An investigation of a pipe bend for determining the amount of flow of water in a small pipe
by John M Batch

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering at Montana State College
Montana State University

Abstract:
The purpose of this investigation was to study the possibility using a pipe bend to measure the quantity of flow of water in a small pipe, The flow was to be metered by measuring the pressure difference across the inside and put-side curves of the pipe bend. Advantages of a pipe bend flow meter include low in itial cost and no additional resistance to flow Tests were run on 90 degree solder-joint oast bronze elbows of sizes from 3/8 inch to 1 inch, and pipe, bends of 3/8 inch outside diameter copper tubing with constant radii but varying amounts of bend. It was found from the tests that when the pressure difference across the curves of the pipe bend and flow were plotted on logarithmic graph paper the curve was a straight line Also it was found that there was a linear relation between pressure difference and the square of the mean velocity of flow, It was concluded from the tests that a small pipe bend may be made into a flow meter with satisfactory results. Pipe bends from 7 1/2 to 180 degrees of bend were tested and found accurate When used as a flow meter. It was also concluded that the pipe bends should be calibrated in the laboratory before being used in an actual installation.

AN INVESTIGATION OF A PIPE BEND FOR DETERMINING THE AMOUNT OF FLOW OF WATER IN A SMALL PIPE

by

JOHN M. BATCH

A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Mechanical Engineering

at

Montana State College

Approved:

Head, Major Department

Chairman, Examining Committee

Dean, Graduate Division

Bozeman, Montana

June, 1952

TABLE OF CONTENTS

CHAPTER		PAGE
I.	THE PROBLEM	8
	Statement of the problem	8
	Validation of the problem	8
	Organization of the thesis	8
	Review of the literature	10
II.	THE METHOD OF PROCEDURE	12
	Construction of the pipe bends	12
	Cast elbows	12
	Long-radius pipe bends	12
	Measuring devices used	14
	Manometers	14
	A metric recording meter	16
	Experimental technique	16
III.	RESULTS ON THE CAST ELBOWS	20
	The relation between pressure difference and flow	20
	Using manometers	20
	Using a metric recording meter	24
	The relation between pressure difference and the square of velocity	30
IV.	RESULTS ON THE LONG-RADIUS PIPE BENDS	34

CHAPTER PAGE

The relation between pressure difference and flow 34

The relation between pressure difference and the square of velocity 37

The effect of imperfectly built pipe bends . . . 39

V. AN ANALYSIS OF THE RELATION BETWEEN PRESSURE DIFFERENCE AND THE SQUARE OF THE VELOCITY . . . 46

Derivation of the relation 46

Comparison of calculated results with test results 49

VI. SUMMARY AND CONCLUSIONS 52

Summary 52

Conclusions 52

LITERATURE CITED 54

APPENDIX 55

LIST OF FIGURES

FIGURE PAGE

1. Cross section of pipe bend showing method of measuring pressure difference 9
2. Construction details of cast elbows 13
3. Construction details of long-radius pipe bends 15
4. Apparatus arrangement for tests on the cast elbows . . 18
5. Apparatus arrangement for tests on the long-radius pipe bends 19
6. Relation between pressure difference and flow for a 1 inch cast elbow 21
7. Relation between pressure difference and flow for a 3/4 inch cast elbow 23
8. Relation between pressure difference and flow for a 1/2 inch cast elbow 25
9. Pressure difference vs. flow for a 1 inch cast elbow using a metric recording meter 26
10. Pressure difference vs. flow for a 3/4 inch cast elbow using a metric recording meter 27
11. Pressure difference vs. flow for a 1/2 inch cast elbow using a metric recording meter 28
12. Pressure difference vs. flow for six 3/8 inch cast elbows using a metric recording meter 29

FIGURE PAGE

13. The relation between pressure difference and the square of velocity for cast elbows 32

14. The relation between pressure difference and flow for long-radius pipe bends 35

15. The relation between pressure difference and the square of velocity for the long-radius pipe bends 38

16. Comparison of results before and after burrs were removed from a 7 1/2 degree pipe bend 40

17. Comparison of results before and after burrs were removed from a 15 degree pipe bend 41

18. Comparison of results before and after burrs were removed from a 22 1/2 degree pipe bend 42

19. Comparison of results before and after burrs were removed from a 45 degree pipe bend 43

20. Comparison of results before and after burrs were removed from a 90 degree pipe bend 44

21. Cross section of a pipe bend 47

LIST OF TABLES

TABLE		PAGE
I.	Recording meter constants and recommended flow ranges	31
II.	Values of n for long-radius pipe bends	36
III.	Comparison of computed elbow constants and test constants	50

ABSTRACT OF THE THESIS

The purpose of this investigation was to study the possibility of using a pipe bend to measure the quantity of flow of water in a small pipe. The flow was to be metered by measuring the pressure difference across the inside and outside curves of the pipe bend.

Advantages of a pipe bend flow meter include low initial cost and no additional resistance to flow.

Tests were run on 90 degree solder-joint cast bronze elbows of sizes from 3/8 inch to 1 inch, and pipe bends of 3/8 inch outside diameter copper tubing with constant radii but varying amounts of bend.

It was found from the tests that when the pressure difference across the curves of the pipe bend and flow were plotted on logarithmic graph paper the curve was a straight line. Also it was found that there was a linear relation between pressure difference and the square of the mean velocity of flow.

It was concluded from the tests that a small pipe bend may be made into a flow meter with satisfactory results. Pipe bends from 7 1/2 to 180 degrees of bend were tested and found accurate when used as a flow meter. It was also concluded that the pipe bends should be calibrated in the laboratory before being used in an actual installation.

CHAPTER I

THE PROBLEM

Statement of the problem. It was the purpose of this study to investigate the possibility of using a pipe bend to measure the quantity of flow of water in small copper pipes. This was to be accomplished by measuring the pressure difference of the water between the inside and outside curves of the bend as shown in Figure 1.

Validation of the problem. When water is flowing in a closed pipe system, operating under a small pressure head, it is often necessary to measure the quantity of water flowing. This necessitates a flow meter that will add a negligible pressure drop to the existing system. It is a characteristic of a flow meter constructed from an existing pipe bend that there is no additional resistance to flow.

The relative simplicity and the small original cost are also desirable qualities of a flow meter constructed from a pipe bend.

Organization of the thesis. The material presented in this study includes (1) the results of tests made on commercial cast bronze 90 degree elbows of sizes between 3/8 inch and 1 inch; (2) the results of tests made on pipe bends of constant radius and diameter but of varying amount of bend;

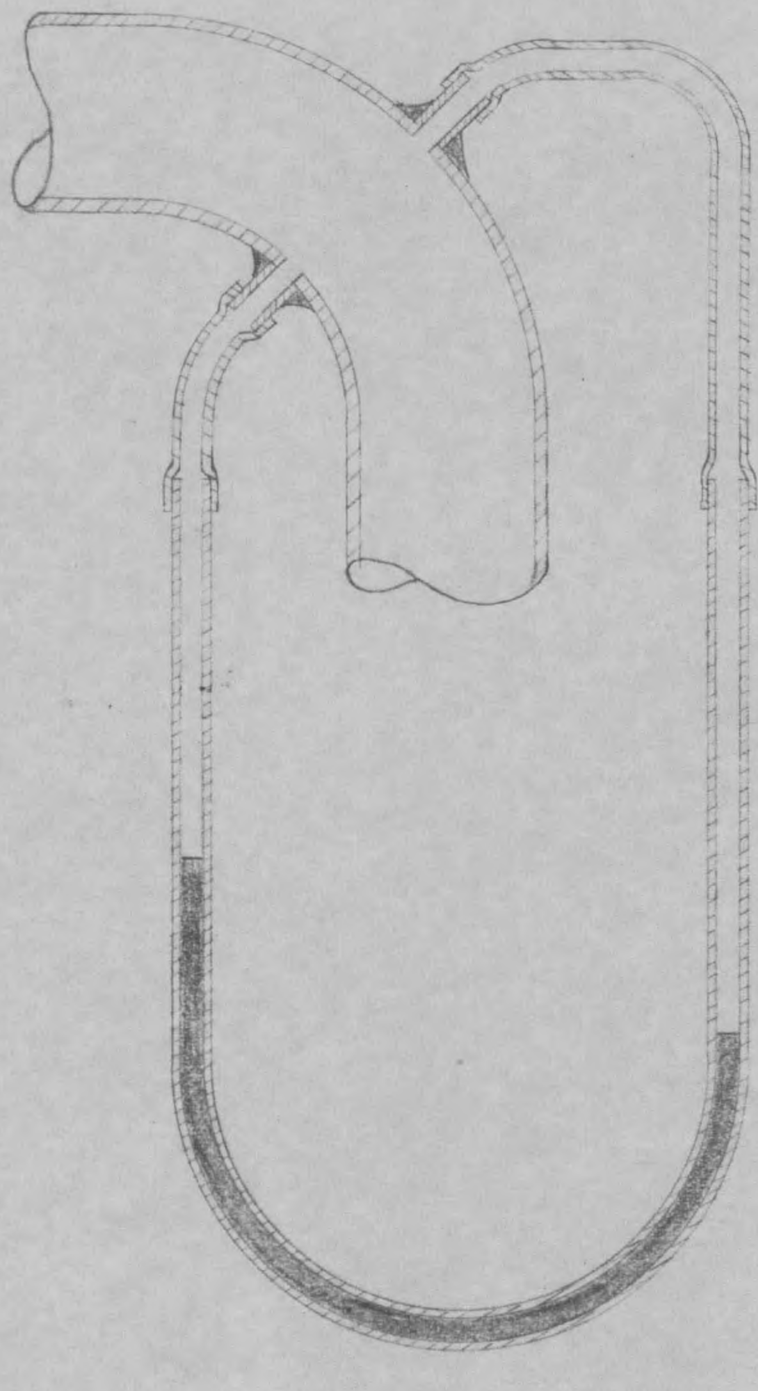


FIGURE 1

CROSS SECTION OF PIPE BEND SHOWING METHOD OF MEASURING PRESSURE DIFFERENCE and (3) an effort to predict the results by mathematical analysis.

Review of the literature. There has not been a great deal of literature published on the subject of using a pipe bend as a flow meter. The subject, however, is not a new one. In 1914 Levin[1] described in an article a flow meter that had the general shape of a pipe elbow, but with a square cross section. Test data gathered from experiments on steam as a flowing fluid was presented.

In an article published in Power[2] a flow meter of a rectangular hyperbolic section was shown. The meter was preceded by straightening vanes and had a rather complicated recording apparatus.

Yarnell and Nagler,[3] in a study of the characteristics of flow of water around large plastic pipe bends, mention that a pipe bend could be used to meter the flow. However, their main study was confined to the flow lines through the bend and the drop in static pressure due to the bend. In their discussion of static pressures they bring out the idea of the pipe bend being used as a flow meter.

---

1 A. M. Levin, "A Flow Metering Apparatus," Transactions A.S.M.E., 36:239-54, September 1914.

2 "The Hyperbo Electric Flow Meter," Power, 57:1024-25, June 26, 1923.

3 David L. Yarnell and Floyd A. Nagler, "Flow of Water Around Bends in Pipes," Transactions A.S.C.E., 100:1018-32, 1935

Ireal A. Winter[4] did experimental work on the measuring of flow in hydraulic turbines. This was done by tapping the scroll case on the inside and outside bend surfaces and measuring the pressure difference. Fairly good results were obtained by this method although it was concluded that the scroll case should be calibrated against a known flow when converted to a flow meter.

W. M. Lansford[5] has done considerable work on 90 degree elbows used as flow meters. He tested threaded elbows between one inch and four inches in size, and flanged elbows ranging in size from four inches to twenty-four inches. Both the threaded and the flanged type elbows were found satisfactory for use as a flow meter.

Thus while the idea of a pipe bend used as a flow meter is not new the investigations previously undertaken were largely limited to large size elbows, 90 degree elbows, or specially made elbows of odd shapes.

---

4 Ireal A. Winter, "Improved Type of Flow Meter for Hydraulic Turbines," Transactions A.S.C.E., 99:847-66, 1934

5 W. M. Lansford, "The Use of an Elbow in a Pipe Line For Determing the Rate of Flow in the Pipe," University of Illinois Engineering Experiment Station Bulletin No. 289, December 22, 1936, 36 pp.

CHAPTER II

THE METHOD OF PROCEDURE

In the construction of the flow meters from pipe bends, and in the experimental data collecting, all materials and tools used were of the common type found in any machine shop. No special apparatus was used or constructed so that duplication of the results of this investigation could be possible.

I. CONSTRUCTION OF THE PIPE BENDS

Cast elbows. Nine 90 degree cast bronze solder-joint type elbows were converted to flow meters. The different sizes and construction details are shown in Figure 2. In the construction process tube adapters were silver soldered on the inside and outside bends of the elbow. Holes were then drilled through the surface of the elbow with the tube adapters serving as guides. Care was taken to remove all burrs formed in the drilling operation. All of the cast elbows had a very rough, unmachined surface on the inside and no effort was made to improve this situation.

Long-radius pipe bends. Eleven long-radius pipe bends were made from 3/8 inch outside diameter copper tubing. These bends had a constant radius of bend of 15/16 of an inch but varied in amount of bend from 7 1/2 degrees to 180 degrees.

