THE DETERMINATION OF THE FRICTION FACTOR FOR NEW 6-INCH ALUMINUM TUBING AND HEAD LOSS IN ELBOWS AND SPRINKLER-PIPE COUPLERS

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Alberto Daker

1950

This is to certify that the

thesis entitled

"The Determination of the Friction Factor For New
6-Inch Aluminum Tubing and Head Loss in
Elbows and Sprinkler-Pipe Couplers"

presented by

Alberto Daker

has been accepted towards fulfillment
of the requirements for

M. S. degree in Agricultural Engineering

Walter M. Carleton
Major professor

Date Sept. 1 1950

O-169

THE DETERMINATION OF THE FRICTION FACTOR FOR NEW 6-INCH ALUMINUM TUBING AND HEAD LOSS IN ELBOWS AND SPRINKLER-PIPE COUPLERS

By

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A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1950

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation of the kindly interest, valuable suggestions, and helpful advice received from Professor E. H. Kidder of the Agricultural Engineering Department during the course of this investigation.

He also wishes to express his appreciation to the following:

Instructor P. E. Schleusener of the Agricultural Engineering Department for many suggestions.

Instructor B. F. Cargill of the Agricultural Engineering Department for the pictures taken.

Perfection Sprinkler Company of Ann Arbor, Mich., for the use of their pipes and couplers in making this study.

Gorman Rupp Company, Mansfield, Ohio, for the use of their engine and pump in this experiment.

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INTRODUCTION

Although sprinkler-irrigation has been practiced in parts of the United States for about fifty years, it was not until about 1930 that light weight pipe with quick-coupling for portable sprinkler systems came into use (1, p. 3).

Since 1942, when extruded aluminum tubing first became available, aluminum has been the dominant material used in manufacturing sprinkler-irrigation tubing and fittings (7, p. 5). That is the reason why the hydraulic characteristics of aluminum tubing, couplers, and bends is essential for the economic design of a portable-sprinkler system for the farm.

In these studies the friction factor was determined for 6-inch diameter of new aluminum tubing and the head loss coefficient determined for 6-inch diameter of coupler when the longitudinal pipe alignment was straight in all planes.

Since the head loss coefficient for couplers varies with varying degrees of poor alignment of connecting sections of tubing through the coupler, three different positions of connections were tested as follows: position 1 - coupler out of alignment in the vertical plane using the maximum amount of vertical displacement within the coupler; position 2 - tubing vertically displaced in the coupler as in position 1 and in addition a three (3) degree deflection from true alignment through the coupler in the horizontal plane; position 3 - identical to position 2, except the angle of deflection was increased to six (6) degrees, the maximum allowed by the test coupling.

This experiment includes also the determination of the head loss coefficient for 90 and 180 degree elbows.

REVIEW OF LITERATURE

Letter symbols

To simplify the discussion and presentation of data, the following symbols will be used. They agree as closely as possible with those presented in hydraulic literature and are given in accordance with Le Conte (6, p. XI).

A	Area of pipe, square feet
C	General constant
d	Diameter of pipe, feet
f	Coefficient of friction (Darcy-Weisbach)
g	Acceleration of gravity (32.2 ft/sec^2)
h_c	Head loss in couplers, feet
h_e	Head loss in elbows, feet
h_f	Head loss due to friction, feet
h_L	Total head loss, feet
K	Coefficient of proportionality
K_a	Coefficient of proportionality for aluminum pipe
K_c	Loss coefficient for couplers
K_e	Loss coefficient for elbows
K_L	Loss coefficient in fittings
L	Length of pipe, feet
m,n	Exponential values
N_R	Reynolds number
p	Pressure, lbs/in^2

Q	Rate of flow, cfs
V	Velocity, ft/sec
w	Unit weight, lbs/ft^3
z	Difference in elevation, feet
ρ	Density, lb-sec^2/ft^4
μ	Viscosity, lb-sec/ft^2

The Bernoulli equation

Head loss in straight pipe flow is illustrated graphically in Fig. 1. Two lines designated respectively the hydraulic gradient and the energy gradient are shown (5, p.196).

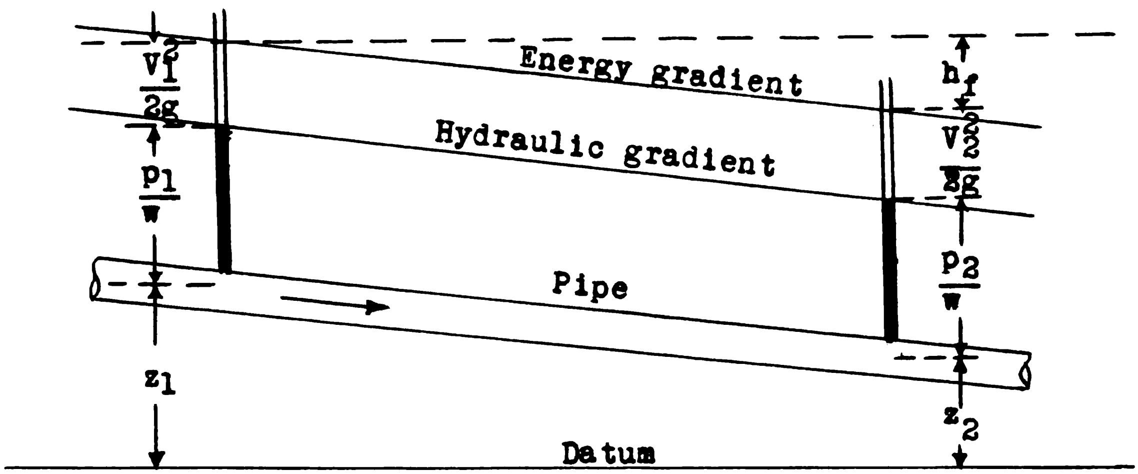


Fig.1 Frictional loss in pipe.

The Bernoulli equation between any two sections of a straight pipe (8, p. 181) as those shown in Fig. 1, is

$$\frac{V_1^2}{2g} + \frac{p_1}{w} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{w} + h_f + z_2 \quad \ldots\ldots\ldots\ldots \quad (1)$$

Durand discusses total energy as being in the primary and secondary forms (7, p. 4). The three primary forms, shown diagrammatically in Fig. 1, are:

1. Pressure energy or pressure head (p/w)
2. Kinetic energy or velocity head ($V^2/2g$)
3. Potential energy or gravity head (z)

The two secondary forms of energy are:

1. The internal energy or the kinetic energy of eddies and turbulence
2. Head energy

The three primary forms may be converted into each other and also into either of the two secondary forms; however, the secondary forms are not convertible into the principal forms of energy. The internal energy is inevitably converted into heat energy, which is dissipated and, therefore, unavailable from a mechanical standpoint in pipe flow. This loss of energy is incidental with the transfer of fluid in a pipe (7, p. 5).

The head loss h_f (See Fig. 1) which occurs when an incompressible fluid flows between two sections of a straight pipe of uniform diameter is due to the viscous shear between fluid particles (8, p. 180).

Head lost by pipe friction

Certain general laws based upon observation and experiment appear to govern fluid friction in pipes and are ex-

pressed in all the generally accepted pipe formulae. These laws briefly stated are (5, p. 181):

1. Frictional loss in turbulent flow generally increases with the roughness of the pipe
2. Frictional loss is directly proportional to the area of the wetted surface, or to πdL
3. Frictional loss varies inversely as some power of the pipe diameter, or as $1/d^x$
4. Frictional loss varies as some power of the velocity, or as V^m
5. Frictional loss varies as some power of the ratio of viscosity to density of the fluid, or as $(\mu/\rho)^r$

Combining these factors, a rational equation for head lost by pipe friction for any fluid can be written in the form:

$$h_f = K' \times \pi dL \times 1/d^x \times V^m \quad \mu/\rho)^r \quad \ldots\ldots\ldots \quad (2)$$

K' in the above formula is a combined roughness coefficient and proportionality factor. If n+1 is substituted for x, equation 2 can be written in the form:

$$h_f = \left[K' \pi \mu/\rho)^r\right] \frac{L}{d^n} V^m \quad \ldots\ldots\ldots\ldots \quad (3)$$

The effect of viscosity and density of water on loss of head at usual flow velocities is so small that it can be easily included in a general coefficient (5, p. 181). K being substituted for the quantity in brackets in equation 3, the base formula for head loss in pipe flow can be written as:

$$h_f = K \frac{L}{d^n} V^m \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Experiments show that the coefficient and exponents vary in value. For laminar flow, m is equal 1 and for turbulent flow its value ranges from 1.70 for smooth pipe to 2.0 or more for a rough pipe. Likewise n has a value of 2 for laminar flow and varies from 1.0 to 1.3 for turbulent flow (8, p. 181).

Unwin (9, p. 217) gives the following mean values for K, n, and m:

Surface	K	n	m
Wrought iron	.000351	1.210	1.75
Asphalted pipes	.000395	1.127	1.85
Riveted wrought iron	.000405	1.390	1.87
New cast iron	.000334	1.168	1.95
Cleaned cast iron	.000378	1.168	2.00
Incrusted cast iron	.000685	1.160	2.00

Many empirical formulae have been proposed to represent the friction factor for smooth tubes over all or part of the range of Reynolds' Numbers. Practically all have been of the form $f = A + B/N_R^n$, the constant A, B, and n being adjusted to fit various sets of experimental results (3, p. 94). Blassius

(3, p. 94) published five such equations to cover the range of Reynolds Number from 2500 to 10^7. Freeman arrived at the equation

$$f = 0.3597/N_R^{.261}$$

as a result of his experiments on hydraulic smooth pipes. This is in agreement with the work of Blassius (3, p. 87) who proposed the equation

$$f = 0.3164/N_R^{.25}$$

from an analyses of experimental data reaching to about $N_R = 100,000$.

Weston (11, p. 1) in reviewing experimental results in pipes, considered lead and brass tubing as being very smooth pipes. He proposed a formula based on his experiment for these kind of tubing. For tubing having interior sides similar to new cast iron pipes, he came to the conclusion that Darcy's formula was very well adapted.

The investigation carried on by Gibson (4, p. 207) indicates that if roughness of the surface of a galvanized iron pipe is taken as a unity, that of other surfaces is approximately as follows:

New uncoated cast iron......................	1.40
New asphalted cast iron.....................	3.55
New wood stave pipes........................	5.65
Concrete pipe carefully hand-finished......	1.50
Concrete pipe with ordinary finish.........	6.00
Rough concrete pipes........................	18.50

Results of experiments on friction losses in pipes of various materials and diameters are commonly expressed by plotting the friction factor versus Reynolds Number. In the region of turbulent flow the results of this plot for hydraulically smooth pipe indicate that the pipe roughness when submerged in the boundary laminar film has no effect on the friction factor. However, as the thickness of the boundary laminar film decreases when the Reynolds Number increases, pipe, which may be hydraulically smooth for low values of the Reynolds Number may become rough as the Reynolds Number increases (10, p. 160).

The Darcy-Weisbach formula

A determination of K, m, and n is necessary for practical application of equation 4 to flow problems. Chezy stated that the head loss in the flow of water in conduits varied approximately as the square of the velocity. Darcy, Weisbach, and others, accepting Chezy's value of 2 for m, further modified equation 4 by proposing a value of 1 for n, and divided and multiplied by 2g (5, p. 182), so that

$$h_f = (K'' \ 2g) \ \frac{L}{d} \frac{V^2}{2g}$$

By substituting a so-called "friction factor" f for K'' 2g, the well-known pipe formula, called the Darcy-Weisbach formula, was obtained (5, p. 182):

$$h_f = f \ \frac{L}{d} \frac{V^2}{2g} \qquad (5)$$

This formula is of convenient form since it expresses the loss of head in terms of the velocity head in the pipe. Moreover, it is dimensionally correct since f is a numerical factor, L/d is a ratio of lengths, and h_f and $V^2/2g$ are both expressed in units of length (5, p. 182).

