ROBINSON

An Investigation of the
Flow of Water Through
Submerged Orifices & Pipes

Civil Engineering

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AN INVESTIGATION OF THE FLOW OF WATER THROUGH SUBMERGED ORIFICES AND PIPES

BY

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THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

WARD REID ROBINSON

ENTITLED AN INVESTIGATION OF THE FLOW OF WATER THROUGH SUBMERGED ORIFICES AND PIPES

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Civil Engineer

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I. Introduction.

1. Scope of the Experiments.– Many experimenters have investigated the flow of water through standard orifices, short tubes, and pipes, with free discharge. The coefficients of discharge for free flow for heads down to 0.4 ft. have been quite well determined.

It was the purpose of the series of experiments reported herein to determine the coefficients of discharge for submerged orifices and pipes of various sizes and kinds under different heads. Special attention was given to heads lower than 0.4 ft.

The orifices were of three kinds, five being circular, eight rectangular, and one triangular. Two short pipes were used. One was the standard short tube used in laboratory work. The other was longer and extended into both the entrance and discharge parts of the apparatus. This second pipe was threaded on the outside at each end so that mouthpieces of varying angles and lengths could be attached and their effect on the discharge studied.

An attempt was made to discover the effect on the flow caused by a variation in the depth of water over the orifice or pipe.

2. Previous Experiments.– Some of the most important previous experiments with submerged orifices and pipes have been made by Venturi, Francis, Smith, and Weisbach. Weis-

bach's work dealt more with the theory of submerged discharge than with the actual coefficients determined by experiments. For the most part, these experiments were made with high heads on quite small openings, all conditions being ideal.

Mr. C. C. Wiley, of the Class of 1904, University of Illinois, made a series of experiments with a short 6-in. pipe, having mouthpieces attached on either the entrance or discharge end. The results were so interesting that the writer continued the experiments in 1906 with mouthpieces of other sizes and angles. In 1907, Mr. G. D. Phillips made a series of experiments on submerged orifices. The data obtained from these experiments may be found in the theses of Messrs. C. C. Wiley, W. R. Robinson, and G. D. Phillips, of the classes of 1904, 1906, and 1907, respectively.

All these experiments gave very consistent results on heads above 0.4 ft. and on velocities above 2 ft. per sec. Below these points the curve left the straight line, the coefficient of discharge generally becoming higher.

The series of experiments described herein was taken up with the purpose of determining more accurately the coefficients below the point where the above-mentioned curves diverge from the straight line.

3. Theory of the Flow of Water through Orifices and Pipes.- When the expression "flow through an orifice" is used in this discussion, it refers to what is known as "an orifice in a thin plate" set vertically. By this is meant an orifice with the outer edges beveled, so that the

outflowing stream touches the edge only along a line.

The following nomenclature will be used:

h = difference in level of the water on the two sides of the partition, expressed in feet.

c = coefficient of discharge.

c' = coefficient of contraction.

c_v = coefficient of velocity.

a = area of orifice or pipe in square feet.

g = acceleration due to gravity = 32.2 ft. per sec.^{2}

q = actual discharge in cu. ft. per sec.

Q = theoretic discharge in cu. ft. per sec.

v = actual average velocity of discharge through orifice or pipe in ft. per sec.

m = coefficient of loss of an orifice.

m_p = coefficient of loss of the 6-in. pipe used in the experiments.

m' = coefficient of loss of the entrance mouthpieces determined in connection with the 6-in. pipe.

n = coefficient of gain of the discharge mouthpieces determined in connection with the 6-in. pipe.

Then, for a combination of entrance and discharge mouthpieces on the pipe, the coefficient of loss for the combination is

$m = (m_p + m' - n)$.

The formula which will be used in these experiments to determine the theoretic discharge is $Q = a\sqrt{2gh}$. This is only an approximate formula when free discharge into air is under consideration, because the head varies on differ-

ent parts of the cross-section of the orifice or pipe. However, this formula is correct for submerged discharge, because the head causing flow is the same at every point, being the difference in level of the water on the two sides of the partition.

Since the head is the same on all parts of the orifice, the coefficient of discharge may be expected to vary less for a given change of head with submerged flow than with free discharge. Especially would this be true on low heads because with free discharge under a low head the diameter of the orifice or pipe might be a large percentage of the total head.

On page 127 of the 1904 edition of Merriman's "Treatise on Hydraulics", the following statements are made regarding submerged discharge through standard orifices. "The discharge through such an orifice....has been found by experiment to be slightly less than when the flow occurs freely into the air....For large orifices and large heads the difference is very small and for orifices 1 in. square under 6-in. head it is about 2%....As a mean value of the coefficient for standard submerged orifices, 0.6 is frequently used".

The head causing flow through an orifice is taken up in two ways: (a) lost head, which includes the loss from contraction of the stream as it enters the orifice and expansion as it leaves, and (b) head which gives velocity to the stream. This condition is expressed by the equation $h = h' + \frac{v^2}{2g}$, where h' is the lost head and $\frac{v^2}{2g}$ is the head

causing the velocity v. An expression for h', the lost head, may be obtained as follows: since $v = c_1\sqrt{2gh}$, then $v^2 = c_1^2(2gh)$ and $h = \frac{v^2}{c_1^2(2g)}$. Substitution in the above equation gives $h' = \frac{v^2}{c_1^2(2g)} - \frac{v^2}{2g} = \left(\frac{1}{c_1^2} - 1\right)\left(\frac{v^2}{2g}\right)$. The quantity $\left(\frac{1}{c_1^2} - 1\right)$ is represented by the letter m and is known as the coefficient of loss. Merriman's "Hydraulics" gives 0.04 as a value to be used for m with standard orifices.

A short tubes is defined as one whose length is not over three times its diameter. A short pipe is one whose length is less than about 500 times its diameter and is said to be very short when the length is less than about 50 diameters. The one used in these experiments had a length of 3.75 times its diameter, but is here called a short pipe, the small friction loss being neglected. In discharge through such a pipe, it is found that a partial vacuum is formed just inside the entrance end. The flow is so increased as to give a coefficient of discharge (for free discharge) varying from 0.83 for low heads to 0.79 for high heads (Merriman).

In the case of a long pipe, the frictional resistance of the sides of the pipe must be considered, the formula for the total head being

$$h = h' + f\left(\frac{l}{d}\right)\left(\frac{v^2}{2g}\right) + \frac{v^2}{2g} = m\frac{v^2}{2g} + f\left(\frac{l}{d}\right)\left(\frac{v^2}{2g}\right) + \frac{v^2}{2g}.$$

An experiment on the pipe used in these tests, made with a velocity of 5.48 ft. per sec., showed a loss due to friction of 2.75% of the total head. As this loss is small, even with a velocity much larger than any used in the experiments herein discussed, the term $f\left(\frac{l}{d}\right)\left(\frac{v^2}{2g}\right)$ will be dropped

in future calculations leaving the expression $h = (m+1)\left(\frac{v^2}{2g}\right)$.

If a converging mouthpiece be put on the inlet end of such a pipe, the contraction of the stream of water is suppressed and a larger discharge is obtained. The amount of the increase will evidently vary somewhat with the angle and length of the mouthpiece. The coefficient m' covers the effect of such an entrance mouthpiece.

If a diverging mouthpiece is put on the discharge end of a pipe, the discharge is increased. The velocity head may be partially regained according to the following theory: if the outer end of the mouthpiece has an area A', the pipe has a cross-section A, and the velocity in the pipe is v, then the velocity at the outer end of the mouthpiece is $\frac{A}{A'}v$, and the velocity head in each case is proportional to the square of the change in velocity. For instance, if the ratio of areas be as one is to two, the average velocity at the outer end will be 1/2 that in the pipe and the velocity head 1/4 as great. In this case, 75% of the velocity head is the maximum amount which may be regained by the use of a diverging outlet. For a 1 to 3 ratio, 88%, and for a 1 to 4 ratio, 94%, is the maximum amount which may theoretically be regained.

The formula given for discharge through a pipe may be made to include the effect of the condition of the outlet by the addition of a term $n\frac{v^2}{2g}$, which will give the amount of velocity head regained. The sign of the coefficient for the discharge end must evidently be opposite from that for the entrance end. The combined effect of the entrance and

and discharge ends $= \left(\frac{1}{C_1^2} - 1\right)$.

If there is no discharge mouthpiece, n does not enter into the equation. The value of m_p for the plain pipe may be determined by experiment. The value of m for the combination of the pipe with any mouthpiece may then be found experimentally and the difference in the two values is the change in m caused by the mouthpiece. The value of n for any discharge mouthpiece may be found by the equation $n = (m_p - m)$, m_p being known for the plain pipe and m being determined by experiment on the combination of pipe and discharge mouthpiece.

If a combination of mouthpieces be used, one on the inlet and one on the discharge end, the resulting value of m obtained experimentally should be much the same as the difference of the values of m and n obtained separately. Experiments bear out this statement, as will be seen later.

It is known that the discharge through an orifice varies slightly with changes in the temperature of the water. Unwin says that the discharge is decreased 1% by a rise of 144° in temperature. In the experiments made for this thesis, the temperature of the water varied between 61° F. and 68° F., averaging about 64° F. Because of this small variation, the effect of temperature will not be considered further.

II. METHOD OF EXPERIMENTATION.

4. Methods used with High Heads.– Since the work of this thesis was mainly with reference to heads under 0.4 ft., which may be termed low heads, heads above this will be spoken of as high heads. Though very few experiments in this series were with high heads, reference is often made to the work of Messrs. Wiley, Robinson, and Phillips and the tables and diagrams contain data obtained therefrom, so it is thought proper to include a statement of the manner in which the earlier experiments were made.

The tank used in all the experiments is shown in Fig. 1. It is made in two compartments, I and II, which are separated by a partition containing an opening at C, into which may be fitted the orifice or pipe to be used. The water coming from the standpipe enters by a main at A and passes through the baffle boards at B, finally leaving compartment II through openings which are regulated by valves or stoppers. For small flows the water was weighed in a tank set on scales. For large flows it was measured in the pit F, the water being wasted by means of the movable pipe G into the pit H until the desired rate of flow had been secured, when it was turned into the measuring pit, where the rise was determined by reading a rod. At the bottom of this rod there was attached a metal ring which was brought just to the surface of the water and the rod was then read.

A scale reading to millimeters was used to determine the head on the orifice or pipe. From either side of the

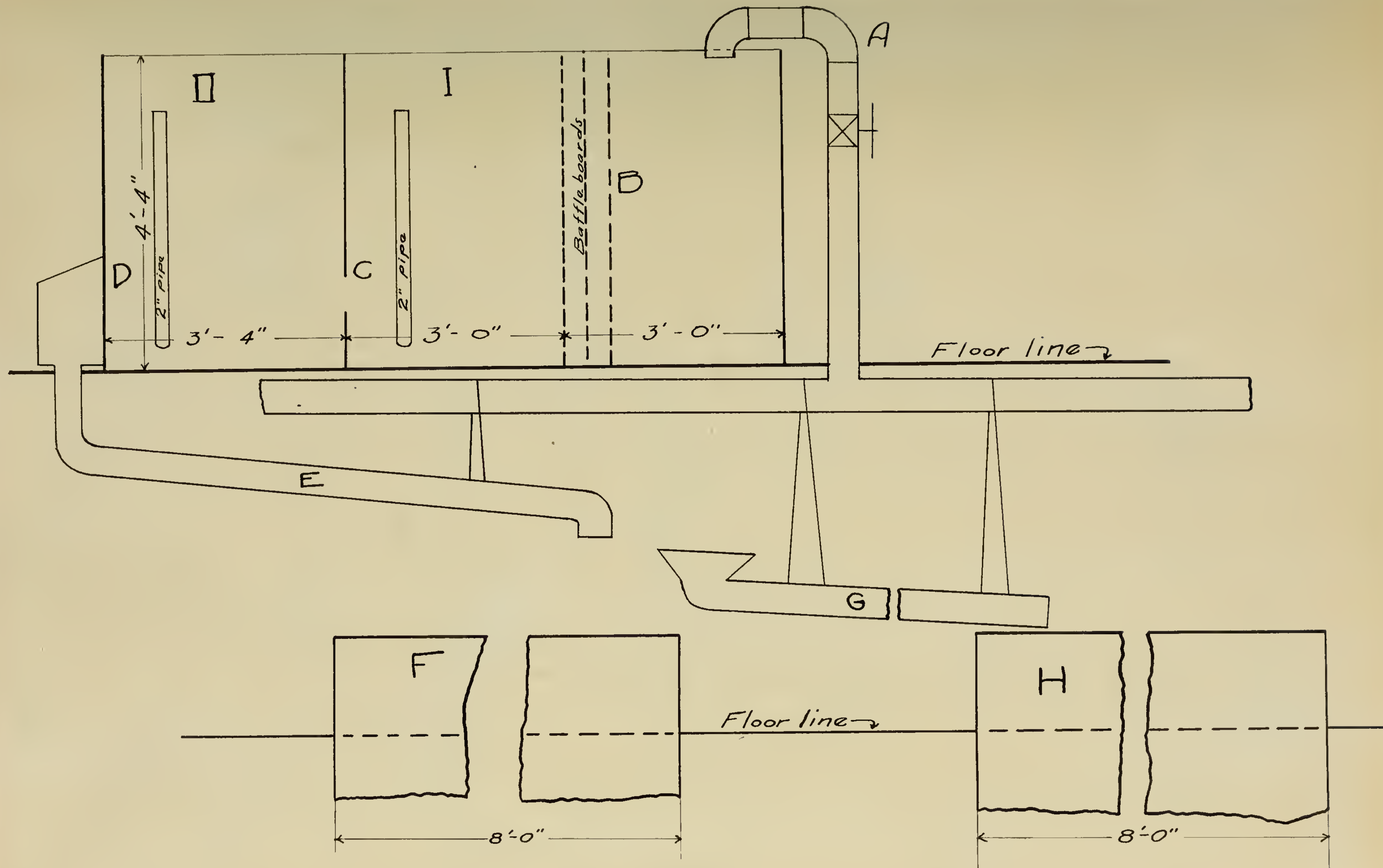


FIG. I.

ARRANGEMENT OF APPARATUS.

TABLE I.

LIST OF ORIFICES, PIPES, AND MOUTHPIECES USED.

ORIFICES No.	Kind	MOUTHPIECES Entrance No.	Angle	Ratio	Discharge No.	Angle	Ratio
1.	1-in. round	17.	5°	1-2	30.	5°	1-2
2.	1 1/2-in. "	18.	10°	"	31.	10°	"
3.	2-in. "	19.	15°	"	32.	15°	"
4.	4-in. "	20.	20°	"	33.	20°	"
5.	6-in. "	21.	30°	"	34.	30°	"
		22..	45°	"	35.	45°	"
6.	1/2-in. square	23.	60°	"	36.	60°	"
7.	1-in. "	24.	10°	1-3	37.	10°	1-3
8.	2-in. "	25.	15°	"	38.	15°	"
9.	4-in. "	26.	20°	"	39.	20°	"
10.	5 1/2-in. "	27.	45°	"	40.	45°	"
		28.	90°	"	41.	90°	"
11.	6-in. x 1/2-in.	29.	20°	1-4	42.	20°	1-4
12.	6-in. x 1-in.						
13.	6-in. x 2-in.						
14.	4-in. triangular.						

PIPES

15. 2-in. x 5 1/2-in.

17. 6-in. x 22 1/2-in.

COMBINATIONS

43. 6-in. pipe, with 20°(1-2) entrance and 5°(1-2) discharge.

44. 6-in. pipe, with 20°(1-3) entrance and 15°(1-3) discharge.

partition in the tank, a glass tube was lead and placed by the scale. The difference of the readings of the height of the water in the two tubes gave the effective head.

5. Methods used with Low Heads.— With two exceptions, the methods used with low heads were the same as with high heads. On most of the runs on orifices 4 in. or less in diameter, the water, after running through the two compartments as before, was weighed in tank instead of being measured by its depth in a pit. The measurement of the head was made more carefully than was done with high heads. A vertical 2-in. pipe was placed on the outside of each compartment and connected with the tank by an elbow. The height of the water in each pipe was then measured by means of a hook gauge reading to 0.001 ft. The zero difference between the two gauges was obtained by taking readings when the tank was full of water and none was flowing in or out. The difference of the readings taken at any time during the flow of the water, subtracted from the zero difference, gives the effective head on the orifice or pipe.

6. Description of Orifices, Pipes, and Mouthpieces.— Table 1 gives a list of the orifices, pipes, and mouthpieces used in these experiments. All the orifices and mouthpieces were made of cast iron and were machined accurately to size. The orifices were cut in 1/2-in. plates and the edges beveled 45° as in a standard orifice. One pipe was 2 in. in inside diameter and projected 5 1/2 in. out from the plate. It was used by the students in laboratory work as a short tube. The other pipe was 22 1/2 in. long and of 6-in. inside diameter. As shown in Fig. 2, it had a flange at the center

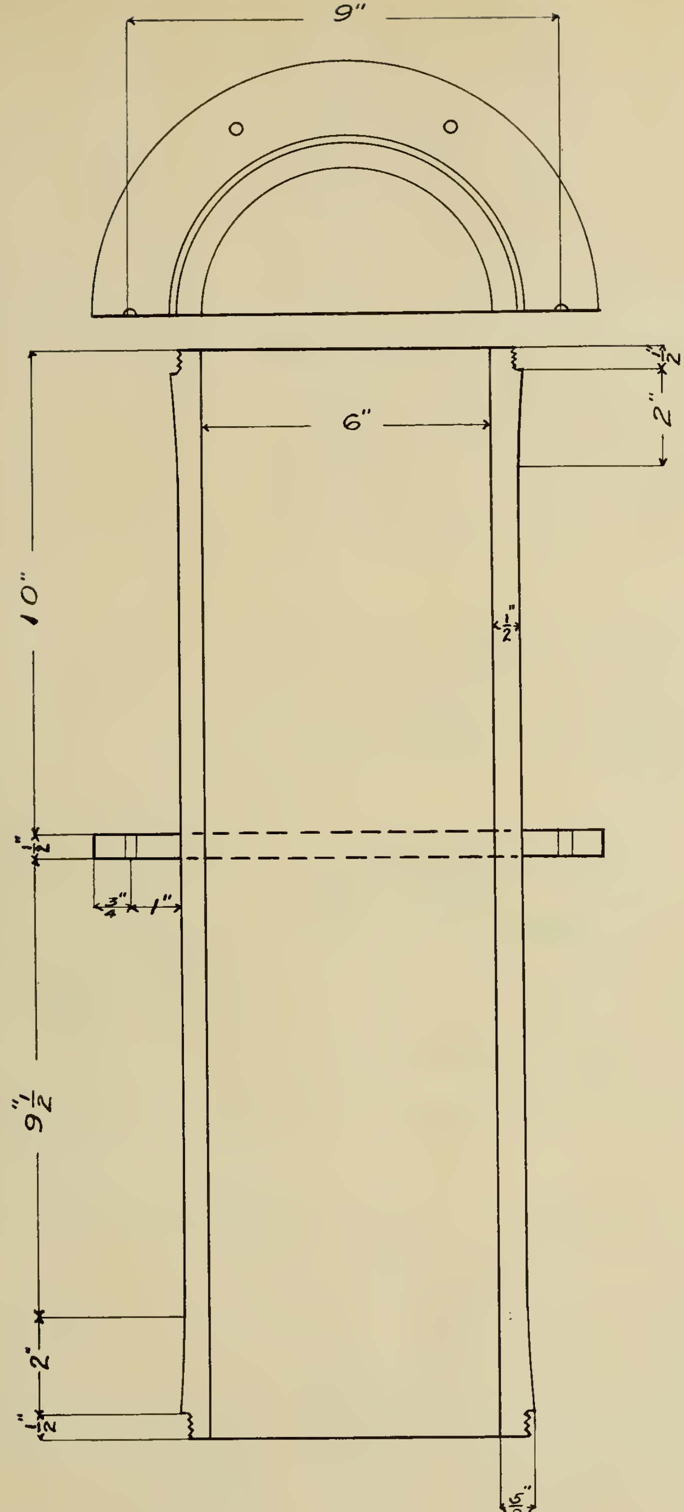


FIG. 2.

PIPE USED WITH MOUTHPIECES.

by which it was attached to the partition, the ends projecting into the two compartments. The mouthpieces are shown with dimensions in Fig. 3 and 4. They were threaded in order to attach them to either end of the pipe. All the mouthpieces were 6 in. in diameter at the smaller end and were made of varying lengths so that some were of such length that the area of the outer end was twice the area of the pipe, (1-2) others were three times the area of the pipe, (1-3) and one was of such length that the ratio of areas was 1 to 4. (1-4)

7. Sources of Error.- Errors may be introduced in the experiments in the following ways, which will afterward be discussed separately:

(a) Error in reading the hook gauges.

(b_1) Error in determining the weight of the water, or

(b_2) Error in determining the rise in the pit.

(c) Error in the measurement of the diameter of the pit.

(d) Error in taking the time of the run.

(a) The hook gauges were read by holding an electric light so that a point of light would be observed just as the hook reached the surface of the water. The light was always held in the same position so that the error due to the method of reading must have been the same each time. Since this is the same for the two gauges and since it is their difference, rather than the reading itself, which is used, the effect of this upon the probable error may be omitted. Sometimes, due probably to vibrations of the building caused by the proximity of the engines in the University

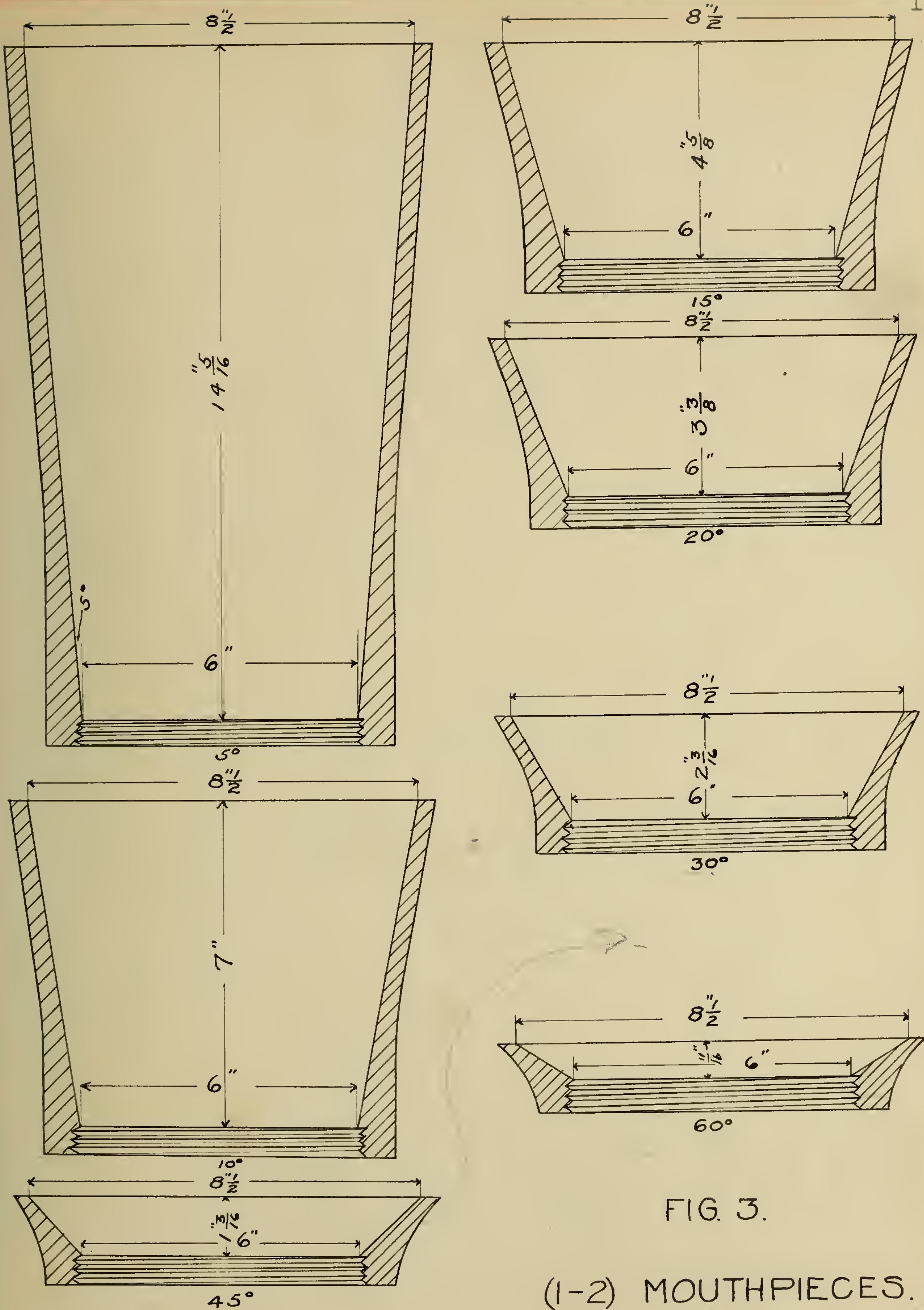


FIG. 3.

(1-2) MOUTHPIECES.

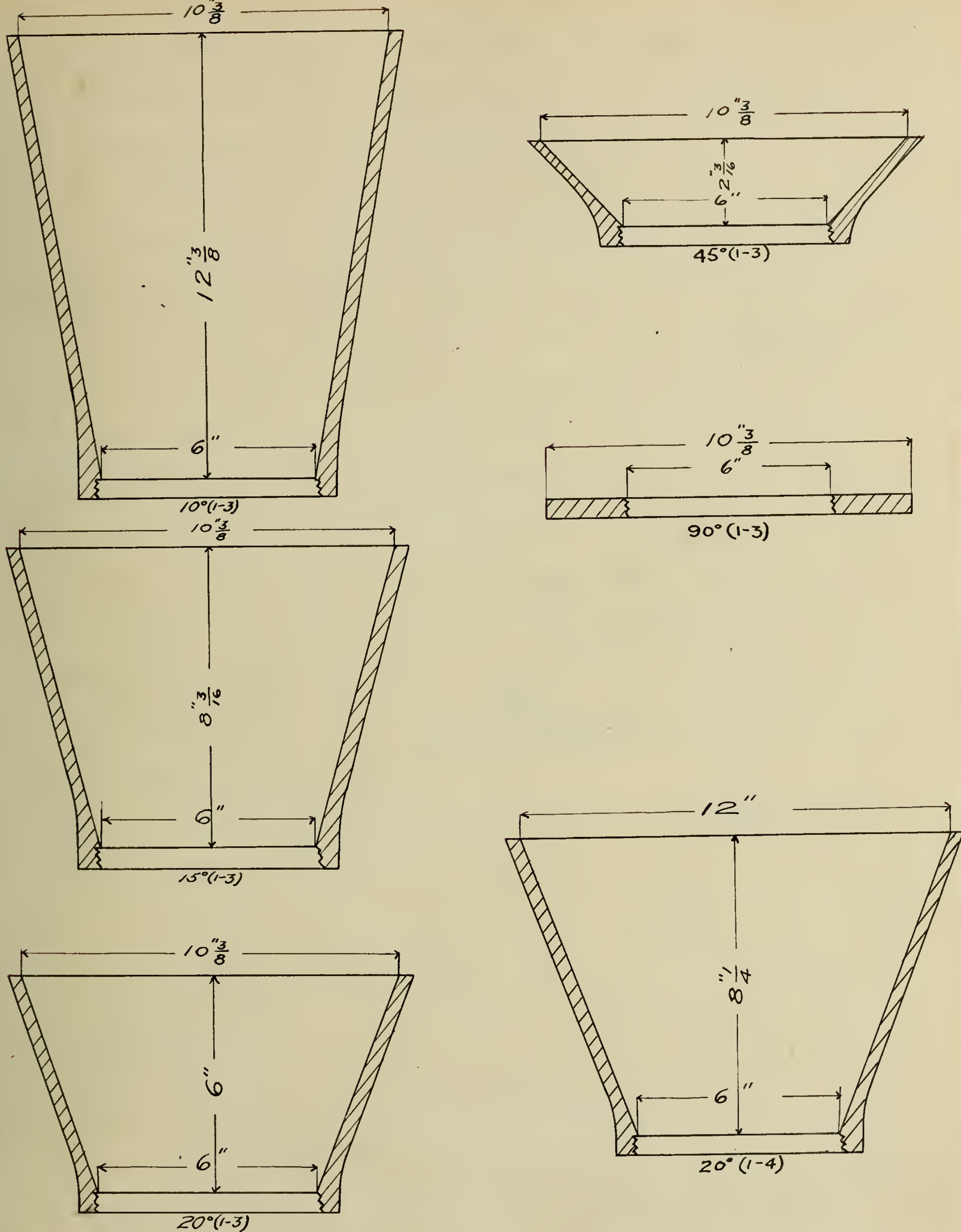


FIG. 4.

(1-3) AND (1-4) MOUTHPIECES.

power plant, the water acquired a slight wave motion which may have affected the gauge readings somewhat although it probably was the same in each compartment.

Taking as an example one of the runs with the 6-in. pipe where the head varied more than usual, the "method of least squares" gives a probable error, with a head of 0.014 ft., of 1.7%. Since the head in this case varied much more than usual, it may be considered that this is the maximum probable error. Calculations on a run where the water was under more nearly quiet conditions give a probable error, on a head of 0.014 ft., of 1.2%. In the work with orifices, the heads which determined the position of the curve were much higher than those discussed above, so the per cent error would be much smaller. For these reasons, the probable per cent error of the head may be taken, for ordinary heads, at 1.0% or less.

(b_1) Calibration of the scales used in weighing the water has shown no noticeable error.

(b_2) The rod readings were very carefully taken and it hardly seems possible that any waves could have produced an error greater than 0.002 ft., and experiments indicate that it would probably be not more than 0.001 ft. With the 6-in. pipe, the lowest rise was 0.492 ft., in which case the error might be 0.41%. In the pipe runs, the rise usually averaged about 2 ft. which, with the above assumptions, might be in error 0.10%. This is so small as to be practically negligible. If this worst case, (0.002 ft. error) happened at the same time that the lowest rise on an orifice

run was used, 0.184 ft., the error would be 1.09%. The next lowest rise was 0.340 ft., which would give possible error of 0.59%.

