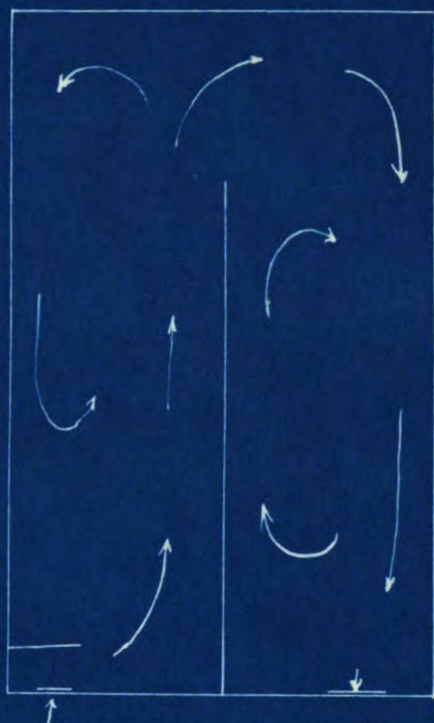


Fig. 4

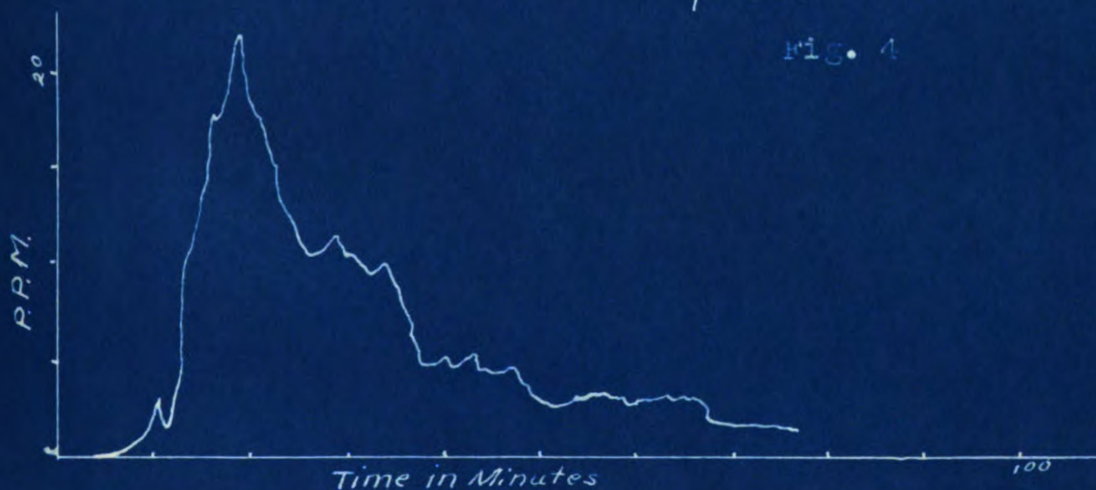


Fig. 5 is a sketch of the model basin showing screens and a curved vane in place. Below is the curve plotted from a salt run with this arrangement. Corner baffles and the original baffle were also in place.

This curve shows that this arrangement is somewhat better than the previous

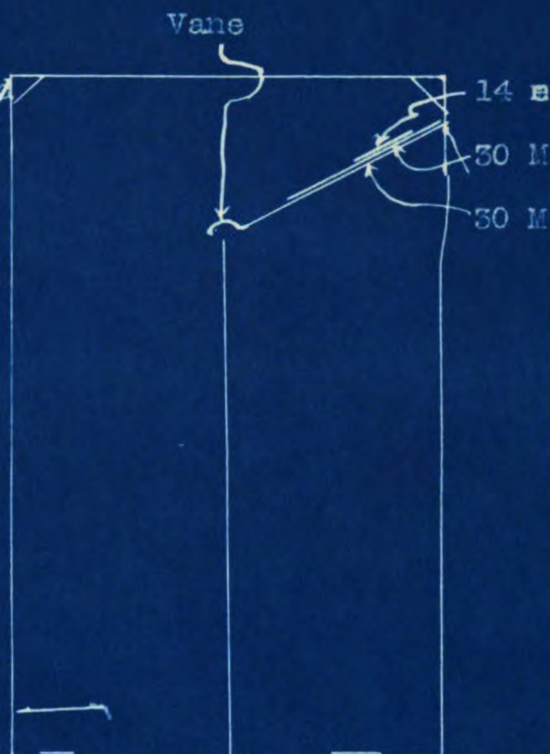
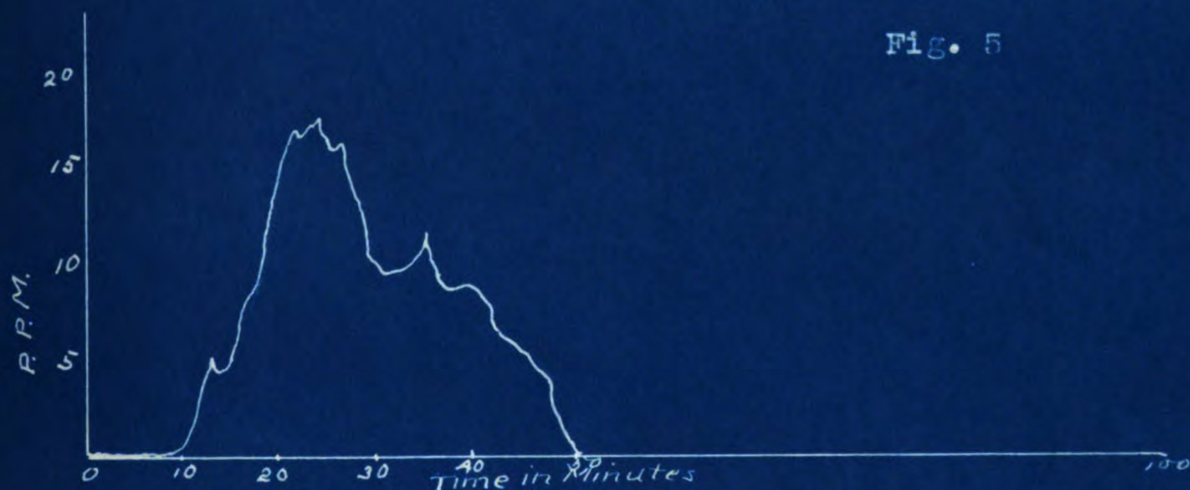


Fig. 5



ones but is quite spread out and very irregular.

The total flow was 122 gal. at the rate of 58 gal. per minute divided flow.

In fig. 6 is shown another arrangement of screens, baffle and vane.