Minor losses

Whenever the velocity of a flowing stream is altered either in direction or in magnitude, such alteration sets up additional eddy currents and thus creates a loss of energy in excess of the usual pipe friction. The magnitude of this loss is proportional to the abruptness of the velocity change. It is customary to refer to such losses as minor losses because in a pipe line of considerable length the pipe friction itself may be so large that the value of these other losses may be relatively insignificant (2, p. 214).

It has been found that minor losses vary roughly as the square of the velocity, and they are commonly expressed by applying variable coefficients to the velocity head (5, p. 203). This led to the proposal of the basic equation:

$$h_L = K_L \frac{V^2}{2g}$$

in which K_L is the loss coefficient. Its value for a particular fitting can be determined only by experiment.

METHODS OF PROCEDURE

Apparatus

A gasoline engine driven centrifugal pump unit was operated to produce the required rates of flow. The water was drawn from a reservoir on the basement floor level and passed through the pump into the irrigation pipe line, then up to the first floor level to a hydraulic flume where the rate of flow was measured by a Cipolletti weir. The flow on passing through the Cipolletti weir returned to the basement reservoir (Fig. 2, 3, 4, and 5).

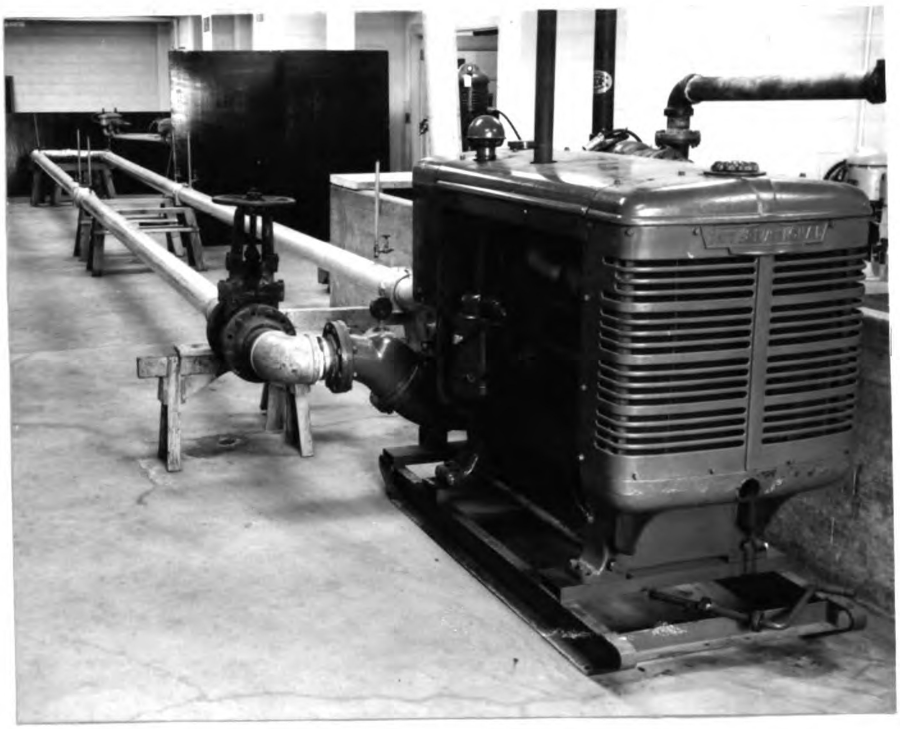


Fig. 2 General view of experimental installations.

Fig. 3 Discharge pipe into hydraulic channel.

Fig. 4 Use of hook gage to determine the discharge over the Cipolletti weir.

Fig. 5 Water flowing over the Cipolletti weir.

The several rates of discharge were obtained by regulating both the throttle of the engine and the gate valve that was placed between the pump and the first section of aluminum tubing. The rate of discharge for the weir is expressed by the equation $Q = 3.1025 H^{1.42}$. The height was determined by the use of a hook gage at a point five feet upstream in the channel from the weir. The temperature of the water ranged between 60 and 65 degrees Fahrenheit.

Orifice openings 3/16 inches in diameter were made near the ends of each of the four 20-foot sections of 6-inch diameter aluminum tubing. A piezometer connection was made at each of these orifices (Fig. 6).

Fig. 6 Close-up of piezometer tube with stop cock and manometer tube attachment fittings.

Friction loss measurements in the tubing were replicated in triplicate for each rate of discharge. The head loss measurements through the couplers were duplicated for each rate of discharge. Single readings were made of the head loss through one quarter turn elbow (90 degrees) and two quarter turn elbows that were paired to give a 180 degree change of direction of flow (Figs 8 and 9). Stop cocks were made a part of each piezometer so that the manometer connecting tubes could be coupled and uncoupled to a pair of piezometers at will (Fig. 6).

A differential manometer filled with carbon tetrachloride was used to determine pressure differences between two piezometers (Fig. 7). The specific gravity of carbon tetrachloride at 60 degrees Fahrenheit is 1.60. The difference in elevation of the two manometer columnes in half inches was multiplied by the constant 0.025 to give the equivalent reading in feet of water. To obtain the pressure in pounds per square inch, the manometer reading in half inches was multiplied by the factor 0.010825.

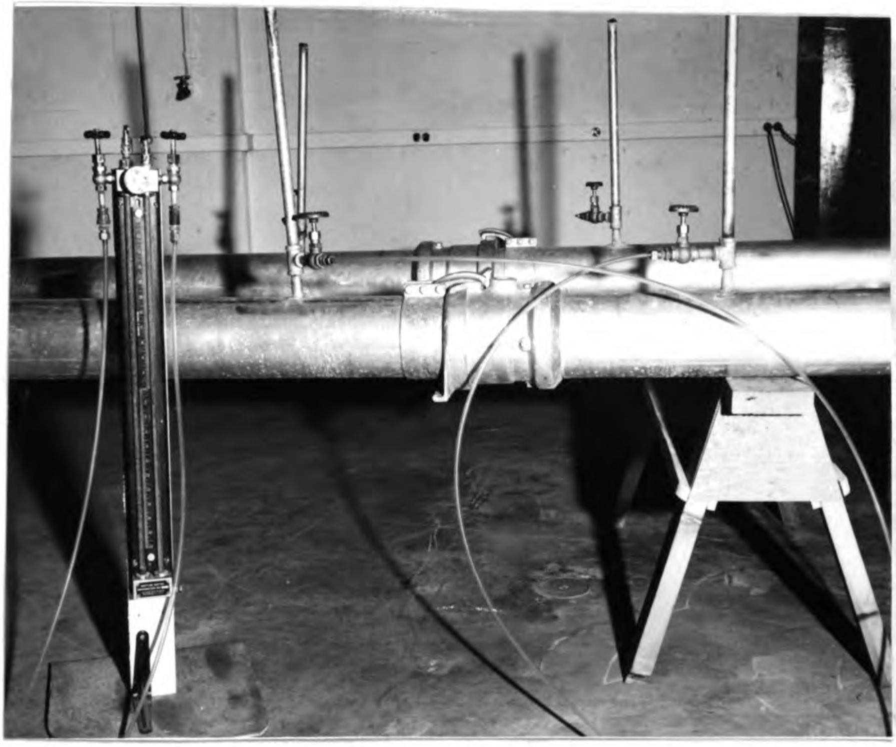


Fig. 7 Carbon tetrachloride differential manometer and piezometer connections.

Material tested

The materials tested were: new 20-foot length of ALCOA 63S-T6 extruded aluminum tubing, having a 6-inch outside diameter, 0.063 inch wall thickness, 5.874 inch inside diameter, and 0.1882 square foot cross sectional area; common couplers as shown in Fig. 7; 90 degree elbow; and 180 degree elbow (Figs. 8 and 9).

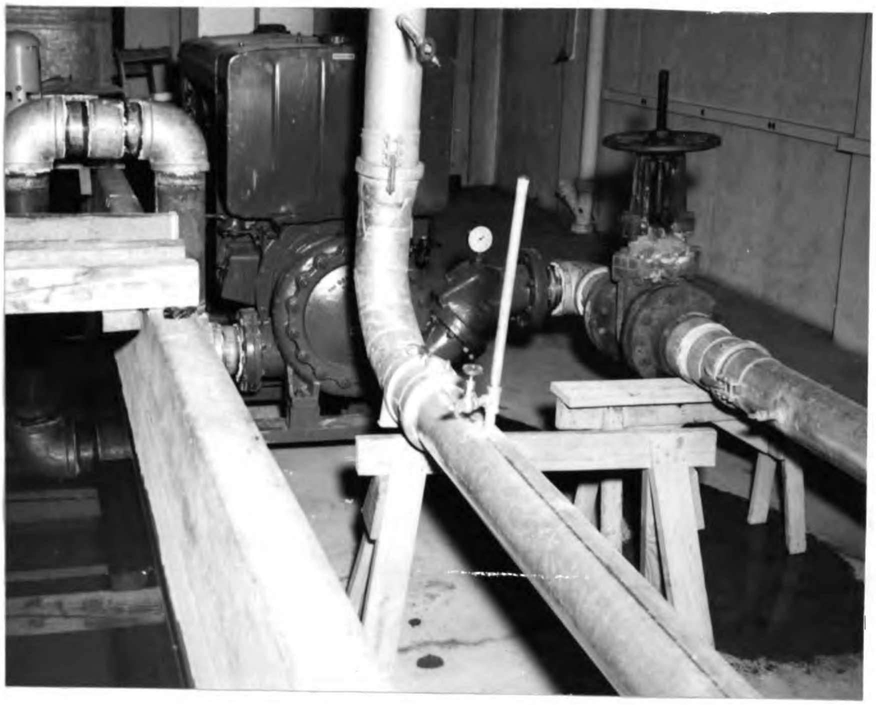


Fig. 8 90^{o} elbow (piezometers 7 and 8)

Fig. 9 180^{o} elbow (piezometers 3 and 4)

Experimental procedure

The purpose of the experiment was to determine the friction loss in pipe, the head loss in couplers, and the head loss in 90 and 180 degree elbows.

The experiment was divided into two parts. The first part was the determination of the friction losses in the tubing and the head losses in couplers when the longitudinal pipe alignment was straight in all planes.

The second part was the determination of the friction losses in couplers due to varying degrees of poor alignment of connecting sections of tubing through the coupling as follows: position 1 - coupler out of alignment in the vertical plane using the maximum amount of vertical displacement within the coupler; position 2 - tubing vertically displaced as in the coupler of position 1 and in addition a 3-degree deflection from true alignment through the coupler in the horizontal plane; position 3 - identical to position 2 except the angle of deflection was increased to 6 degrees, the maximum allowed by the test coupling (Fig. 10).

