THE EFFECT OF REYNOLDS NUMBER ON FRICTION LOSS IN GLOBE VALVES

By

W. Wilson Bond

and

Charles F. Wallace

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SUMMARY

In commercial practice the transportation of fluids is a problem to manufacturers. In most processes where fluids are being handled the common method of handling is by means of pipe lines. From an economical standpoint it is of importance to the manufacturer to know the pressure drop in the line in his selection of pumps to be used. In the case of straight lengths of pipe the procedure for finding the loss in head due to friction is thoroughly standardized and quite reliable, but relatively little work has been done on the determination of the loss in head due to fluid flow through fittings. It is the purpose of this thesis to attempt to derive experimentally an empirical formula for the calculation of the pressure drop across globe valves ranging from 1/2 inch to 1-1/2 inch.

According to Badger and McCabe[1], recent work has shown that the loss in head due to fluid flow through fittings is a function of Reynolds number. With this in mind an attempt is being made to correlate the data on friction loss in globe valves with Reynolds number. This

work was started by Monday and Fox[6]. The present authors used some of their equipment in an attempt to check their results on the head loss through 1-1/2 inch, 1-1/4 inch, and 1 inch globe valves. Two additional pipes (3/4 inch and 1/2 inch) were constructed similar to the larger sizes, and similar tests were made on them.

The 1-1/2 inch valve was tested with the fluid velocity varying from 9.60 ft./sec. to 4.23 ft./sec.; velocity through the 1-1/4 inch valve varied from 11.61 ft./sec. to 4.02 ft./sec.; the velocity through the 1 inch valve varied from 11.45 ft./sec. to 5.71 ft./sec.; the velocity through the 3/4 inch valve varied from 19.05 ft./sec. to 9.75 ft./sec.; and the velocity through the 1/2 inch valve varied from 23.75 ft./sec. to 17.75 ft./sec.

General formulas for friction loss in globe valves have been derived by Corp[2], Meir and Foster[4], Greve[5], and Thomas[9]. These expressions involve velocity raised to a power varying from 1.86 to 2. Monday and Fox[6] did not derive a general formula, but arrived at the following expressions:

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, $H = 5.13 \times 10^{-8}(Re)^{1.7}$

The results of the present work indicate the following formulas:

For 1 1/2 inch globe valves, $H = 2.26 \times 10^{-11}(Re)^{2.23}$

For 1 1/4 inch globe valves, $H = 3.94 \times 10^{-12}(Re)^{2.42}$

For 1 inch globe valves, $H = 2.897 \times 10^{-13}(Re)^{2.78}$

For 3/4 inch globe valves, $H = 1.387 \times 10^{-25}(Re)^{5.0}$

For 1/2 inch globe valves, $H = 8.8 \times 10^{-34}(Re)^{6.62}$

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 feet, and μ is the viscosity in English units (pounds per foot per second).

The exponent of Reynolds number is almost constant for the 1-1/2 inch, 1-1/4 inch, and 1 inch globe valves. This indicates the possibility of a general formula. However, consideration of the formulas resulting from tests on 3/4 inch and 1/2 inch globe valves tends to remove the probability of a general formula for friction loss across globe valves. It seems that the size of the valve enters into the formula in addition to the power of Reynolds number. Therefore, the formulas shown should be considered as approximate.

EXPERIMENTAL SECTION

LITERATURE SURVEY

The first work done on friction loss in valves was probably done by M. E. Thomas[9] in 1906, at the University of Illinois Engineering Experiment Station. His work was on 1 inch and 2 inch angle, gate, and globe valves at various openings. The only one of interest to the present investigation was the 1 inch globe valve. The apparatus consisted of a test valve in a horizontal pipe with three-way gage connections, one foot upstream and one foot downstream, for measuring pressure head. Water was supplied from a standpipe with a static head of fifty feet. The difference in pressure head between the two gage connections was measured by a differential mercury-water gage. The loss of head due to friction in the pipe between the valve and the gage connection was subtracted from the reading of the mercury-water manometer to give only the loss of head due to the valve. The velocity for the 1 inch globe valve was varied from 2 ft./sec. to 18 ft./sec. A plot on logarithmic paper of the head loss versus velocity gave a series of parallel, straight lines whose slope was approximately 2. This indicated that the head loss varied with the velocity according to the formula: $H = \frac{mV^2}{2g}$, where "H" is the velocity head

in feet of water, "m" is the coefficient of loss, "V" is velocity in feet per second, and "g" is the acceleration of gravity in feet per second per second. The value of the coefficient of loss as determined from experimental data was 7.12. He stated that the loss of head seemed to vary almost inversely as the diameter.

Frederick W. Greve, Jr.[5] performed tests on a 1-1/2 inch globe valve with velocities varying from 0.5 ft./sec. to 21.0 ft./sec. For measuring loss of head, he used a mercury-water manometer with a range of 60.0 feet of water, and a water-air manometer that would record a loss of head of nearly 5.0 feet. As a result of his experimental work, Greve stated that the relation between loss of head and discharge could be represented in all cases by the general equation: $H_L = mQ^n$, where "H_L" is the head loss, "m" and "n" are constants whose values for the 1-1/2 inch globe valve were 953.7 and 1.915 respectively, and "Q" is the discharge in cubic feet per second.

Some of Greve's results on the 1-1/2 inch globe valve are shown in table No. 6, along with that of Monday and Fox.

Dean E. Foster[4] in his article entitled "Effect of Fittings on Flow of Fluids Through Pipe Lines," states that Konrad Meir gives the equation: $Le = 53.75\ r(d^{1.25})$,

where "L_e" represents the number of feet of equivalent pipe in resistance to a fitting, "r" is the factor of resistance which depends on the shape of the fitting, and "d" is the diameter of pipe in inches. This equation is a combination of two equations. One, which gives the loss of pressure through pipe lines, is: $H_f = \frac{.0257}{2g} \times V^{1.86} \times \frac{L}{d^{1.25}}$ where "H_f" is the loss of pressure in feet, "V" is velocity in ft./sec., "d" is the diameter of pipe in inches, "L" is the length of pipe in feet, and "g" is the acceleration of gravity in feet per second per second; the other which gives the loss of pressure due to fittings, is: $H_r = 1.38r(V^{1.86})/2g$, where "H_r" is feet of pressure loss per fitting, "r" is a factor of resistance whose value depends on the shape of the fitting, and "V" is the velocity in feet per second.

Corp[2] states that the loss of head due to a globe valve in a pipe line could be expressed by the formula $H = \frac{kV^2}{2g}$, where "H" is the head loss in feet of water, "V" is the velocity in ft./sec., "g" is the acceleration of gravity in ft./sec. per sec., and "k" is a constant. Tests were made on 1/2 inch, 3/4 inch, 1 inch, and 2 inch globe valves. The average "k" for these valves was 13.55, 6.54, 6.03, 7.13 respectively, as determined from experimental data. As a

result of his experiments Corp concluded that the loss of head due to the flow of water through 1/2 inch globe valves fully open is approximately equivalent to the loss in 35 feet of 1/2 inch pipe at the same pipe velocity, and for larger sizes tested it is probably equivalent to approximately 20 feet of straight pipe of the valve size.

R. L. Daugherty[3] states that the loss of head in pipe fittings could be expressed as $kV^2/2g$, where the value of "k" for globe valves is 10. This formula is identical with that of Corp and Thomas, except for the value of "k".

J. F. Monday and G. J. Fox[6], using some of the same equipment that was used in the present work, arrived at the following formulas for the 1 1/2 inch, 1 1/4 inch, and 1 inch globe valves respectively: $H = 1.51 \times 10^{-8}(Re)^{1.7}$, 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).

DESCRIPTION OF APPARATUS

Since the present work was a continuation of the work started by J. F. Monday and G. J. Fox, some of the same equipment was used, and the same design was used for the construction of additional apparatus. The apparatus can be described best by referring to Figure 1, Appendix A. It was constructed first entirely of 1-1/2 inch galvanized pipe with provisions for replacing the top pipe with 1-1/4 inch, 1 inch, 3/4 inch, and 1/2 inch pipes. Bushings were used to connect the smaller pipes to the 1-1/2 inch pipe. The upper pipe contained the valve to be tested in all cases. Five manometer connections were placed on the upstream side and eight on the downstream side at two foot intervals from the valve. Mercury-water and air-water manometers were used, and the connections were of 3/16 inch copper tubing. The lower pipe contained an orifice of 1 inch diameter.

All of the apparatus used except the 1/2 inch and 3/4 inch pipes was constructed by Monday and Fox. These pipes were cut to the required lengths and 3/32 inch holes were drilled at two foot intervals for manometer connections. To eliminate any burrs caused by drilling, emery cloth on a slender rod was run through the pipes several times.

One and one-half inch collars for manometer connections were made from 1 inch and 1 1/4 inch pipes. For details

of collar and valve controlling flow through manometer leads see Figure 1, Appendix A, parts No. 9 and No. 10.

Both air-water and mercury-water manometers were used in order to cover a larger range of pressure drops.

MANIPULATIVE PROCEDURE

In the following discussion, the numbers in parentheses refer to the part number on the drawing, Figure 1.

The first experimental work consisted in calibrating the orifice meter (14) in order that velocities could be taken directly from a plot of pressure drop across the orifice versus velocity through the pipe.

The rate of flow was controlled at the discharge by a 1-1/2 inch gate valve (5) to insure a full pipe of water at all times. With the valve completely open and with enough weights added to the scale pan so that the arm was depressed, the pump (18) was started and water was allowed to discharge into a weighing tank (1) until the arm moved up. At the instant the scale arm moved up a Kodak timer was started. The time required to collect 300 pounds of water in the weighing tank was noted. The velocity was varied from 9.68 ft./sec. to 2.45 ft./sec. in the 1-1/2 inch pipe containing the 1.00 inch diameter orifice. The temperature of the water was taken for each run.

With the orifice meter calibrated it was possible to start the experimental runs for determining the head loss due to the globe valve. The friction loss across the 1-1/2 inch valve (7) was found as follows: The first manometer

connection on the upstream side was kept open throughout all the runs. With the second manometer connection open, and with water flowing through the pipe at the maximum velocity obtainable, the pressure drop from the first to second connection was read on the manometers (3 & 4). Then the second connection was closed and the third opened, and the pressure drop from the first to the third connection was read. This was continued for each successive connection. The rate of flow was then decreased and the various pressure drops read as above for each section of pipe. In so far as possible the water-air manometer was used because of its greater sensitivity. Frequently it was necessary to change from the air-water to the mercury-water manometer in the middle of a run, due to the great pressure drop across the valve. Where possible readings were taken on both air-water and mercury-water manometers as a check.

When the runs for the 1-1/2 inch pipe were completed, the 1-1/2 inch pipe was replaced by a 1-1/4 inch pipe. This was made possible by using bushings and unions. The same procedure described above was carried out. The velocity for this pipe as read from the calibration curve had to be corrected by multiplying the value indicated by the graph by the ratio of the squares of the internal diameters of the two pipes.

The top pipe was then replaced successively by 1 inch, 3/4 inch, and 1/2 inch pipes, and the same procedure carried out. In every case the valve being tested was completely open.

Before tests were made on a pipe, air was removed from the lines by allowing water to flow from the entrance of the manometers.

The hydraulic gradient method was used for determining the loss of head due to the globe valve in the line. This gradient was obtained by plotting the loss of head expressed in centimeters of water against distance along the pipe in feet. The reason for using this non-consistent scale was to eliminate converting each individual reading along the pipe. Thus it was necessary to convert only the friction loss due to the valve from centimeters of water to feet of water. Figures 5-14 in Appendix C show these gradients.

The experimental data are shown in tables No. 8-13 in Appendix B.

SAMPLE CALCULATIONS

Using data for 1 1/2 inch pipe:

ΔH = 41.6 cm. Hg. as read from the orifice manometer.

Velocity = 9.60 ft./sec. as read from calibration curve.

Average temperature of water = 29.75°C.

Density of water at 29.75°C = 62.16 lbs./cu. ft.

Viscosity of water at 29.75°C = 0.805 centipoise.

Internal diameter of 1 1/2 inch pipe = 1.610 inches.

Reynolds number = $Du\rho/\mu$.

$$Du\rho/\mu = \frac{1.61 \text{ in.} \times 9.60 \text{ ft./sec.} \times 62.16 \text{ lbs./cu. ft.}}{12 \text{ in./ft.} \times (.805 \times .000672) \text{ lb./ft.} \times \text{sec.}} = 148{,}200$$

Head Loss across Valve from Figure 6:

ΔH_f = 312.5 - 77.0 = 235.5 cm. water

$$\Delta H_f = \frac{235.5 \text{ cm. water}}{2.5 \text{ cm./in.} \times 12 \text{ in./ft.}} = 7.70 \text{ ft. of water}$$

Head Loss in Equivalent Feet of Pipe:

$$L = H_f D/u^2 \phi Re$$

If Re = 148,200, then ϕRe = .00032 from Figure 14, page 37 in Badger and McCabe[1].

$$L = \frac{7.7 \times 1.610}{(9.6)^2 (.00032) (12)} = 35.1 \text{ equivalent feet of pipe.}$$

Derivation of equation for head loss in 1-1/2 inch globe valves:

The equation is a power function of Reynolds number, and may be represented by:

$H = y(Re)^x$ or $\log H = \log y - x \log Re$

If Re = 100,000, H = 3.2 (from Figure 3).