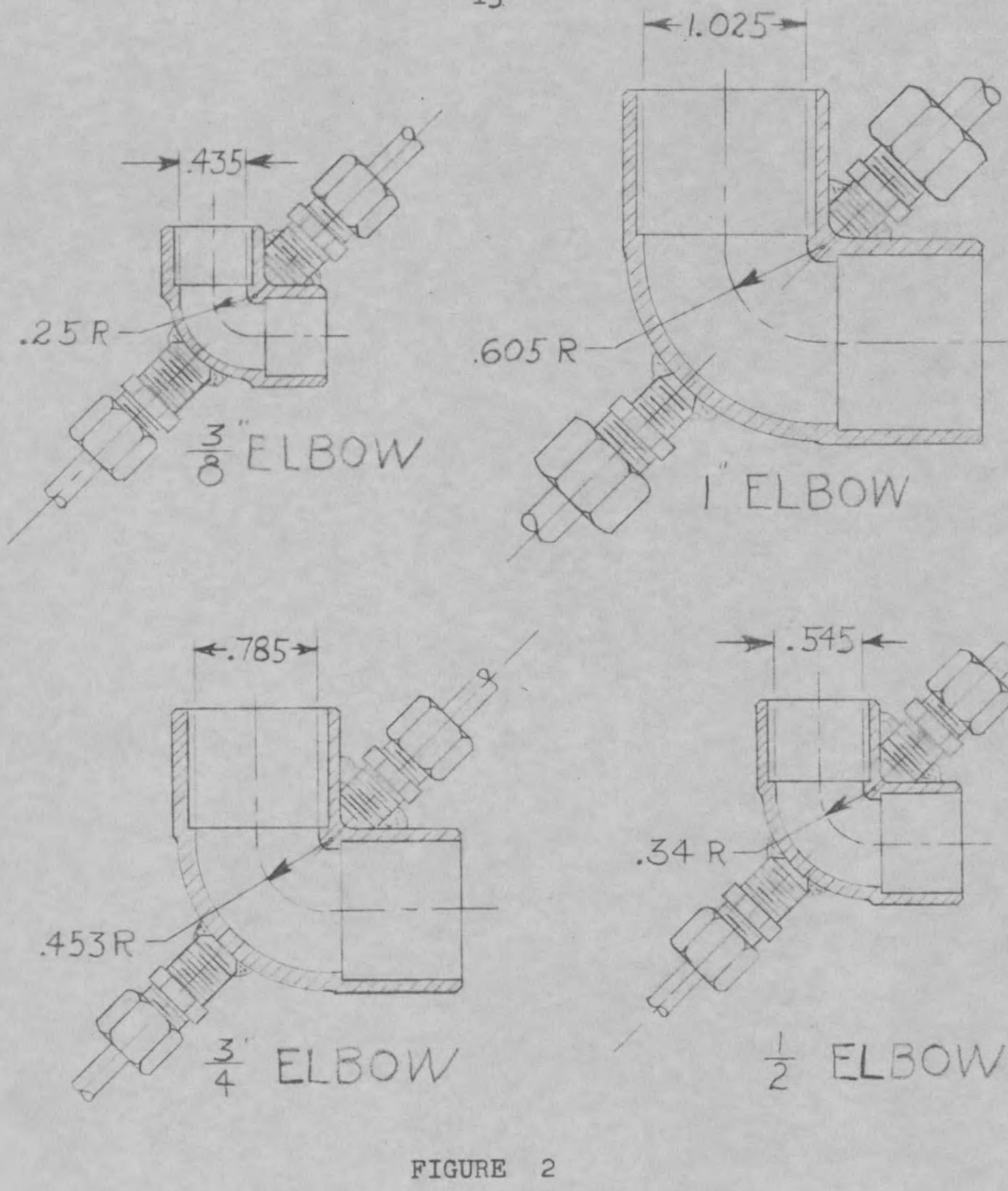


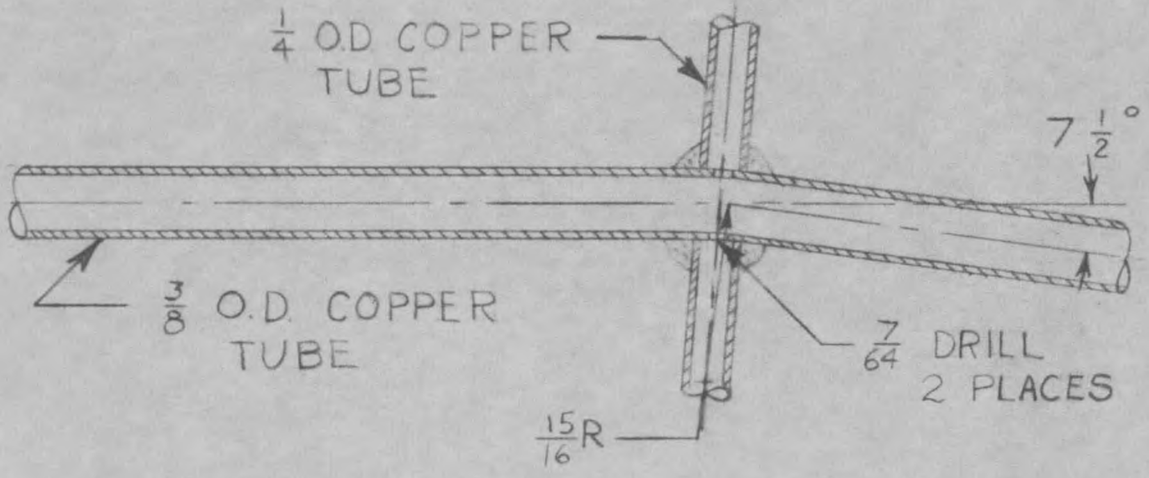
FIGURE 2

CONSTRUCTION DETAILS OF CAST ELBOWS

Seven pipe bends of different amounts of bend were constructed; 7½, 15, 22½, 45, 90, 135, and 180 degrees. Typical construction detail is shown on two of the bends in Figure 3. As these pipe bends were not intended for permanent construction, adapters for copper pipe were not silver soldered on as in the case of the cast elbows. Instead, rubber tubing adapters, in the form of one quarter inch copper tubing, were soldered on the inside and outside of the bend. Holes were drilled through the surfaces of the pipe using the adapters as guides. Very prominent burrs were formed on the inside of the pipe resulting from the drilling operation. These burrs were not removed until after the first series of tests were run in an effort to find the effect of the burrs on the performance of the pipe bend as a flow meter.

II. MEASURING DEVICES USED

<u>Manometers</u>. Straight U-tube manometers were found very satisfactory for measuring the pressure differential across the pipe bends and elbows. Mercury, water, and Gage Fluid No. 3 of the Meriam Instrument Company of Cleveland, Ohio were all used in the manometers. The gage fluid had a specific gravity of 2.95. Water was used in the manometers when the pressure differential was very low, while the gage fluid and mercury were used for pressure differences of higher values.



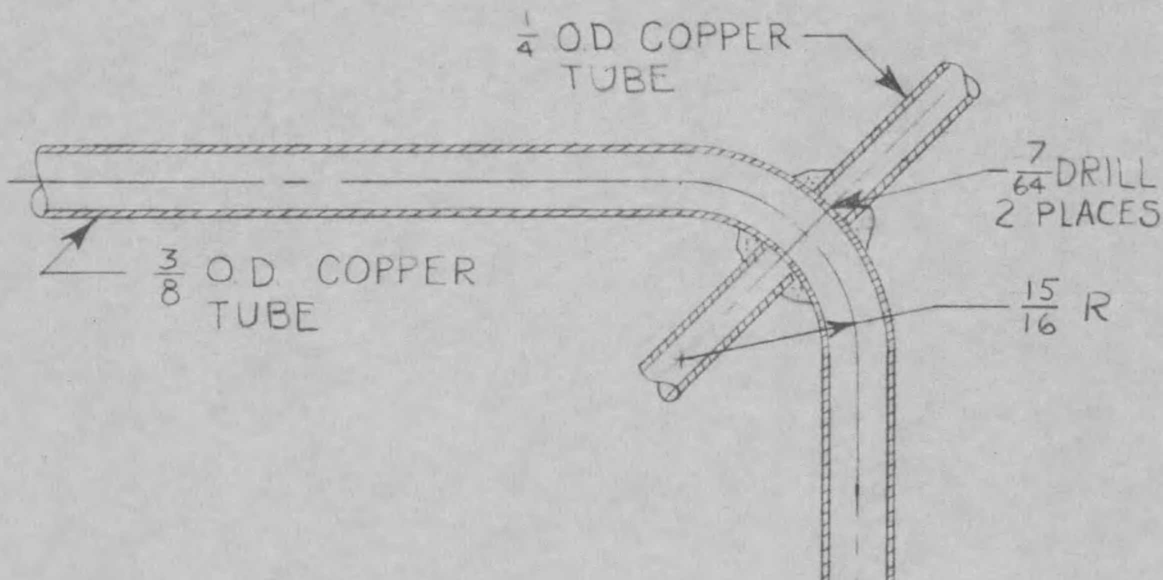


FIGURE 3

CONSTRUCTION DETAILS OF LONG RADIUS PIPE BENDS

<u>A metric recording meter.</u> A recording pressure differential meter was obtained from the American Meter Company of Philiadelphia and was used to record some of the readings on the cast elbows. The meter had a float resting in mercury which was acted on by the differential pressure below and above the float. The float in turn actuated a marking point which recorded the reading on a rotating chart. The meter recorded a maximum pressure differential of either two and one half or ten inches of water, depending upon the size of float used. The pressure differential was measured according to the mathematical equation

$$M = 10\sqrt{\frac{h}{2.5}} \qquad (1)$$

for the "$2\frac{1}{2}$ inch" float, and

$$M = 10\sqrt{\frac{h}{10}} \qquad (2)$$

for the "10 inch" float

where M = recording meter reading

h = pressure differential in inches of water

The circular recording chart had a linear scale from one to ten starting from the inside and running radially to the outside. The metric recording meter proved to be a sensitive instrument for recording small pressure differentials.

III. EXPERIMENTAL TECHNIQUE

For all tests on the cast elbows the equipment was set up as shown in Figure 4. City water was run into a pressure tank to smooth out variations in flow and to subject the water to a definite static pressure. The water was throttled by the discharge valve and the valve on the entrance to the pressure tank. The total amount of flow for each reading of the flow meter was weighed in a weigh tank against time taken with a stop watch. With the use of the pressure tank very little pulsation took place in the manometer. For tests using the recording meter the manometer was replaced with the metric recording meter and the rest of the equipment set up was the same.

For the tests on the long-radius pipe bends the equipment was set up as shown in Figure 5. As the pressure differential in these tests was relatively small, water was used in the manometer. To control the amount of air in the pressure lines leading to the manometer a water reservoir was placed in each pressure line. The water flowing through the pipe bend was weighed against time to determine the rate of flow. The manometer readings were quite steady, especially for the very low rates of flow.

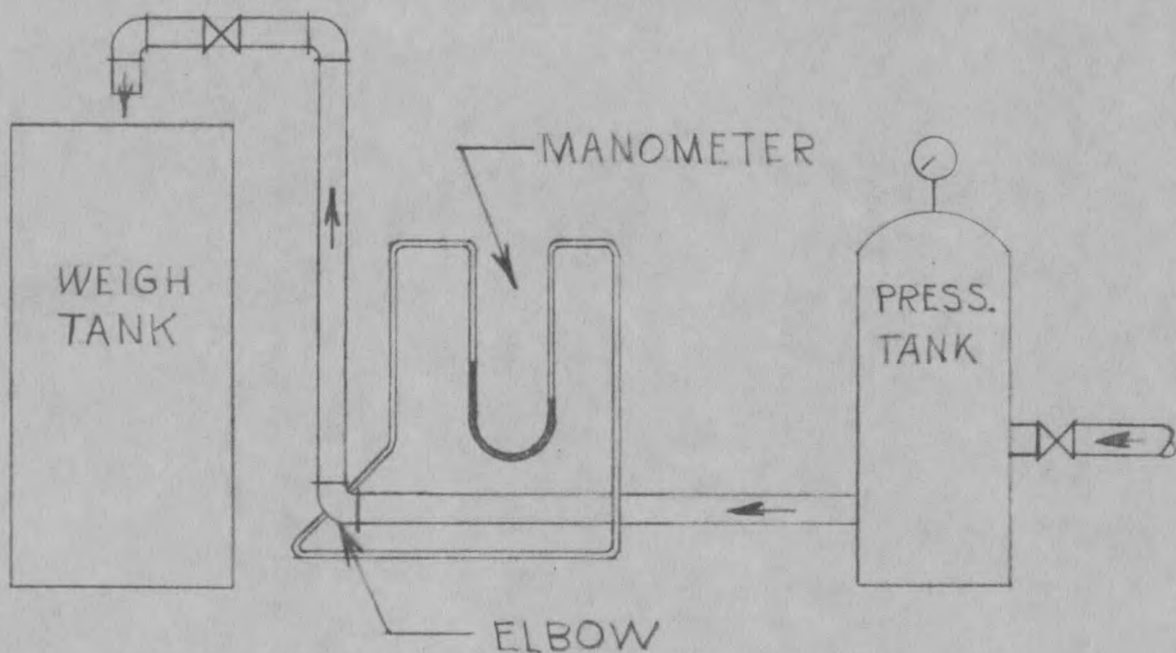


FIGURE 4

APPARATUS ARRANGEMENT FOR TESTS ON THE CAST ELBOWS

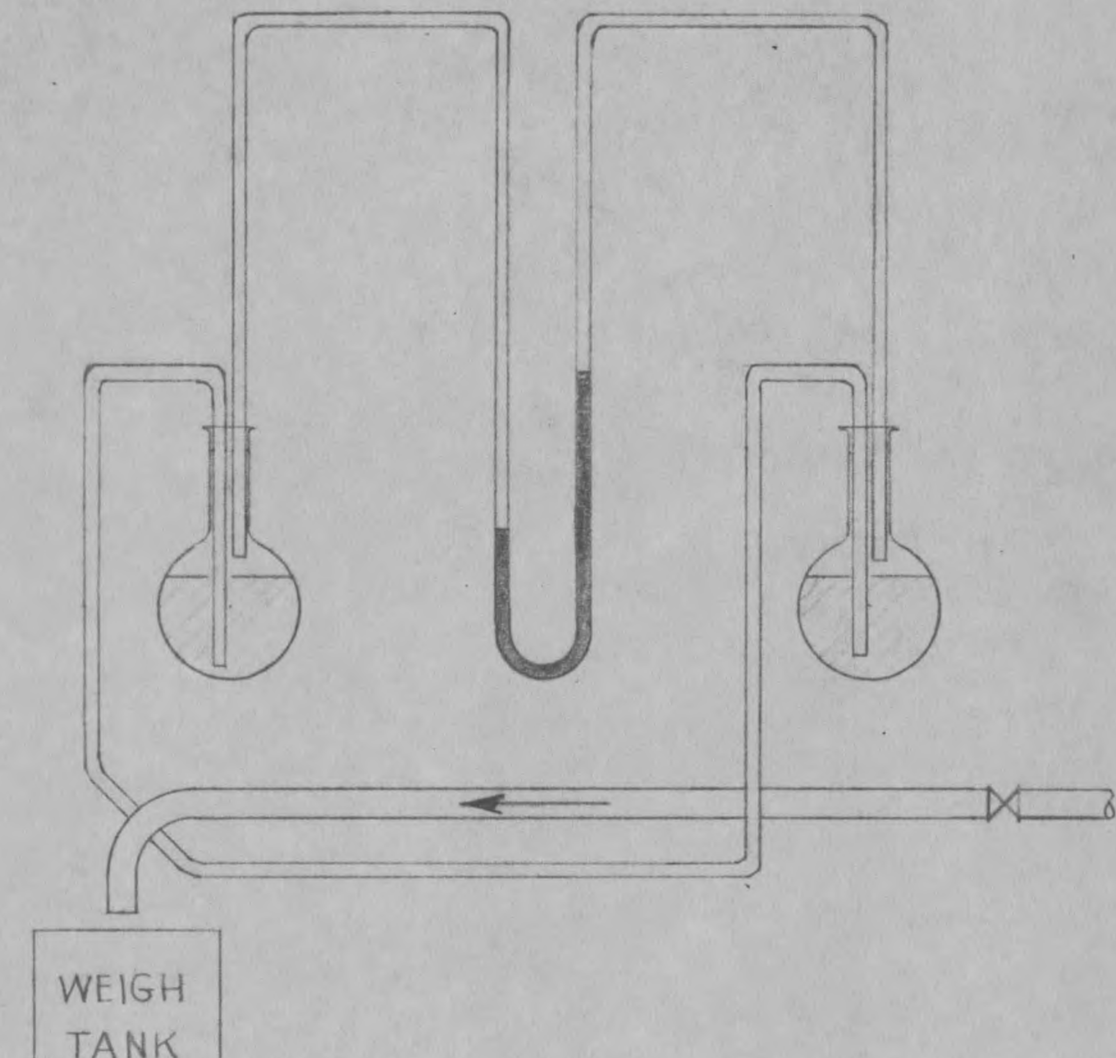


FIGURE 5

APPARATUS ARRANGEMENT FOR TESTS ON THE LONG RADIUS PIPE BENDS

CHAPTER III

RESULTS ON THE CAST ELBOWS

The results of the investigation on coverting commercial type 90 degree solder-joint cast bronze elbows of less than 1 inch in size into flow meters are reported in this chapter. The relation between pressure differential across the elbow to the quantity of flow and to the square of the velocity of flow will be discussed. Also, a comparison of the results of six elbows of the same size will be shown.

I. THE RELATION BETWEEN PRESSURE DIFFERENCE AND FLOW

Using manometers. In Figure 6 is shown the relation between the pressure difference across the inside and outside curves of a 1 inch 90 degree solder-joint cast bronze elbow, and the quantity of flow in gallons per minute. This curve includes three different tests. In the first test the manometer was filled with Meriam gage fluid No. 3 and the pressure in the pressure tank (Figure 4, page 18) was allowed to vary from 4.4 psig to 16.0 psig. In the second test the same manometer was used but an effort was made to hold the pressure in the pressure tank constant at 12.2 psig. In the third test mercury was used in the manometer and the pressure in the pressure tank was varried in three steps; at 4.0 psig, 6.5 psig, and 10.0 psig.