(c) The diameter assumed for the pit is that obtained by Mr. Wiley in his experiments of 1903 -04. It was the mean of thirty readings carefully taken and, as the largest variation from the mean was 0.008 ft., the maximum error will not be over 0.10%. - Diam = 7.995 ft

(d) The time of each run was noted by means of a stop watch. The error in starting or stopping the watch coincidently with the experiment could not have amounted to more than 1/5 second. The maximum on this account would occur when the shortest run, 180 sec., was made and would amount to 0.11%. As most of the runs were from 600 to 1200 sec. long, this error is not appreciable.

These errors will hardly occur in maximum amount at the same time and they may even help to balance each other, Besides, in calculating the theoretic discharge, the square root of h and not h itself is used and hence the resulting error is only about one-half the proportional error in h. For the heads which determine the position of the important part of the curves, the combined effect of these errors will probably not be over 0.50%, and may be much less. For lower heads, the per cent error will increase, as is shown by the erratic turns taken by the curves at velocities below 0.5 or 0.4 ft. per sec. The reasons for this condition will be discussed later.

III. EXPERIMENTAL DATA.

8. Data of Experiments with Orifices.– Table 2 gives data of the experiments made on orifices. The calculated data, that is, the coefficients of discharge and loss, are summarized in Tables 7 to 12 inclusive. The values given in the tables of calculated data are taken from the plotted curves, as it was impossible to obtain exactly the same velocity in every trial. As the orifices included many sizes, the heads used and the velocities obtained varied much more than in the pipe runs. With small orifices, great difficulty was experienced in obtaining a steady head. For that reason and in order to obtain a sufficient number of points for determining the position of the curve, more runs were made with orifices than with pipes. Fig. 6 to 14 inclusive show the results obtained experimentally.

9. Data of Experiments with Short Pipes.– In Table 2 will be found the test data taken with the 2-in. standard short tube and Table 3 gives the data for the 6-in. pipe which was afterward used with the mouthpiece experiments. The observations for the 6-in. pipe runs were very carefully made in order to accurately determine the value of m_p to be used in succeeding experiments with mouthpieces. Tables 13 and 14 give a summary of the calculated data. Fig. 15 and 16 show the results of the tests graphically.

10. Data of Experiments with Mouthpieces.– Tables 3, 4, 5, and 6 give the data obtained from the experiments

with mouthpieces attached to the 6-in. pipe. The summary of calculated data is given in Tables 15 to 19 inclusive. In this set of experiments an effort was made to determine carefully the position of the straight part of the diagram and also to determine approximately for each mouthpiece the point where the digression from the straight line commenced. Less attention was paid to heads lower than that at the point of digression. Since the pipe was the same for all the mouthpiece experiments, the velocities in all the runs had much the same range and the diagrams are easily comparable. In Fig. 16 to 30 inclusive may be found diagrams showing the data experimentally determined.

IV. COMPARISON OF RESULTS.

11. Effect of Variation of Head.- The observed effect of variation of head on the coefficients of discharge and loss was in accord with the results noted in the three previous investigations made on this subject.

One prominent element in the results is the point at which the coefficients of discharge and loss commence to vary markedly from a constant value. The diagrams have the same general characteristics as those obtained from previous experiments. Fig. 5 indicates the effect which accuracy and care in the experimental work have on the position of the curve. The experiments made in 1906 showed that the coefficients were constant at velocities higher than 1.5 ft. per sec. to 2.0 ft. per sec. The present

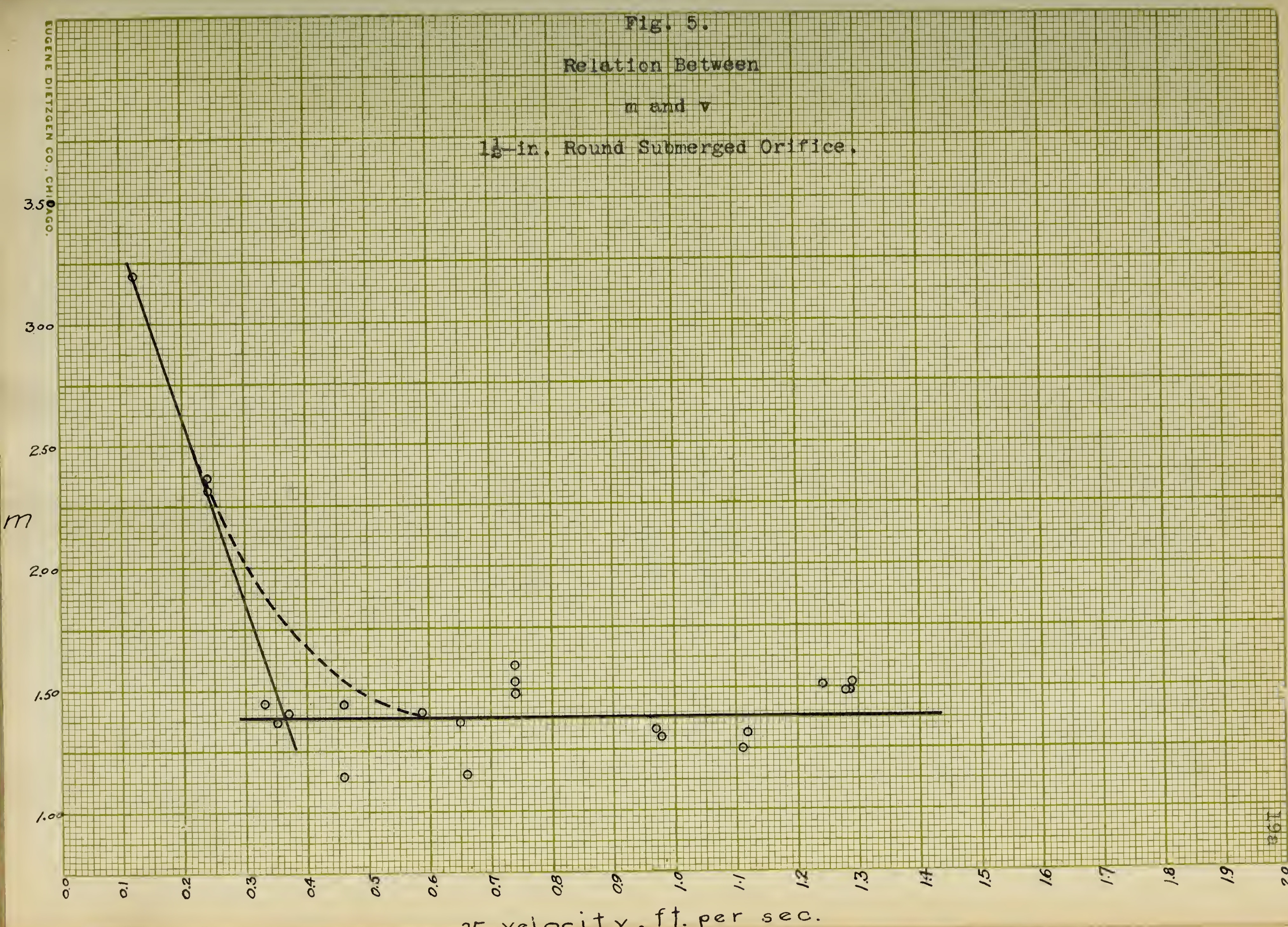


Fig. 5.
Relation Between
m and v
1½-in. Round Submerged Orifice.
m
3.50
3.00
2.50
2.00
1.50
1.00
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
v, velocity, ft. per sec.
19a
EUGENE DIETZGEN CO., CHICAGO.

series were made at velocities lower than this, and the coefficients were the same as those obtained for the higher velocities and remained constant until a much slower velocity than the limiting value named above.

The reason for this change in the position of a part of the curve was not at first apparent. In the first experiments on the 1 1/2-in. round orifice, no runs were made at velocities between 0.240 ft. per sec. and 0.60 ft. per sec. and a curve was drawn in the position shown by the dotted line. Since the coefficients at the low heads were so different from those at higher heads, a careful attempt was made to check the results. This resulted in obtaining a second point very close to the first one at a velocity of 0.24 ft. per sec. and several points around 0.34 ft. per sec. These last points were on a continuation of the straight line first obtained (constant coefficient) and this line was therefore extended through them. It appeared that this velocity of 0.34 ft. per sec. may in this case be termed the "critical velocity", i. e., the velocity below which the coefficient commences to vary.

As experiments on other orifices and pipes gave similar results, the experiments reported herein would seem to indicate that the more accurate the manner of measuring the head and flow, the greater will be the range over which constant values are obtained for the coefficients, and that the coefficients of discharge and loss for any orifice or short pipe are constant for practically all velocities and that the divergence of the curve from the straight line

indicates the point at which the methods used become inaccurate. However, there is probably a "critical velocity" below which the usual conditions do not obtain, and below which a change in the coefficients takes place.

Values of the coefficient of discharge for different heads, as determined from the tests and recommended for use, are given in Tables 15, 17, and 19. In deciding upon the values, the curves shown in Fig. 16 to 30 inclusive were used. These values may be considered to be representative coefficients for the range of sizes and heads studied.

12. Effect of the Angle of the Mouthpiece.– Tables 15 to 19 and Fig. 16 to 30 inclusive will aid in obtaining an idea of the changes in the coefficients resulting from varying the angle of the inlet or discharge mouthpiece.

The most noticeable result is the great change in the coefficients caused by the addition of a small-angle inlet or discharge mouthpiece to the plain pipe. This was to be expected on the discharge end, (see page 6), but it is probable that the good results at the entrance end came mainly from the fact that quite low velocities were used. Mr. Wiley's experiments, made in 1904, showed that for velocities above 1.5 ft. per sec. a 20° inlet was much better than a 10° or 15° one. The probable reason for this is that, at velocities higher than 1.5 ft. per sec., such a suppression of the pipe entrance as is caused by a 20° or 30° inlet very nearly corresponds to the path that the water would follow in entering the pipe. The result is that there is very little contraction in the pipe proper, the inlet having taken care of that. With the low

velocities used in these experiments, the smaller the angle the less was the water disturbed and a higher coefficient of discharge resulted.

When mouthpieces were used on the inlet end of the pipe, the length did not seem to affect the coefficient and only change in the angle produced variations. On the discharge end, however, as indicated by the theory given on page 6, there was a difference caused by the length of the mouthpieces, the longer ones giving the larger discharge. Placing the 5°(1-2) mouthpiece on the discharge end raised the coefficient of discharge of the pipe from 0.80 for the plain pipe to 1.04 for the combination. This result was to be expected as the longer the mouthpiece the more chance the water has to conform to the shape of the mouthpiece in its flow, thus producing a stream with less disturbance in it than with the shorter mouthpieces. The very short mouthpieces produced almost no beneficial results and the 60°(1-2) was an absolute hindrance to the flow, giving a negative value for n, -0.14.

Combining two mouthpieces with the plain pipe, one on either end, gives results in accord with what might be expected from a study of the equations on page 7. If in the equation $m = m_p + m' - n$ we substitute the values obtained for m_p, m', and n in the experiments made with only one mouthpiece at a time, the resulting value of m is very near to that obtained experimentally for the combination. For instance, the calculated value of m for a 20°(1-2) entrance mouthpiece on a 6-in. pipe with a 5°(1-2) discharge mouthpiece is $m = .56 + (-.38) - .63 = -.45$, and

$m_c = m_p - (m_p - m_e, - (m_p - m_a)$

the value of m obtained by experiment was −0.44. When a 20°(1−3) entrance mouthpiece was used with a 15°(1−3) discharge, the value of m obtained from the formula is −0.19, while that obtained experimentally is −0.16.

The coefficient of discharge obtained with the first combination mentioned is 1.35, and for the second, 1.12. Evidently a small-angle convergence and divergence of the pipe ends is very helpful in increasing the flow under any given head.

13. Depth of Submergence of Orifice or Pipe.– Experiments for determining the effect of varying the depth of submergence were made only on the 1 1/2-in. round orifice and these were not carried on at any length as it soon became evident that it was a subject far too large to cover in the time at hand.

The coefficient of discharge obtained for this orifice in the first runs made in a manner similar to the others discussed herein, was 0.646. These were made with a depth of submergence of 36 in. or 24 diameters. The experiments to determine the effect of the depth of submergence were made under a depth of 14 in. or slightly over 9 diameters. The average coefficient of discharge obtained on two runs was 0.43+. This was so different from that previously obtained that two more runs at another head were made, giving coefficients of 0.439 and 0.435, checking the value obtained above.

The determination of the head in these experiments was made by reading the height of the water in glass tubes, as

described on page 11, because the apparatus on the box had been changed to permit its use in student laboratory work. This difference in the apparatus may have accounted for some of the change, but it evidently could not account for all or even a large part of it. For this reason it was evident that the subject was one which could not be adequately investigated in the short time available.

14. Comparison of Results.- The constants obtained in these experiments and given in the tables and diagrams are quite different in some respects from the values commonly quoted and used in practice. The coefficient of discharge commonly given for an inward projecting tube of a length less than two and one-half diameters is 0.50, and 0.72 is given for a tube of such length that the water fills the entire section at the discharge end, say a length of three or more diameters. The present experiments give c = 0.80 for the latter case. For a standard tube which does not project into the tank, i.e. with the inward end flush with the wall of the tank, Hoskins' "Hydraulics" uses 0.5 as the value of the coefficient of loss. The value obtained in these experiments for a similar condition, when a ring or 90° inlet mouthpiece was used, is 0.20. This is a large difference, and there is no reason to believe that the condition of the discharge end of the pipe (whether submerged or unsubmerged) affected the discharge in such a way as to produce this difference. When this ring was placed on the discharge end, the value obtained for m was 0.56, the same as found for the plain pipe. This indicates that under such conditions, all

the velocity head is lost.

For such an inward projecting pipe as was here used, the value of c ordinarily used is 0.72, and the coefficient of loss = 0.93. This does not agree with the value 0.56 obtained experimentally for m.

15. Use in Practice.- Since the coefficients of discharge for submerged orifices are now well determined, such orifices may well be used as a means of measuring the flow or discharge from a filter or reservoir, or in other cases where the rate of flow is to be regulated. The effective head at any time may easily be measured or indicated. This manner of measurement of discharge would be very accurate, as experiments show that under a steady head the flow in long periods would only differ from 1/3 to 1/2 of 1% from that calculated with coefficients experimentally determined. Inorder to insure this accuracy, however, it is necessary that all the conditions be kept like those of a "standard orifice", and they must not become fouled as may possibly occur with low velocities, reducing the effective size of the orifice.

All experiments indicate that the coefficients of discharge for large orifices are even more constant than with small ones and hence would be even better to use than ones of the size used in the experiments described herein. Even in the absence of experimental data for the coefficients of orifices of larger sizes, the error resulting from the use of an average coefficient is not likely to be as much as 2%.

The results of the investigations of submerged pipes

may be applied in practice in three general ways, (a) to effect a decrease in the entrance loss, (b) to regain or utilize velocity head which would otherwise be a total loss, and (c) to produce smooth or uniform flow of water.

A converging inlet to a pipe takes care of the contraction of the stream, so that the effective diameter of the pipe is increased and hence the flow for a given head is increased. This is often made use of in entrances to sluiceways in dams in order to get as large a discharge as possible. An angle of about 20° with the axis seems best on the entrance end.

Conical inlets on suction pipes would doubtless increase their efficiency.

A diverging outlet to a submerged pipe is of great aid in regaining and utilizing velocity head. On the end of discharge pipes it may be of great service. Given, say, a discharge pipe of 36-in. diameter. If an increaser be placed on the discharge end, raising its diameter to 51 in. in a length of about 7 1/2 ft., 75% of the velocity head may be regained, which may be a great saving where a small lift is used.

Such an increaser might be used with a centrifugal pump to reduce the high velocity in the pump to a lower one in the pipe line and at the same time make use of much of the velocity head.

An important application of the slowly diverging outlet may be found in the horizontal turbine, where a diverging tube may be used to take the water away from the turbine. The velocity head may in great part be used in the wheel because the velocity decreases slowly as the tube widens and thus head is

gained which would otherwise be a total loss.

Sluiceways in dams have been mentioned as benefiting by converging inlets. If now a long diverging outlet of about 5° angle with the axis be used in connection with such an inlet, still larger flow may be obtained for any given head. In a concrete structure, a converging inlet and diverging outlet of proper angles could easily be built. This would very much increase the flow and would aid in discharging a large quantity of water in minimum time.

Another important use of these facts is in the use of the draft tube with turbines, where the slightly diverging tube under the turbine makes it possible to utilize all the available head. Here a 5° angle with the axis of the pipe would probably give the best results as a smaller angle would necessitate a longer pipe than is ordinarily practicable and a larger angle would make it impossible to keep a solid column of water in a short tube.

A set of slowly diverging openings would be of great benefit at the entrance to a septic tank or a sedimentation basin, where it is desirable to have the flow steady and uniformly distributed over the cross-section of the tank or basin. The gradually widening openings reduce the velocity slowly and make the velocity practically constant at all points. They help greatly in bringing in a large flow without troublesome eddies.

16. General Conclusions.- A study of the data obtained in these experiments results in the following deductions:

(1) The velocity above which the coefficient of discharge for submerged orifices remains constant appears to be higher

for small orifices than for large ones. With the 1/2-in. square orifice, owing to the great difficulty of maintaining a steady high head, the point where constant coefficient began was not obtained. Careful work with the 1 1/2-in. round orifice brought the point of divergence down to a head of about 0.005 ft. With the 2-in. round and square orifices, the point comes when the head is about 0.04 ft., with the 4-in. at 0.007 ft., and with the 5 1/2-in. square and the 6-in. round at 0.006 ft. The point seems to be at about the same position for orifices of the same side or diameter regardless of their shape.

Of the four values given, that for the 2-in. orifices is much the highest. The reason for this is that far greater care was taken with 1 1/2-in. orifice to establish the point of divergence than was used with the other orifices. With the two large orifices, the flow was so large at low heads that no difficulty was met in obtaining a steady head. With the 1 1/2-in. round orifice, often as much as 3 or 3 1/2 hours was taken up in obtaining a steady flow of water, while with the 2-in. orifices never more than an hour was consumed. If less care had been taken with the 1 1/2-in. orifice, the point of divergence would probably have been higher than that for the 2-in. orifice. Conversely, if care had been used with the 2-in. orifice similar to that with the 1 1/2-in. orifice, the point would probably have come at a head of about 0.006 ft. or 0.007 ft.

The position found for this point of divergence, as pointed out before, is probably dependent on the care and precision used in the measurements made during the tests. For such

openings as would be used in practice, it seems evident that the point of divergence will be at so low an effective head that it will not be necessary in designing to consider the change in values for such low heads and that constant coefficients may be used. Attention is called to the fact that in this respect the results of the tests differ markedly from tables of the coefficients of discharge for circular vertical orifices usually quoted, which give coefficients increasing as the head decreases. The present experiments do not indicate that this is the case.

(2) At velocities below those noted above, the values of the coefficients change, c usually rising, though in the case of the 1 1/2-in. round and the 5 1/2-in. square, it became lower. It is not possible at present to state why these values increase in some cases and decrease in others, or just why they should differ at all from those obtained at higher velocities. It is easy to see that errors in taking readings would give wrong values, but why these inaccuracies should always be such as to produce a change in the same direction is not apparent.

(3) As may be seen from Tables 7, 8, and 9, the coefficient for submerged orifices may be taken, for ordinary velocities, at about 0.61, the range being from 0.59 to 0.64 for the different sizes and shapes investigated. Study of the tables shows that the round orifices run slightly higher than the square ones, and the triangular ones (Table 9) average higher than the round ones. The values of c run higher for small orifices than for large ones.

(4) Placing a converging inlet on a pipe increases its coefficient of discharge and decreases the coefficient of loss. The value of c for the 6-in. pipe ran about 0.80 while an entrance mouthpiece raises it to from 0.90 to 0.96, depending on the angle of the inlet, the small angles being the better.

The coefficient of loss for the 6-in. inward projecting pipe is 0.56. The value ordinarily given for this is 0.93. Converging inlets decrease the coefficient of loss, making it from 0.09 to 0.28, the small angles giving the better results. With the 90° angle, -that is, as if the pipe were set flush with a wall-, the coefficient of loss is 0.20 and the coefficient of discharge is 0.913. The amount ordinarily given for m for a standard tube is 0.49 and for c is 0.82. It will appear from this that the values ordinarily quoted for the coefficients of discharge and loss are far from correct.

Lengthening the mouthpiece was not productive of any important results. With a 20°(1-2) inlet on the 6-in. pipe, c = 0.923, the 20°(1-3) gave c = 0.914, and the 20°(1-4) gave c = 0.930. The angle rather than the length affects the coefficients. Angles up to 15° and 20° give the best results on the entrance end.

The highest values of c given in the tables in Merriman's "Hydraulics" for water discharging freely into air through converging tubes is, for a tube the sides of which make an angle of 6° 42' with the axis, 0.946. For a given least diameter of a submerged opening, a converging tube of an angle of about 15° to 20° with the axis would give higher discharge than a diverging tube of the same angle and the same diameter

at small end unless the space available were long enough to have a small-angle diverging tube of considerable length.

(5) Diverging mouthpieces placed on the discharge end of a pipe raise the coefficient of discharge and lower the coefficient of loss. Up to an angle of 15°, the effect is greater on the discharge end than by the use of the same mouthpiece on the entrance end, but above 15° the result is just the reverse. This may be noticed by comparing Tables 15 and 17. As mentioned on page 22, the longer mouthpieces, that is, the ones with the smaller angles, produced the better results. Figs. 31 to 39 and especially Fig. 34, indicate that there is small change in the coefficients if the mouthpiece be lengthened but the angle remain the same. With long mouthpieces the flowing water has more time to comform to the shape of the outlet. With large-angle outlets, the water flows out without having time for the stream to expand and take up all the space.

When this happens, eddies are probably formed between the stream and the sides of the outlet, retarding the flow. This is probably the reason for the lower discharge with the discharge angles over 15°, as compared with inlet angles of the same sizes.

(6) As might be expected from conclusions (4) and (5), the simultaneous use of converging inlets and diverging outlets on a pipe increases its capacity under a given head more than does either mouthpiece alone. As shown on page 22, the result, when small-angle mouthpieces are used is practically the sum of the separate effects of the inlet and discharge mouthpieces.

The best combination of inlet and discharge angles used in these experiments gave a coefficient of discharge of 1.35 and if the inlet had been curved instead of straight the value obtained would doubtless have been much larger.

In any place where it is desired to obtain the highest possible coefficient of discharge with even flow and small loss from eddies, (a) a converging inlet of about 15° or 20° angle with the axis, or (b) a diverging outlet of about 5° angle with the axis, with its length at least double its least diameter, or (c) a combination of (a) and (b), will give the best results.

The facts determined from these experiments may be applied in the design of such works as filters, sedimentation basins, septic tanks, suction pipes and discharge pipes of all kinds, dams , meters, turbines, pumps, and, in fact, in almost any hydraulic work.

TABLE 2.

EXPERIMENTAL DATA WITH ORIFICES AND 2-IN. SHORT PIPE.

1	2	3	4	5	6	7	8	9
Ref. No.	Head in feet	Time in sec.	in pounds	Discharge: Actual cu.ft. per sec. q	Discharge: Theoretic cu. ft. per sec. Q	Average Actual Velocity feet per sec. v	Coeff. of Dis-charge c	Coeff. of Loss m
				1-inch round Submergence = 36 diameters				
1	.004	900	35	.0006	.0028	0.11	.222	2.20
2	.004	900	36	.0006	.0028	0.11	.222	2.20
3	.007	900	122	.0022	.0037	0.40	.595	1.78
4	.007	900	121	.0022	.0037	0.40	.595	1.78
5	.014	900	181	.0032	.0052	0.59	.615	1.62
6	.014	900	181	.0032	.0052	0.59	.615	1.62
7	.024+	900	249	.0044	.0068	0.81	.648	1.35
8	.024+	900	248	.0044	.0068	0.81	.648	1.35
9	.040	900	325	.0058	.0088	1.06	.660	1.30
10	.041	900	324	.0058	.0088	1.06	.660	1.35
11	.051	900	342	.0061	.0099	1.12	.616	1.62
12	.051+	900	343	.0061	.0099	1.12	.616	1.62
13	.070	900	410	.0073	.0116	1.34	.629	1.51
14	.071	900	420	.0075	.0117	1.38	.641	1.31
15	.079	900	435	.0078	.0123	1.43	.634	1.46
16	.079	900	437	.0078	.0123	1.43	.634	1.46
17	.150	900	603	.0107	.0169	1.96	.631	1.52
18	.151	900	600	.0107	.0170	1.96	.630	1.52
19	.231	1080	901	.0134	.0210	2.46	.637	1.48
20	.236	900	754	.0134	.0213	2.46	.630	1.53
21	.329	900	894	.0159	.0251	2.92	.634	1.49
22	.350	900	916	.0163	.0259	2.99	.630	1.52
23	.355	900	927	.0165	.0261	3.03	.632	1.50
				1½-inch round Submergence = 24 diameters				
1	.001	1800	169	.0015	.0031	0.12	.484	3.39
2	.001	1800	168	.0015	.0031	0.12	.484	3.39
3	.003	6300	1128.	.0029	.0054	0.24	.546	2.31
4	.003	6300	1128	.0029	.0054	0.24	.546	2.31
5	.003	1800	330	.0029	.0054	0.24	.537	2.36
6	.003	1200	219	.0029	.0054	0.24	.537	2.36
7	.003	1200	218	.0029	.0054	0.24	.537	2.36
8	.003	1800	332	.0029	.0054	0.24	.546	2.31
9	.003	1800	338	.0030	.0054	0.24	.556	2.31
10	.004+	900	242	.0043	.0066	0.35	.652	1.37

1	2	3	4	5	6	7	8	9
11	.004+	1200	310	.0041	.0064	0.33	.645	1.45
12	.005	1800	517	.0046	.0070	0.37	.660	1.36
13	.005	1200	343	.0046	.0070	0.37	.658	1.36
14	.005	900	256	.0045	.0070	0.37	.654	1.36
15	.007	600	213	.0057	.0082	0.46	.695	1.14
16	.007	900	319	.0057	.0082	0.46	.695	1.14
17	.008	900	318	.0057	.0089	0.46	.625	1.44
18	.013	900	410	.0073	.0112	0.59	.652	1.41
19	.013	900	409	.0073	.0112	0.59	.652	1.41
20	.014+	900	453	.0080	.0118	0.66	.683	1.15
21	.015+	900	450	.0080	.0122	0.65	.665	1.37
22	.021	1200	684	.0091	.0142	0.74	.641	1.48
23	.021	900	511	.0091	.0142	0.74	.640	1.48
24	.021+	900	508	.0091	.0144	0.74	.632	1.53
25	.022	900	514	.0091	.0146	0.74	.625	1.59
26	.034	900	670	.0119	.0181	0.97	.656	1.33
27	.034	900	668	.0119	.0181	0.97	.656	1.33
28	.034	900	671	.0120	.0181	0.98	.661	1.30
29	.043	900	766	.0136	.0204	1.11	.665	1.25
30	.045	600	514	.0137	.0208	1.12	.657	1.32
31	.060	1680	1594	.0152	.0241	1.24	.631	1.51
32	.063	900	886	.0157	.0247	1.28	.635	1.48
33	.064	900	891	.0158	.0249	1.29	.635	1.48
34	.065	900	888	.0158	.0251	1.29	.630	1.52
				Submergence = 9 diameters				
35	.211	900	1590	.0280	.0650	2.20	.431	1.81
36	.221	900	1636	.0290	.0665	2.36	.436	1.56
37	.676	1800	5745	.0510	.1160	4.16	.439	1.50
38	.707	1800	5830	.0518	.1190	4.22	.435	1.56
				2-inch round Submergence = 12 diameters				
1	.008+	600	419	.0112	.0160	0.514	.700	1.04
2	.009	600	420	.0112	.0166	0.514	.676	1.19
3	.013	700	579	.0132	.0200	0.608	.661	1.27
4	.013	600	497	.0132	.0200	0.608	.661	1.27
5	.019	600	584	.0155	.0241	0.711	.645	1.41
6	.043+	600	850	.0226	.0364	1.038	.620	1.59
7	.043+	600	848	.0226	.0364	1.038	.620	1.59
8	.091	600	1218	.0325	.0528	1.490	.615	1.65
9	.092−	300	612	.0326	.0530	1.493	.615	1.63
10	.161	600	1625	.0434	.0702	1.991	.618	1.62
11	.162+	600	1627	.0434	.0705	1.991	.615	1.64
12	.213	500	1546	.0495	.0808	2.271	.613	1.67
13	.213	500	1544	.0495	.0808	2.271	.613	1.67
14	.213	450	1393	.0496	.0808	2.277	.614	1.65