The curve plotted from this data is less irregular than the previous ones but the peak comes rather early and it is long drawn out on the end indicating that there is still quite a lot of dispersion

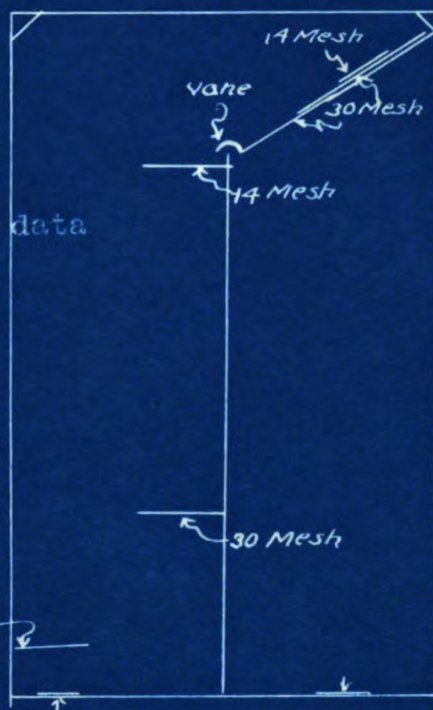
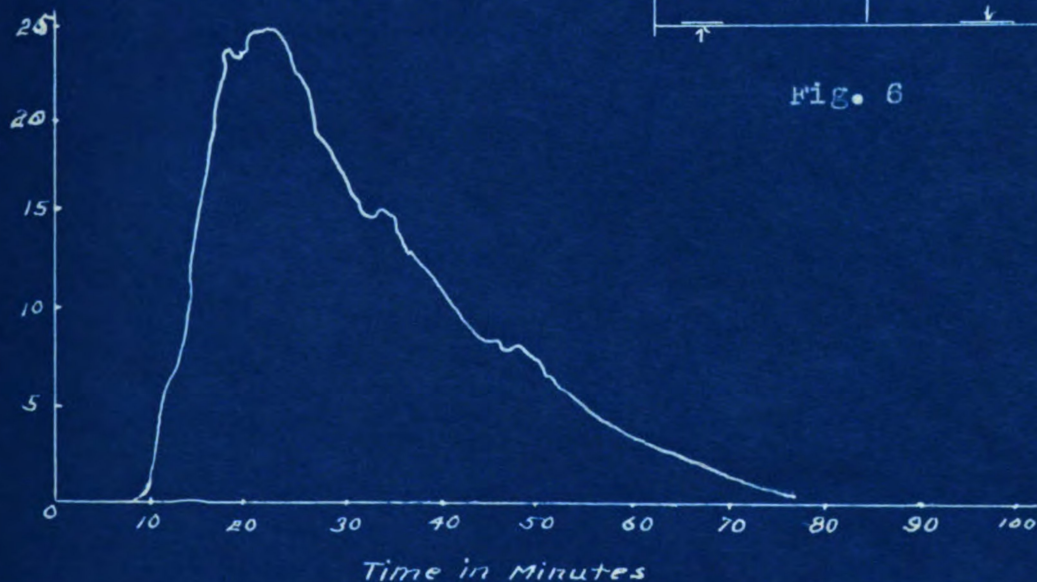


Fig. 6



and that there is a strong direct current that carries most of the water through in a short while.

The arrangement shown in fig. 7 gives but little better results than that in fig. 6. The curve is a little smoother and comes to a narrower peak. Other than ~~this~~ it has the same characteristics as the preceding one.

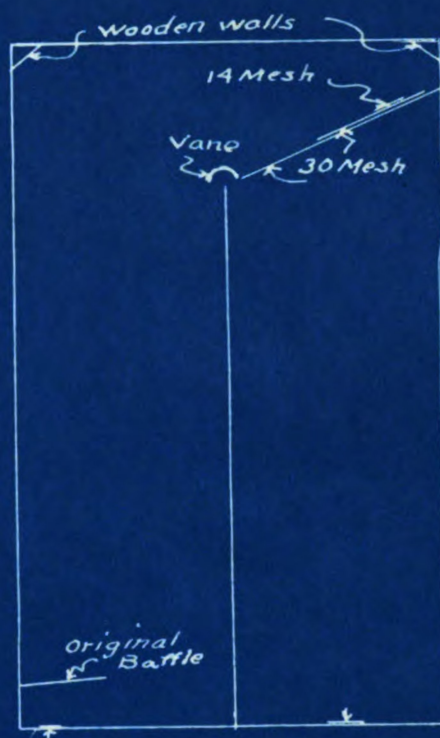
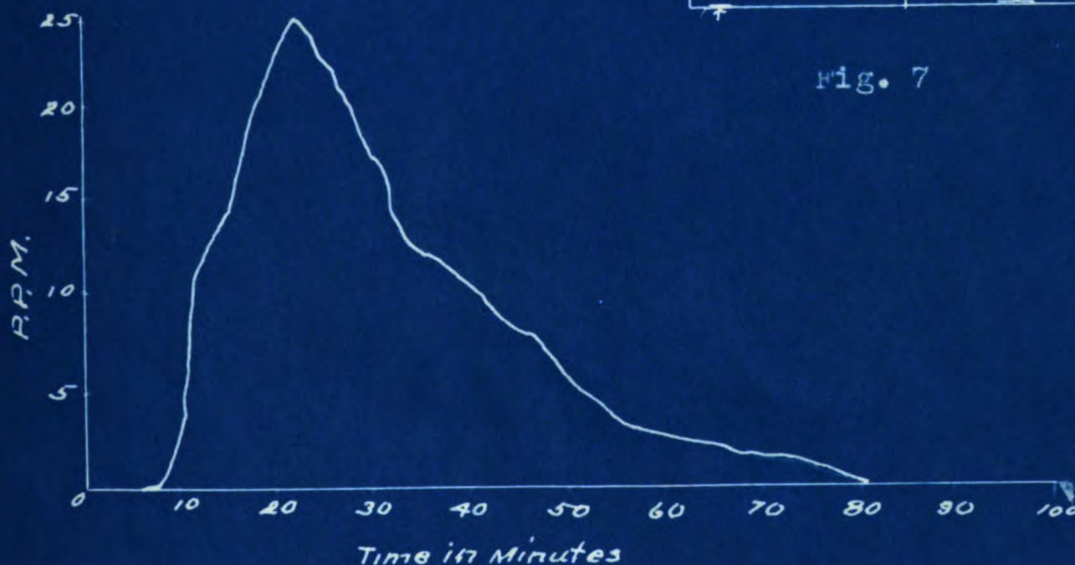


Fig. 7



The arrangement shown in Fig. 8 is not much better than the original baffle alone. The curve is fairly smooth but it returns to normal very slowly indicating very great dispersion.

The original baffle was left out and 14 and 30 mesh screens were placed around

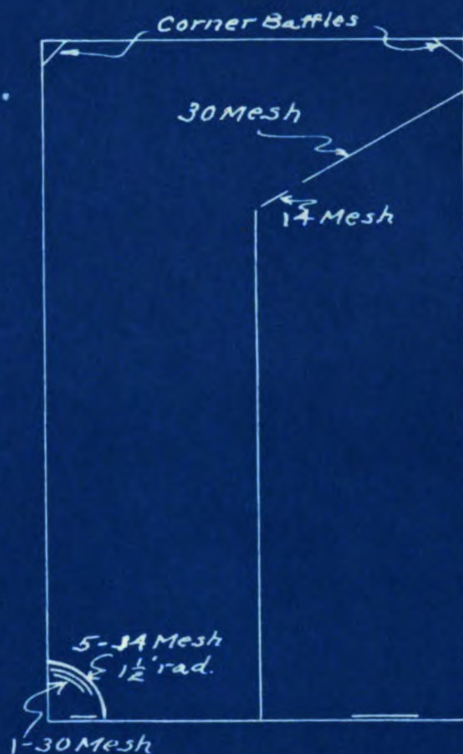
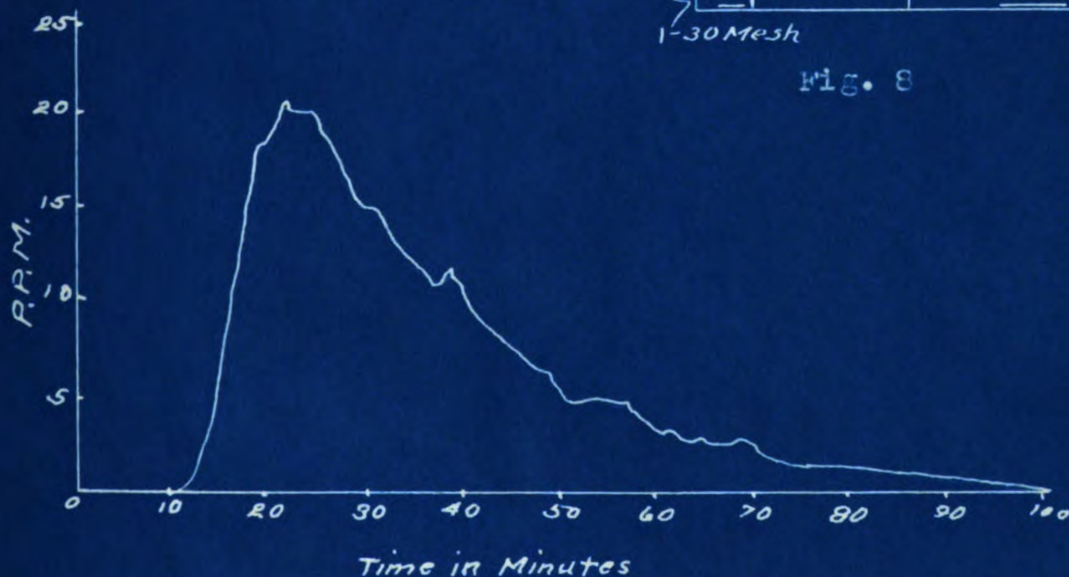


