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THESIS

FACTOR LOSSES IN HYDRAULIC LABORATORY

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1922

THESIS

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Hydrocarbon degradation in the environment

Care engineering - High level engineering

**THE FACTOR LOSSES
IN THE PIPING SYSTEM OF
THE MICHIGAN AGRICULTURAL COLLEGE HYDRAULIC LABORATORY.**

**The Thesis Submitted To The Faculty
of
MICHIGAN AGRICULTURAL COLLEGE**

by

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and

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**Candidates for the degree of
BACHELOR OF SCIENCE**

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THESIS

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F O R E W O R D

The purpose of this thesis is to determine by a series of experiments the factor losses for various commercial fittings which are installed in the piping system of the Michigan Agricultural College Hydraulic Laboratory.

INTRODUCTION.

The Michigan Agricultural College Hydraulic Laboratory is located in the east end of the basement of the engineering building. The laboratory itself was built in 1916, but the commercial fittings were not installed until the summer of 1921. The Civil Engineering Class of 1922 was the first to perform any experiments in the laboratory. Before the fittings were installed the apparatus was very limited, only a few nozzles, short tubes, and the weir in the steam laboratory being available.

The source of supply of the water which is used in the laboratory comes from wells which are located on the college grounds back of the Forestry Building. From the wells the water is pumped to the water tower which is located just east of the Power Plant. From the water tower, by means of a system of pipes and valves the water is run into a tank located in the top of the Engineering Building. From there it is drawn directly through the piping system on which we performed our experiments. After running through the piping system it is discharged into a pit in the floor of the laboratory which empties directly into the sewer.

The water was run through the pipes for several hours before any good results were obtained. This was due to a collection of rust and various bacterial collections in the pipes.

For references on the subject of hydraulics the following texts were used:

Hydraulics-----Hughes and Stafford

Hydraulics-----Russell

Kings Hydraulic Handbook

Merrimans Hydraulics

Hydraulics-----Church

Waterworks Handbook--Flinn

Engineering News Record

Wegman's Conveyance and Distribution

We wish to thank Mr. Ren Saxton and H. L. Publow for the personal assistance which they rendered us while working on this thesis.



Pressure Tank.

*Weighing Tank and
Scales*



View of Piping System.

OUTLINE

1. Determination of the Weight of Water.
2. Calibration of the Weir.
3. Calibration of the Venturi Meter.
4. Calibration of the Pitometer.
5. Coefficient of Friction in the Two-Inch Pipe.
6. Coefficient of Friction in the Three-Inch Pipe.
7. Losses on Abrupt Expansion.
8. " " " Contraction.
9. " in Two-Inch Valves (Straight and Angle Globe
 Valves & Gate Valves)
10. " in Flanges.
11. " in Unions.
12. " in Straight and Angle Tees.
13. " in Elbows.
14. Curves and theoretical valves on each of the Losses and Calibrations.

GAUGES

This discussion of gauges is made that the reader may know in detail the kinds of gauges used. The two principal kinds of gauges used were the Differential Gauge and the Hook Gauge.

The Differential Gauge was used to measure losses over fittings. The gauge itself consisted of a glass U-tube with a valve on each end so that it could be closed thus shutting off the pressure. The two legs of the U were half filled with Mercury (Hg) or Carbon Tetrachloride (CCl_4), and the other half with water. The ends of the U were each connected to the pipe, one on each side of the fitting over which the loss of head was desired. If the loss of head was great enough, Mercury was used, otherwise Carbon Tetrachloride.



Differential U Gauge.



The water in the U was under a different intensity of pressure in each leg, which gave the difference in elevation. If the liquids are quiet, the equation of equilibrium, using heads to represent pressures, may be written as follows:

$$S\left(\frac{P_1}{r} + h_0 + d\right) = S\left(\frac{P_2}{r} + h_0\right) + S'd.$$

S = the specific gravity of the lighter liquid.

S' = the specific gravity of the heavier liquid.

Then $\frac{P_1}{r} - \frac{P_2}{r} = d\left(\frac{S' - S}{S}\right).$

r here is the weight of a unit column of the lighter liquid. Therefore to change feet of Mercury or Carbon Tetrachloride to feet of water the following formula is used.

$d = d' \left(\frac{s' - s}{s} \right)$ in which s is the specific gravity of water, and s' the specific gravity of the heavier liquid, d' the difference in levels of the liquid in the tube, and d the equivalent difference in feet of water. For Mercury the conversion is $d = 12.59d'$. For Carbon Tetrachloride the conversion is $d = 0.584d'$. It is easily seen from these conversion factors that Carbon Tetrachloride shows a much greater difference in elevation than Mercury under the same head.

The scale graduated in feet and decimals of feet was between the two legs on the mounting of the U-tube. The zero of the scale was in the middle. The readings above and below the zero mark were taken, added together and their sum divided by two.

The gauge which was used to calibrate the Pitometer was somewhat different from the one described above. The shape

of this gauge somewhat resembled an inverted U. A valve was in the end of each leg of the U to shut off the water. At the upper part of the gauge between the two legs of the U another valve was attached. An air pressure pump was attached at this valve and air pumped into the U until the water was forced about one-half way down the gauge. Since there was an equal intensity of pressure of air in each leg, the difference in levels of the two water columns would give the true difference in head in feet of water. The scale was placed between the two legs of the U and graduated in feet and decimals of feet. The zero of the scale was at the bottom. The level of the water in each leg of the tube was read and the difference taken as the difference in head in feet of water.



Diverted Differential U Gauge
used in Calibrating Pitometer.

A Hook Gauge was used to measure the difference in levels of water in the weir. The Hook Gauge is a graduated sliding scale with a sharp hook on the lower end fitted with

a vernier, and attached vertically to a frame. The hook was placed in a still box outside of the weir. The purpose of the still box was to keep the water quiet while the readings were being taken. The still box was connected to the bottom of the weir by means of a tube, so that the water in the still box was exactly the same elevation as the water in the weir due to the fact that water everywhere seeks its own level.

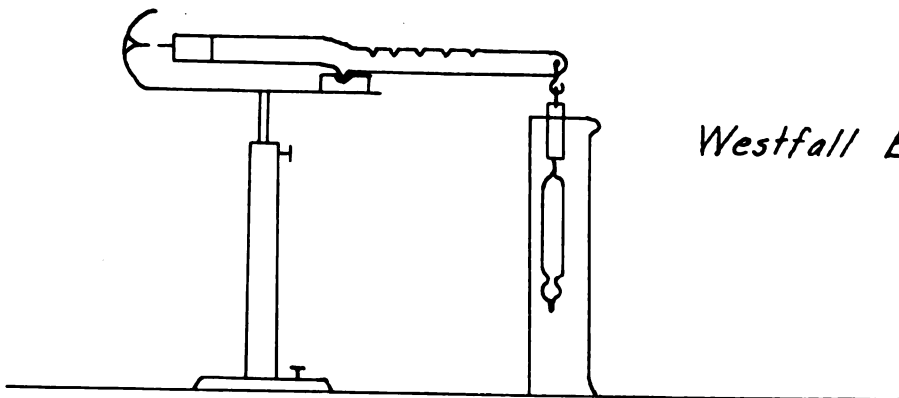
With this preliminary discussion of the gauges used, it is seen that any time a particular kind of gauge is referred to, the reader has only to refer to this discussion to understand the principle on which it works.



Hook Gauge.

UNIT WEIGHT OF WATER

The weight of water per cu. ft. is ordinarily taken as 62.5 $\frac{1}{2}$, but in this thesis work in order to get accurate results, it was thought best to accurately determine the unit weight of water. This was done by means of the Westfall Balance. The Westfall Balance consists of a balance arm with a weight on one end and a counterpoise on the other suspended in water, the arm itself being supported in the middle on a knife edge. In finding the unit weight of water, water was allowed to run out of the faucet until it was of about the same temperature as the water in the laboratory. Then water was drawn from the faucet and put in the glass until the weight was entirely submerged. Weights were then put on the balance arm until it balanced. The specific gravity of water was then determined by adding the weights.



Westfall Balance.

The specific gravity of the water was found to be larger than one because of the impurities in it. Also we found that the specific gravity increased as the temperature decreased. After determining the specific gravity of the water, the unit weight of it was easily found. (See sample of Computation.) We found that the average unit weight of water to be 62.6415 at 14 degrees Centigrade.

Results:

Trial	Sp. Gr.	Temp.	Unit wt. of Water
1	1.001	20.7	62.578 #
2	1.0015	16.0	62.6103 #
3	1.002	14.2	62.6415 #
4	1.002	14.2	62.6415 #
5	1.002	14.0	62.6415 #

Sample of Computation:

1 cu. ft. = 28,320 cu. cm.

1.001 is the weight in grams of one cu. cm. of water at 20.7 degrees Centigrade.

Then $1.001 \times 28,320 = 28,348.32$ gms. the weight of one cu. ft. of water.