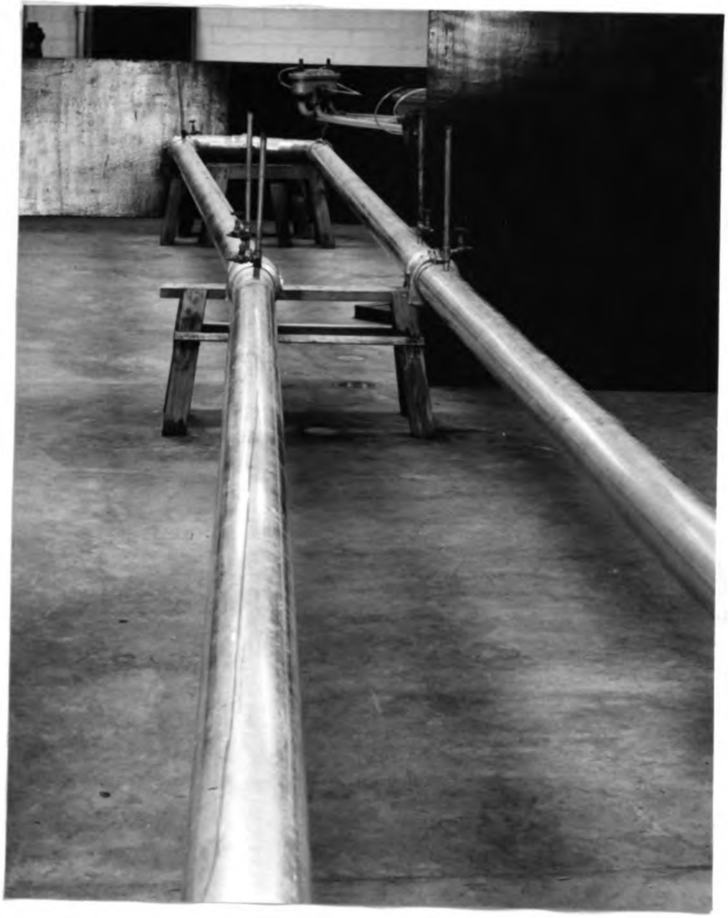
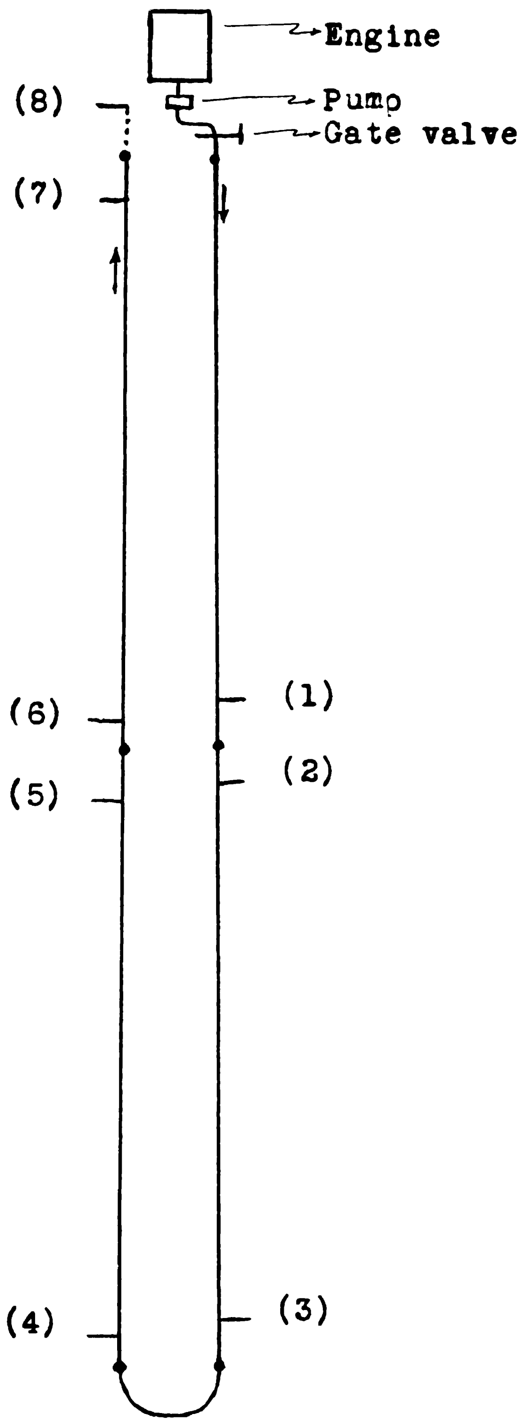


Fig. 10 Coupler set with pipes forming a 6-degree horizontal deflection.

For each test run, 11 manometer readings were made according to the following sequence (Fig. 11).

1st:	Piez.	1-7	(Check)
2nd:	"	1-2	(Head loss in 2.63' of tubing with coupler)
3rd:	"	1-3	(" " " 20.16' " " " ")
4th:	"	2-3	(" " " 17.53' " " only)
5th:	"	3-4	(" " " 180-degree elbow)
6th:	"	4-5	(" " " 17.53' of tubing only)



Scale: 1 inch 5.5 feet

. : Couplers
- : Piezometers

Note: Figures in parenthesis are piezometer numbers.

Fig. 11 Sketch of layout of experiment

7th:	Piez.	4-6	(Head loss in	20.16'	of tubing with coupler)
8th:	"	5-6	(" " "	2.63'	" " " ")
9th:	"	5-7	(" " "	20.16'	" " " ")
10th:	"	6-7	(" " "	17.53'	" " " ")
11th:	"	7-8	(" " "	90-degree elbow)	

These data are shown in Tables 1 and 2.

For the three different positions of tubing in the second part of the study, two manometer readings were made for each test run: between piezometers 1-2 and 5-6, to give the head loss in 2.63 feet of tubing and one coupler; and between piezometers 1-3 and 5-7 to give the head loss in 20.16 feet of tubing and one coupler (Tables 3, 4, 5, 6, 7, and 8).

Sequence of operation

The pumping unit was started and as soon as the engine had warned up sufficiently to give a reasonably steady running speed, and the rate of discharge through the Cipolletti weir had become reasonably constant the test data was collected in the following order: (1) measurement of rate of flow through the pipe system by means of the Cipolletti weir at the end of the hydraulic flume; (2) tabulation of the 11 manometer readings as indicated under Experimental Procedure; (3) redetermination of the rate of flow through the pipe system.

Table 1 General Experimental Data (Head loss in half inches as read on a CCl_4 differential manometer.

Run:		Piezometers:											Weir:	
(No	(*)	(1-7	1-2	1-3	2-3	3-4	4-5	4-6	5-6	5-7	6-7	7-8)	Height (feet)	Disch (cfs)
1	2	2.7	0.1	0.6	0.5	0.9	0.4	0.5	0.1	0.9	0.8	0.3	.145	.199
2	23	3.2	-	0.8	0.7	0.9	0.6	0.8	0.1	0.8	0.7	0.4	.156	.221
3	4	4.0	0.2	1.2	1.0	1.0	0.9	1.2	0.2	1.1	0.9	0.5	.173	.257
4	31	4.7	0.2	1.4	1.1	1.1	0.9	1.3	0.1	1.3	1.2	0.6	.186	.285
5	1	5.5	0.2	1.6	1.3	1.2	1.1	1.5	0.2	1.4	1.3	0.8	.196	.307
6	41	6.3	0.3	1.8	1.4	1.5	1.3	1.7	0.2	1.5	1.4	1.1	.209	.336
7	5	7.5	0.3	2.3	1.9	1.8	1.5	2.0	0.3	1.9	1.5	1.8	.228	.380
8	32	8.7	0.3	2.4	2.0	2.6	1.4	2.0	0.3	2.2	1.8	2.3	.241	.411
9	24	9.7	0.3	2.5	2.1	3.2	1.8	2.2	0.4	2.4	2.0	2.4	.247	.426
10	3	10.2	0.4	2.5	2.1	3.6	1.6	2.4	0.3	2.6	2.2	2.4	.254	.443
11	8	10.7	0.5	2.4	2.2	3.4	1.8	2.7	0.4	2.8	2.4	2.6	.262	.448
12	42	12.5	0.7	3.0	2.3	4.5	2.2	3.1	0.6	2.9	2.4	3.1	.273	.491
13	6	14.6	1.0	3.4	2.3	5.8	2.2	3.2	0.7	3.3	2.7	3.4	.284	.519
14	40	18.5	1.1	3.4	3.1	7.2	2.9	3.6	0.9	3.7	2.9	4.0	.304	.572
15	33	23.1	1.3	4.6	3.5	10.1	3.7	4.7	1.2	4.9	3.6	4.8	.326	.632
16	25	27.3	1.3	5.4	4.0	12.3	4.1	5.4	1.4	7.3	4.9	5.7	.345	.684
17	9	31.6	1.4	6.0	4.5	14.5	4.6	5.8	1.5	6.6	5.5	6.6	.365	.741
18	11	32.8	1.5	6.1	4.6	15.2	4.5	6.5	1.5	6.8	5.7	6.7	.368	.750
19	39	37.3	1.6	7.1	5.7	16.5	6.0	7.8	1.7	8.0	6.2	7.1	.383	.794
20	22	41.7	1.8	8.8	6.8	17.2	7.1	8.4	1.7	8.6	7.0	7.5	.396	.833
21	43	44	1.9	10.1	7.9	19.8	8.1	10.3	2.0	10.7	8.5	9.9	.412	.871
22	7	"	2.1	11.3	8.7	22.2	9.0	11.0	2.2	11.9	10.0	13.0	.434	.948
23	26	"	2.4	12.9	10.3	25.8	10.1	12.3	2.3	13.1	10.9	15.1	.456	1.016
24	34	"	2.4	13.6	10.9	28.1	11.5	13.9	2.5	14.0	11.8	15.5	.469	1.058
25	10	"	2.6	15.8	12.8	30.0	11.8	14.9	2.4	15.1	12.5	16.0	.479	1.091

Table 1 (Concluded)

Run: No.	(*)	Piezometers: (1-7	1-2	1-3	2-3	3-4	4-5	4-6	5-6	5-7	6-7	7-8)	Weir: Height (feet)	Disch (cfs)
26	38	>44	3.0	16.8	13.5	32.1	13.7	16.7	3.1	16.6	13.4	17.8	.496	1.146
27	21	"	3.9	18.9	14.8	35.2	15.7	19.2	3.7	19.1	16.4	19.3	.519	1.222
28	37	"	4.2	20.6	16.3	38.3	17.1	21.1	4.1	20.9	16.9	22.1	.532	1.266
29	27	"	4.4	22.5	18.2	41.2	18.3	22.8	4.6	23.1	18.9	23.5	.546	1.314
30	19	"	4.7	24.6	19.7	43.3	19.1	24.5	4.8	24.0	20.1	24.6	.559	1.358
31	16	"	4.8	24.8	19.9	43.5	18.7	25.1	4.5	24.1	20.2	24.5	.559	1.358
32	35	"	5.5	27.5	22.2	>44	20.5	26.1	5.2	27.1	21.8	26.9	.573	1.407
33	12	"	5.9	29.6	23.5	"	21.4	28.9	5.4	28.2	22.2	28.0	.584	1.442
34	15	"	6.6	31.0	24.2	"	23.7	30.7	6.3	30.5	23.2	29.5	.599	1.498
35	28	"	6.9	32.3	24.9	"	25.2	32.5	6.9	32.4	25.3	31.1	.607	1.516
36	13	"	7.2	34.8	25.5	"	26.3	35.1	7.4	34.2	26.5	33.0	.615	1.556
37	17	"	7.4	34.3	28.5	"	28.4	35.3	7.4	34.8	27.2	32.5	.616	1.559
38	29	"	7.6	36.9	29.4	"	29.8	37.2	7.7	36.3	28.5	33.3	.622	1.581
39	18	"	7.8	38.2	30.7	"	30.3	38.4	7.9	38.3	30.1	34.8	.630	1.609
40	36	"	7.8	38.9	30.9	"	30.6	38.5	8.1	38.8	30.8	35.5	.634	1.624
41	20	"	8.0	39.3	31.1	"	30.7	39.1	8.2	39.8	31.4	36.6	.639	1.642
42	30	"	8.6	40.8	32.1	"	31.5	40.2	8.5	40.6	32.9	38.1	.649	1.679
43	14	"	8.8	42.4	33.5	"	32.3	43.0	9.2	43.2	34.5	40.2	.663	1.731

(*) Order of experiment

Table 2 General Experimental Data (Head loss given in feet of water and in p.s.i.).

