THE EFFECT OF REYNOLDS NUMBER ON FRICTION LOSS IN GLOBE VALVES

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN CHEMICAL ENGINEERING

The University of Tennessee

June, 1940

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SUMMARY

The handling of fluids in pipes is a common procedure. To handle fluids most efficiently and economically it is important that the friction loss through the pipe be known in order that power consumption may be estimated and that excessive power consumption may be avoided. The procedure for finding this loss through straight lengths of pipe is thoroughly standardized and quite reliable. When the question of friction loss in fittings arises the problem is different since values for these losses are not well recognized and vary according to the source of information. This is especially true in regard to globe valves. According to Badger and McCabe[1] recent work has shown that the loss in fittings is a function of Reynolds number. With this in mind the following thesis was undertaken to attempt to correlate data on friction loss in 1 inch, 1-1/4 inch, and 1-1/2 inch globe valves with Reynolds number.

All valves were tested in a galvanized iron pipe system to prevent contamination by rust. The 1 inch valve was tested under velocities varying from approximately

6.5 ft./sec. to 12 ft./sec. at 1 ft./sec. intervals. The 1-1/4 inch valve was tested under velocities varying from approximately 3 ft./sec. to 12 ft./sec. at intervals of approximately 1 ft./sec. Velocities varying from 2 ft./sec. to 10 ft./sec. at 1 ft./sec. intervals were used for testing the 1-1/2 inch valve.

As a result of previous work by Thomas[2], Meier and Foster[3], and Greve[4] the general formula for the friction loss in globe valves is a power function involving the velocity raised to a power varying from 1.86 to 2.

As a result of the present work the following formulas are indicated:

For 1-1/2 inch globe valves $H = 1.51 \times 10^{-8} (Re)^{1.64}$

For 1-1/4 inch globe valves $H = 1.925 \times 10^{-8} (Re)^{1.6}$

For 1 inch globe valves $H = 5.13 \times 10^{-8} (Re)^{1.7}$

where H is the friction loss expressed in feet of water and Re is Reynolds number ($Du\rho/\mu$) where D is the diameter in feet, u is the velocity in feet per second, ρ is the density in pounds per cubic foot, and μ is the viscosity in English units (pounds per foot per second). However, any consistent set of dimensions may be used for the calculation of Reynolds number.

It is to be noted that a different formula is necessary to correlate the data on each size valve tested. There is hence a probability that the size of the valve enters into the equation in addition to the effect of the Reynolds

number. The formulas shown should be regarded as tentative only until more valves and conditions are investigated.

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EXPERIMENTAL SECTION

Literature Survey

The earliest literature available on the subject of friction loss in globe valves is that by M. E. Thomas[2] in 1906. A number of valves were tested but the only one of interest was a 1 inch globe valve. The apparatus consisted of a horizontal pipe containing the valve, the source of water being a standpipe under a static head of about fifty feet. Three-way gage connections for obtaining the pressure head in the pipe were made one foot upstream and one foot downstream from the valve. The difference in head at the two sections was measured by a differential mercury-water manometer. The loss in head across the valve was obtained by subtracting the theoretical loss in the pipe from the total loss. The velocity was varied from about 2 ft./sec. to 18 ft./sec. A plot on logarithmic paper of the velocity versus the lost head resulted in parallel straight lines with a slope varying little from two. As a result, the formula $H = kV^2$ or $H = mV^2/2g$ was found to apply, where H is the loss in head expressed in feet of water; k is a constant equal to m/2g, where m is called the coefficient of loss and g is the effect of gravity; and V is the velocity in feet per second. The value of m for 1 inch

globe valves is 7.12

Frederick W. Greve Jr.[4] gives the results of experiments on 1-1/2 inch pipe and valves. The apparatus used was very similar to that used in the present thesis. The manometer connections were placed twenty feet on each side of the valve. Very careful calibrations were made on all instruments and meticulous care was taken throughout. As a result of his experiments, Greve states the following formula: $H_l = MQ^n$ where M and n are constants with the values 953.7 and 1.915 respectively, and Q is the discharge in cubic feet per second, and H is the loss expressed in feet of water.

A portion of Greve's results on 1-1/2 inch valves are given in the following table:

Velocity, ft./sec.	Loss of Head, feet of water
9.85	21.52
7.87	14.06
5.04	5.94
4.08	3.93
3.73	3.29
3.55	3.01
3.19	2.46
2.91	2.06
2.63	1.70
2.07	1.07

Dean E. Foster[3] states that Konrad Meier gives the resistance to flow by fittings as: $H_r = 1.38\ r\ (V^{1.86})/2g$ where H_r is the feet of pressure loss per fitting; r is a

factor of resistance; and V is the velocity in feet per second. Meier also gives the formula $L_e = 53.75\ r\ (d^{1.25})$ where d is the diameter in feet; r is the factor of resistance; and L_e is the friction loss expressed in equivalent feet of pipe.

According to R. L. Daugherty[5] in his text-book on hydraulics, the loss of head through globe valves may be expressed by: $H = kV^2/2g$ where H is the loss in feet of water; k is a constant having the value 10; V is the velocity in feet per second; and g is the effect of gravity. Thomas[2] gave the same formula except that his value of k was different.

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Construction of Apparatus

The first step in the construction of the apparatus was the design. The most important problem in this design was to prevent turbulence set up by the bends and fittings from interfering with the manometer readings. Russell[6] recommends 75 diameters to clear the stream of turbulence caused by a 90° bend. In the design the first connection was made approximately 9.5 feet from the last fitting thereby providing ample room for the turbulence to die out. It was decided that the hydraulic gradient method of determining the drop across the valve was to be used since it is more accurate than any other methods known. Five manometer connections were considered ample for the upstream side of the valve since five points are sufficient for the determination of a line such as the hydraulic gradient, and since they would not be subjected to any influencing factors other than the normal friction due to the pipe. Eight connections were placed on the downstream side of the valve. More connections were placed downstream because it was feared that the first two or three connections might be in error due to the turbulence set up by the valve. Details may be seen in Figure 1, a drawing of the complete apparatus.

Galvanized pipe was used throughout to prevent contamination of manometer connections by rust. The entire

apparatus was first constructed entirely of 1-1/2 inch pipe with provisions for replacing the upper pipe containing the valve to be tested, by pipes of different sizes. This was made possible by the use of unions for removing the pipe. When smaller pipes were used, bushings were used to connect the smaller pipe to the 1-1/2 inch pipe.