One pound avoirdupois = 453 gms.

$28,348.32$ divided by $453 = 62.578\frac{2}{3}$ the weight of a cu. ft. of water.

Conclusion:

The value of 62.65 was used as the unit weight of water in the experiments in this thesis.

WEIR

A description of the weir will first be given.

The weir was set in one end of a tank of which the approximate dimensions were $20' \times 4\frac{1}{2}' \times 4\frac{1}{2}'$. Water flowed into the tank from a two inch pipe at the upper end. The amount of flow was regulated by a valve set in the incoming pipe, only very low heads being used. The weir itself was of the rectangular type made of sharp edged thin metal. The length of crest was 5 and $15/16$ inches.

In the work of calibrating the weir, water was first allowed to run freely through the weir for some time in order to get the water to a constant temperature, and also to get rid of any sediment which might have collected in the tank. Then the water in the tank was allowed to become quiet. The Hook Gauge was then set at zero. (See discussion of gauges and the picture of the Hook Gauge.) Water was then turned into the tank and allowed to run freely a few minutes in order to obtain a uniform flow, after which we began to take readings.

The readings consisted in measuring the difference in levels of the water in the tank by means of the Hook Gauge and measuring the actual quantity flowing through the weir in a certain time by weighing it on the scales and changing to equivalent cu. ft. per sec. About thirty readings were taken, the head varying from $0.047'$ to $0.248'$.

In obtaining the theoretical quantity the weir formula $q = cLH^{3/2}$ was used. For example: Time = 180 sec., Weight of water = 892.5#, Hook Gauge reading = 0.125'.

Actual quantity = $\frac{892.5}{180 \times 62.65} = 0.0729$ cu. ft. per sec.
Theoretical quantity = $LH \text{ or } 0.495' \times 0.0442 = 0.0219$ where 0.495 is the length of the crest in feet and 0.0442 is H raised to the $3/2$ power. The weir coefficient "c" = actual quantity / theoretical quantity.

In this example "c" = $0.0729/0.0219 = 3.329$.

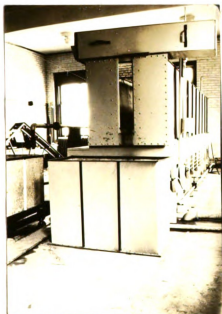
Velocity of approach was neglected in all our computations. We followed this procedure in all of our readings.

Our results were very consistent. We took the average of thirty readings and found the mean value to be 3.494. All of the values of the coefficient were close to this value except under very low heads when the highest value of "c" obtained was 4.52. The actual quantity was plotted against the difference in head for each of the thirty readings. A smooth curve was drawn through these points. The greatest variation of head from the curve was .001 feet which would seem to indicate that our results were quite accurate. The relation of quantity to head was found to be a constant for heads over 0.15'.

The result that we obtained in our calibration was higher than Francis obtained in his experiments. His value of "c" was 3.33. However, Francis used heads which varied from 0.5' to over 2', while our greatest head was about 0.3'.

Taking into account the consistency of our results and

the fact that Francis obtained a value of "c" but slightly higher than ours by using higher heads, we wish to recommend the weir coefficient "c" for the weir in the Michigan Agricultural College Hydraulic Laboratory to be 3.494.



End View of the Weir.

CALIBRATION OF WEIR

Run	Time Sec.	Lbs. of Water	Actual Quant.	H) Hooks H) Gauge	H ³ / ₂	Theor. Quant.	$\frac{Q_A}{Q_T} = c$
1	180	892.5	0.0729	0.125	0.0442	0.0219	3.329
2	120	603.5	0.0803	0.128	0.0458	0.0227	3.540
3	120	1128.2	0.1500	0.198	0.0881	0.0436	3.440
4	120	1126.5	0.1498	0.199	0.0888	0.0440	3.404
5	150	1430.7	0.1521	0.1985	0.0881	0.0436	3.490
6	180	904.5	0.0803	0.125	0.0442	0.0218	3.685
7	120	546.0	0.0726	0.116	0.0395	0.0196	3.700
8	90	1136.3	0.207	0.249	0.1243	0.0616	3.360
9	90	1166.2	0.207	0.249	0.1243	0.0616	3.360
10	240	1081.0	0.0719	0.1145	0.0387	0.0192	3.745
11	90	668.5	0.1186	0.166	0.0676	0.0335	3.540
12	90	671.7	0.1191	0.167	0.0682	0.0340	3.508
13	120	898.5	0.1196	0.169	0.0695	0.0344	3.475
14	120	893.0	0.1190	0.166	0.0676	0.0334	3.561
15	90	978.2	0.1736	0.219	0.1025	0.0507	3.425
16	90	1009.0	0.1790	0.224	0.1060	0.0525	3.410
17	120	1316.5	0.1750	0.221	0.1039	0.0514	3.406
18	90	988.2	0.1755	0.2205	0.1035	0.0513	3.420
19	120	1312.5	0.1749	0.2215	0.1043	0.0517	3.381
20	90	1419.0	0.2524	0.284	0.1514	0.1750	3.368
21	60	935.6	0.2488	0.2835	0.1510	0.0748	3.326
22	60	918.0	0.2445	0.2800	0.1482	0.0735	3.326
23	90	931.0	0.1654	0.213	0.0983	0.0487	3.395
24	90	930.2	0.1652	0.211	0.0969	0.0480	3.440
25	120	791.5	0.1053	0.154	0.0604	0.0299	3.522
26	180	585.0	0.0518	0.0985	0.0309	0.0153	3.385
27	90	1167.0	0.2071	0.248	0.1235	0.0613	3.380
28	180	257.6	0.0228	0.047	0.0102	0.00505	4.520

Av. Value of C = 3.494

Actual Quantity in Cu. Ft. per Sec.

0.30
0.25
0.20
0.15
0.10
0.05
0

Curve showing Relation
of
Head of Water to Quantity
in the Weir
of the
M.A.C. Hydraulic Laboratory.

Head in Feet of Water as Measured
on the Hook Gauge.

0.05

0.10

0.15

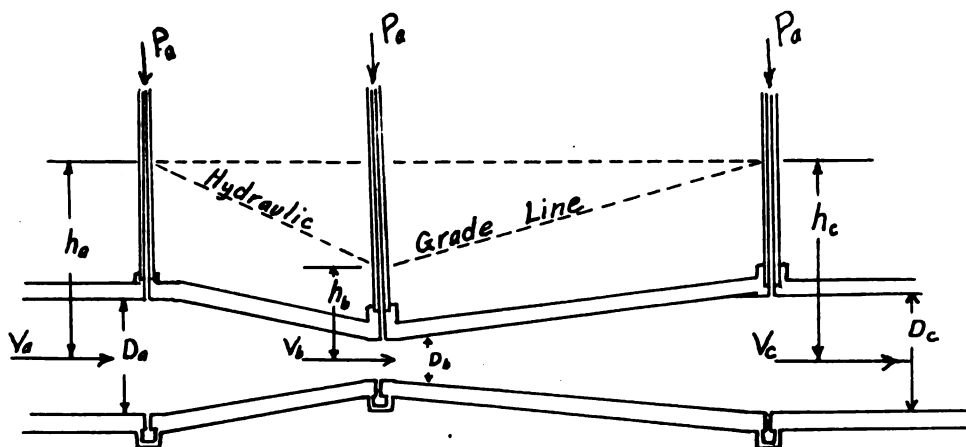
0.20

0.25

0.3

CALIBRATION OF THE VENTURI METER.

The Venturi Meter was invented by Clemens Herschel in 1886-88, and named after an Italian hydraulican Venturi who discovered its principle. Two truncated hollow cones are inserted in a line of pipe having the same internal diameter as the base of the cone. The tube is built of cast iron with a bronze lined throat. Pressure chambers (Piezometer Rings) surround the up-stream end and throat and pressure lines lead from there to the manometer. A valve was placed in each pipe close to the meter tube so that if an accident occurred the water could be shut off.



Longitudinal Cross Section of a Venturi Meter.

The Venturi Meter is a practical application of Bernoulli's theorem to the measurement of the flow of water in pipes under pressure. The same quantity of water passes through both the inlet and the throat, but since the area at

the throat is smaller the velocity will be greater than at the inlet. They have a constant relation for any meter depending upon the ratio of the two areas and a simultaneous observation of the pressure heads at the inlet and throat provides a method of determining the velocity at the throat, and from the velocity and areas the discharge can be obtained. This ratio was taken as

$$\text{Then } K = \frac{\sqrt{R^2 (2g)}}{4 (R^2 - 1)}$$

$$\text{Then } Q = CKD^2 H^{\frac{1}{2}}$$

For a value of R equal to 2/1 the value of K was found to be 6.505. As an example of our computation let: Time = 240. sec., Lbs. of water = 1050.5#, H in mercury = 0.21'.

$$\text{Actual quantity} = \frac{1050.5}{240 \times 62.65} = 0.0698 \text{ cu. ft. per sec.}$$

$$0.21 \times 12.59 = 2.645' \text{ head in water.}$$

$$\text{Theoretical quantity} = 6.505 \times 0.0694 \times 1.625 = 0.0734.$$

The coefficient "c" equals actual quantity / theoretical quantity or in this case equals 0.0698 / 0.0734 = 0.951. This same procedure was followed in computing all of our readings.

