

SOME PHENOMENON REGARDING THE RESISTANCE OF
STEAM FLOW IN DIFFERENT KINDS OF PIPE BENDS

by

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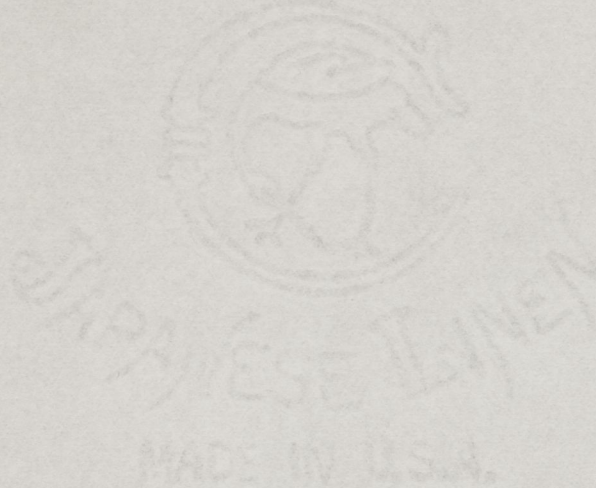
JAPANESE LINE
MADE IN U.S.A.

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APPRECIATION

At this time I wish to express my appreciation for the cooperation given me by W. R. Woolrich, Professor of Mechanical Engineering, and Mr. H. E. Ayres, Instructor of Mechanical Engineering, at the University of Tennessee, in making this thesis possible.



PREFACE

This experiment is conducted in the hope of bringing to light some knowledge regarding the resistance to steam flow in different pipe bends. Four kinds of bends are used in this experiment: the 90° standard elbow, the long radius bend, tube turns, and the corrugated type of bend. In this thesis the author relies altogether on experimental data taken direct from the experiment, as there is no outside data available except the formula for calculating the discharge. All curves and values that are found in this thesis are obtained from the data taken by the author in performing the experiment.

GENERAL SURVEY OF THE FIELD

It has long been known that the walls of a pipe offer resistance to any kind of medium flowing through the pipe. More or less work has been done to determine the intensity of this resistance in the case of fluids, and particularly water, but no experiments are on record, or, at least, the writer has not been able to find any, to indicate this resistance in case of steam. There has been work done in steam flow in pipes sufficient to give us a formula for the discharge of steam through an orifice. The author is assuming that this formula will apply in this case to calculate the discharge, and will use this formula in his calculations.

The experiments that have been performed in the case of water to determine the resistance of the pipe walls were experiments using a straight pipe and will not have any value in this experiment.

All of the writers reviewed have not been able to tell much about flow principles. The meager data available seems to have been accepted. Originally there were available two types of bends, the 90° standard ell and the long radius bend. But today we have several types of bends and there is a prospect of more. The resistance of these different types is becoming of more importance and more interest is being indicated

in resistance studies. Resistance experiments help the purchaser to select the pipe bend with the least resistance. This might be an important factor in laying pipe lines where there were to be a great number of bends, and if the engineer knew the resistance of the pipe and the resistance of each bend, he could calculate how much this would cut down his pressure between the power plant and the end of the pipe line. He could also calculate the resistance of the pipe to any point.

In the case of water it would be of great help to know how to make the bends in the long pipe lines, that often contain many bends, to have the least resistance.

The resistance due to different bends can be determined accurately by experimental research. The resistance of pipes is well known. The author hopes that in a very short time there will be more data on this subject.

STATEMENT OF PURPOSE

It is the author's purpose in this thesis study to find the resistance values of bends, determining by discharge formulas for rounded approach orifices the steam flow. Test data are to be given for a series of pressure ranges, for the 90° elbow, long radius bend, tube turn, and corrugated bend. These values are taken from experimental work done by the author. The resistance values are shown by curves and experimental data. The discharge values are obtained by the use of Napier's formula¹, and the data taken from the experiment.

¹Napier's formula taken from Gebhardt's Steam Power Plant Engineering, pp. 773.

GENERAL THEORY

Several engineers have advanced the theory that the long radius bend would have the least resistance. This theory was not backed up by any proof, and the men that advanced this theory did it from mere reasoning. It does look as if this is right, looking at it from the standpoint of reasoning, and most men would be inclined to take this theory as true, until proven to be wrong. The long radius bend is a smooth welded bend, and the steam is not reflected so much as it is in the other bends.

The instruments for such a study should be some type of differential gage to determine the pressure drop across the bends, and an orifice to determine the discharge at various pressures. The problem might be attacked by the use of a Venturi meter to measure the discharge of the steam at the different pressures, using the same differential gage to measure the resistance. The instruments used in this experiment were a thin plate orifice to measure the discharge, and a manometer to measure the resistance of the various bends.