The pipes were cut to the required lengths and 3/32 inch holes were drilled at 2 foot intervals for the manometer connections. To remove any burrs caused by this operation, the inside of the pipes were reamed by means of emery cloth wrapped around a slender rod.

Collars for the manometer connections were made and placed on the pipes along with the valves for controlling the lines leading to the manometers. These are shown in Part Number 9 and 10 respectively of Figure 1.

Calculations showed that an orifice meter containing an orifice of 1 inch diameter would be satisfactory. The meter was constructed out of ordinary pipe flanges with a 3/32 inch hole drilled through the flange and pipe for connections to the manometer. This may be seen in Part Number 5, Figure 1.

Welded hangers were made of 1-1/4 inch angle iron and tied to the floor with 1/4 inch anchor bolts.

Two mercury-water and one water-air manometers were assembled and erected on 1-1/4 inch angle iron stand. One of the mercury manometers was connected to the orifice

meter. The other mercury manometer and the water manometer were connected to the upstream and downstream connections on the pipe containing the valve to be tested. Both water-air and mercury-water manometers were used for measuring the drop across the valve since at times the friction drop was very small yet at other times very high. Three-sixteenth inch copper tubing was used in making all manometer connections as shown in Figure 1.

The entire apparatus was then assembled, placed on the hangers, connected to the pump, Part Number 1, Figure 1, connected to the tank and manometers and checked for all possible leaks.

Procedure

In all the following discussion, the numbers in parentheses refer to the Part Numbers on the drawing, Figure 1.

Before any experimental data could be obtained it was necessary to calibrate the orifice (5). This was done by plotting the velocity against the manometer readings. The velocity through the pipe was determined by weighing the discharge. This weighing was performed in the following manner. The velocity was set by regulating the opening of a 1-1/2 inch gate valve at the discharge point (14). With water flowing into a weighing tank placed on a pair of scales, weights were added to the scale pan until the arm was depressed. At the instant the arm moved upward an Eastman Kodak timer was started and 300 pounds were placed on the scale pan. This of course caused the arm to be depressed again. At the instant the arm moved upward after the weights had been placed on the pan, the timer was stopped and the elapsed time was that required for a discharge of 300 pounds of water. The temperature of the water was taken to obtain the correct density of the water.

When using pipe of sizes smaller than 1-1/2 inch, it was necessary to convert the velocity in the 1-1/2 inch pipe to that in the smaller pipe by multiplying the velocity in the large pipe by the ratio of the square of the diameter

of the 1-1/2 inch pipe to the square of the diameter of the smaller pipe.

With the orifice calibrated it was possible to start the experimental runs. With the velocity set at the desired rate, all manometer connections (10) were closed. The first manometer connection was then opened and allowed to remain open through the entire run. Then the second manometer connection was opened and the friction loss due to the two feet of pipe between the connections was read in terms of the manometer deflection. In as far as possible all readings were taken on the water-air manometer (16) since it is more accurate than the mercury-water manometer due to the large deflection on the water manometer as compared to the mercury. The second connection was then closed and the third opened, keeping the first one open at all times, and the reading taken. This was repeated for each connection. It was often necessary to change from the water to the mercury manometer in the middle of a run due to the large drop across the valve.

During the runs the manometers were checked for air in the lines. This was done by closing the discharge valve (14) and leaving the pump (1) running. If the two columns of liquid in the manometer did not come down until both were at the zero position, air was present in the lines. Water was allowed to flow from the entrances to the manometer to remove any air which might have been present.

During the course of a run, the pressure drop was checked by readings on both the mercury-water and water-air manometers in as far as possible.

When the data were completed for the 1-1/2 inch pipe and valve, it was removed and replaced by 1-1/4 inch pipe containing a 1-1/4 inch valve. The data for this valve were taken in the same manner as that for the 1-1/2 inch valve, keeping in mind the fact that the velocity as read from the orifice calibration was for 1-1/2 inch pipe and had to be converted to the velocity in the 1-1/4 inch pipe.

On completion of the run for the 1-1/4 inch valve, the pipe was replaced by the 1 inch pipe and valve and the same procedure followed as for the two previous valves.

The friction loss across the valve was obtained graphically from a hydraulic gradient obtained by plotting the loss in head expressed in centimeters of water against the distance along the pipe in feet. This non-consistent scale was used because it was easier to convert the resulting friction loss due to the valve alone from centimeters to feet of water than to convert each reading along the pipe.

The experimental data are shown in the tables in Appendix B.

Results

The following tables represent the detailed results as shown by experimental data. The loss expressed in equivalent feet of pipe are calculated according to the method given by Badger and McCabe[1]. The graphs from which the head lost in the valve was obtained may be found in Appendix C and are titled Figures 4, 5, 6, 7, 8, and 9.

1-1/2 Inch Chapmen 200 Pound Globe Valve

Velocity in ft./sec.	Head Lost in Feet of Water	Reynolds Number	Head Lost in Equivalent Feet of Pipe
1.97	0.266	26,650	21.2
3.05	0.83	42,800	30.8
4.10	1.69	58,500	37.7
4.80	2.66	71,700	43.0
5.90	3.41	90,500	38.7
7.10	4.59	110,000	37.0
8.10	5.59	125,500	34.7
9.00	6.33	143,000	32.8
9.80	6.30	156,000	27.5

1-1/4 Inch Chapman 200 Pound Globe Valve

Velocity in ft./sec.	Head Lost in Feet of Water	Reynolds Number	Head Lost in Equivalent Feet of Pipe
2.83	1.11	37,600	40.0
3.96	2.40	55,800	47.5
5.78	3.61	83,200	35.6
6.94	5.30	101,000	37.2
8.27	7.02	120,500	35.8
9.80	8.70	142,500	32.6
11.00	11.35	162,000	34.8
11.85	12.85	175,000	34.0

1 Inch Globe Valve, Maker Unknown

Velocity in ft./sec.	Head Lost in Feet of Water	Reynolds Number	Head Lost in Equivalent Feet of Pipe
6.60	6.4	73,000	36.7
8.03	9.7	88,000	37.8
10.20	16.7	110,000	41.3
11.00	19.5	122,000	42.7
11.80	22.1	126,000	42.0

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Discussion

After a survey of the available literature on the subject it seems to the authors that the method of finding the loss of head across a valve by means of a hydraulic gradient is the best method. Other investigators did not use this procedure, but found the drop across the valve with lengths of pipe upstream and downstream from the valve. By subtracting the theoretical loss in the two lengths of pipe from the total loss over the pipe and valve, the loss across the valve alone was obtained. This method presumes that the loss in the pipe may be accurately given by theoretical considerations which might not be true in all cases.