Fig. 8



the inlet at a radius of approximately one and one half feet.

In this arrangement seven glass vanes were used at the inlet to deflect the water over the entire width of the pass. A 30 mesh screen was also used at the turn. These gave the most uniform flow of any combination yet tried as is evidenced by narrow uniform curve.

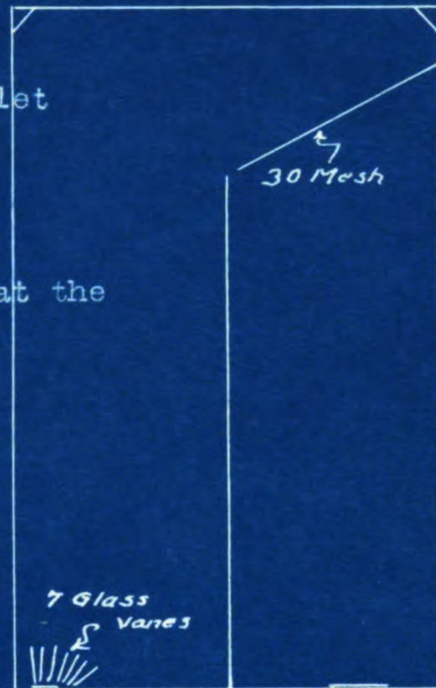
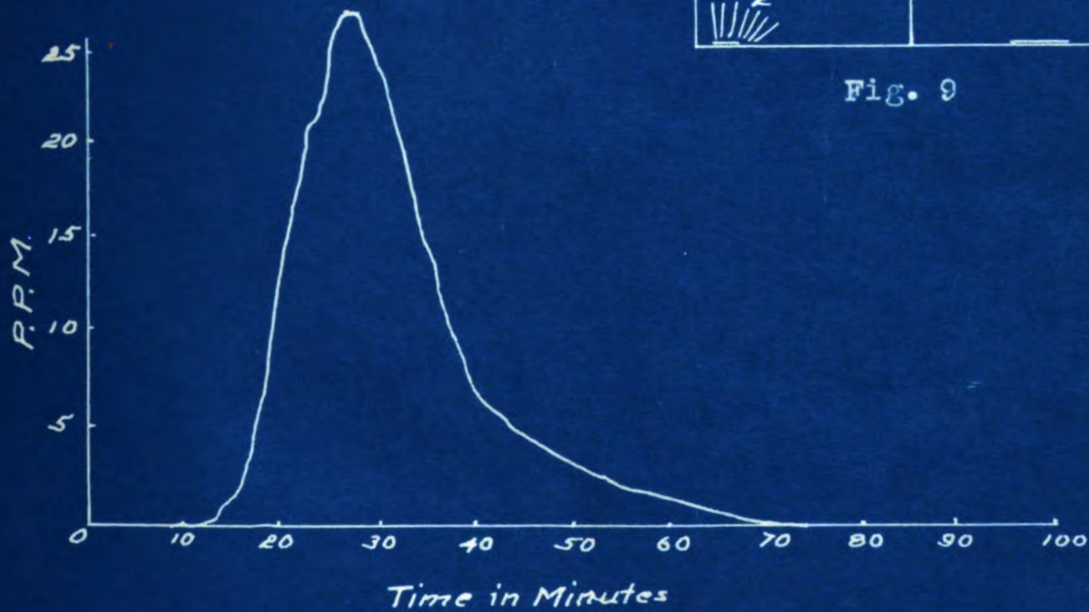


Fig. 9



Here 6 tin vanes were used with the original baffle in place. These vanes were curved and so placed as to distribute the flow as uniformly as possible over the entire passage way. A 14 mesh and a 30 mesh screen were used at the turn as shown. This arrangement gave much the same curve as the glass vanes.

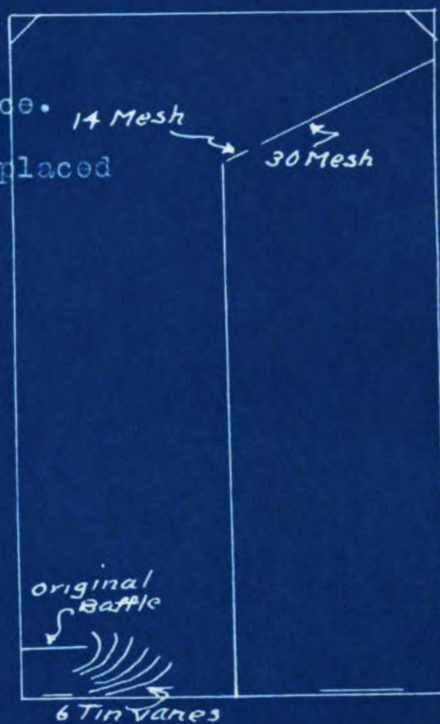
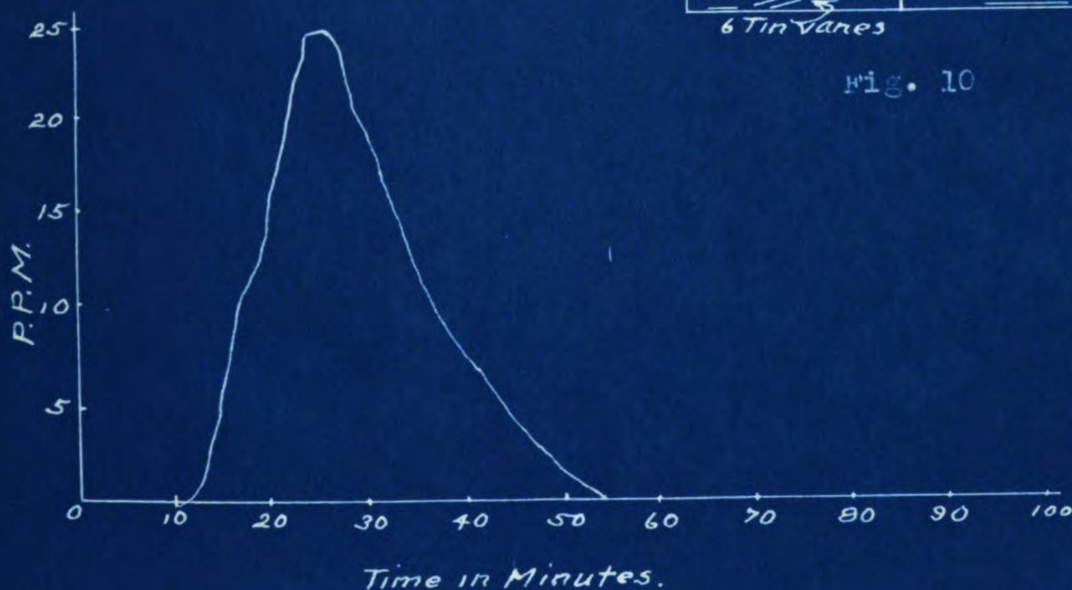