If Re = 200,000, H = 15.0

$\log 15.0 = \log y - x \log 200{,}000$ (1)

$\log 3.2 = \log y - x \log 100{,}000$ (2)

Subtracting (2) from (1):

$1.17609 - .50515 = 5.30103x - 5.00x$

$x = 2.23$

$\log 3.2 = \log y - 2.23 \log 100{,}000$

$\log y = -10.645$ or -11.355

$y = 2.26 \times 10^{-11}$

The equation is, therefore,

$H = 2.26 \times 10^{-11}(Re)^{2.23}$

RESULTS

The detailed results are shown in the following tables. The graphs (Figures 5-14) showing the head loss due to the valve may be found in Appendix C. The loss expressed in equivalent feet of pipe was calculated by the formula: $\Delta H_f D/u^2 L = \phi Re$, where " Re" is found from a plot of "ϕRe" versus Reynolds number as found in Figure 14, page 37 in Badger and McCabe[1]. "ΔH_f" is loss in head due to friction in feet, "D" is inside diameter of pipe in feet, "u" is velocity of water in feet per second, "L" is equivalent length of pipe in feet, "Re" is Reynolds number ($Du\rho/\mu$), and "ϕ" is a factor of roughness.

The graphs (Figures 3 & 4) showing the relation between Reynolds number and friction loss due to globe valves may be found on pages 15, 16, and 17.

TABLE NO. 1

1 1/2 inch Chapman 200 Pound Globe Valve

Velocity in ft./sec.	Head Loss in Feet of Water	Reynolds Number	Head Loss in Equivalent Feet of Pipe
9.60	7.70	148,200	35.1
9.00	6.76	140,500	34.9
8.35	5.15	125,000	30.6
7.78	4.97	121,000	33.9
6.50	3.26	108,000	30.5
5.85	2.62	102,000	30.2
5.13	2.62	83,600	38.3
4.23	1.98	73,500	42.4

TABLE NO. 2

1 1/4 inch Chapman 200 Pound Globe Valve

Velocity in ft./sec.	Head Loss in Feet of Water	Reynolds Number	Head Loss in Equivalent Feet of Pipe
11.61	13.60	148,000	36.2
11.00	12.69	145,000	37.0
10.20	10.50	138,000	35.2
9.23	8.93	126,000	36.2
7.95	7.35	110,000	39.4
6.80	5.70	100,000	41.1
5.71	4.00	85,500	40.5
4.02	1.58	60,600	30.5

TABLE NO. 3

1 inch Globe Valve, Maker Unknown

Velocity in ft./sec.	Head Loss in Feet of Water	Reynolds Number	Head Loss in Equivalent Feet of pipe
11.45	25.50	115,500	49.90
10.45	20.50	108,000	47.75
9.29	15.45	97,000	45.30
7.60	9.92	80,800	43.00
5.71	5.15	61,500	37.20

TABLE NO. 4

3/4 inch Crane Globe Valve

Velocity in ft./sec.	Head Loss in Feet of Water	Reynolds Number	Head Loss in Equivalent Feet of pipe
19.05	23.20	160,000	14.45
17.30	16.60	145,800	12.18
15.61	11.10	133,000	9.92
13.35	6.34	115,000	7.55
9.75	0.787	84,800	1.67

TABLE NO. 5

1/2 inch Pratt and Cady Globe Valve

Velocity in ft./sec.	Head Loss in Feet of Water	Reynolds Number	Head Loss in Equivalent Feet of pipe
23.75	20.40	150,000	5.63
23.05	17.60	153,300	5.37
21.90	9.82	147,000	3.32
18.40	3.08	117,000	1.44
17.75	4.76	119,800	2.14

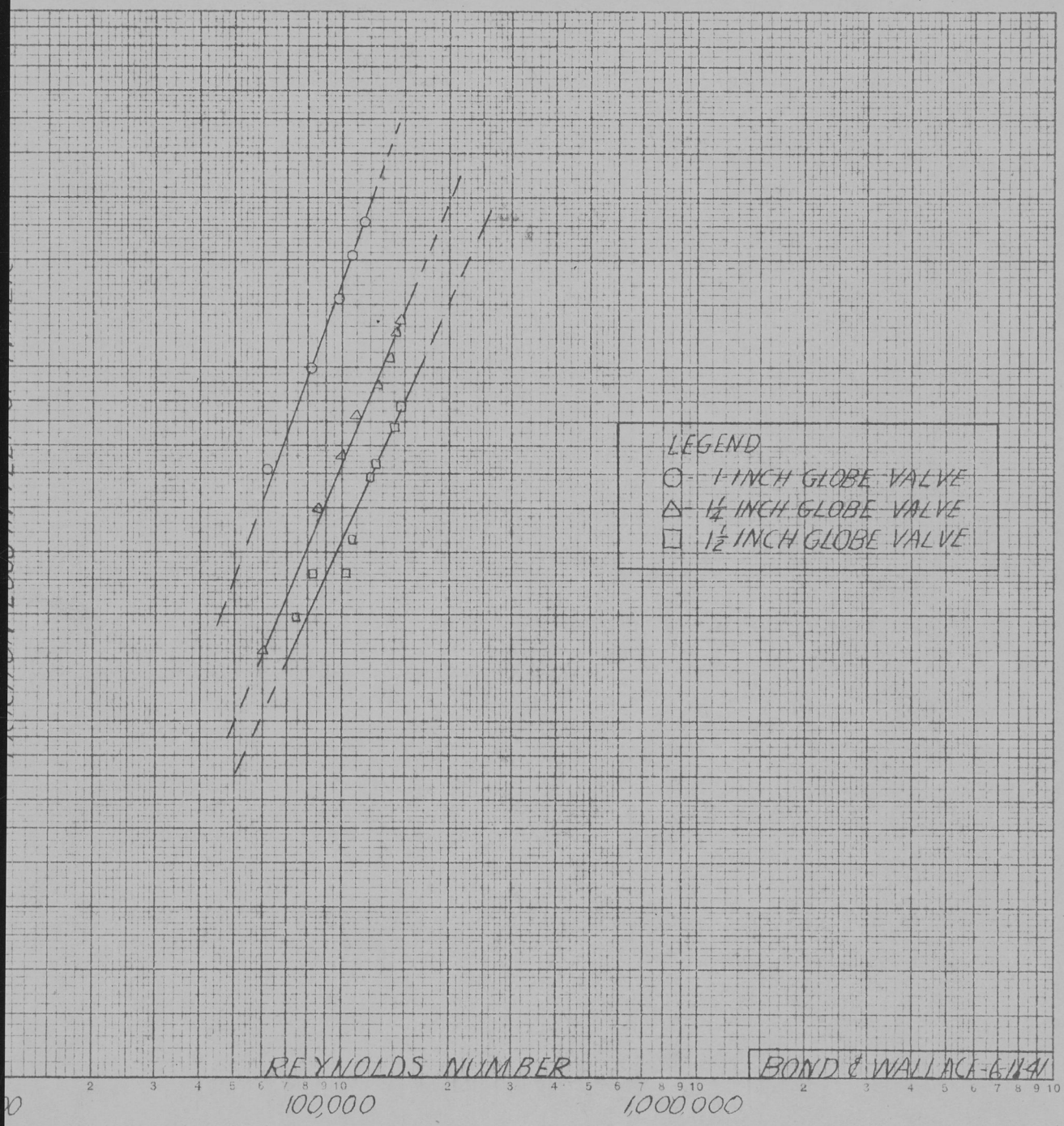

FIGURE 3

EFFECT OF REYNOLDS NUMBER ON FRICTION LOSS IN GLOBE VALVES

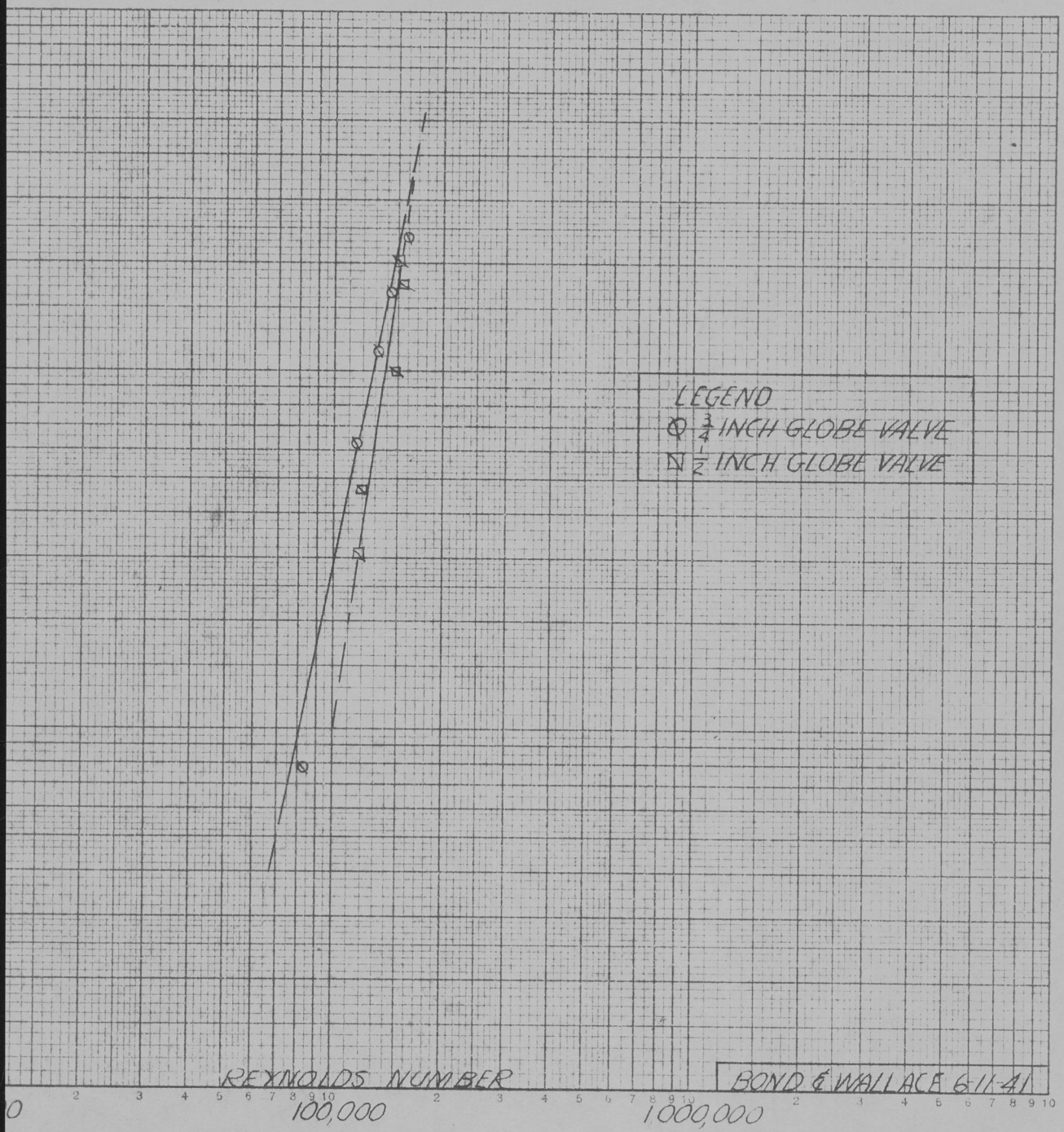

FIGURE 4

EFFECT OF REYNOLDS NUMBER ON FRICTION LOSS IN GLOBE VALVES

DISCUSSION

Other investigators in their experiments on globe valves, found the total head loss due to the valve and lengths of pipe on each side of the valve. To get the head loss due to the valve alone they subtracted the loss of head due to the lengths of pipe as found in tables. After a survey of the available literature, Monday and Fox[6] concluded that the method of finding the friction loss across a valve by the hydraulic gradient was the best. In view of the fact that the equipment used by Monday and Fox was also to be used in the present work, the authors used the same method.