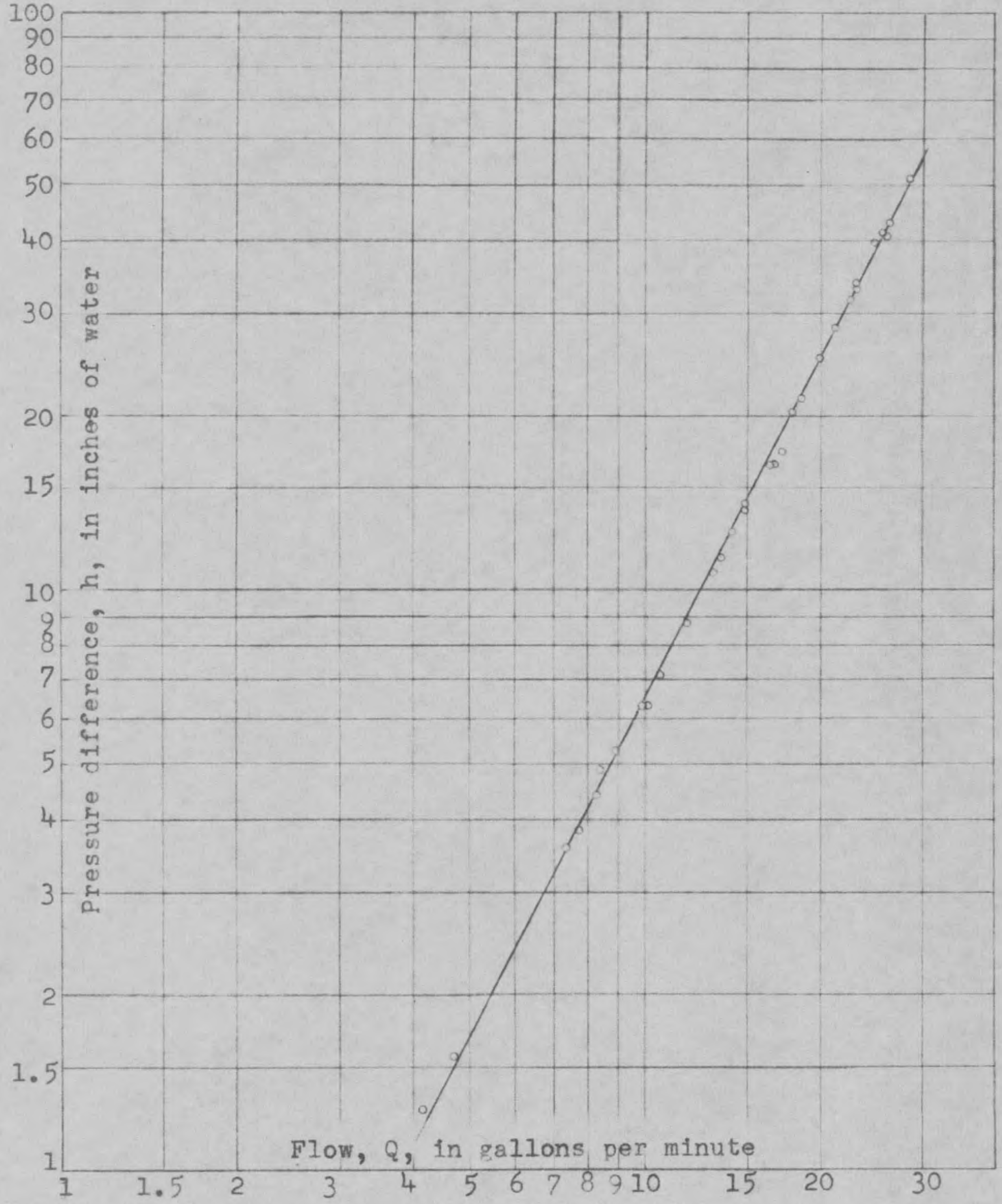


FIG. 6 RELATION BETWEEN PRESSURE DIFFERENCE AND FLOW FOR A 1 INCH CAST ELBOW

As noted in Figure 6 the relation between pressure difference and flow is a straight line when plotted on logarithmic graph paper. The mathematical equation for this straight line may be written

$$\frac{d(\ln h)}{d(\ln Q)} = n \tag{3}$$

where h = pressure difference between the inside and outside curves of the elbow in inches of water

Q = quantity of flow in gallons per minute

n = slope of the curve, a constant

The solution of this equation is

$$\int d(\ln h) = n \int d(\ln Q)$$

$$\ln h = n \ln Q + \ln Z$$

$$h = ZQ^n \tag{4}$$

where Z = a constant of integration and depends on the elbow. The value of n was found to be 1.96 for the 1 inch and ½ inch elbows, and 1.91 for the 3/4 inch elbow. These values compare favorably with 1.93 and 2.00 found by Lansford[1] on investigation of larger iron pipe.

In Figure 7 is shown the relation between the pressure difference across the inside and outside curves of a 3/4 inch 90 degree solder-joint cast bronze elbow, and the quantity of

---

1 W. M. Lansford, "The Use of an Elbow in a Pipe Line For Determining the Rate of Flow in the Pipe," University of Illinois Engineering Experiment Station Bulletin No. 289, December 22, 1936, p 18.

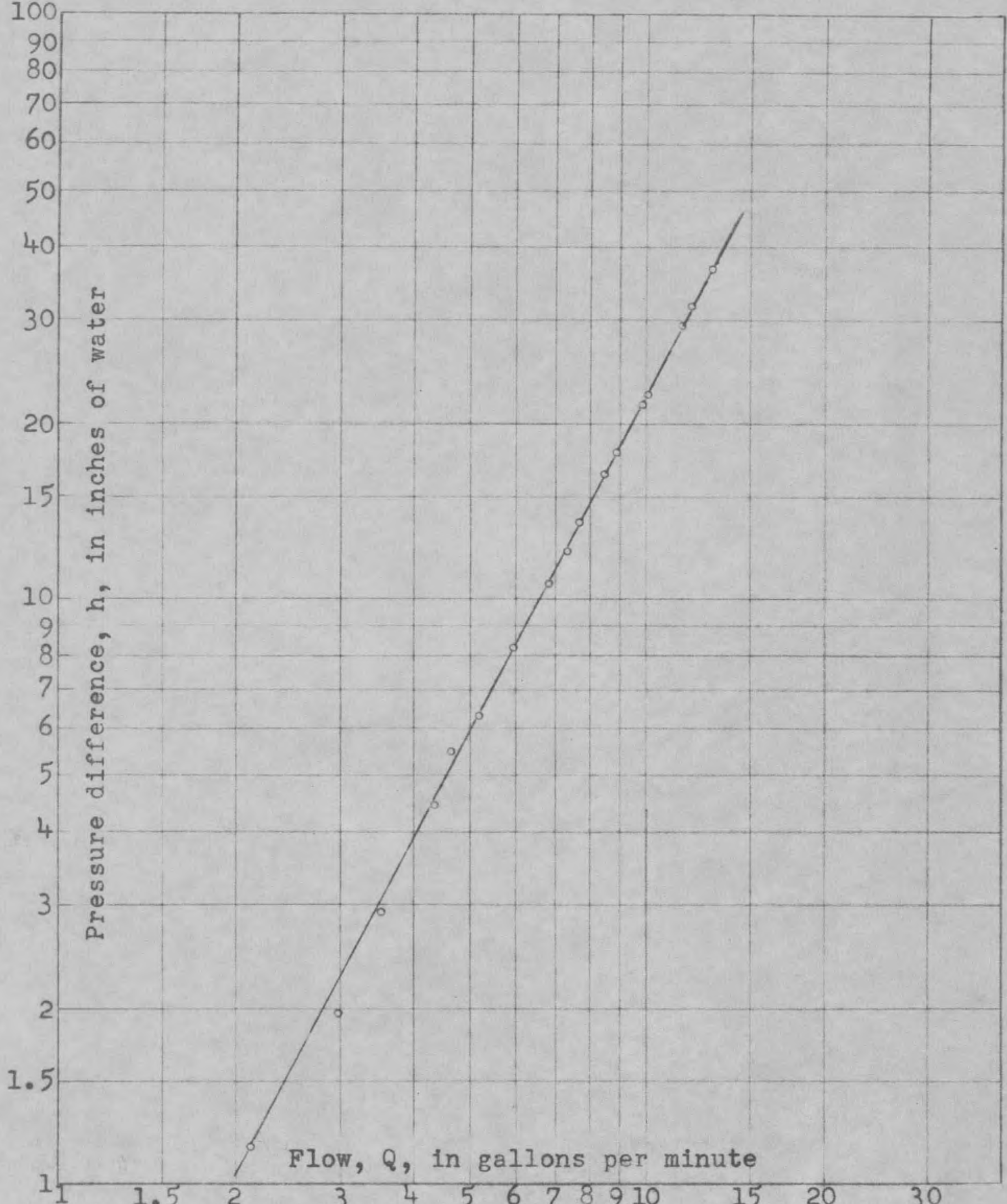


FIG. 7 RELATION BETWEEN PRESSURE DIFFERENCE AND FLOW FOR A 3/4 INCH CAST ELBOW

flow in gallons per minute. In this test the manometer was filled with Meriam gage fluid No. 3 and the pressure in the pressure tank was allowed to vary.

In Figure 8 is shown the results on a 1/2 inch 90 degree solder-joint cast bronze elbow. The test conditions were the same as with the 3/4 inch elbow.

Using a metric recording meter. In Figures 9, 10, 11, and 12 are shown the relation between the pressure difference across the inside and outside curves of 90 degree solder-joint cast bronze elbows as recorded on a metric recording meter, and the quantity of flow in gallons per minute.

The six curves shown in Figure 12 are for six 3/8 inch 90 degree cast elbows that were constructed as similar to each other as possible. The results indicate that in the case of the elbows tested the curve of one elbow may be applied to another elbow of the same size, if extreme accuracy is not required.

As shown in Figures 9, 10, 11, and 12 the slope of the curve plotted from the meter reading and flow is a constant. Thus an equation may be set up expressing the relation between the two variables.