Run No.	2.63' of pipe with coupler				17.53' of pipe (No coupler)					
	(Piez. 1-2		Piez. 5-6)		(Piez. 2-3		Piez. 4-5		Piez. 6-7)	
	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)
1	.0025	.00108	.0025	.00108	.0125	.00541	.0100	.00433	.0200	.00866
2	-	-	.0025	.00108	.0175	.00757	.0150	.00649	.0175	.00757
3	.0025	.00108	.0050	.00216	.0250	.01082	.0225	.00974	.0225	.00974
4	.0050	.00216	.0025	.00108	.0275	.01190	.0225	.00974	.0300	.01299
5	.0050	.00216	.0050	.00216	.0325	.01407	.0275	.01190	.0325	.01407
6	.0075	.00324	.0050	.00216	.0350	.01515	.0325	.01407	.0350	.01515
7	.0075	.00324	.0075	.00324	.0475	.02056	.0375	.01623	.0375	.01623
8	.0075	.00324	.0075	.00324	.0500	.02165	.0350	.01515	.0450	.01948
9	.0075	.00324	.0075	.00433	.0525	.02273	.0450	.01948	.0500	.02165
10	.0100	.00433	.0100	.00324	.0525	.02273	.0400	.01732	.0550	.02381
11	.0125	.00541	.0100	.00433	.0550	.02381	.0450	.01948	.0600	.02598
12	.0175	.00757	.0150	.00649	.0575	.02489	.0550	.02381	.0600	.02598
13	.0250	.01082	.0175	.00757	.0575	.02489	.0550	.02381	.0675	.02922
14	.0275	.01190	.0225	.00974	.0775	.03355	.0725	.03139	.0625	.03139
15	.0325	.01472	.0300	.01299	.0875	.03788	.0925	.04005	.0900	.03897
16	.0325	.01472	.0350	.01515	.1000	.04330	.1025	.04438	.1225	.05304
17	.0350	.01515	.0375	.01623	.1125	.04871	.1150	.04979	.1375	.05953
18	.0375	.01623	.0375	.01623	.1150	.04979	.1125	.04871	.1425	.06170
19	.0400	.01723	.0425	.01840	.1425	.06170	.1500	.06495	.1550	.06711
20	.0450	.01948	.0425	.01840	.1700	.07361	.1700	.07361	.1750	.07577
21	.0475	.02056	.0500	.02165	.1975	.08551	.2050	.08768	.2125	.09201
22	.0525	.02273	.0550	.02381	.2175	.09417	.2250	.09742	.2500	.10825
23	.0600	.02598	.0575	.02489	.2575	.11149	.2525	.10933	.2725	.11799
24	.0600	.02598	.0625	.02706	.2725	.11799	.2875	.12448	.2950	.12773
25	.0650	.02814	.0600	.02598	.3200	.13856	.2950	.12778	.3125	.13531

Table 2 (Continued)

Run No.	2.63' of pipe with coupler				17.53' of pipe (No coupler)					
	(Piez. 1-2		Piez. 5-6)		(Piez. 2-3		Piez. 4-5		Piez. 6-7)	
	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)
26	.0750	.03247	.0775	.03355	.3375	.14613	.3425	.14832	.3350	.14505
27	.0975	.04221	.0925	.04005	.3700	.16021	.3925	.16995	.4100	.17753
28	.1050	.04546	.1025	.04438	.4075	.17644	.4275	.18510	.4225	.18294
29	.1100	.04763	.1150	.04979	.4550	.19701	.4575	.19809	.4725	.20459
30	.1175	.05087	.1200	.05196	.4925	.21325	.4775	.20675	.5025	.21758
31	.1200	.05196	.1125	.04871	.4975	.21541	.4675	.20242	.5050	.21866
32	.1375	.05953	.1300	.05629	.5550	.24031	.5125	.22191	.5450	.23598
33	.1475	.06638	.1350	.05845	.5875	.25438	.5350	.23165	.5550	.24031
34	.1650	.07144	.1575	.06819	.6050	.26196	.5925	.25655	.5800	.25114
35	.1725	.07469	.1725	.07469	.6225	.26954	.6300	.27279	.6325	.27387
36	.1800	.07794	.1850	.08010	.6375	.27603	.6575	.28469	.6625	.28686
37	.1825	.08010	.1850	.08010	.7125	.29444	.7100	.30743	.6800	.29444
38	.1875	.08227	.1925	.08335	.7350	.31825	.7450	.32258	.7125	.30851
39	.1950	.08443	.1975	.08551	.7675	.33232	.7575	.32799	.7525	.32583
40	.1950	.08768	.2025	.08768	.7725	.33449	.7650	.33124	.7700	.33341
41	.2000	.08660	.2050	.08876	.7775	.33665	.7675	.33232	.7850	.33990
42	.2150	.09326	.2100	.09259	.8025	.34748	.7875	.34098	.8225	.35614
43	.2200	.09591	.2325	.09901	.8375	.36263	.8075	.34964	.8625	.37343

Table 2 (Continued)

RUN No.	20.16 feet of pipe with coupler						Elbows				Weir	
	(Piez. 1-3		Piez. 4-6		Piez. 5-7)		(Piez. 3-4		Piez. 7-8)		(Height	Disch)
	(feet	p.s.i)	(feet	p.s.i)	(feet	p.s.i)	(feet	p.s.i)	(feet	p.s.i)	(feet)	(cfs)
1	.0150	.0065	.0125	.0054	.0225	.0097	.0225	.0097	.0075	.0032	.145	.199
2	.0200	.0083	.0200	.0086	.0200	.0086	.0225	.0097	.0100	.0043	.156	.222
3	.0300	.0129	.0300	.0129	.0275	.0119	.0250	.0108	.0125	.0054	.173	.255
4	.0350	.0151	.0325	.0140	.0325	.0140	.0275	.0119	.0150	.0064	.186	.284
5	.0400	.0173	.0375	.0162	.0350	.0151	.0300	.0129	.0200	.0086	.196	.306
6	.0450	.0195	.0425	.0184	.0375	.0162	.0375	.0162	.0275	.0119	.209	.336
7	.0575	.0248	.0500	.0216	.0475	.0205	.0450	.0194	.0375	.0162	.228	.380
8	.0600	.0259	.0500	.0216	.0550	.0238	.0650	.0281	.0450	.0194	.241	.411
9	.0625	.0270	.0550	.0238	.0600	.0259	.0800	.0346	.0575	.0248	.247	.426
10	.0625	.0270	.0600	.0259	.0650	.0281	.0900	.0389	.0600	.0259	.254	.443
11	.0600	.0259	.0675	.0292	.0700	.0303	.0850	.0368	.0650	.0281	.262	.448
12	.0750	.0324	.0775	.0335	.0725	.0313	.1125	.0487	.0775	.0335	.273	.491
13	.0850	.0368	.0800	.0346	.0825	.0357	.1450	.0627	.0850	.0368	.284	.519
14	.0850	.0368	.0900	.0389	.0925	.0400	.1800	.0779	.1000	.0433	.304	.572
15	.1150	.0497	.1175	.0508	.1225	.0530	.2525	.1093	.1200	.0519	.326	.631
16	.1350	.0584	.1350	.0584	.1575	.0681	.3075	.1331	.1425	.0617	.345	.684
17	.1500	.0649	.1450	.0627	.1650	.0714	.3625	.1569	.1650	.0714	.365	.741
18	.1525	.0660	.1625	.0703	.1700	.0736	.3800	.1645	.1675	.0725	.368	.750
19	.1775	.0768	.1950	.0844	.2000	.0866	.4125	.1786	.1775	.0768	.383	.793
20	.2200	.0952	.2100	.0909	.2150	.0930	.4300	.1861	.1875	.0812	.396	.832
21	.2525	.1093	.2575	.1144	.2675	.1158	.4950	.2143	.2475	.1071	.412	.871
22	.2825	.1223	.2750	.1190	.2975	.1288	.5550	.2403	.3250	.1407	.434	.948
23	.3225	.1396	.3075	.1331	.3275	.1418	.6450	.2792	.3775	.1634	.456	1.015
24	.3400	.1472	.3475	.1504	.3500	.1515	.7025	.3041	.3875	.1677	.469	1.058
25	.3950	.1710	.3725	.1612	.3775	.1634	.7500	.3247	.4000	.1732	.479	1.090

Table 2 (Concluded)

RUN No.	20.16 feet of pipe with coupler						Elbows				Weir	
	(Piez. 1-3		Piez. 4-6		Piez. 5-7)		(Piez. 3-4		Piez. 7-8)		(height	Disch)
	(feet	p.s.i)	(feet	p.s.i)	(feet	p.s.i))	(feet	p.s.i)	(feet	p.s.i)	(feet)	(cfs)
26	.4200	.1818	.4175	.1807	.4150	.1796	.8025	.3437	.4450	.1922	.496	1.146
27	.4725	.2045	.4800	.2078	.4775	.2067	.8800	.3810	.4825	.2089	.519	1.222
28	.5150	.2229	.5257	.2284	.5225	.2262	.9575	.4145	.5525	.2392	.532	1.266
29	.5625	.2435	.5700	.2468	.5775	.2500	1.030	.4461	.5875	.2543	.546	1.314
30	.6150	.2662	.6125	.2652	.6000	.2598	1.092	.4730	.6150	.2662	.559	1.358
31	.6200	.2684	.6275	.2717	.6025	.2608	1.087	.4708	.6125	.2652	.559	1.358
32	.6875	.2976	.6825	.2825	.6775	.2933	>1.1	>.48	.6725	.2911	.573	1.406
33	.7400	.3204	.7225	.3128	.7050	.3052	"	"	.7000	.3031	.584	1.442
34	.7750	.3355	.7675	.3323	.7875	.3301	"	"	.7375	.3193	.599	1.498
35	.8075	.3496	.8125	.3518	.8100	.3507	"	"	.7775	.3366	.607	1.516
36	.8700	.3767	.8775	.3799	.8550	.3702	"	"	.8225	.3572	.615	1.555
37	.8575	.3712	.8825	.3821	.8950	.3767	"	"	.8125	.3518	.616	1.558
38	.9225	.3994	.9300	.4026	.9075	.3929	"	"	.8325	.3604	.622	1.581
39	.9550	.4135	.9600	.4156	.9575	.4145	"	"	.8700	.3767	.630	1.609
40	.9725	.4210	.9625	.4167	.9700	.4200	"	"	.8875	.3842	.634	1.624
41	.9825	.4254	.9775	.4233	.9950	.4308	"	"	.9150	.3961	.639	1.642
42	1.020	.4416	1.005	.4351	1.015	.4384	"	"	.9525	.4124	.649	1.679
43	1.060	.4589	1.075	.4654	1.080	.4676	"	"	1.005	.4351	.663	1.731

Table 3 Experimental data on couplers in position 1 (Head losses in half inches as read on a CCl_4 differential manometer).