In calibrating the Venturi Meter we first connected the pressure lines with the manometer. (See the discussion of gauges.) Then water was allowed to run through the meter and a reading was taken of the difference in level of the mercury in the gauge. The actual quantity flowing was measured by catching in a tank for a certain length of time and weighing on the scales. This weight was then changed to cu. ft. per sec. About 20 readings were taken in this manner and computed by the method outlined above.

The actual quantity was plotted against the difference in head in each case and a smooth curve drawn through these points. The curve showed that the relation between quantity and head was a constant when the quantity flowing was more than 0.1 cu. ft. per min. The average value of "c" for these 20 readings was found to be 0.9558.

The coefficient "c" varies with the velocity at the throat, the ratio of the diameters at the inlet and outlet, and the actual dimensions of the meter. As meters are ordinarily constructed the coefficient varies between 0.97 and 1.0. Probably the reason why we obtained a lower value was because of the condition of the meter. The meter had not been used for about four months and in that time had probably collected some rust or other growth.

We wish to recommend as a value of the coefficient "c" of the Venturi Meter now in the Michigan Agricultural College Hydraulic Laboratory as 0.9558.

CALIBRATION OF VENTURI METER

Run	Time Sec.	Lbs.of Water	Actual Quant.	H Hg	H Water	K	D _b	Q Theor.	C.
1	240	1050.5	.0698	.21	2.645	6.505	.00694	.0734	0.951
2	180	783	.0694	.21	2.645			.0734	0.947
3	180	1069.3	.0947	.385	4.848			.0995	0.953
4	180	1061.7	.0943	.380	4.78			.0989	0.954
5	180	1184.6	.1051	.485	6.105	1.02		.1116	0.943
6	150	1186.0	.1262	.675	8.50			.1317	0.960
7	120	1160.5	.1547	1.02	10.85			.1487	1.044
8	240	760.5	.0507	.11	1.385			.0532	.953
9	180	569.5	.0506	.11	1.385			.0532	.952
10	180	293.8	.0261	.03	.378			.0278	.939
11	180	430.8	.03825	.065	.818			.0408	.937
12	180	1039.0	.0923	.365	4.60			.0970	.952
13	150	992.0	.1057	.465	5.85	1.211		.109	.968
14	120	912.2	1.211	.63	7.93			.1272	.953
15	180	1007.0	.0895	.34	4.28			.0933	.962
16	150	1174.3	.1250	.66	8.30			.1301	.960
17	150	1255.5	.1336	.77	9.69	11.70		.140	.954
18	150	1320.5	.1405	.85	11.70			.1554	.905
19	150	1167.0	.1240	.65	8.18			.1286	.965
20	150	1156.5	.1230	.64	8.05			.1275	.963

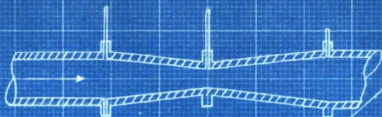
Av. Value of (C) = 0.9558

Actual Quantity in Cu. Ft. per Sec.

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5

Head in Feet of Water.

Curve showing Relation
of
Quantity to Head of Water
in a Venturi Meter.



Longitudinal Cross Section
of a Venturi Meter.

CALIBRATION OF THE PITOMETER

The Pitot tube was first used in 1730 by Pitot to determine the velocity of flow. His apparatus consisted of a bent cylindrical tube with one leg horizontal and its orifice opposed to the current and a straight vertical tube set with its opening at the same level as the orifice of the bent tube. h being the difference in level in the two vertical tubes, Pitot assumed that V was equal to $(2gh)^{1/2}$

Experiments have proved that in tubes having small points so shaped as not to disturb the flow, with openings of cylindrical or converging or diverging cone form, h very nearly equals $V^2/2g$. Therefore if h can be measured the velocity at any point can be obtained. The apparatus that Pitot used did not give a true measure of the velocity head because the vertical tube is not a true piezometer and did not accurately measure the pressure head. Darcy found that oscillations of the water surface in the tube made an accurate reading of the velocity head difficult, so he made the orifices much smaller than the tubes. Also the water in a pipe does not flow at the same velocity at the center as on the outside, the velocity at the center being greater so it was necessary for us to first determine some ratio between the center velocity and the mean velocity before we could calibrate the pitometer. This ratio is called the pipe coefficient.

In finding the pipe coefficient we used the same shaped orifice as shown in the drawing. Water flowed against the orifice and the upper end of the tube was connected to the gauge. Another tube was run from the pipe to the gauge so that the difference in levels in the gauge was the velocity head. Then water was caused to flow through the pipe at a constant velocity. Spot readings were taken at points in the pipe $1/8"$, $3/8"$, etc. up from the bottom. The velocity at each of the points was then obtained. The mean velocity was obtained as the arithmetical mean of the observations made at the center of rings of equal value, or the mean velocity of the whole pipe is the total of these ring volumes divided by the area of the pipe. The mean velocity divided by the center velocity as read from the curve is the pipe coefficient. We took five trials in determining the pipe coefficient and we found the average value of pipe coefficient to be 0.953. This value was found to be practically a constant for different velocities. Now with this value of a pipe coefficient, by simply taking readings at the center of the pipe and multiplying by this coefficient the average velocity in the pipe was obtained. The quantity was then easily obtained by multiplying by the cross-sectional area of the pipe. We were then ready to calibrate the pitometer.

It was necessary that we make three calibrations, one with the impact tube, and two with Pitot tube shaped as the one shown in the drawing. One calibration was made of the Pitot tube when the impact opening was against the stream and one when it was

with the stream. The first calibration made was of the impact tube. A series of about 20 readings were taken in calibrating the tube under different heads. The opening was held in the center of the pipe in each case, and a reading taken of the difference in levels in the gauge. (See discussion of gauges.) The average velocities were plotted against quantities in each case and a smooth curve drawn through these points. The curve was practically a straight line. This shows that the quantity of water discharged increased as the velocity increased.

The second calibration to be made was of the Pitot tube with the opening turned against the stream. About the same number of readings were taken as in the previous calibration, and the same method of procedure was followed. This method of measuring the discharge of a stream is not as accurate as the Venturi meter method but it is useful in finding losses in pipe systems.

The third calibration was made with the opening with the current. In this case a negative head was developed and no accurate readings could be obtained. The curve plotted from our results followed no definite course showing that our results were not accurate. The reason that the attempt was made to calibrate this pitometer with the opening with the current was to show the impossibility of its accomplishment. Only about ten readings were taken, this being deemed all that was necessary to show how inaccurate our results were.

PITOMETER CALIBRATION

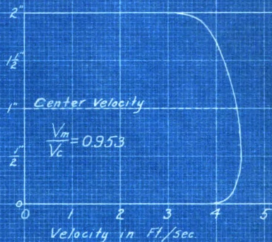
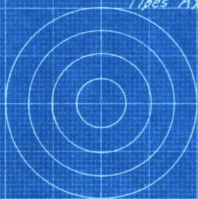
PIPE COEFFICIENT Short Tube

Dia. in Inches	Dia. in feet	Area in sq. ft.	Area of bands	Av. Vel. #1	Av. Vel. #2	Av. Vel. #2	Av. Vel. #3	Av. Vel. #3	Av. Vel. #4	Av. Vel. #4	Av. Vel. #5	Av. Vel. #5
2"	0.1667	.021813		.0557	.0659	.0365	.0387	.0387	.0387	.0387	.0437	.0437
1½"	0.1250	.01227	.009543	.0421	.0493	.0271	.0292	.0292	.0292	.0292	.0330	.0330
1"	0.0833	.00545	.00682	.0258	.0303	.0166	.0178	.0178	.0178	.0178	.0202	.0202
¾"	0.04166	.001363	.004087	.0086	.0102	.0055	.0060	.0060	.0060	.0060	.0068	.0068
			.001363	.1322	.1557	.0857	.0917	.0917	.0917	.0917	.1037	.1037
Mean Velocity												
Velocity at center												
Coefficient												
Av. Value of Coefficient												
				6.06	7.13	3.93	4.20	4.20	4.20	4.20	4.75	4.75
				6.36	7.55	4.08	4.39	4.39	4.39	4.39	5.02	5.02
				.953	0.945	0.963	.0957	.0957	.0957	.0957	.0947	.0947
				0.953								