$$\frac{dQ}{dM} = C$$

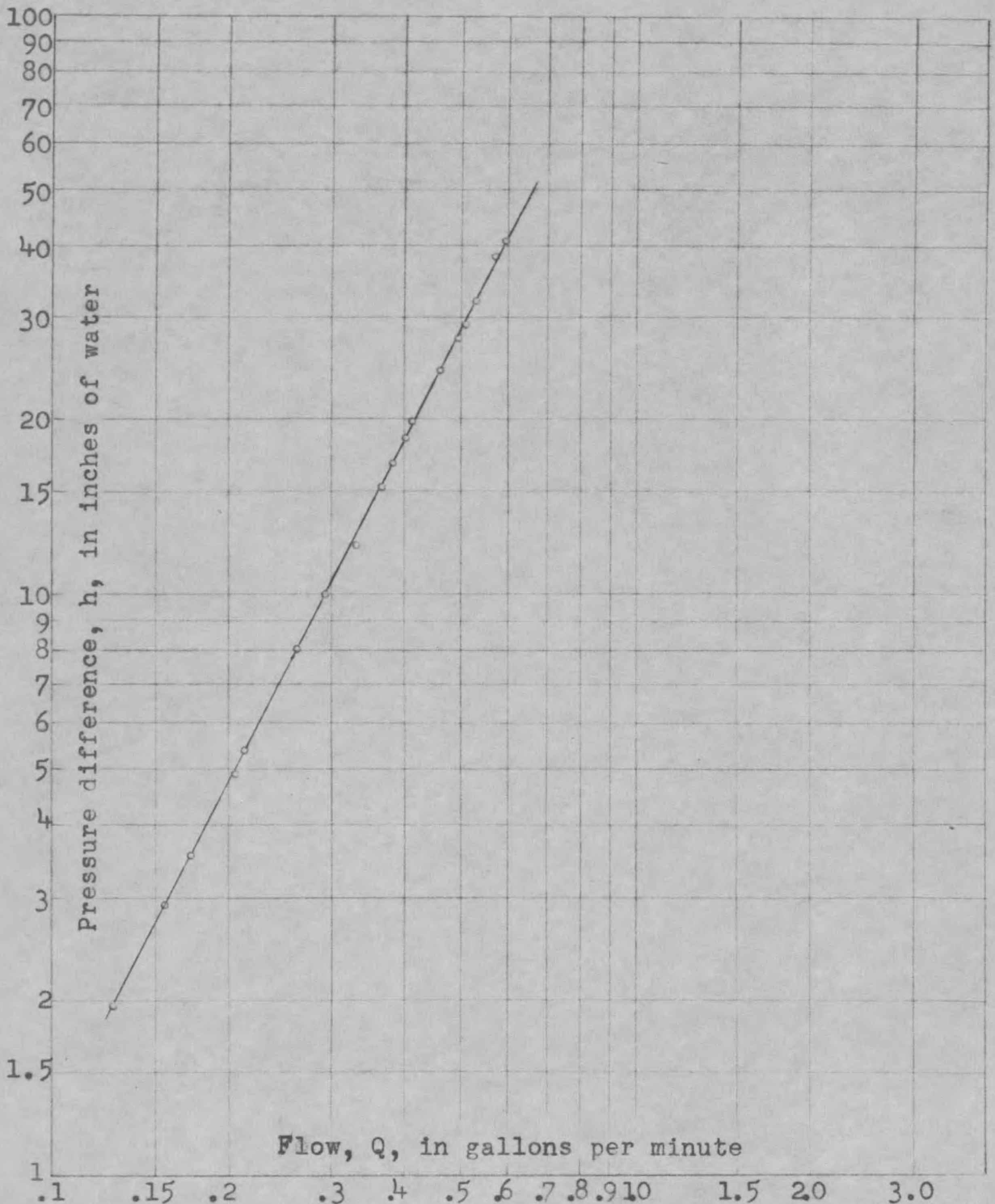


FIG. 8 RELATION BETWEEN PRESSURE DIFFERENCE AND FLOW FOR A 1/2 INCH CAST ELBOW

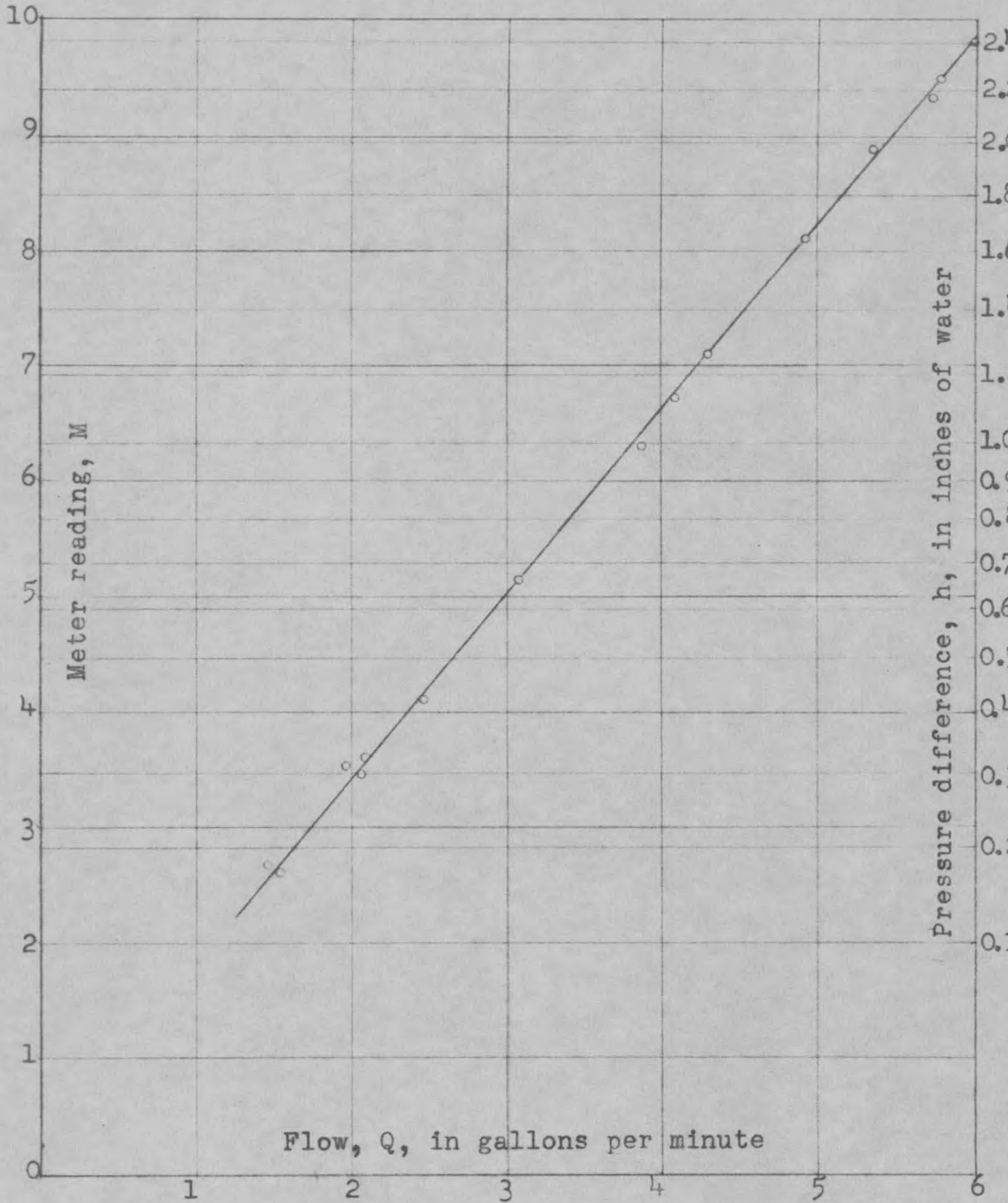


FIG. 9 PRESSURE DIFFERENCE vs. FLOW FOR A 1 INCH CAST ELBOW USING A METRIC RECORDING METER

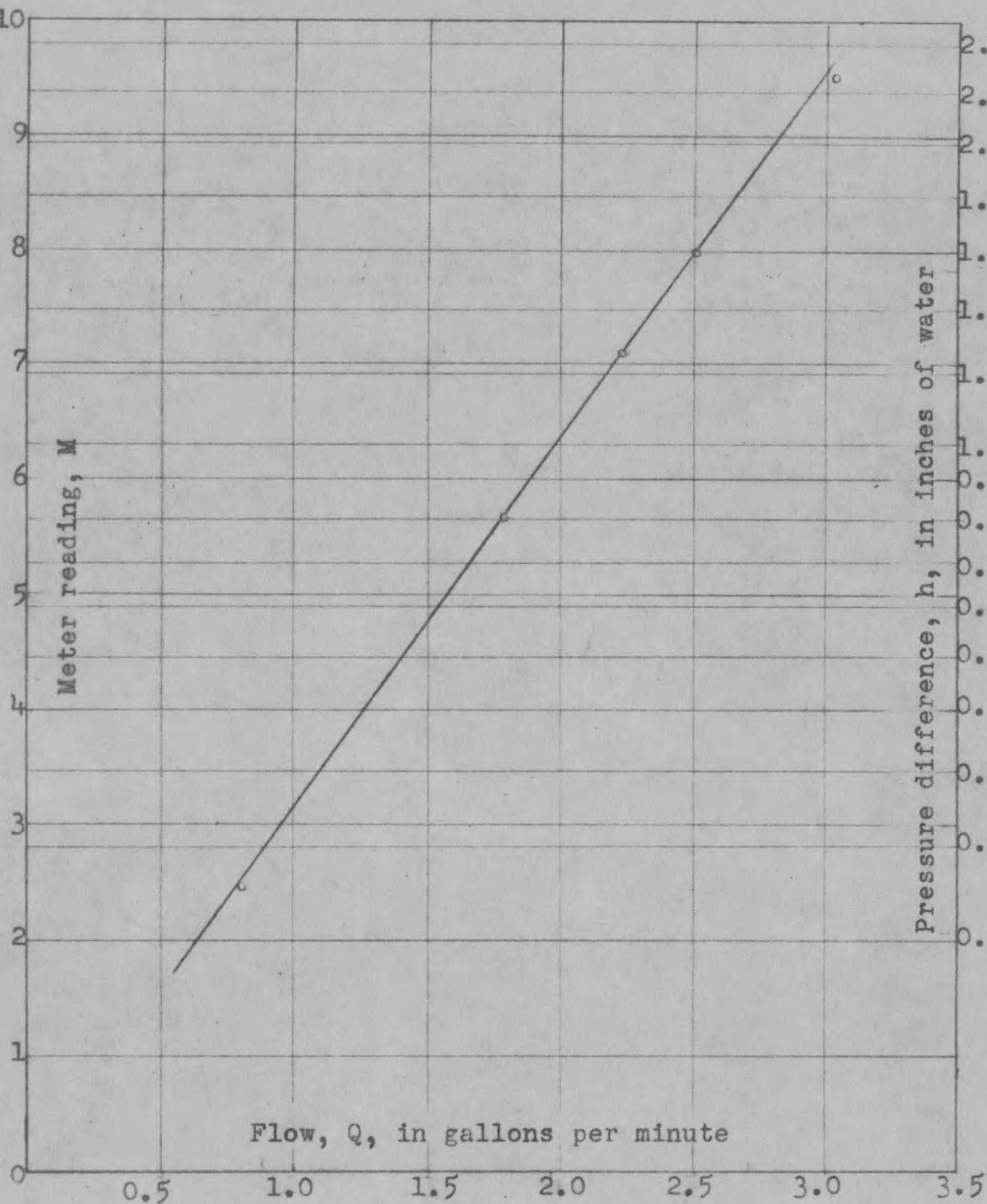


FIG. 10 PRESSURE DIFFERENCE vs. FLOW FOR A 3/4 INCH CAST ELBOW USING A METRIC RECORDING METER

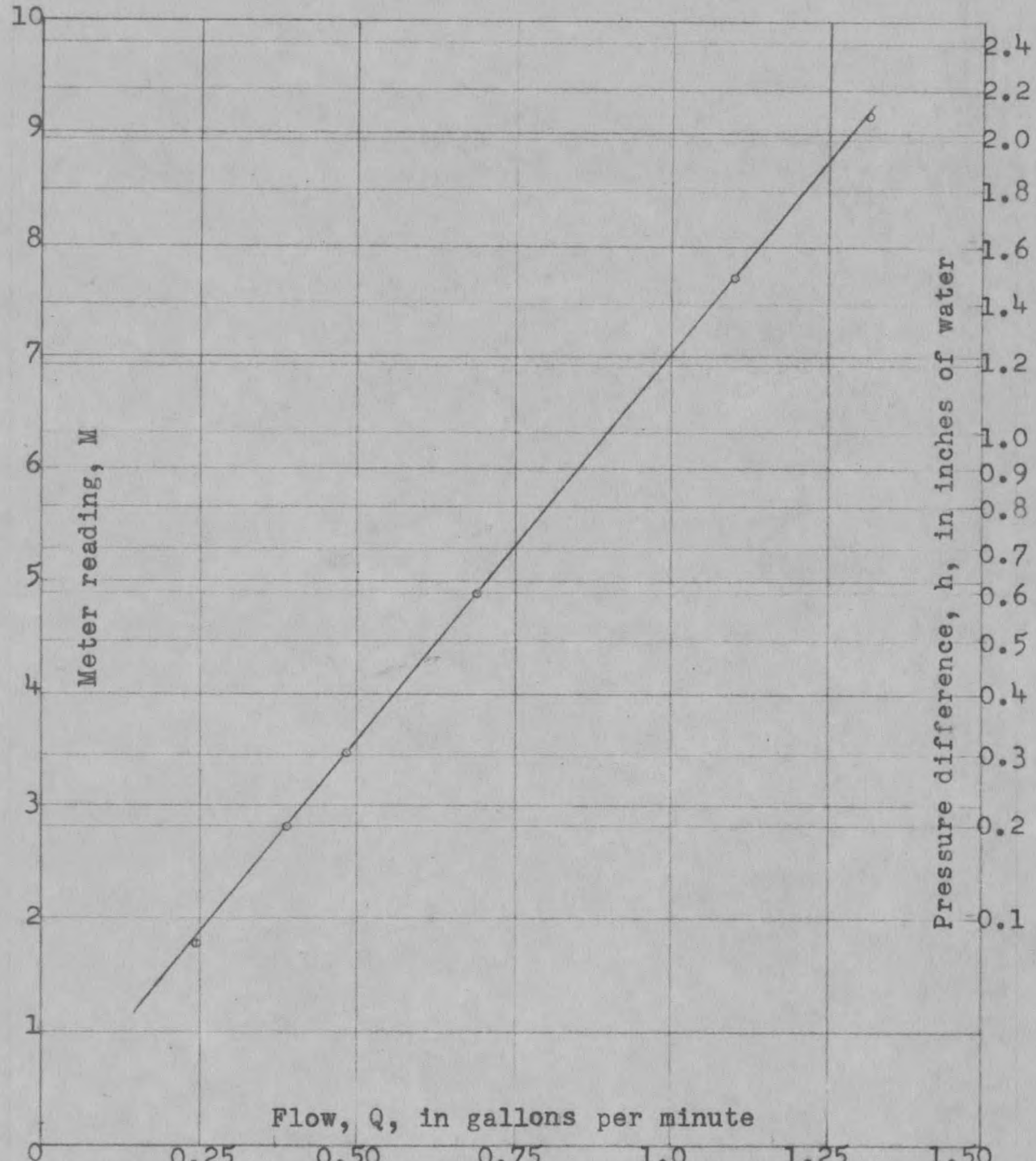


FIG. 11 PRESSURE DIFFERENCE vs. FLOW FOR A 1/2 INCH CAST ELBOW USING A METRIC RECORDING METER

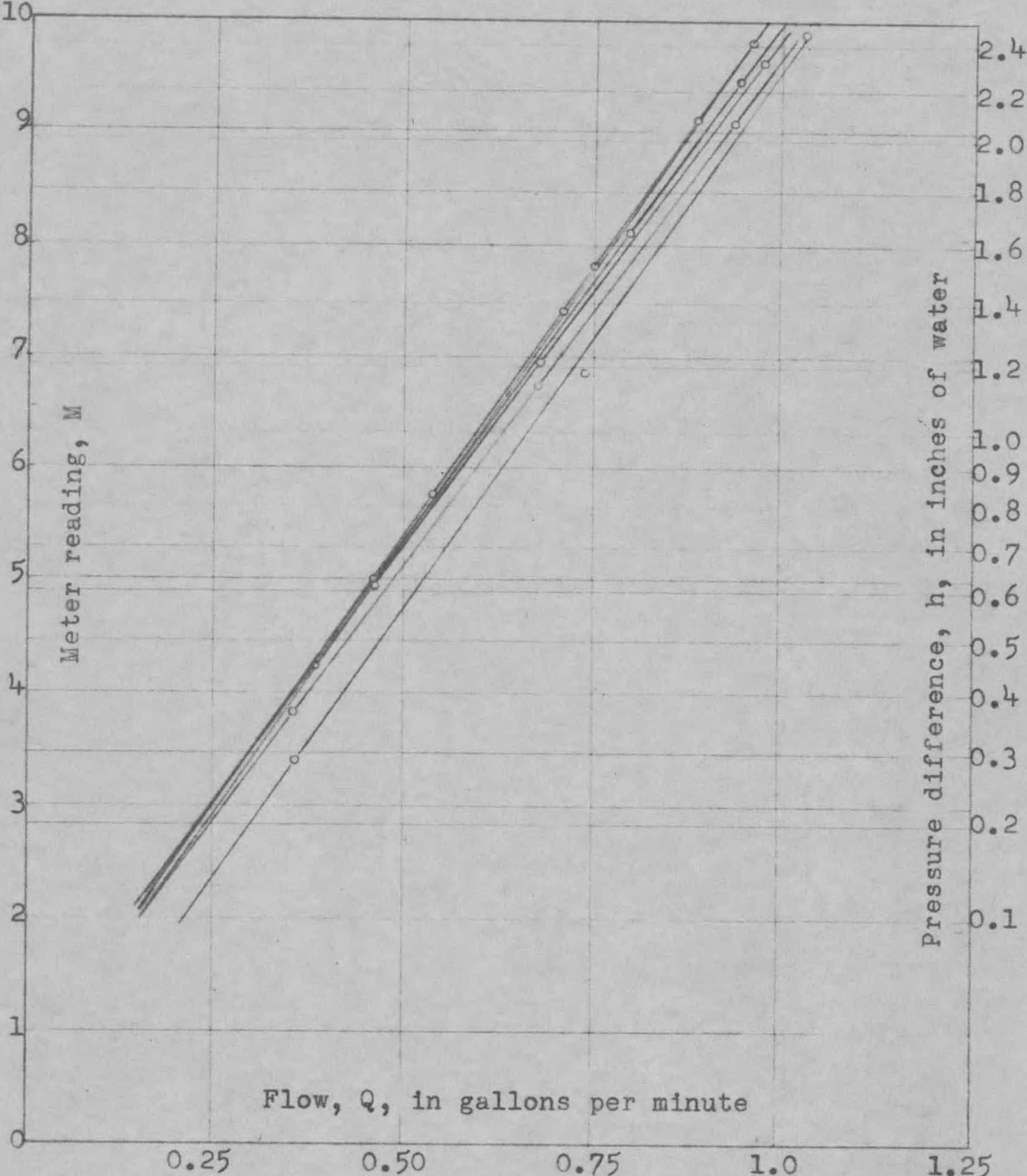


FIG. 12 PRESSURE DIFFERENCE vs. FLOW FOR SIX 3/8 INCH CAST ELBOWS USING A METRIC RECORDING METER

$$\int_0^Q dQ = C\int_0^M dM$$

$$Q = CM \qquad (5)$$

where Q = quantity of flow in gallons per minute

M = meter reading

C = a constant, depending upon the elbow

The constant, C, may be calibrated for each individual elbow in the laboratory. Then the flow at any time will be the constant times the meter reading.

The constant in equation (5) along with recommended flow ranges for each size elbow tested when using the metric recording meter are shown in table 1.

III. THE RELATION BETWEEN PRESSURE DIFFERENCE AND THE SQUARE OF VELOCITY

The relation between the pressure difference across the inside and outside bends of the 90 degree solder-joint cast bronze elbows tested, and the square of the mean velocity of flow in the pipe is shown in Figure 13. The slope of the curve for each elbow is approximately a constant. Thus a linear equation expressing the relationship of pressure difference and velocity squared may be shown.

$$\frac{dh}{d(V^2)} = K$$

TABLE I

RECORDING METER CONSTANT AND RECOMMENDED FLOW RANGES

Elbow size	Float Installed	Meter Constant	Recommended Max. Flow
Inches	Inches	G.P.M. per Chart div.	Gallons per minute
1	2½	0.605	6.0
3/4	2½	0.314	3.0
1/2	2½	0.143	1.4
3/8	2½	0.098	1.0
1	10	1.21	12.0
3/4	10	0.628	6.0
1/2	10	0.286	2.8
3/8	10	0.196	2.0

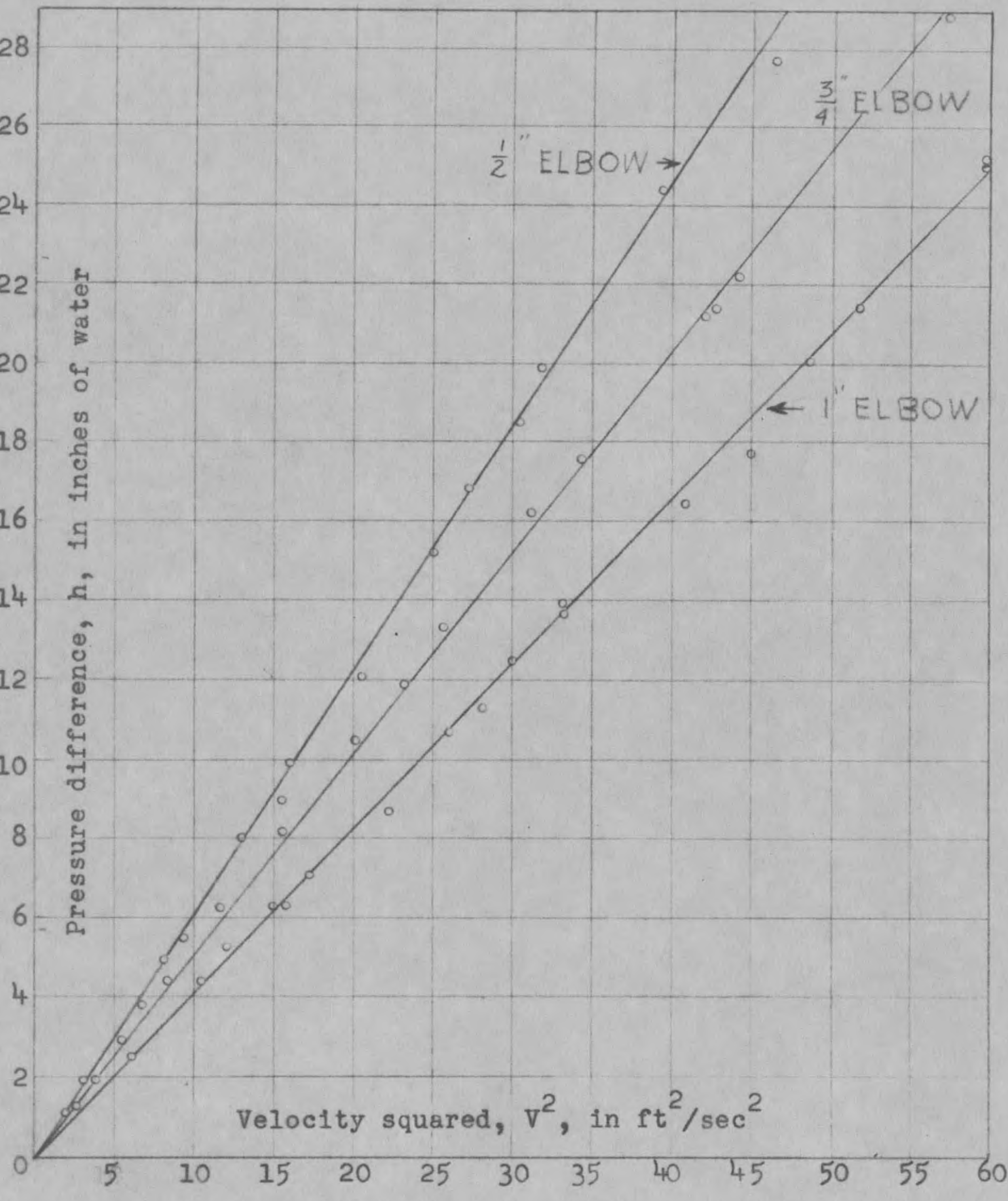


FIG. 13 THE RELATION BETWEEN PRESSURE DIFFERENCE AND THE SQUARE OF VELOCITY FOR CAST ELBOWS

$$\int_0^h dh = K\int_0^V d(V^2)$$

$$h = KV^2 \tag{6}$$

where h = pressure difference between the inside and outside curves of the elbow in inches of water

V = the mean velocity of flow in the pipe in feet per second

K = a dimensional constant, depending upon the elbow

If the constant, K, depends upon the physical dimensions of the elbow, and if the constant could be calculated accurately, then the flow through a pipe could be calculated by knowing the pressure differential across an elbow. Thus a pipe bend could be converted into a flow meter without first calibrating the elbow in the laboratory. A further investigation of the constant, K, will be made in chapter V.