Run: No.	Run: *	Piezometers: 1-2	1-3	5-6	5-7	Weir: Height (feet)	Disch. (cfs)
1	3	0.6	2.4	0.7	2.6	.265	.471
2	14	1.0	3.0	0.9	3.1	.278	.504
3	7	1.1	3.4	1.0	3.3	.292	.540
4	22	1.1	3.8	1.1	3.7	.306	.577
5	8	1.1	3.9	1.2	3.8	.306	.577
6	23	1.2	4.2	1.3	4.1	.314	.599
7	21	1.3	4.4	1.3	4.5	.322	.621
8	15	1.4	4.6	1.4	4.7	.331	.645
9	28	1.5	5.3	1.4	5.2	.343	.679
10	1	1.6	6.0	1.5	5.9	.356	.716
11	24	1.7	6.4	1.6	6.5	.370	.756
12	16	1.8	7.1	1.8	7.0	.382	.791
13	4	1.9	8.8	2.0	8.9	.390	.815
14	9	2.0	9.4	2.0	9.3	.397	.835
15	6	2.3	11.2	2.2	11.5	.409	.872
16	32	2.3	11.9	2.4	12.1	.416	.893
17	13	2.5	12.5	2.4	12.9	.425	.921
18	29	2.6	13.8	2.6	13.7	.434	.948
19	2	2.7	14.7	2.7	14.3	.445	.983
20	10	2.9	14.8	2.7	14.2	.446	.986
21	25	2.9	15.5	3.0	15.4	.457	1.020
22	20	3.0	16.1	3.1	15.9	.470	1.062
23	5	3.3	16.4	3.3	16.3	.482	1.100
24	30	3.7	18.2	3.8	18.5	.496	1.146
25	33	4.3	21.3	4.2	20.9	.509	1.189
26	19	4.7	23.5	4.8	23.2	.521	1.233
27	11	5.1	23.9	5.0	23.7	.524	1.239
28	26	5.4	24.3	5.3	24.8	.535	1.276
29	12	5.8	25.1	5.8	25.5	.550	1.328
30	17	6.0	25.6	5.8	25.7	.555	1.345
31	34	6.8	28.5	6.7	28.7	.572	1.404
32	27	7.9	31.2	7.5	30.8	.587	1.456
33	35	8.5	34.9	8.3	35.0	.611	1.541
34	31	9.0	38.0	9.2	38.3	.625	1.592
35	18	9.9	41.1	10.1	41.9	.636	1.631

* Order of experiment

Table 4 Experimental data on couplers in position 1 (Head losses given in feet of water and in lb./in^2).

Run No.	2.63 feet of pipe with coupler			
	Piez. 1-2		Piez.5-6	
	feet	p.s.i.	feet	p.s.i.
1	.0150	.006495	.0175	.007577
2	.0250	.010825	.0225	.009742
3	.0275	.011907	.0250	.010825
4	.0275	.011907	.0275	.011907
5	.0275	.011907	.0300	.012990
6	.0300	.012990	.0325	.014072
7	.0325	.014072	.0325	.014072
8	.0350	.015155	.0350	.015155
9	.0375	.016223	.0350	.015155
10	.0400	.017320	.0375	.016223
11	.0425	.018402	.0400	.017320
12	.0450	.019485	.0450	.019485
13	.0475	.020567	.0500	.021650
14	.0500	.021650	.0500	.021650
15	.0575	.024897	.0550	.023815
16	.0575	.024897	.0600	.025980
17	.0625	.027062	.0600	.025980
18	.0650	.028145	.0650	.028145
19	.0675	.029227	.0675	.029227
20	.0725	.031392	.0675	.029227
21	.0725	.031392	.0750	.032475
22	.0750	.032475	.0775	.033557
23	.0825	.035722	.0825	.035722
24	.0925	.040052	.0950	.041135
25	.1075	.046547	.1050	.045465
26	.1175	.050877	.1200	.051960
27	.1275	.055207	.1250	.054125
28	.1350	.058455	.1325	.057372
29	.1450	.062785	.1450	.062785
30	.1500	.064950	.1450	.062785
31	.1700	.073610	.1675	.072527
32	.1975	.085517	.1875	.081187
33	.2125	.092012	.2075	.089847
34	.2250	.097425	.2400	.099590
35	.2475	.107167	.2525	.109332

Table 4 (Concluded)

Run No.	(20.16' of pipe with coupler)				(Weir)		
	(Piez.1-3		Piez.5-7)		(Height	Discharge)	
	(feet	p.s.i.)	(feet	p.s.i.)	feet	(cfs	g.p.m.)
1	.0600	.025980	.0650	.028145	.265	.47064	211.237
2	.0750	.032475	.0775	.033557	.278	.50384	226.138
3	.0850	.036805	.0825	.035722	.292	.54014	242.431
4	.0950	.041135	.0925	.040052	.306	.57675	258.862
5	.0975	.042217	.0950	.041135	.306	.57675	258.862
6	.1050	.045465	.1025	.044382	.314	.59878	268.750
7	.1100	.047630	.1125	.048712	.322	.62081	278.638
8	.1150	.049795	.1175	.050877	.331	.64532	289.638
9	.1325	.057372	.1300	.056290	.343	.67882	304.674
10	.1500	.064950	.1475	.063867	.356	.71574	321.245
11	.1600	.069280	.1625	.070362	.370	.75607	339.346
12	.1775	.076857	.1750	.075775	.382	.79113	355.082
13	.2200	.095260	.2225	.096342	.390	.81471	365.666
14	.2350	.101755	.2325	.100672	.397	.83550	374.997
15	.2800	.121240	.2875	.124487	.409	.87180	391.289
16	.2975	.128817	.3025	.130982	.416	.89287	400.755
17	.3125	.135312	.3225	.139642	.425	.92051	413.152
18	.3450	.149385	.3425	.148302	.434	.94843	425.683
19	.3675	.159127	.3575	.154797	.446	.98566	442.393
20	.3700	.160210	.3550	.153715	.446	.98566	442.393
21	.3875	.167787	.3850	.166705	.457	1.02041	457.990
22	.4025	.174282	.3975	.172117	.470	1.06167	476.509
23	.4100	.177530	.4075	.176447	.482	1.10076	494.054
24	.4550	.197015	.4625	.200262	.496	1.14637	514.525
25	.5325	.230572	.5225	.226242	.509	1.18918	533.739
26	.5875	.254387	.5800	.251140	.521	1.23262	553.236
27	.5975	.258717	.5925	.256552	.524	1.23913	556.158
28	.6075	.263047	.6200	.268460	.535	1.27636	572.868
29	.6275	.271707	.6375	.276037	.550	1.32755	595.844
30	.6400	.277120	.6425	.278202	.555	1.34462	603.505
31	.7125	.308512	.7175	.310677	.572	1.40357	629.964
32	.7800	.337740	.7700	.333410	.587	1.45600	653.496
33	.8725	.377792	.8750	.378875	.611	1.54101	691.651
34	.9500	.411350	.9575	.414597	.625	1.59158	714.348
35	1.0275	.444907	1.0475	.453567	.636	1.63160	732.311

Table 5 Experimental data on couplers in position 2 (Head losses in half inches as read on a CCl_4 differential manometer).

Run:		Piezometers:				Weir:	
(No.	*)	(1-2	1-3	5-6	5-7)	Height (feet)	Disch) (cfs)
1	3	0.8	2.7	0.7	2.7	.265	.471
2	15	1.0	3.9	0.9	3.6	.284	.519
3	11	1.2	5.1	1.2	4.9	.306	.577
4	19	1.3	6.3	1.4	6.4	.329	.640
5	8	1.5	7.2	1.5	7.1	.351	.701
6	1	1.8	7.5	1.7	7.3	.356	.716
7	22	2.0	8.3	1.9	8.4	.372	.762
8	4	2.3	9.1	2.2	9.2	.390	.815
9	12	2.4	11.9	2.4	12.0	.406	.863
10	6	2.5	12.2	2.4	11.9	.409	.872
11	16	2.6	13.5	2.7	13.2	.426	.924
12	7	2.7	14.1	2.8	13.9	.435	.951
13	20	2.8	14.0	2.8	14.3	.437	.959
14	2	3.1	14.5	3.0	14.5	.445	.983
15	5	3.5	16.3	3.5	16.6	.482	1.101
16	23	3.7	17.5	3.9	17.3	.491	1.130
17	13	4.9	21.8	5.0	22.2	.512	1.200
18	9	5.6	24.5	5.5	24.2	.523	1.236
19	17	6.7	28.4	6.6	28.1	.545	1.341
20	21	7.6	31.2	7.8	31.4	.563	1.372
21	14	8.5	34.5	8.5	34.5	.586	1.453
22	18	9.8	39.0	9.9	38.7	.604	1.517
23	10	10.6	40.1	10.8	39.7	.620	1.574

* Order of experiment

Table 6 Experimental data on couplers in position 2 (Head loss given in feet of water and in p.s.i.).

Run No.	2.63' of pipe with coupler				20.16' of pipe with coupler				Weir	
	Piez. 1-2		Piez. 5-6		Piez. 1-3		Piez. 5-7		Height	Disch
	feet	p.s.i	feet	p.s.i	feet	p.s.i	feet	p.s.i	feet	cfs
1	.0200	.0086	.0175	.0075	.0675	.0293	.0675	.0293	.265	.470
2	.0250	.0108	.0200	.0086	.0975	.0422	.0900	.0389	.284	.519
3	.0300	.0129	.0300	.0129	.1275	.0422	.1225	.0530	.306	.578
4	.0325	.0140	.0350	.0151	.1575	.0681	.1600	.0692	.329	.640
5	.0375	.0162	.0375	.0162	.1800	.0779	.1775	.0768	.351	.701
6	.0450	.0194	.0425	.0184	.1875	.0811	.1825	.0790	.356	.715
7	.0500	.0216	.0475	.0205	.2075	.0898	.2100	.0909	.372	.761
8	.0575	.0248	.0550	.0238	.2275	.0985	.2300	.0995	.390	.814
9	.0600	.0259	.0600	.0259	.2975	.1288	.3000	.1299	.406	.862
10	.0625	.0270	.0600	.0259	.3050	.1320	.2975	.1288	.409	.871
11	.0650	.0281	.0675	.0292	.3375	.1463	.3325	.1428	.426	.923
12	.0675	.0292	.0700	.0303	.3525	.1526	.3475	.1504	.435	.951
13	.0700	.0303	.0700	.0303	.3500	.1515	.3575	.1547	.437	.958
14	.0775	.0335	.0750	.0324	.3625	.1569	.3625	.1569	.445	.982
15	.0875	.0378	.0875	.0378	.4075	.1764	.4150	.1796	.482	1.100
16	.0925	.0400	.0975	.0422	.4375	.1894	.4325	.1872	.491	1.129
17	.1225	.0530	.1025	.0541	.5450	.2359	.5550	.2403	.512	1.200
18	.1400	.0602	.1375	.0595	.6125	.2652	.6050	.2619	.523	1.236
19	.1675	.0725	.1650	.0714	.7100	.3074	.6050	.3041	.545	1.340
20	.1900	.0822	.1950	.0844	.7800	.3377	.7850	.3399	.563	1.372
21	.2125	.0920	.2125	.0920	.8625	.3734	.8625	.3734	.586	1.452
22	.2450	.1060	.2475	.1076	.9750	.4221	.8675	.4189	.604	1.516
23	.2650	.1147	.2700	.1169	1.002	.4340	.9925	.4297	.620	1.573

Table 7 Experimental data on couplers in position 3 (Head losses in half inches as read on a CCl_4 differential manometer).