In the literature survey, the formula most often given was $H = kV^2/2g$. Daugherty[3] gave "k" a value of 10 for globe valves of all sizes. This value was taken from the Crane Company's "Flow of Fluid in Pipes and Heat Transmission." Values calculated by the above equation do not agree with the results obtained in the present work. This equation is a modification of the orifice formula as given in Badger and McCabe[1]. The present authors think that an orifice formula would not hold in the case of globe valves since the direction of flow is changed several times in going through the valve. Although similar in some respects, the shape of the valve

opening is much more complicated than that of an ordinary orifice meter. These two factors are not considered unless they are taken into account in the value of "k".

Badger and McCabe give the formula: $H_f = \phi Re(u^2L/D)$ for calculations of loss of head due to fluid flow through straight pipes. "H_f" is the head loss in feet, "ϕ" is a constant combining the effect of gravity, another constant, and a roughness factor, "Re" is Reynolds number ($Du\rho/\mu$), "u" is velocity in feet per second, "L" is length of pipe in feet, and "D" is inside diameter of pipe in feet. They also state that if an experimental value of "H_f" is determined, the loss of head in equivalent feet of pipe may be calculated for fittings by solving for the value of "L".

Konrad Meir[4] gave the formula: $H_r = 1.38r(V^{1.86})/2g$ for the calculation of head loss due to fittings, where "r" is a factor of resistance. The determination of "r" limits the use of the formula in the calculation of head loss. For fluids flowing through straight pipes without fittings, the head loss may be calculated according to Meir by the formula: $H_f = .0257(V^{1.86})L/2g(d^{1.25})$, where "$H_f$" is loss of head in feet, "V" is velocity in feet per second, "L" is the length of pipe in feet, "D" is inside diameter of pipe in inches, "g" is the acceleration of gravity in feet per second per second. By combination of his two formulas, Meir obtained the formula

$L_e = 53.75r(d^{1.25})$, where "L_e" is the head loss in equivalent length of pipe for all cases. It may be seen that Meir does not take into account the effect of density and viscosity as do Badger and McCabe. It was for this reason that the formula of Badger and McCabe was used in the calculation of the head loss in equivalent length of pipe for the valves tested.

Foster[4] in his calculations of equivalent lengths of pipe for loss of head due to flow through globe valves, found that the loss was 5.12, 7.22, and 8.72 for 1 inch, 1-1/4 inch, and 1-1/2 inch pipes respectively. These values are somewhat higher, according to Perry, than they should be. Perry gives the values as 4.68, 6.54, and 7.84 respectively. The values as calculated by Badger and McCabe are about 7 to 9 times as much.

Greve[5], as a result of careful experiments on 1-1/2 inch globe valves, arrived at the formula: $H_1 = 953.7\ Q^{1.915}$.

Monday and Fox[6], in their experiments, arrived at the following formulas: $H = 1.51 \times 10^{-8}(Re)^{1.64}$ for 1 1/2 inch globe valves; $H = 1.925 \times 10^{-8}(Re)^{1.6}$ for 1 1/4 inch globe valves; and $H = 5.13 \times 10^{-8}(Re)^{1.7}$ for 1 inch globe valves.

The formulas resulting from the present work are as follows: $H = 2.26 \times 10^{-11}(Re)^{2.23}$ for 1 1/2 inch globe valves; $H = 3.94 \times 10^{-12}(Re)^{2.42}$ for 1-1/4 inch globe valves; $H = 2.897 \times 10^{-13}(Re)^{2.78}$ for 1 inch globe valves; $H = 1.387 \times 10^{-25}(Re)^{5.0}$

for 3/4 inch globe valves; and $H = 8.8 \times 10^{-34}(Re)^{6.62}$ for the 1/2 inch globe valves.

The results of experiments of Greve, Monday and Fox, and the present authors will be given for the 1 1/2 inch globe valves for comparison, (See Tables No. 6 and 7). Figure 15, page 25, shows a plot of the three sets of data.

TABLE NO. 6

1-1/2 Inch Globe Valves

Data of Greve		Data of Monday and Fox	
Velocity in ft./sec.	Loss of Head in Feet of Water	Velocity in ft./sec.	Head Loss in Feet of Water
9.84	21.52	9.80	6.30
7.87	14.06	9.00	6.33
5.04	5.94	8.10	5.59
4.08	3.93	7.10	4.59
3.73	3.29	5.90	3.41
3.55	3.01	4.80	2.66
3.19	2.46	4.10	1.69
2.91	2.06	3.05	0.83
2.63	1.70	1.97	0.266
2.07	1.07		

TABLE NO. 7

1 1/2 Inch Globe Valve

Data of Bond and Wallace

Velocity in ft./sec.	Head Loss in Feet of Water
9.60	7.70
9.00	6.76
8.35	5.15
7.78	4.97
6.50	3.25
5.85	2.62
5.13	2.62
4.23	1.98

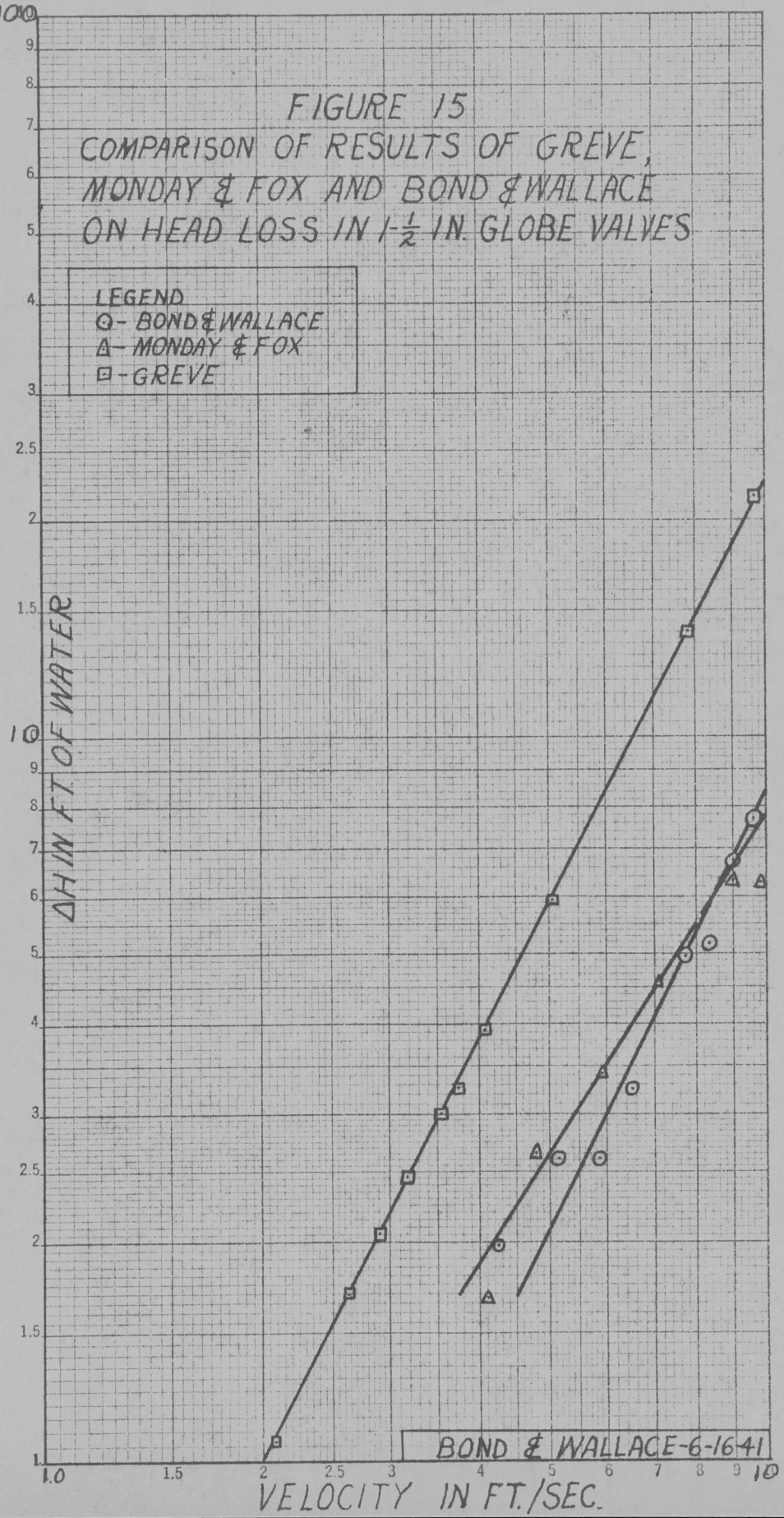
FIGURE 15
COMPARISON OF RESULTS OF GREVE, MONDAY & FOX AND BOND & WALLACE ON HEAD LOSS IN 1-½ IN. GLOBE VALVES
LEGEND
⊙ - BOND & WALLACE
△ - MONDAY & FOX
⊡ - GREVE
ΔH IN FT. OF WATER
VELOCITY IN FT./SEC.
BOND & WALLACE-6-16-41

Monday and Fox state that a plot of Reynolds number versus head loss in feet of water gave straight lines which could be considered parallel for 1-1/2 inch, 1-1/4 inch, and 1 inch valves. The present authors found this approximately true for these three valves. However, in the case of 3/4 inch and 1/2 inch valves, the slopes of the lines were much greater, and the lines were not parallel (see Figures 3 & 4). This tends to point toward the fact that both the exponent of Reynolds number and its coefficient vary with the size of valve.

If further experiments are to be made using this same equipment, it is suggested that a brine solution be used as the fluid flowing in order to find the effect of density and viscosity on the head loss through globe valves. Or, perhaps a heating coil could be used to change the properties of the fluid by varying the temperature. In any case an air-water manometer with a much greater range should be used. The mercury-water manometers are not nearly sensitive enough. The orifice meter should be replaced by a venturi meter. This would give a better range of velocities since there would not be as much permanent head loss.

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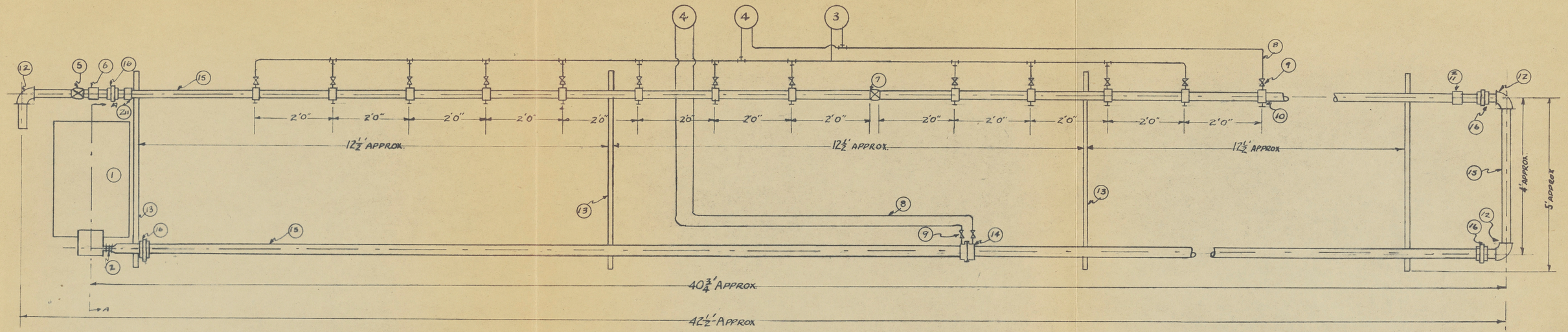
Acknowledgment

The authors are indebted to J. F. Monday and G. J. Fox for the design of the equipment, and for the construction of all equipment except the 3/4 inch and 1/2 inch pipes used in this work.