Many formulas have been advanced to represent the loss in head across a valve. R. L. Daugherty[5] in his text-book on hydraulics gives the formula: $H = kV^2/2g$. For globe valves the constant k has the value 10. This relationship does not give values which agree with the experimental results of the present thesis. This formula is a modification of the orifice formula. It is true that there is an opening in globe valves corresponding to an orifice, but there are also changes of direction of the flow of the fluid and eddies set up due to the design of the valve which are not apparently considered in the above formula unless they are included in the value of the constant, k.

Konrad Meier[3] offers the formula: $H_r = 1.38\ r(V^{1.86})/2g$. It seems reasonable to include a factor of resistance in such a formula although its determination would somewhat restrict the use of the formula.

Meier also presents a formula for the flow through straight lengths of pipe: $H_f = \frac{0.0257\ V^{1.86}\ L}{2g\ d^{1.25}}$

where H_f is the loss in feet of pressure; V is the velocity in feet per second; r is the resistance factor; L is the length of the pipe in feet; and d is the diameter of the pipe in feet. This expression is quite different from that given by Badger and McCabe: $H_f = O\ (Re)\ u^2L/D$ where Re is Reynolds number; O is a constant combining the effect of gravity, another constant, and a factor of roughness; H_f is the loss in head expressed in feet; D is the diameter of the pipe in feet; u is the velocity in feet per second; and L is the length of the pipe in feet.

By combining his two formulas Meier obtains: $L_e = 53.75\ r\ (d^{1.25})$ for the loss in equivalent feet of pipe for all fittings. According to Badger and McCabe, the loss in equivalent feet for fittings may be obtained from their formula given above if H_f is determined experimentally. Meier's formula does not take into account the effect of variables such as viscosity, velocity, and density. Due to this disregard of these variables, it seems that Meier's

Formula for the equivalent loss in fittings is not comprehensive.

Dean E. Foster[3] has calculated equivalent lengths of pipe expressing the loss in globe valves from Meier's formula. For 1 inch valves this loss is 5.12 feet, for 1-1/4 inch valves--7.22, and for 1-1/2 inch valves the value 8.72 is given. According to Perry[7] these values should be 4.68, 6.54, and 7.84 respectively. These values differ greatly from those calculated according to Badger and McCabe[1]. Calculated from their formula the results are 6 to 7 times as much.

In discussing Meier's results, F. E. Giesecke[3] states that the results are only about one-fourth as high as his determinations showed. Giesecke's work was not available.

Frederick W. Greve Jr.[4] performed experiments on 1-1/2 inch globe valves with seemingly particular carefulness. He obtained the formula: $H_l = 953.7\ Q^{1.915}$. His experimental data is shown in the following table along with that of the present authors for comparison.

1-1/2 Inch Globe Valve

Greve's Data		Data by Monday & Fox	
Velocity in ft./sec.	Loss of Head in Feet of Water	Velocity in ft./sec.	Loss of Head in Feet of Water
9.84	21.52	9.8	6.30
7.87	14.06	9.0	6.33
5.04	5.94	8.1	5.59
4.08	3.93	7.1	4.59
3.73	3.29	5.9	3.41
3.55	3.01	4.8	2.66
3.19	2.46	4.1	1.69
2.91	2.06	3.05	0.83
2.63	1.70	1.97	0.266
2.07	1.07		

This thesis cannot try to fully develop a general formula to hold for all globe valves. However on the basis of the small amount of data taken it can attempt to point toward the direction and form of such an equation. As a result of the work performed and the literature survey it appears that such a formula involves the Reynolds number raised to some power and that there is a possibility that the size of the valve enters into the equation in addition to the effect of Reynolds number. Plots of Reynolds number versus the loss in head give straight lines which may be considered parallel. Due to the small range and small amount of data these curves are only an indication of the right direction. Before definite conclusions may be drawn, the experimental runs must be extended and enlarged.

An unexplained condition occurred in the runs on

1 inch and 1-1/4 inch valves. The friction loss across the first two feet of pipe, that is between the first two manometer connections, in almost all cases was a very small amount varying from approximately 1 to 10 centimeters of water. However in several instances in the 1-1/4 inch valve and in all cases in the 1 inch valve runs, the drop between these two connections was out of all proportion. Thereafter the increase in friction loss was quite normal. The manometers were checked for the presence of air in the lines but were found to be air free. If an error in operation were made, the resulting friction loss across the valve would not be effected, the graph would be lowered toward the X axis by the amount of the error.

After concluding the experimental work, several recommendations concerning the apparatus may be made. The orifice meter should be replaced by a Venturi meter to prevent the permanent loss accompanying the orifice meter. With the Venturi meter a greater range in velocity should be obtained. A water-air manometer should be used in conjunction with the mercury-water manometer for measuring velocities. This will give greater accuracy in determining the velocity especially on pipes smaller than 1-1/2 inch. Bell reducers should be used in installing pipes less than 1-1/2 inch in the system instead of bushings. A small valve should be installed in the lines to the manometers for

the purpose of removing air from the system in the event such is present. If possible, manometers with ranges greater than 100 centimeters should be used. These proposed changes would in no way effect the present data with the exception of the velocity.

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(3) Foster, D. E., Effect of Fittings on Flow of Fluids Through Pipe Lines, The American Society of Mechanical Engineers Transactions, Volume 42, p. 647, 1920.

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(5) Daugherty, R. L., Hydraulics, A Text-Book on Practical Fluid Mechanics, McGraw-Hill Book Co., Inc., fourth edition, 1937.

(6) Russell, G. E., Text-Book on Hydraulics, Henry Holt and Company, fourth edition, 1938.

(7) Perry, J. H., Chemical Engineers' Handbook, McGraw-Hill Book Co., Inc., first edition, 1934.