1	2	3	4	5	6	7	8	9
				4-inch round Submergence = 6 diameters				
1	.006	600	1223	.0326	.0540	0.374	.604	1.77
2	.006+	500	1008	.0323	.0564	0.370	.573	2.07
3	.007	450	994	.0353	.0584	0.405	.605	1.75
4	.008−	450	1049	.0373	.0617	0.428	.605	1.77
5	.008	450	993	.0353	.0624	0.405	.565	2.12
6	.008	450	993	.0353	.0624	0.405	.565	2.12
7	.008+	450	1060	.0377	.0641	0.433	.590	1.88
8	.009	500	1211	.0388	.0661	0.445	.587	1.94
9	.010−	500	1210	.0388	.0676	0.445	.574	2.13
10	.010−	500	1211	.0388	.0689	0.445	.564	2.20
11	.011	450	1328	.0472	.0733	0.541	.645	1.48
12	.012	450	1340	.0476	.0765	0.546	.624	1.59
13	.012	450	1347	.0479	.0765	0.549	.626	1.55
14	.016+	400	1428	.0571	.0890	0.655	.642	1.42
15	.017	400	1428	.0571	.0910	0.655	.628	1.55
16	.018−	360	1290	.0573	.0930	0.657	.615	1.65
17	.018−	300	1074	.0572	.0930	0.656	.614	1.66
18	.063+	200	1379	.1102	.1760	1.264	.625	1.56
19	.066-	225	1559	.1110	.1790	1.271	.620	1.62
20	.071	200	1428	.1141	.1860	1.309	.614	1.68
21	.072	180	1295	.1151	.1875	1.320	.614	1.67
				6-inch round Submergence = 4 diameters				
1	.004	600	2771	.0739	.0996	0.376	.742	0.82
2	.005	900	4168	.0741	.1112	0.377	.666	1.27
3	.006	300	1434	.0765	.1220	0.389	.627	1.55
4	.006	300	1430	.0764	.1220	0.388	.627	1.56
5	.009−	500	2890	.0925	.1472	0.470	.628	1.56
6	.009	600	3379	.0901	.1494	0.459	.603	1.75
7	.013+	225	1559	.1105	.1820	0.562	.608	1.72
8	.014	250	1726	.1105	.1862	0.562	.593	1.86
9	.014	400	2770	.1108	.1865	0.563	.593	1.85
10	.014+	400	2750	.1100	.1900	0.560	.580	1.89
11	.020	180	1547	.1357	.2230	0.700	.616	1.63
12	.024+	320	2870	.1435	.2460	0.730	.585	1.94
				½-inch square Submergence = 47 diameters				
1	.040	900	108	.0019	.0028	1.098	.672	1.15
2	.041	900	108	.0019	.0028	1.098	.672	1.19
3	.119	1200	236	.0030	.0048	1.732	.625	1.56
4	.119	1200	224	.0030	.0048	1.732	.625	1.56
5	.177	900	196	.0035	.0059	2.023	.594	1.79
6	.178	900	197	.0035	.0059	2.023	.594	1.81

1	2	3	4	5	6	7	8	9
				1-inch square Submergence = 24 diameters				
1	.027	1200	411	.005+	.009	0.790	.596	1.79
2	.030	900	338	.006	.010-	0.864	.619	1.59
3	.030	600	222	.006	.010-	0.864	.619	1.59
4	.055	600	298	.008	.013	1.15	.615	1.69
5	.056	900	446	.008	.013	1.15	.615	1.73
6	.057	1200	608	.008	.013	1.15	.615	1.79
7	.130	900	698	.012	.020	1.73	.600	1.80
8	.131	600	466	.012	.020	1.73	.600	1.82
9	.264	600	661	.018	.029	2.59	.621	1.54
10	.265	900	993	.018	.029	2.59	.621	1.55
11	.266	1140	1260	.018	.029	2.59	.621	1.55
				2-inch square Submergence = 12 diameters				
1	.006	900	652	.0116	.0172	0.42	.673	1.21
2	.006	600	436	.0116	.0172	0.42	.673	1.21
3	.030	600	928	.0247	.0386	0.89	.639	1.44
4	.031	600	915	.0244	.0392	0.88	.623	1.59
5	.062	600	1295	.0345	.0553	1.24	.624	1.58
6	.062	600	1297	.0346	.0555	1.24	.624	1.57
7	.077	600	1446	.0386	.0621	1.39	.621	1.58
8	.077	600	1441	.0385	.0621	1.39	.621	1.59
9	.322	300	1468	.0782	.1266	2.82	.618	1.60
10	.325	300	1472	.0786	.1270	2.83	.619	1.62
11	.327	360	1773	.0788	.1275	2.84	.618	1.60
			Rise in Pit. feet.					
				4-inch square Submergence = 6 diameters				
1	.002	300	.184	.0308	.0398	0.277	.774	0.68
2	.003	900	.561	.0313	.0487	0.282	.642	1.43
3	.011	600	.690	.0577	.0934	0.519	.618	1.64
4	.012	300	.340	.0569	.0977	0.512	.583	1.96
5	.020	600	.932	.0780	.1260	0.702	.618	1.62
6	.021	360	.543	.0757	.1290	0.681	.588	1.90
7	.0215	300	.472	.0790	.1308	0.710	.605	1.74
8	.033	300	.599	.1001	.1620	0.902	.618	1.61
9	.034	300	.606	.1024	.1642	0.922	.623	1.51
10	.037	300	.636	.1063	.1712	0.957	.620	1.61
11	.040	400	.859	.1078	.1780	0.970	.610	1.75
				5½-inch square Submergence = 3⅓ diameters				
1	.002	900	0.706	.0394	.0752	0.187	.524	2.68
2	.002	600	0.465	.0390	.0752	0.186	.519	2.73
3	.006	900	1.418	.0792	.1300	0.376	.609	1.73
4	.006	600	0.957	.0801	.1300	0.381	.615	1.67
5	.010	900	1.764	.0985	.1680	0.468	.586	1.94

1	2	3	4	5	6	7	8	9
6	.010	600	1.180	.0987	.1680	0.470	.587	1.92
7	.012	900	1.952	.1089	.1840	0.518	.593	1.87
8	.012	600	1.293	.1083	.1840	0.516	.588	1.91
9	.019	900	2.548	.1423	.2325	0.677	.615	1.67
10	.020	600	1.678	.1405	.2378	0.669	.592	1.87

pounds.

6 x $\frac{1}{2}$-inch
Submergence = 44 diameters

1	.003	900	262	.0047	.0091	0.226	.513	2.79
2	.003	900	258	.0046	.0091	0.221	.505	2.95
3	.006	900	477	.0085	.0129	0.408	.658	1.34
4	.006	700	364	.0083	.0129	0.399	.645	1.42
5	.008	900	520	.0092	.0149	0.441	.617	1.65
6	.0275	4350	4929	.0181	.0277	0.870	.654	1.34
7	.0278	600	679	.0181	.0278	0.870	.651	1.36
8	.049	600	906	.0242	.0370	1.161	.654	1.34
9	.050	600	905	.0242	.0373	1.161	.649	1.39
10	.0553	400	611	.0245	.0393	1.175	.624	1.59
11	.0555	600	900	.0240	.0394	1.151	.610	1.70
12	.1965	600	1760	.0469	.0740	2.251	.634	1.50
13	.197	500	1472	.0472	.0741	2.262	.636	1.49

Rise in
Pit.
feet.

6 x 1-inch.
Submergence = 24 diameters

1	.006	600	.248	.0207	.0259	0.497	.800	0.57
2	.007	600	.246	.0206	.0279	0.494	.740	0.85
3	.017	800	.473	.0297	.0436	0.713	.682	1.15
4	.017	800	.460	.0289	.0436	0.694	.663	1.28
5	.033	600	.333	.0398	.0606	0.956	.656	1.32
6	.086	1000	1.249	.0627	.0979	1.505	.641	1.45
7	.0865	600	.755	.0631	.0982	1.513	.642	1.44
8	.134	600	.932	.0780	.1221	1.871	.638	1.47
9	.140	1000	1.569	.0788	.1250	1.890	.630	1.53
10	.2483	600	1.273	.1064	.1660	2.557	.640	1.46
11	.251	1000	2.110	.1060	.1670	2.542	.635	1.50
12	.2647	1000	2.169	.1089	.1714	2.614	.635	1.51

6 x 2-inch
Submergence = 12 diameters

1	.0024	1200	.692	.0290	.0326	0.348	.889	0.28
2	.0028	900	.522	.0292	.0353	0.350	.828	0.48
3	.010	600	.562	.0471	.0668	0.565	.705	1.02
4	.0105	900	.841	.0470	.0684	0.565	.688	1.11
5	.024	900	1.210	.0676	.1032	0.811	.655	1.35
6	.024	600	0.813	.0681	.1032	0.819	.660	1.32
7	.040	900	1.517	.0845	.1332	1.013	.634	1.51
8	.0404	900	1.527	.0851	.1340	1.020	.635	1.50
9	.062	900	1.883	.1050	.1660	1.260	.632	1.51

1	2	3	4	5	6	7	8	9
10	.064	1200	2.557	.1070	.1685	1.284	.635	1.50
11	.1198	800	2.358	.1480	.2310	1.776	.640	1.46
12	.1205	800	2.319	.1454	.2318	1.742	.629	1.55

4–inch triangular
Submergence = 6 diameters

1	2	3	4	5	6	7	8	9
1	.005	1800	.650	.0181	.0273	0.378	.665	1.26
2	.005	1800	.650	.0181	.0273	.0378	.665	1.26
3	.010	1800	.903	.0252	.0386	0.524	.653	1.35
4	.0108	6300	3.135	.0250	.0401	0.520	.623	1.57
5	.0313	1200	1.014	.0425	.0682	0.885	.624	1.59
6	.0314	1200	1.023	.0428	.0683	0.890	.627	1.55
7	.0736	900	1.171	.0654	.1047	1.360	.625	1.57
8	.074	900	1.176	.0656	.1050	1.363	.625	1.56
9	.112	900	1.452	.0811	.1291	1.686	.628	1.54
10	.1138	600	.963	.0805	.1300	1.672	.620	1.63
11	.2142	600	1.312	.1100	.1782	2.288	.634	1.65
12	.215	900	2.000	.1130	.1787	2.350	.633	1.51

Short Pipe (Flush)

Calculated Data

2 x 5½–inch submerged short pipe
Submergence = 12 diameters

corrected

	h	t	lb/sec	Qa	QT		V		C		m
1	.0094	1800	0.512	.0143	.0170	.0185	0.656	.603	.843	.775	0.41
2	.010	7200	2.019	.0141	.0175	.0191	0.648	.596	.804	.738	0.53
3	.014	9900	3.484	.0177	.0207	.0225	0.811	.746	.857	.789	0.37
4	.016	1500	0.547	.0183	.0221	.0240	0.840	.773	.826	.761	0.46
5	.018	7200	2.946	.0206	.0235	.0255	0.946	.871	.878	.808	0.29 30
6	.018	1200	0.492	.0206	.0235	.0255	0.946	.871	.878	.808	0.29 30
7	.052	1200	0.841	.0352	.0399	.0434	1.62	1.49	.884	.814	0.29 27
8	.052	1200	0.843	.0353	.0399	.0434	1.62	1.49	.886	.816	0.27
9	.122	1200	1.290	.0540	.0611	.0664	2.48	2.28	.884	.814	0.29 27
10	.123	900	0.959	.0535	.0613	.0666	2.45	2.25	.872	.802	0.32
11	.325	600	0.959	.0804	.0996	.1082	3.69	3.40	.806	.743	0.54
12	.330	600	1.066	.0891	.1004	.1090	4.09	3.77	.888	.827	0.27

area 2" pipe = .0218 sq ft
" 2.085" pipe = .0237 " "

TABLE 3.

EXPERIMENTAL DATA WITH 6-IN. SHORT PIPE AND (1 - 2) MOUTHPIECES.

1	2	3	4	5	6	7	8	9
Ref. No.	Head in feet	Time in sec.	Discharge: Rise in Pit. feet	Discharge: Actual cu. ft. per sec. q	Discharge: Theoretic cu. ft. per sec. Q	Average Actual Velocity feet per sec. v	Coeff. of Dis-charge c	Coeff. of Loss m
			6-in. x 22½ in. pipe, extending into each box Submergence = 4 diameters					
1	.003	900	1.150	.0641	.0865	0.326	.742	0.83
2	.003	900	1.149	.0641	.0865	0.326	.742	0.83
3	.0048	900	1.435	.0800	.1090	0.407	.734	0.87
4	.005	900	1.422	.0794	.1113	0.404	.712	0.97
5	.0066	900	1.735	.0969	.1279	0.493	.758	0.75
6	.0072	900	1.769	.0985	.1334	0.502	.738	0.84
7	.008	900	2.033	.1135	.1410	0.578	.805	0.54
8	.008	900	2.030	.1131	.1410	0.576	.803	0.55
9	.012	900	2.470	.1379	.1726	0.701	.800	0.57
10	.0136	900	2.632	.1470	.1841	0.749	.800	0.57
11	.0142	600	1.797	.1502	.1874	0.765	.803	0.56
			6-in. pipe, with 5° (1 - 2) entrance mouthpiece Submergence = 4 diameters					
1	.002	900	1.038	.0580	.0704	0.295	.835	0.48
2	.002	900	1.039	.0580	.0704	0.295	.835	0.48
3	.004	900	1.767	.0986	.0995	0.501	.991	0.02
4	.004	1200	2.354	.0985	.0991	0.501	.991	0.02
5	.0048	600	1.299	.1086	.1090	0.553	.995	0.01
6	.005	900	1.934	.1080	.1113	0.549	.970	0.07
7	.005	900	1.806	.1008	.1113	0.513	.905	0.22
8	.005	900	1.820	.1015	.1113	0.516	.912	0.21
9	.009	900	2.611	.1458	.1491	0.741	.975	0.06
10	.0106	900	2.672	.1490	.1620	0.758	.920	0.15
			6-in. pipe, with 5° (1 - 2) discharge mouthpiece Submergence = 4 diameters					
1	.003	900	1.617	.0902	.0863	0.459	1.045	-.080
2	.003	900	1.623	.0906	.0863	0.461	1.050	-.090
3	.0043	600	1.322	.1106	.1032	0.563	1.070	-.124
4	.0044	900	1.980	.1104	.1042	0.562	1.059	-.102
5	.006	900	2.415	.1344	.1220	0.685	1.101	-.176
6	.0065	900	2.397	.1337	.1269	0.680	1.055	-.068
7	.008	900	2.676	.1491	.1408	0.759	1.059	-.106
8	.009	900	2.707	.1510	.1492	0.767	1.010	-.014
9	.009	900	2.645	.1477	.1492	0.751	.989	+.03
10	.009	900	2.648	.1479	.1492	0.753	.990	+.02

6-in. pipe, with 10° (1 – 2) entrance mouthpiece
Submergence = 4 diameters

1	2	3	4	5	6	7	8	9
1	.004	900	1.677	.0935	.0996	0.475	.939	0.14
2	.004	900	1.683	.0940	.0996	0.478	.945	0.13
3	.005	600	1.289	.1079	.1076	0.549	1.002	0.07
4	.0056	600	1.303	.1090	.1178	0.555	.926	0.17
5	.008	900	2.381	.1329	.1409	0.676	.944	0.13
6	.0085	900	2.365	.1320	.1450	0.671	.911	0.21
7	.010	1200	3.661	.1530	.1575	0.779	.971	0.06
8	.010	1200	3.664	.1530	.1575	0.779	.971	0.06
9	.011	900	2.629	.1469	.1650	0.747	.889	0.27
10	.011	900	2.605	.1451	.1650	0.739	.880	0.30

6-in. pipe, with 10° (1 – 2) discharge mouthpiece
Submergence = 4 diameters

1	2	3	4	5	6	7	8	9
1	.0023	1800	2.503	.0698	.0755	0.355	.923	0.18
2	.0027	1800	2.516	.0701	.0819	0.356	.857	0.37
3	.004	900	1.645	.0918	.0996	0.468	.923	0.18
4	.004	900	1.649	.0918	.0996	0.468	.923	0.18
5	.005	1200	2.727	.1141	.1113	0.581	1.03	–.046
6	.0055	900	2.052	.1145	.1148	0.583	.998	0.04
7	.0064	1800	4.572	.1278	.1259	0.650	1.015	–.026
8	.007	1800	4.648	.1295	.1318	0.659	.983	0.04
9	.008	900	2.591	.1445	.1408	0.735	1.03	–.046 } wrong —.06
10	.008	600	1.730	.1448	.1408	0.736	1.03	–.021
11	.009	1200	3.472	.1450	.1492	0.738	.972	0.07

6-in. pipe, with 15° (1 – 2) entrance mouthpiece
Submergence = 4 diameters

1	2	3	4	5	6	7	8	9
1	.0032	900	1.491	.0834	.0890	0.424	.936	0.15
2	.0034	900	1.509	.0841	.0918	0.428	.918	0.19
3	.006	900	2.025	.1130	.1219	0.575	.929	0.17
4	.0062	900	2.051	.1144	.1239	0.582	.925	0.18
5	.008	900	2.406	.1341	.1409	0.683	.953	0.11
6	.008	900	2.398	.1338	.1409	0.681	.951	0.11
7	.009	600	1.709	.1428	.1494	0.727	.955	0.10
8	.0098	900	2.570	.1434	.1558	0.730	.921	0.19

6-in. pipe, with 15° (1 – 2) discharge mouthpiece
Submergence = 4 diameters

1	2	3	4	5	6	7	8	9
1	.003	900	1.395	.0780	.0864	0.397	.903	0.22
2	.003	1200	1.870	.0782	.0864	0.398	.906	0.22
3	.003	2100	3.265	.0781	.0864	0.398	.905	0.22
4	.003	1000	1.566	.0787	.0864	0.401	.911	0.20
5	.003	900	1.440	.0803	.0876	0.408	.915	0.19
6	.0037	900	1.630	.0910	.0959	0.463	.950	0.11
7	.0038	900	1.627	.0908	.0970	0.462	.937	0.11
8	.0039	900	1.666	.0930	.0984	0.473	.945	0.12
9	.004	900	1.700	.0948	.0995	0.482	.952	0.11
10	.0046	1800	3.686	.1028	.1069	0.523	.962	0.08
11	.0046	720	1.461	.1020	.1069	0.519	.955	0.10

1	2	3	4	5	6	7	8	9
12	.0047	1080	2.225	.1035	.1079	0.527	.960	0.09
13	.0048	600	1.233	.1031	.1090	0.525	.947	0.12
14	.0048	1200	2.453	.1025	.1090	0.522	.940	0.14
15	.0048	600	1.220	.1020	.1090	0.519	.937	0.15
16	.006	900	1.973	.1101	.1219	0.561	.905	0.23
17	.006	900	1.945	.1086	.1219	0.553	.892	0.22
18	.0062	1200	2.691	.1127	.1240	0.574	.909	0.21
19	.0064	600	1.313	.1100	.1259	0.559	.875	0.32
20	.014	600	2.019	.1690	.1865	0.860	.906	0.22
21	.0142	1200	4.034	.1689	.1878	0.860	.899	0.24
22	.0145	600	2.015	.1686	.1893	0.859	.891	0.27
		6-in. pipe, with 20° (1 – 2) entrance mouthpiece Submergence = 4 diameters						
1	.004	900	1.544	.0860	.0995	0.438	.865	0.34
2	.004	900	1.558	.0870	.0995	0.442	.875	0.32
3	.004	1800	3.102	.0866	.0995	0.441	.871	0.32
4	.0058	600	1.323	.1109	.1199	0.564	.925	0.17
5	.0059	1200	2.652	.1110	.1209	0.565	.919	0.19
6	.006	600	1.329	.1111	.1219	0.566	.913	0.21
7	.0067	900	2.161	.1208	.1289	0.615	.937	0.15
8	.0067	1500	3.594	.1202	.1289	0.612	.933	0.15
9	.0068	600	1.433	.1200	.1296	0.611	.926	0.17
10	.0068	900	2.123	.1185	.1299	0.604	.915	0.20
11	.0068	900	2.114	.1180	.1299	0.600	.909	0.22
12	.0178	600	2.325	.1949	.2101	0.991	.927	0.17
13	.018	900	3.510	.1960	.2113	0.997	.928	0.17
		6-in. pipe, with 20° (1 – 2) discharge mouthpiece Submergence = 4 diameters						
1	.004	900	1.488	.0829	.0996	0.422	.832	0.45
2	.0044	900	1.499	.0836	.1042	0.426	.801	0.56
3	.007	900	1.989	.1109	.1318	0.564	.842	0.42
4	.007	900	2.013	.1122	.1318	0.571	.853	0.39
5	.007	1800	4.002	.1115	.1318	0.568	.847	0.40
6	.0082	900	2.355	.1315	.1425	0.669	.923	0.18
7	.0088	700	1.815	.1302	.1477	0.663	.883	0.29
8	.009	900	2.388	.1332	.1494	0.679	.893	0.26
9	.013	900	2.839	.1581	.1795	0.805	.881	0.29
10	.0132	900	2.841	.1588	.1809	0.808	.878	0.31
11	.015	900	3.018	.1682	.1929	0.856	.873	0.32
12	.0154	900	3.040	.1695	.1954	0.862	.867	0.33
		6-in. pipe, with 30° (1 – 2) entrance mouthpiece Submergence = 4 diameters						
1	.0027	1200	1.967	.0823	.0818	0.418	1.005	–.009
2	.003	1200	1.933	.0807	.0850	0.411	.950	0.14
3	.0032	900	1.666	.0930	.0891	0.474	1.044	–.082
4	.0038	900	1.718	.0959	.0970	0.489	.990	0.03
5	.007	900	2.121	.1185	.1317	0.603	.900	0.24
6	.007	900	2.118	.1181	.1317	0.601	.898	0.25
7	.007	1800	4.239	.1181	.1317	0.601	.898	0.25

1	2	3	4	5	6	7	8	9
8	.0082	900	2.374	.1325	.1427	0.674	.928	0.15
9	.0084	900	2.378	.1327	.1442	0.675	.920	0.18
10	.010	900	2.716	.1517	.1575	0.771	.964	0.08
11	.010	900	2.719	.1517	.1575	0.771	.964	0.08
12	.0137	900	3.083	.1720	.1843	0.875	.933	0.15
13	.0147	900	3.079	.1719	.1909	0.875	.900	0.24

6-in. pipe, with 30° (1 - 2) discharge mouthpiece
Submergence = 4 diameters

1	.0046	1800	3.417	.0956	.1068	0.486	.893	0.25
2	.0046	900	1.715	.0958	.1068	0.488	.897	0.25
3	.0047	900	1.702	.0950	.1079	0.484	.882	0.29
4	.0058	900	1.567	.0874	.1199	0.445	.730	0.89
5	.006	600	1.017	.0851	.1219	0.433	.699	1.06
6	.0066	1800	3.801	.1061	.1279	0.540	.831	0.46
7	.007	1800	3.825	.1068	.1317	0.543	.811	0.53
8	.0096	1200	3.141	.1315	.1541	0.670	.854	0.37
9	.010	1200	3.146	.1318	.1575	0.670	.837	0.43
10	.0124	900	2.584	.1441	.1754	0.734	.823	0.47
11	.013	900	2.598	.1449	.1794	0.737	.807	0.54
12	.0168	900	2.894	.1613	.2040	0.821	.791	0.61
13	.017	1200	4.012	.1678	.2054	0.855	.818	0.50

6-in. pipe, with 45° (1 - 2) entrance mouthpiece
Submergence = 4 diameters

1	.0058	900	1.915	.1069	.1199	0.544	.893	0.27
2	.0066	900	1.918	.1070	.1279	0.545	.838	0.43
3	.0085	900	2.195	.1225	.1450	0.624	.845	0.41
4	.009	900	2.173	.1212	.1491	0.617	.813	0.52
5	.0112	900	2.591	.1447	.1667	0.736	.868	0.34
6	.0115	1200	3.406	.1422	.1690	0.724	.843	0.41
7	.0117	1200	3.530	.1475	.1704	0.751	.865	0.34
8	.014	1200	4.010	.1679	.1863	0.854	.901	0.24
9	.014	900	2.975	.1660	.1863	0.845	.892	0.26
10	.0153	1200	4.060	.1698	.1949	0.865	.872	0.32
11	.0154	1200	4.088	.1709	.1953	0.870	.875	0.31

6-in. pipe, with 45° (1 - 2) discharge mouthpiece
Submergence = 4 diameters

1	.0073	1200	2.693	.1126	.1346	0.573	.837	0.43
2	.0074	900	1.923	.1073	.1355	0.546	.793	0.59
3	.0137	1200	3.378	.1414	.1843	0.720	.768	0.70
4	.014	900	2.701	.1508	.1863	0.768	.809	0.53
5	.0142	600	1.823	.1527	.1877	0.776	.813	0.52
6	.015	900	2.731	.1526	.1929	0.776	.792	0.60
7	.017	900	3.106	.1732	.2053	0.883	.844	0.41
8	.018	1200	4.009	.1679	.2113	0.855	.795	0.59
9	.018	1200	4.012	.1679	.2113	0.855	.795	0.59

1	2	3	4	5	6	7	8	9
			6–in. pipe, with 60° (1 – 2) entrance mouthpiece Submergence = 4 diameters					
1	.0047	1080	2.079	.0967	.1080	0.493	.895	0.25
2	.0047	1200	2.373	.0994	.1080	0.506	.920	0.18
3	.0047	2280	4.452	.0982	.1080	0.500	.908	0.21
4	.0094	900	2.449	.1369	.1527	0.697	.896	0.25
5	.0096	1800	4.899	.1369	.1543	0.697	.886	0.28
6	.0098	900	2.450	.1369	.1559	0.697	.879	0.30
7	.013	900	2.902	.1620	.1796	0.824	.901	0.24
8	.0135	900	2.894	.1612	.1830	0.820	.882	0.29
			6–in. pipe, with 60° (1 – 2) discharge mouthpiece Submergence = 4 diameters					
1	.0083	900	1.991	.1111	.1435	0.565	.775	0.67
2	.0086	1800	3.993	.1114	.1460	0.567	.764	0.72
3	.0088	900	2.002	.1119	.1477	0.569	.758	0.75
4	.017	900	2.786	.1557	.2053	0.792	.758	0.74
5	.017	600	1.874	.1568	.2053	0.796	.764	0.73
6	.018	900	2.963	.1655	.2113	0.844	.784	0.63
7	.018	900	2.926	.1632	.2113	0.830	.764	0.68

TABLE 4.

EXPERIMENTAL DATA WITH (1 – 3) MOUTHPIECES.

1	2	3	4	5	6	7	8	9
Ref. No.	Head in feet	Time in sec.	Discharge: Rise in Pit. feet	Discharge: Actual cu.ft. per sec. q	Discharge: Theoretic cu. ft. per sec. Q	Average Actual Velocity feet per sec. v	Coeff. of Dis-charge c	Coeff. of Loss m
	6-in. pipe, with 10° (1 – 3) entrance mouthpiece Submergence = 4 diameters							
1	.003	1200	1.694	.0709	.0863	0.361	.822	0.49
2	.003	1200	1.670	.0700	.0863	0.356	.812	0.51
3	.0092	600	1.604	.1341	.1510	0.682	.889	0.27
4	.0094	1500	4.010	.1341	.1527	0.682	.880	0.30
5	.0096	900	2.406	.1341	.1543	0.682	.870	0.33
6	.0112	900	2.658	.1481	.1666	0.755	.891	0.27
7	.0116	900	2.691	.1502	.1697	0.764	.885	0.24
8	.014	900	3.061	.1710	.1863	0.870	.918	0.19
9	.0142	900	3.072	.1715	.1877	0.873	.914	0.20
	6-in. pipe, with 10° (1 – 3) discharge mouthpiece Submergence = 4 diameters							
1	.0039	1200	2.285	.0956	.0984	0.487	.972	0.06
2	.004	1200	2.322	.0973	.0996	0.495	.977	0.06
3	.009	1200	3.262	.1369	.1494	0.696	.915	0.20
4	.0098	900	2.628	.1410	.1559	0.718	.905	0.22
5	.011	960	2.877	.1504	.1652	0.766	.910	0.21
6	.012	900	2.835	.1581	.1725	0.805	.917	0.19
7	.012	900	2.839	.1582	.1725	0.806	.918	0.19
8	.0132	900	2.916	.1626	.1809	0.828	.900	0.24
9	.0138	900	2.938	.1639	.1851	0.834	.885	0.28
	6-in. pipe, with 15° (1 – 3) entrance mouthpiece Submergence = 4 diameters							
1	.0093	900	2.600	.1451	.1518	0.739	.956	0.10
2	.0096	900	2.663	.1487	.1543	0.757	.963	0.06
3	.0109	1200	3.650	.1529	.1645	0.777	.928	0.16
4	.011	1200	3.707	.1551	.1652	0.790	.939	0.14
5	.0145	600	2.127	.1782	.1896	0.906	.940	0.14
6	.0164	1200	4.560	.1909	.2017	0.972	.948	0.12
7	.0167	900	3.403	.1900	.2035	0.967	.935	0.15

1	2	3	4	5	6	7	8	9
			6-in. pipe, with 15° (1 – 3) discharge mouthpiece Submergence = 4 diameters					
1	.0023	1800	2.192	.0611	.0755	0.311	.810	0.53
2	.0023	900	1.134	.0632	.0755	0.322	.838	0.43
3	.0114	900	2.803	.1564	.1681	0.796	.930	0.16
4	.0114	900	2.792	.1560	.1681	0.793	.927	0.17
5	.0135	1067	3.592	.1690	.1830	0.861	.925	0.18
6	.0142	900	3.047	.1700	.1877	0.866	.907	0.22
7	.0157	900	3.255	.1819	.1973	0.925	.921	0.18
8	.0172	900	3.324	.1858	.2066	0.945	.897	0.24
9	.018	900	3.392	.1892	.2113	0.964	.896	0.25
10	.018	900	3.375	.1881	.2113	0.958	.892	0.26
			6-in. pipe, with 20° (1 – 3) entrance mouthpiece Submergence = 4 diameters					
1	.005	900	1.867	.1041	.1114	0.530	.935	0.15
2	.005	900	1.848	.1030	.1114	0.524	.925	0.17
3	.0108	900	2.759	.1539	.1637	0.784	.939	0.14
4	.011	900	2.731	.1525	.1652	0.776	.923	0.18
5	.012	900	2.782	.1553	.1725	0.790	.901	0.24
6	.0138	900	2.996	.1671	.1851	0.851	.904	0.23
7	.0147	900	3.055	.1705	.1910	0.868	.894	0.26
8	.0165	900	3.375	.1882	.2023	0.959	.930	0.16
9	.0172	900	3.352	.1870	.2066	0.951	.905	0.22
10	.0174	600	2.266	.1895	.2078	0.964	.913	0.21
			6-in. pipe, with 20° (1 – 3) discharge mouthpiece Submergence = 4 diameters					
1	.006	900	1.996	.1113	.1220	0.566	.914	0.21
2	.006	900	2.017	.1125	.1220	0.573	.922	0.18
3	.0077	900	2.272	.1268	.1382	0.645	.917	0.19
4	.008	900	2.284	.1276	.1409	0.650	.906	0.22
5	.0094	900	2.455	.1370	.1527	0.697	.897	0.25
6	.010	900	2.461	.1376	.1575	0.699	.875	0.32
7	.0148	900	3.143	.1754	.1916	0.894	.916	0.20
8	.0164	900	3.069	.1713	.2017	0.871	.850	0.39
9	.0174	900	3.301	.1843	.2078	0.937	.889	0.27
10	.018	1200	4.502	.1889	.2113	0.961	.894	0.26
			6-in. pipe, with 45° (1 – 3) entrance mouthpiece Submergence = 4 diameters					
1	.004	900	1.819	.1015	.0996	0.517	1.02	–.037
2	.0043	900	1.840	.1026	.1022	0.522	1.004	+.015
3	.0065	900	2.091	.1169	.1270	0.594	.919	0.19
4	.007	900	2.068	.1154	.1318	0.587	.877	0.31
5	.0115	600	1.824	.1528	.1689	0.778	.905	0.22
6	.012	900	2.707	.1510	.1725	0.769	.876	0.31
7	.018	900	3.414	.1905	.2113	0.970	.902	0.23
8	.018	600	2.264	.1895	.2113	0.965	.898	0.25

1	2	3	4	5	6	7	8	9
		6-in. pipe, with 45° (1 – 3) discharge mouthpiece Submergence = 4 diameters						
1	.007	900	1.895	.1058	.1318	0.539	.803	0.56
2	.0072	900	1.920	.1071	.1337	0.545	.802	0.56
3	.0092	900	2.194	.1225	.1510	0.623	.812	0.53
4	.0093	900	2.177	.1214	.1518	0.618	.800	0.57
5	.0122	900	2.511	.1402	.1740	0.714	.806	0.54
6	.0126	600	1.676	.1402	.1768	0.714	.795	0.59
7	.015	900	2.750	.1537	.1929	0.783	.797	0.58
8	.015	900	2.828	.1580	.1929	0.806	.819	0.49
9	.0156	900	2.833	.1580	.1967	0.806	.805	0.55
10	.0228	900	3.432	.1917	.2378	0.977	.807	0.48
11	.0238	900	3.501	.1953	.2430	0.995	.804	0.55
		6-in. pipe, with 90° (1 – 3) entrance mouthpiece Submergence = 4 diameters						
1	.006	900	1.848	.1031	.1220	0.525	.845	0.40
2	.007	900	1.971	.1100	.1318	0.560	.836	0.44
3	.010	900	2.582	.1441	.1575	0.734	.916	0.19
4	.0103	920	2.671	.1459	.1598	0.742	.913	0.21
5	.0172	900	3.407	.1900	.2066	0.968	.920	0.18
6	.0173	900	3.350	.1870	.2072	0.952	.903	0.23
		6-in. pipe, with 90° (1 – 3) discharge mouthpiece Submergence = 4 diameters						
1	.004	900	1.439	.0804	.0996	0.409	.806	0.54
2	.004	900	1.412	.0789	.0996	0.401	.791	0.60
3	.008	900	1.999	.1114	.1409	0.567	.792	0.60
4	.008	900	2.030	.1133	.1409	0.576	.805	0.55
5	.0192	900	3.171	.1770	.2183	0.901	.811	0.53
6	.020	600	2.087	.1749	.2228	0.888	.785	0.63
7	.022	910	3.452	.1904	.2336	0.970	.815	0.51
8	.0228	900	3.436	.1917	.2378	0.975	.806	0.55

TABLE 5.