DESCRIPTION OF THE METHOD AND APPARATUS USED

The late Leo Holdredge, Assistant Professor of Mechanical Engineering, at the University of Tennessee, set up much of the apparatus shown in Figure 1. His apparatus did not include the water head container, which was added to his apparatus by the author. Mr. Holdredge aimed to do some experimenting with the apparatus on the resistance to steam flow in the different types of pipe bends, but death took him away before he had time to do anything except set up the apparatus. No one did anything with the apparatus until 1932, when W. R. Woolrich, Professor of Mechanical Engineering at the University of Tennessee, decided to let any senior in the mechanical engineering class do some experimenting with the apparatus for a thesis to find out what he could about the resistance to steam flow in the four types of pipe bends already named. The author being interested in doing some experimental work in a new field choose this experiment for his thesis.

As there had been nothing done in this field, and no one had ever done any work with the apparatus, the author was forced to rely upon his own reasoning and a few suggestions made to him (all of these suggestions were merely suppositions made by the other fellow that did not know any more about it than the author did) in attacking the problem.

In the original set-up, difficulties were encountered. There were leaks at the connections, and these leaks made the values inaccurate. After losing a pound of mercury trying to take readings, the writer filled the manometer tube with water and stopped all the leaks around the connections. Correct deflection readings were then possible, but even then the readings were inaccurate due to the pulsations in the mercury column. This was probably due to entrained air that was in the small pressure tubes that lead from the main. We know that air is compressible and the unequal pressures caused by the difference would cause a pulsation in the mercury column. Readings could not be made with any great degree of accuracy, as the author had to guess at what he thought was about the average deflection. After trying to get readings in this manner for some time and again losing more mercury, the writer decided that the reading taken in this way would be of little value.

Mr. H. E. Ayres suggested that the author fill the small lead pipes B B' full of water, since water was nearly incompressible. If the leads were filled full of water and the steam admitted to the large pipe A, the deflection would cause some water to spill from the tube when there was any deflection.

There was only one place for the water to go and that was back out in the large pipe. This would be sure to cause trouble with the mercury column. This was overcome by putting a water head container in each lead as shown in Figure 1. The pipe being horizontal gave an equal head on each lead. The head containers were made of such diameters so that the deflection reading on the manometer would be only a very small part of the water that they contained (the diameter of the water head containers being $2\frac{1}{2}$ " while that of the leads was about $1/8$ "). The author connected an equalizing valve to the two leads so that the static head in the two leads could be equalized after each run. This gave a zero reading for the deflection at zero pressure. This seemed to give a very accurate deflection reading for each run.

After the water head containers were put into the leads as shown in Figure 1, the readings were taken with very little difficulty.

The only errors to be guarded against in using the present apparatus is the inaccurate reading of the manometer and the pressure gage.

When turning the steam into the test pipe A, as shown in Figure 1, it must be turned on gradually at first so as not to

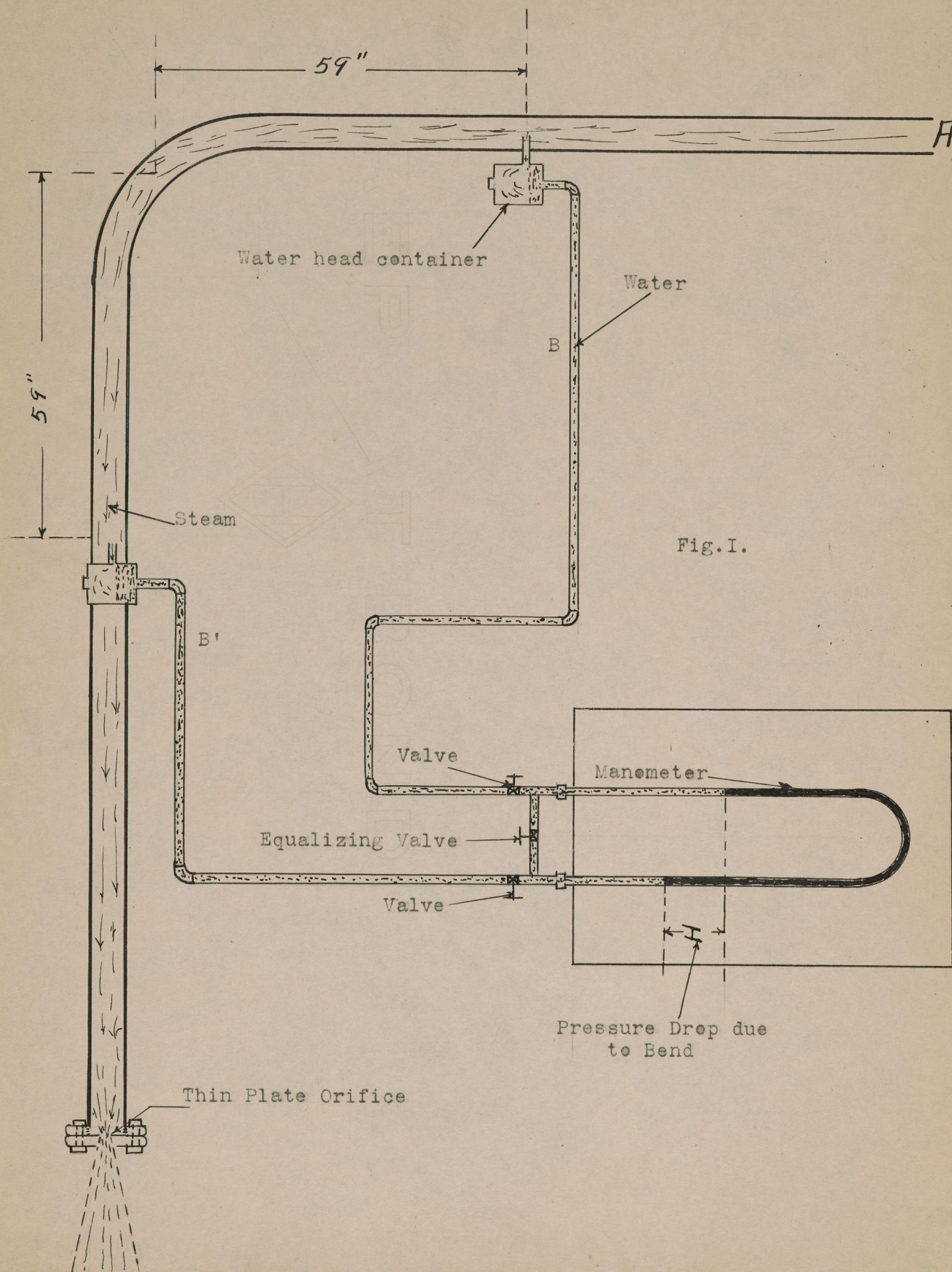
cause too much pressure in one lead before the steam has had time to travel around to the other lead. If this is not done, the pressure may be so great that it will drive the mercury out of the manometer. The writer lost so much mercury in trying to get readings at first that he never took any chance after he got the apparatus working. When cutting the pressure off of the test pipe, it is best to cut off about 20 pounds at a time, otherwise the cutting off of the steam may create such a vacuum that it will pull the mercury out of the manometer.