APPENDIX A

APPENDIX B

Calibration of 1 Inch Orifice Meter

Temperature of Water--78° F. 1-1/2 Inch Galvanized Pipe

Pounds of Water	Time in Seconds	H in Cm. Mercury	Velocity Through 1-1/2 Inch Pipe, ft./sec.
300	106.0	5.2	3.22
300	70.0	10.9	4.86
300	55.0	17.0	6.20
300	52.0	18.3	6.55
300	48.0	21.4	7.10
300	45.0	24.2	7.56
300	41.0	28.6	8.31
300	41.0	30.1	8.31
300	42.0	31.3	8.13
300	34.0	40.2	10.02
300	34.0	40.4	10.02
300	39.5	31.8	8.63
300	38.0	33.0	9.21
300	46.5	24.4	7.34
300	65.5	12.1	5.20
300	40.5	30.0	8.42
300	75.0	9.4	4.54
300	91.5	6.4	3.72
300	147.0	2.7	2.32

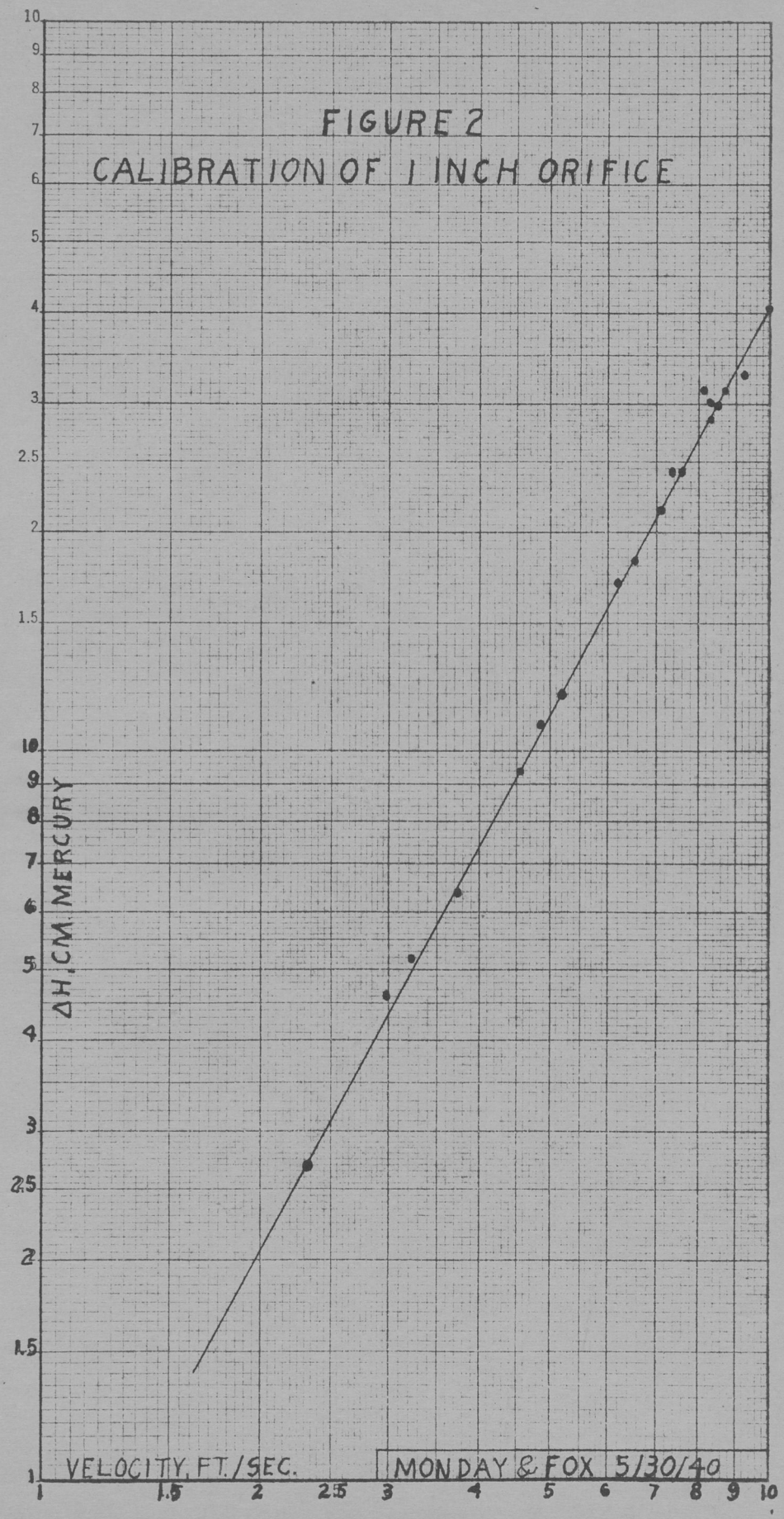
FIGURE 2
CALIBRATION OF 1 INCH ORIFICE
ΔH, CM. MERCURY
VELOCITY, FT./SEC.
MONDAY & FOX 5/30/40
10
9
8
7
6
5
4
3
2.5
2
1.5
1
1
1.5
2
2.5
3
4
5
6
7
8
9
10