CHAPTER IV

RESULTS ON THE LONG-RADIUS PIPE BENDS

In the use of small size copper tubing, bends are often made in the tubing itself rather than inserting a cast elbow. Thus it may be of interest to realize the possibility of using the bend as a flow meter by taping the inside and outside curves and measuring the pressure difference across the bend. The results reported here are of tests made on bends of varying degrees of bend in 3/8 inch outside diameter copper tubing. All bends were made with a standard pipe bender, which gave a radius of bend of 15/16 of an inch.

<u>The relation between pressure difference and flow.</u> In Figure 14 is shown the relation between the pressure difference across the inside and outside pipe bend curves, and the quantity of flow for eleven long-radius pipe bends with bends ranging from $7\frac{1}{2}$ degrees to 180 degrees. During these tests water was used in the manometer to measure pressure difference in inches of water, while the flow was measured in gallons per minute by means of a weigh tank and a stop watch.

Equation (4), $h = ZQ^n$, derived on page 22 in chapter III may be applied to each of the bends whose curve is shown in Figure 14. The value of n in equation (4) for each of the long-radius bends tested is given in table II.

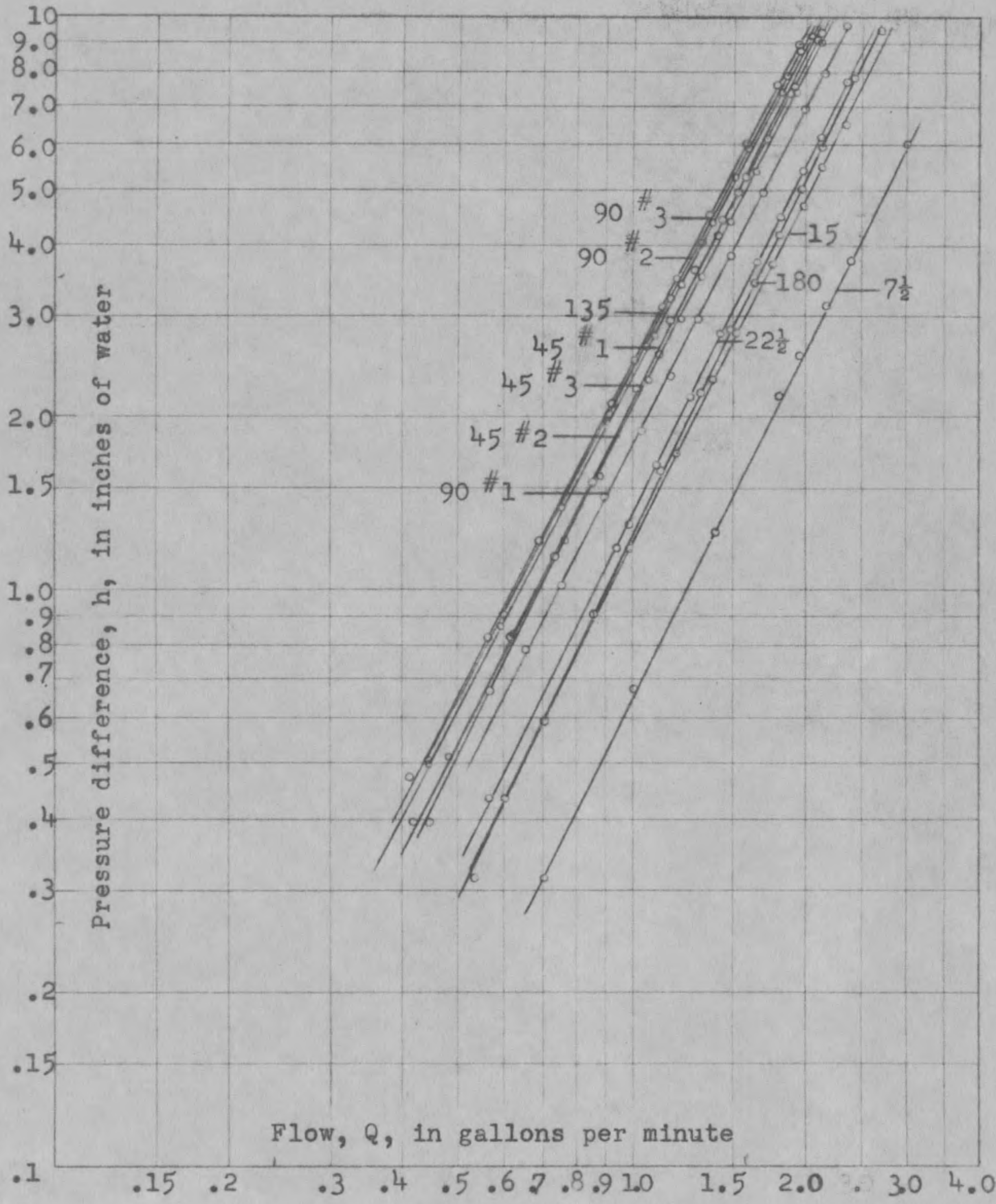


FIG. 14 THE RELATION BETWEEN PRESSURE DIFFERENCE AND FLOW FOR LONG-RADIUS PIPE BENDS

TABLE II

VALUES OF n FOR LONG-RADIUS PIPE BENDS

Size of Bend	n
Degrees	
7½	2.03
15	2.03
22½	2.02
45 No. 1	2.02
45 NO. 2	1.95
45 No. 3	1.97
90 No. 1	1.95
90 No. 2	1.91
90 No. 3	1.93
135	1.95
180	2.09

It may be noted from Figure 14 that the three 45 degree pipe bends, the 135 degree bend, and two of the 90 degree bends gave almost identical results and produced the highest pressure difference for any given flow. This would indicate that for a given flow through a pipe the maximum pressure difference across a bend will be produced in a bend of at least 45 degrees. However even the 7½ degree bend shows a high sensitivity of pressure difference to a given flow, and the flow has deviated only approximately 3 3/4 degrees from its path through the pipe before it comes to the pressure taps.

Three pipe bends of each of the 45 and 90 degree bends were constructed and tested to make certain that the curves could be duplicated.

<u>The relation between pressure difference and the square of velocity.</u> In Figure 15 is shown the relation between the pressure difference across the inside and outside elbow curves and the square of the mean velocity of flow in the pipe for the eleven long-radius pipe bends tested. The approximate straight line for each bend shown in Figure 15 may be represented by equation (6), $h = KV^2$, derived on page 33 in chapter III. It may be noted from Figure 15 that there is a large variation in the slope of the seven different kinds of pipe bends. This shows the difference of pressure differential across pipe bends of the same size and radius of bend, but of

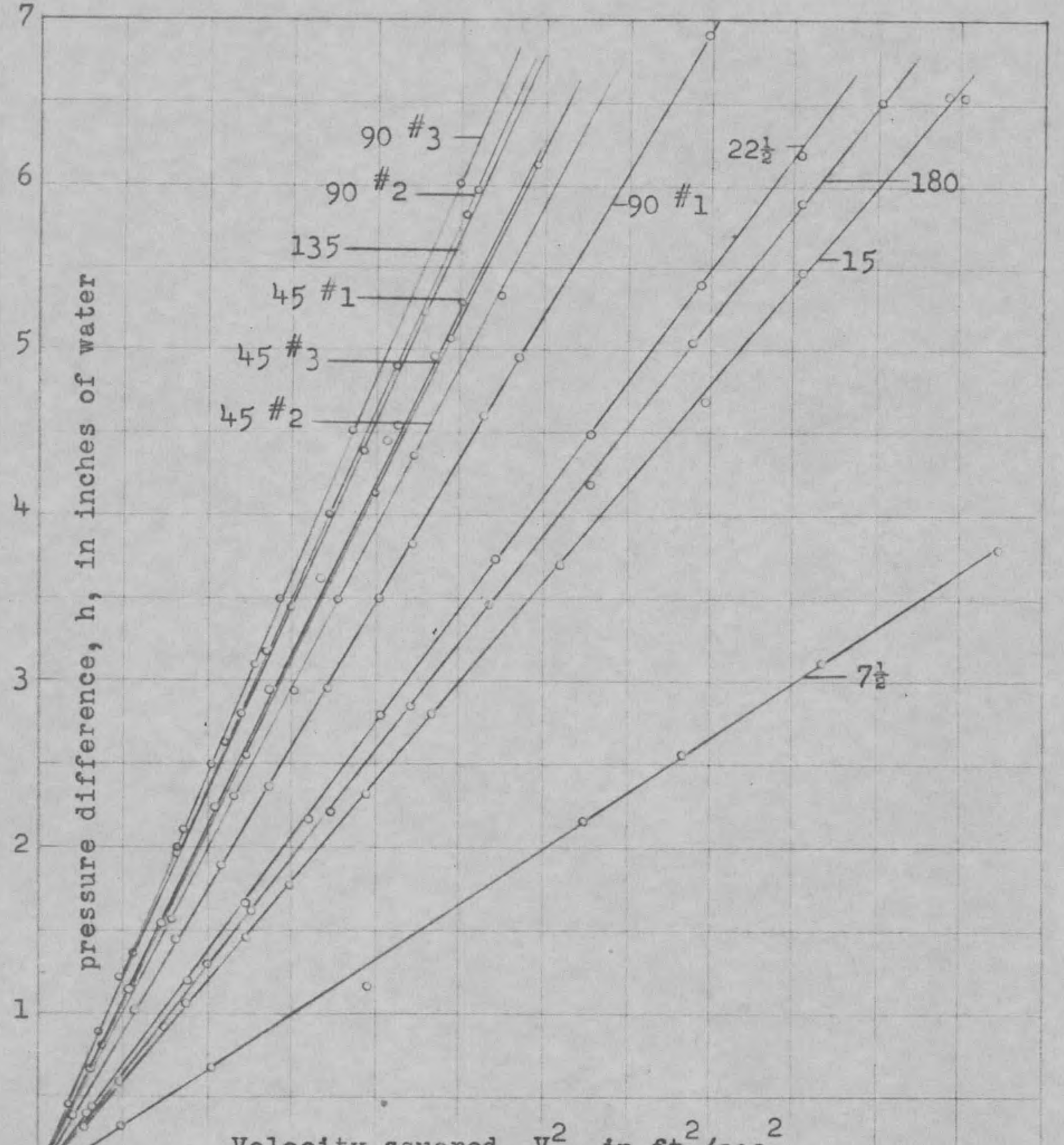


FIG. 15 THE RELATION BETWEEN PRESSURE DIFFERENCE AND THE SQUARE OF VELOCITY FOR THE LONG-RADIUS PIPE BENDS

different degrees of bend.

The effect of imperfectly built pipe bends. When the long-radius bends were constructed it was noticed that the drilling of the pressure taps produced prominent burrs on the inside of the very ductile pipe bends. An effort was made to see what effect these burrs had on the use of a pipe bend as a flow meter. Before the burrs were removed tests were run on the elbows, measuring pressure difference against flow. The comparison of the results of tests run on the pipe bends before the burrs were removed to the results of tests run after the burrs were removed are shown in Figures 16, 17, 18, 19, and 20.

It may be noted from the Figures that the burrs produced a higher pressure difference across the pipe bend for a given flow in all cases except for the 90 degree bend. Thus burrs, or imperfectly built pipe bends, certainly changed the flow characteristics of the bends. But the change was not predictable as to how much the pressure difference would be effected, or even whether the pressure difference would be larger or smaller for a given flow. The amount of effect of burrs in some cases was quite large. For a flow of one gallon per minute through the 7½ degree pipe bend the pressure difference created across the inside and outside curves is over 3½ times as great for the bend with burrs as the same bend