In this experiment the author used four thin plate rounded approach orifices. The orifice diameters were as follows: 11/16", 10/16", 9/16", 8/16". All four orifices were used on each pipe as shown by the curves in Figures 3, 4, 5, and 6. A drawing of type of orifice is shown in Figure 7. The curves in Figures 3, 4, 5, and 6, show the resistance of each type of pipe bend using all the orifices named above for the different pressures used in the experiment.

The test pipes were all 2½" cast iron pipes, and have bends as shown in Figure 2.

APPARATUS USED IN THE EXPERIMENT

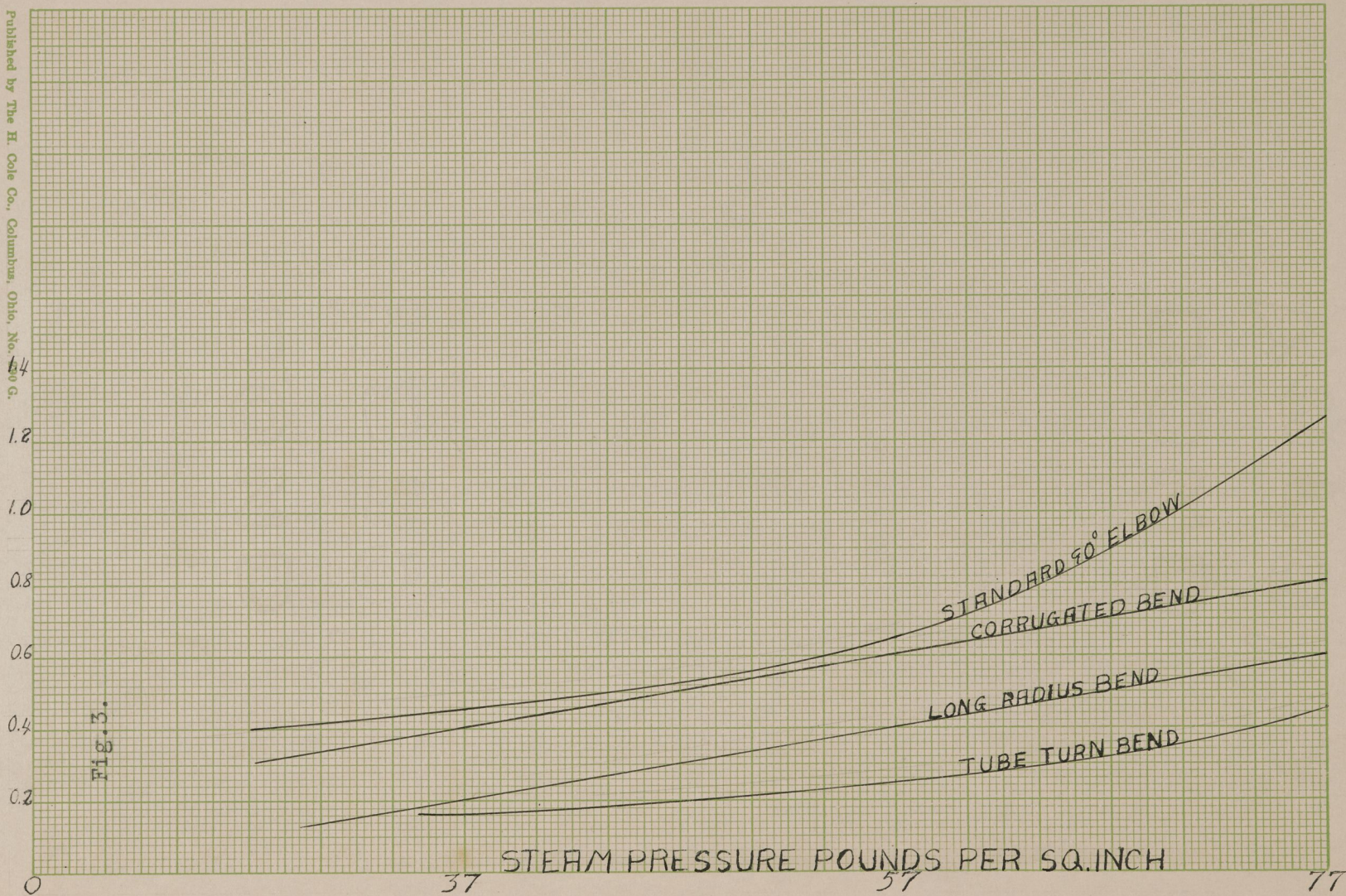
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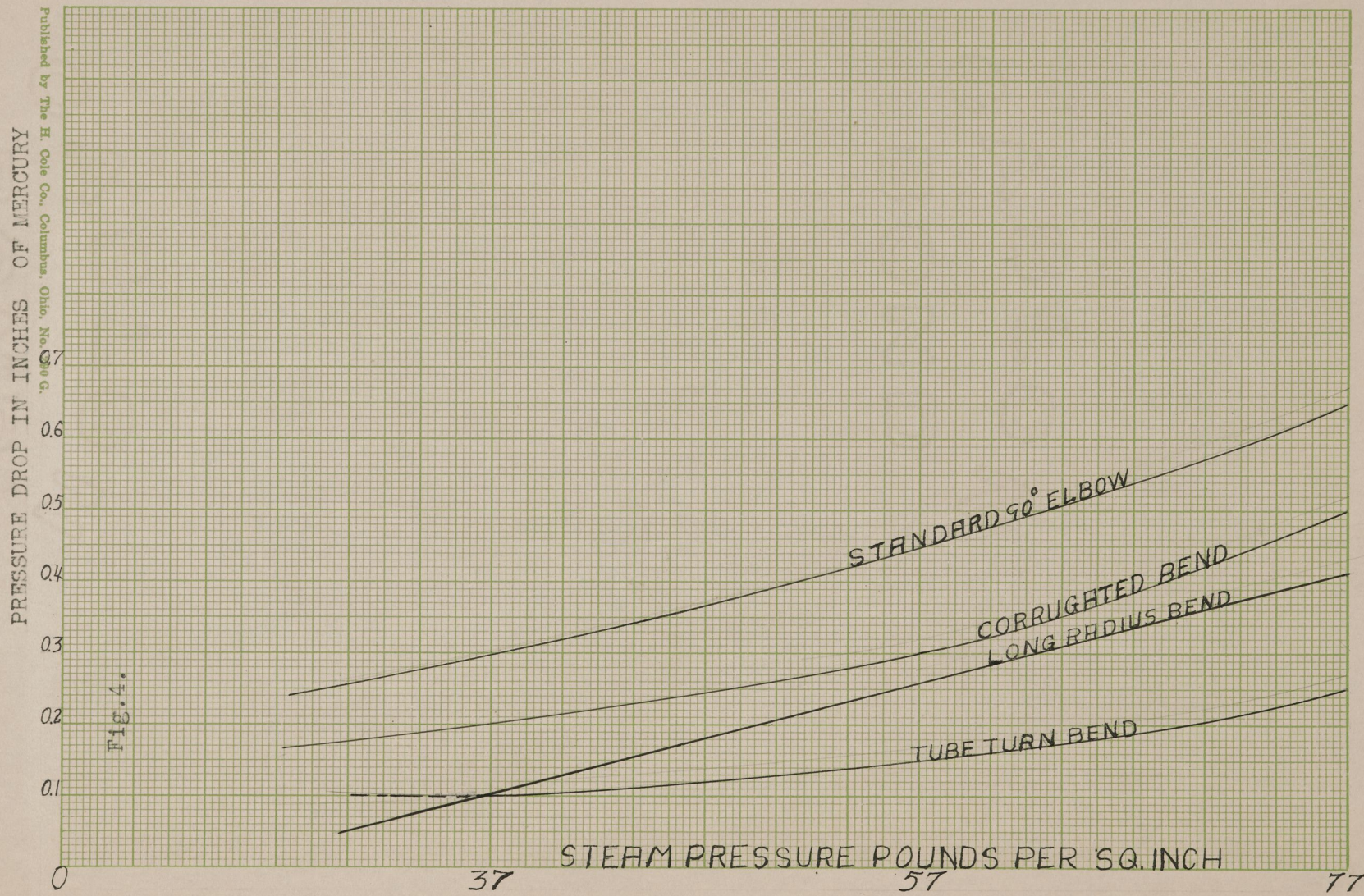
PRESSURE DROP IN INCHES OF MERCURY