Fig. 10



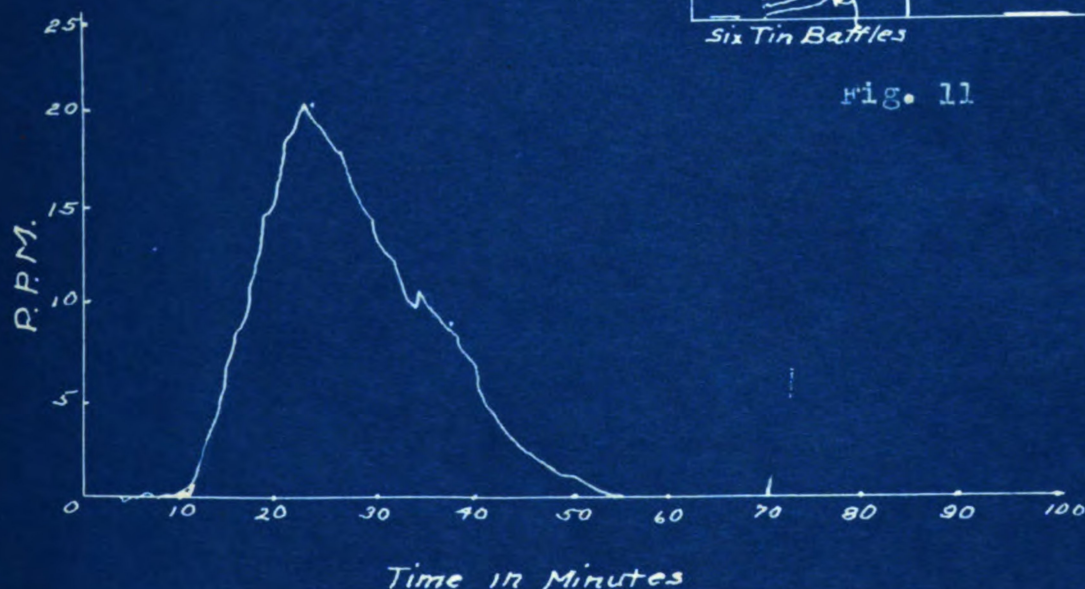
The tin vanes have the advantage over the glass of being flexible and easier to adjust.

This is the same arrangement as that on the previous page with the exception that there is a curved tin vane for a deflector at the end of the center baffle. The deflector makes very little difference in the appearance of the curve.

This same arrangement was tried without the 14 mesh



Fig. 11



screen and with the 30 mesh run all the way across. The only effect that this had was to spread out the curve a little.

This set up is the same as that shown in fig. 11 with the addition of 27 - $\frac{3}{4}$ inch couplings on the bottom at the center line of each pass transversely.

These give practically the same results as the two previous arrangements.

This was also tried with 82

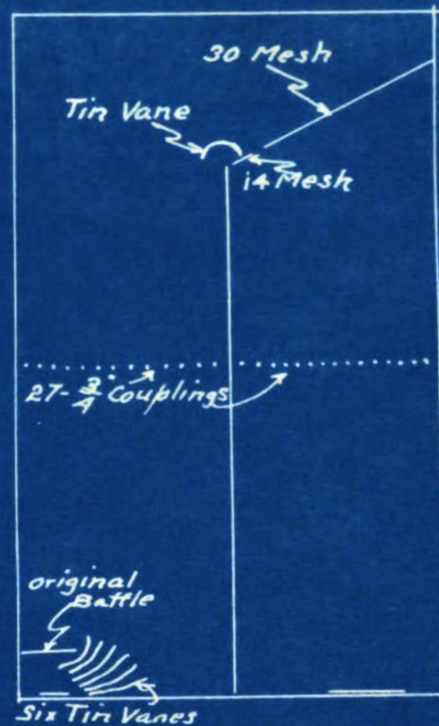
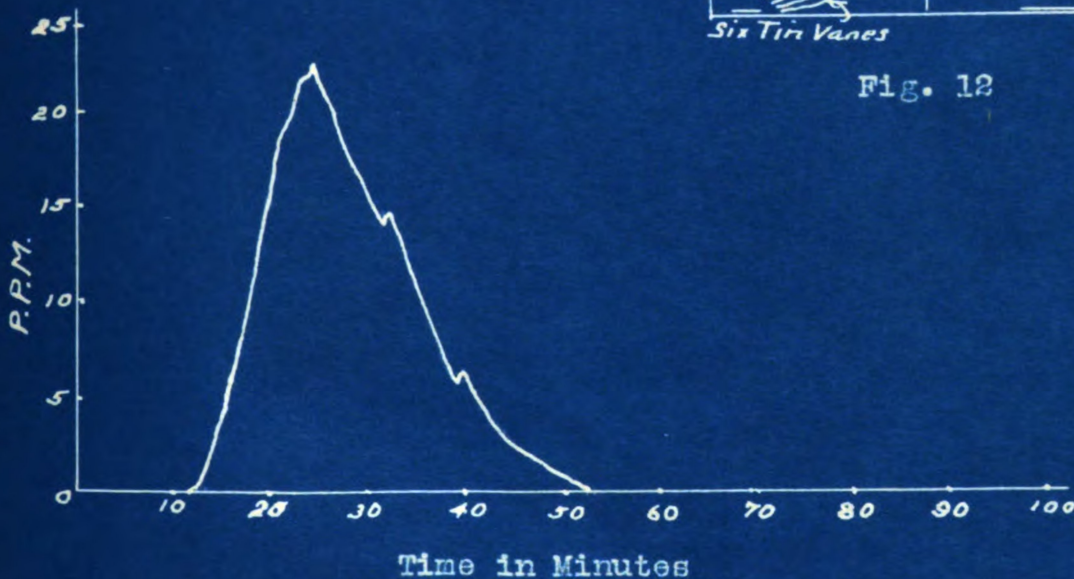


Fig. 12



1 inch couplings on each side with very little change in results. The distribution efficiency was computed by the method perviously discussed and was found to be 81.9%.