EXPERIMENTAL DATA WITH (1 – 4) MOUTHPIECES.

Ref. No.	Head in feet	Time in sec.	Discharge: Rise in Pit. feet	Discharge: Actual cu. ft. per sec. q	Discharge: Theoretic cu. ft. per sec. Q	Average Actual Velocity feet per sec. v	Coeff. of Discharge c	Coeff. of Loss m
	6-in. pipe, with 20° (1 – 4) entrance mouthpiece Submergence = 4 diameters							
1	.007	900	2.080	.1160	.1318	0.590	.881	0.29
2	.0075	600	1.349	.1128	.1364	0.574	.826	0.47
3	.0104	856	2.455	.1439	.1606	0.731	.896	0.25
4	.011	900	2.556	.1427	.1652	0.726	.863	0.35
5	.0145	900	3.157	.1760	.1896	0.896	.929	0.16
6	.0146	900	3.148	.1758	.1903	0.894	.924	0.18
7	.0146	900	3.209	.1790	.1903	0.912	.941	0.13
8	.016	900	3.299	.1839	.1992	0.935	.922	0.18
9	.016	600	2.226	.1864	.1992	0.948	.935	0.15
	6-in. pipe, with 20° (1 – 4) discharge mouthpiece Submergence = 4 diameters							
1	.007	900	2.215	.1235	.1318	0.629	.937	0.14
2	.0072	900	2.208	.1232	.1337	0.626	.922	0.18
3	.0104	900	2.416	.1349	.1606	0.687	.840	0.42
4	.0106	900	2.449	.1369	.1621	0.696	.843	0.41
5	.013	900	2.857	.1593	.1796	0.811	.888	0.27
6	.0136	900	2.870	.1602	.1837	0.816	.872	0.31
7	.0148	900	3.034	.1691	.1916	0.861	.882	0.29
8	.0148	900	3.076	.1715	.1916	0.874	.895	0.25
9	.018	900	3.419	.1909	.2113	0.970	.905	0.23
10	.0182	600	2.258	.1890	.2125	0.962	.890	0.27

TABLE 6.

EXPERIMENTAL DATA WITH

COMBINATIONS OF ENTRANCE AND DISCHARGE MOUTHPIECES.

Ref. No.	Head in feet	Time in sec.	Rise in Pit. feet	Discharge Actual cu. ft. per sec. q	Discharge Theoretic cu. ft. per sec. Q	Average Actual Velocity feet per sec. v	Coeff. of Dis-charge c	Coeff. of Loss m
6-in. pipe, with 20° (1-2) entrance and 5° (1-2) discharge Submergence = 4 diameters								
1	.0028	900	1.504	.0840	.0833	0.427	1.01	-0.01
2	.0034	900	1.513	.0845	.0919	0.430	0.920	+0.19
3	.0038	600	1.526	.1276	.0971	0.649	1.32	-0.42
4	.0042	600	1.548	.1296	.1020	0.659	1.27	-0.47
5	.0054	900	2.871	.1600	.1157	0.814	1.38	-0.42
6	.0056	900	2.851	.1591	.1179	0.810	1.35	-0.45
7	.008	600	2.272	.1901	.1409	0.969	1.35	-0.45
8	.008	600	2.248	.1882	.1409	0.958	1.34	-0.44
6-in. pipe, with 20° (1-3) entrance and 15° (1-3) discharge Submergence = 4 diameters								
1	.004	900	2.007	.1120	.0996	0.570	1.13	-0.21
2	.004	600	1.329	.1110	.0996	0.565	1.12	-0.19
3	.008	900	2.786	.1555	.1409	0.791	1.10	-0.18
4	.008	360	1.121	.1565	.1409	0.796	1.11	-0.19
5	.0096	900	3.063	.1710	.1543	0.870	1.11	-0.19
6	.010	900	3.037	.1693	.1575	0.862	1.08	-0.13
7	.0114	900	3.510	.1956	.1681	0.995	1.15	-0.26
8	.0122	900	3.526	.1969	.1740	1.001	1.13	-0.21

TABLE 7.

SUBMERGED CIRCULAR ORIFICES.

Coefficients of Discharge.

Effective Head in Feet	Size of orifice				
	1-in.	1 1/2-in.	2-in.	4-in.	6-in.
0.005		0.646			0.670
0.010	0.600	0.646	0.672	0.612	0.598
0.015	0.611	0.646	0.654	0.625	0.596
0.020	0.619	0.646	0.643	0.626	0.596
0.030	0.629	0.646	0.627	0.622	0.599+
0.040	0.630	0.646	0.620	0.621	0.599+
0.050	0.630	0.646	0.616	0.620	0.599+
0.100	0.630	0.646	0.616	0.601	0.599+
0.200	0.630	0.646	0.616	0.599	0.599+

+ From thesis of G. D. Phillips, '07.

TABLE 8.

SUBMERGED SQUARE ORIFICES.

Coefficients of Discharge.

Effective Head in Feet	Size of Orifice.				
	1/2-in.	1-in.	2-in.	4-in.	5 1/2-in.
0.005				0.635	0.596
0.010			0.660	0.609	0.598
0.015			0.651	0.609	0.598
0.020			0.646	0.609	0.598
0.030		0.613	0.632	0.609	
0.040	0.673	0.612	0.627	0.609	
0.050	0.667	0.612	0.622		
0.100	0.637	0.611	0.620		
0.200	0.591	0.611	0.620	0.601+	

+ From thesis of G. D. Phillips, '07.

TABLE 9.

SUBMERGED RECTANGULAR AND TRIANGULAR ORIFICES.

Coefficients of Discharge.

Effective Head in Feet.	Size of Orifices. Rect. 6-in.x1/2-in.	Rect. 6-in.x1-in.	Rect. 6-in.x2-in.	Tri'r. 4-in.
0.005			0.745	
0.010	0.639	0.705	0.699	0.627
0.015	0.639	0.680	0.675	0.627
0.020	0.639	0.667	0.660	0.627
0.030	0.639	0.650	0.642	0.627
0.040	0.639	0.640	0.634	0.627
0.050	0.639	0.637	0.634	0.627
0.100	0.639	0.637	0.634	0.627
0.200	0.639	0.637	0.634	0.627

TABLE 10.

SUBMERGED CIRCULAR ORIFICES.

Coefficients of Loss.

Average Velocity, Ft./Sec.	Size of Orifices. 1-in.	1 1/2-in.	2-in.	4-in.	6-in.
0.4	1.78	1.38		2.00	1.43
0.5	1.68	1.38	1.01	1.64	1.76
0.6	1.59	1.38	1.25	1.58	1.82
0.7	1.53	1.38	1.41	1.58	1.82
0.8	1.51	1.38	1.48	1.58	1.82
0.9	1.50	1.38	1.53	1.58	1.82
1.0	1.50	1.38	1.56	1.58	1.82
1.5	1.50	1.38	1.64	1.70+	
2.0	1.50		1.64	1.70+	

+ From thesis of G. D. Phillips, '07.

TABLE 11.

SUBMERGED SQUARE ORIFICES.

Coefficients of Loss.

Average Velocity, Ft./Sec.	Size of Orifices. 1/2-in.	1-in.	2-in.	4-in.	5 1/2-in.
0.4			1.18	1.63	1.82
0.5			1.28	1.69	1.82
0.6			1.36	1.69	1.82
0.7			1.42	1.69	1.82
0.8		1.68	1.46	1.69	
0.9		1.68	1.50	1.69	
1.0	1.15	1.68	1.52	1.69	
1.5	1.38	1.68	1.60		
2.0	1.80	1.68	1.60		

TABLE 12.

SUBMERGED RECTANGULAR AND TRIANGULAR ORIFICES.

Coefficients of Loss.

Average Velocity, Ft. / sec.	Size of Orifices. 6-in.x1/2-in. Rect.	6-in.x1-in. Rect.	6-in.x2-in. Rect.	4-in. Tri'r.
0.4	1.47		0.68	
0.5	1.47	0.88	0.96	1.57
0.6	1.47	1.09	1.13	1.57
0.7	1.47	1.20	1.26	1.57
0.8	1.47	1.28	1.35	1.57
0.9	1.47	1.34	1.42	1.57
1.0	1.47	1.39	1.50	1.57
1.5	1.47	1.48	1.51	1.57
2.0	1.47	1.48		1.57

TABLE 13.

SUBMERGED SHORT PIPES.

Coefficients of Discharge.

Pipe Used	Head in Feet. .005	.010	.015	.020	.030	.040	.050	.100
2-in. x 5 1/2-in.		.830	.868	.882	.882	.882	.882	.882
6-in. x 22 1/2-in.	.750	.802	.802					

TABLE 14.

SUBMERGED SHORT PIPES.

Coefficients of Loss.

Pipe Used	Velocity, Ft. per Sec. 0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5
2-in. x 5 1/2-in.				0.47	0.38	0.29	0.29	0.29
6-in. x 22 1/2-in.	0.86	0.61	0.56	0.56	0.56			

TABLE 15.

SUBMERGED 6-IN. PIPE WITH ENTRANCE MOUTHPIECES.

Coefficients of Discharge.

Mouth-piece	Head in Feet. .002	.004	.006	.008	.010	.015	.020
5° (1-2)	.836	.960	.960	.960	.960		
10° "		.958	.958	.958	.958		
15° "		.936	.936	.936	.936		
20° "		.870	.923	.923	.923	.923	
30° "		.945	.923	.923	.923	.923	
45° "		.	.864	.864	.864	.864	
60° "			.888	.888	.888	.888	
10° (1-3)		.827	.845	.862	.880	.925	
15° "					.947	.943	
20° "			.914	.914	.914	.914	
45° "		1.015	.901	.896	.896	.896	.896
90° "			.825	.902	.913	.913	
20° (1-4)				.860	.880	.930	

TABLE 16.

SUBMERGED ENTRANCE MOUTHPIECES.

Coefficients of Loss.

m'

Mouth-piece	Velocity in Ft. per Sec. .30	.40	.50	.75	1.00
5° (1–2)	–.08	–.42	–.47	–.47	
10° "			–.41	–.41	
15° "		–.41	–.41	–.41	
20° "			–.38	–.38	–.38
30° "			–.38	–.38	–.38
45° "				–.23	–.32
60° "			–.34	–.29	
10° (1–3)	–.02	–.08	–.15	–.30	
15° "				–.46	–.42
20° "			–.45	–.36	–.36
45° "				–.31	–.31
90° "				–.30	–.30
20° (1–4)			–.10	–.29	–.40

TABLE 17.

SUBMERGED 6–IN. PIPE WITH DISCHARGE MOUTHPIECES.

Coefficients of Discharge.

Mouth-piece	.002	.004	Head in Feet. .006	.008	.010	.015	.020
5°(1–2)		1.043	1.043	1.043			
10° "	.855	.953	1.008	1.008	1.008		
15° "		.945	.895	.895	.895	.895	
20° "		.790	.865	.885	.885	.885	
30° "			.821	.821	.821	.821	
45° "			.803	.803	.803	.803	
60° "				.767	.767	.767	.767
10°(1–3)		.970	.910	.907	.907	.907	
15° "					.937	.910	.883
20° "			.920	.893	.893	.893	
45° "			.805	.805	.805	.805	.805
90° "		.801	.801	.801	.801	.801	.801
20°(1–4)			.889	.889	.889	.889	.889

TABLE 18.

SUBMERGED DISCHARGE MOUTHPIECES.

Coefficients of Gain.

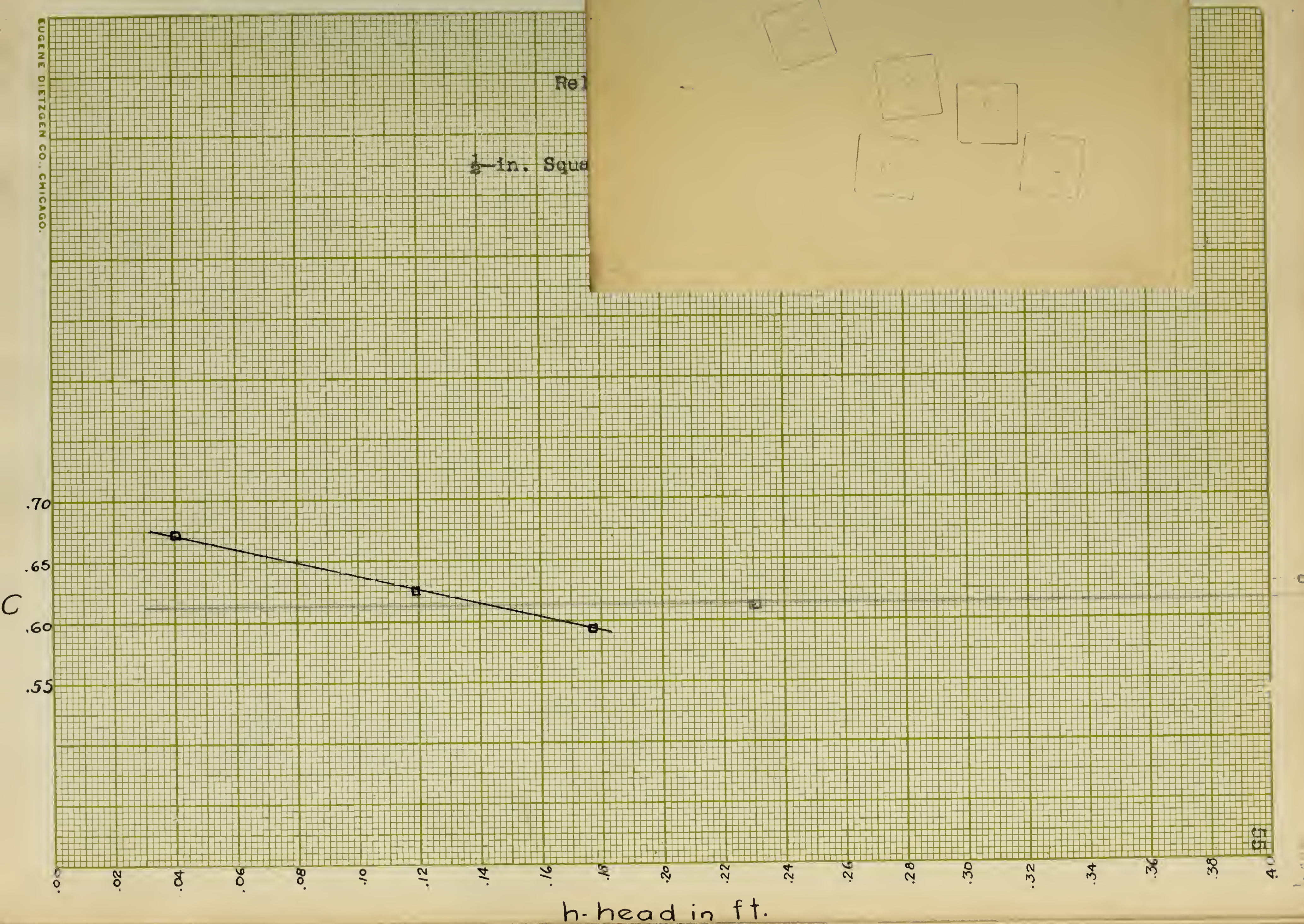
n

Mouth-piece	Velocity in Ft. per Sec. .30	.40	.50	.75	1.00
5°(1-2)		+.63	+.63	+.63	
10° "		+.33	+.47	+.56	
15° "		+.36	+.45	+.30	+.30
20° "		-.03	+.09	+.28	
30° "		+.07	+.07	+.07	
45° "			+.01	+.01	+.01
60° "			-.14	-.14	
10°(1-3)			+.47	+.34	
15° "				+.42	+.29
20° "				+.30	+.30
45° "			+.01	+.01	+.01
90° "		.00	.00	.00	.00
20°(1-4)				+.29	+.29

TABLE 19.

COEFFICIENTS FOR 6-IN. PIPE
WITH
MOUTHPIECES ON BOTH ENDS.

Mouthpieces Entrance	Discharge	c Head in Feet = .003	.005	.010	m Velocity in Ft./Sec= 0.50	0.75	1.00
20°(1-2)	5°(1-2)	.970	1.355	1.355	-.02	-.44	-.44
20°(1-3)	15°(1-3)	1.12	1.12	1.12	-.19	-.19	-.19



Rel
$\frac{1}{2}$-in. Squa
.70
.65
C
.60
.55
.00
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
h-head in ft.
55
EUGENE DIETZGEN CO., CHICAGO.

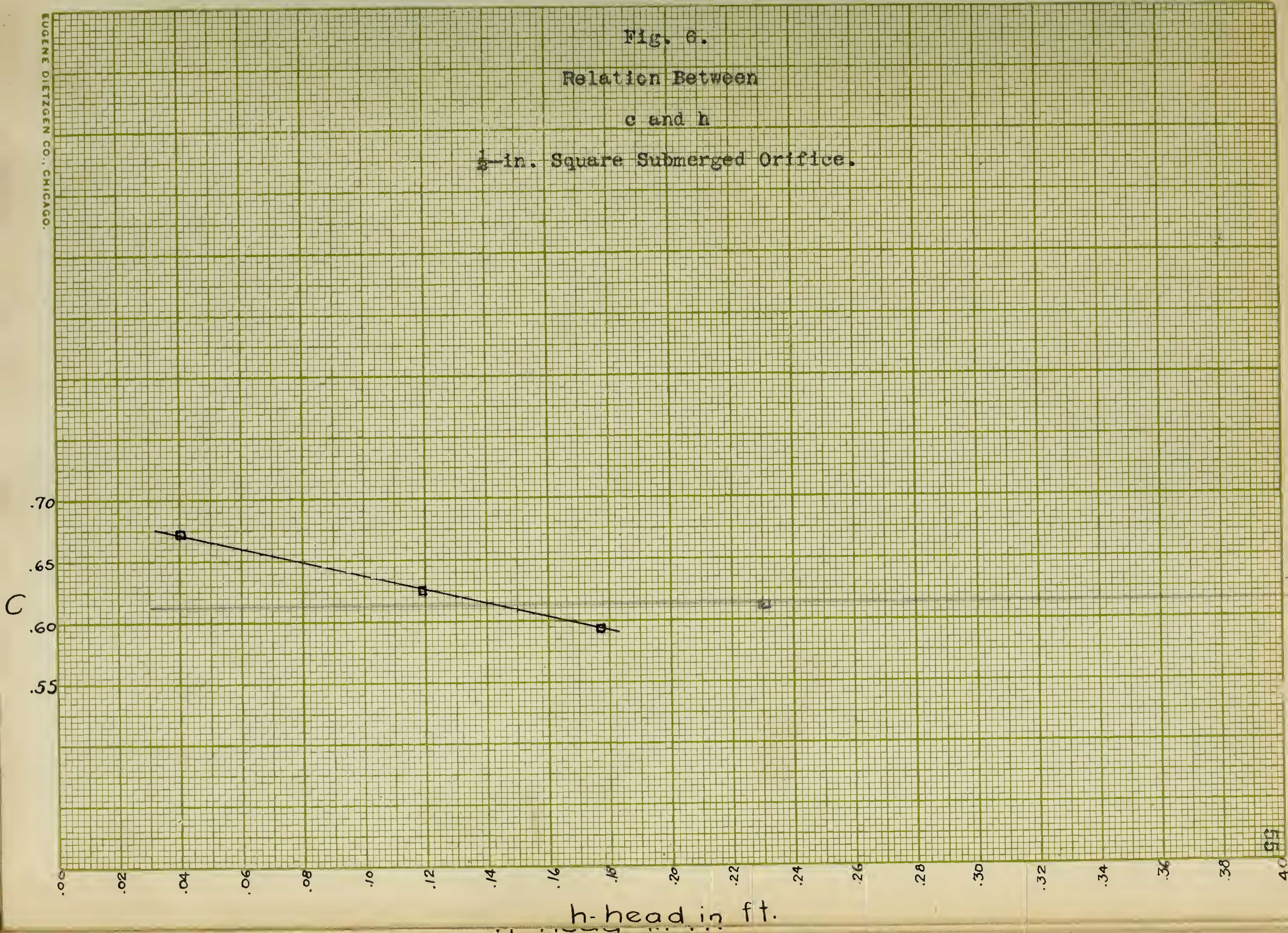


Fig. 6.

Relation Between

c and h

$\frac{1}{2}$-in. Square Submerged Orifice.

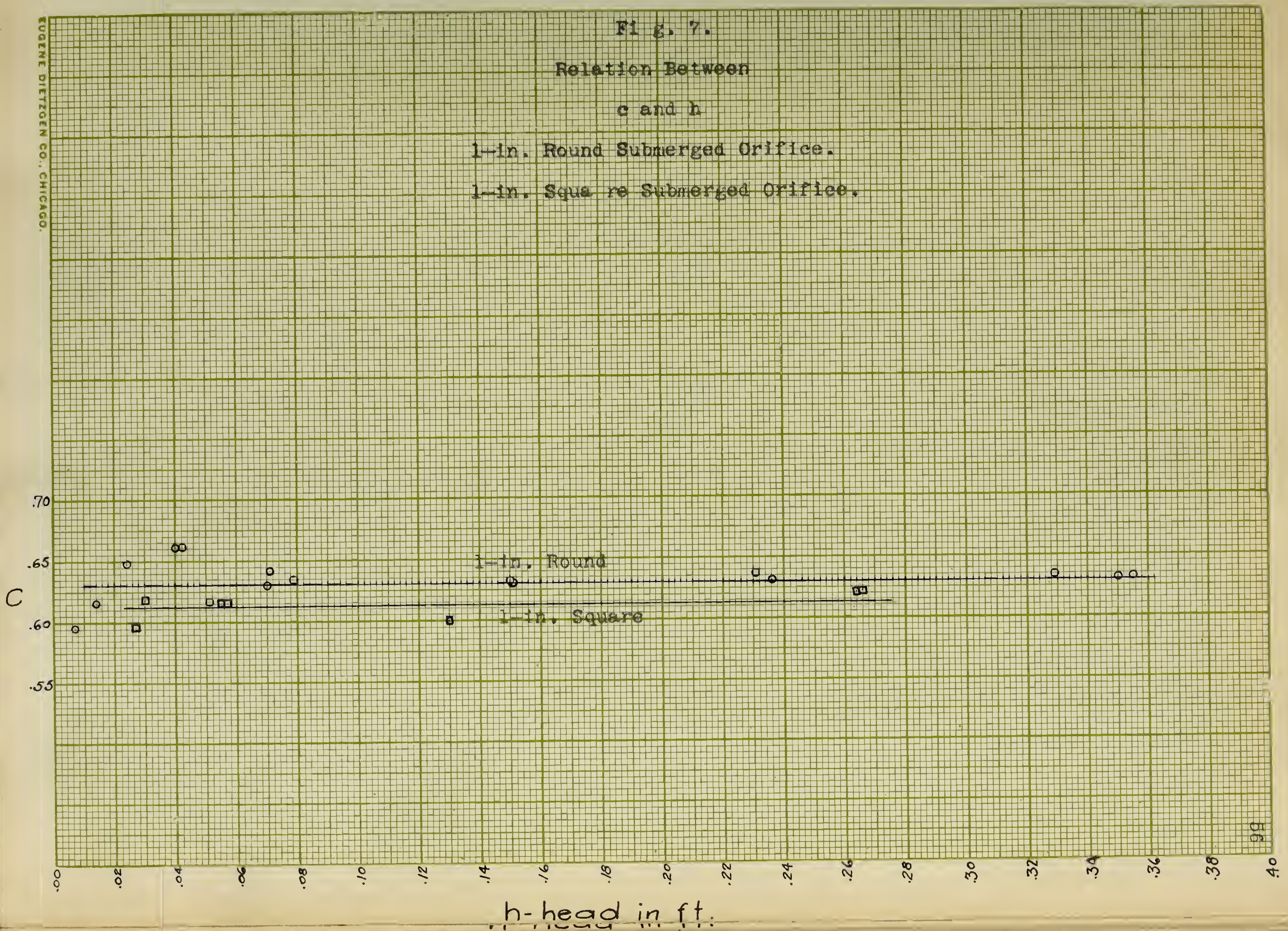


Fig. 7.

Relation Between

c and h

1-in. Round Submerged Orifice.

1-in. Squa re Submerged Orifice.

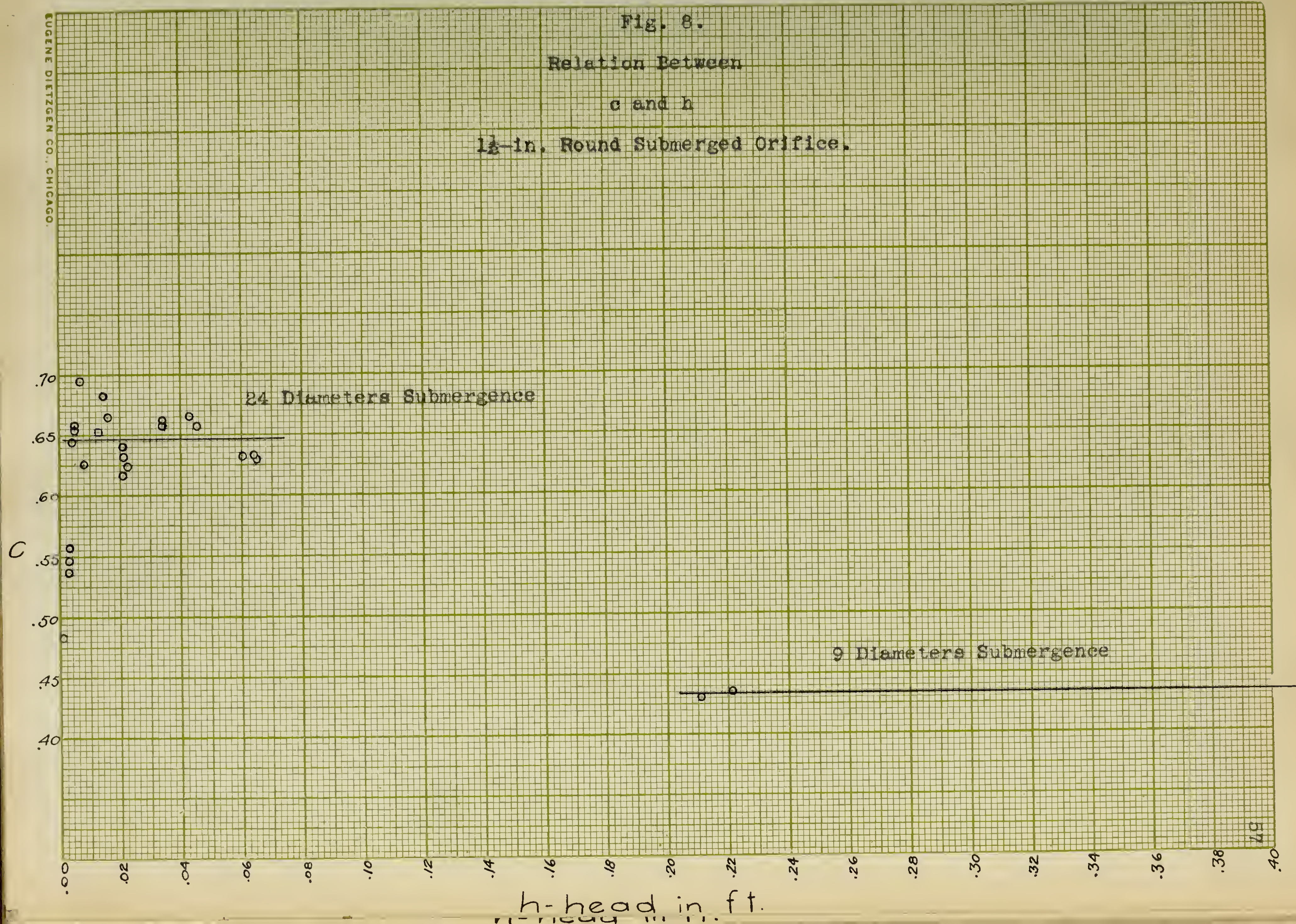


Fig. 8.
Relation Between
c and h
1½-in. Round Submerged Orifice.
24 Diameters Submergence
9 Diameters Submergence
C
.70
.65
.60
.55
.50
.45
.40
.00
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
h-head in ft.
EUGENE DIETZGEN CO., CHICAGO.