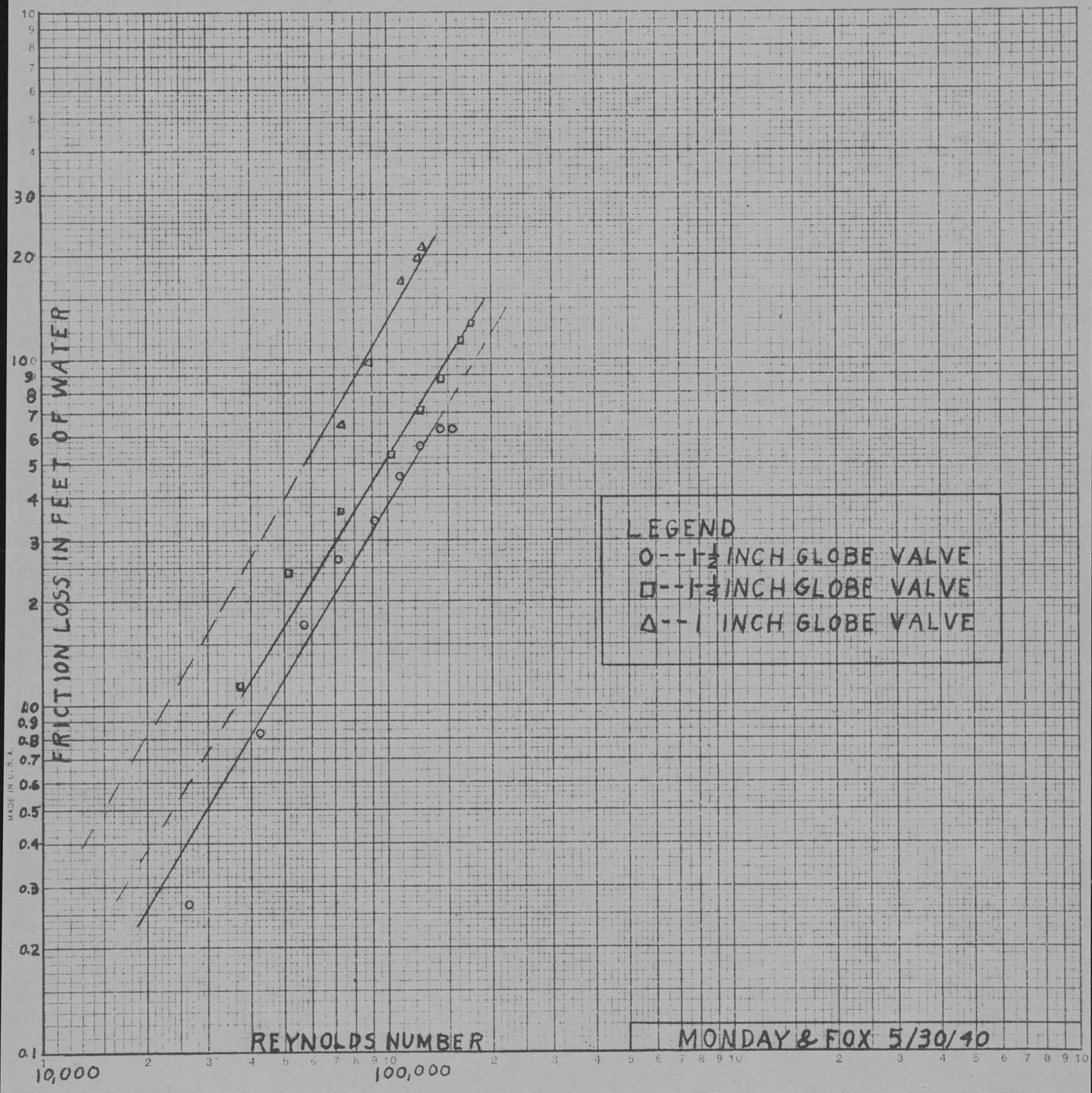

FIGURE 3
EFFECT OF REYNOLDS NUMBER ON THE FRICTION LOSS IN GLOBE VALVES

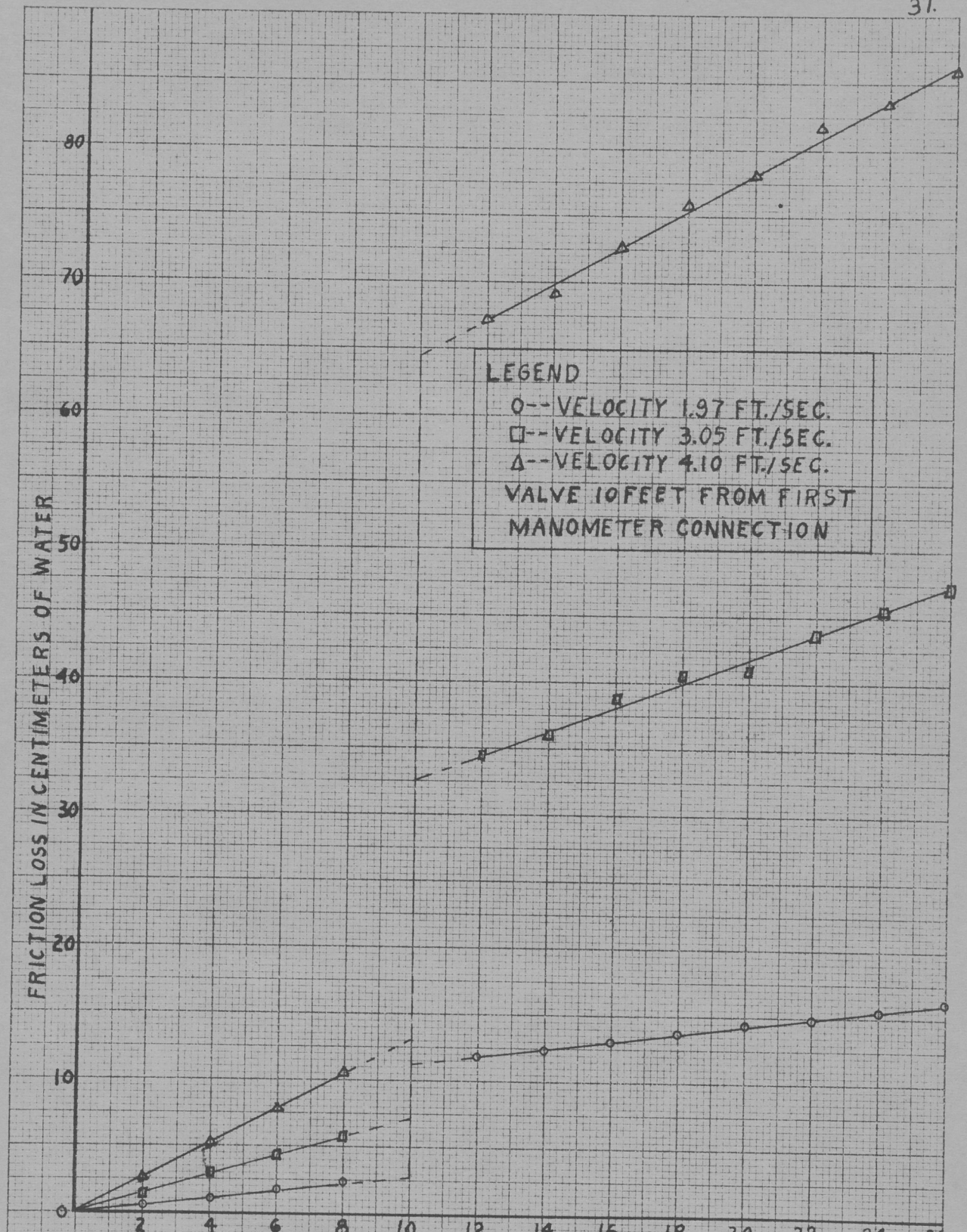

FIGURE 4

HYDRAULIC GRADIENT FOR 1-1/2 INCH GLOBE VALVE

MONDAY & FOX 5/30/40