This combination of screens curved vane at the end of the center baffle, couplings, and 25 small tin vanes at the inlet gave very poor results. It seems that the vanes at the inlet were too small and difficult to adjust. The curve indicates that there was a strong direct current from the inlet to the outlet and that

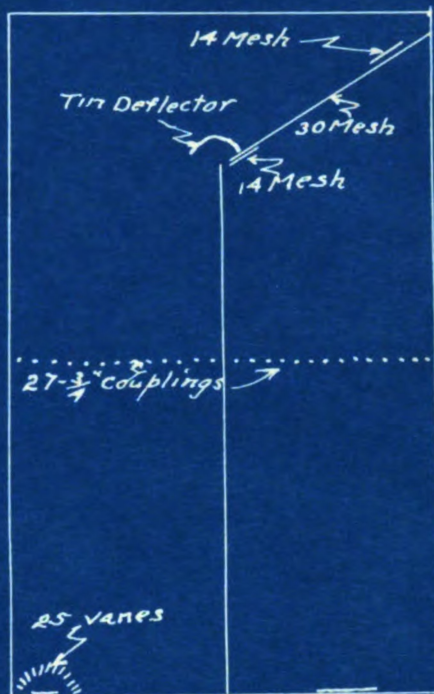
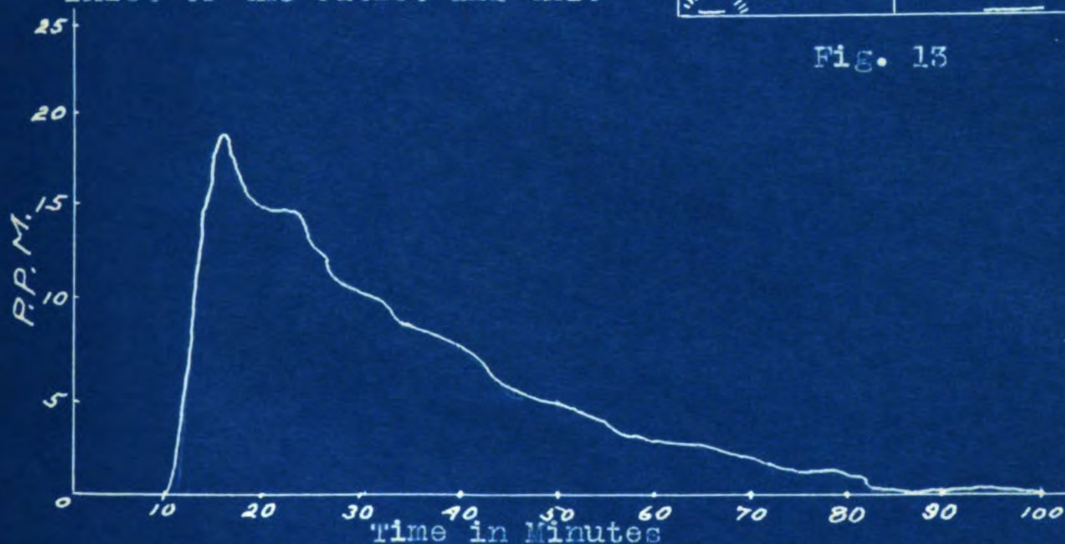


Fig. 13



eddies were numerous.

The stilling baffle shown in fig. 14 was drilled with $\frac{7}{8}$ " holes. Corks were fitted to these holes so that any desired number of them could be closed. With all of them open the test gave a fair curve but not as good as some other arrangements previously shown.

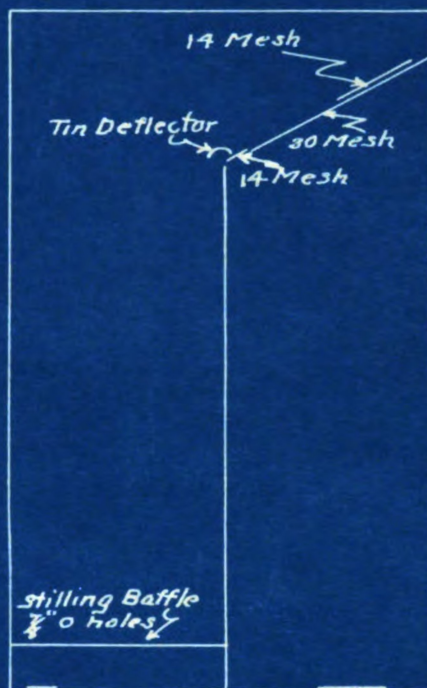
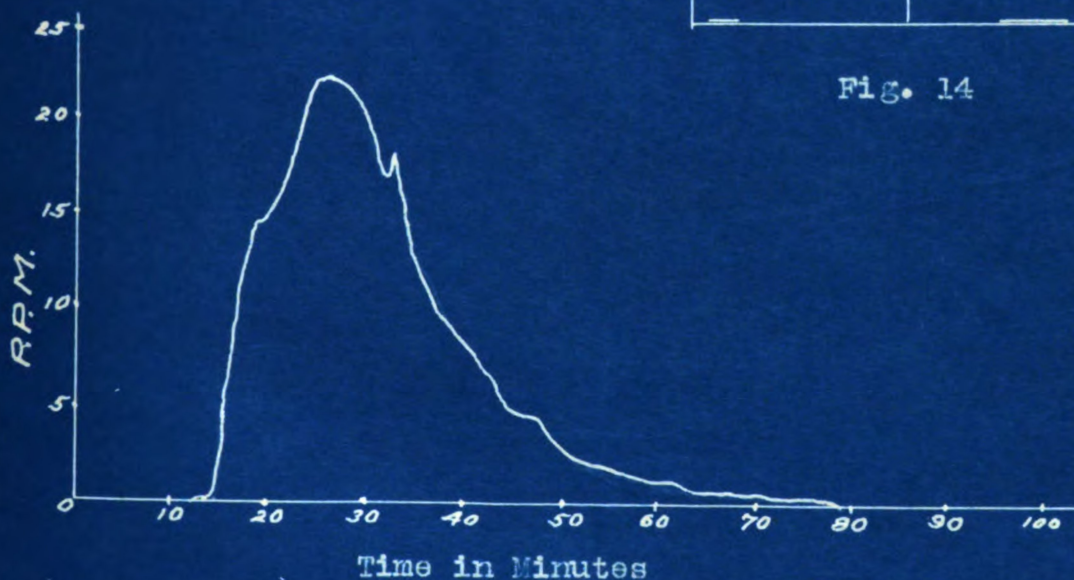


Fig. 14



Here the stilling baffle was used with 165 holes and tin deflectors were placed as shown.

This gave a very irregular curve indicating that eddies were prevalent and that currents were ever changing.

The arrangement is not good.

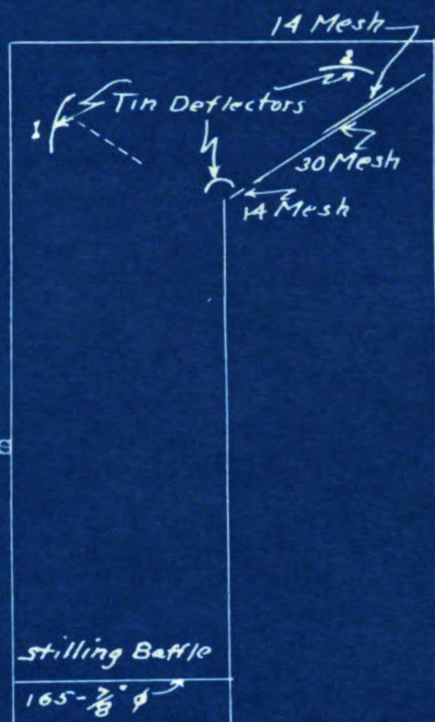
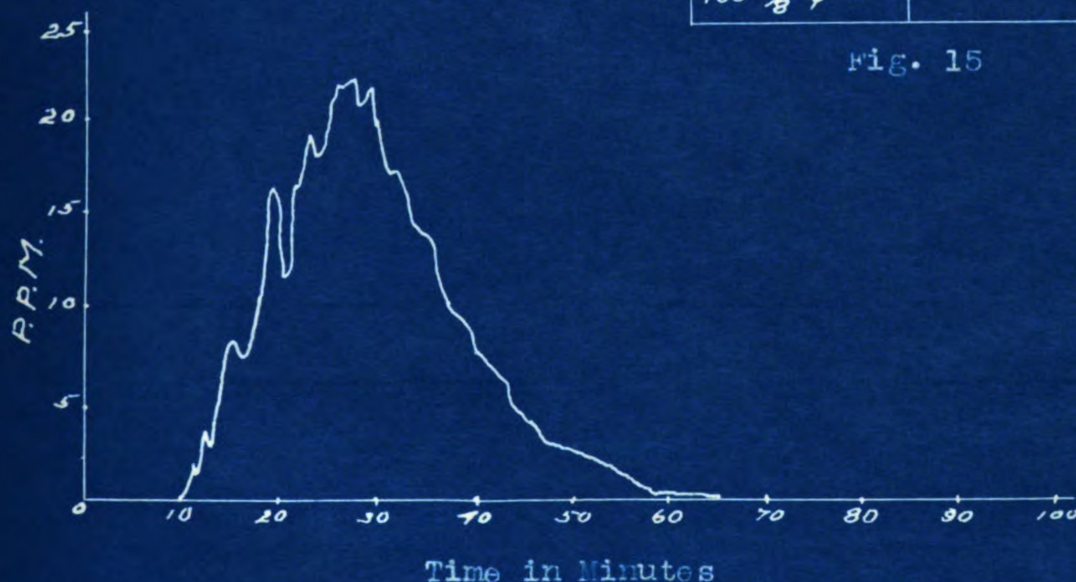