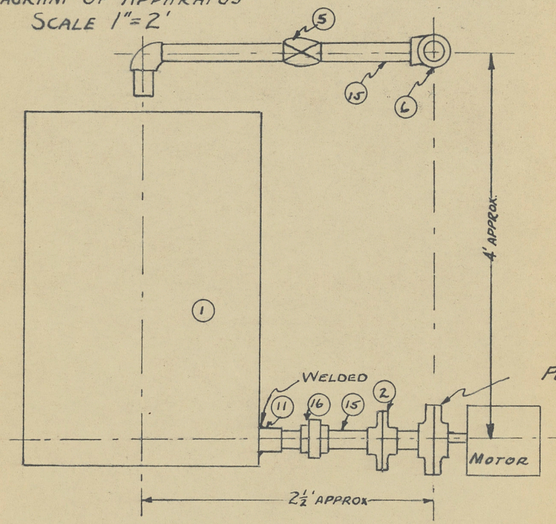


NOTE: ALL PIPE FITTINGS ARE GALVANIZED

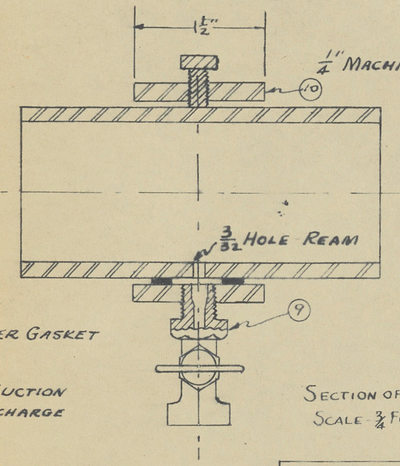
LIST OF PARTS	
No.	DESCRIPTION
1	TANK FOR CIRCULATING WATER
2	FILTER
3	WATER-AIR MANOMETER (MAX. ROG. 100cm. H_2O)
4	MERCURY-WATER MANOMETER (MAX. ROG. 100cm. HG)
5	1½" GATE VALVE
6	1½" x 1½" x 1½" TEE
7	1½" GLOBE VALVE TO BE TESTED
8	3/16" COPPER TUBING
9	DOLE COMPRESSION NEEDLE VALVE NO. VA-3
10	COLLAR - MADE FROM 2" PIPE
11	1½" - COUPLING
12	1½" - 90° ELBOW
13	FRAMES-MADE 1¼" ANGLE IRON
14	ORIFICE -MADE FROM 1½" FLANGES (DIA. OF ORIFICE PLATE 1.0")
15	1½" GALVANIZED PIPE
16	1½" UNION
17	1½"-1" BELL REDUCER
18	220v G.E. MOTOR & INGERSOL-RAND CENTRIFUGAL PUMP No:-100779

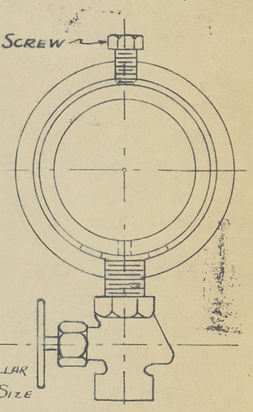
NOTE: COLLAR SIZES
1" I.P.S. FOR ½" I.P.S.
1¼" I.P.S. FOR ¾" I.P.S.
1½" I.P.S FOR 1" I.P.S.
1½" I.P.S FOR 1¼" I.P.S.
2" I.P.S. FOR 1½" I.P.S.

DIAGRAM OF APPARATUS
SCALE 1"=2'



SECTION A-A
SCALE 1"=1'





SECTION OF COLLAR
SCALE - ¾ FULL SIZE

NOTE: THE 1¼" PIPE BETWEEN SECTION Z-Z MAY BE REMOVED AND REPLACED WITH ½", ¾", 1" & 1¼" PIPE (USING ½", ¾", 1" & 1¼" BUSHINGS) TO TEST ½", ¾", 1" & 1¼" VALVES RESPT.

UNIVERSITY OF TENNESSEE
CHEMICAL ENGINEERING DEPARTMENT

FLUID FLOW APPARATUS FOR DETERMINATION OF FRICTION LOSS IN VALVES

DR. BY: C.F.W. DATE - 6/2/41 | SCALE - AS SHOWN
CK'D. BY: W.W.B. DATE - 6/2/41 | FIG. No 1

APPENDIX A



APPENDIX B

TABLE NO. 8

Calibration of 1 Inch Orifice Meter

Temperature of Water - 44.5° F 1-1/2 Inch Galvanized Pipe

Pounds of Water	Time in Seconds	H in Cm. Mercury	Velocity Through 1-1/2 Inch Pipe in ft./sec.
300	35.25	36.05	9.68
300	38.75	34.30	8.81
300	40.75	31.50	8.39
300	42.25	28.95	8.09
300	44.00	26.35	7.76
300	47.50	23.25	7.19
300	50.75	21.30	6.73
300	52.25	19.60	6.53
300	57.50	15.65	5.95
300	64.00	12.50	5.34
300	68.00	10.90	5.02
300	76.50	8.60	4.47
300	88.50	6.40	3.86
300	102.50	4.80	3.33
300	139.75	2.70	2.46

Sample Calculations For Orifice Calibration:

Internal area of 1-1/2 inch pipe = 2.036 sq. in.

Density of water at 44.5°F. = 62.42 lbs./cu. ft.

Velocity in ft./sec.:

$$\frac{300 \text{ lbs.}}{35.25 \text{ sec.}} \times \frac{1}{62.4 \text{ lbs./cu.ft.}} \times \frac{144 \text{ sq. in./sq. ft.}}{2.036 \text{ sq. ft.}} = 9.68 \text{ ft./sec.}$$

TABLE NO. 9

ORIFICE METER MERCURY MANOMETER		1-1/2 INCH CHAPMAN 200 POUND GLOBE VALVE DROP FROM FIRST MANOMETER CONNECTION TO CONNECTION INDICATED													TEMP OF WATER °C
			2	3	4	5	6	7	8	9	10	11	12	13	
ΔH-CM. MERCURY	7.8	ΔH-CM AS INDICATED	3.9 H_2O	6.5 H_2O	9.7 H_2O	12.5 H_2O	6.4 HG	6.6 HG.	6.9 HG	7.2 HG	7.5 HG	7.6 HG	7.9 HG	8 HG	26
VELOCITY FT./SEC.	4.23	ΔH-CM. OF WATER	3.9	6.5	9.7	12.5	80.6	81.3	87.0	90.7	94.5	95.8	99.5	100.4	
ΔH-CM MERCURY	11.5	ΔH-CM. AS INDICATED	5.1 H_2O	9.4 H_2O	13.6 H_2O	17.7 H_2O	8.5 HG	8.9 HG	9.4 HG	9.7 HG	10.2 HG	10.5 HG	11.0 HG	11.6 HG	25.0
VELOCITY FT./SEC.	5.13	ΔH-CM OF WATER	5.1	9.4	13.6	17.7	107	112	1185	122	128	132	138.5	146	
ΔH CM. MERCURY	15.3	ΔH CM AS INDICATED	6.5 H_2O	11.5 H_2O	16.3 H_2O	21.1 H_2O	8.8 HG	9.2 HG	9.6 HG	10.0 HG	10.4 HG	10.8 HG	11.1 HG	11.5 HG	35.0
VELOCITY FT./SEC	5.85	ΔH-CM. OF WATER	6.5	11.5	16.3	21.1	111	116	121	126	131	136	140	145	
ΔH CM. MERCURY	18.6	ΔH-CM. AS INDICATED	1.0 HG	1.4 HG	1.7 HG	2.1 HG	10.7 HG	11.4 HG	11.8 HG	12.2 HG	12.7 HG	13.1 HG	13.3 HG	14.0 HG	33.0
VELOCITY FT./SEC	6.50	ΔH-CM. OF WATER	12.6	17.6	21.4	28.6	135	143.5	148.5	154	160	165	162.5	176	
ΔH-CM. MERCURY	186	ΔH-CM. AS INDICATED	5.0 H_2O	12.6 H_2O	17.6 H_2O	25.2 H_2O	14.9 HG	16.1 HG	16.9 HG	17.6 HG	18.5 HG	19.1 HG	19.9 HG	20.5 HG	30.0
VELOCITY-FT/SEC	7.78	ΔH-CM. OF WATER	5.04	12.6	17.6	25.2	188	203	213	222	233	241	251	258	
ΔH-CM. MERCURY	31.3	ΔH-CM. AS INDICATED	6.3 H_2O	15.1 H_2O	24.0 H_2O	31.5 H_2O	16.4 HG	17.4 HG	18.2 HG	19.3 HG	20.1 HG	20.9 HG	21.8 HG	22.6 HG	28.5
VELOCITY FT./SEC.	8.35	ΔH-CM. OF WATER	6.3	15.1	24.0	31.5	207	219	229	243	253	263	275	285	
ΔH-CM. MERCURY	37	ΔH-CM AS INDICATED	12.5 H_2O	25.4 H_2O	45.0 H_2O	55.5 H_2O	22.8 HG	24.0 HG	25.7 HG	27.0 HG	28.2 HG	29.4 HG	30.6 HG	31.5 HG	30.25
VELOCITY FT/SEC.	9.00	ΔH-CM. OF WATER	12.5	25.4	45.0	55.5	288	302	324	340	355	370	386	397	
ΔH CM. MERCURY	41.6	ΔH-CM AS INDICATED	16.4 H_2O	31.5 H_2O	49.2 H_2O	4.8 HG	25.6 HG	27.1 HG	28.6 HG	29.5 HG	30.9 HG	31.8 HG	33.1 HG	34.1 HG	29.75
VELOCITY FT./SEC.	9.60	ΔH-CM. OF WATER	16.4	31.5	49.2	61.8	323	342	360	372	390	400	417	430	

TABLE NO. 10

ORIFICE METER MERCURY MANOMETER VELOCITY GIVEN FOR 1 INCH PIPE		UNKNOWN 1 INCH GLOBE VALVE DROP FROM FIRST MANOMETER CONNECTION TO CONNECTION INDICATED													TEMP. OF WATER °C
			2	3	4	5	6	7	8	9	10	11	12	13	
ΔH CM. MERCURY	4.5	ΔH-CM. AS INDICATED	14.6 H_2O	28.1 H_2O	43.2 H_2O	55.2 H_2O	30.3 HG	31.2 HG	32.0 HG	32.8 HG	34.3 HG	35.1 HG	35.9 HG	36.8 HG	29
VELOCITY FT./SEC.	7.6	ΔH-CM. OF WATER	14.6	28.1	43.2	55.2	382	393	403	413	432	442	453	464	
ΔH CM. MERCURY	2.5	ΔH CM. AS INDICATED	9.3 H_2O	12.8 H_2O	24.3 H_2O	31.1 H_2O	16.4 HG	16.8 HG	17.7 HG	18.1 HG	18.5 HG	19.4 HG	20.0 HG	20.3 HG	30.5
VELOCITY FT./SEC.	5.71	ΔH-CM. OF WATER	9.3	12.8	24.3	31.1	207	212	223	228	233	244	252	256	
ΔH CM. MERCURY	6.7	ΔH-CM. AS INDICATED	1.8 HG	41.5 H_2O	63.5 H_2O	6.8 HG	47.5 HG	48.5 HG	50.0 HG	50.8 HG	52.7 HG	53.9 HG	55.2 HG	65.4 HG	31
VELOCITY FT./SEC.	9.29	ΔH-CM. OF WATER	22.7	41.5	63.5	85.5	599	611	630	640	665	690	695	824	
ΔH CM MERCURY	8.6	ΔH-CM. AS INDICATED	29.5 H_2O	56.7 H_2O	7.4 HG	9.2 HG	62.8 HG	64.6 HG	66.5 HG	68.4 HG	71 HG	72.3 HG	74.1 HG	75.9 HG	32
VELOCITY FT./SEC.	10.45	ΔH-CM-OF WATER	29.5	56.7	93.3	116	791	815	838	863	895	988	935	956	
ΔH CM. MERCURY	10.4	ΔH-CM. AS INDICATED	36.6 H_2O	70.9 H_2O	9.0 HG	11.4 HG	78.7 HG	80.6 HG	83.1 HG	84.8 HG	88.9 HG	90.7 HG	93.1 HG		33
VELOCITY FT./SEC.	11.45	ΔH-CM. OF WATER	36.6	70.9 H_2O	113.5	14.4	988	1015	1050	1070	1120	1140	1175		