PITOMETER CALIBRATION
Data for Velocity Curves.
Short Tube

Height from bottom of pipe	1		2		3		4		5	
	Run #	H_{ccl_4} $H_{h_0} = \frac{V^2}{2g}$	Run #	H_{ccl_4} $H_{h_0} = \frac{V^2}{2g}$	Run #	H_{ccl_4} $H_{h_0} = \frac{V^2}{2g}$	Run #	H_{ccl_4} $H_{h_0} = \frac{V^2}{2g}$	Run #	H_{ccl_4} $H_{h_0} = \frac{V^2}{2g}$
1/8"	1.07	.625 6.33	1.53	.893 7.60	.47	.274 4.20	.50	.292 4.34	.62	.362 4.83
3/8"	1.13	.66 6.5	1.59	.928 7.74	.50	.292 4.34	.54	.316 4.51	.66	.386 4.98
5/8"	1.145	.67 6.55	1.60	.935 7.76	.48	.281 4.26	.53	.310 4.47	.72	.420 5.20
7/8"	1.10	.643 6.43	1.54	.900 7.60	.45	.263 4.12	.52	.304 4.43	.67	.392 5.03
1 1/8"	1.04	.608 6.25	1.50	.877 7.50	.43	.251 4.02	.50	.292 4.34	.66	.386 4.98
1 3/8"	.99	.578 6.08	1.53	.788 7.11	.42	.245 3.98	.47	.275 4.21	.63	.368 4.86
1 5/8"	.93	.544 5.90	1.21	.707 6.74	.41	.240 3.93	.46	.269 4.17	.58	.339 4.67
1 7/8"	.79	.462 5.45	1.14	.665 6.55	.345	.2015 3.36	.38	.222 3.78	.50	.292 4.33
2"							.18	.105 2.60	.31	.181 3.42

Typical Cross Section of a 2" Pipe
showing Velocity Curve Under high
velocities this curve becomes a
Parabola, symetrical with respect to the
Pipes Axis.



$$\frac{\text{Discharge of Pipe}}{\text{Area of Pipe}} = \text{Mean Velocity.}$$

$$\frac{\text{Mean Velocity}}{\text{Center Velocity}} = \text{Pipe Coefficient.}$$

CALIBRATION OF THE PITOT TUBE

Short Nozzle

Run	Time Sec.	Lbs.of Water	Quant. Cu.Ft. / Sec.	$\frac{V^2}{2g}$ CCl ₄	$\frac{V^2}{2g}$ H ₂ O	$V_{Fl./sec.}$	V _o
1	120	823.0	.1096	0.875	.512	5.75	5.48
2		922.0	.1228	.95	.555	5.98	5.70
3		995.0	.1325	1.21	.707	6.74	6.42
4		1068.0	.1422	1.32	.772	7.05	6.73
5		1121.5	.1492	1.49	.871	7.49	7.14
6	120	1205.0	.1605	1.75	1.022	8.12	7.75
7	90	869.0	.1542	1.61	.941	7.78	7.43
8	120	586.5	.1561	1.55	.906	7.64	7.30
9		1083.0	.1441	1.43	.836	7.34	7.01
10		102.9	.1369	1.24	.724	6.83	6.52
11		950.5	.1248	1.09	.637	6.40	6.11
12		898.0	.1195	.94	.549	5.95	5.68
13		818.0	.1089	.82	.479	5.56	5.30
14		770.0	.1026	.76	.444	5.35	5.11
15		731.0	.0973	.63	.368	4.87	4.65
16		601.0	.0801	.44	.257	4.07	3.88
17		531.5	.0708	.34	.199	3.58	3.42
18		464.0	.0618	.27	.158	3.19	3.14
19		419.0	.0557	.225	.131	2.91	2.78
20		374.0	.0498	.185	.108	2.64	2.52
21		323.0	.0430	.15	.088	2.39	2.28
22		300.0	.0399	.11	.064	2.03	1.94
23		234.0	.03115	.10	.058	1.93	1.84
24		155.0	.0206	.04	.234	1.23	1.175

Quantity in Cu. Ft. per Sec.

0
.02
.04
.06
.08
.10
.12
.14

0 10 20 30 40 50 60 70 80 90 100



Cross Section of a
Pitot Tube (Impact
Opening)

Curve showing Relation
of
Quantity to Av. Velocity
in the Calibration of the
Pitot Tube (Impact
Opening).

Av. Velocity in Ft. per Sec. = Vel. at Center of Pipe
X Pipe Coefficient (0.953)

**CALIBRATION OF PITOT TUBE (Long Nozzle)
AGAINST THE DIRECTION OF FLOW**

Run	Time Sec.	Lbs. of Water	Quant. Actual Cu. Ft. / Sec.	$H_{h_0} = \frac{V^2}{2g}$	V	V _c	Quant. Theor.	$\frac{Q_A}{Q_T}$
1	120	436	.0582	.14	3.01	2.87	.0625	.93
2		1103	.1470	.96	7.88	7.52	.1639	.90
3		1042	.1385	.87	7.50	7.15	.1560	.89
4		977	.1300	.68	6.60	6.29	.1370	.947
5		890	.1185	.59	6.17	5.86	.1277	.928
6		791	.1053	.50	5.66	5.38	.1172	.904
7		759	.1011	.45	5.39	5.15	.112	.905
8		704	.0937	.38	4.95	4.72	.1028	.910
9		659	.0877	.34	4.68	4.47	.0973	.900
10		618	.0825	.30	4.39	4.19	.0914	.903
11		573	.0763	.25	4.02	3.85	.0836	.912
12		524	.0697	.21	3.68	3.51	.0766	.910
13		490	.0652	.18	3.41	3.25	.0708	.922
14		460	.0612	.17	3.31	3.16	.0688	.890
15		405	.0540	.13	2.89	2.75	.0600	.90
16		374	.0497	.11	2.66	2.54	.0555	.895
17		322	.0429	.08	2.27	2.16	.0472	.908
18		285	.0379	.06	1.97	1.88	.0409	.927
19		242	.0322	.045	1.71	1.63	.0355	.907
20		218.5	.0291	.04	1.61	1.54	.0337	.870

Actual Quantity in Cu. Ft. per Sec.

.14

.12

.10

.08

.06

.04

.02

0

20

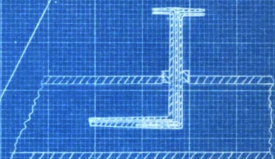
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60

80

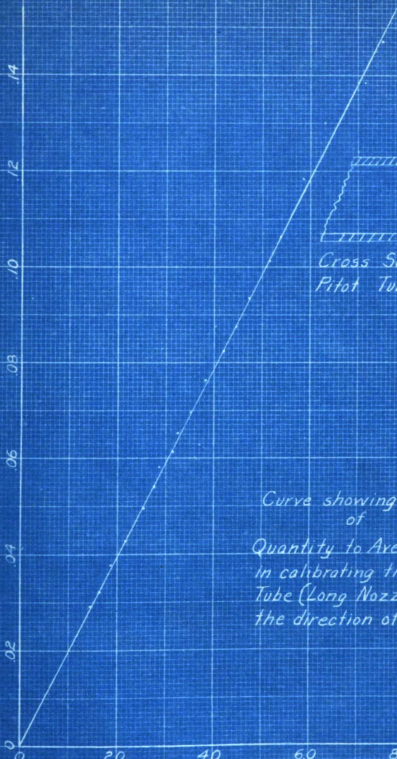
100

Average Velocity " V_c " in Ft./Sec.



Cross Section of
Pitot Tube (Long Nozzle).

Curve showing relation
of
Quantity to Average Velocity
in calibrating the Pitot
Tube (Long Nozzle) against
the direction of flow



CALIBRATION OF PITOT TUBE (Long Nozzle)
WITH THE DIRECTION OF FLOW

Run	Time Sec.	Lbs.of Water	Quant. Actual Cu.Ft. / Sec.	$H_{h.o} = \frac{V^2}{2g}$	V	V _c	Quant. Theor.	$\frac{Q_A}{Q_T}$
1	60	367	.0712	0.04	1.61	1.535	.0334	2.13
2	60	444	.1182	.28	4.25	4.06	.0887	1.335
3	60	539	.1436	.20	3.6	3.44	.075	1.91
4	120	685	.0913	.15	3.12	2.98	.065	1.40
5	60	247	.0658	.01	2.54	2.42	.0528	1.25
6	60	135	.0360	.05	1.80	1.72	.0375	.96

LOSSES THROUGH COMMERCIAL FITTINGS.

The commercial fittings used in the laboratory were made by the Crane Company. They were all made of cast iron finished on the inside. Their cross sections were as shown on the page containing the curve. The fittings were in good condition, water having been run through them for some time before any readings were taken. Four fittings of each kind were placed together in the piping system. In finding the loss coefficient, one reading was taken over all four fittings and the result divided by four.

One general method of procedure was followed. The gauge was first connected to the fittings in such a way as to measure the loss of head. (See discussion of gauges.) Then about thirty readings were taken of the difference in head and quantity of water flowing under varying heads. The quantity was determined in cu. ft. per sec. The method of determining the quantity was to catch the water in a tank for a certain length of time and then weigh it. The quantity equals the weight of water divided by time in seconds times the unit weight of water. The loss coefficient was found from the formula $H = \xi \frac{V^2}{2g}$ where H is the difference in head in feet of water. A curve was plotted showing the relation of quantity to head of water. In each case it was found that above a certain velocity this relation was a constant.