Fig. 15



This set up was tried with the deflector marked 1 removed and a 14 mesh screen placed as shown by the dotted line. This gave practically no change except to smooth out the curve a little.

The arrangement shown in fig 16 seems to give the best results of any yet tried. The curve is fairly smooth showing that eddies are few and small and that the larger portion of the dose passes through in about 30 minutes.

With an overflow weir at the outlet as shown by the

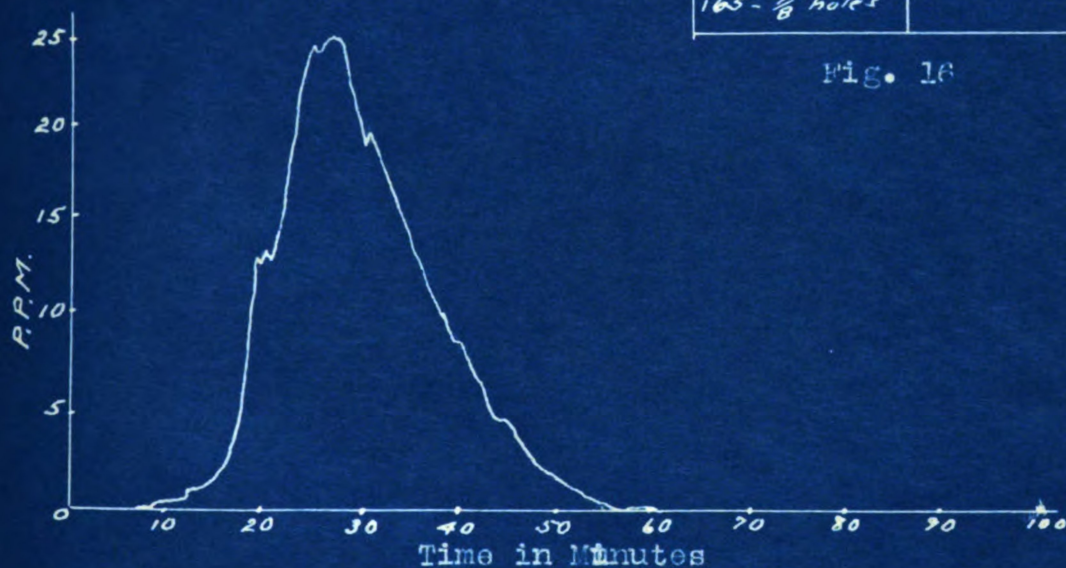


Fig. 16

dotted line in the figure the curve was spread out much more at the base indicating that the weir did more harm than good.

The arrangement shown in fig. 16 was also tried without the tin vanes but this too was unsatisfactory.

In this set up the 14 mesh screens were doubled and tripled at the points where the velocity was greatest and the 30 mesh placed between as shown. It did not seem to improve conditions much except to move the center of gravity of the curve a little farther over.

an arrangement similar to

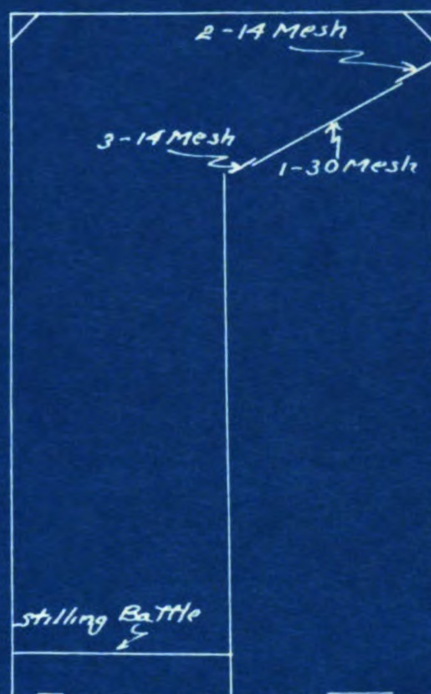
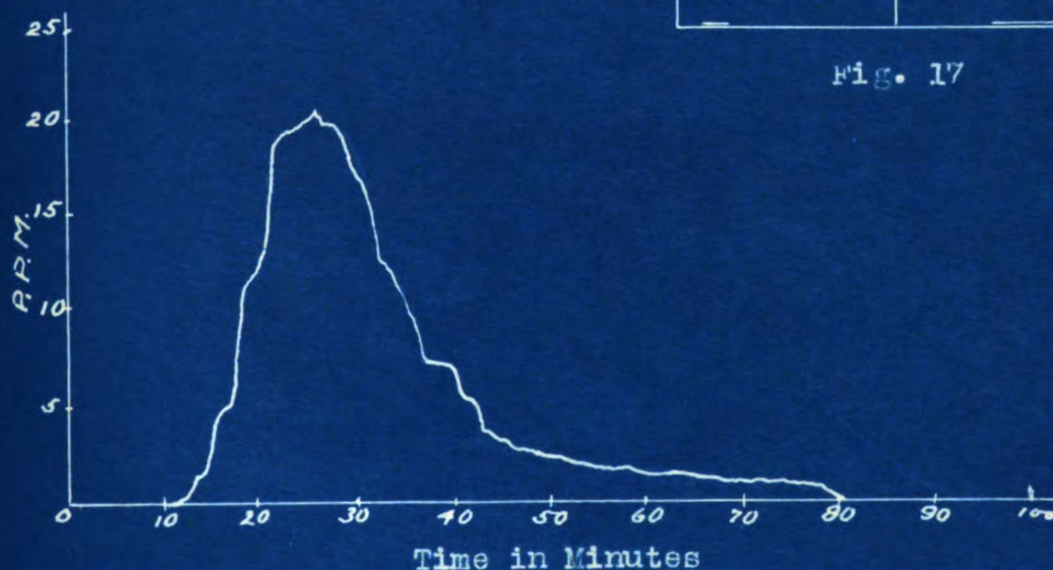


Fig. 17



this but with vertical slots in the stilling baffle fitted with small swinging gates was tried. This gave a better looking curve than that shown above but the coefficient of dispersion was only 77.7% . The gates when placed on an angle did not distribute the flow as was expected but rather let the greater flow through where the velocity was the greatest.