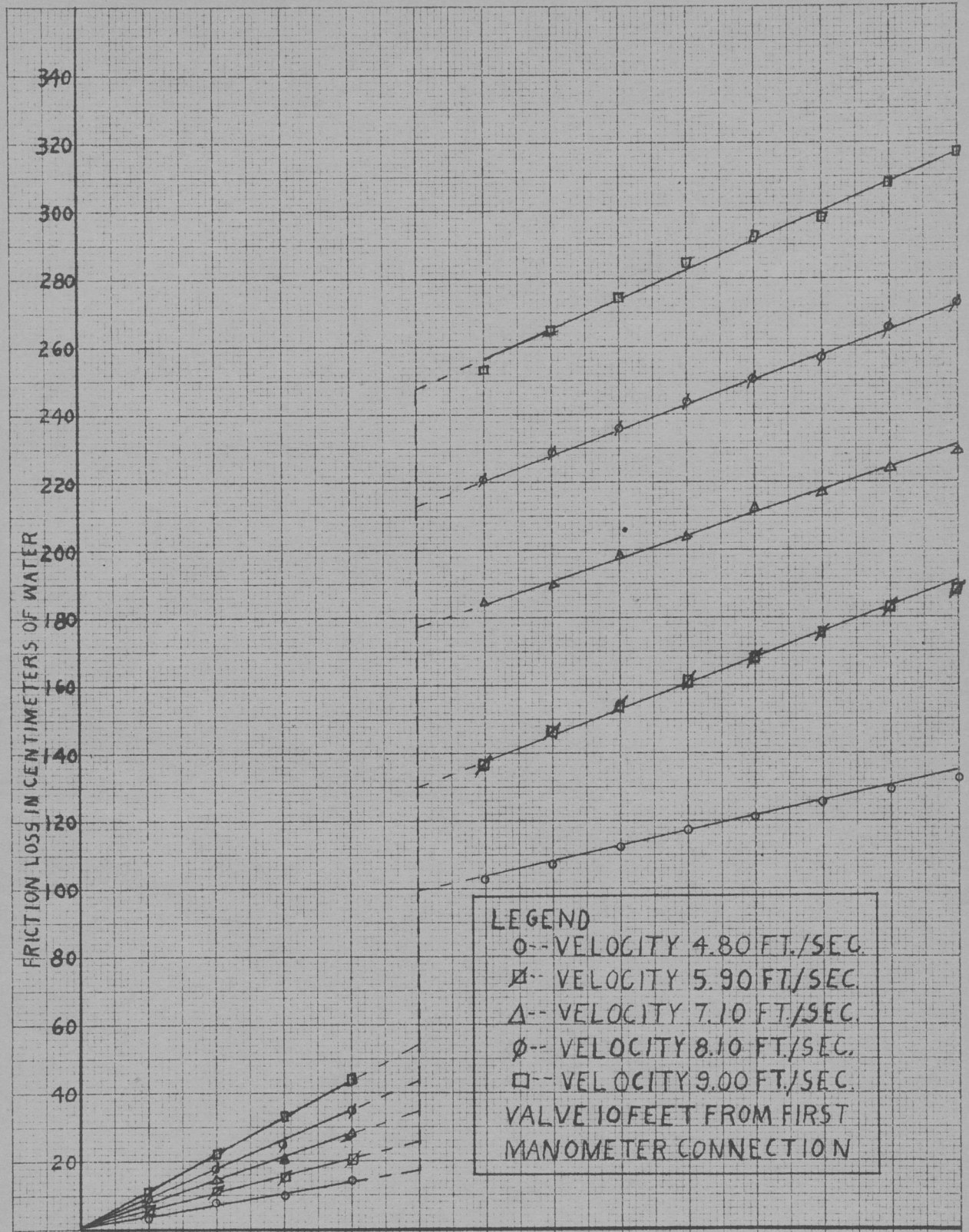

FIGURE 5

HYDRAULIC GRADIENT FOR 1-1/2 INCH GLOBE VALVE

MONDAY & FOX 5/30/40

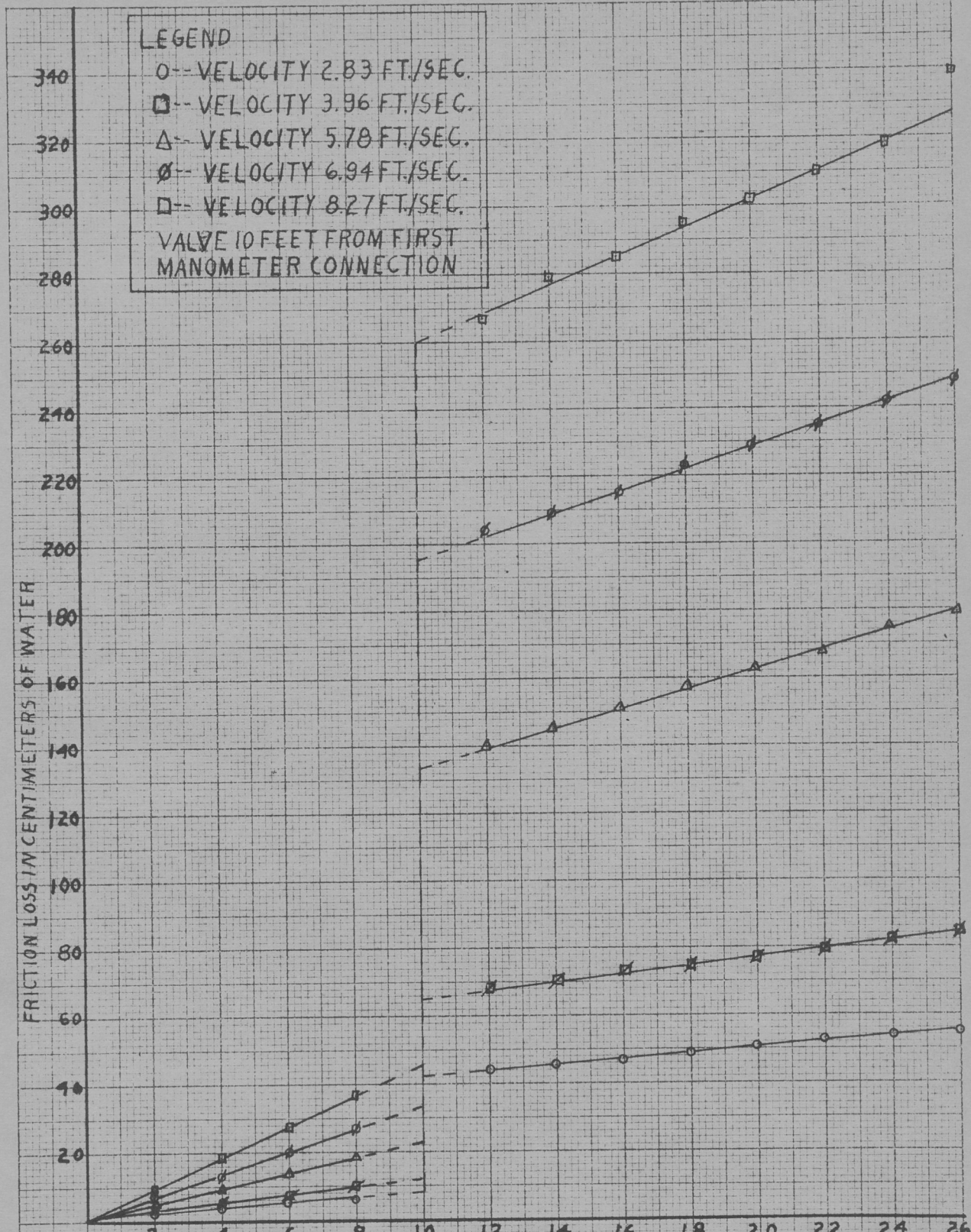

FIGURE 6

HYDRAULIC GRADIENT FOR 1-1/4 INCH GLOBE VALVE

MONDAY & FOX 5/30/40