Run:		Piezometers:				Weir:	
(No.	*)	(1-2	1-3	5-6	5-7)	(Height (feet)	Disch) (cfs)
1	3	1.0	2.9	0.9	2.8	.265	.471
2	18	1.2	4.2	1.1	4.1	.296	.551
3	12	1.4	5.6	1.5	5.7	.329	.640
4	1	1.6	7.3	1.7	7.4	.356	.716
5	7	1.8	7.4	1.8	7.4	.360	.727
6	16	1.8	7.5	1.9	7.6	.362	.733
7	4	2.4	9.4	2.4	9.5	.390	.815
8	9	2.6	10.3	2.7	10.1	.403	.853
9	6	2.7	12.4	2.8	12.7	.409	.872
10	19	2.9	13.4	3.0	13.3	.422	.911
11	13	3.2	14.5	3.2	14.5	.436	.955
12	2	3.4	15.2	3.3	15.0	.445	.983
13	21	3.4	15.5	3.4	15.4	.447	.989
14	5	4.1	17.5	4.0	17.1	.482	1.100
15	8	4.5	18.9	4.4	18.5	.488	1.120
16	14	5.1	20.8	5.0	20.5	.505	1.177
17	20	5.7	23.2	5.8	23.1	.522	1.233
18	10	6.2	25.6	6.3	25.5	.538	1.285
19	15	7.4	29.0	7.2	28.8	.557	1.351
20	17	8.4	32.4	8.0	32.5	.579	1.428
21	22	9.3	36.2	9.1	35.0	.596	1.488
22	11	11.2	39.5	11.0	38.9	.613	1.548

* Order of experiment

Table 8 Experimental data on couplers in position 3 (Head loss given in feet of water and in p.s.i.).

Run	2.63' of pipe with coupler				20.16' of pipe with coupler				Weir	
No.	(Piez. 1-2		Piez. 5-6)		(Piez. 1-3		Piez. 5-7		(Height	Disch)
	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)	(feet	p.s.i.)	(feet)	(cfs)
1	.0250	.0108	.0225	.0097	.0725	.0313	.0700	.0303	.265	.470
2	.0300	.0129	.0275	.0119	.1050	.0454	.1025	.0443	.296	.550
3	.0350	.0151	.0375	.0162	.1450	.0606	.1425	.0617	.329	.640
4	.0400	.0173	.0425	.0184	.1825	.0790	.1850	.0801	.356	.715
5	.0450	.0194	.0450	.0194	.1850	.0801	.1850	.0801	.360	.727
6	.0450	.0194	.0475	.0205	.1875	.0811	.1900	.0822	.362	.733
7	.0600	.0259	.0600	.0259	.2350	.1017	.2375	.1028	.390	.814
8	.0650	.0281	.0675	.0292	.2575	.1114	.2525	.1093	.403	.853
9	.0675	.0292	.0700	.0303	.3100	.1342	.3175	.1374	.409	.871
10	.0725	.0313	.0750	.0324	.3350	.1450	.3325	.1439	.422	.911
11	.0800	.0346	.0800	.0346	.3625	.1569	.3625	.1569	.436	.954
12	.0850	.0368	.0825	.0357	.3800	.1645	.3750	.1623	.445	.982
13	.0850	.0368	.0850	.0368	.3875	.1677	.3850	.1667	.447	.989
14	.1025	.0443	.1000	.0433	.4375	.1894	.4775	.1851	.482	1.100
15	.1125	.0487	.1100	.0476	.4727	.2045	.4625	.2002	.488	1.120
16	.1275	.0552	.1250	.0541	.5200	.2251	.5125	.2219	.505	1.176
17	.1425	.0617	.1450	.0627	.5800	.2511	.5775	.2500	.522	1.232
18	.1550	.0671	.1575	.0681	.6400	.2771	.6375	.2760	.538	1.284
19	.1850	.0801	.1800	.0779	.7250	.3139	.7200	.3117	.557	1.350
20	.2100	.0909	.2000	.0866	.8100	.3507	.8125	.3518	.579	1.428
21	.2325	.0995	.2275	.0985	.9050	.3918	.8975	.3886	.596	1.487
22	.2800	.1212	.2750	.1190	.9875	.4275	.9725	.4210	.613	1.548

For the second part of the study where the degree of alignment of two sections of tubing through a coupling was varied, a complete set of runs at different rates of discharge was made for one position; then the tubing was shifted to the next position and another series of measurement made at various rates of discharge.

If there was a small difference in discharge readings, an average between the first and the second measurements was considered. If the difference was great, the run was discarded.

For the three different positions the head losses were, at the beginning, determined for each rate of discharge, that is, the pipes had to move to give each one of the different positions for each discharge. Later it was noted that the best was to determine the head loss in each position, varying the discharge. This was done and Tables 3, 4, 5, 6, 7, and 8 give the results.

PRESENTATION OF DATA

Evaluation of exponents and coefficients in the general pipe flow equation.

The general equation for friction loss in tubing is:

$$h_f = K_a \frac{L}{d^n} V^m$$

It may be modified and written in the forms: $h_f = KQ^m$ for fiction loss in pipe; $h_L = KQ^m$ for the head loss in pipe and couplers; $h_c = KQ^m$ for the head loss in couplers; and $h_e - KQ^m$ for the head loss in elbows.

By plotting experimental values of h_f, h_L, h_c, and h_e against corresponding values of Q on logarithimic paper, the value of the exponent m and the coefficient K is determined. The slope of the line is m, and K is the intercept at $Q = 1$. h_f and h_L used in these plottings were the average of friction losses and head losses found in experiment.

These values of h_f and h_L were determined from Figs. 12, 13, 14, and 15, and are given as follows on the base of losses per 100-foot length of tubing.

Pipe without coupler.................. $h_f = 1.471\ Q^{1.881}$

Pipe with well set coupler (*)....... $h_L = 1.622\ Q^{1.881}$

Pipe with coupler in position 1 (*)... $h_L = 1.682\ Q^{1.978}$

Pipe with coupler in position 2 (*)... $h_L = 1.831\ Q^{1.917}$

Pipe with coupler in position 3 (*)... $h_L = 1.911\ Q^{1.958}$

(*) See explanations on p. 19.

Fig. 12 Friction loss vs. flow rate in 17.53' length of tubing, and head loss vs. flow rate in 20.16' length of tubing with one coupler correctly aligned with the second section of tubing.

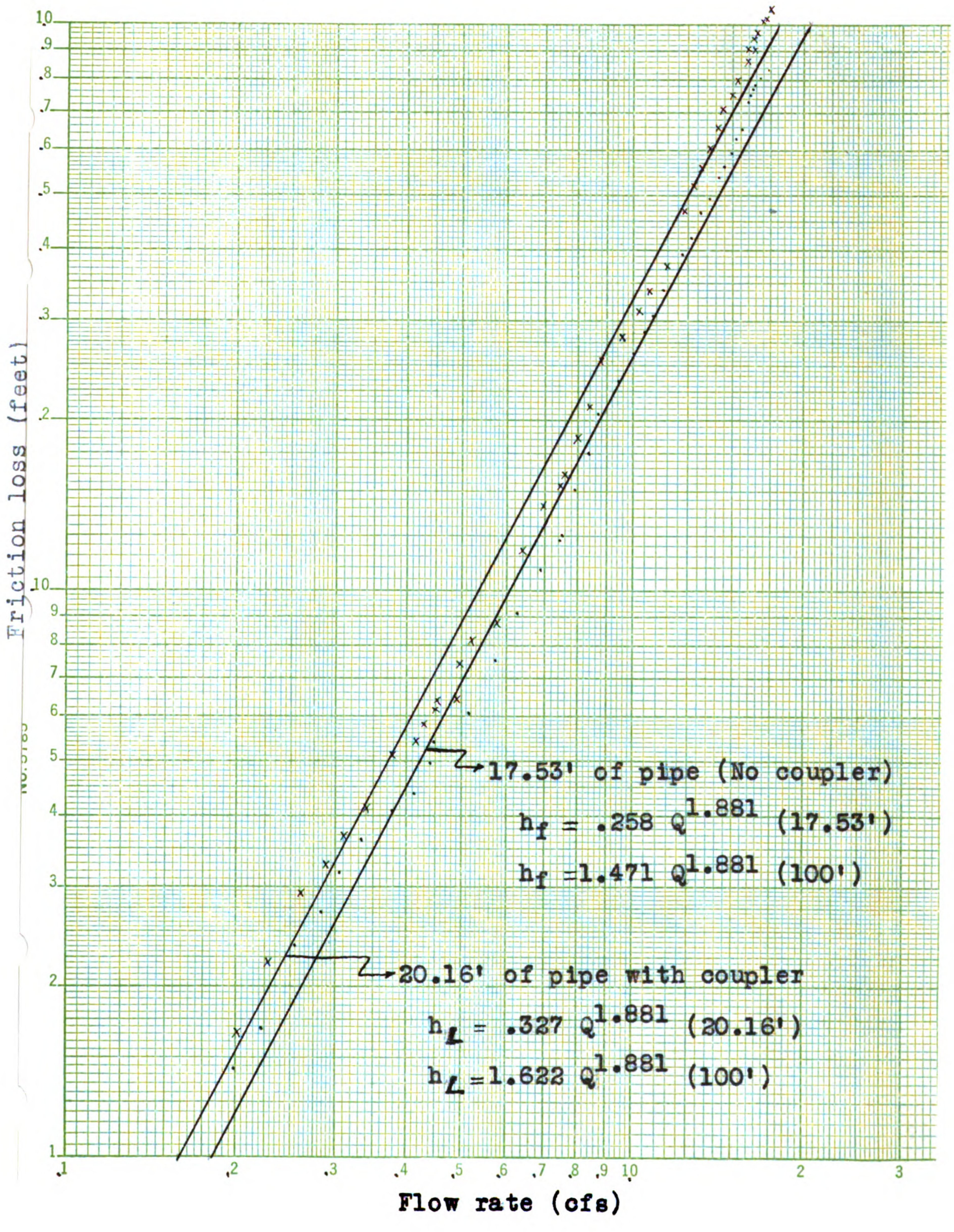


Fig. 13 Head loss vs. flow rate (20.16-foot length of tubing and one connecting coupler in position 1).