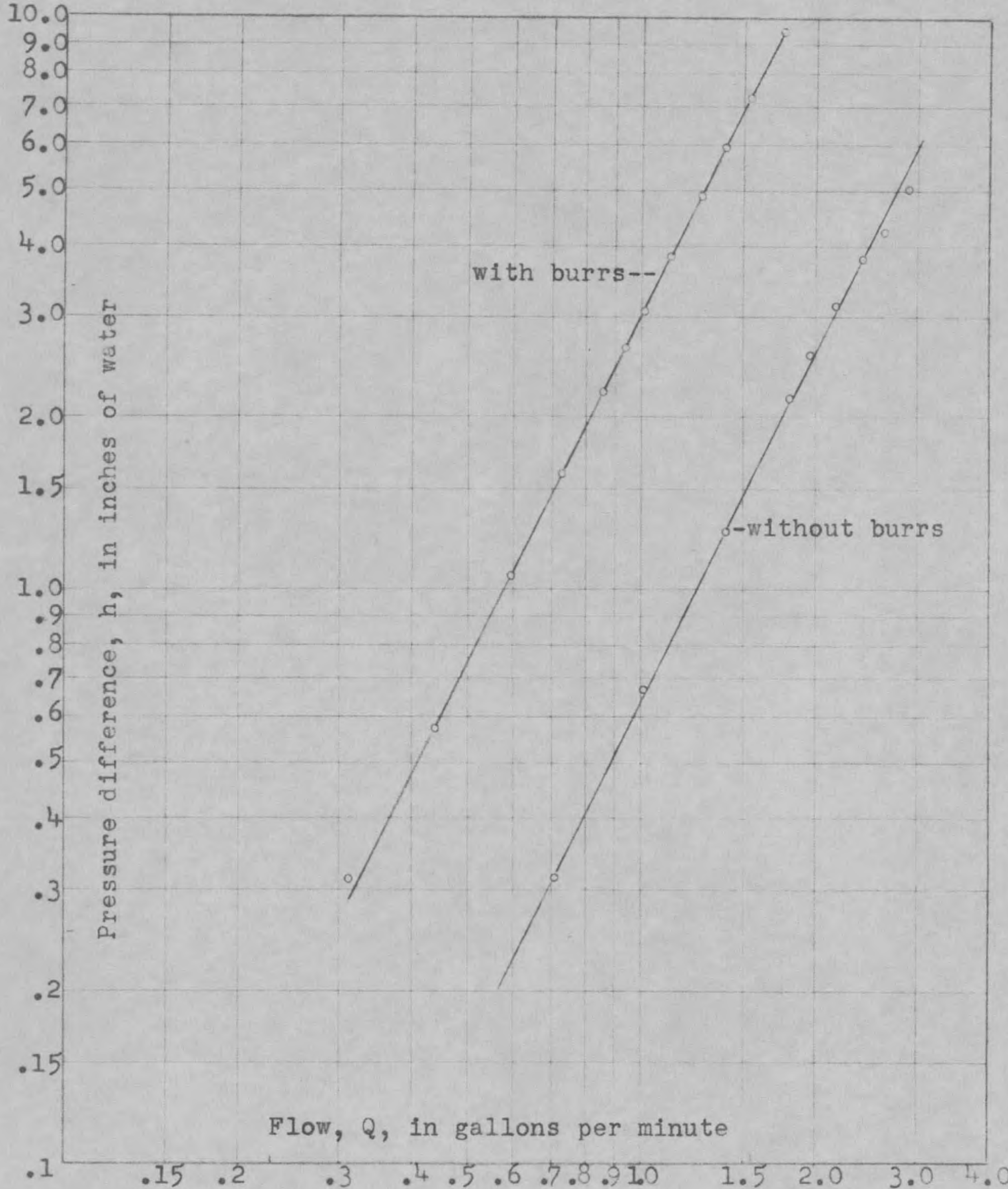


FIG. 16 COMPARISON OF RESULTS BEFORE AND AFTER BURRS WERE REMOVED FROM A 7 1/2 DEGREE PIPE BEND

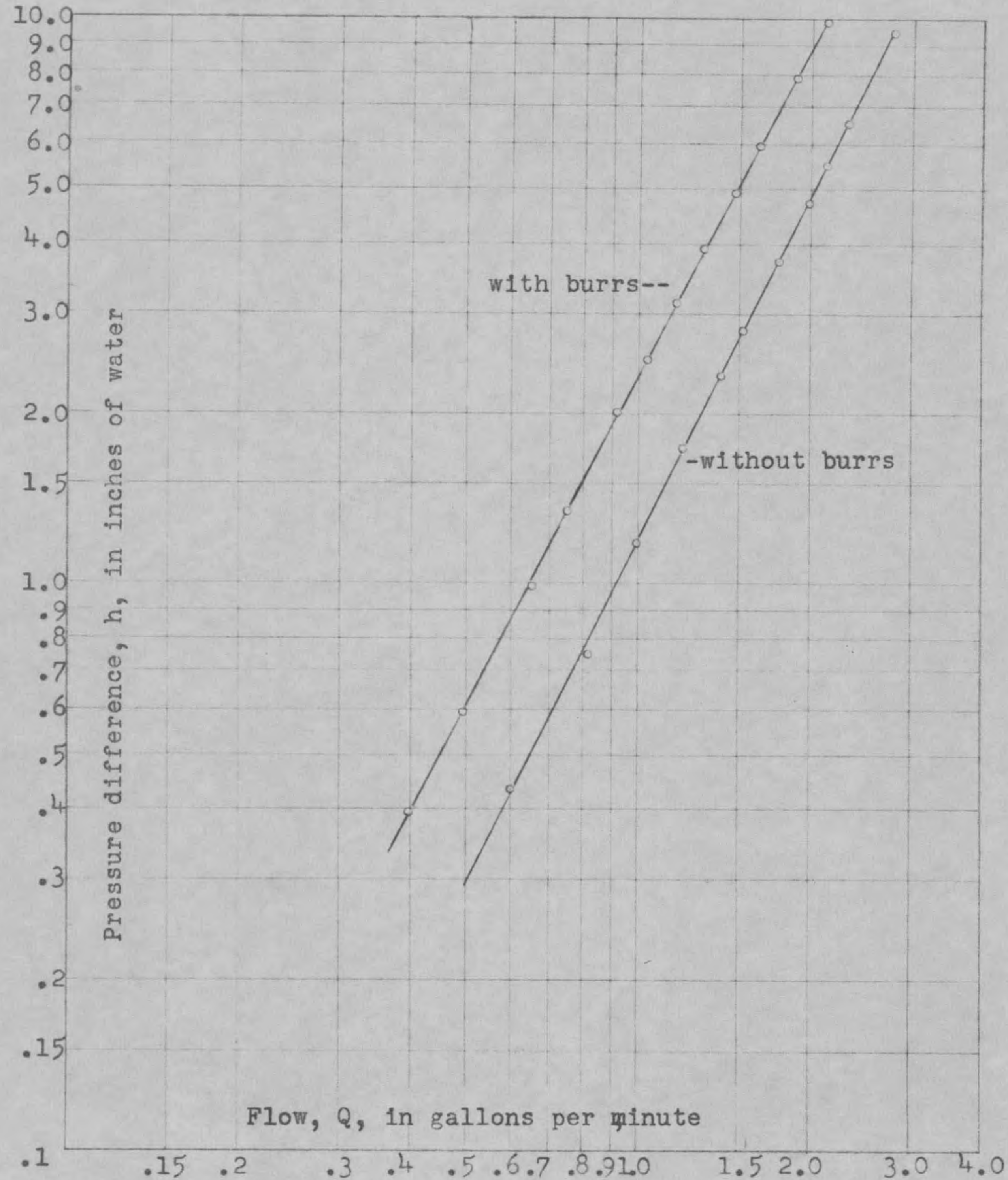


FIG 17 COMPARISON OF RESULTS BEFORE AND AFTER BURRS WERE REMOVED FROM A 15 DEGREE PIPE BEND

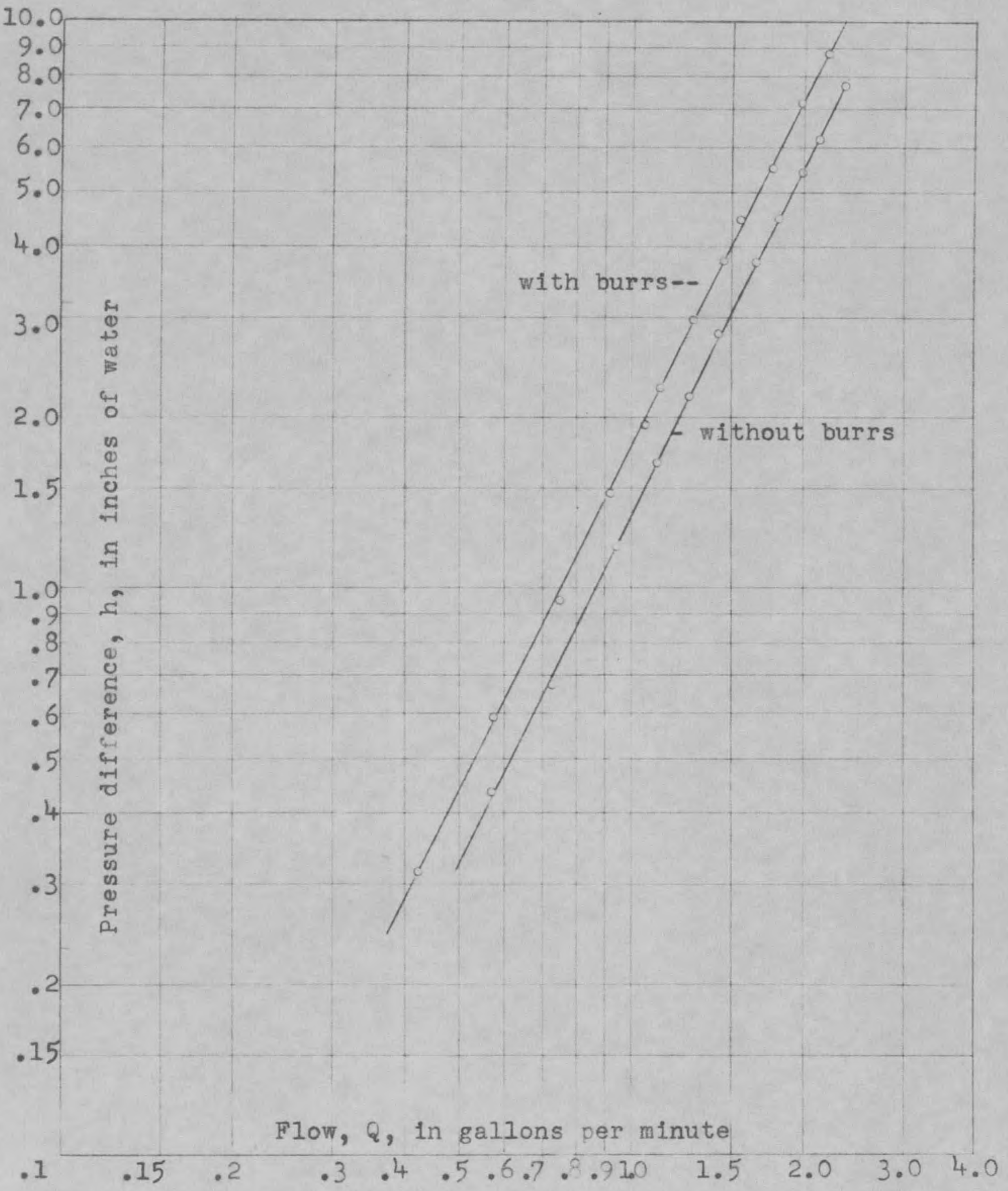


FIG. 18 COMPARISON OF RESULTS BEFORE AND AFTER BURRS WERE REMOVED FROM A 22 1/2 DEGREE PIPE BEND

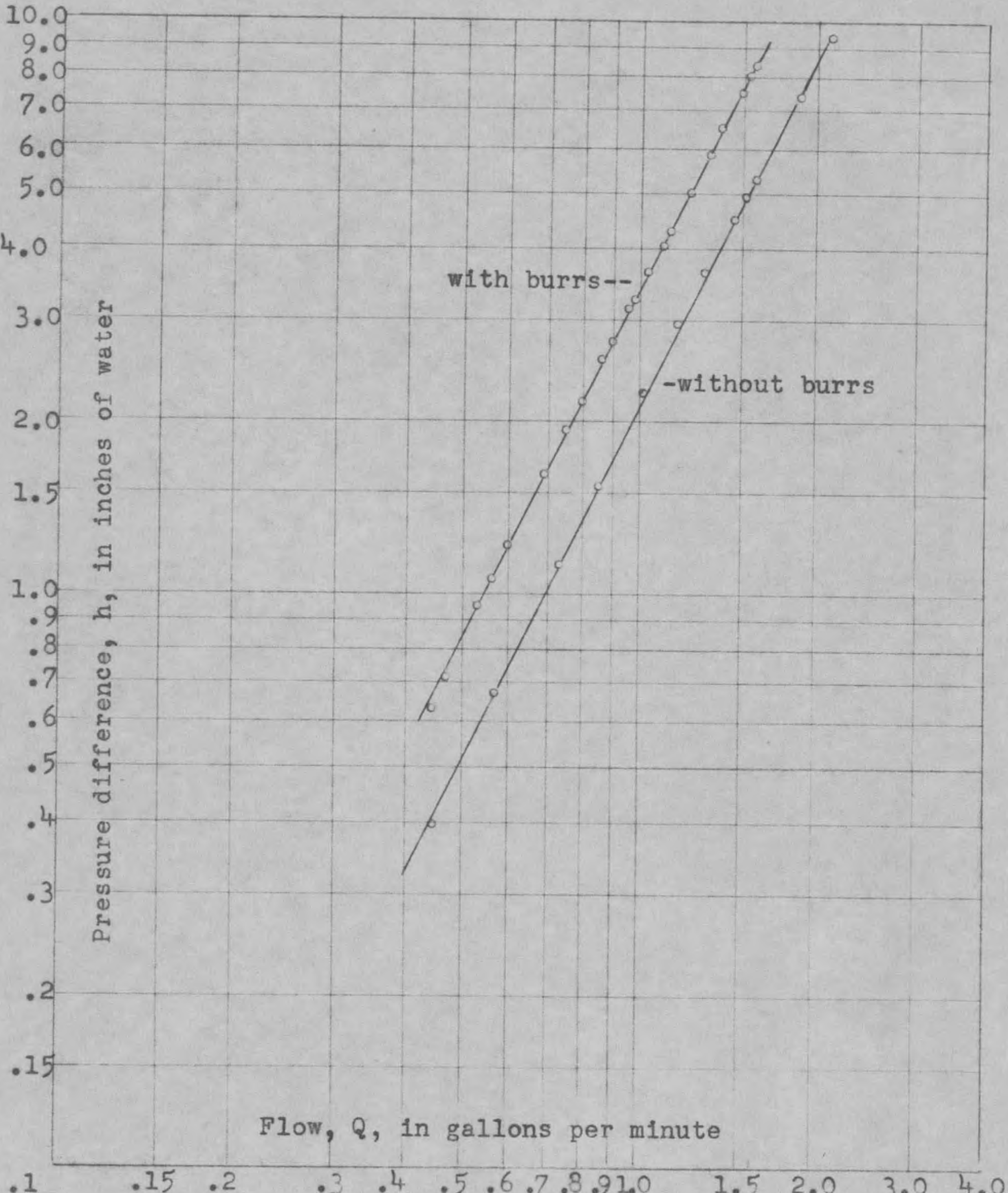


FIG. 19 COMPARISON OF RESULTS BEFORE AND AFTER BURRS WERE REMOVED FROM A 45 DEGREE PIPE BEND

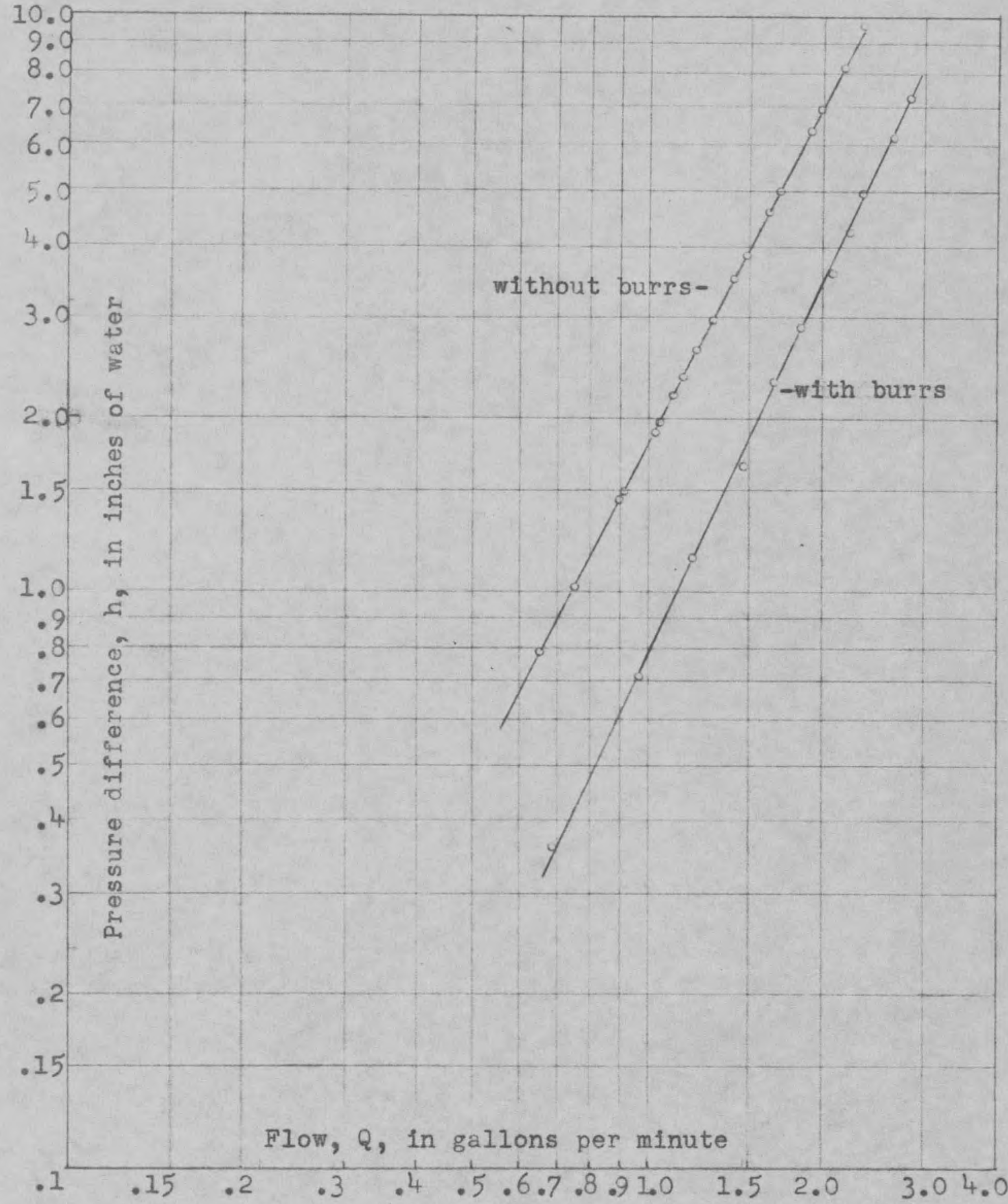


FIG. 20 COMPARISON OF RESULTS BEFORE AND AFTER BURRS WERE REMOVED FROM A 90 DEGREE PIPE BEND

without burrs. Thus it is recommended that each individual elbow be calibrated in the laboratory before being put into actual use as a flow meter.

It may also be noted from Figures 16, 17, 18, 19, and 20 that although the elbows had definite imperfections in the form of burrs near the pressure tap holes the relation between pressure difference and flow for each elbow is still definite and a straight line when plotted on logarithmic graph paper. So although a pipe bend is imperfectly built it will still produce satisfactory results if calibrated before being used in actual installation.

CHAPTER V

AN ANALYSIS OF THE RELATION BETWEEN PRESSURE DIFFERENCE AND THE SQUARE OF THE VELOCITY

In chapters III and IV when the pressure difference between the inside and outside curves of the pipe bend and the square of the mean velocity of flow were plotted against each other, the resulting relation was a straight line. This relation was represented by equation (6), $h = KV^2$, on page 33 in chapter III. If the constant, K, could be calculated from the physical dimensions of the pipe bend then the pipe bend would not need to be calibrated in the laboratory before being used as a flow meter.

In this chapter an effort will be made to express the value K in the equation $h = KV^2$ in terms of the physical dimensions of the pipe bend.

<u>Derivation of the relation</u>. Applying Newton's second law of motion to a weight traveling about a fixed point with a radius, R, the following expression is obtained.

$$F = \frac{WV^2}{gR}$$

where W = weight of the object in pounds

V = velocity of the object in feet per second

R = radius of the object about a fixed point in feet

g = gravitational constant in feet per second squared

Let this equation be applied to a small column of water moving through a pipe bend as shown in Figure 21.