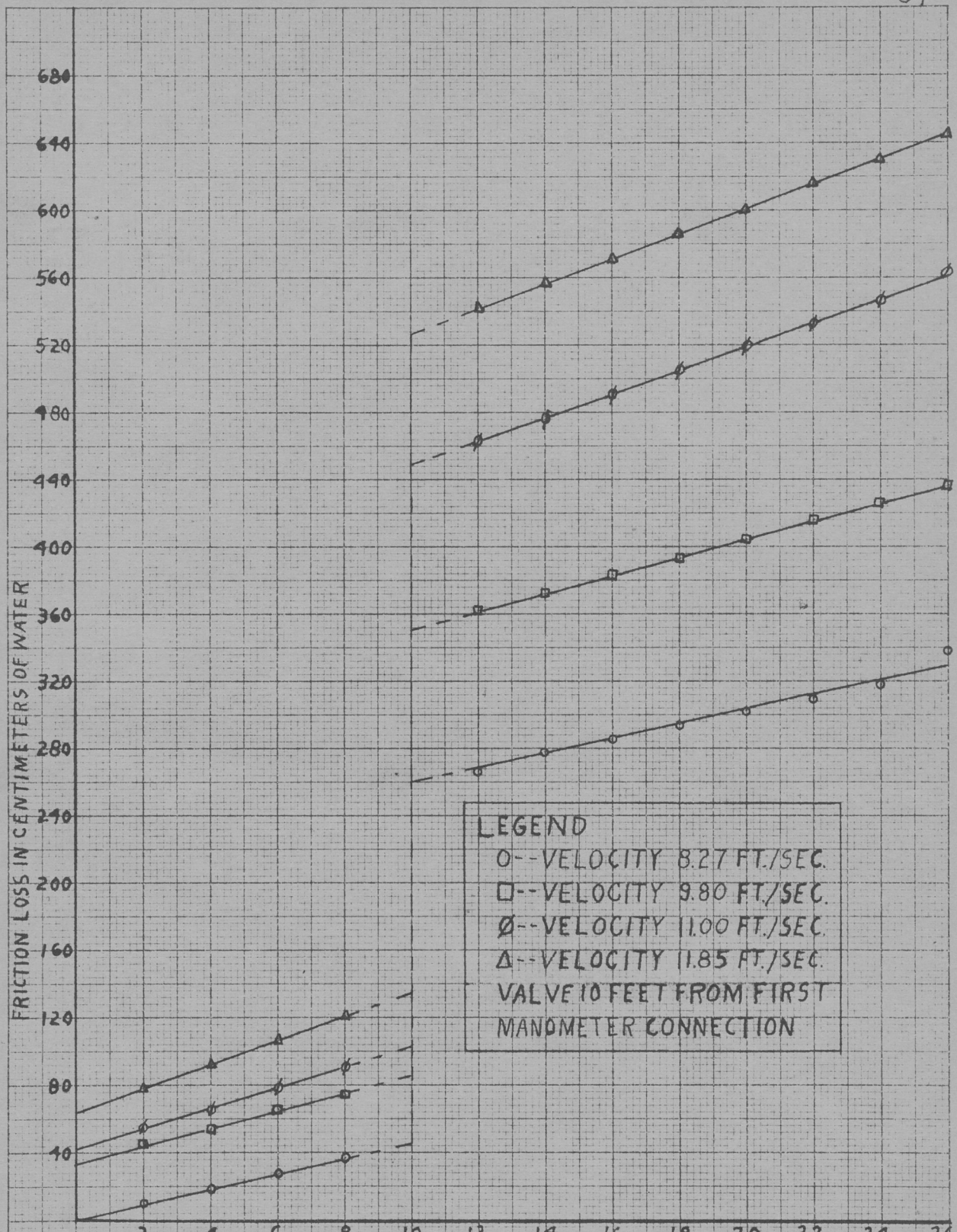

FIGURE 7

HYDRAULIC GRADIENT FOR 1-1/4 INCH GLOBE VALVE

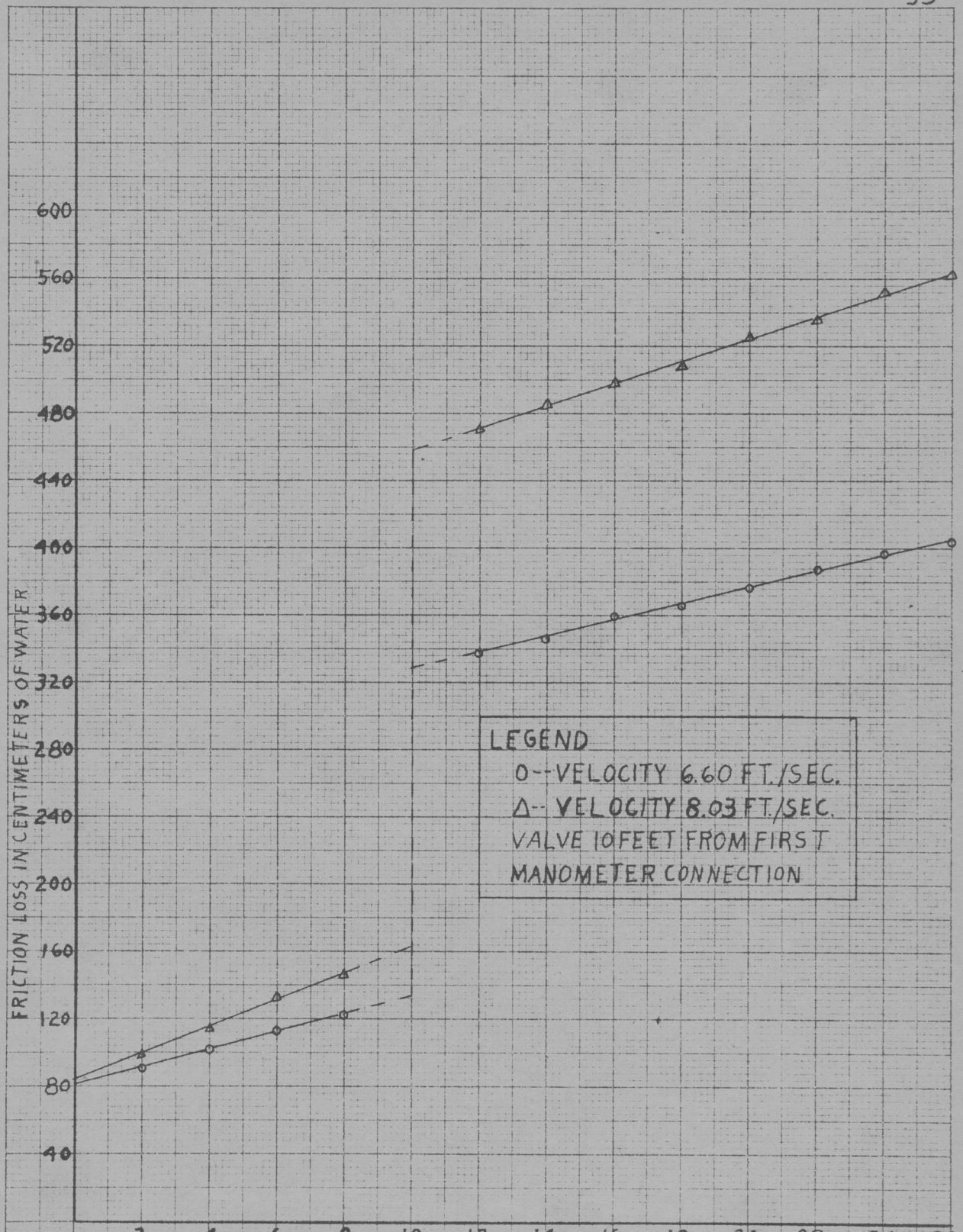

FIGURE 8

HYDRAULIC GRADIENT FOR 1 INCH GLOBE VALVE

MONDAY & FOX 5/30/40