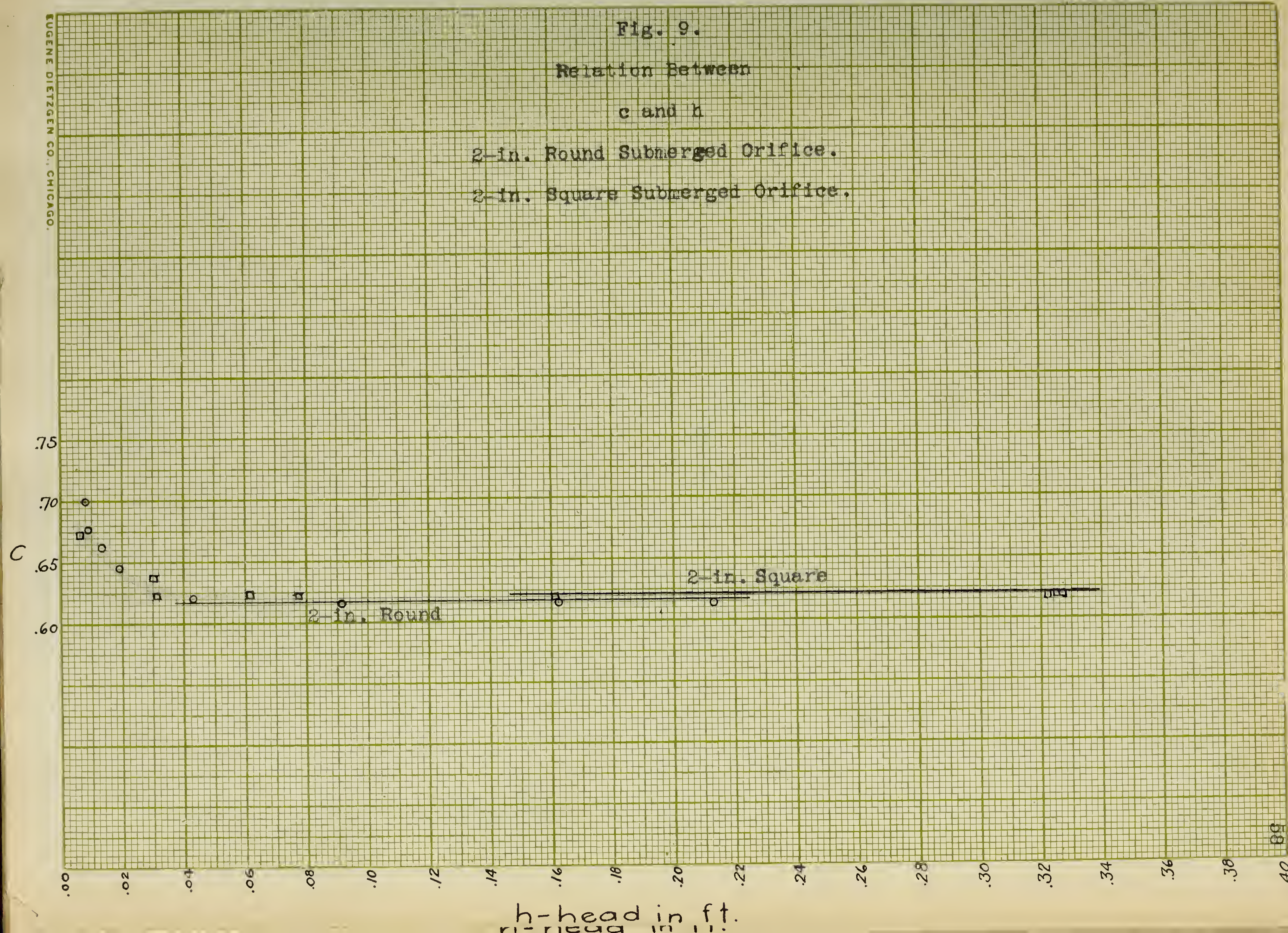


Fig. 9.
Relation Between
c and h
2-in. Round Submerged Orifice.
2-in. Square Submerged Orifice.
2-in. Square
2-in. Round
.75
.70
C
.65
.60
.00
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
h-head in ft.

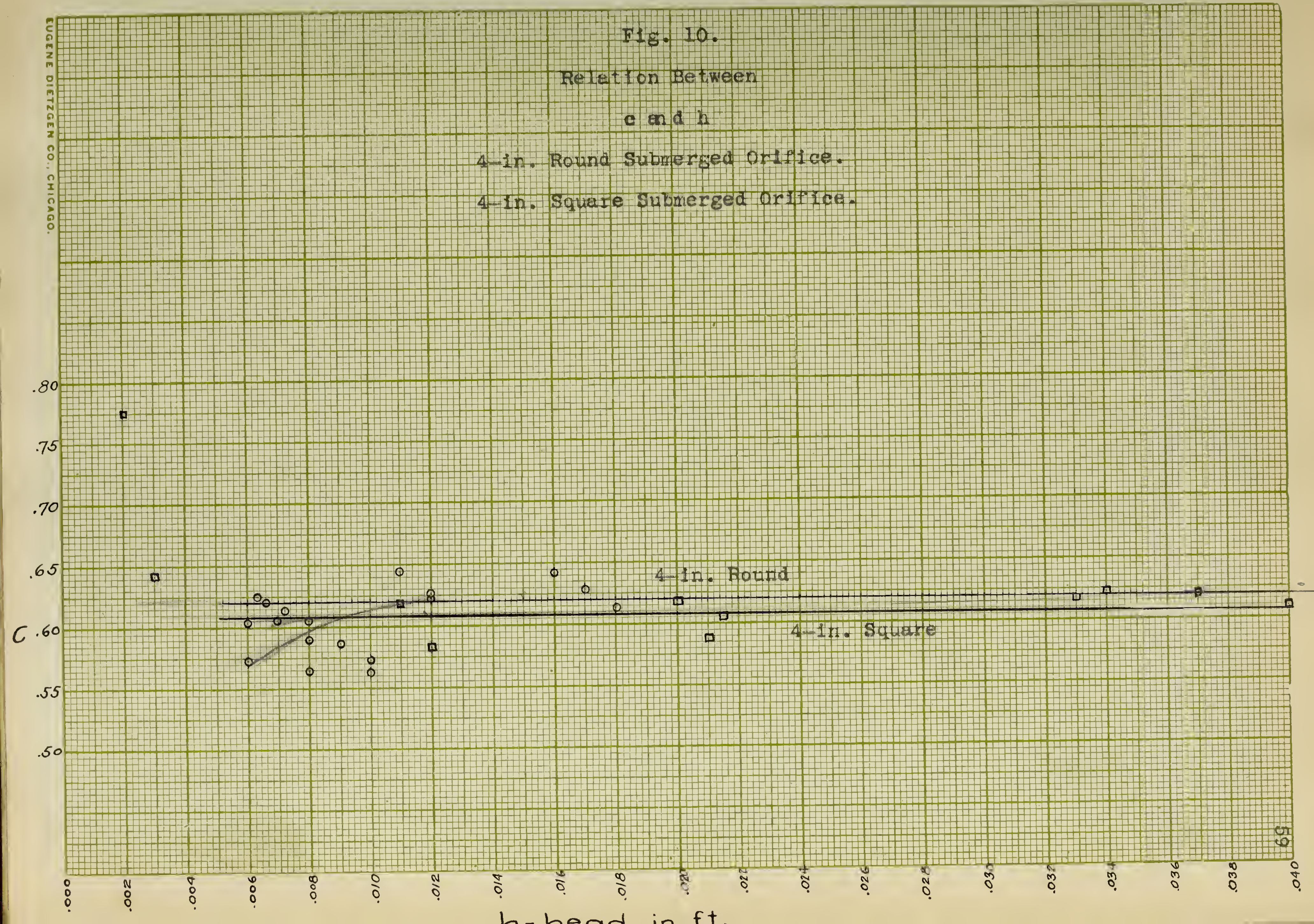


Fig. 10.
Relation Between
c and h
4-in. Round Submerged Orifice.
4-in. Square Submerged Orifice.
4-in. Round
4-in. Square
C
.80
.75
.70
.65
.60
.55
.50
.000
.002
.004
.006
.008
.010
.012
.014
.016
.018
.020
.022
.024
.026
.028
.030
.032
.034
.036
.038
.040
h-head in ft.
EUGENE DIETZGEN CO., CHICAGO.

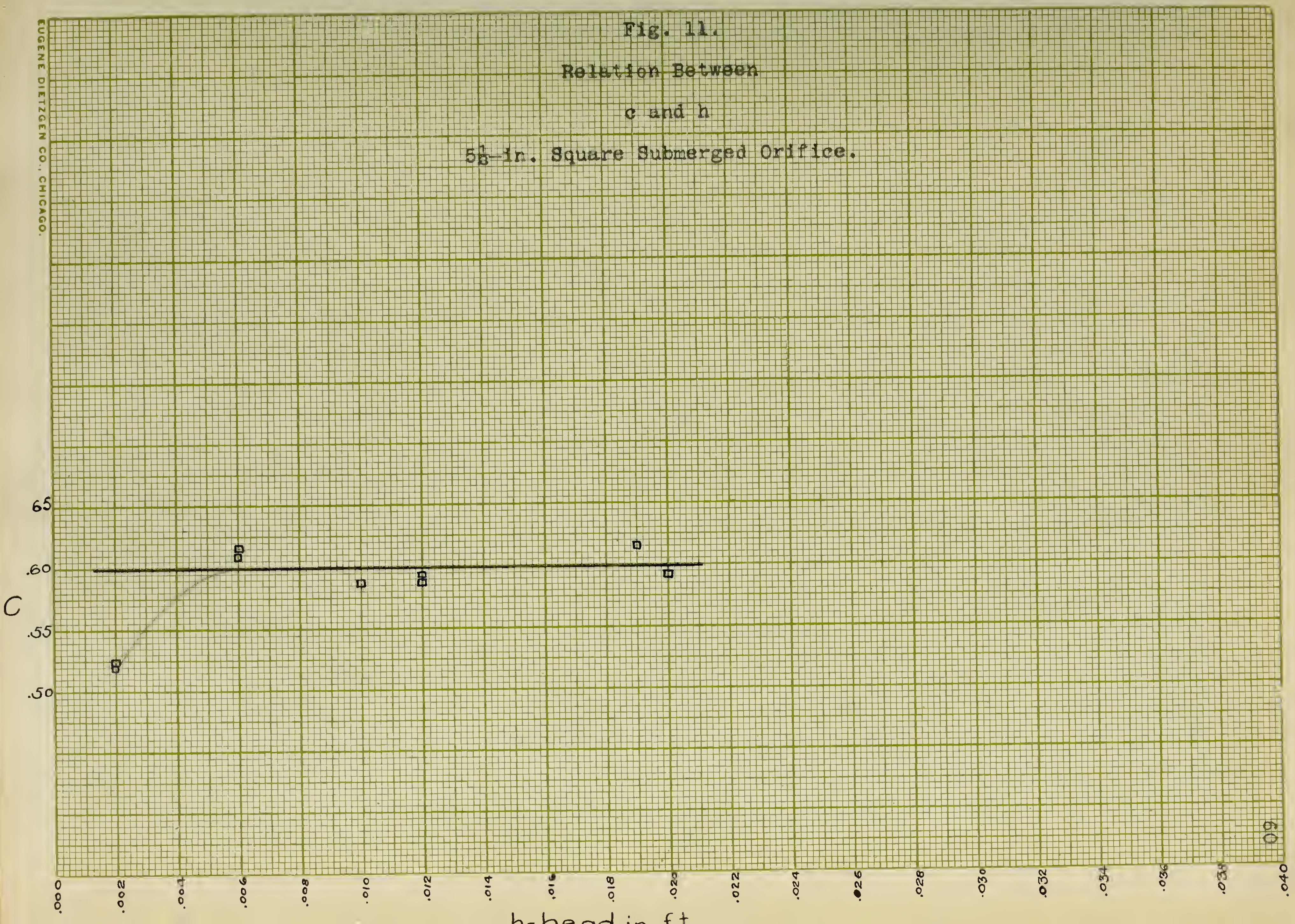


Fig. 11.
Relation Between
c and h
$5\frac{1}{8}$-in. Square Submerged Orifice.
C
.65
.60
.55
.50
.000
.002
.004
.006
.008
.010
.012
.014
.016
.018
.020
.022
.024
.026
.028
.030
.032
.034
.036
.038
.040
h-head in ft.
60
EUGENE DIETZGEN CO., CHICAGO.

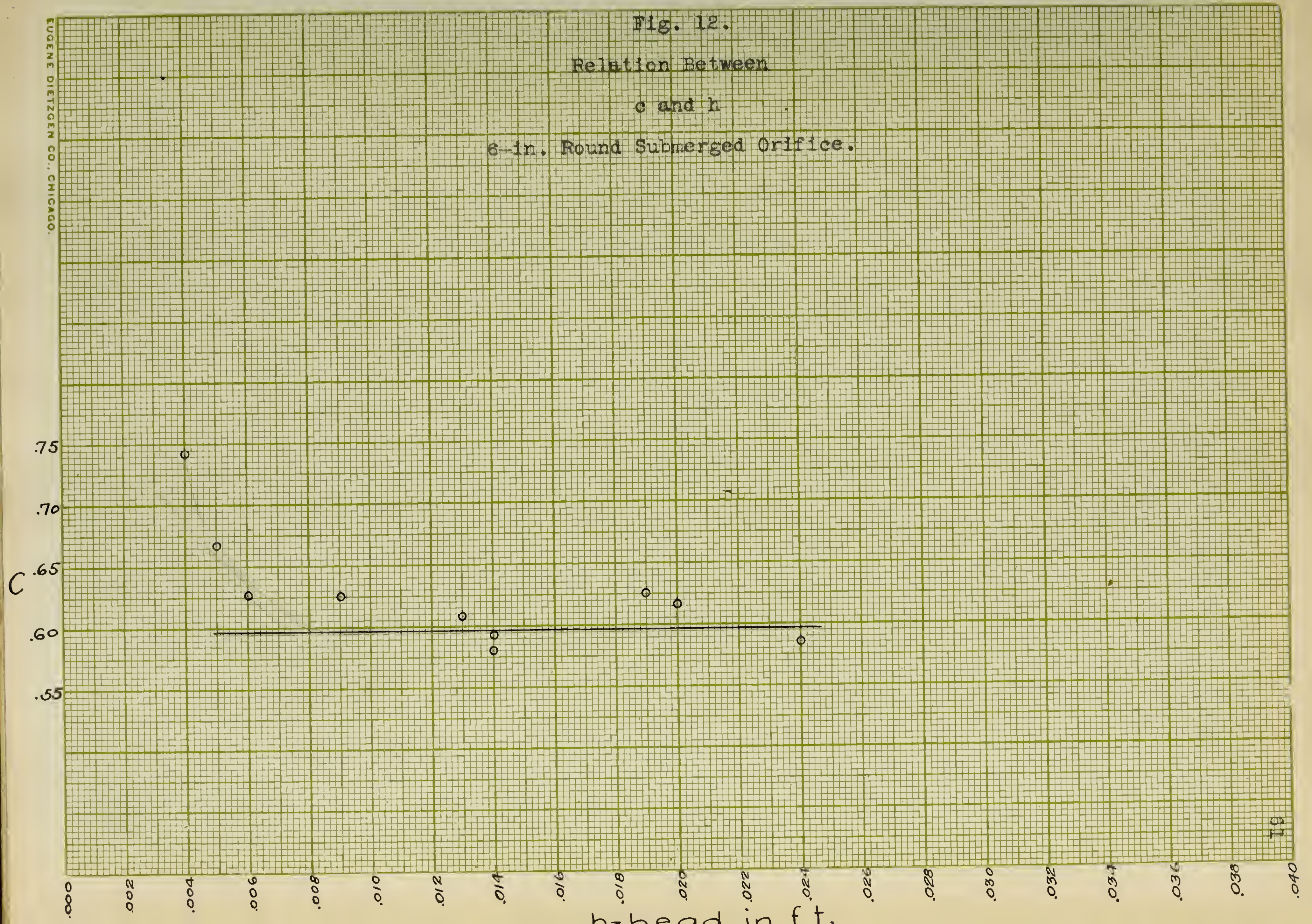


Fig. 12.

Relation Between

c and h

6-in. Round Submerged Orifice.

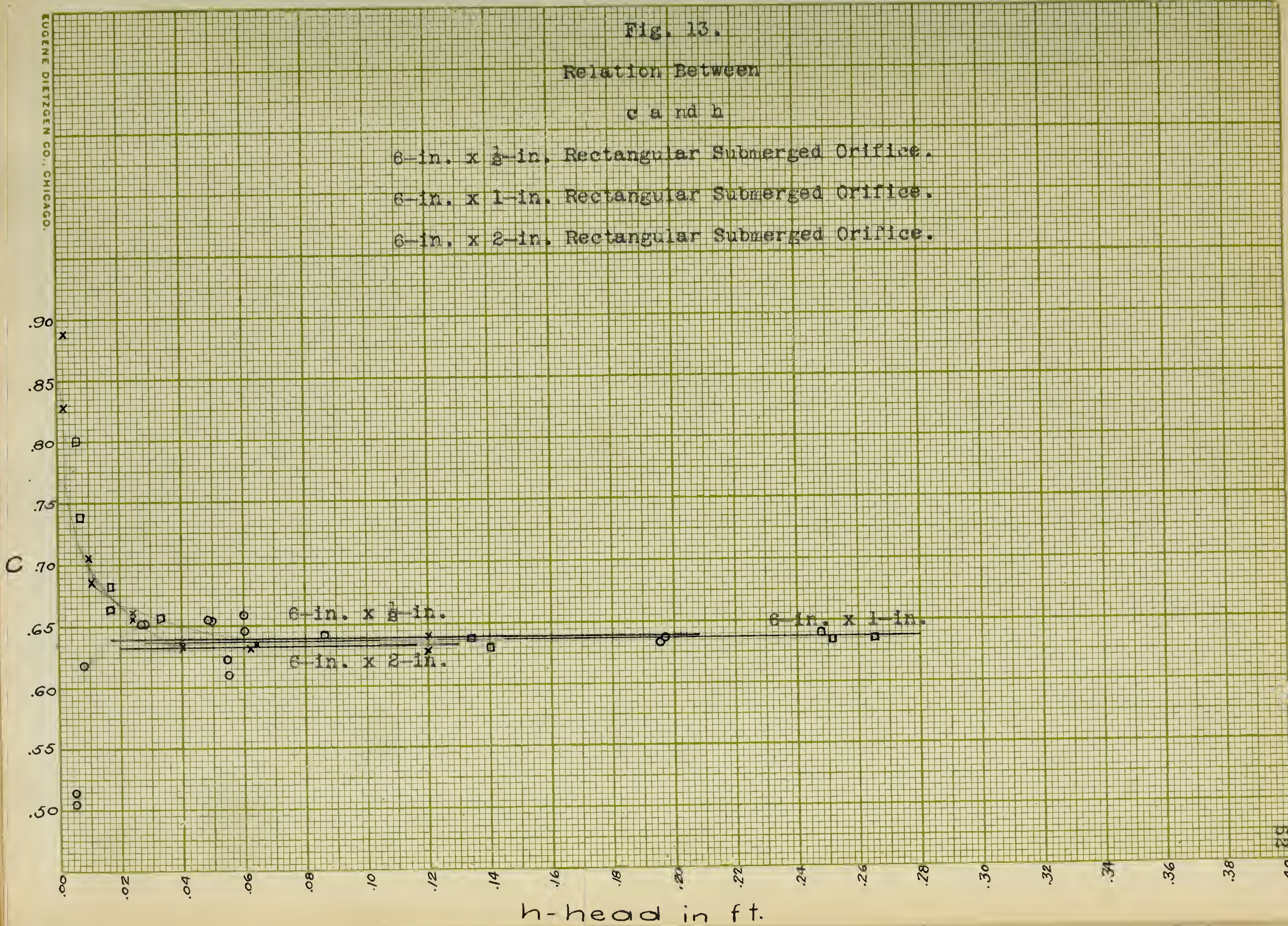


Fig. 13.
Relation Between
c and h
6-in. x ½-in. Rectangular Submerged Orifice.
6-in. x 1-in. Rectangular Submerged Orifice.
6-in. x 2-in. Rectangular Submerged Orifice.
6-in. x ½-in.
6-in. x 1-in.
6-in. x 2-in.
C
.90
.85
.80
.75
.70
.65
.60
.55
.50
.00
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
h-head in ft.
EUGENE DIETZGEN CO., CHICAGO.

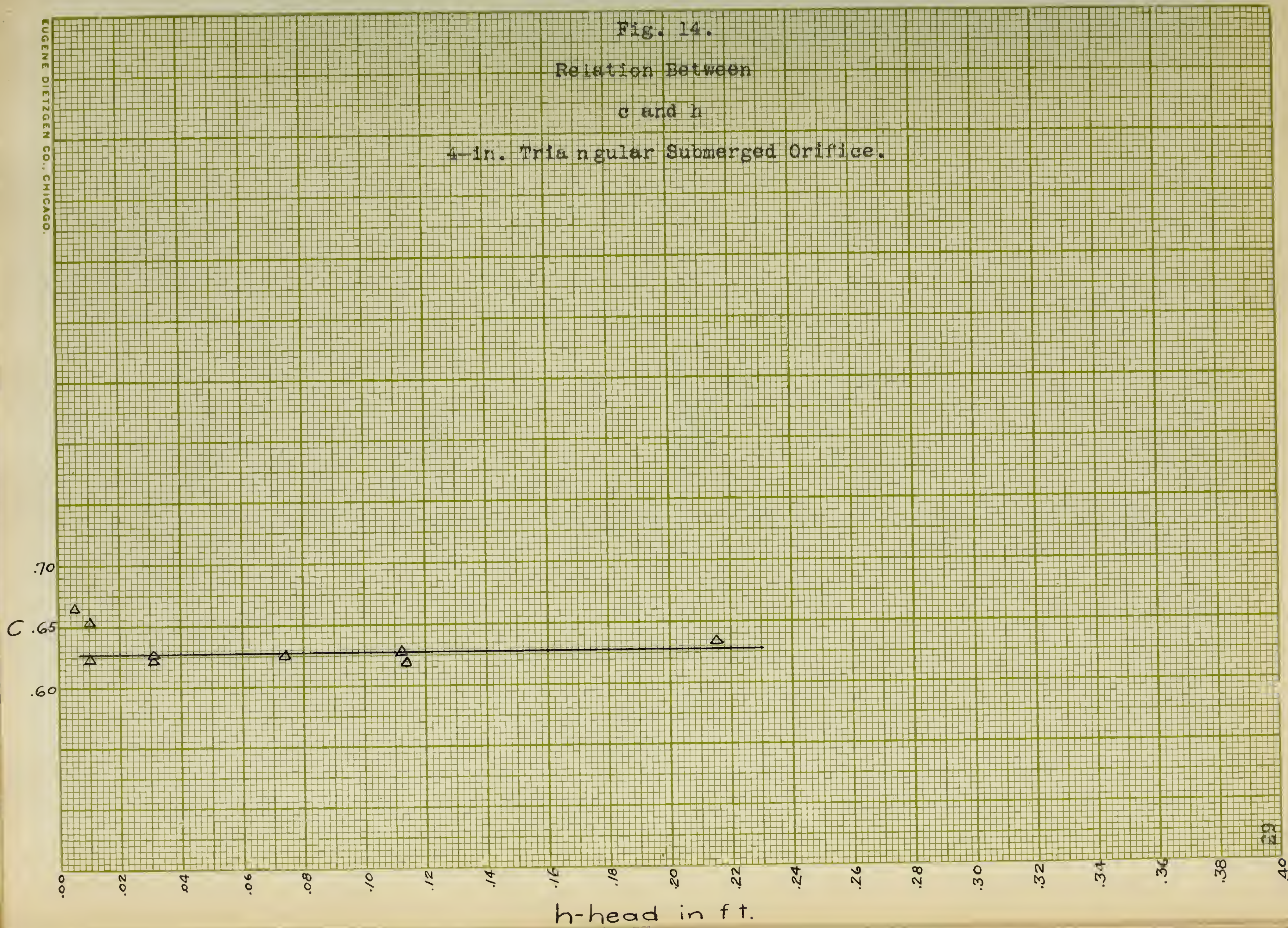


Fig. 14.

Relation Between

c and h

4-in. Triangular Submerged Orifice.

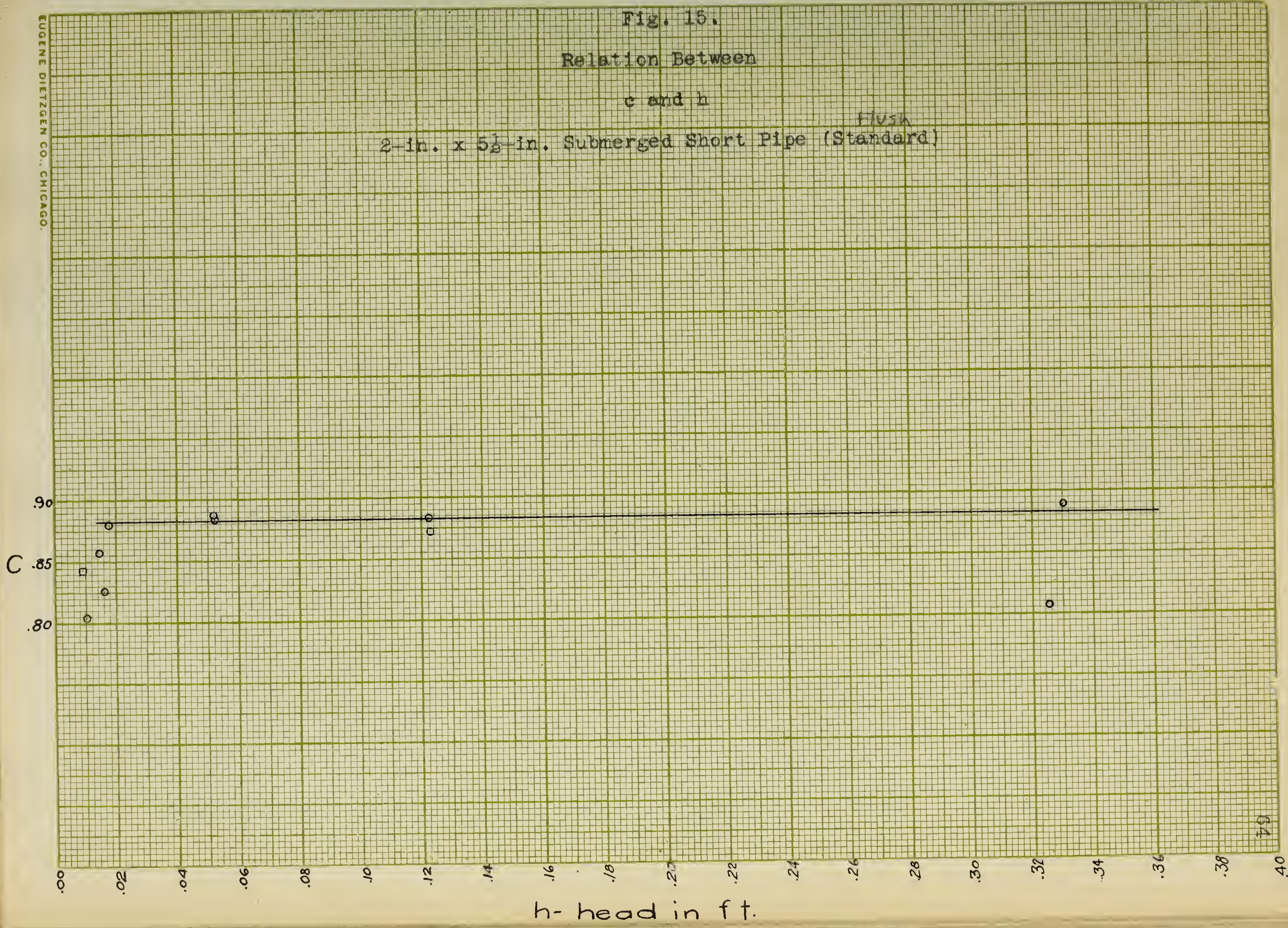


Fig. 15.