The results obtained for the coefficient were all tabulat-

ed. The loss in head and the loss coefficient varies greatly with the kind of fitting used. Nearly all the fittings have coefficients less than one. The part having the greatest loss coefficient was the angle globe valve. The more the inside of a fitting obstructs the flow of water the greater will be the loss coefficient. Friction in a 2" pipe is greater than in a 3" pipe. The smaller the diameter of a pipe, the greater the loss by friction. The reader has only to read the tabulated value of "c" to make for himself a comparison of the losses for various fittings.

In performing these experiments care was taken to get as accurate results as possible, therefore we wish to recommend the results of "c" as tabulated for each fitting, be accepted as the loss coefficient for that fitting in the hydraulic laboratory.

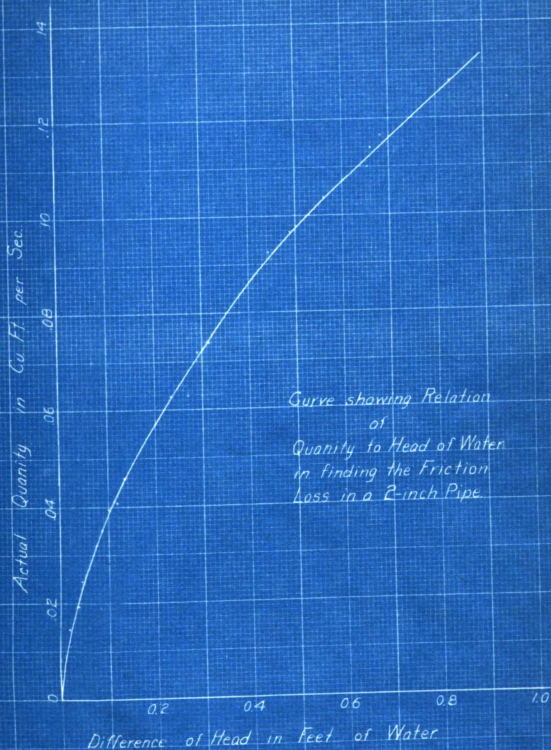
TABLE OF AVERAGE VALUES OF COEFFICIENT "C"
FOR EACH COMMERCIAL FITTING IN THE LABORATORY.

Commercial Fitting	Value of "c"	
	Four Fittings	One Fitting
1. Straight Globe Valve	2.600	0.650
2. Angle Tees	3.558	0.8895
3. Straight Tees	1.3884	0.3471
4. Couplings	0.4633	0.1158
5. Flanges	0.7751	0.1938
6. Elbows	2.625	0.656
7. Angle Globe Valve	6.761	1.690
8. Gate Valve	1.1127	0.2781
9. Unions	0.9511	0.2378
10. Abrupt Contraction		1.365
11. " Expansion		0.5453
12. Friction in 2" pipe		1.929
13. Friction in 3" pipe		1.461

COEFFICIENT OF FRICTION
in a 2" pipe

Run	Time Sec.	Lbs.of Water	Quant. Cu.Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	C
1	120	538.	.0718	.169	.51	.292	1.73
2		693.0	.0924	.278	.76	.444	1.59
3		827.0	.110	.392	1.12	.655	1.67
4		874.0	.1165	.442	1.17	.684	1.55
5		955.0	.1274	.527	1.42	.830	1.57
6		857.0	.114	.422	1.13	.660	1.56
7		777.0	.1036	.348	.96	.561	1.61
8		725.0	.0966	.304	.84	.491	1.62
9		641.5	.0855	.237	.67	.450	1.90
10		554.0	.0738	.178	.54	.315	1.77
11		470.0	.0626	.1275	.40	.234	1.83
12	120	395.0	.0525	.0990	.29	.017	1.72
13	150	431.0	.0458	.0687	.23	.135	1.96
14	120	307.5	.0409	.0545	.20	.117	2.15
15	180	158.0	.0141	.0644	.03	.018	2.80
16	120	143.0	.0191	.0119	.055	.032	2.69
17		185.0	.0246	.0199	.08	.047	2.36
18		240.0	.0320	.0332	.13	.076	2.29
19		263.0	.0351	.0402	.15	.088	2.19
20		296.0	.0395	.0508	.175	.103	2.03

Average Coefficient 1.929



COEFFICIENT OF FRICTION in a 3" pipe

[illegible]

Actual Quantity in Cu. Ft. per Sec.

.14

.12

.10

.08

.06

.04

.02

0

.02

.04

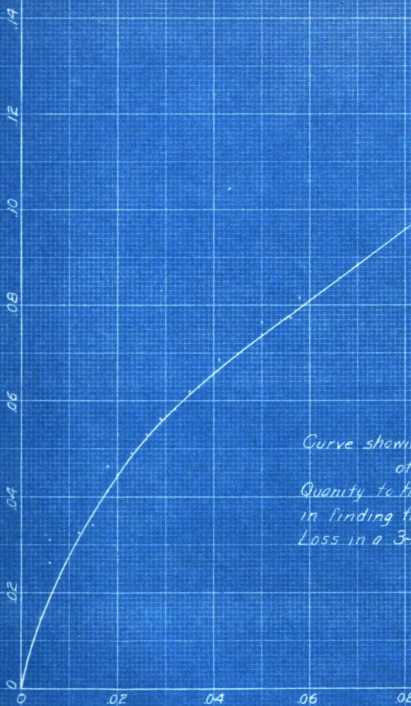
.06

.08

.10

Difference of Head in Feet of Water

Curve showing Relation
of
Quantity to Head of Water
in finding the Friction
Loss in a 3-inch Pipe.

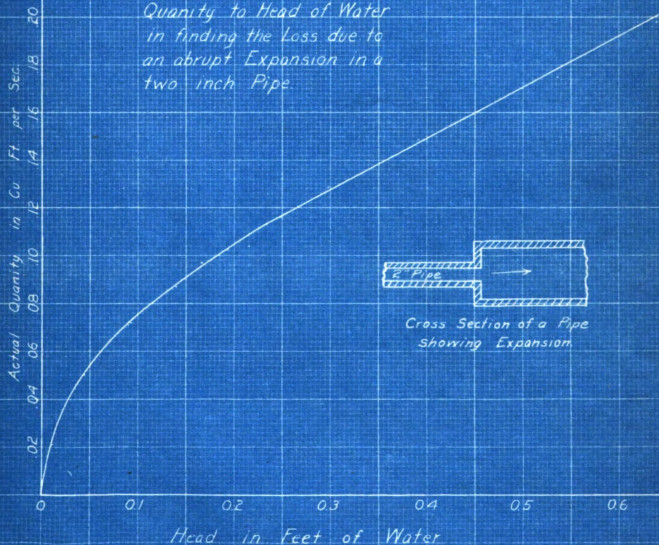


LOSSES ON EXPANSION

Run	Time Sec.	Lbs.of Water	Quant. Actual Cu.Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	C
1	120	1442.0	.1918	1.204	1.10	.642	.533
2		1315.0	.1750	1.002	0.92	.537	.535
3		1201.0	.1598	.8354	0.77	.45	.538
4		1117.0	.1485	.721	0.67	.392	.543
5		963.0	.1282	.5376	0.51	.298	.554
6		851.0	.1132	.4196	0.40	.234	.557
7		768.0	.1023	.342	0.33	.193	.564
8		655.5	.0872	.2487	0.24	.140	.562
9		541.5	.0720	.1693	0.16	.093	.549
10		448.0	.0597	.1167	0.105	.061	.523
11		379.0	.0504	.0830	0.075	.044	.530
12		535.5	.0713	.1662	0.155	.0905	.544
13		649.0	.0863	.2438	0.23	.135	.554
14		728.0	.0970	.3079	0.285	.167	.542
15		821.0	.1092	.3917	0.37	.216	.551

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

Curve showing Relation
of
Quantity to Head of Water
in finding the Loss due to
an abrupt Expansion in a
two inch Pipe.



Cross Section of a Pipe
showing Expansion.

LOSSES ON CONTRACTION

Run	Time Sec.	Lbs. of Water	Quant. Cu.Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	C
1	120	922.0	.1226	.4928	1.14	.666	1.352
2	120	815.0	.1083	.3840	0.90	.526	1.37
3	180	872.5	.0773	.1959	0.47	.257	1.312
4	180	1202.0	.1066	.3702	0.87	.508	1.372
5	120	648.6	.0863	.2438	0.575	.336	1.378
6	120	442.5	.0588	.1133	.27	.158	1.394
7	180	343.5	.0304	.0302	.07	.041	1.358
8	180	281.3	.0249	.0203	.05	.029	1.428
9	120	278.0	.0370	.0448	.105	.061	1.36
10	120	376.5	.0502	.0823	.195	.114	1.385
11	120	435.5	.0599	.1096	.255	.149	1.36
12	120	480.0	.0638	.1335	.31	.181	1.355
13	120	534.5	.0712	.1662	.39	.228	1.372
14	120	705.0	.0938	.2888	.67	.392	1.356
15	120	758.5	.1009	.3333	.78	.456	1.368

Average 1.365

Actual Quantity in Cu Ft. per Sec.