TABLE NO. 11

ORIFCE METER MERCURY MANOMETER VELOCITY GIVEN FOR 1¼" PIPE		1-1/4 INCH CHAPMAN 200 POUND GLOBE VALVE DROP FROM FIRST MANOMETER CONNECTION TO CONNECTION INDICATED													TEMP. OF WATER °C
			2	3	4	5	6	7	8	9	10	11	12	13	
ΔH-CM MERCURY	3.7	ΔH-CM. AS INDICATED	2.6 H_2O	4.9 H_2O	7.3 H_2O	9.9 H_2O	5.0 HG	5.2 HG	5.3 HG	5.6 HG	5.8 HG	6.1 HG	6.3 HG	6.5 HG	33.2
VELOCITY - FT./SEC.	4.02	ΔH-CM. OF WATER	2.6	4.9	7.3	9.9	63.0	65.5	66.8	70.6	73.1	76.9	79.4	81.9	
ΔH-CM MERCURY	7.6	ΔHCM. AS INDICATED	5.3 H_2O	9.7 H_2O	14.4 H_2O	19.4 H_2O	11.9 HG	12.4 HG	12.8 HG	13.2 HG	13.7 HG	14.2 HG	14.5 HG	14.9 HG	32.8
VELOCITY - FT./SEC.	5.71	ΔH-CM. OF WATER	5.3	9.7	14.4	19.4	150.0	156.0	161.0	166.0	172.5	179.0	183.0	188.0	
ΔH-CM. MERCURY	12.04	ΔH- CM. AS INDICATED	7.6 H_2O	14.2 H_2O	21.2 H_2O	2.2 HG	17.2 HG	17.8 HG	18.5 HG	19.2 HG	19.6 HG	20.1 HG	20.9 HG	21.3 HG	32.3
VELOCITY - FT./SEC.	6.8	ΔH-CM. OF WATER	7.6	14.2	21.2	27.8	217.0	224.0	233.0	242.0	247.0	254.0	264.0	269.0	
ΔH-CM. MERCURY	15.8	ΔH-CM. AS INDICATED	10.2 H_2O	19.8 H_2O	2.6 HG	3.2 HG	22.5 HG	23.4 HG	24.2 HG	25.0 HG	25.5 HG	26.3 HG	27.1 HG	27.8 HG	31.8
VELOCITY FT./SEC.	7.95	ΔH-CM. OE WATER	10.2	19.8	32.8	40.4	284.0	295.0	305.0	315.0	321.0	331.0	342.0	350.0	
ΔH-CM. MERCURY	20.5	ΔH-CM AS INDICATED	13.3 H_2O	24.0 H_2O	36.2 H_2O	48.4 H_2O	27.4 HG	28.6 HG	29.6 HG	30.7 HG	31.6 HG	32.4 HG	33.5 HG	34.2 HG	31.2
VELOCITY - FT./SEC.	9.23	ΔH-CM. OF WATER	13.3	24.0	36.2	48.4	345.0	360.0	373.0	387.0	398.0	408.0	423.0	431.0	
ΔH-CM. MERCURY	25.17	ΔH-CM. AS INDICATED	15.0 H_2O	28.5 H_2O	42.8 H_2O	57.1 H_2O	32.3 HG	33.3 HG	34.6 HG	36.3 HG	37.1 HG	38.1 HG	39.8 HG	40.8 HG	30.5
VELOCITY- FT./SEC	10.2	ΔH-CM OF WATER	15.0	28.5	42.8	57.1	407.0	420.0	436.0	457.0	467.0	480.0	502.0	515.0	
ΔH-CM. MERCURY	29.5	ΔH-CM AS INDICATED	18.5 H_2O	33.5 H_2O	50.5 H_2O	67.8 H_2O	38.5 HG	39.6 HG	41.3 HG	42.4 HG	43.7 HG	44.8 HG	45.9 HG	46.9 HG	29.5
VELOCITY- FT./SEC	11.0	ΔH-CM OF WATER	18.5	33.5	50.5	67.8	485.0	499.0	520.0	535.0	550.0	565.0	578.0	591.0	
ΔH-CM. MERCURY	33.3	ΔH-CM AS INDICATED	21.2 H_2O	37.2 H_2O	56.7 H_2O	6.7 HG	42.3 HG	43.8 HG	45.6 HG	47.4 HG	49.1 HG	50.5 HG	52.2 HG	53.7 HG	28.0
VELOCITY FT./SEC	11.61	ΔH-CM OF WATER	21.2	37.2	56.7	84.4	534.0	554.0	575.0	596.0	619.0	636.0	657.0	676.0	

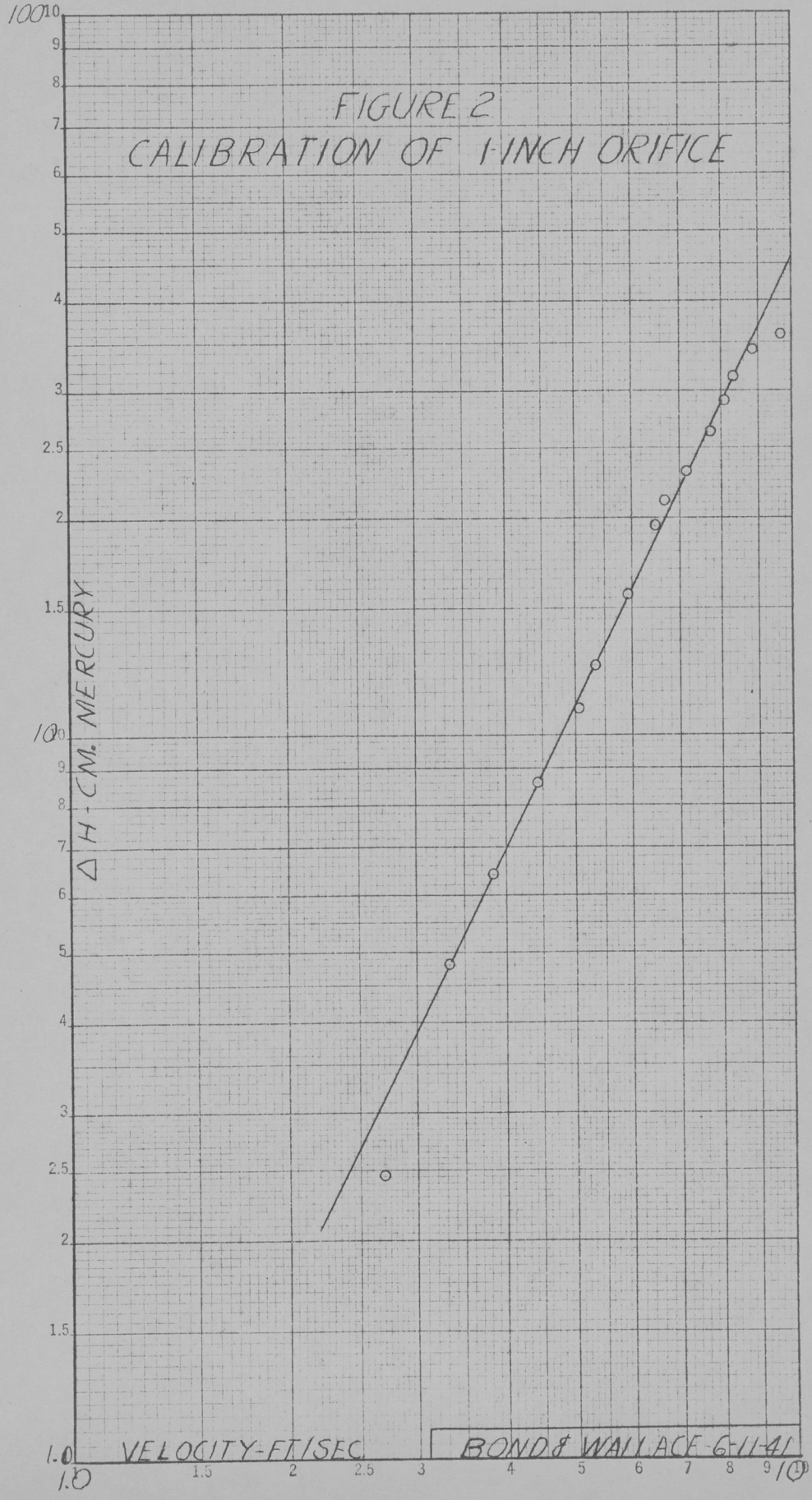
TABLE NO. 12

ORIFICE METER MERCURY MANOMETER VELOCITY GIVEN FOR 3/4" PIPE		3/4 INCH CRANE 150 POUND GLOBE VALVE DROP FROM FIRST MANOMETER CONNECTION TO CONNECTION INDICATED													TEMP. OF WATER °C
			2	3	4	5	6	7	8	9	10	11	12	13	
ΔH-CM. MERCURY	2.8	ΔH-CM. AS INDICATED	2.9 H_2O	6.0 H_2O	8.7 H_2O	11.5 H_2O	3.3 HG	3.8 HG	4.0 HG	4.3 HG	4.6 HG	5.1 HG	5.5 HG	5.7 HG	31.25
VELOCITY - FT./SEC.	9.75	ΔH-CM. OF WATER	2.9	6.0	8.7	11.5	42.8	47.9	50.4	54.2	58.0	64.3	69.3	71.8	
ΔH-CM. MERCURY	5.3	ΔH-CM. AS INDICATED	11.6 H_2O	31.9 H_2O	50.8 H_2O	70.0 H_2O	23.5 HG	24.8 HG	26.1 HG	27.5 HG	28.8 HG	30.2 HG	31.8 HG	32.8 HG	31.75
VELOCITY - FT./SEC.	13.35	ΔH-CM. OF WATER	11.6	31.9	50.8	70.0	296.0	312.0	329.0	346.0	363.0	380.0	400.0	414.0	
ΔH-CM. MERCURY	7.3	ΔH-CM. AS INDICATED	33.0 H_2O	65.7 H_2O	8.7 HG	11.8 HG	44.6 HG	47.8 HG	50.7 HG	53.8 HG	57.1 HG	60.2 HG	63.9 HG	66.9 HG	32.25
VELOCITY - FT./SEC.	15.61	ΔH-CM. OF WATER	33.0	65.7	109.8	149.0	561.0	604.0	638.0	679.0	720.0	757.0	805.0	842.0	
ΔH-CM. MERCURY	9.1	ΔH-CM. AS INDICATED	3.9 HG	8.1 HG	12.4 HG	16.7 HG	65.6 HG	70.1 HG	74.4 HG	78.9 HG	83.5 HG	87.9 HG	93.4 HG		32.75
VELOCITY - FT./SEC.	17.3	ΔH-CM OF WATER	48.2	102.0	156.0	210.0	826.0	885.0	936.0	994.0	1050.0	1108.0	1175.0		
ΔH-CM. MERCURY	11.0	ΔH-CM. AS INDICATED	5.1 HG	10.0 HG	15.4 HG	20.2 HG	87.5 HG	94.8 HG	97.0 HG						33.50
VELOCITY - FT./SEC.	19.05	ΔH-CM. OF WATER	64.3	126.0	195.2	254.0	1102.0	1192.0	1230.0						

TABLE NO. 13

ORIFICE METER MERCURY MANOMETER VELOCITY GIVEN FOR 1/2" PIPE		1/2 INCH PRATT AND CADY 125 LB. GLOBE VALVE DROP FROM FIRST MANOMETER CONNECTION TO CONNECTION INDICATED													TEMP. OF WATER °C
			2	3	4	5	6	7	8	9	10	11	12	13	
ΔH-CM. MERCURY	3.05	ΔH-CM. AS INDICATED	2.7 HG	3.4 HG	4.1 HG	4.9 HG	13.7 HG	14.4 HG	15.1 HG	15.7 HG	16.5 HG	17.2 HG	17.9 HG	18.7 HG	32.0
VELOCITY - FT./SEC.	17.75	ΔH-CM. OF WATER	34.0	42.8	51.6	61.7	172.2	181.5	190.0	198.0	204.0	216.0	225.0	236.0	
ΔH-CM. MERCURY	3.2	ΔH-CM. AS INDICATED	2.7 HG	4.3 HG	5.3 HG	6.6 HG	20.3 HG	21.3 HG	22.2 HG	23.1 HG	24.1 HG	25.1 HG	26.0 HG	26.9 HG	34.0
VELOCITY - FT./SEC.	18.4	ΔH-CM. OF WATER	34.0	54.2	66.8	83.0	256.0	268.0	280.0	291.0	304.0	316.0	328.0	339.0	
ΔH-CM. MERCURY	4.6	ΔH-CM. AS INDICATED	4.3 HG	7.0 HG	9.1 HG	12.1 HG	40.9 HG	43.2 HG	45.1 HG	47.3 HG	49.4 HG	51.8 HG	53.3 HG	56.1 HG	34.8
VELOCITY - FT./SEC.	21.9	ΔH-CM. OF WATER	54.2	88.2	114.5	152.5	510.0	544.0	569.0	596.0	622.0	654.0	671.0	706.0	
ΔH-CM. MERCURY	5.1	ΔH-CM. AS INDICATED	5.7 HG	10.3 HG	14.2 HG	19.4 HG	70.4 HG	74.0 HG	76.8 HG	80.5 HG	84.3 HG	88.3 HG	89.7 HG		35.0
VELOCITY - FT./SEC.	23.05	ΔH-CM. OF WATER	71.8	129.8	179.0	244.0	885.0	932.0	968.0	1015.0	1060.0	1110.0	1130.0		
ΔH-CM. MERCURY	5.4	ΔH-CM AS INDICATED	11.4 HG	15.9 HG	19.4 HG	24.2 HG	82.1 HG	87.3 HG	91.7						35.3
VELOCITY - FT./SEC.	23.75	ΔH-CM. OF WATER	143.5	200.0	244.0	303.0	103.5	1100.0	1155.0						