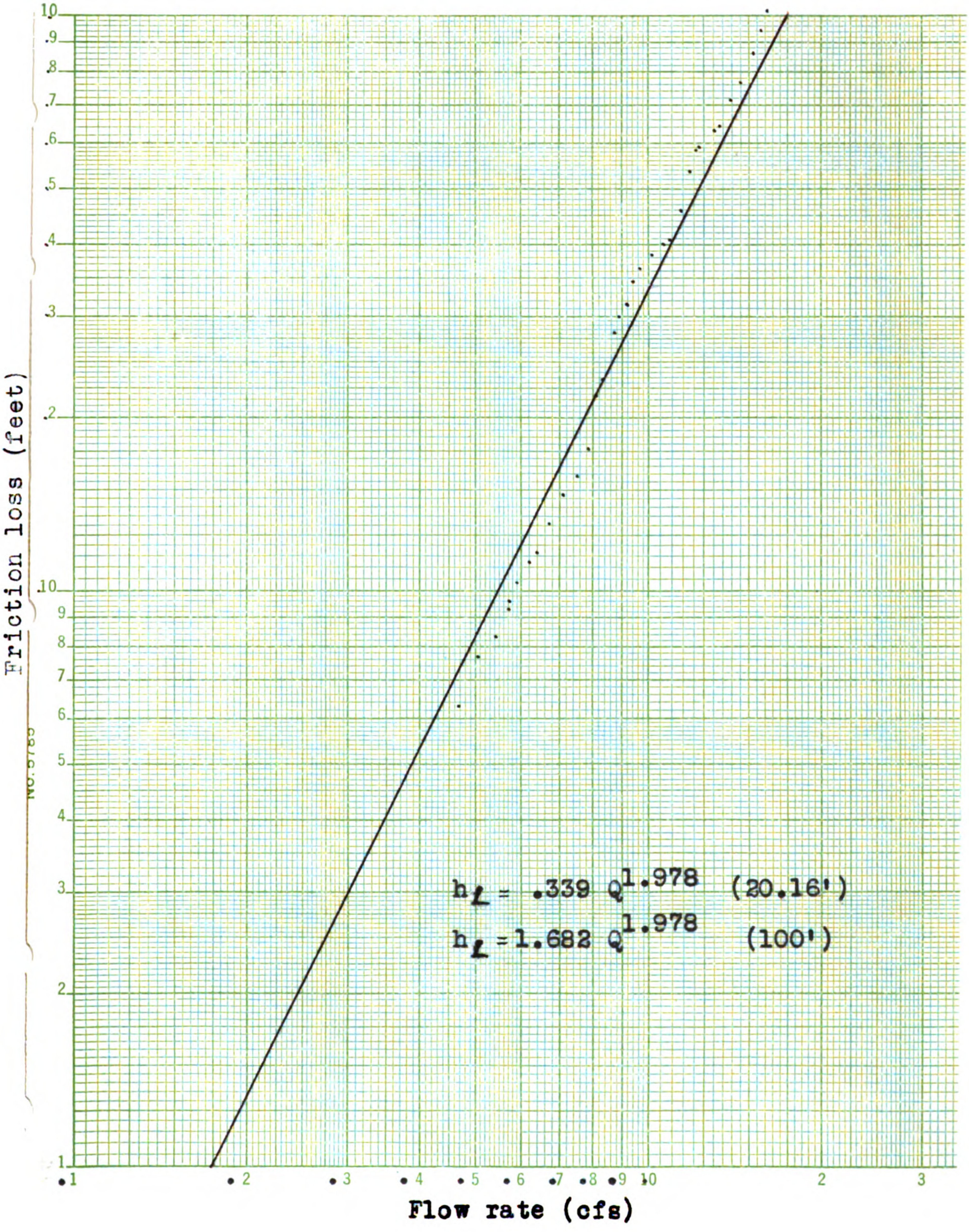


Fig. 14 Head loss vs. flow rate (20.16-foot length of tubing and one connecting coupler in position 2).

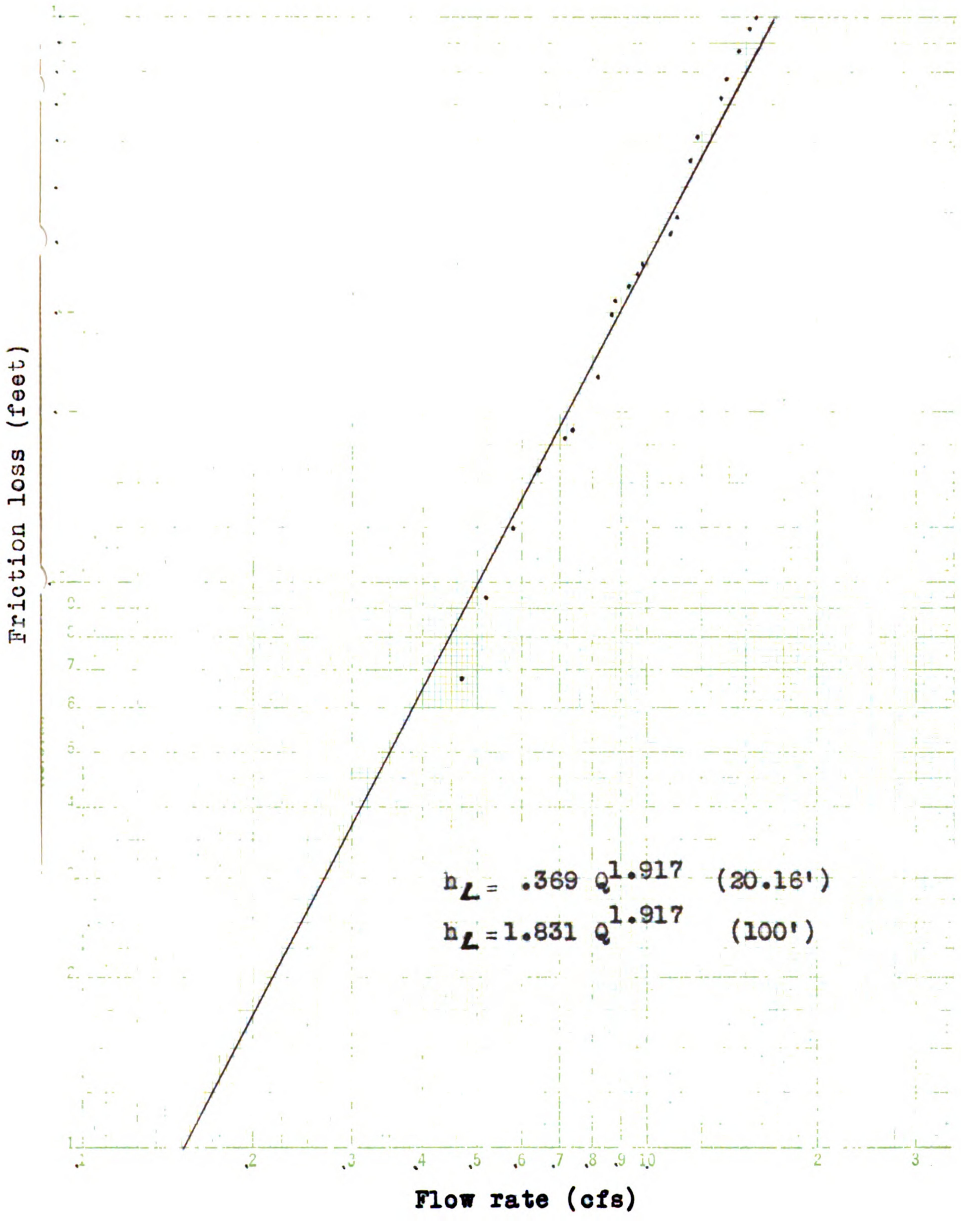
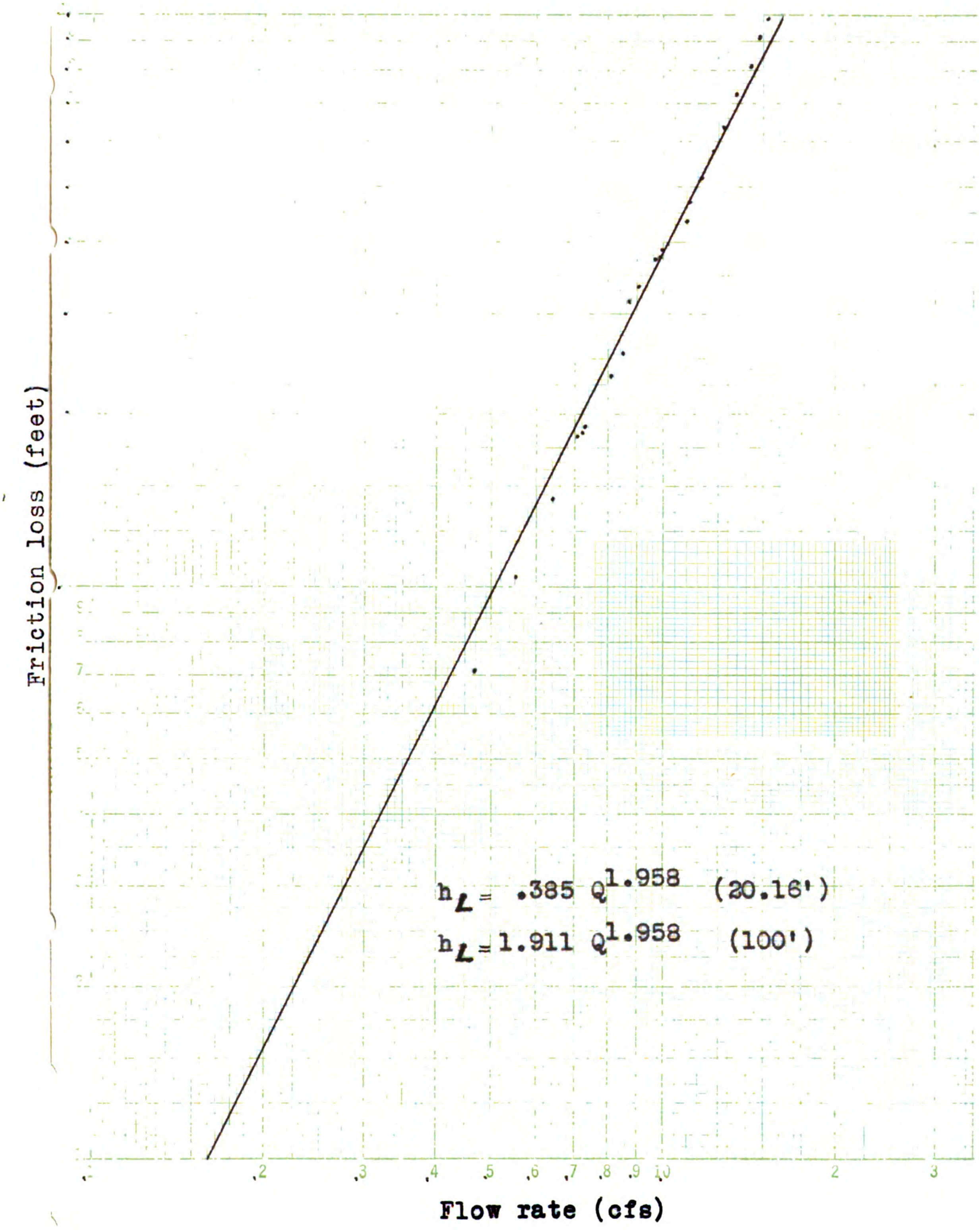


Fig. 15 Head loss vs. flow rate (20.16-foot length of tubing and one connecting coupler in position 3).



The average value of the exponent m to the nearest hundreth is 1.92, and it is used to recalculate the value of K in the five equations above:

Pipe without coupler	$h_f = 1.500\ Q^{1.92}$	(1)
Pipe with well set coupler	$h_L = 1.649\ Q^{1.92}$	(2)
Pipe with coupler in position 1 ...	$h_L = 1.662\ Q^{1.92}$	(3)
Pipe with coupler in position 2 ...	$h_L = 1.836\ Q^{1.92}$	(4)
Pipe with coupler in position 3 ...	$h_L = 1.885\ Q^{1.92}$	(5)

These equations (1 through 5) were used for calculating the values of h_f and h_L for the various flow rates as shown in Table 9.

<u>Pipe without coupler</u>

Its equation for the friction factor in tubing as based on the form $h_f = KQ^m$, was found to be $h_f = 1.471\ Q^{1.881}$. To solve for the expression $h_f = K_a \frac{L}{d^n} V^m$ it is necessary to assume a value for n, as it is impossible to determine its value when only one diameter is tested.

The value of n is assumed to be 1.14 to compare the result with those found by Olson (7, p. 17). K_a can be evaluated as follows:

$$h_f = KQ^m = KA^mV^m = K_a \frac{L}{d^n} V^m \quad \therefore$$

$$K_a = \frac{Kd^nA^m}{L} = \frac{1.471(.4895)^{1.14}\ (.1882)^{1.881}}{100} = .000281$$

Table 9 Loss of head per 100-foot length of six inches aluminum tubing with and without couplers.