0.14
0.12
0.10
0.08
0.06
0.04
0.02
0

0.2 0.4 0.6 0.8 1.0
Head in Feet of Water



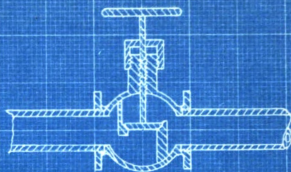
Cross Section of
Contraction in Pipe

Curve showing Relation
of
Quantity to Head of Water
in finding the Loss due to
an abrupt Contraction in a
two inch Pipe.

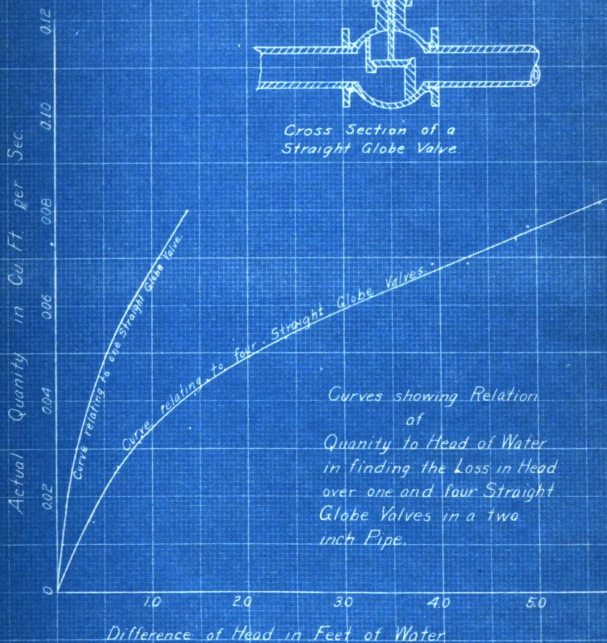
LOSSES THROUGH STRAIGHT GLOBE VALVES

Run	Time Sec.	Lbs.of Water	Quant. Cu.Ft. / Sec.	$\frac{V^2}{2g}$	H Hg	H H ₂ O	4ξ
1	240	476	.0311	.0314	.07	.882	2.71
2	240	514	.0342	.0383	.11	1.385	2.765
3	180	525	.0466	.0705	.14	1.764	2.50
4		597.5	.0530	.0915	.19	2.39	2.61
5		698.5	.0619	.1250	.26	3.275	2.62
6		774.5	.0687	.1533	.31	3.905	2.55
7	180	861.5	.0764	.140	.39	4.92	2.59
8	120	611.0	.0813	.216	.45	5.67	2.62
9	120	666.0	.0886	.257	.51	6.42	2.50
10	180	872.5	.0774	.196	.41	5.17	2.64
11	210	972.0	.0738	.178	.38	4.79	2.69
12	120	514.0	.0684	.153	.34	4.28	2.80
13	120	437.5	.0581	.111	.22	2.77	2.50
14		460.5	.0614	.123	.25	3.15	2.56
15		421.5	.0561	.101	.20	2.52	2.49
16		389.5	.052	.0885	.18	2.27	2.57
17		368.0	.0491	.0785	.16	2.015	2.57
18		333.0	.0444	.0633	.125	1.575	2.49
19		309.0	.0412	.0545	.115	1.45	2.66
20		243.5	.0325	.0345	.07	.882	2.56

Average Coefficient 2.605

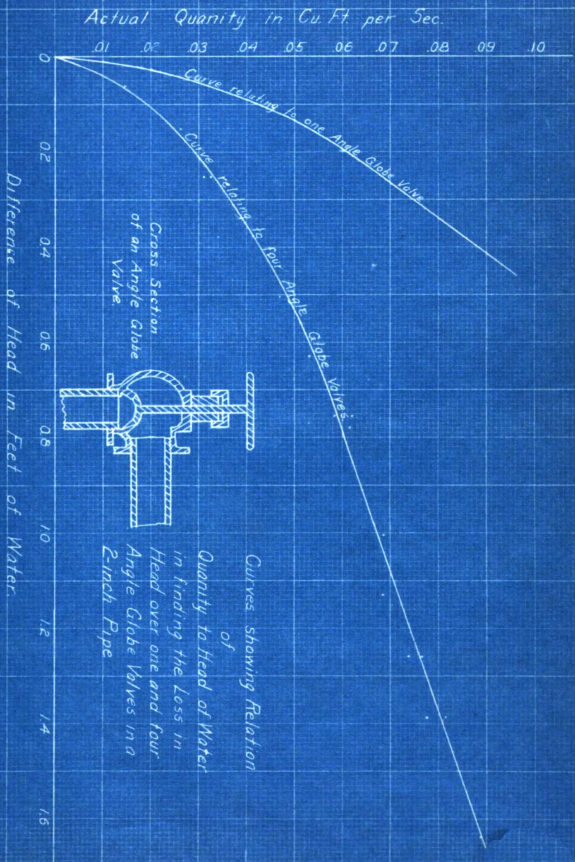


Cross Section of a
Straight Globe Valve



LOSSES THROUGH ANGLE GLOBE VALVES

[illegible]



LOSSES THROUGH GATE VALVES

Run	Time Sec.	Lbs. of Water	Quant. Cu. Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	4ξ
1	120	212.0	.0282	.0260	.05	.029	1.115
2		508.5	.0676	.1494	.27	.158	1.057
3		569.5	.0757	.1872	.35	.205	1.094
4		638.5	.0848	.2352	.45	.263	1.119
5		702.0	.0933	.2848	.53	.310	1.088
6		766.0	.1019	.3390	.63	.368	1.085
7	120	794.0	.1056	.3642	.67	.392	1.077
8	150	1065.	.1133	.4203	.77	.450	1.071
9	120	775.0	.1030	.3478	.65	.380	1.091
10		740.0	.0985	.3176	.61	.356	1.121
11		682.5	.0907	.2690	.51	.298	1.108
12	120	625.5	.0831	.2257	.44	.257	1.138
13	150	762.0	.0811	.2151	.39	.228	1.060
14	120	547.0	.0727	.1724	.32	.187	1.083
15		471.0	.0627	.1284	.25	.146	1.136
16		428.0	.0569	.1058	.20	.117	1.105
17		392.0	.0521	.0888	.18	.105	1.182
18		367.5	.0488	.0780	.16	.093	1.191
19	120	323.0	.0430	.0605	.12	.070	1.158
20	90	229.0	.0406	.0539	.11	.064	1.186

Average Coefficient 1.1127

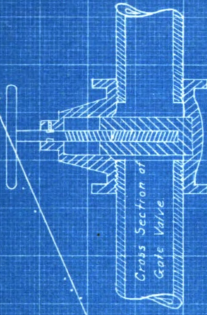
1	2	3	4	5	6
7	8	9	10	11	12
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19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36
37	38	39	40	41	42
43	44	45	46	47	48
49	50	51	52	53	54
55	56	57	58	59	60
61	62	63	64	65	66
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313	314	315	316	317	318
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409	410	411	412	413	

Actual Quantity in Cu. Ft. per Sec.

0.10 0.09 0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01

Curve relating to one Gate Valve

Curve relating to four Gate Valves



Curves showing Relation of Quantity to Head of Water in finding the Loss in Head over one and four Gate Valves in a 2-inch Pipe.

Difference of Head in Feet of Water.