FIGURE 2
CALIBRATION OF 1-INCH ORIFICE



APPENDIX C



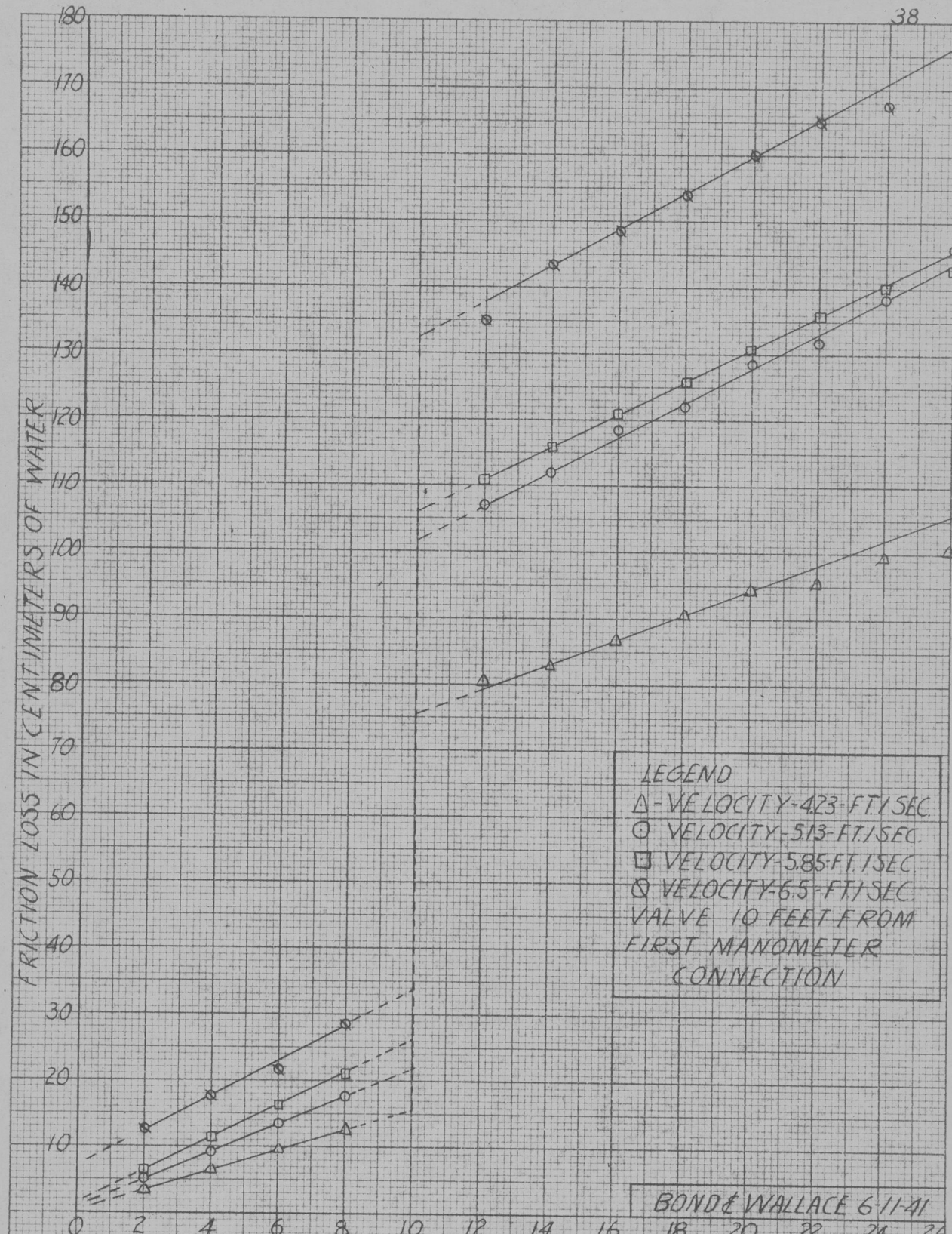


FIGURE 5

HYDRAULIC GRADIENT FOR 1-1/2 INCH GLOBE VALVE

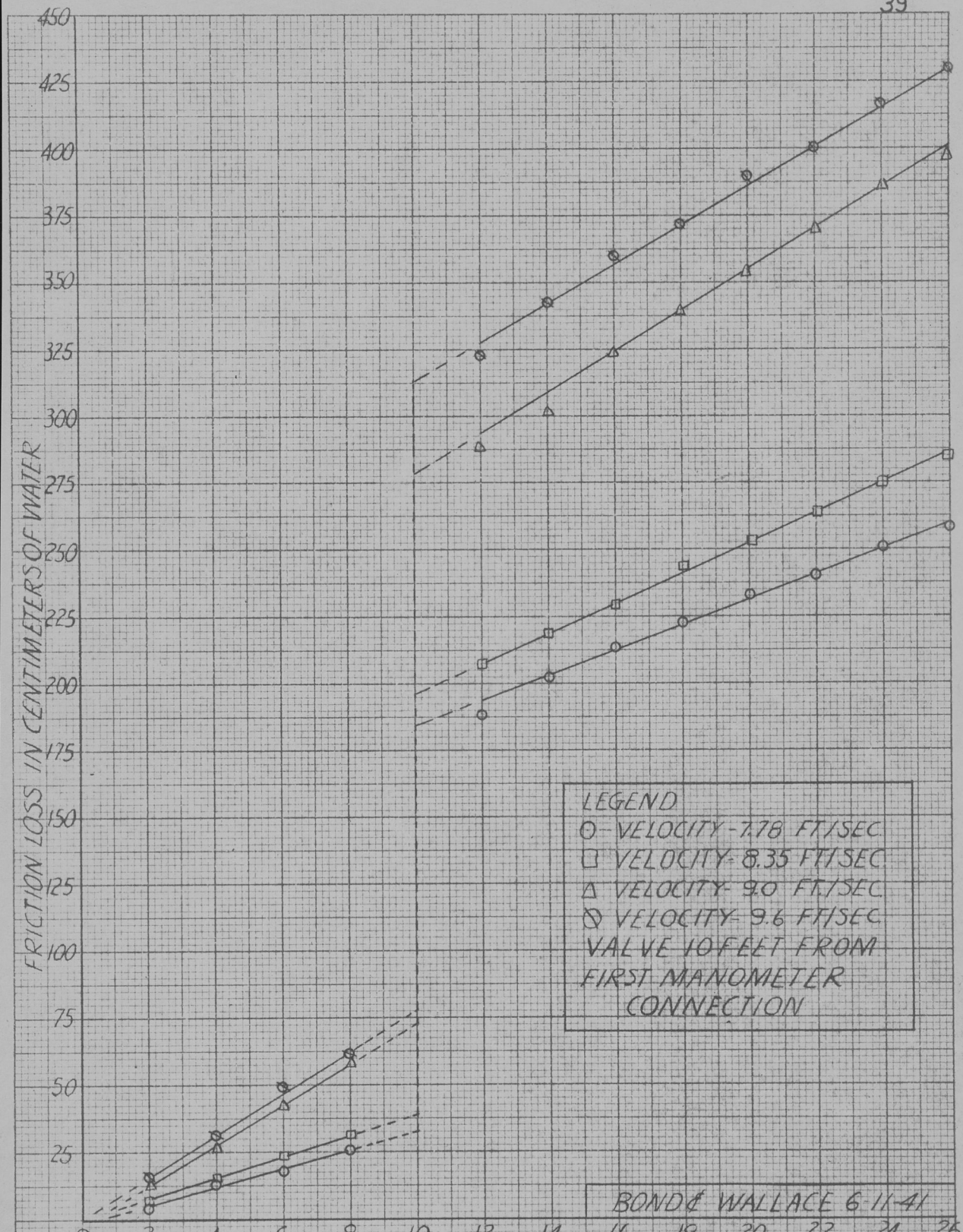


FIGURE 6
HYDRAULIC GRADIENT FOR 1-1/2 INCH GLOBE VALVE

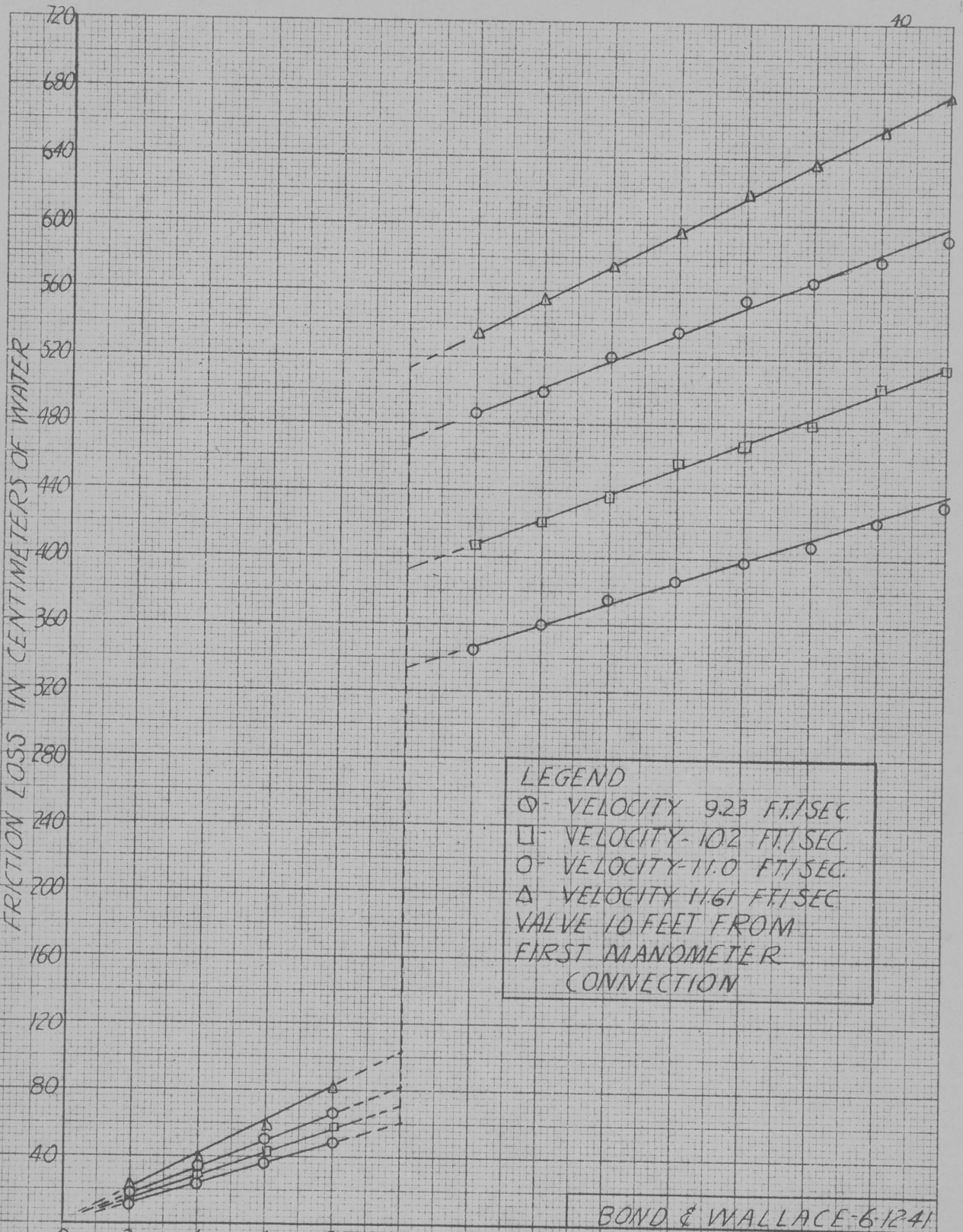


FIGURE 7

HYDRAULIC GRADIENT FOR 1-1/4 INCH GLOBE VALVE

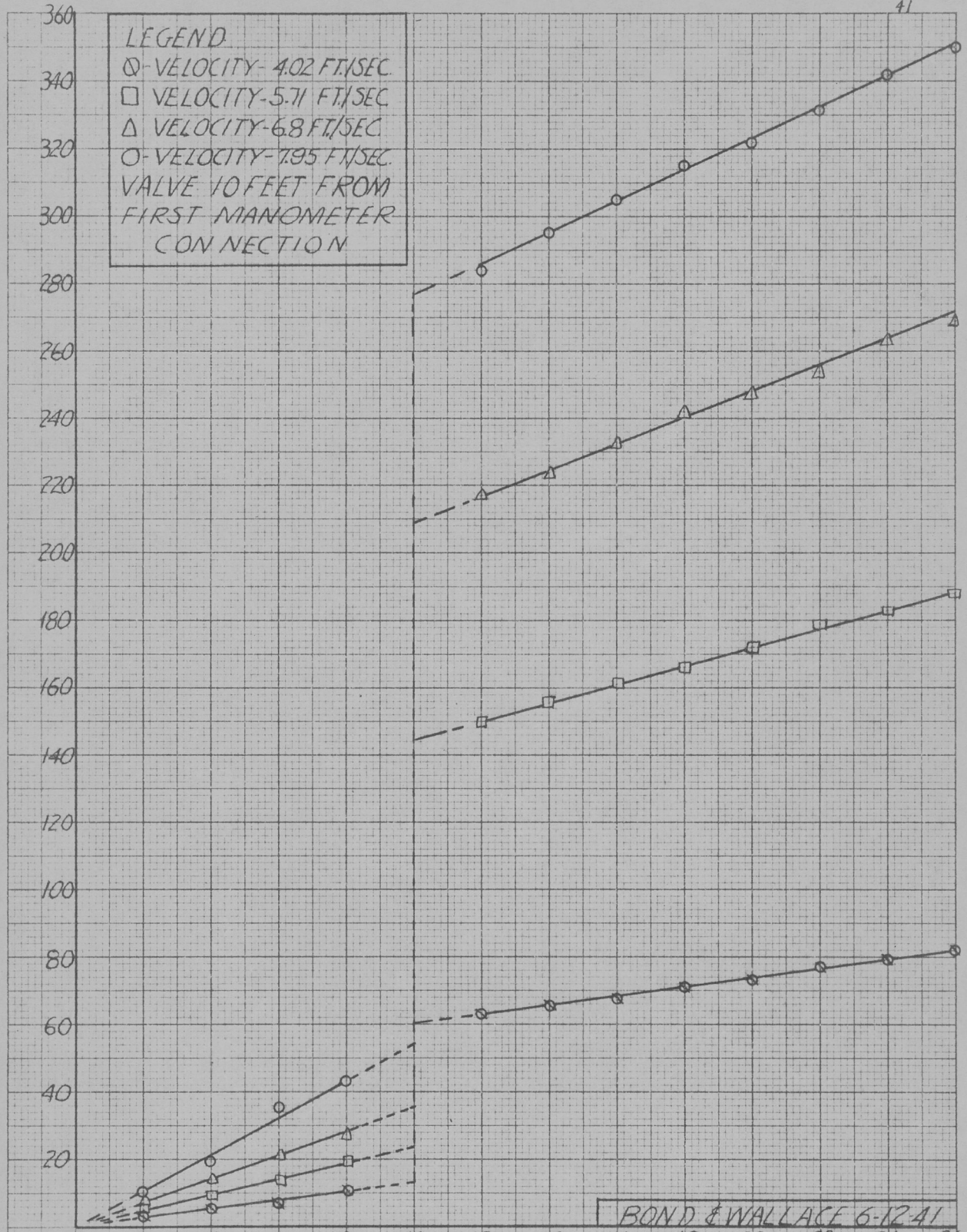