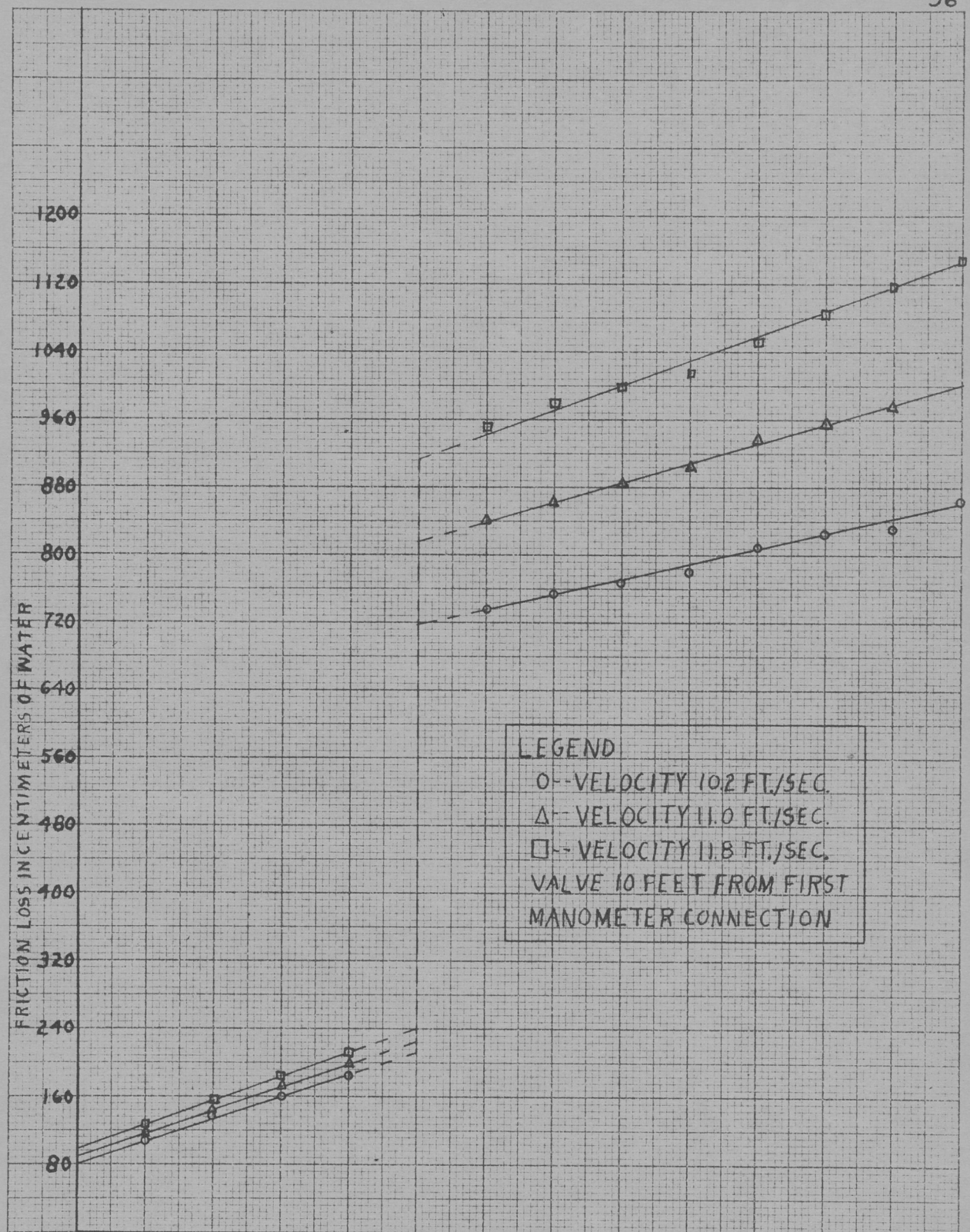

FIGURE 9

HYDRAULIC GRADIENT FOR 1 INCH GLOBE VALVE

MADE IN U.S.A.

MONDAY & FOX 5/30/40

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name R. W. Boarts

Title Professor of Chemical Eng.

Date May 27, 1940