0

0.05

0.10

0.15

0.20

0.25

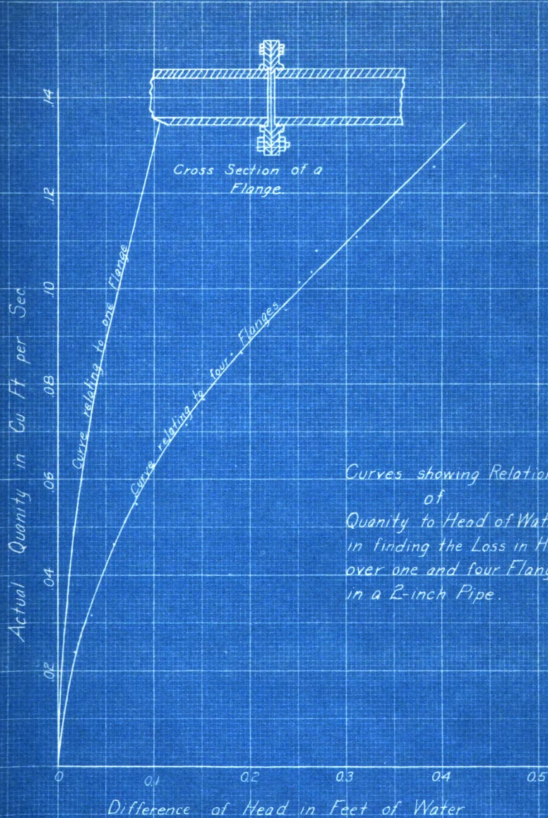
0.30

0.35

0.40

LOSSES THROUGH FLANGES

[illegible]

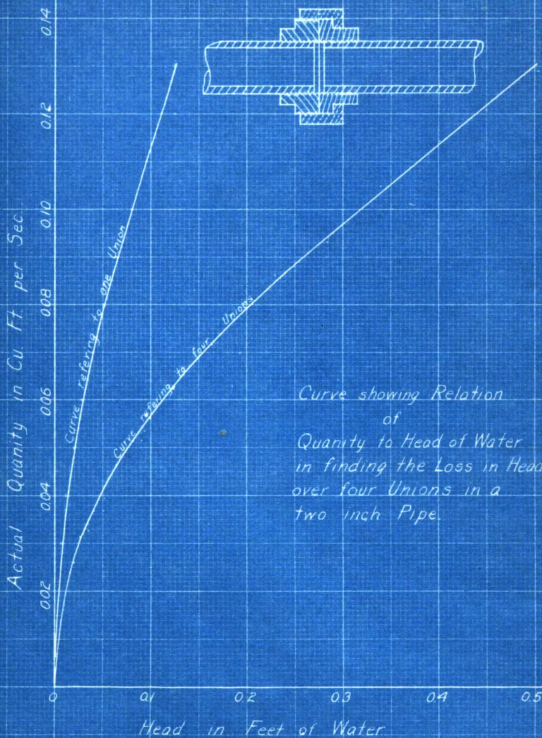


Curves showing Relation
of
Quantity to Head of Water
in finding the Loss in Head
over one and four Flanges
in a 2-inch Pipe.

LOSSES IN UNIONS

Run	Time Sec.	Lbs.of Water	Quant. Cu.Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	ϵ
1	120	970.0	.129	.5449	.86	.503	.924
2		909.0	.1208	.4772	.77	.450	.943
3		860.5	.1144	.4285	.69	.402	.938
4		788.0	.1048	.3597	.58	.339	.943
5		653.0	.0869	.2470	.41	.240	.971
6		598.0	.0796	.2071	.34	.199	.961
7		539.0	.0717	.1678	.28	.164	.977
8		468.0	.0623	.1272	.21	.123	.967
9		349.0	.0464	.0705	.11	.064	.908
10		195.5	.0260	.0221	.035	.020	.905
11		179.5	.0239	.0187	.025	.015	.803
12		236.0	.0314	.0322	.045	.026	.808
13		277.5	.0369	.0445	.07	.041	.922
14		349.0	.0464	.0705	.11	.064	.908
15		386.5	.0513	.0862	.14	.082	.951
16		423.0	.0562	.1031	.17	.099	.959
17		470.5	.0625	.1276	.21	.123	.965
18		512.0	.0680	.1513	.25	.146	.964
19		578.5	.0770	.1937	.32	.187	.966
20		648.5	.0862	.2426	.39	.228	.939

Average .9511



LOSSES IN COUPLINGS

Run	Time Sec.	Lbs. of Water	Quant. Cu. Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	ϵ
1	120	673.0	.0896	.2626	.20	.117	.445
2		716.0	.1013	.3362	.26	.152	.452
3		812.0	.1080	.3809	.29	.169	.444
4		943.0	.1255	.5158	.41	.240	.465
5		858.0	.1141	.4253	.34	.199	.468
6		777.5	.1034	.3508	.28	.164	.468
7		720.0	.0958	.2999	.25	.146	.486
8		698.0	.0929	.2821	.22	.128	.454
9		538.0	.0715	.1673	.14	.082	.489
10		466.0	.0620	.2156	.10	.058	.462
11		357.0	.0474	.0735	.06	.035	.476
12		263.0	.0349	.0398	.03	.0175	.440
13		212.0	.0282	.0260	.02	.0117	.451
14		508.5	.0677	.1495	.12	.070	.468
15		569.5	.0757	.1872	.15	.087	.464
16		638.5	.0848	.2352	.19	.111	.473
17		702.0	.0933	.2848	.23	.134	.471
18		766.0	.1019	.3397	.27	.158	.465
19		794.0	.1056	.3642	.295	.172	.473
20		1065.0	.1134	.4220	.33	.193	.452

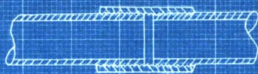
Average Coefficient .4633

Actual Quantity in Cu. Ft. per Sec.

0.2
0.4
0.6
0.8
1.0
1.2
1.4

Curve referring to one Coupling

Curve referring to four Couplings



Cross Section of a Coupling.

Curve showing Relation
of
Quantity to Head of Water
in finding the Loss in Head
over four Couplings in a
two inch Pipe.

0 0.4 0.8 1.2 1.6 2.0

Difference of Head in Feet of Water

LOSSES THROUGH STRAIGHT TEES

Run	Time Sec.	Lbs. of Water	Quant. Cu. Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	4ϵ
1	120	323.0	.0431	.06095	.145	.085	1.395
2		362.0	.0482	.07593	.185	.108	1.42
3		393.0	.0524	.08998	.205	.120	1.335
4		419.5	.0558	.10189	.245	.143	1.405
5		450.0	.0600	.11758	.275	.161	1.369
6		479.0	.0639	.13347	.31	.181	1.355
7		518.0	.0692	.15623	.36	.210	1.345
8		604.0	.0806	.21210	.49	.286	1.348
9		729.0	.0973	.30927	.70	.41	1.327
10		970.0	.1291	.5449	1.24	.725	1.331
11		909.0	.1211	.4789	1.09	.638	1.333
12		860.5	.1148	.4302	.97	.566	1.315
13		788.0	.1040	.35375	.83	.485	1.372
14		653.0	.0870	.24752	.59	.345	1.393
15		598.0	.0799	.20826	.51	.289	1.432
16		539.0	.1718	.16828	.41	.240	1.425
17		468.0	.0624	.12717	.31	.181	1.423
18		403.	.0539	.09485	.23	.134	1.412
19		349.0	.0466	.07120	.18	.105	1.474
20		195.5	.0261	.02259	.06	.035	1.56

Average Coefficient 1.3884

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1345	1346				

Actual Quantity in Cu. Ft. per Sec.

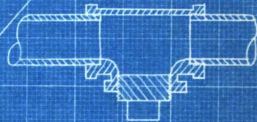
.01 .02 .03 .04 .05 .06 .07 .08 .09 .10 .11 .12 .13

Curve refers to one Straight Tee

Curve refers to four Straight Tees

0 0.2 0.4 0.6 0.8

Difference of Head in Feet of Water



Cross Section of a Straight Tee

Curve showing Relation of Quantity to Head of Water in finding the Loss in Head over four Straight Tees in a two inch Pipe.

LOSSES THROUGH ANGLE TEES

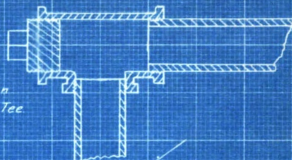
Run	Time Sec.	Lbs. of Water	Quant. Cu.Ft. / Sec.	$\frac{v^2}{2g}$	H CCl ₄	H H ₂ O	4ξ
1	240	476	.0311	.0314	.19	.111	3.53
2	180	525	.0466	.0705	.41	.240	3.41
3	180	597.5	.0529	.0915	.55	.321	3.51
4	180	698.5	.0619	.1250	.76	.444	3.56
5	180	774.5	.0687	.1533	.90	.526	3.43
6	180	861.5	.0765	.190	1.15	.672	3.53
7	120	611.0	.0813	.216	1.30	.760	3.52
8	180	872.5	.0775	.196	1.15	.672	3.43
9	210	972.0	.0739	.178	1.10	.643	3.61
10	120	437.5	.0583	.111	.71	.415	3.74
11	120	538.0	.0720	.169	1.08	.63	3.73
12		693.0	.0924	.278	1.73	1.01	3.64
13		827.0	.1105	.413	2.58	1.51	3.65
14		874.0	.1165	.442	2.81	1.64	3.72
15		857.0	.1141	.426	2.75	1.61	3.78
16		777.0	.1035	.350	2.16	1.26	3.60
17		725.0	.0966	.304	1.83	1.07	3.52
18		641.5	.0856	.239	1.40	.818	3.43
19		554.0	.0739	.179	1.075	.629	3.515
20		470.0	.0627	.128	.753	.440	3.41

Average Coefficient 3.558

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1345	1346				

Actual Quantity in Cu Ft per Sec.