Relation Between

c and h

2-in. x $5\frac{1}{2}$-in. Submerged Short Pipe (Standard) Flush

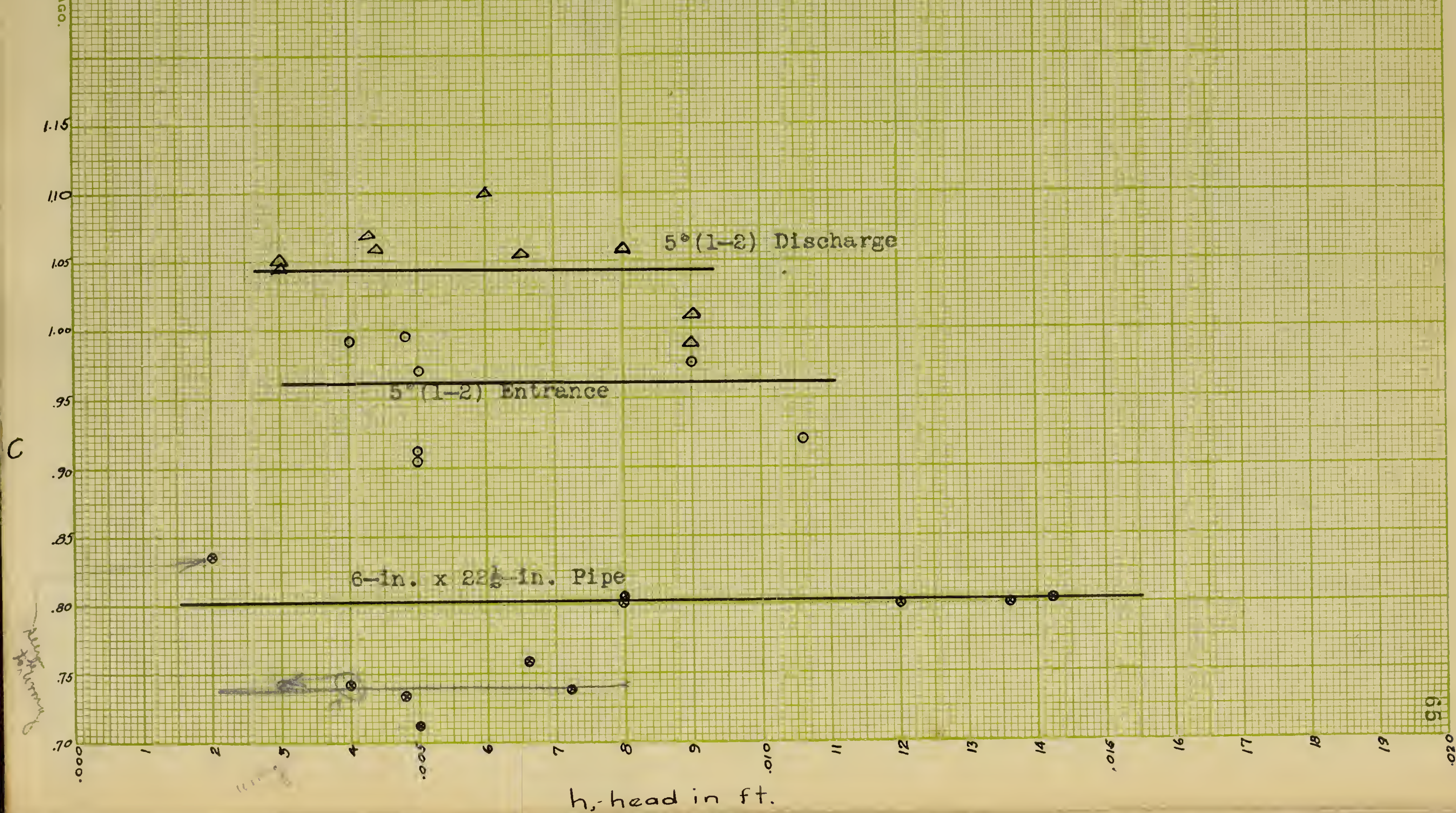
Fig. 16.

Relation Between

c and h

6-in. x 22½-in. Submerged Short Pipe.

6-in. Pipe with 5°(1-2) Mouthpiece.



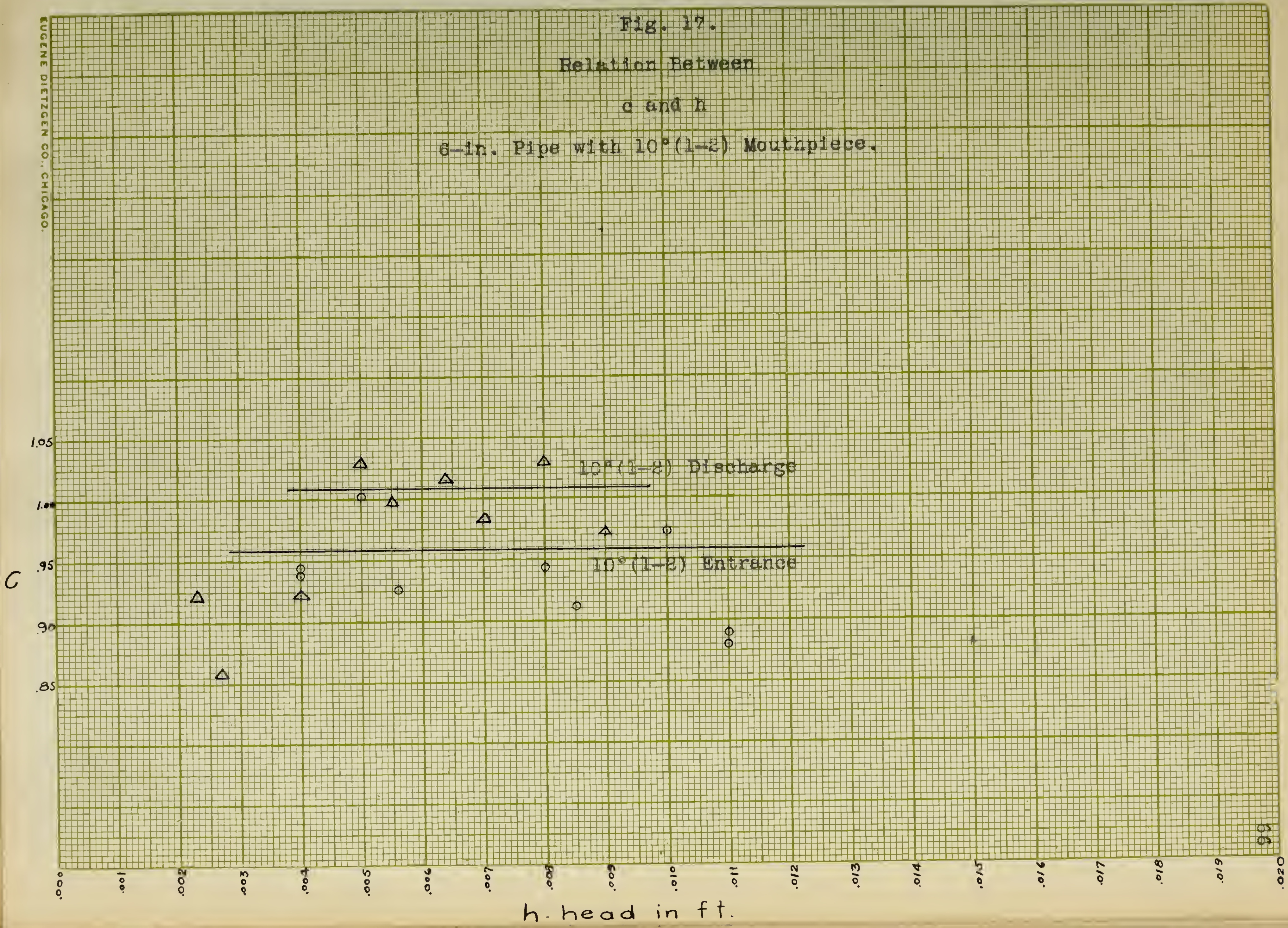


Fig. 17.

Relation Between

c and h

6-in. Pipe with 10°(1-2) Mouthpiece.

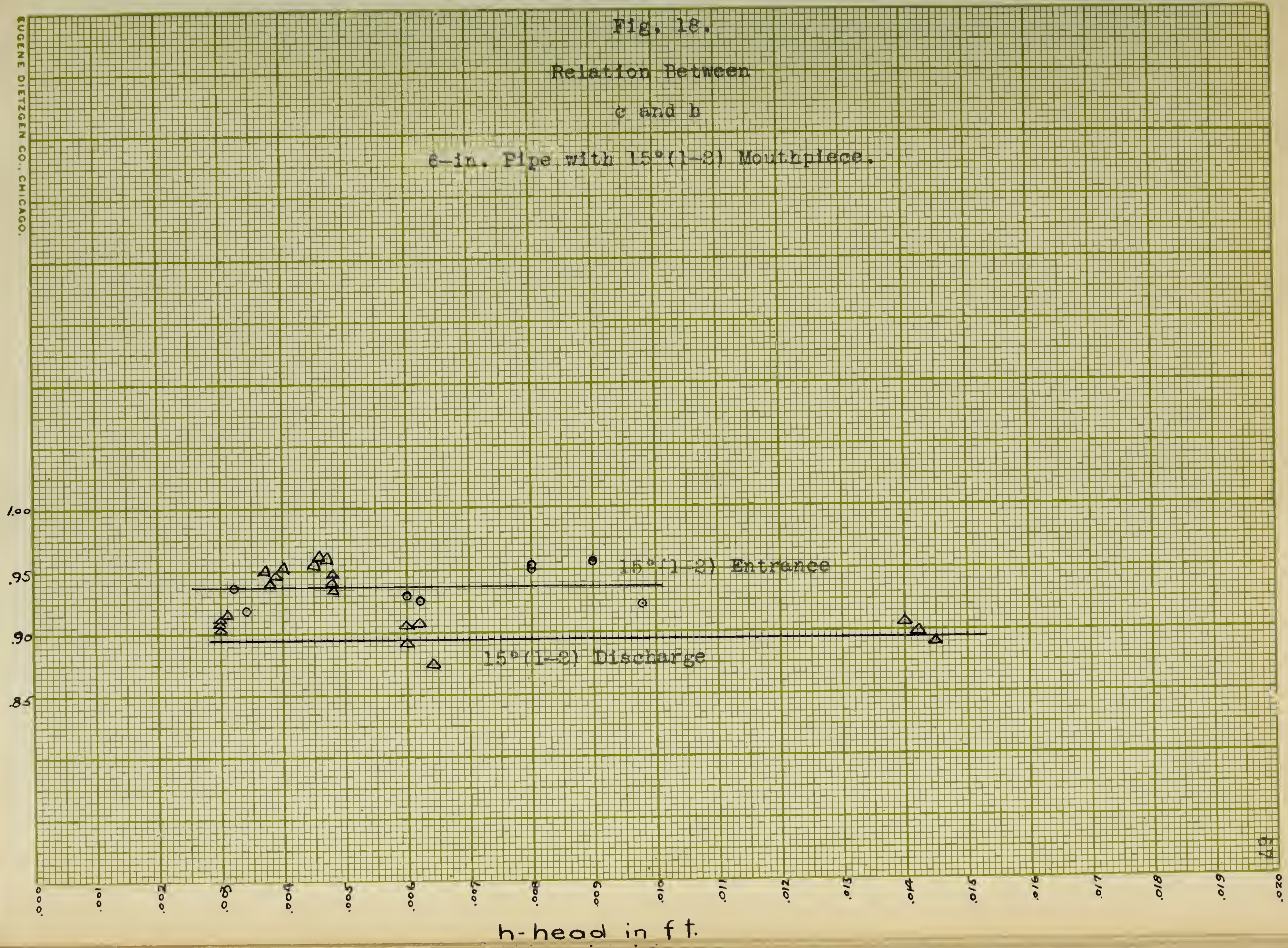


Fig. 18.
Relation Between
c and h
6-in. Pipe with 15°(1-2) Mouthpiece.
15°(1-2) Entrance
15°(1-2) Discharge
C
1.00
.95
.90
.85
.000
.001
.002
.003
.004
.005
.006
.007
.008
.009
.010
.011
.012
.013
.014
.015
.016
.017
.018
.019
.020
h-head in ft.
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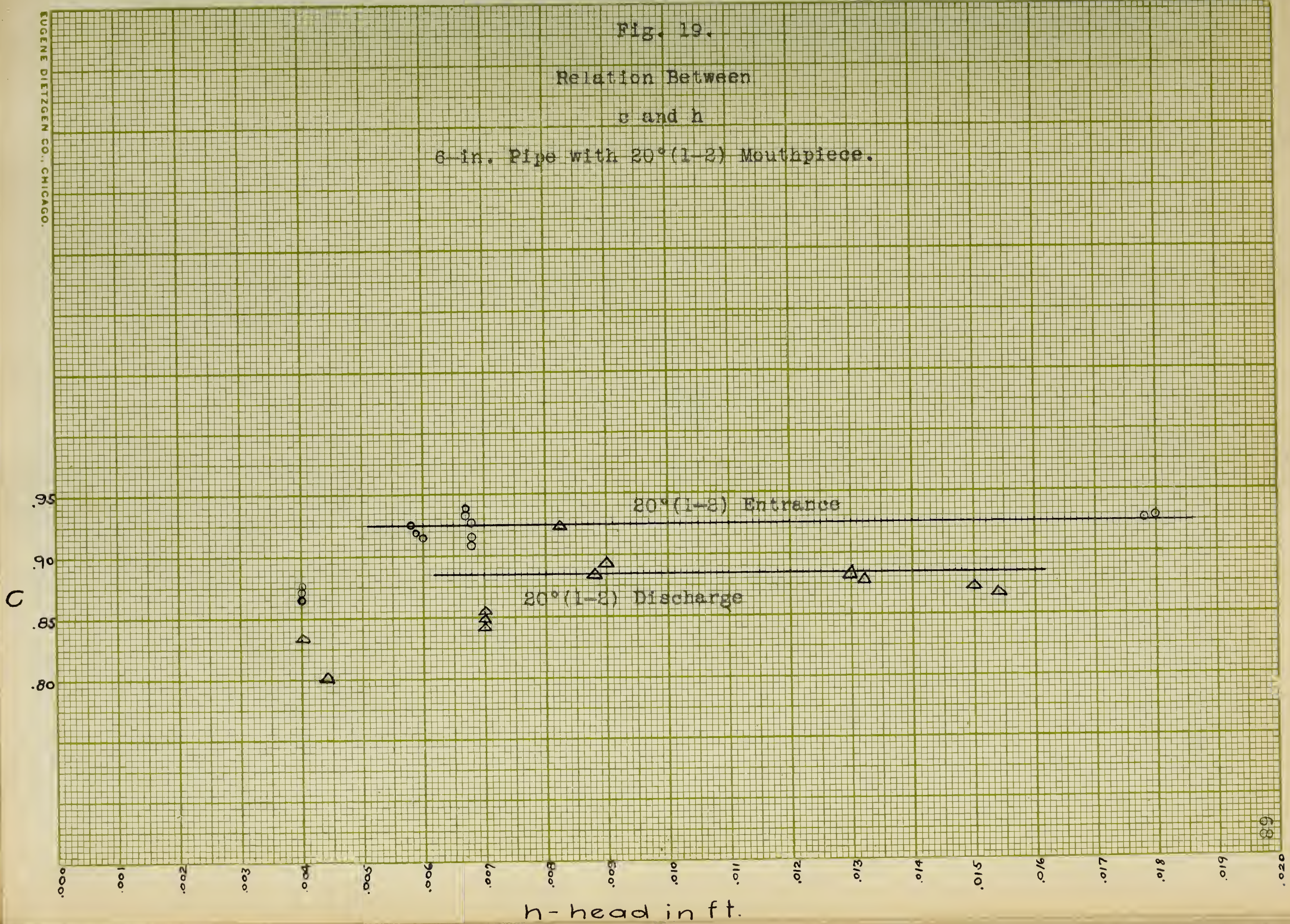
Fig. 19.

Relation Between

c and h

6-in. Pipe with 20°(1-2) Mouthpiece.



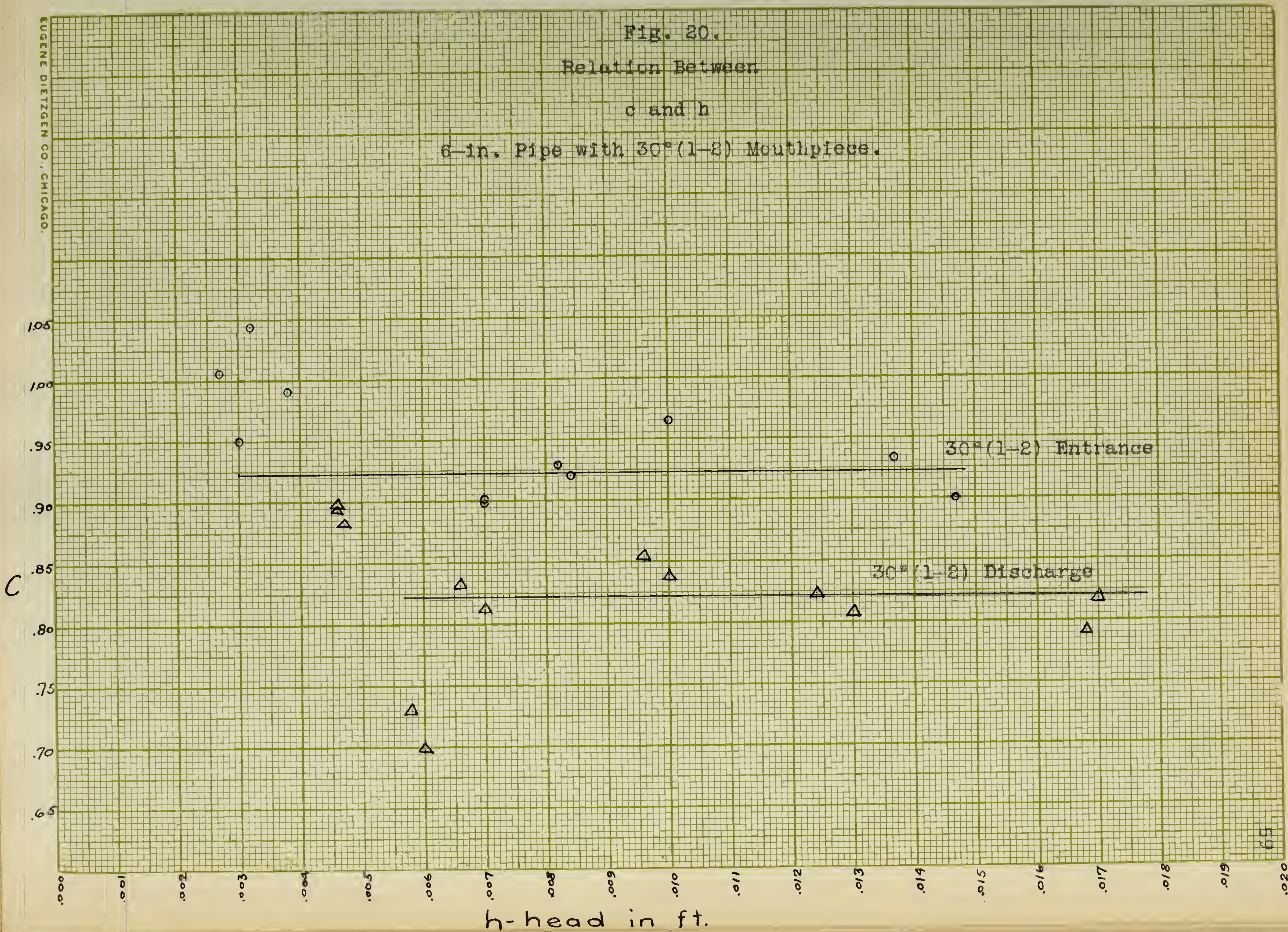


Fig. 20.
Relation Between
c and h
6-in. Pipe with 30°(1-2) Mouthpiece.
30°(1-2) Entrance
30°(1-2) Discharge
C
1.05
1.00
.95
.90
.85
.80
.75
.70
.65
.000
.001
.002
.003
.004
.005
.006
.007
.008
.009
.010
.011
.012
.013
.014
.015
.016
.017
.018
.019
.020
h-head in ft.
69
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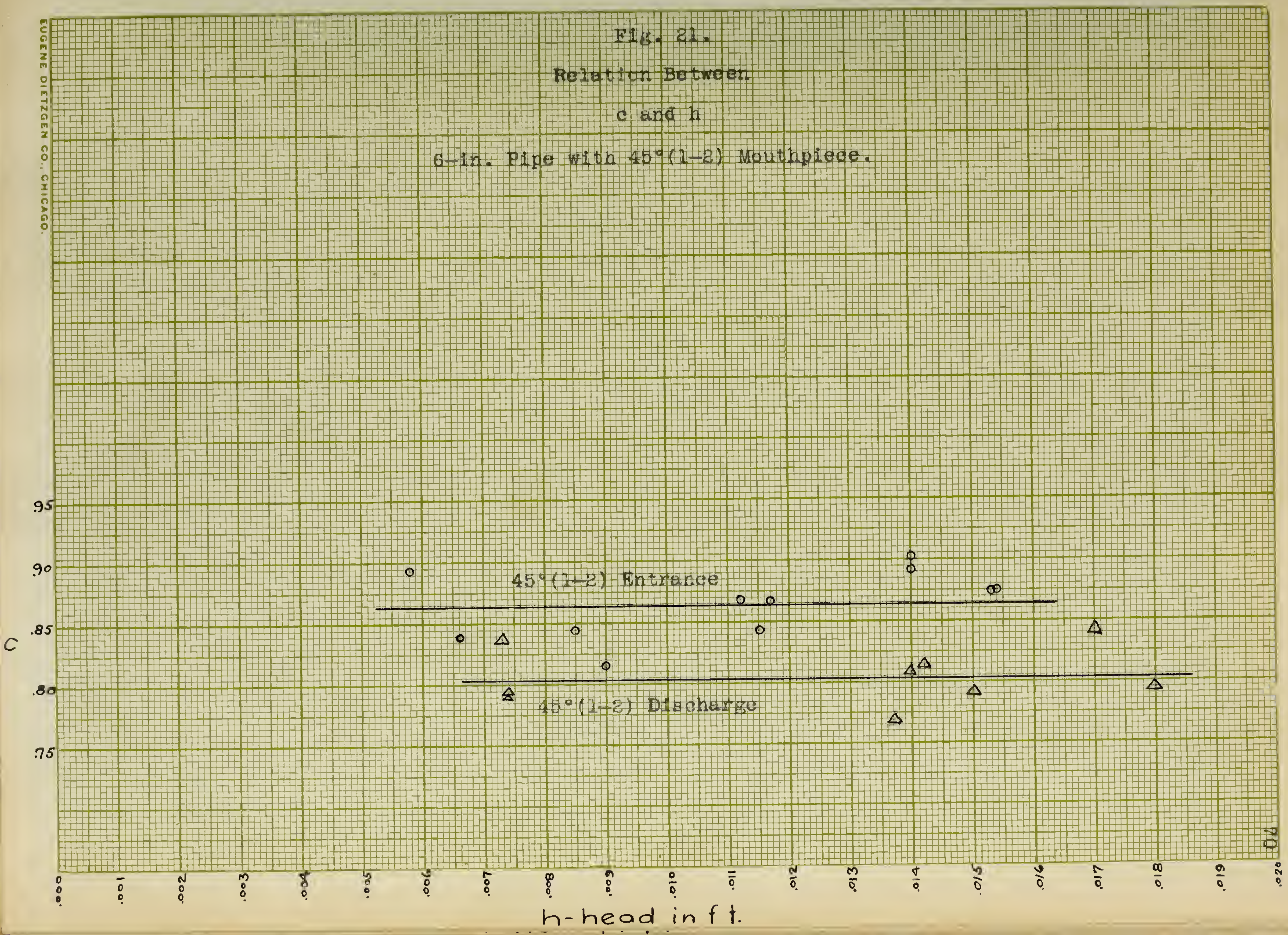


Fig. 21.
Relation Between
c and h
6-in. Pipe with 45°(1-2) Mouthpiece.
45°(1-2) Entrance
45°(1-2) Discharge
c
.95
.90
.85
.80
.75
h-head in ft.
.000
.001
.002
.003
.004
.005
.006
.007
.008
.009
.010
.011
.012
.013
.014
.015
.016
.017
.018
.019
.020
70
EUGENE DIETZGEN CO., CHICAGO.

Fig. 22.

Relation Between

c and h

6-in. Pipe with 60°(1-2) Mouthpiece.

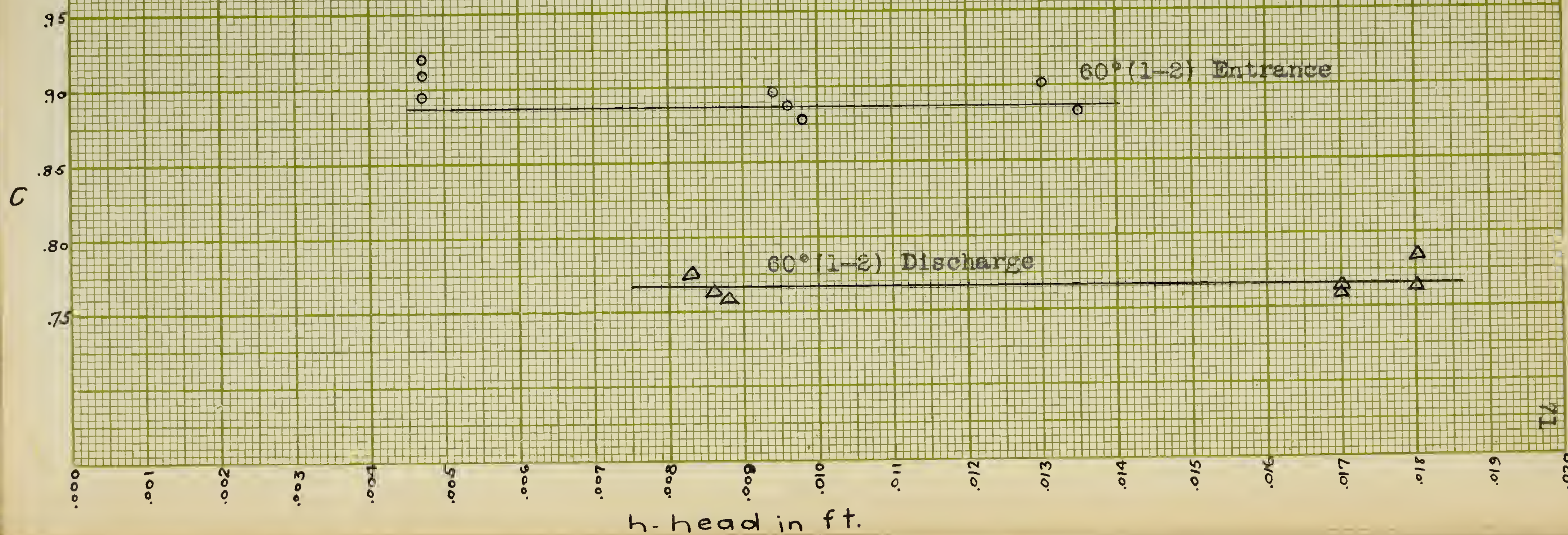


Fig. 23.

Relation Between

c and h

6-in. Pipe with 10°(1-3) Mouthpiece.

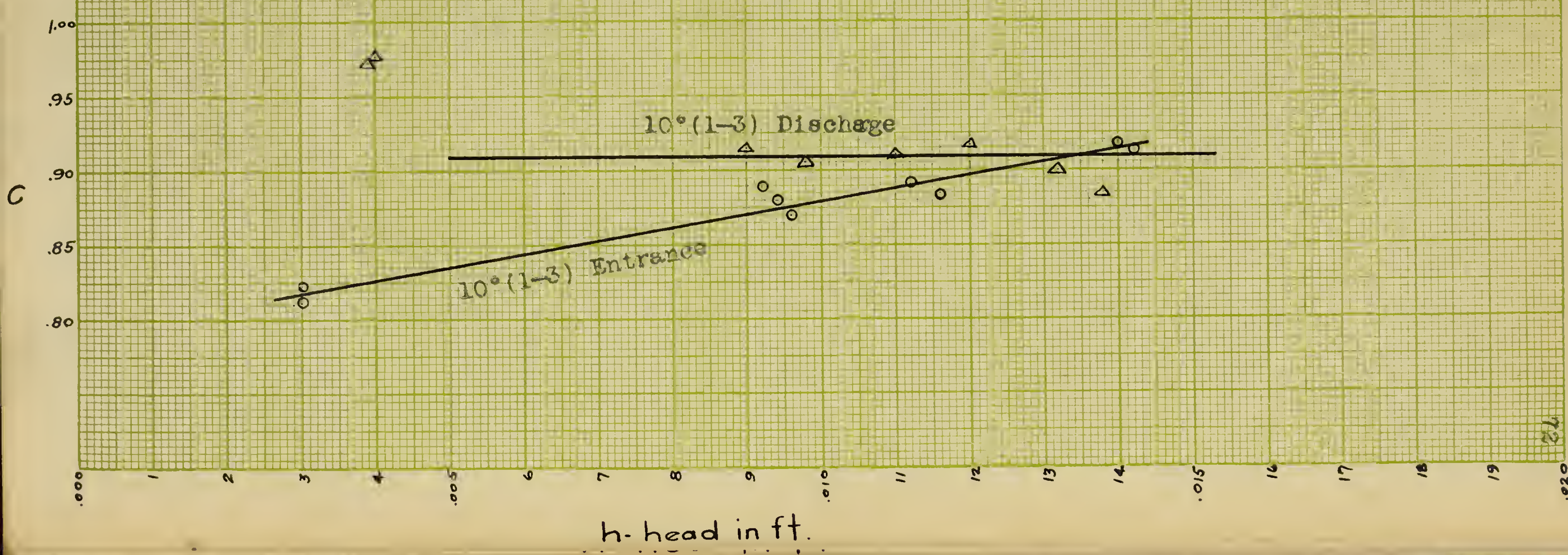
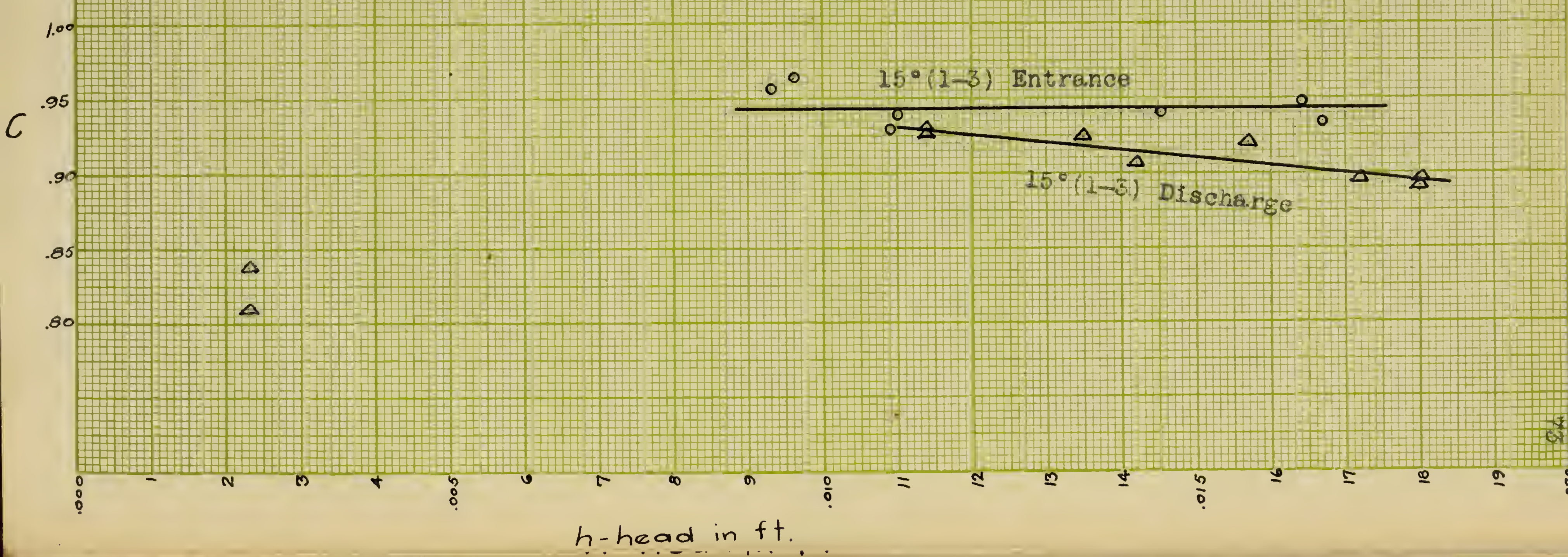


Fig. 24.