In this set up a larger amount of water was cut off in the corner by a wall and an A baffle was substituted for the screens at the turn. A detail of the A baffle is shown below. The coefficient of dispersion for this arrangement is 74.3. The curve shows that there is still too much dispersion as

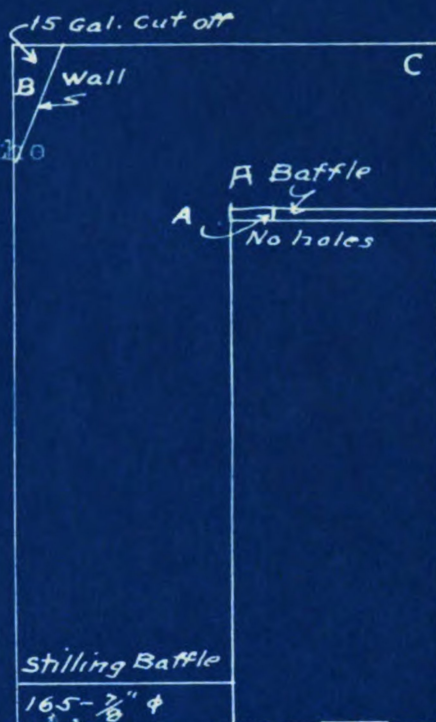
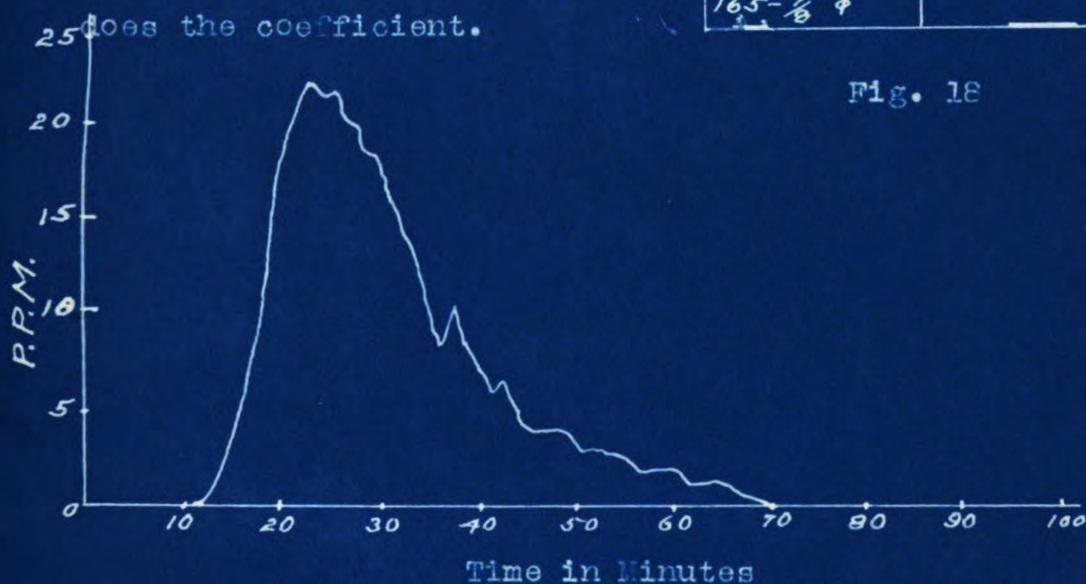
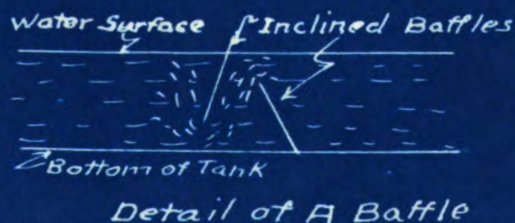


Fig. 18



This was also tried with $\frac{5}{8}$ " holes at A with little change in results.



Six tin vanes were next placed as shown in fig. 19 with corner boards and the original baffle. Several tests were made on this arrangement with the vanes in various positions. The highest coefficient that was obtained was 81.9.

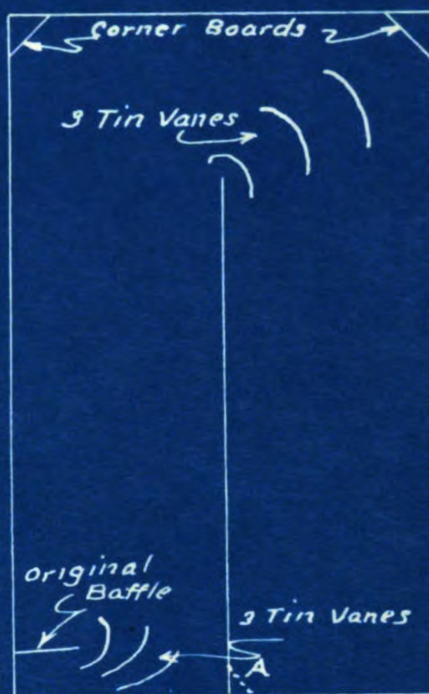
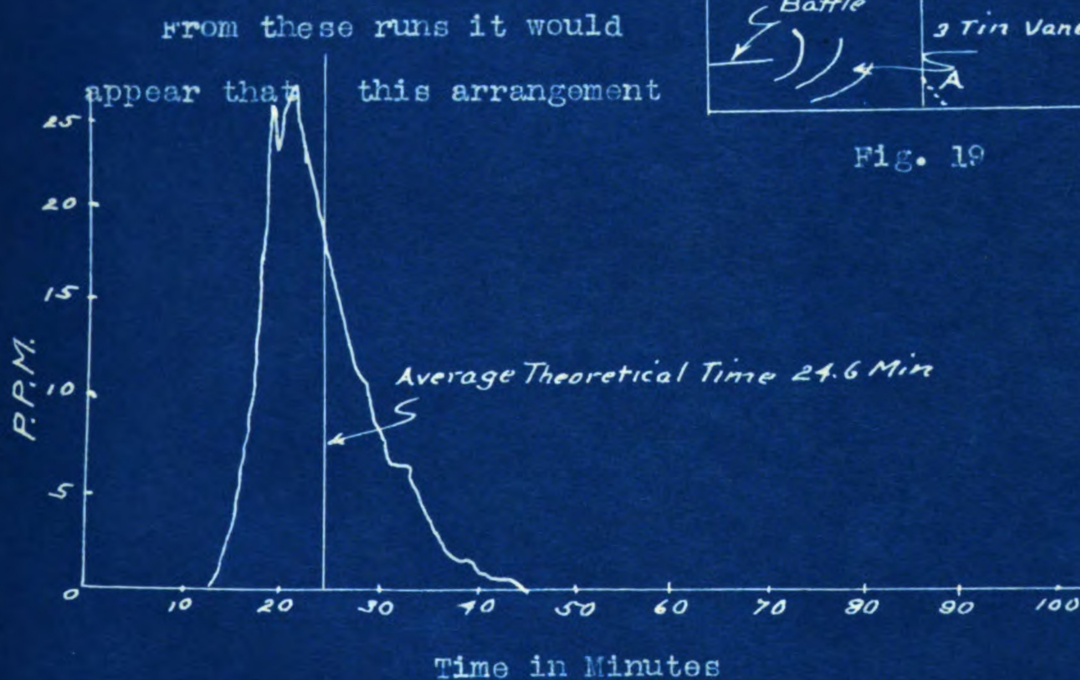


Fig. 19



that tin vanes give a more even flow than any thing that has yet been tried.