Cross Section
of an Angle Tee



Curve relating to One Angle Tee

Curve relating to Four Angle Tees

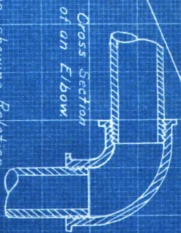
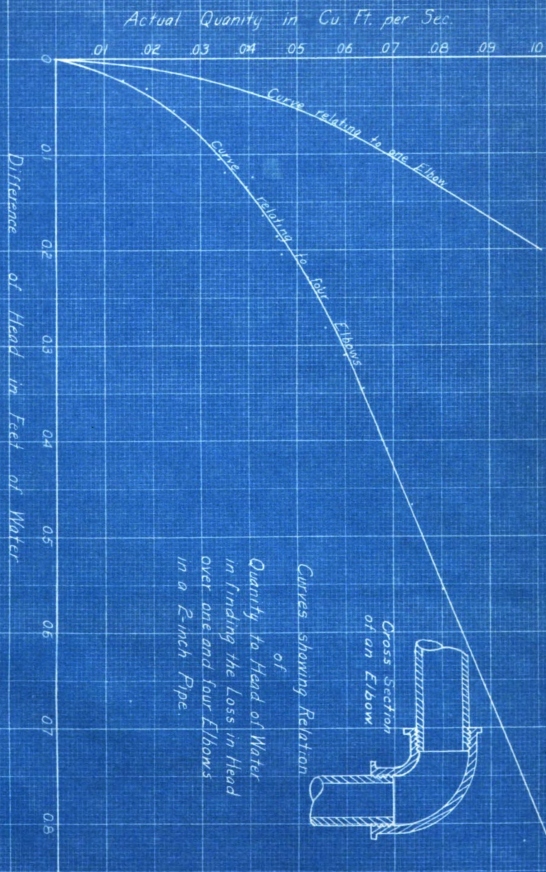
Curves showing Relation
of
Quantity to Head of Water
in finding the Loss in Head
over one and four Angle Tees
in a two inch Pipe.

Difference of Head in Feet of Water

LOSSES THROUGH ELBOWS

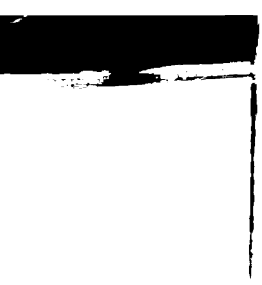
Run	Time Sec.	Lbs. of Water	Quant. Cu.Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	4ξ
1	120	395.0	.0526	.0903	0.40	.234	2.59
2	150	431.0	.0459	.0986	.32	.187	2.71
3	120	307.5	.0408	.0544	.21	.123	2.26
4		147.5	.0196	.0125	.06	.035	2.80
5		143.0	.0190	.0118	.055	.032	2.71
6		185.0	.0246	.0198	.09	.053	2.68
7		223.0	.0296	.0287	.125	.073	2.54
8		240.0	.0319	.0332	.155	.091	2.74
9		263.0	.0350	.0400	.185	.108	2.70
10		296.0	.0394	.0508	.23	.134	2.63
11		323.0	.0430	.0604	.28	.164	2.71
12		362.0	.0468	.0715	.35	.205	2.86
13		393.0	.0522	.0888	.39	.228	2.56
14		419.5	.0558	.1019	.41	.240	2.24
15		450.0	.0598	.1167	.53	.310	2.65
16		479.0	.0637	.1326	.59	.345	2.60
17		518.0	.0689	.1552	.70	.408	2.63
18		556.0	.0739	.1787	.80	.467	2.61
19		604.0	.0803	.2112	.95	.555	2.63
20		729.0	.0970	.3079	.40	.818	2.66

Average Coefficient 2.625



Cross Section of an Elbow

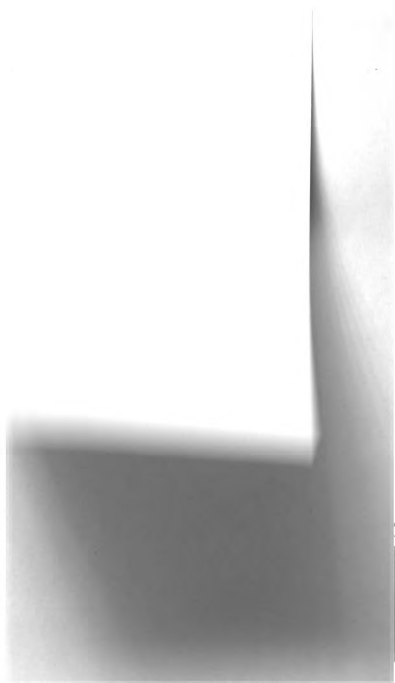
Curves showing Relation of Quantity to Head of Water in finding the Loss in Head over one and four Elbows in a 2-inch Pipe.



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ROOM USE ONLY.





LOSSES THROUGH STRAIGHT TENS

Run	Time Sec.	Lbs. of Water	Quant. Cu. Ft. / Sec.	$\frac{V^2}{2g}$	H CO ₂	H H ₂ O	4ϵ
1	120	323.0	.0431	.06095	.145	.085	1.395
2		362.0	.0482	.07593	.185	.108	1.42
3		393.0	.0524	.08998	.205	.120	1.335
4		419.5	.0558	.10189	.245	.143	1.405
5		450.0	.0600	.11758	.275	.161	1.369
6		479.0	.0639	.13347	.31	.181	1.355
7		518.0	.0692	.15623	.36	.210	1.345
8		604.0	.0806	.21210	.49	.286	1.348
9		729.0	.0973	.30927	.70	.41	1.327
10		970.0	.1291	.5449	1.24	.725	1.331
11		909.0	.1211	.4789	1.09	.638	1.333
12		860.5	.1148	.4302	.97	.566	1.315
13		788.0	.1040	.35375	.83	.485	1.372
14		653.0	.0870	.24752	.59	.345	1.393
15		598.0	.0799	.20826	.51	.289	1.432
16		539.0	.1718	.16828	.41	.240	1.425
17		468.0	.0624	.12717	.31	.181	1.423
18		403.	.0539	.09485	.23	.154	1.412
19		349.0	.0466	.07120	.18	.105	1.474
20		195.5	.0261	.02259	.06	.035	1.56

Average Coefficient 1.3884

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Actual Quantity in Cu. Ft. per Sec.

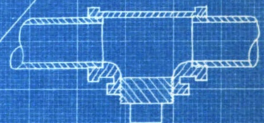
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Curve referring to one Straight Tee

Curve referring to four straight Tee

Difference of Head in Feet of Water

0 0.2 0.4 0.6 0.8



Cross Section of a Straight Tee

Curve showing Relation of Quantity to Head of Water in finding the Loss in Head over four Straight Tees in a two inch Pipe.

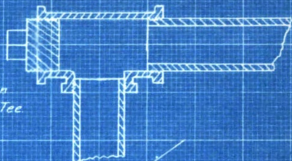
LOSSES THROUGH ANGLE TEES

Run	Time Sec.	Lbs. of Water	Quant. Cu. Ft. / Sec.	$\frac{V^2}{2g}$	H CCl ₄	H H ₂ O	4ξ
1	240	476	.0311	.0314	.19	.111	3.53
2	180	525	.0466	.0705	.41	.240	3.41
3	180	597.5	.0529	.0915	.55	.321	3.51
4	180	698.5	.0619	.1250	.76	.444	3.56
5	180	774.5	.0687	.1533	.90	.526	3.43
6	180	861.5	.0765	.190	1.15	.672	3.53
7	120	611.0	.0813	.216	1.30	.760	3.52
8	180	872.5	.0775	.196	1.15	.672	3.43
9	210	972.0	.0739	.178	1.10	.643	3.61
10	120	437.5	.0583	.111	.71	.415	3.74
11	120	538.0	.0720	.169	1.08	.63	3.73
12		693.0	.0924	.278	1.73	1.01	3.64
13		827.0	.1105	.413	2.58	1.51	3.65
14		874.0	.1165	.442	2.81	1.64	3.72
15		857.0	.1141	.426	2.75	1.61	3.78
16		777.0	.1035	.350	2.16	1.26	3.60
17		725.0	.0966	.304	1.83	1.07	3.52
18		641.5	.0856	.239	1.40	.818	3.43
19		554.0	.0739	.179	1.075	.629	3.515
20		470.0	.0627	.128	.753	.440	3.41

Average Coefficient 3.558



Cross Section
of an Angle Tee



Curves showing Relation
of
Quantity to Head of Water
in finding the Loss in Head
over one and four Angle Tees
in a two inch Pipe.

Difference of Head in Feet of Water

LOSSES THROUGH ELBOWS

[illegible]

Actual Quantity in Cu. Ft. per Sec.

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

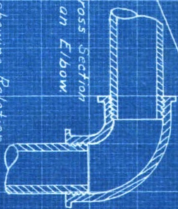
Curve relating to one Elbow

Curve relating to four Elbows

Difference of Head in Feet of Water

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

Cross Section of an Elbow



Curves showing Relation

of

Quantity to Head of Water
in finding the Loss in Head
over one and four Elbows
in a 2-inch Pipe.

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