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Fig. 3.



FOR A THIN PLATE ROUNDED APPROACH ORIFICE 11/16" IN DIAMETER

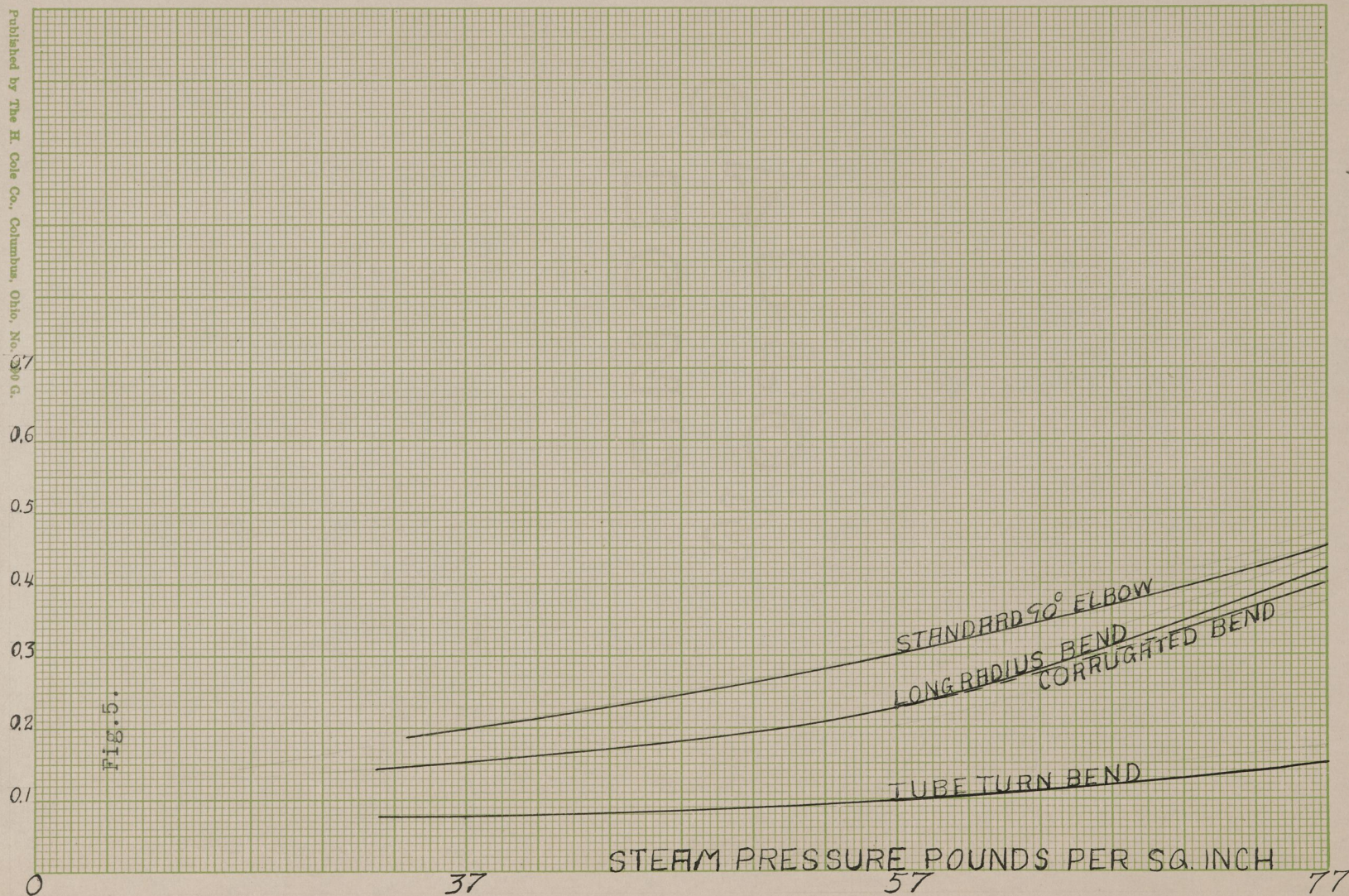


FOR A THIN PLATE ROUNDED APPROACH ORIFICE 10/16" IN DIAMETER

PRESSURE DROP IN INCHES OF MERCURY

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Fig. 5.