FIGURE 8

HYDRAULIC GRADIENT FOR 1-1/4 INCH GLOBE VALVE

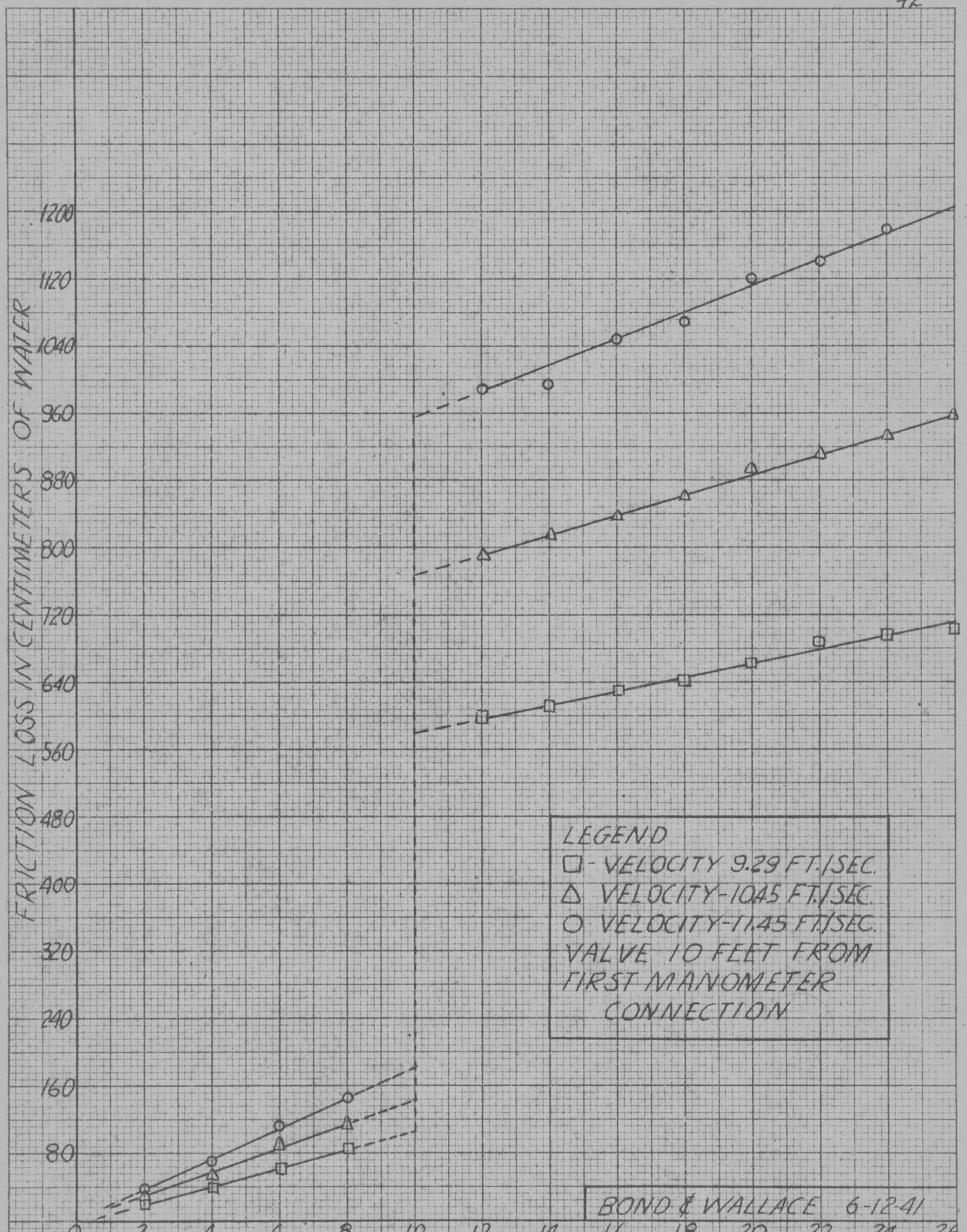


FIGURE 9
HYDRAULIC GRADIENT FOR 1-INCH GLOBE VALVE

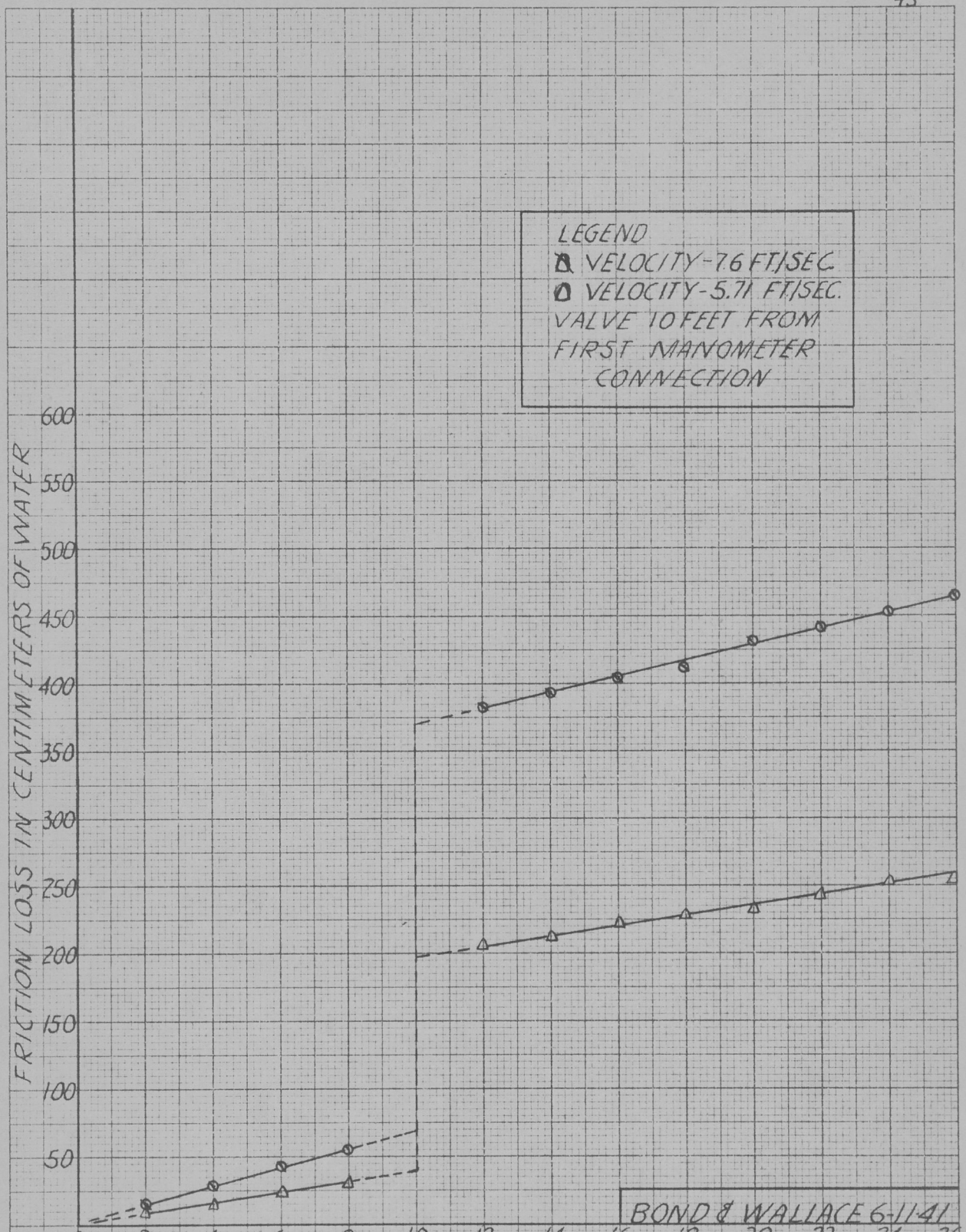


FIGURE 10

HYDRAULIC GRADIENT FOR 1-INCH GLOBE VALVE

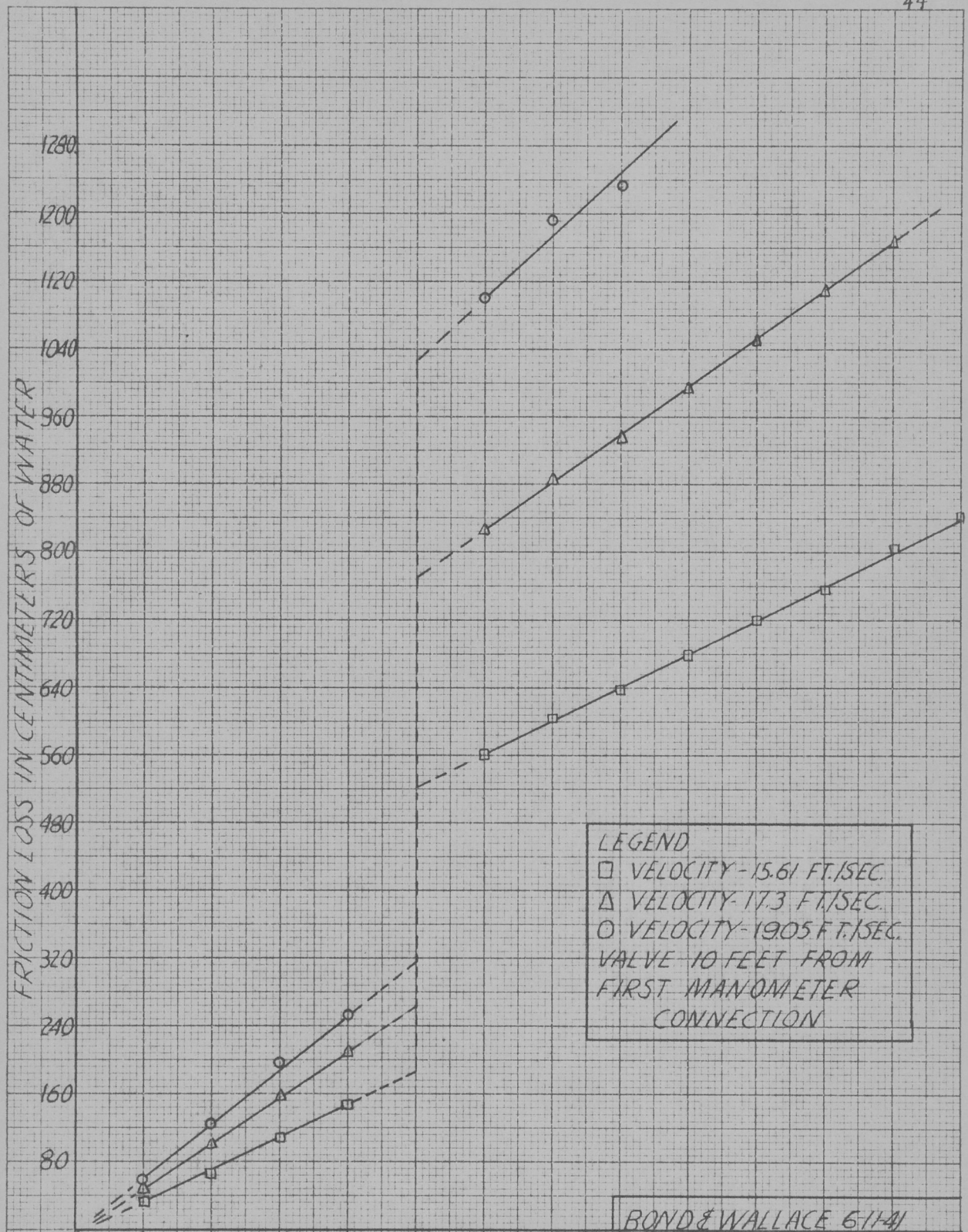


FIGURE 11
HYDRAULIC GRADIENT FOR 3/4 INCH GLOBE VALVE

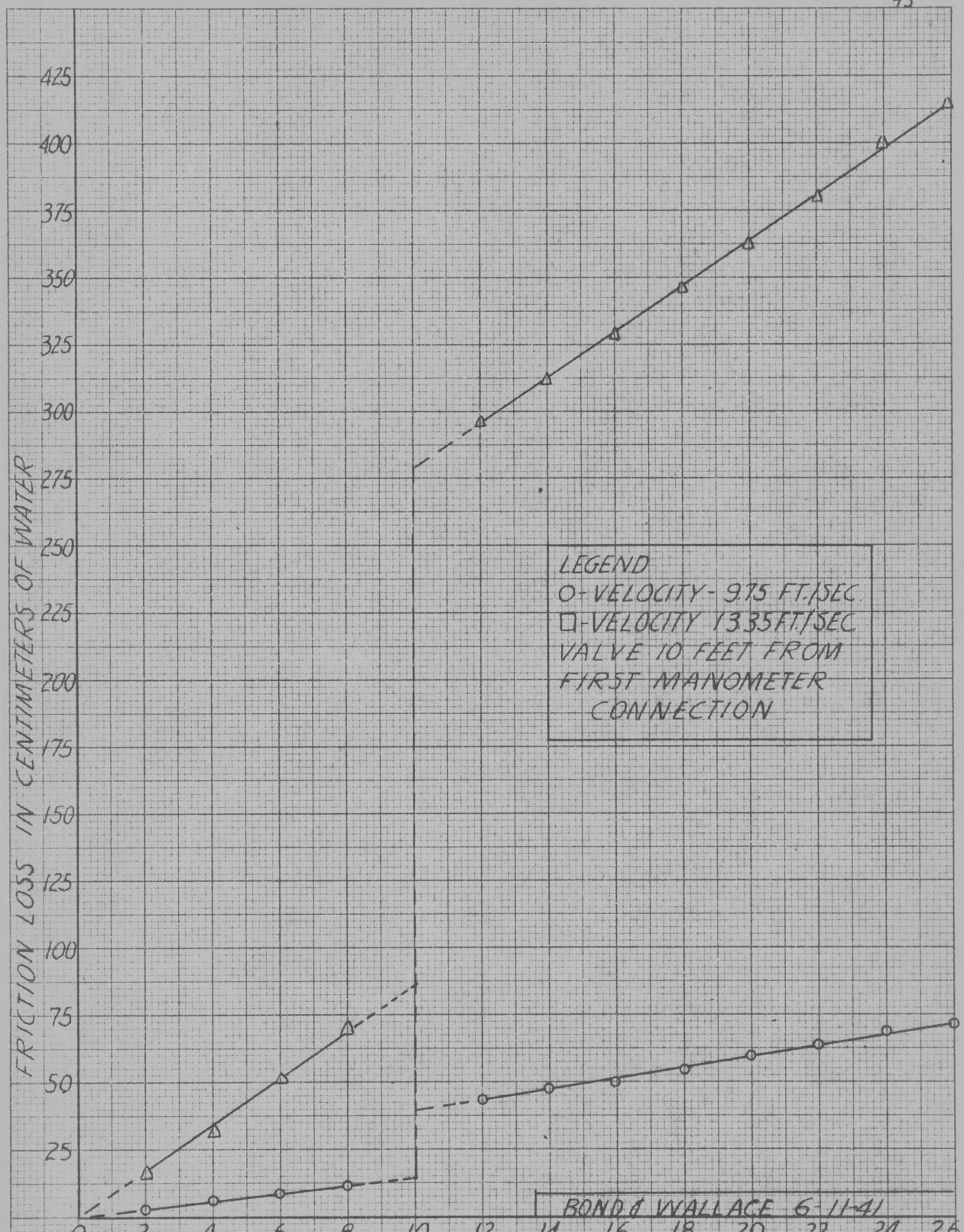