The six vanes were also tried with the corner baffles curved and in addition a curved corner baffle at A. The coefficient then was only 75.6 but this might have been bettered by shifting the curved vanes to various positions.

It was thought that by putting the curved vanes in the dead corners that the eddies might be eliminated but it was found that large slow eddies occurred in both passes. The coefficient was only 46. The curve also shows a poor distribution.

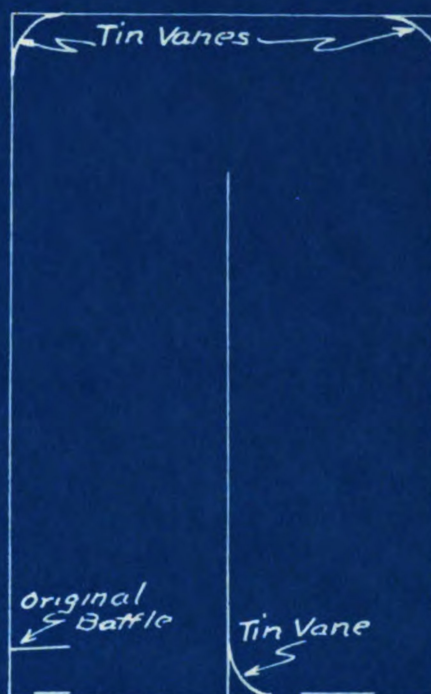
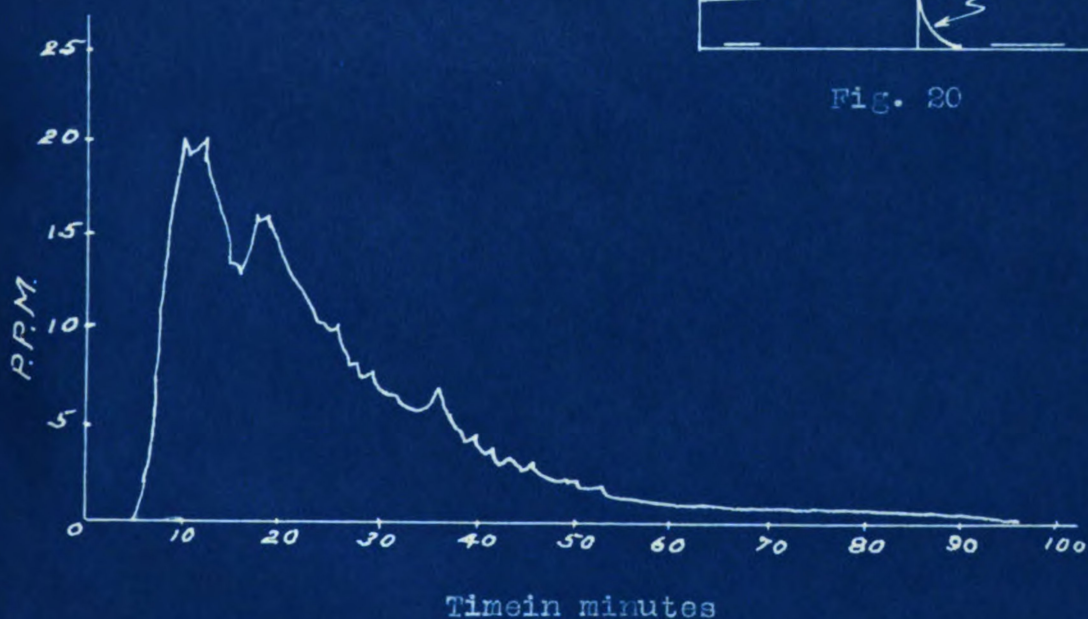


Fig. 20



This is the arrangement that was finally adopted to be used in the large basin. It consists of nine curved vanes, one in each of the three dead corners, three at the inlet and three at the turn. The highest coefficient obtained from this set up was 81.2.

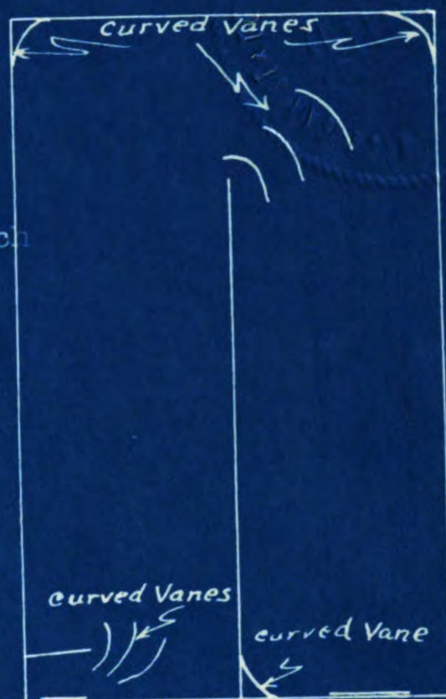
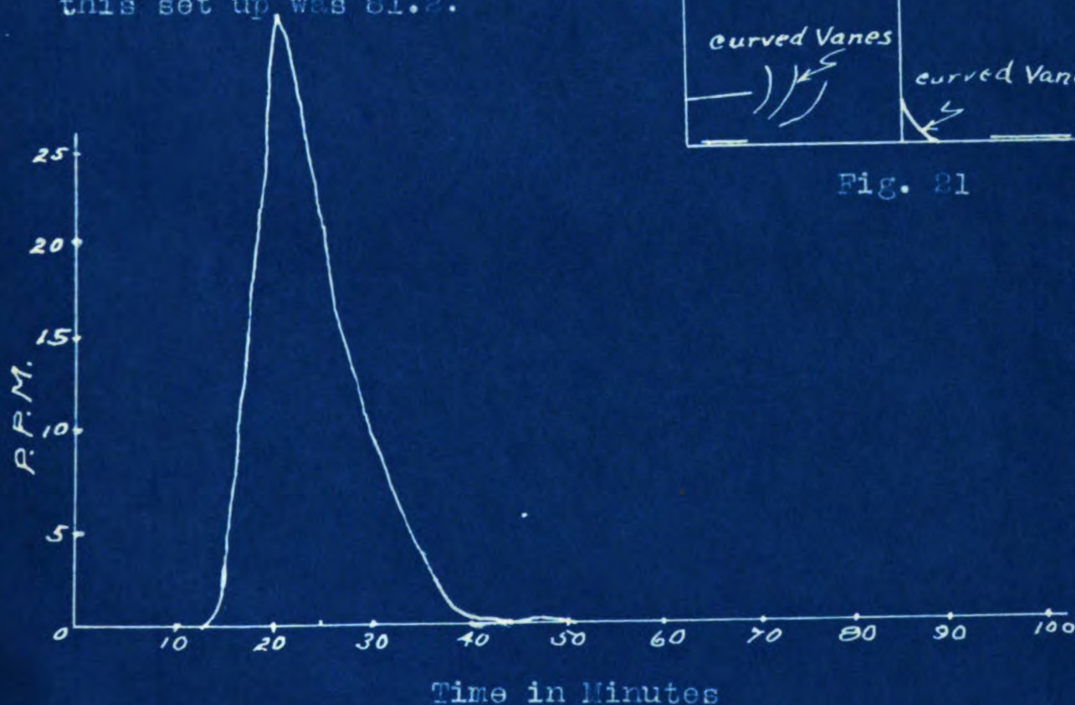


Fig. 21



The exact location of these vanes and other details have been previously given. The exact setting of these vanes is quite materially effected by the quantity of flow. Therefore the ends of the vanes have been so designed that they can be moved to accomodate varying conditions of flow.

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