Relation Between

c and h

6-in. Pipe with 15°(1-3) Mouthpiece.



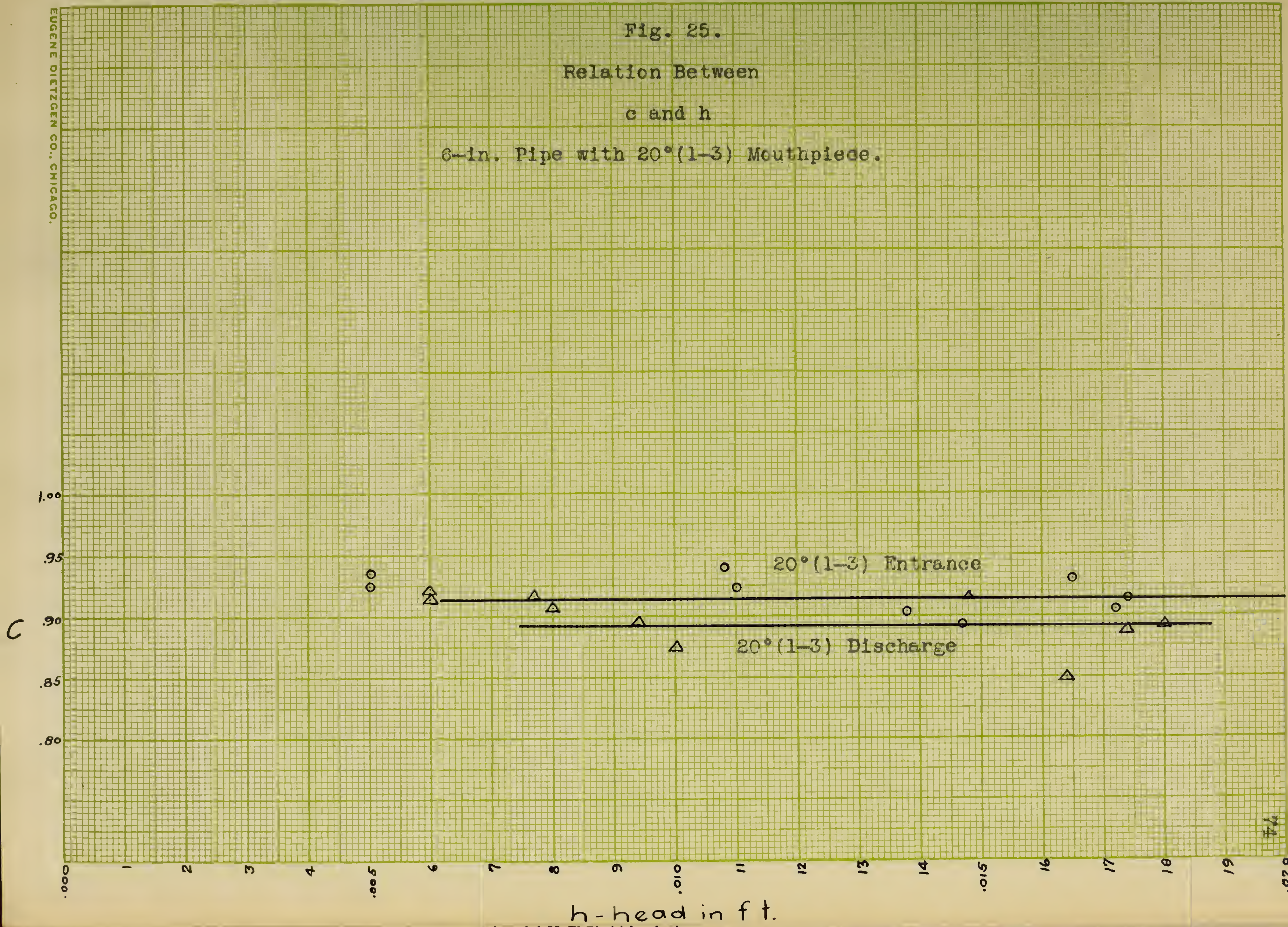


Fig. 25.
Relation Between
c and h
6-in. Pipe with 20°(1-3) Mouthpiece.
20°(1-3) Entrance
20°(1-3) Discharge
1.00
.95
.90
.85
.80
C
.000
1
2
3
4
.005
6
7
8
9
.010
11
12
13
14
.015
16
17
18
19
.020
h-head in ft.

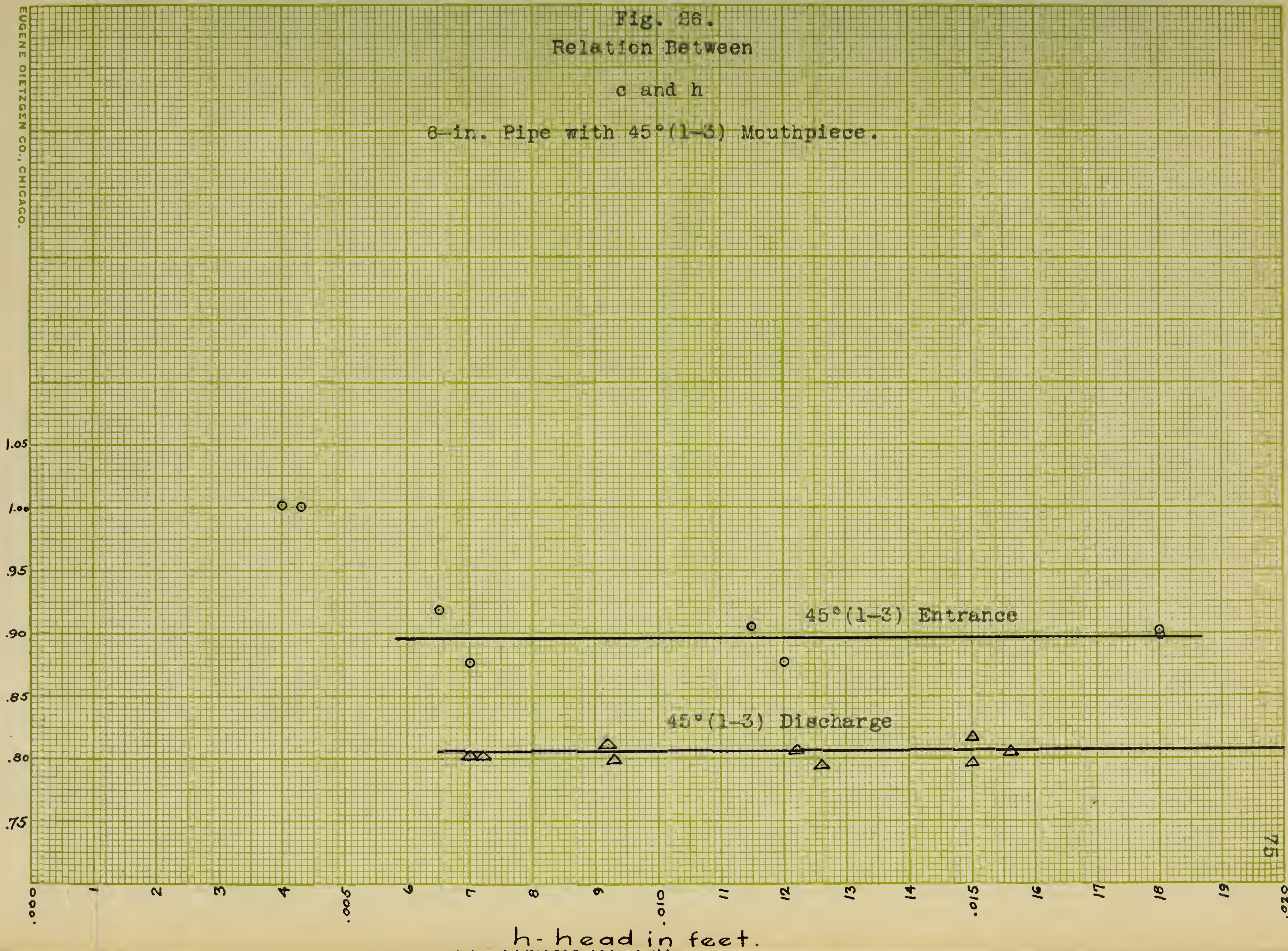


Fig. 26.
Relation Between
c and h
6-in. Pipe with 45°(1-3) Mouthpiece.
45°(1-3) Entrance
45°(1-3) Discharge
1.05
1.00
.95
.90
.85
.80
.75
C
.000
1
2
3
4
.005
6
7
8
9
.010
11
12
13
14
.015
16
17
18
19
.020
h-head in feet.
EUGENE DIETZGEN CO., CHICAGO.

Fig. 27.

Relation Between

c and h

6-in. Pipe with 90°(1-3) Mouthpiece.

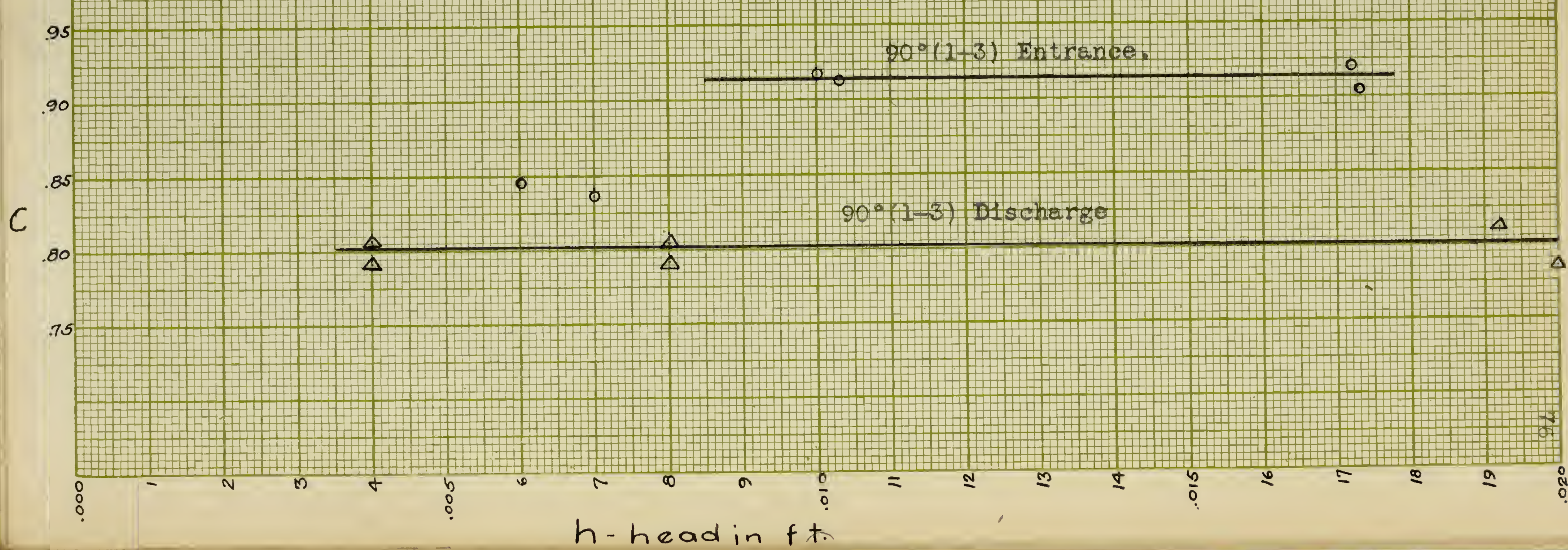
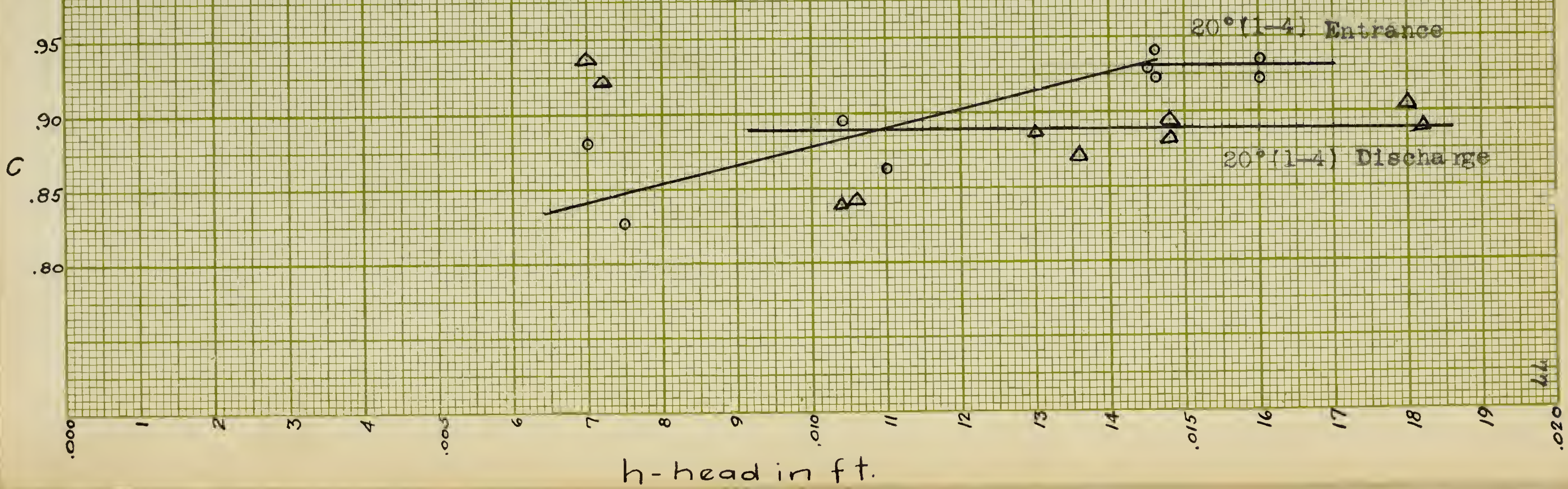


Fig. 28.

Relation Between

c and h

6-in. Pipe with 20°(1-4) Mouthpiece.



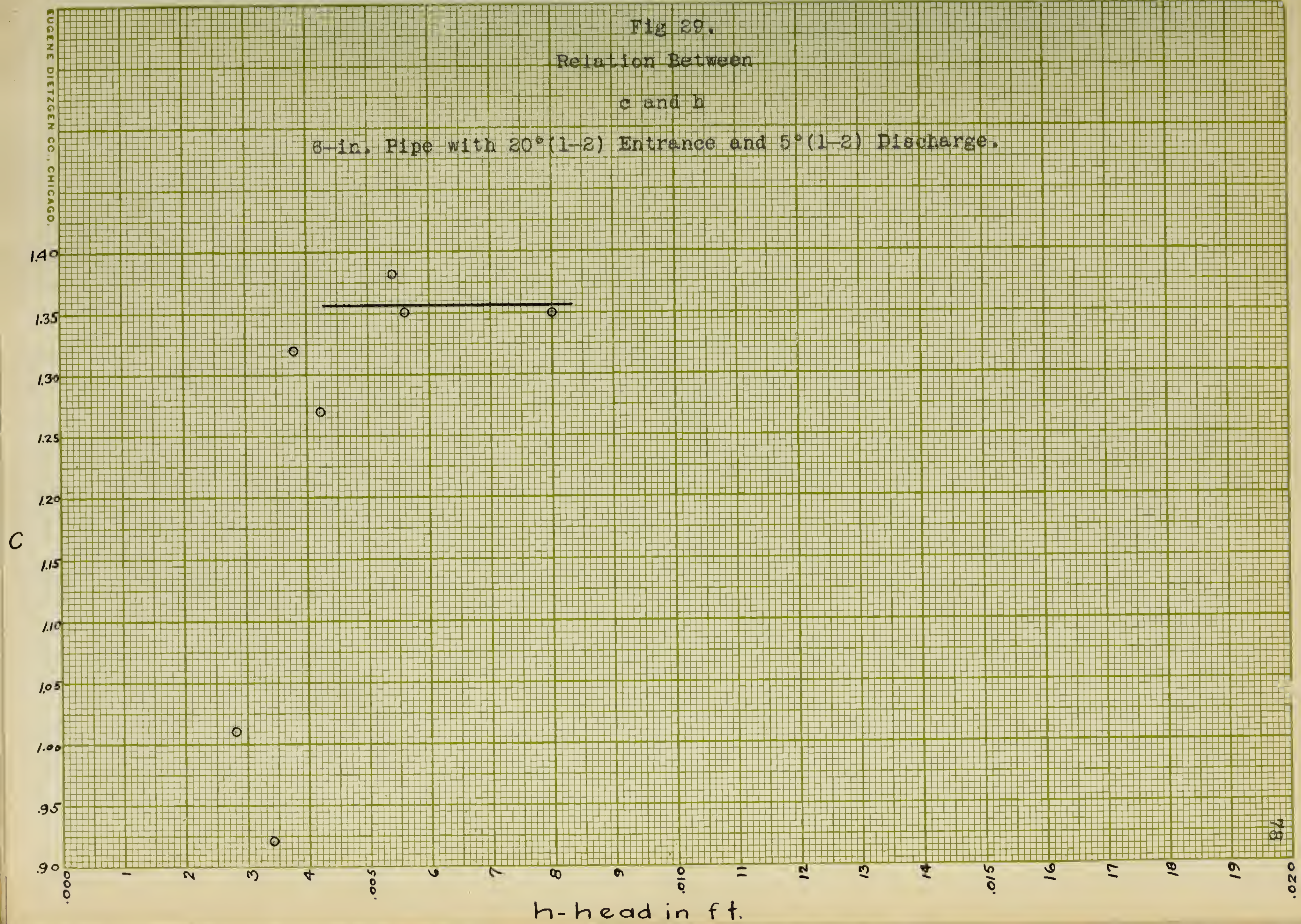


Fig 29.
Relation Between
c and h
6-in. Pipe with 20°(1-2) Entrance and 5°(1-2) Discharge.
C
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
.95
.90
.000
1
2
3
4
.005
6
7
8
9
.010
11
12
13
14
.015
16
17
18
19
.020
h-head in ft.
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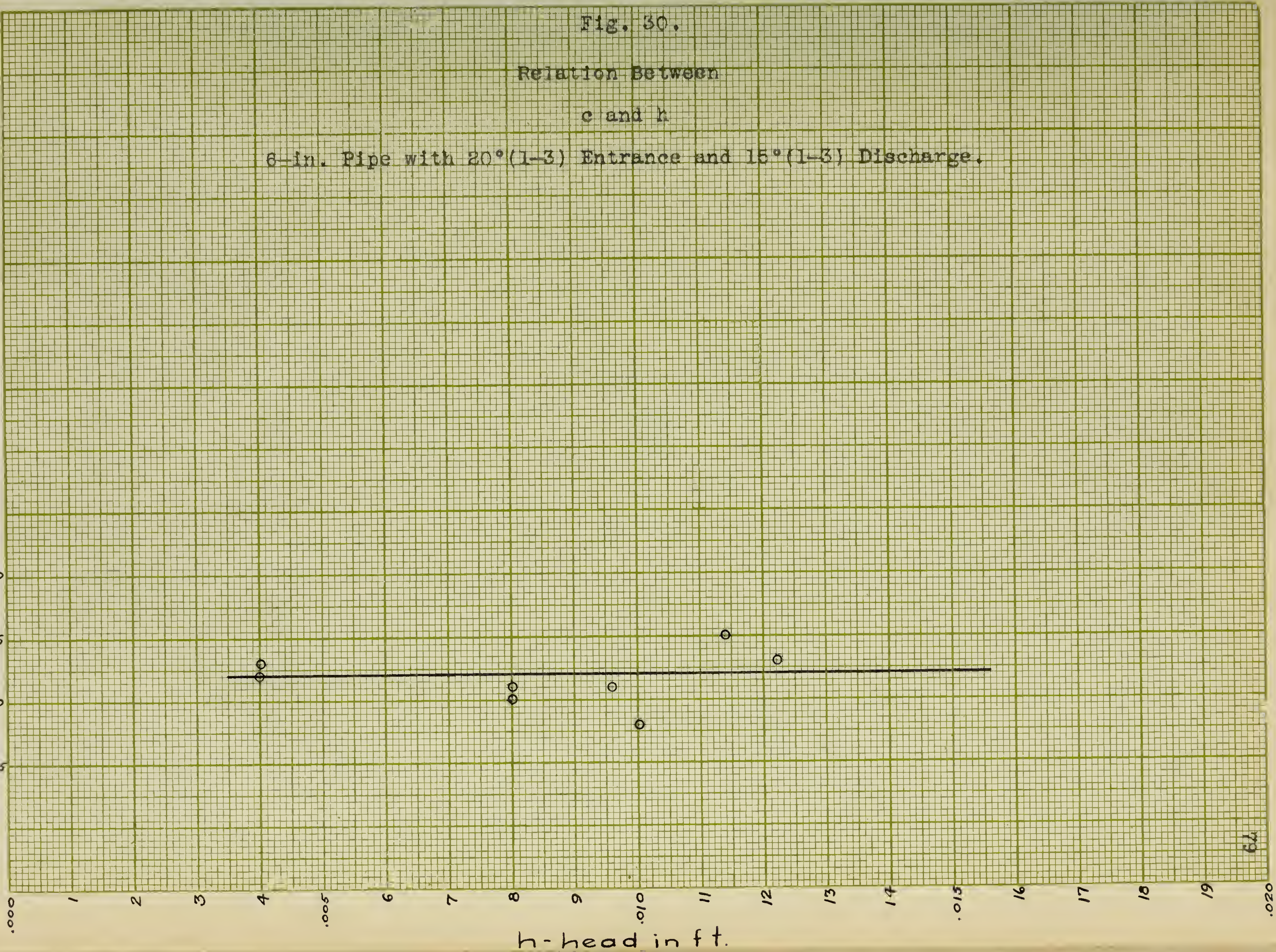


Fig. 30.
Relation Between
c and h
6-in. Pipe with 20°(1-3) Entrance and 15°(1-3) Discharge.
1.20
1.15
1.10
1.05
C
.000
1
2
3
4
.005
6
7
8
9
.010
11
12
13
14
.015
16
17
18
19
.020
h-head in ft.

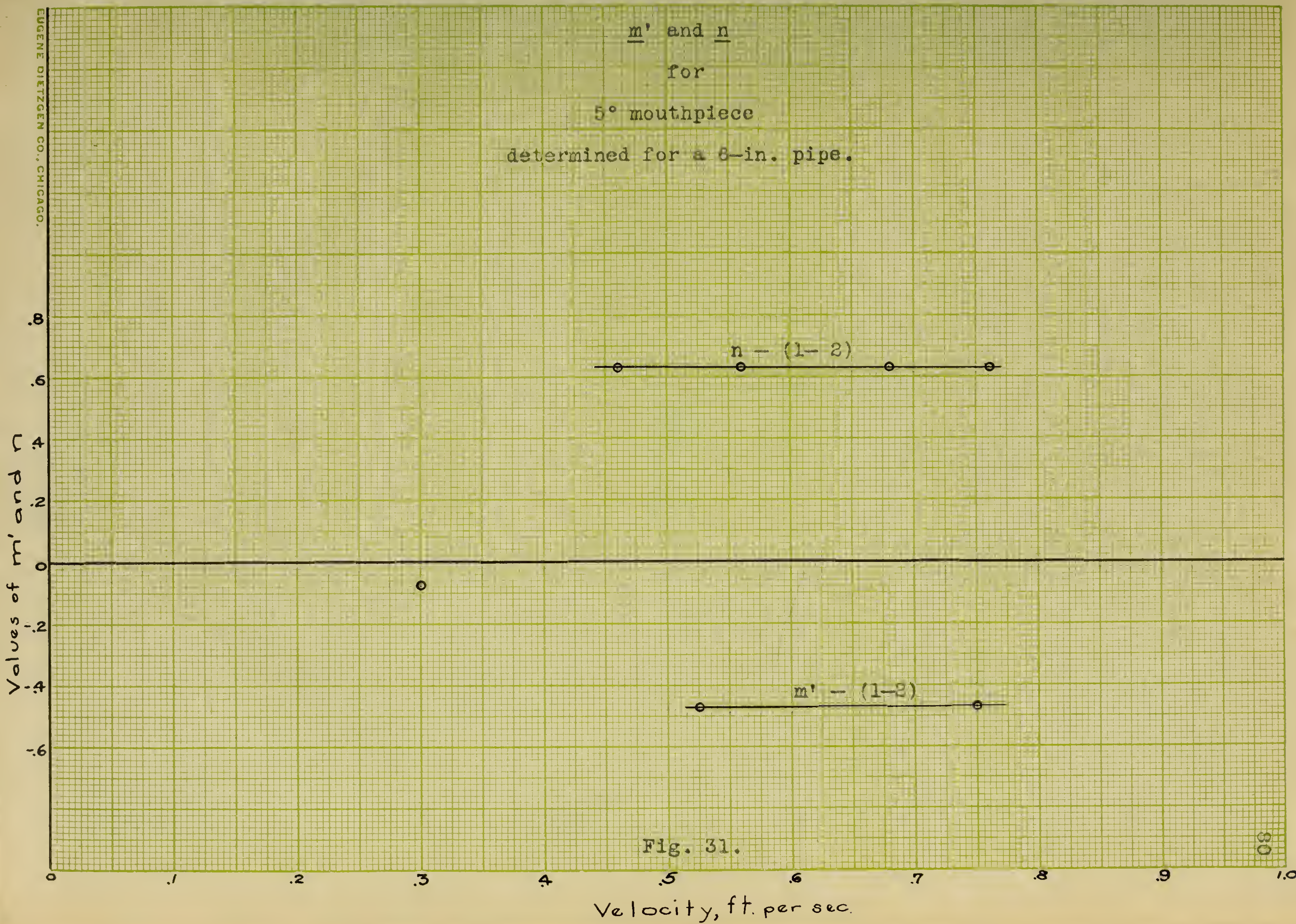

m' and n
for
5° mouthpiece
determined for a 6-in. pipe.
n — (1— 2)
m' — (1—2)
Values of m' and n
.8
.6
.4
.2
0
-.2
-.4
-.6
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Velocity, ft. per sec.
EUGENE DIETZGEN CO., CHICAGO.

Fig. 31.

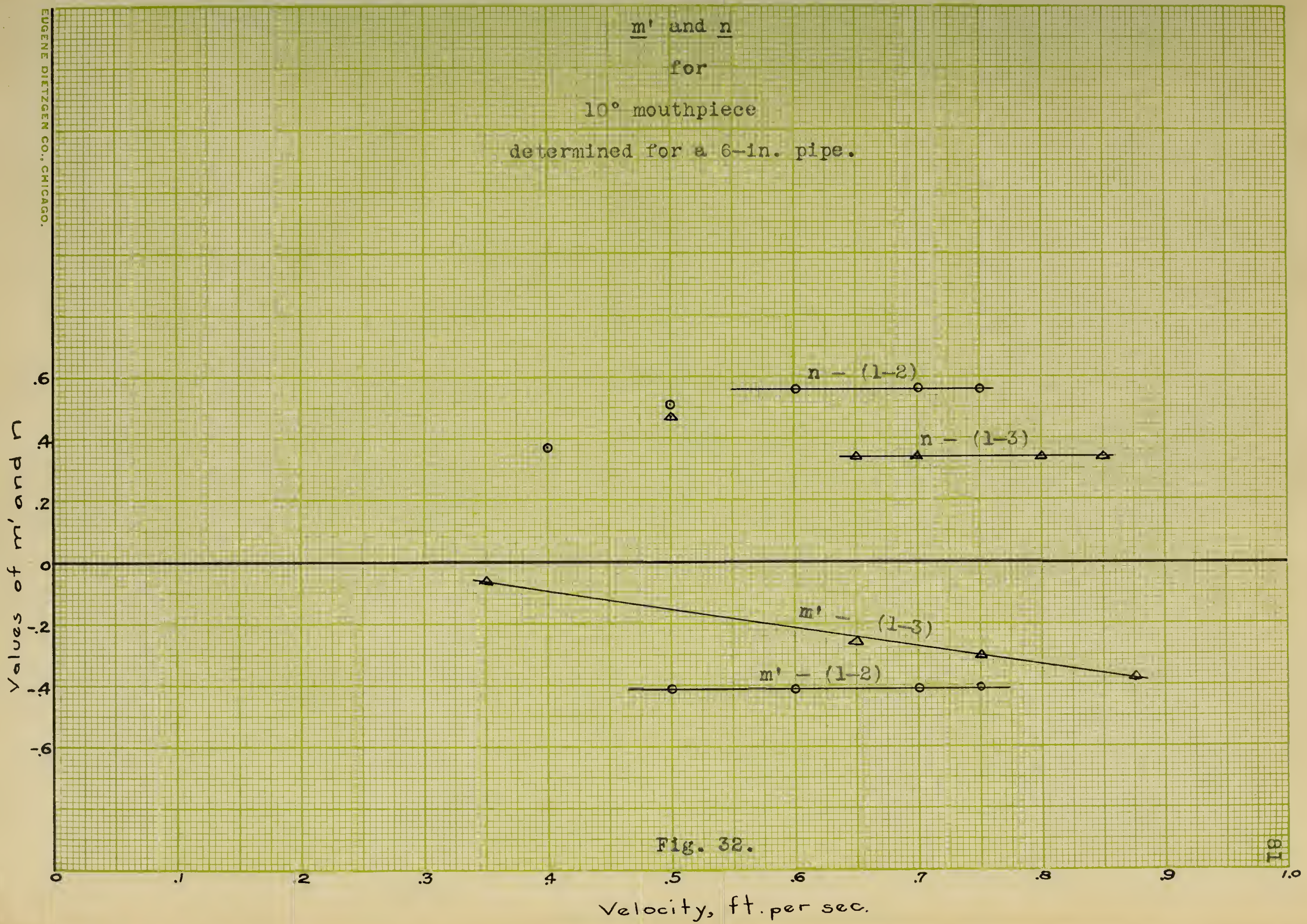

m' and n
for
10° mouthpiece
determined for a 6-in. pipe.
n — (1-2)
n — (1-3)
m' — (1-3)
m' — (1-2)
Values of m' and n
.6
.4
.2
0
-.2
-.4
-.6
Velocity, ft. per sec.
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
EUGENE DIETZGEN CO., CHICAGO.