FIGURE-12
HYDRAULIC GRADIENT FOR 3/4 INCH GLOBE VALVE

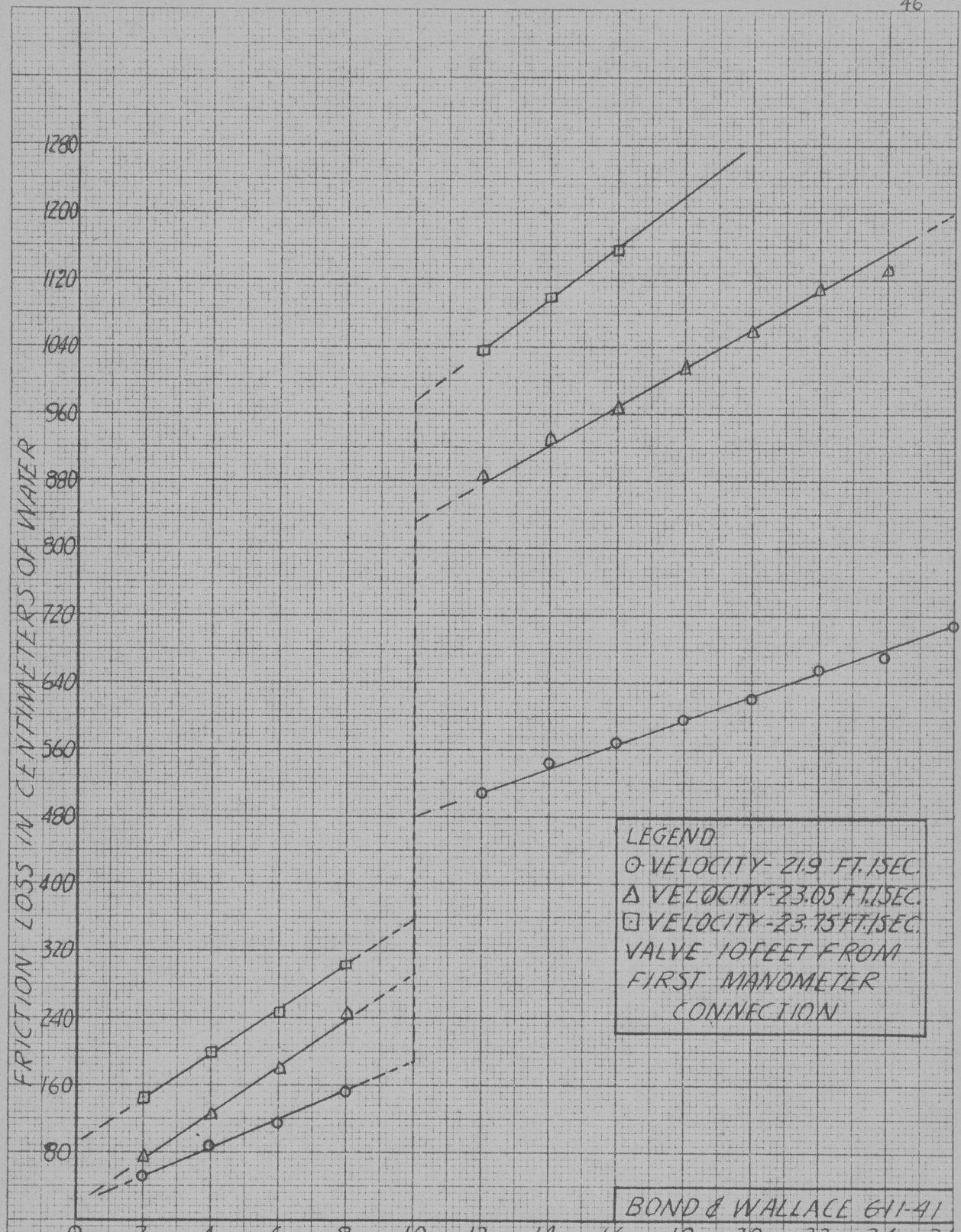


FIGURE 13

HYDRAULIC GRADIENT FOR 1/2 INCH GLOBE VALVE

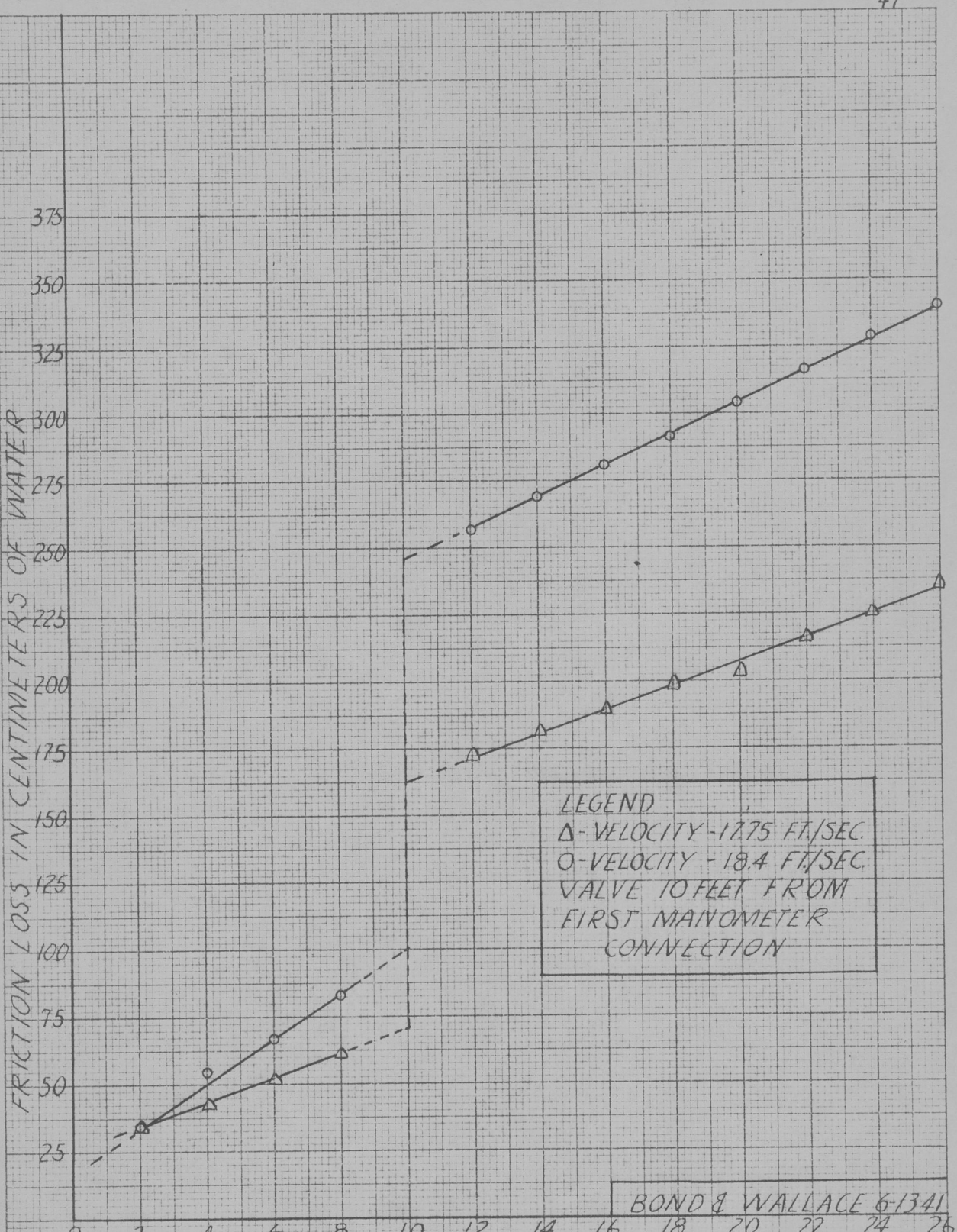


FIGURE 14

HYDRAULIC GRADIENT FOR 1 1/2 INCH GLOBE VALVE

APPENDIX D

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 Ken Boarts

Title Prof Chem Eng

Date July 17. 1941