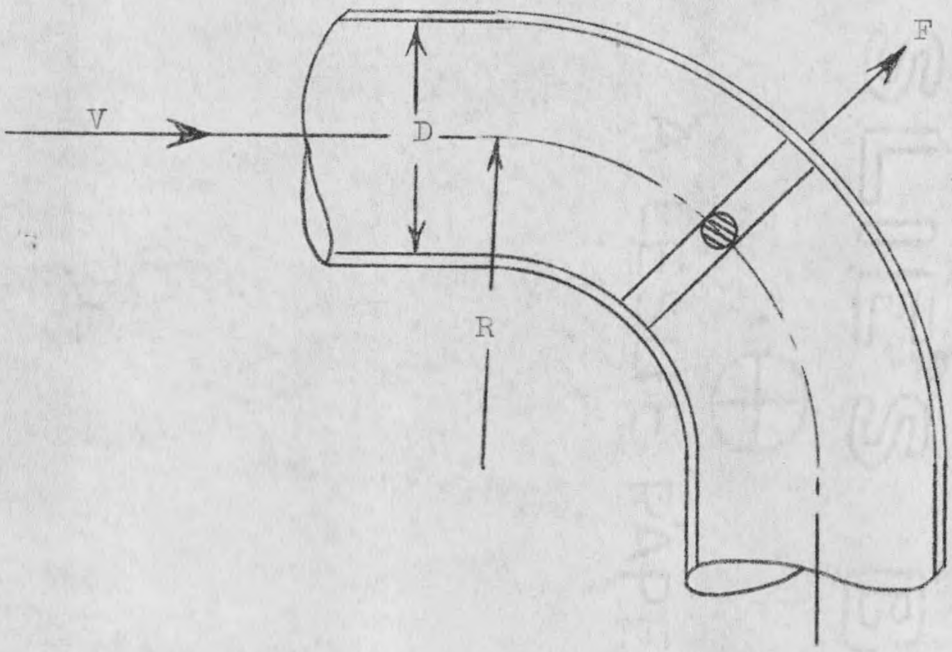


FIGURE 21. CROSS SECTION OF A PIPE BEND

If it is assumed that the column rotates about the center of curvature of the pipe bend then for a small column it may be written

$$F = \frac{ADwV^2}{g\ R} \tag{7}$$

where A = the cross section area of the column in square feet

D = length of the column, or diameter of the pipe bend, in feet

w = specific weight of the water column in pounds per cubic foot

Writing equation (7) in terms of head of fluid flowing results in

$$h' = \frac{F}{Aw} = \frac{ADwV^2}{AwgR}$$

$$h' = \frac{2D}{R}\frac{V}{2g} \qquad (8)$$

where h' = head in feet of fluid flowing

It is realized that equation (8) is an approximation, based on the assumption that the velocity distribution of the water flowing through the pipe bend is directly proportional to the distance from the point of rotation. However, equation (8) was used by several previous investigators on larger size pipe bends with fair results.[1, 2, 3]

---

1 A. M. Levin, "A Flow Metering Apparatus," Transactions A.S.M.E., 36:247, September 1914.

2 David L. Yarnell and Floyd A. Nagler, "Flow of Water Around Bends in Pipes," Transactions A.S.C.E., 100:1030, 1935

3 W. M. Lansford, "The Use of an Elbow in a Pipe Line For Determining the Rate of Flow in the Pipe," University of Illinois Engineering Experiment Station Bulletin No. 289, December 22, 1936, p. 23.

<u>Comparison of calculated results with test results.</u>
Before a comparison can be made between equation (8), $h' = \frac{2D}{R}\frac{V}{2g}$, and equation (6), $h = KV^2$, from page 33 chapter III, it is necessary to express the two equations in the same dimensions. The pressure difference, h, in equation (6) is expressed in inches of water while h' in equation (8) is expressed in feet of water.

$$h' = \frac{h}{12} = \frac{KV^2}{12} = \frac{2D}{R}\frac{V^2}{2g}$$

and

$$\frac{K}{12} = \frac{2D}{R\,2g}$$

$$K = \frac{12\,D}{Rg} \qquad (9)$$

The comparison of test values of K taken from the curves of pressure difference plotted against velocity squared, to the computed values of $\frac{12\,D}{Rg}$ is shown in table III. The values of diameter and radius of curvature were taken from the manufacture's blueprints for the cast elbows and were measured for the long-radius pipe bends.

It may be noted from table III that there is considerable deviation of the test constant from the computed constant. Thus it may be assumed that the actual flow is different from that assumed in the derivation of equation (8).

It is recommended that a flow meter constructed from a small copper pipe bend be calibrated in the laboratory before

TABLE III

COMPARISON OF COMPUTED ELBOW CONSTANTS AND TEST CONSTANTS

Type of Elbow	Computed Constant	Test Constant
	$\frac{12D}{Rg}$	K
1 inch cast	0.63	0.42
3/4 inch cast	0.64	0.51
1/2 inch cast	0.61	0.62
7½ degree	0.12	0.033
15 degree	0.12	0.06
22½ degree	0.12	0.069
45 degree No. 1	0.12	0.105
45 degree No. 2	0.12	0.098
45 degree No. 3	0.12	0.104
90 degree No. 1	0.12	0.087
90 degree No. 2	0.12	0.115
90 degree No. 3	0.12	0.121
135 degree	0.12	0.112
180 degree	0.12	0.065

being used in an actual installation. The actual flow through the pipe is difficult to predict because of the large variation in pressure difference due to imperfectly built pipe bends, and the inability to calculate an accurate flow constant.

CHAPTER VI

SUMMARY AND CONCLUSIONS

<u>Summary</u>. The purpose of this study was to investigate the possibility of using a pipe bend to measure the quantity of flow of water in small copper pipes. This was to be done by measuring the pressure difference between the inside and outside curves of the pipe bend.

Advantages of a pipe bend used as a flow meter include no additional resistance to flow and small original cost.

<u>Conclusions</u>. It was found that commercial 90 degree cast bronze solder-joint elbows may be used as flow meters in small copper pipes with good results. Also pipe bends between 7½ degrees and 180 degrees, made with a standard tube bender, will give satisfactory results when used as flow meters in small copper pipes.

The pressure difference, h, in inches of water and the flow, Q, in gallons per minute are related by the equation $h = ZQ^n$, where n takes the value of approximately 2, and Z is a constant depending upon the elbow.

The pressure difference, h, in inches of water and the square of the mean velocity of flow, V^2, in feet per second, squared, may be related by the equation $h = KV^2$, where K is a constant depending upon the pipe bend. The value of K found from the tests varies considerably from a calculated value when using a derived relation, $K = \frac{12\ D}{Rg}$.

When large burrs were left on the inside of the long-radius pipe bends, the effect on the pipe bend as a flow meter was to increase or decrease the pressure difference for a given flow but the relation between pressure difference and flow still remained a straight line when plotted on logarithmic graph paper.

It was found that a small cast elbow may be used very satisfactory as a flow meter when using a metric recording meter to measure the pressure differential.

When using a pipe bend as a flow meter in small copper pipes, the bend should be calibrated in the laboratory before being put into actual use.

LITERATURE CITED

"The Hyperbo Electric Flow Meter," Power, 57:1024-25, June 26, 1923.

Lansford, W. M., "The Use of an Elbow in a Pipe Line for Determining the Rate of Flow in the Pipe," University of Illinois Engineering Experiment Station Bulletin No. 289, December 22, 1936. 36 pp.

Levin, A. M., "A Flow Metering Apparatus," Transactions A.S.M.E., 36:239-54, September 1914.

Winter, Ireal A., "Improved Type of Flow Meter for Hydraulic Turbines," Transactions A.S.C.E., 99:847-66, 1934.

Yarnell, David L., and Floyd A. Nagler, "Flow of Water Around Bends in Pipes," Transactions A.S.C.E., 100:1018-32, 1935

APPENDIX

TEST OF A 1 INCH 90 DEGREE SOLDER-JOINT CAST BRONZE ELBOW

Manometer fluid sp. gr. 2.95 Water temp. 40 F

	Static Press.	Water Weight	Time	Flow	Manometer	Press. Diff.	V^2	Reynold's Number
	Psig.	lb.	Min.	G.P.M.	Inches Fluid	Inches Water	$\frac{ft^2}{sec^2}$	-
1	4.5	200	6.0	4.0	0.70	1.36	2.44	7,700
2	9.7	200	3.913	6.15	1.1	2.14	5.76	11,850
3	14.9	200	3.14	7.33	1.83	3.57	8.12	14,000
4	19.6	200	2.735	8.4	2.5	4.88	10.7	16,100
5	5.0	200	3.35	6.87	1.5	2.92	7.19	13,200
6	4.9	200	2.0	12.0	4.8	9.36	21.8	23,000
7	4.9	200	1.493	16.7	8.2	16.0	42.3	32,000
8	4.4	200	1.166	20.6	14.4	28.1	64.1	39,600
9	4.45	200	1.067	22.5	16.2	31.6	76.6	44,000
10	7.15	200	0.85	28.3	26.2	51.1	121.0	54,500
11	10.65	200	0.983	24.4	20.5	40.0	90.3	47,000
12	9.75	200	1.33	18.05	10.55	20.6	49.5	34,700
13	10.35	200	2.30	10.42	3.2	6.25	16.5	20,000
14	15.0	200	2.92	7.89	2.4	5.7	9.43	15,150
15	15.1	200	1.87	12.87	5.4	10.5	25.0	24,700
16	15.25	200	1.27	18.85	11.2	21.8	54.0	36,200
17	16.0	200	1.12	21.5	14.8	28.9	70.0	41,300
18	15.2	200	0.93	25.7	21.0	41.0	100.0	49,500
19	14.65	200	0.83	28.8	27.1	53.0	125.0	55,300

TEST OF A 1 INCH 90 DEGREE SOLDER-JOINT
CAST BRONZE ELBOW

Manometer fluid sp. gr. 2.95 Water temp. 40 F

	Static Press.	Water Weight	Time	Flow	Manometer	Press. Diff.	V^2	Reynold's Number
	Psig.	lb.	Min.	G.P.M.	Inches Fluid	Inches Water	$\frac{ft^2}{sec^2}$	-
1	12.0	200	5.79	4.15	0.65	1.27	2.6	7,960
2	12.4	200	5.02	4.69	0.80	1.56	3.3	9,000
3	12.4	200	3.13	7.68	1.95	3.8	6.75	12,800
4	12.4	200	2.69	8.93	2.60	5.25	12.02	17,100
5	12.4	200	2.42	9.94	3.20	6.25	14.9	19,000
6	12.1	200	2.25	10.68	3.60	7.03	17.2	20,500
7	12.0	200	2.04	11.81	4.45	8.68	22.2	22,700
8	12.0	200	1.71	15.05	6.40	12.5	30.0	27,000
9	12.2	200	1.62	14.8	7.0	13.65	33.2	28,500
10	12.1	200	1.41	17.2	9.1	17.7	45.0	33,000
11	12.1	200	1.30	18.48	11.0	21.4	51.6	35,500
12	12.2	200	1.21	19.85	12.8	25.0	59.6	38,200
13	12.6	200	1.05	22.85	17.4	33.9	79.3	44,000
14	12.6	200	0.97	24.70	20.4	39.8	92.4	47,500
15	12.0	200	1.13	21.20	14.6	28.4	68.0	40,700

TEST OF A 1 INCH 90 DEGREE SOLDER-JOINT
CAST BRONZE ELBOW

Manometer fluid sp. gr. 13.6 Water temp 40 F

	Static Press.	Water Weight	Time	Flow	Manometer	Press. Diff.	V^2	Reynold's Number
	Psig	lb.	Min.	G.P.M.	Inches Fluid	Inches Water	$\frac{ft^2}{sec^2}$	-
1	6.5	200	1.63	14.75	1.10	13.9	33.1	28,400
2	6.5	200	2.36	10.2	0.5	6.3	15.75	19,600
3	6.8	200	3.82	6.3	0.20	2.52	6.0	12,000
4	6.5	200	1.44	16.7	1.3	16.4	42.3	32,000
5	6.3	200	1.21	19.85	2.0	25.2	59.6	38,200
6	6.5	200	0.913	26.3	3.4	42.8	104.0	50,500
7	6.3	200	1.34	17.9	1.6	20.2	48.6	35,500
8	6.8	200	1.74	13.65	0.9	11.3	28.2	26,300
9	10.0	200	1.46	16.4	1.3	16.4	40.8	31,500
10	10.0	200	1.21	19.9	2.0	25.2	60.0	28,300
11	10.0	200	1.04	23.1	2.6	32.8	81.0	44,500
12	10.0	200	0.94	25.4	3.25	41.0	97.5	49,000
13	4.2	200	2.91	8.25	0.35	4.4	10.24	15,800
14	4.1	200	1.83	13.1	0.85	10.7	26.0	25,200
15	4.0	200	1.27	18.85	1.6	21.4	54.0	36,200
16	4.0	200	0.92	26.0	3.2	40.3	102.0	50,000

TEST OF A 3/4 INCH 90 DEGREE SOLDER-JOINT
CAST BRONZE ELBOW

Manometer fluid sp. gr. 2.95 Water temp. 40 F

	Static Press.	Water Weight	Time	Flow	Manometer	Press. Diff.	V^2	Reynold's Number
	Psig.	lb.	Min.	G.P.M.	Inches Fluid	Inches Water	$\frac{ft^2}{sec^2}$	-
1	7.0	200	1.87	12.9	18.5	36.1	72.6	32,300
2	5.5	200	2.45	9.81	10.9	21.2	42.0	24,500
3	4.0	100	1.65	7.29	6.1	11.9	23.2	18,300
4	5.0	325	4.40	8.86	9.0	17.55	34.2	22,200
5	5.25	200	2.43	9.90	11.0	21.4	42.7	24,800
6	6.5	200	2.02	11.9	16.0	31.2	61.6	29,900
7	6.0	200	2.10	11.5	14.9	29.05	57.9	28,900
8	5.5	200	2.38	10.05	11.4	22.2	44.1	25,200
9	5.-	100	1.42	8.45	8.3	16.2	31.2	21,200
10	8.0	100	1.57	7.67	6.85	13.35	25.6	19,200
11	7.25	100	1.77	6.80	5.4	10.5	20.2	17,100
12	6.0	100	2.02	5.96	4.2	8.2	15.5	15,000
13	5.5	75	1.74	5.16	3.2	6.25	11.6	13,000
14	5.0	75	1.95	4.62	2.8	5.46	9.3	11,600
15	4.75	75	2.07	4.35	2.25	4.4	8.24	10,900
16	4.0	50	1.7	3.52	1.50	2.92	5.43	8,850
17	3.75	50	2.01	2.98	1.0	1.95	3.88	7,500
18	3.5	30	1.7	2.12	0.60	1.17	1.96	5,330

TEST OF A 1/2 INCH 90 DEGREE SOLDER-JOINT
CAST BRONZE ELBOW

Manometer fluid sp. gr. 2.95 Water temp. 40 F

	Static Press.	Water Weight	Time	Flow	Manometer	Press. Diff.	V	Reynold's Number
	Psig.	lb.	Min.	G.P.M.	Inches Fluid	Inches Water	$\frac{ft^2}{sec^2}$	-
1	9.8	100	2.03	5.91	20.8	40.6	66.1	21,400
2	10.1	100	2.43	4.94	14.2	27.7	46.3	17,900
3	7.4	100	3.00	4.0	9.5	18.5	30.3	14,500
4	5.2	100	2.38	5.05	15.0	29.2	48.2	18,250
5	10.5	100	3.30	3.64	7.8	15.2	25.0	13,150
6	7.5	75	3.09	2.91	5.1	9.95	16.0	10,500
7	9.7	50	2.29	2.62	4.1	8.0	12.96	9,500
8	8.5	50	2.8	2.14	2.75	5.36	8.65	7,730
9	6.0	50	3.51	1.71	1.80	3.51	6.0	6,450
10	5.0	50	3.85	1.56	1.50	2.92	4.62	5,650
11								

TEST OF A 1 INCH 90 DEGREE SOLDER-JOINT CAST BRONZE ELBOW USING A METRIC RECORDING METER

Water temp. 58 F.