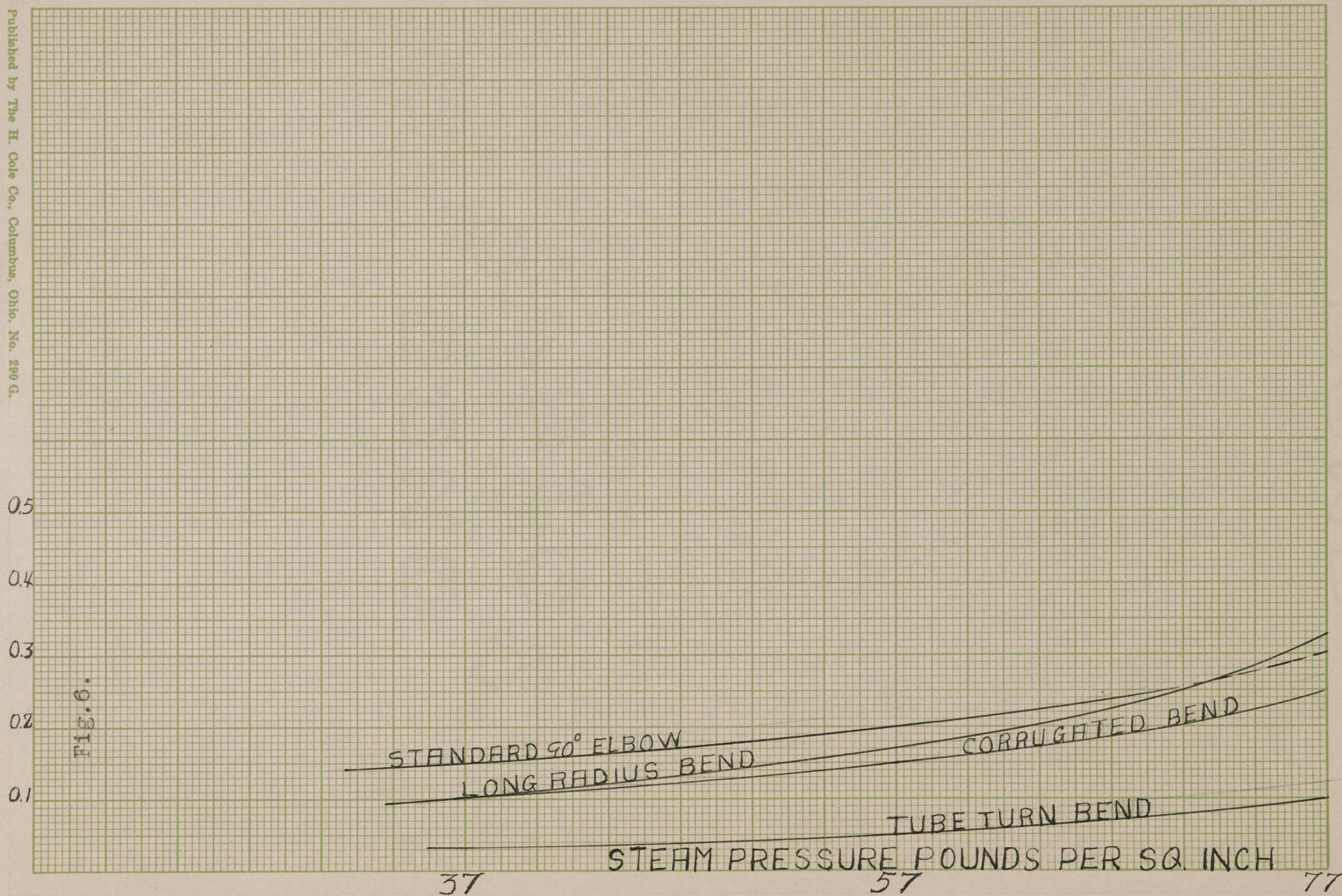


FOR A THIN PLATE ROUNDED APPROACH ORIFICE 9/16" IN DIAMETER

PRESSURE DROP IN INCHES OF MERCURY

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Fig. 6.