Fig. 32.

m' and n
for
15° mouthpiece
determined for a 6-in. pipe.

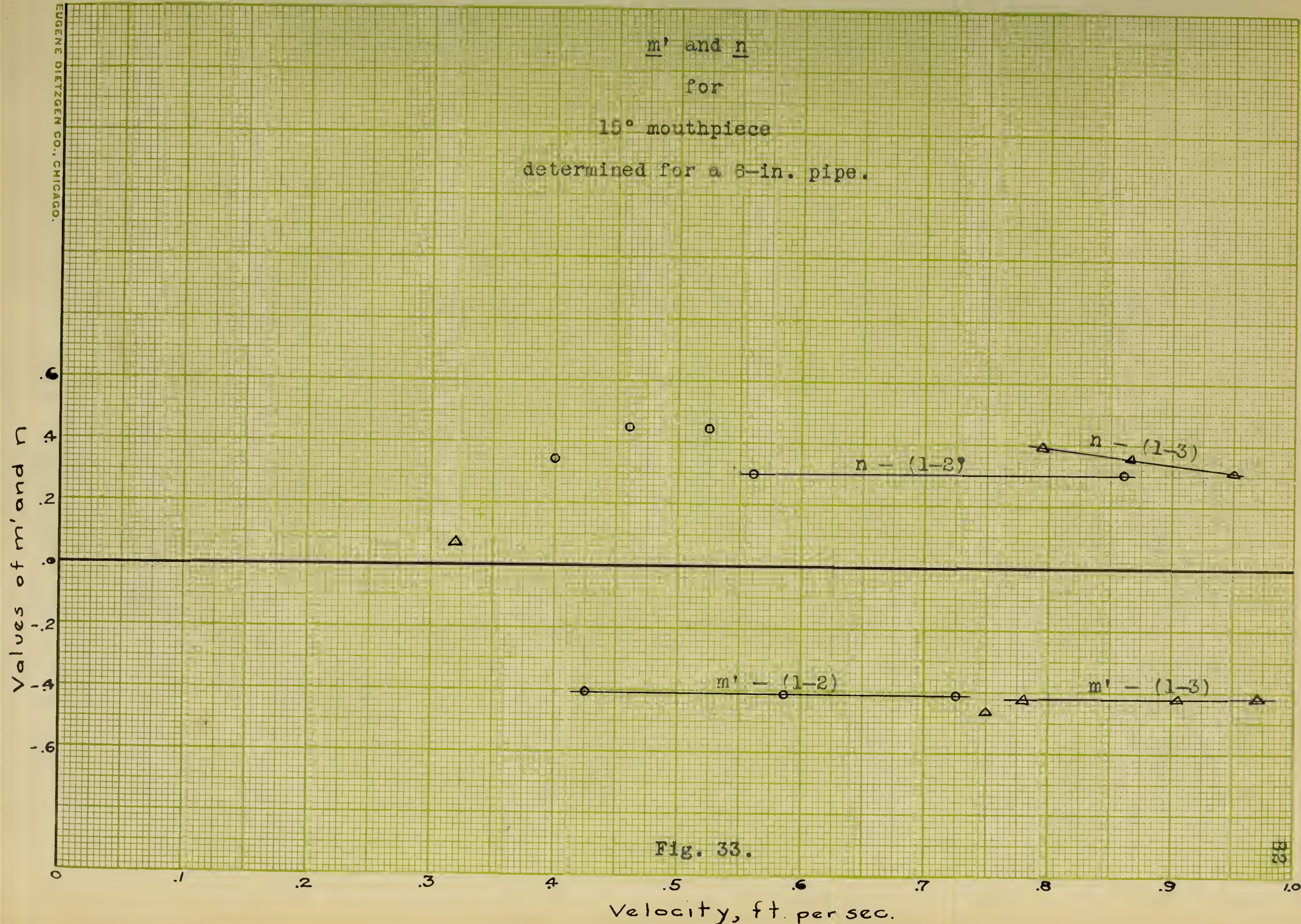


Fig. 33.

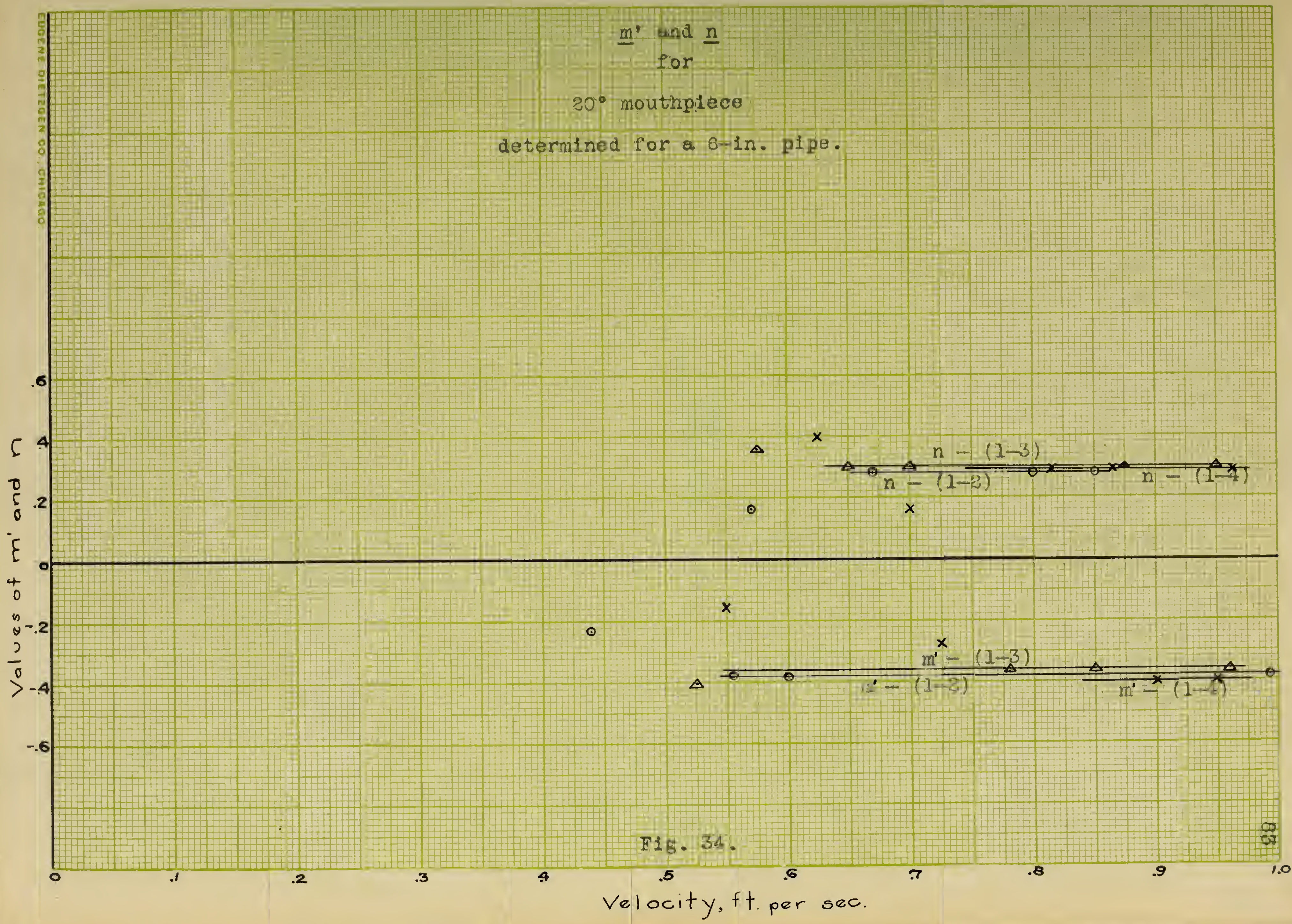
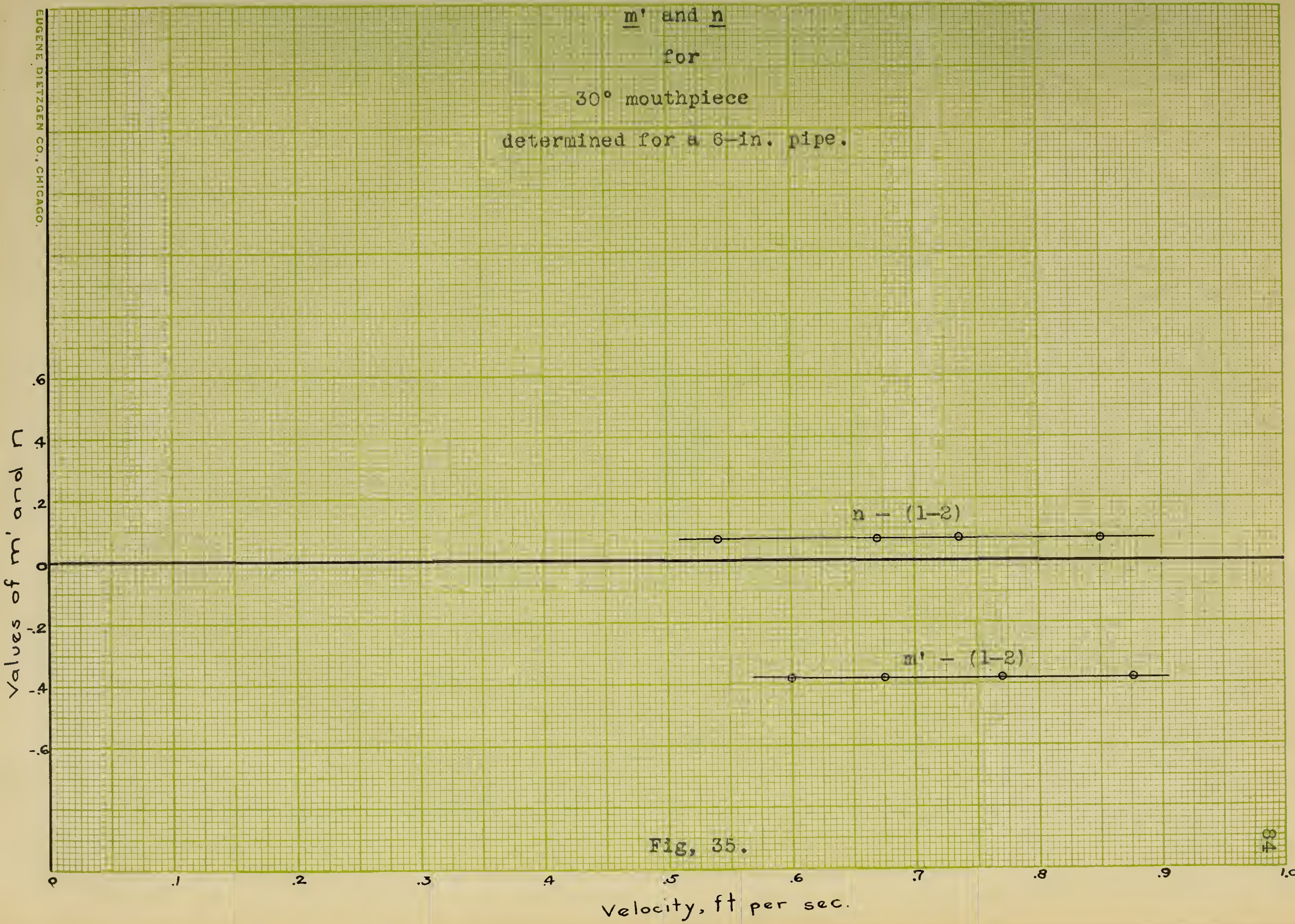

m' and n
for
20° mouthpiece
determined for a 6-in. pipe.
n — (1-3)
n — (1-2)
n — (1-4)
m' — (1-3)
m' — (1-2)
m' — (1-4)
.6
.4
.2
0
-.2
-.4
-.6
Values of m' and n
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Velocity, ft. per sec.
EUGENE DIETZGEN CO., CHICAGO

Fig. 34.


m' and n
for
30° mouthpiece
determined for a 6-in. pipe.
n — (1-2)
m' — (1-2)
Values of m' and n
.6
.4
.2
0
-.2
-.4
-.6
Velocity, ft per sec.
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
EUGENE DIETZGEN CO., CHICAGO.

Fig, 35.

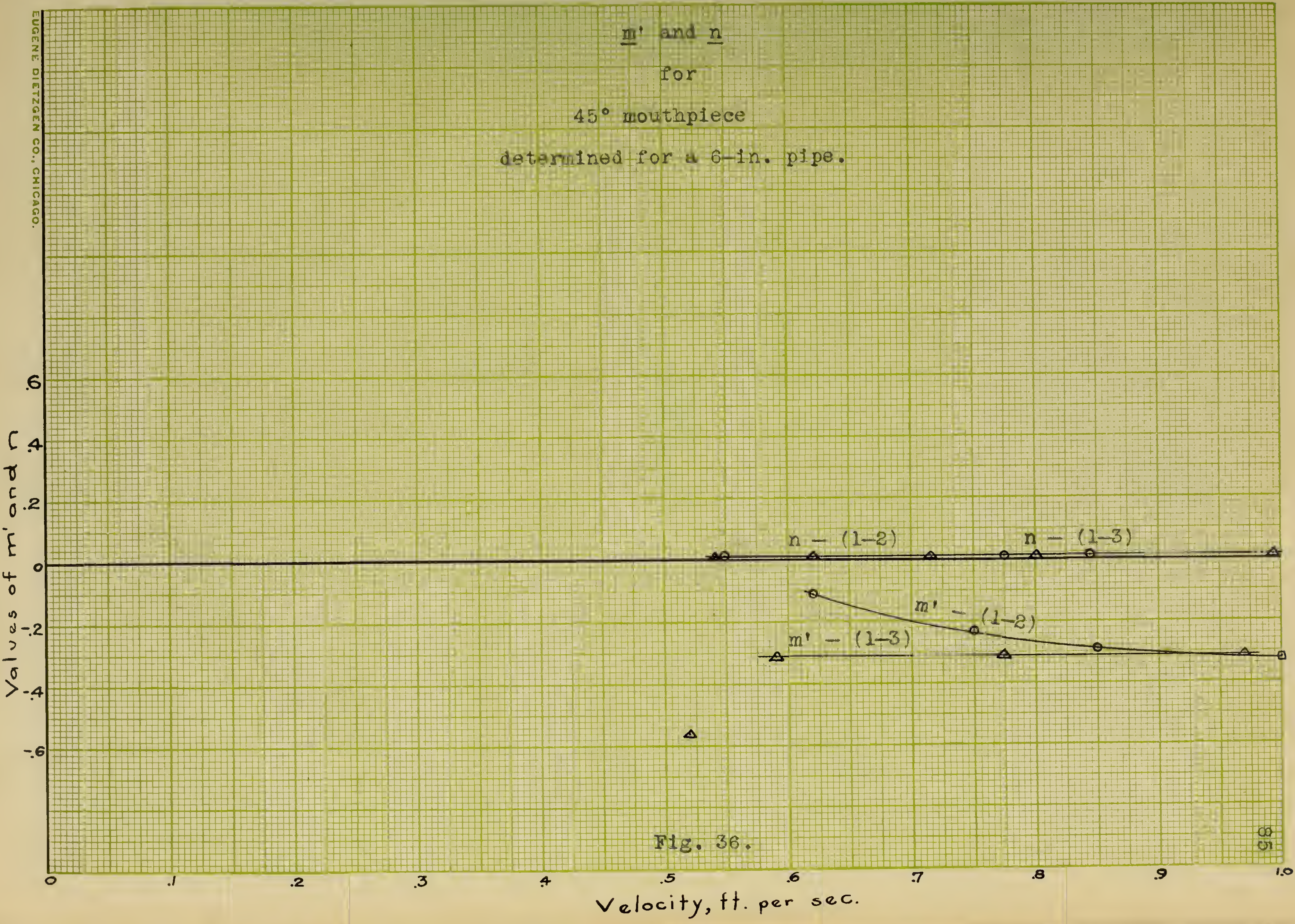

m' and n
for
45° mouthpiece
determined for a 6-in. pipe.
n — (1-2)
n — (1-3)
m' — (1-2)
m' — (1-3)
Values of m' and n
.6
.4
.2
0
-.2
-.4
-.6
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Velocity, ft. per sec.
EUGENE DIETZGEN CO., CHICAGO.

Fig. 36.

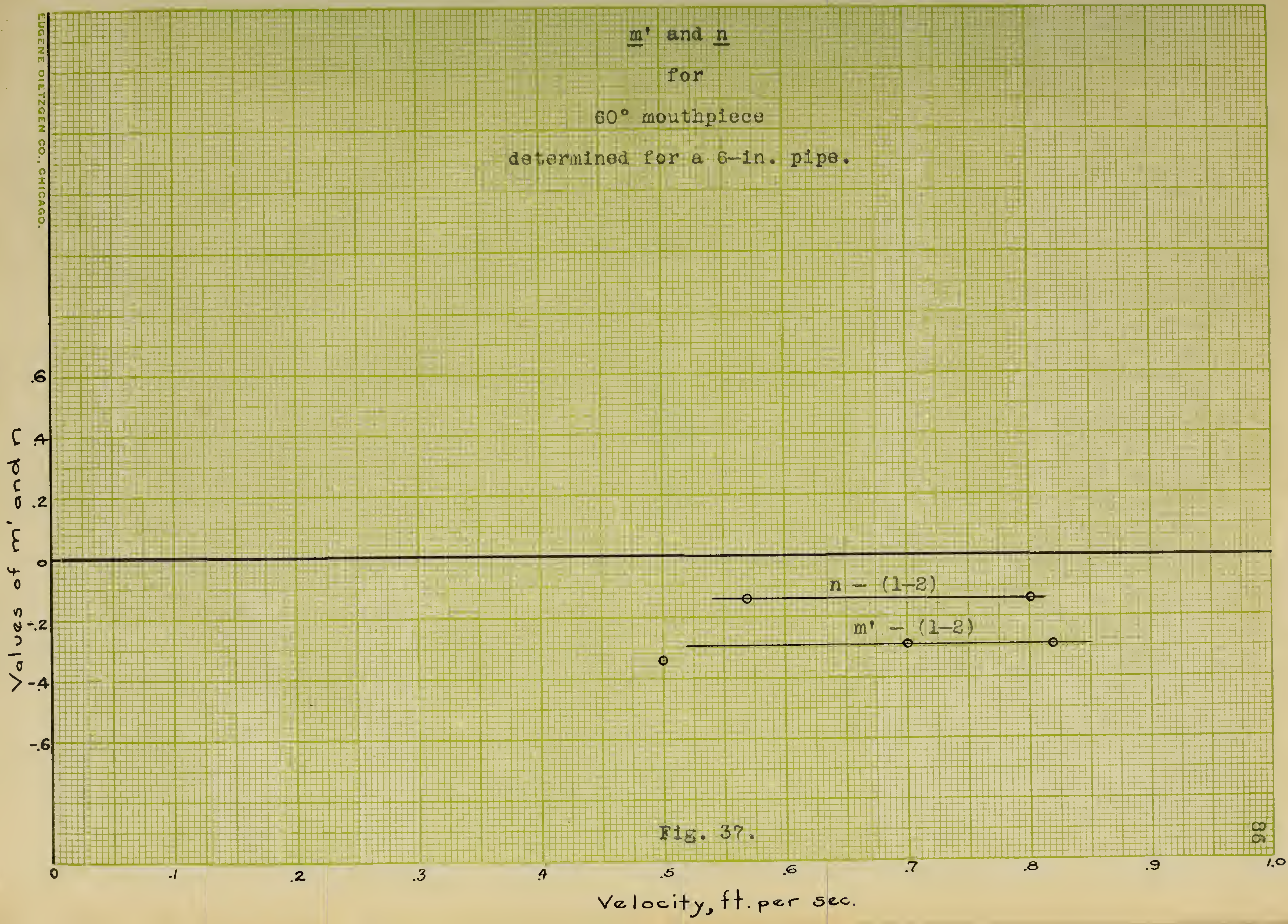

m' and n
for
60° mouthpiece
determined for a 6-in. pipe.
n — (1-2)
m' — (1-2)
Values of m' and n
.6
.4
.2
0
-.2
-.4
-.6
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Velocity, ft. per sec.
EUGENE DIETZGEN CO., CHICAGO.

Fig. 37.

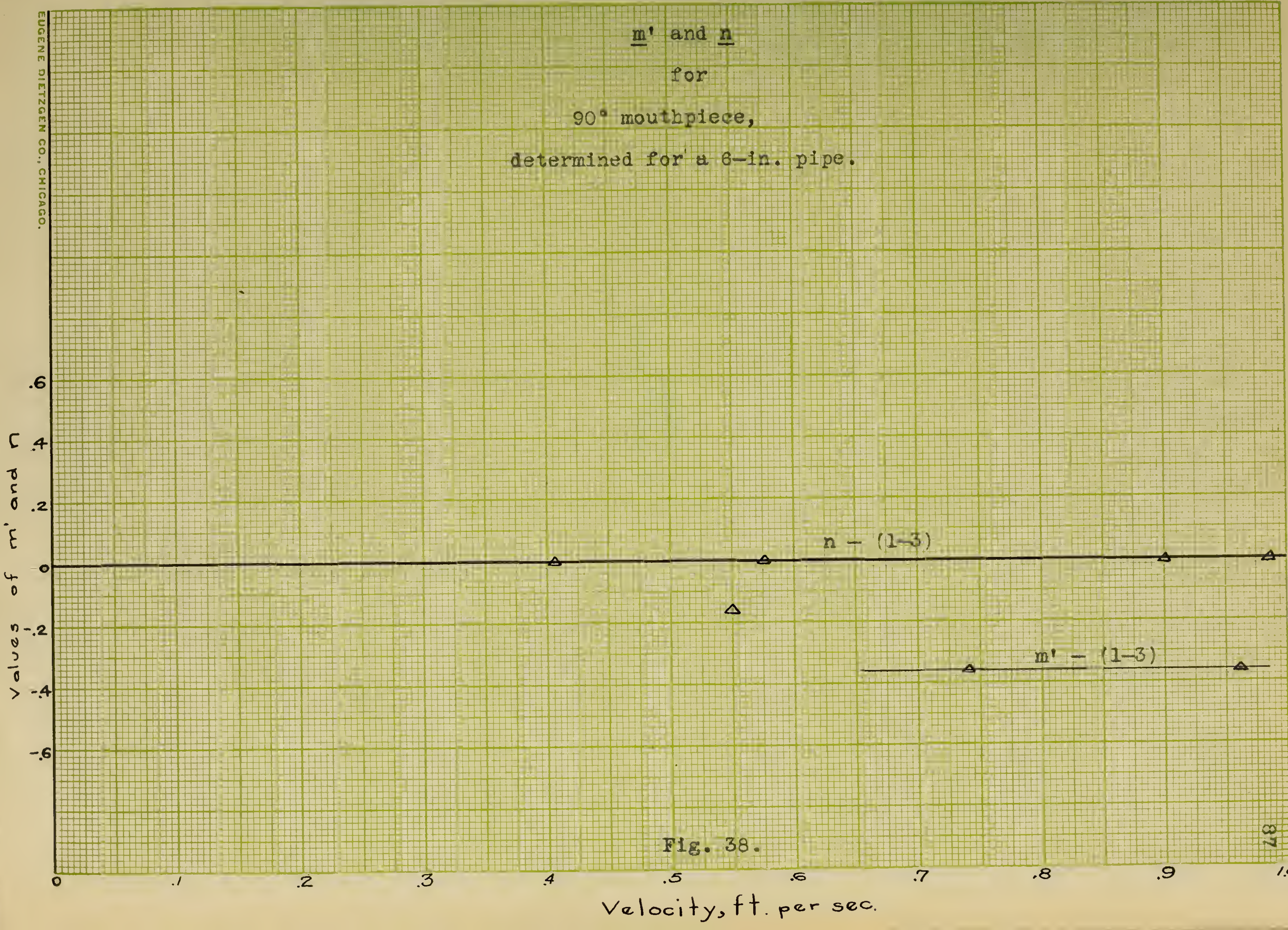

m' and n
for
90° mouthpiece,
determined for a 6-in. pipe.
n – (1–3)
m' – (1–3)
Values of m' and n
.6
.4
.2
0
-.2
-.4
-.6
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Velocity, ft. per sec.

Fig. 38.

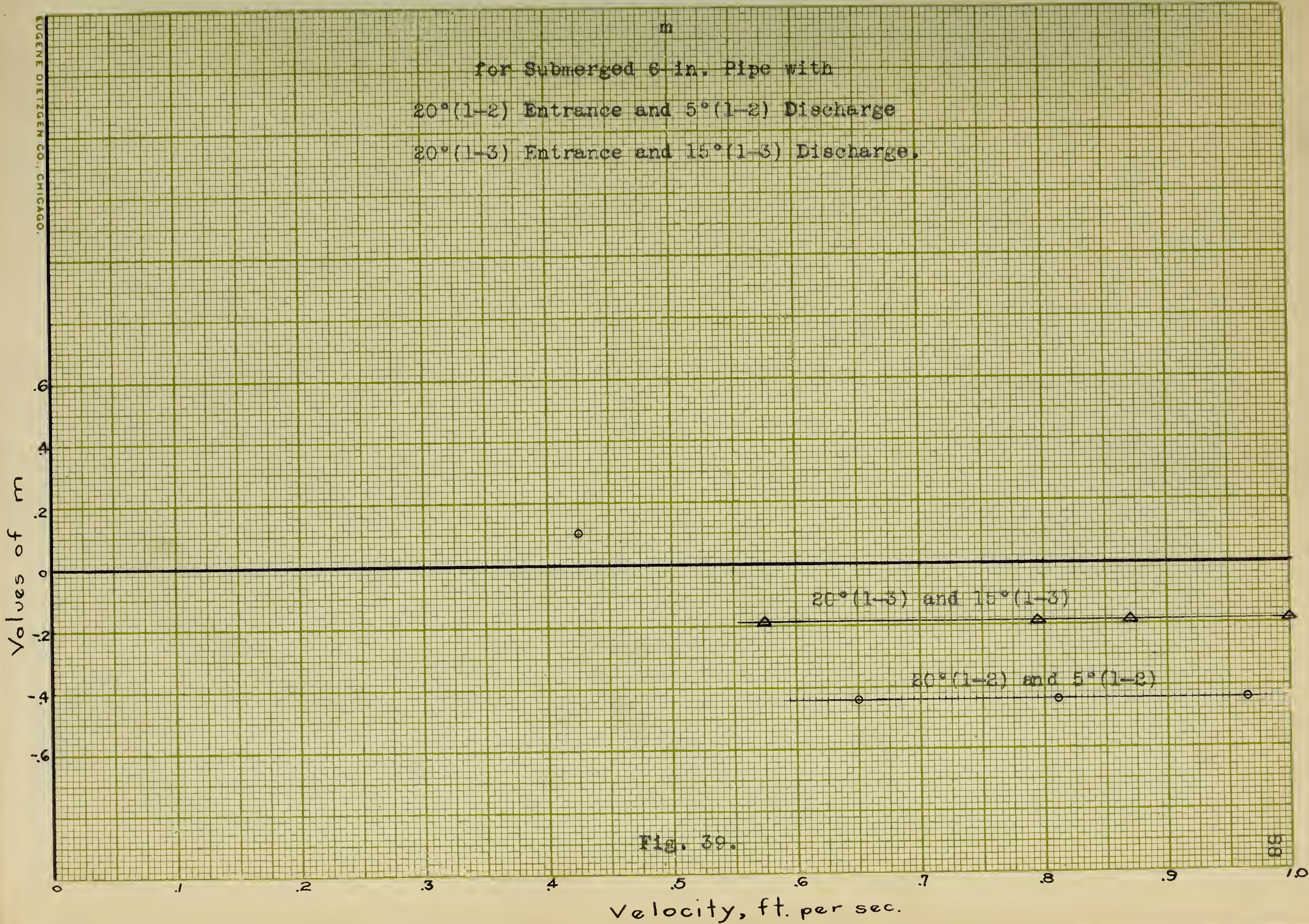

m
for Submerged 6 in. Pipe with
20°(1-2) Entrance and 5°(1-2) Discharge
20°(1-3) Entrance and 15°(1-3) Discharge.
20°(1-3) and 15°(1-3)
20°(1-2) and 5°(1-2)
Values of m
.6
.4
.2
0
-.2
-.4
-.6
Velocity, ft. per sec.
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
EUGENE DIETZGEN CO., CHICAGO.

Fig. 39.