	Water Weight	Time	Flow	Meter Reading	Press. Diff.	V	Reynold's Number
	lb.	Min.	G.P.M.	-	Inches Water	$\frac{ft^2}{sec^2}$	
1	200	9.87	2.43	4.1	0.42	0.895	6,250
2	200	7.85	3.06	5.15	0.664	1.42	7,860
3	200	6.21	3.86	6.3	0.993	2.25	9,900
4	200	5.62	4.27	7.1	1.26	2.76	11,000
5	200	4.92	4.88	8.1	1.64	3.61	12,500
6	200	4.16	5.77	9.5	2.26	5.02	14,800
7	200	4.56	5.26	8.9	1.98	4.1	13,500
8	200	4.0	6.0	9.85	2.42	5.47	15,500
9	200	12.19	1.97	3.65	0.333	0.589	5,050
10	200	16.42	1.46	2.8	0.196	0.323	3,750
11	500	14.09	4.26	7.1	1.26	2.76	11,000
12	500	10.56	5.68	9.33	2.175	4.89	14,600
13	300	16.98	2.12	3.75	0.352	0.68	5,450
14	275	20.8	1.58	2.75	0.189	0.381	4,100
15	200	11.36	2.11	3.6	0.324	0.675	5,400
16	500	14.58	4.12	6.76	1.14	2.56	10,500
17	500	10.39	5.78	9.55	2.28	5.07	15,000

TEST OF A 3/4 INCH 90 DEGREE SOLDER-JOINT CAST BRONZE ELBOW
USING A METRIC RECORDING METER

Water temp. 58 F

	Water Weight	Time	Flow	Meter Reading	Press. Diff.	V^2	Reynold's Number
	lb.	Min.	G.P.M.	-	Inches Water	$\frac{ft^2}{sec^2}$	-
1	275	18.53	1.78	5.7	0.813	1.39	5,940
2	105	15.55	0.81	2.5	0.156	0.286	2,700
3	500	19.58	3.06	9.6	2.3	4.04	10,200
4	300	14.35	2.51	8.0	1.6	2.76	8,400
5	320	17.18	2.24	7.125	1.28	2.19	7,500

TEST OF A 1/2 INCH 90 DEGREE SOLDER-JOINT CAST BRONZE ELBOW
USING A METRIC RECORDING METER

Water temp. 58 F

	Water Weight	Time	Flow	Meter Reading	Press. Diff.	V	Reynold's Number
	lb.	Min.	G.P.M.	-	Inches Water	$\frac{ft^2}{sec^2}$	-
1	105	9.63	1.31	9.13	2.08	3.24	6,310
2	92	10.04	1.10	7.7	1.48	2.28	5,300
3	74	12.87	0.69	4.9	0.6	0.903	3,330
4	57	14.03	0.49	3.5	0.31	0.45	2,350
5	30	9.15	0.39	2.85	0.203	0.293	1,900
6	21	10.08	0.25	1.8	0.081	0.118	1,200

TEST OF SIX 3/8 INCH 90 DEGREE SOLDER-JOINT CAST BRONZE ELBOWS USING A METRIC RECORDING METER

Water temp. 58 F

	Water Weight	Time	Flow	Meter Reading	Press. Diff.	V^2	Reynold's Number
	lb.	Min.	G.P.M.	-	Inches Water	$\frac{ft^2}{sec^2}$	
	74	11.81	0.751	7.73	1.49	2.76	4,600
1	54	11.83	0.548	5.71	0.815	1.46	3,350
	100	12.44	0.963	9.81	2.4	4.5	5,860
	66	9.77	0.81	8.15	1.66	3.17	4,920
2	56	14.42	0.465	5.0	0.625	1.04	2,820
	85	10.78	0.947	9.4	2.21	4.37	5,780
	75	10.18	0.885	9.08	2.06	3.8	5,400
3	47	7.94	0.71	7.36	1.35	2.44	4,300
	34	10.49	0.389	4.25	0.451	0.74	2,380
	86	9.99	1.033	9.9	2.45	5.2	6,300
4	59	9.57	0.74	6.85	1.17	2.66	4,500
	28	9.57	0.351	3.4	0.289	0.59	2,120
	102	12.62	0.98	9.7	2.35	4.66	6,000
5	55	9.72	0.68	6.97	1.215	2.25	4,150
	55	14.52	0.455	4.95	0.613	1.0	2,670
	85	10.98	0.93	9.05	2.04	4.1	5,670
6	64	11.36	0.676	6.72	1.13	2.22	4,120
	33	11.29	0.35	3.8	0.36	0.594	2,120

TEST OF A 7 1/2 DEGREE 3/8 INCH O.D. COPPER PIPE BEND

Water filled manometer   Water temp. 40 F.

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.315	10	1.712	0.701	9.85	5,750
2	0.67	10	1.2	1.0	20.2	8,200
3	1.26	10	0.862	1.39	39.0	11,400
4	2.16	20	1.34	1.79	64.6	14,700
5	2.56	20	1.232	1.946	76.4	16,000
6	3.11	20	1.117	2.15	93.1	17,650
7	3.78	20	1.005	2.39	114.7	19,600
8	5.0	20	0.833	2.88	166.5	23,000

TEST OF A 15 DEGREE 3/8 INCH O.D. COPPER PIPE BEND

Water filled manometer — Water temp. 40 F.

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	
1	0.434	10	2.007	0.598	7.18	4,900
2	0.749	10	1.475	0.814	13.3	6,700
3	1.18	10	1.216	0.988	19.6	8,100
4	1.73	10	1.008	1.19	28.5	9,800
5.	2.32	20	1.726	1.39	39.0	10,400
6	2.80	20	1.577	1.52	46.5	12,500
7	3.70	20	1.374	1.75	61.9	14,400
8	4.69	20	1.21	1.98	79.0	16,300
9	5.48	20	1.133	2.12	90.6	17,400
10	6.54	20	1.035	2.32	108.0	19,000
11	6.54	20	1.027	2.34	110.0	19,200
12	9.45	20	0.867	2.75	151.0	22,500

TEST OF A 22½ DEGREE 3/8 INCH O.D. COPPER PIPE BEND

Water filled manometer — Water temp. 40 F.

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.434	10	2.133	0.563	6.35	4,610
2	0.67	10	1.66	0.722	10.5	5,940
3	1.18	10	1.278	0.94	17.7	7,700
4	1.65	10	1.087	1.103	24.5	9,060
5	2.16	10	0.95	1.26	32.0	10,300
6	2.80	20	1.695	1.417	40.4	11,600
7	3.74	20	1.46	1.64	54.0	13,450
8	4.49	20	1.332	1.80	65.4	14,800
9	5.4	20	1.217	1.975	78.5	16,200
10	6.19	20	1.135	2.12	90.5	17,400
11	7.65	20	1.027	2.34	110.0	19,200
12	10.3	20	0.892	2.69	146.4	22,200

TEST OF A 45 DEGREE 3/8 INCH O.D.
COPPER PIPE BEND

ELBOW #1

Water filled manometer Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	
1	0.394	10	2.704	0.444	3.92	3,630
2	0.67	10	2.125	0.565	6.2	4,560
3	1.14	10	1.647	0.73	10.7	6,000
4	1.535	10	1.417	0.848	14.4	6,970
5	2.24	10	1.19	1.01	20.5	8,300
6	2.95	10	1.037	1.16	27.0	9,520
7	3.62	20	1.87	1.28	33.1	10,500
8	4.45	20	1.68	1.43	41.1	11,750
9	5.28	20	1.527	1.57	49.8	12,900
10	4.96	20	1.58	1.52	46.5	12,500
11	4.53	20	1.65	1.45	42.3	11,900
12	7.36	20	1.284	1.87	70.5	15,400
13	9.38	20	1.138	2.11	89.5	17,300

TEST OF A 45 DEGREE 3/8 INCH O.D.
COPPER PIPE BEND

ELBOW #2

Water filled manometer | Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.512	10	2.481	0.484	4.71	3,980
2	0.828	10	1.912	0.627	7.90	5,150
3	1.22	10	1.565	0.767	11.8	6,300
4	1.575	10	1.362	0.88	16.0	7,330
5	2.32	10	1.115	1.075	23.2	8,830
6	2.95	10	0.977	1.23	30.5	10,100
7	3.50	10	0.904	1.33	35.6	10,900
8	4.37	10	0.804	1.49	44.8	12,250
9	5.35	20	1.455	1.65	55.0	13,600
10	7.33	20	1.25	1.92	74.1	15,800
11	8.98	20	1.127	2.13	91.4	17,500

TEST OF A 45 DEGREE 3/8 INCH O.D. COPPER PIPE BEND

ELBOW #3

Water filled manometer Water temp. 40 F.

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.394	10	2.945	0.408	3.35	3,350
2	0.827	10	1.954	0.615	7.61	5,060
3	1.22	10	1.575	0.762	11.70	6,260
4	1.57	10	1.387	0.866	15.10	7,120
5	1.97	10	1.247	0.965	18.75	7,930
6	2.56	10	1.082	1.11	24.8	9,110
7	3.35	20	1.913	1.25	31.5	10,300
8	4.14	20	1.70	1.41	40.1	11,600
9	5.09	20	1.545	1.55	48.5	12,750
10	6.15	20	1.404	1.71	59.0	15,000
11	7.56	20	1.264	1.90	72.8	15,600
12	9.02	20	1.155	2.08	87.3	17,100

TEST OF A 90 DEGREE 3/8 INCH O.D. COPPER PIPE BEND

ELBOW #1

Water filled manometer — Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	--
1	0.788	10	1.85	0.65	8.53	5,350
2	1.45	20	2.68	0.895	16.1	7,350
3	1.02	10	1.60	0.75	11.3	6,150
4	1.89	10	1.163	1.03	21.4	8,460
5	2.95	10	0.925	1.30	34.15	10,700
6	3.82	30	2.43	1.48	44.1	12,150
7	4.95	20	1.43	1.68	56.9	13,800
8	6.92	10	0.607	1.98	79.0	16,250
9	7.98	20	1.13	2.15	93.1	17,650
10	7.98	20	1.028	2.33	109.5	19,150
11	9.63	10	1.037	1.16	27.2	9,550
12	2.36	10	1.84	0.65	8.53	5,350
13	0.788	10	1.61	0.745	11.16	6,120
14	1.02	10	1.304	0.92	17.06	7,560
15	1.49	10	1.135	1.06	22.65	8,720
16	1.97	10	1.084	1.11	24.8	9,120
17	2.20	10	0.99	1.21	29.5	9,950

TEST OF A 90 DEGREE 3/8 INCH O.D.

COPPER PIPE BEND

ELBOW #2

Water filled manometer — Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.512	10	2.78	0.432	3.77	3,560
2	0.906	10	2.003	0.599	7.18	4,900
3	1.38	10	1.587	0.757	11.6	6,230
4	2.01	10	1.314	0.913	16.8	7,500
5	2.64	10	1.13	1.06	22.8	8,710
6	3.19	10	1.032	1.16	27.0	9,520
7	4.01	10	0.917	1.31	34.6	10,800
8	4.92	10	0.824	1.46	43.0	12,000
9	5.83	10	0.754	1.59	51.0	13,100
10	7.8	20	1.304	1.84	68.2	15,100
11	8.67	20	1.24	1.94	76.0	16,000

TEST OF A 90 DEGREE 3/8 INCH O.D.
COPPER PIPE BEND

ELBOW #3

Water filled manometer — Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.473	10	2.937	0.41	3.38	3,370
2	0.827	10	2.152	0.559	6.25	4,580
3	1.22	10	1.738	0.691	9.60	5,690
4	1.69	10	1.427	0.842	14.3	6,920
5	2.12	20	2.602	0.922	17.1	7,560
6	2.52	10	1.185	1.01	20.5	8,300
7	3.11	10	1.068	1.125	25.5	9,250
8	3.50	20	2.012	1.19	28.6	9,770
9	4.53	20	1.77	1.36	37.2	11,200
10	6.03	20	1.525	1.575	49.9	12,900
11	7.64	20	1.354	1.77	63.2	14,500

TEST OF A 135 DEGREE 3/8 INCH O.D.
COPPER PIPE BEND

Water filled manometer — Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	
1	0.512	10	2.76	0.435	3.80	3,570
2	0.865	10	2.013	0.597	7.18	4,910
3	1.38	10	1.59	0.755	11.5	6,210
4	1.97	10	1.327	0.905	16.5	7,450
5	2.76	10	1.102	1.09	24.0	8,970
6	3.46	10	0.98	1.22	30.0	10,000
7	4.4	10	0.87	1.38	38.5	11,350
8	5.24	10	0.798	1.50	45.4	12,300
9	6.00	10	0.749	1.60	51.6	13,100
10	7.40	20	1.338	1.80	65.4	14,700
11	8.85	20	1.22	1.97	78.1	16,200

TEST OF A 180 DEGREE 3/8 INCH O.D. COPPER PIPE BEND

Water filled manometer — Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	
1	0.315	10	2.262	0.53	5.66	4,360
2	0.59	10	1.71	0.702	9.92	5,770
3	0.906	10	1.392	0.862	15.0	7,100
4	1.3	10	1.214	0.989	19.7	8,130
5	1.61	10	1.07	1.12	25.3	9,200
6	2.20	10	0.914	1.315	34.8	10,800
7	2.84	20	1.625	1.48	44.1	12,150
8	3.46	20	1.47	1.63	53.5	13,400
9	4.18	20	1.337	1.80	65.4	14,800
10	5.04	20	1.222	1.96	77.5	16,100
11	5.91	20	1.132	2.12	90.5	17,400
12	7.8	20	0.983	2.40	116.8	19,800
13	9.41	20	0.895	2.68	14410	22,000

TEST OF A 7 1/2 DEGREE 3/8 INCH O.D. COPPER PIPE
BEND BEFORE BURRS WERE REMOVED

Water filled manometer Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	
1	0.315	10	3.907	0.308	1.91	2,530
2	0.571	10	2.754	0.437	3.84	3,590
3	1.06	10	2.025	0.593	7.07	4,870
4	1.58	10	1.664	0.722	10.5	5,940
5	2.01	10	1.50	0.80	12.9	6,580
6	2.20	10	1.407	0.855	14.75	7,040
7	2.64	10	1.294	0.928	17.3	7,620
8	3.07	10	1.188	1.01	20.6	8,300
9	3.82	20	2.14	1.12	25.3	9,200
10	4.89	20	1.904	1.26	32.1	10,400
11	5.91	20	1.72	1.395	39.2	11,500
12	7.21	20	1.572	1.536	47.6	12,600
13	9.46	20	1.377	1.745	61.5	14,350
14	11.0	20	1.270	1.89	72.0	15,500

TEST OF A 15 DEGREE 3/8 INCH O.D. COPPER PIPE BEND BEFORE BURRS WERE REMOVED

Water filled manometer Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	
1	0.394	10	3.052	0.394	3.14	3,240
2	0.591	10	2.432	0.494	4.89	4,070
3	0.985	10	1.854	0.648	8.40	5,310
4	1.34	10	1.614	0.745	11.15	6,120
5	2.01	10	1.31	0.917	16.9	7,540
6	2.48	10	1.163	1.03	21.4	8,460
7	3.11	10	1.04	1.16	27.0	9,520
8	3.90	20	1.852	1.295	33.8	10,650
9	4.89	20	1.65	1.456	42.6	11,950
10	5.95	20	1.492	1.61	52.1	13,200
11	7.80	20	1.288	1.865	70.0	15,300
12	9.90	20	1.137	2.11	89.6	17,300

TEST OF A 22 1/2 DEGREE 3/8 INCH O.D. COPPER PIPE BEND BEFORE BURRS WERE REMOVED

Water filled manometer — Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.315	10	2.84	0.423	3.62	3,480
2	0.59	10	2.095	0.573	6.6	4,710
3	0.945	10	1.607	0.749	11.3	6,150
4	1.46	10	1.302	0.921	17.1	7,580
5	1.93	10	1.136	1.06	22.7	8,720
6	2.24	10	1.068	1.125	25.5	9,250
7	2.95	20	1.870	1.28	33.1	10,500
8	3.74	20	1.65	1.45	42.5	11,900
9	4.47	20	1.556	1.54	47.8	12,650
10	5.48	20	1.358	1.77	63.2	14,550
11	7.17	20	1.219	1.97	78.4	16,200
12	8.75	20	1.09	2.18	96.0	17,950

TEST OF A 45 DEGREE 3/8 INCH O.D. COPPER PIPE BEND BEFORE BURRS WERE REMOVED

ELBOW #1

Water filled manometer Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	-
1	0.71	10	2.57	0.47	4.45	3,860
2	1.06	10	2.157	0.56	6.30	4,600
3	1.61	10	1.748	0.69	9.60	5,680
4	2.16	10	1.505	0.80	12.90	6,580
5	2.75	20	2.662	0.90	16.30	7,400
6	3.26	20	2.449	0.98	19.4	8,060
7	4.05	20	2.189	1.10	24.3	9,010
8	5.0	20	1.97	1.22	30.0	10,000
9	5.86	20	1.82	1.32	35.2	10,850
10	7.51	20	1.612	1.49	44.8	12,200
11	8.38	20	1.527	1.57	49.7	12,900
12	10.10	20	1.387	1.73	60.3	14,200

TEST OF A 90 DEGREE 3/8 INCH O.D. COPPER PIPE BEND BEFORE BURRS WERE REMOVED

ELBOW #1

Water filled manometer Water temp. 40 F

	Press. Diff.	Water Weight	Time	Flow	V^2	Reynold's Number
	Inches Water	lb.	Min.	G.P.M.	$\frac{ft^2}{sec^2}$	
1	0.354	10	1.762	0.681	9.36	5,600
2	0.71	10	1.247	0.964	18.75	7,930
3	1.14	10	0.996	1.195	28.8	9,840
4	1.65	20	1.65	1.456	42.9	12,000
5	2.32	20	1.46	1.644	54.8	13,550
6	2.88	20	1.308	1.84	68.2	15,100
7	3.58	20	1.157	2.08	87.5	17,100
8	4.21	20	1.077	2.23	100.0	18,300
9	4.96	20	1.028	2.34	110.0	19,200
10	6.19	20	0.912	2.64	140.0	21,700
11	7.25	20	0.85	2.82	160.0	23,200