FOR A THIN PLATE ROUNDED APPROACH ORIFICE 8/16" IN DIAMETER

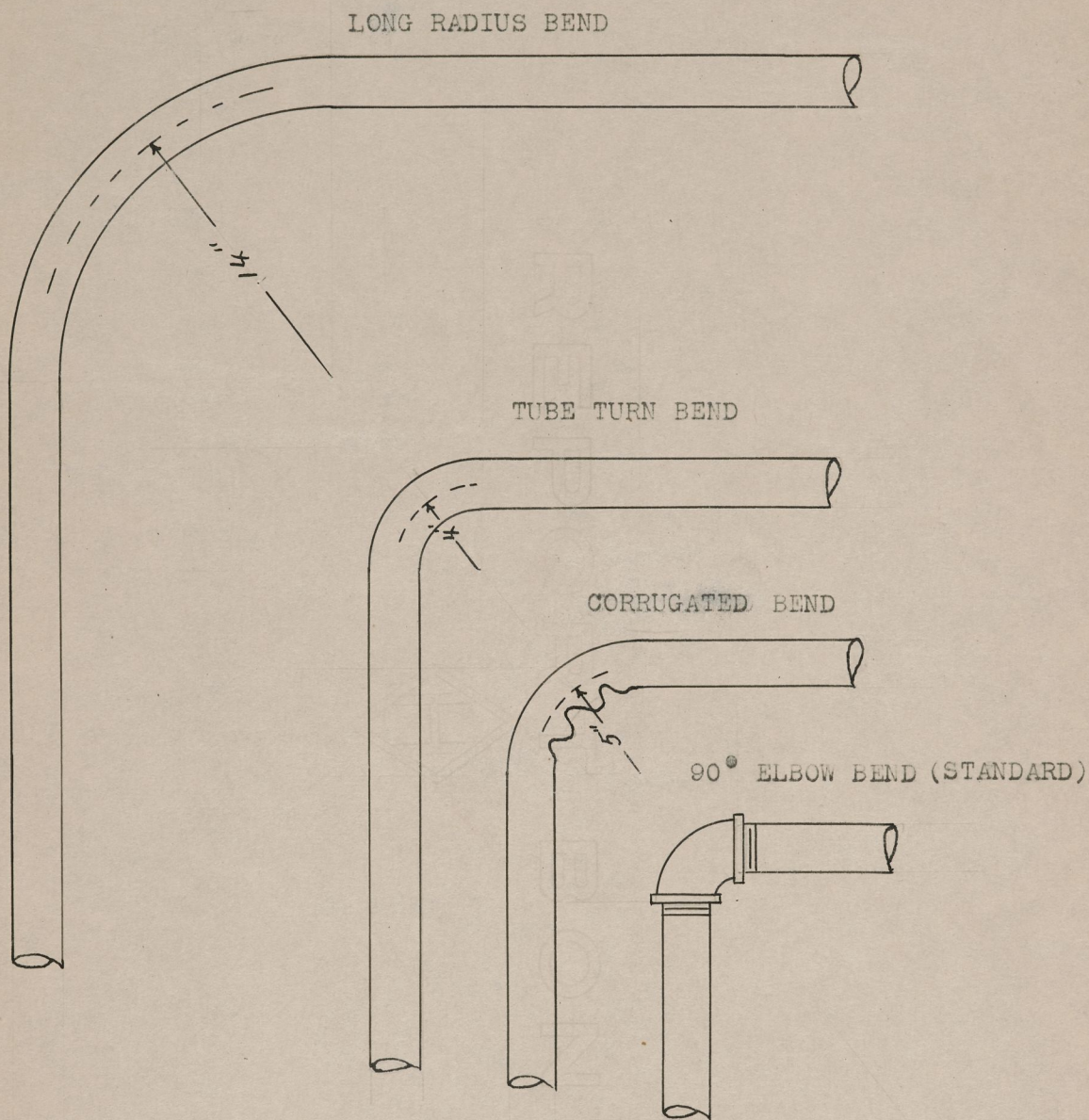
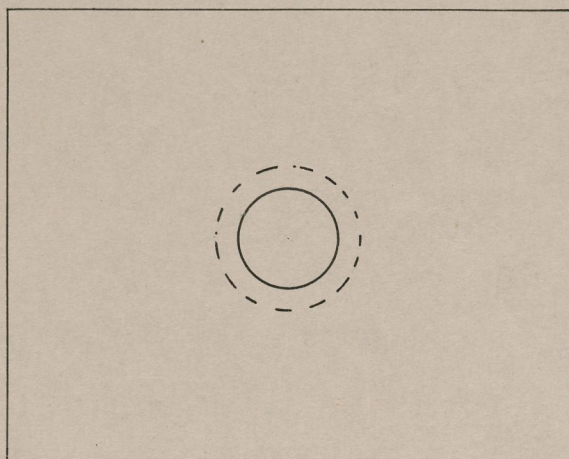


Fig.2.

Front view



THIN PLATE ORIFICE

Side view

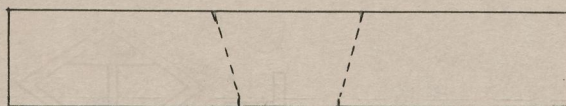


Fig 7.

CALCULATIONS

Calculation of the steam discharge through the different orifices at the different pressures by the use of Napier's equation:

The equation: $W = \frac{PA}{70}$

Where W = Weight of steam discharged per second

P = The pressure in pounds per square inch

A = The area of the orifice in square inches

Area of orifices in square inches

$$11/16" = \frac{(.6875)^2 \times 3.1416}{4} = 0.371 \text{ sq. in.}$$

$$10/16" = \frac{(0.625)^2 \times 3.1416}{4} = 0.3068 \text{ sq. in.}$$

$$9/16" = \frac{(0.5625)^2 \times 3.1416}{4} = 0.248 \text{ sq. in.}$$

$$8/16" = \frac{(0.5)^2 \times 3.1416}{4} = 0.196 \text{ sq. in.}$$

For a 77# pressure and using the 11/16" orifice

$$W = \frac{77 \times 0.371 \times 60}{70} = 24.486\# \text{ per minute (steam)}$$

For a 57# pressure and using 11/16" orifice

$$W = \frac{57 \times 0.371 \times 60}{70} = 18.15\# \text{ per minute (steam)}$$

For a pressure of 37# and using the 11/16" orifice

$$W = \frac{37 \times 0.371 \times 60}{70} = 11.87\# \text{ per minute (steam)}$$

For a pressure of 77# and using the 10/16" orifice

$$W = \frac{77 \times 0.3068 \times 60}{70} = 20.249\# \text{ of steam per minute}$$

For a pressure of 57# and using 10/16" orifice

$$W = \frac{57 \times 0.3068 \times 60}{70} = 14.989\# \text{ of steam per minute}$$

For a pressure of 37# and using 10/16" orifice

$$W = \frac{37 \times 0.3068 \times 60}{70} = 9.725\# \text{ of steam per minute}$$

For a pressure of 77# and using 9/16" orifice

$$W = \frac{77 \times 0.248 \times 60}{70} = 16.38\# \text{ of steam per minute}$$

For a pressure of 57# and using 9/16" orifice

$$W = \frac{57 \times 0.248 \times 60}{70} = 12.12\# \text{ of steam per minute}$$

For a pressure of 37# and using the 9/16" orifice

$$W = \frac{37 \times 0.248 \times 60}{70} = 7.87\# \text{ of steam per minute}$$

For a pressure of 77# and using the 8/16" orifice

$$W = \frac{77 \times 0.196 \times 60}{70} = 12.94\# \text{ of steam per minute}$$

For a pressure of 57# and using the 8/16" orifice

$$W = \frac{57 \times 0.196 \times 60}{70} = 9.575\# \text{ of steam per minute}$$

For a pressure of 37# and using the 8/16" orifice

$$W = \frac{37 \times 0.196 \times 60}{70} = 6.22\# \text{ of steam per minute}$$

You will note that the writer has just calculated the discharge for one pipe using the orifices. The discharge for all the pipes are the same, and he used the same range of pressures on all four pipes and the same orifices were used on all the pipes.

CONCLUSIONS

When using this apparatus, the system should be kept absolutely tight, and the leads kept full of water with an equal head on each lead so that all readings shall be accurate. The apparatus is shown in Figure 1 in the way that it should be when in use. The pressure should be turned on the test pipe gradually and cut off gradually so as not to drive or pull out the mercury.

The author is inclined to believe that larger orifices should be used to obtain the best results. The small orifice readings are so small that there is danger of error in reading them. If all deflections were as great as 0.5" of mercury, there would not be so much chance of an error in taking the readings. All deflections should be great enough so that the experimenter will not have any difficulty in taking the readings from the manometer scale.

Summary

The leads should be kept full of water when in use, as shown in Figure 1. The experimenter should be careful in turning the steam on, and cutting the steam off of the pipe, so as not to drive or pull the mercury out of the manometer. Larger orifices should be used.

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Treatise on Thermodynamics by Planck

Graphic Thermodynamics by Huntington

Principles of Thermodynamics by Goodenough

Thermodynamics for Engineers by Ewing

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APPENDIX

EXPERIMENTAL DATA SHEET

PRESSURE (STEAM) AND THE PRESSURE DROP

Long Radius Bend

<u>Diam.</u>	<u>31#</u>	<u>54#</u>	<u>77#</u>
11/16"	0.2" Hg.	0.4" Hg.	0.6" Hg.
10/16"	0.1"	0.25"	0.425"
9/16"	0.15"	0.225"	0.42"
8/16"	0.10	0.17"	0.325"

90° Elbow Bend

11/16"	0.45"	0.65"	0.25"
10/16"	0.30"	0.45"	0.65"
9/16"	0.20"	0.30"	0.45"
8/16"	0.15"	0.20"	0.30"

Tube Turn

11/16"	0.18"	0.25"	0.45"
10/16"	0.10"	0.15"	0.25"
9/16"	0.075"	0.10"	0.15"
8/16"	0.025"	0.05"	0.10"

Corrugated Bend

11/16"	0.40"	0.60"	0.80"
10/16"	0.20"	0.30"	0.50"
9/16"	0.15"	0.225"	0.40"
8/16"	0.10"	0.15"	0.25"

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 W. R. Woodrich

Title Professor Mech Eng.