Disch.		h_f and h_L values:				
(cfs	gpm)	(1)	(2)	(3)	(4)	(5)
.1	45	.0180	.0198	.0199	.0220	.0227
.2	90	.0682	.0750	.0756	.0835	.0858
.3	135	.1486	.1634	.1647	.1819	.1868
.4	180	.2583	.2839	.2862	.3161	.3246
.5	225	.3964	.4358	.4393	.4852	.4982
.6	270	.5626	.6185	.6234	.6887	.7071
.7	315	.7563	.8314	.8380	.9257	.9504
.8	360	.9774	1.074	1.083	1.196	1.228
.9	404	1.225	1.347	1.358	1.500	1.540
1.0	449	1.500	1.649	1.662	1.836	1.885
1.1	494	1.800	1.978	1.994	2.203	2.262
1.2	539	2.127	2.338	2.357	2.603	2.672
1.3	584	2.481	2.727	2.748	3.037	3.117
1.4	629	2.860	3.144	3.169	3.501	3.594
1.5	674	3.264	3.588	3.616	3.995	4.102
1.6	719	3.697	4.065	4.096	4.526	4.646
1.7	764	4.155	4.567	4.603	5.086	5.221
1.8	809	4.635	5.095	5.135	5.673	5.824
1.9	853	5.145	5.656	5.700	6.297	6.465
2.0	898	5.670	6.233	6.282	6.940	7.125

(1) $h_f = 1.500\ Q^{1.92}$ (Pipe without coupler)

(2) $h_L = 1.649\ Q^{1.92}$ (Pipe with well set coupler)

(3) $h_L = 1.662\ Q^{1.92}$ (Pipe with coupler in position 1)

(4) $h_L = 1.836\ Q^{1.92}$ (Pipe with coupler in position 2)

(5) $h_L = 1.885\ Q^{1.92}$ (Pipe with coupler in position 3)

So, $h_f = .000281 \dfrac{L}{d^{1.14}} V^{1.881}$ .... (6)

To compare the above equation with Olson's equation (7, p. 17) for $h_f = .000330 \dfrac{L}{d^{1.14}} V^{1.78}$ and with values of h_f given by the Aluminum Company of America's general table, Table No. 10 was developed on the basis of 100-foot length of tubing for purposes of comparison.

$$h_f = .000281 \frac{100}{(.4895)^{1.14}} V^{1.881} = .0635\ V^{1.881} \quad ..... (7)$$

$$h_f = .000330 \frac{100}{(.4895)^{1.14}} V^{1.78} = .0747\ V^{1.78} \quad ... (Olson)$$

Table 10 Comparison of equations (Loss of head per 100-foot length of six inches aluminum tubing without coupler)

Vel. (ft/sec)	Disch. (cfs)	$V^{1.881}$	$V^{1.78}$	Equ(7) (feet)	Olson (feet)	ALCOA (feet)
1	.188	1.00	1.00	.063	.074	.070
2	.376	3.68	3.44	.234	.257	.250
3	.565	7.90	7.08	.503	.528	.510
4	.753	13.6	11.8	.865	.881	.850
5	.942	20.6	17.6	1.31	1.31	1.27
6	1.13	28.9	24.4	1.83	1.82	1.74
7	1.32	39.0	32.1	2.48	2.39	2.28
8	1.50	49.9	40.3	3.16	3.02	2.88
9	1.69	62.0	50.1	3.94	3.73	3.62
10	1.88	76.0	60.0	4.82	4.48	4.38

Coupler losses

The head loss in couplers was determined by subtracting the friction loss in 17.53-foot length of tubing from the head loss in 20.16-foot length of tubing and coupler. To accomplish this the equation $h_f = KQ^m$ for 100-foot length of tubing was subtracted from the equation $h_L = KQ^m$ for 100-foot length of tubing and couplers:

$h_f = 1.500\ Q^{1.92}$; for 100 feet of tubing (5 couplers),

$h_c = h_L - h_f$, so:

Well set coupler (*)......... $h_c = .149\ Q^{1.92}$
Coupler in position 1 (*) ... $h_c = .162\ Q^{1.92}$
Coupler in position 2 (*) ... $h_c = .336\ Q^{1.92}$
Coupler in position 3 (*) ... $h_c = .385\ Q^{1.92}$

For each coupler the equation will be:

Well set coupler (*) .... $h_c = .0298\ Q^{1.92}$ (8)
Coupler in position 1 (*) ... $h_c = .0324\ Q^{1.92}$ (9)
Coupler in position 2 (*) ... $h_c = .0672\ Q^{1.92}$ (10)
Coupler in position 3 (*) ... $h_c = .0770\ Q^{1.92}$ (11)

Table 11 gives values of h_c determined from the above equations for several flow rates.

Loss coefficient for couplers

The determination of the loss coefficient K_c for couplers in the equation for head loss in fittings, $h_c = K_c \frac{V^2}{2g}$, can be done as follows:

(*) See explanations on page 19.

Table 11 Loss of head h_c and loss coefficient K_c for couplers.

Disch:		h_c values:				K_c values:			
cfs	gpm	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
.1	45	.00036	.00039	.00081	.00093	.0816	.0887	.1843	.2112
.2	90	.00135	.00147	.00305	.00350	.0772	.0840	.1745	.1995
.3	135	.00295	.00321	.00666	.00763	.0748	.0813	.1698	.1934
.4	188	.00513	.00557	.01175	.01322	.0731	.0785	.1675	.1885
.5	225	.00788	.00856	.01776	.02035	.0718	.0781	.1620	.1856
.6	270	.01117	.01215	.02520	.02888	.0708	.0770	.1596	.1829
.7	315	.01502	.01633	.03388	.03882	.0699	.0760	.1577	.1807
.8	360	.01941	.02111	.04378	.05017	.0691	.0752	.1560	.1788
.9	404	.02434	.02647	.05490	.06290	.0685	.0745	.1546	.1771
1.0	449	.02980	.03240	.06720	.07700	.0679	.0739	.1532	.1756
1.1	494	.03576	.03888	.08064	.09240	.0674	.0732	.1520	.1741
1.2	539	.04225	.04594	.09528	.10918	.0669	.0727	.1509	.1729
1.3	584	.04928	.05358	.11114	.12735	.0665	.0723	.1500	.1718
1.4	629	.05682	.06178	.12815	.14683	.0661	.0718	.1491	.1708
1.5	674	.06484	.07050	.14622	.16755	.0657	.0714	.1482	.1699
1.6	719	.07345	.07983	.16564	.18980	.0654	.0711	.1475	.1691
1.7	764	.08254	.08974	.18614	.21329	.0651	.0708	.1469	.1683
1.8	809	.09208	.09976	.20764	.23793	.0648	.0704	.1461	.1675
1.9	853	.10221	.11113	.23049	.26411	.0645	.0702	.1456	.1668
2.0	898	.11263	.12247	.25401	.29106	.0642	.0698	.1448	.1659

(8) $h_c = .0298\ Q^{1.92}$; (12) $K_c = .0679\ Q^{-.08}$ (Well set)

(9) $h_c = .0324\ Q^{1.92}$; (13) $K_c = .0739\ Q^{-.08}$ (Position 1)

(10) $h_c = .0672\ Q^{1.92}$; (14) $K_c = .1532\ Q^{-.08}$ (Position 2)

(11) $h_c = .0770\ Q^{1.92}$; (15) $K_c = .1756\ Q^{-.08}$ (Position 3)

$$h_c = K_c \frac{V^2}{2g} = KQ^{1.92} \quad \therefore \quad K_c = \frac{2g}{V^2} KQ^{1.92} = \frac{2gA^2}{Q^2} KQ^{1.92}$$

$$K_c = 64.4\ (.1882)^2\ KQ^{-.08} = 2.281KQ^{-.08}\ .$$ So, for:

Well set coupler	$K_c = .0679\ Q^{-.08}$	(12)
Coupler in position 1	$K_c = .0739\ Q^{-.08}$	(13)
Coupler in position 2	$K_c = .153\ Q^{-.08}$	(14)
Coupler in position 3	$K_c = .176\ Q^{-.08}$	(15)

Table 11 gives values of K_c obtained from the above equations.

Elbow losses

Experimental values of h_e and corresponding values of Q were plotted on logarithmic paper (Fig. 16) to give the coefficient K and the exponent m of the equation $h_e = KQ^m$. The equations become:

For 90-degree elbow (piez. 7-8) ... $h_e = .315\ Q^{2.25}$ (16)

For 180-degree elbow (piez. 3-4) ... $h_e = .600\ Q^{2.25}$ (17)

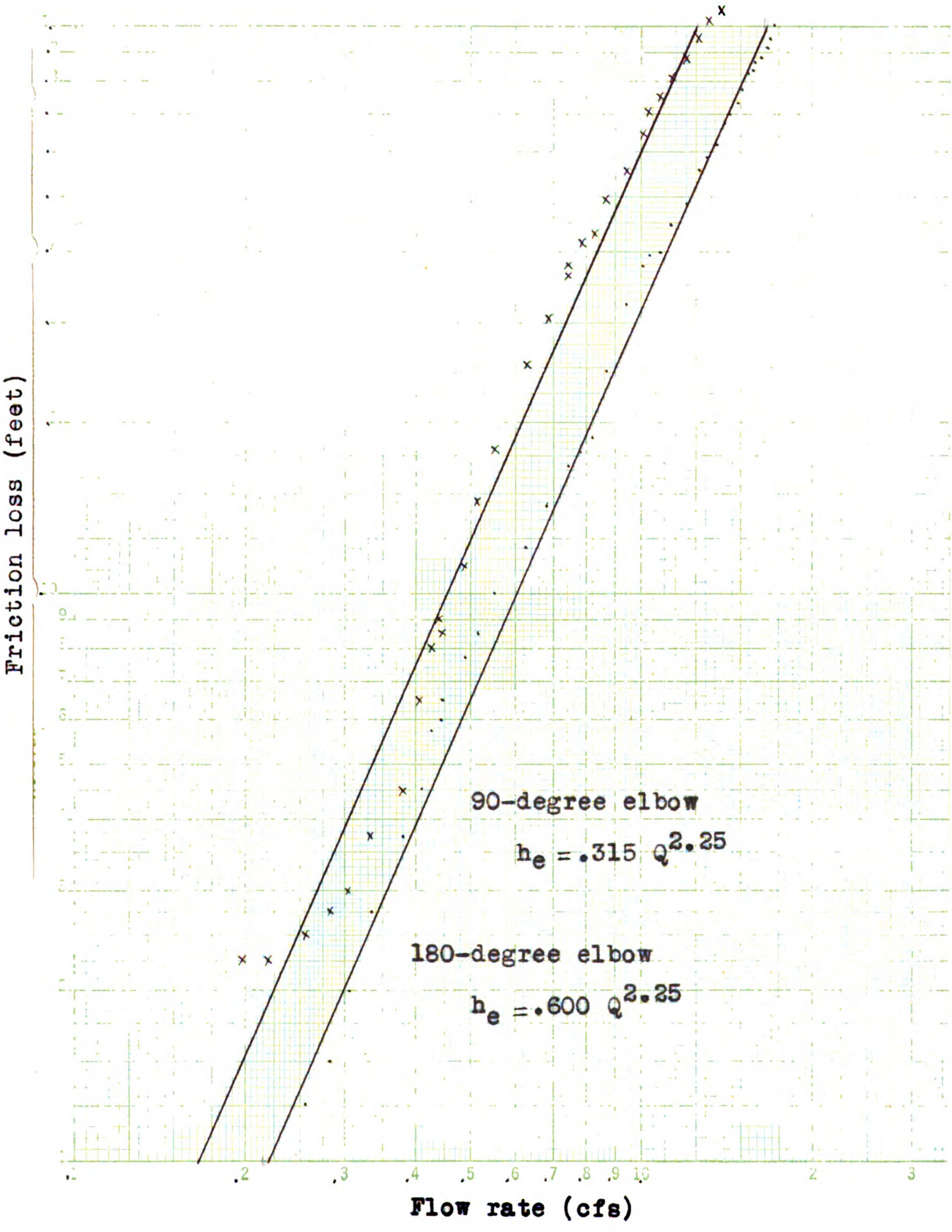
Table 12 gives values of h_e for several flow rates according to equations (16) and (17).

Loss coefficient for elbows

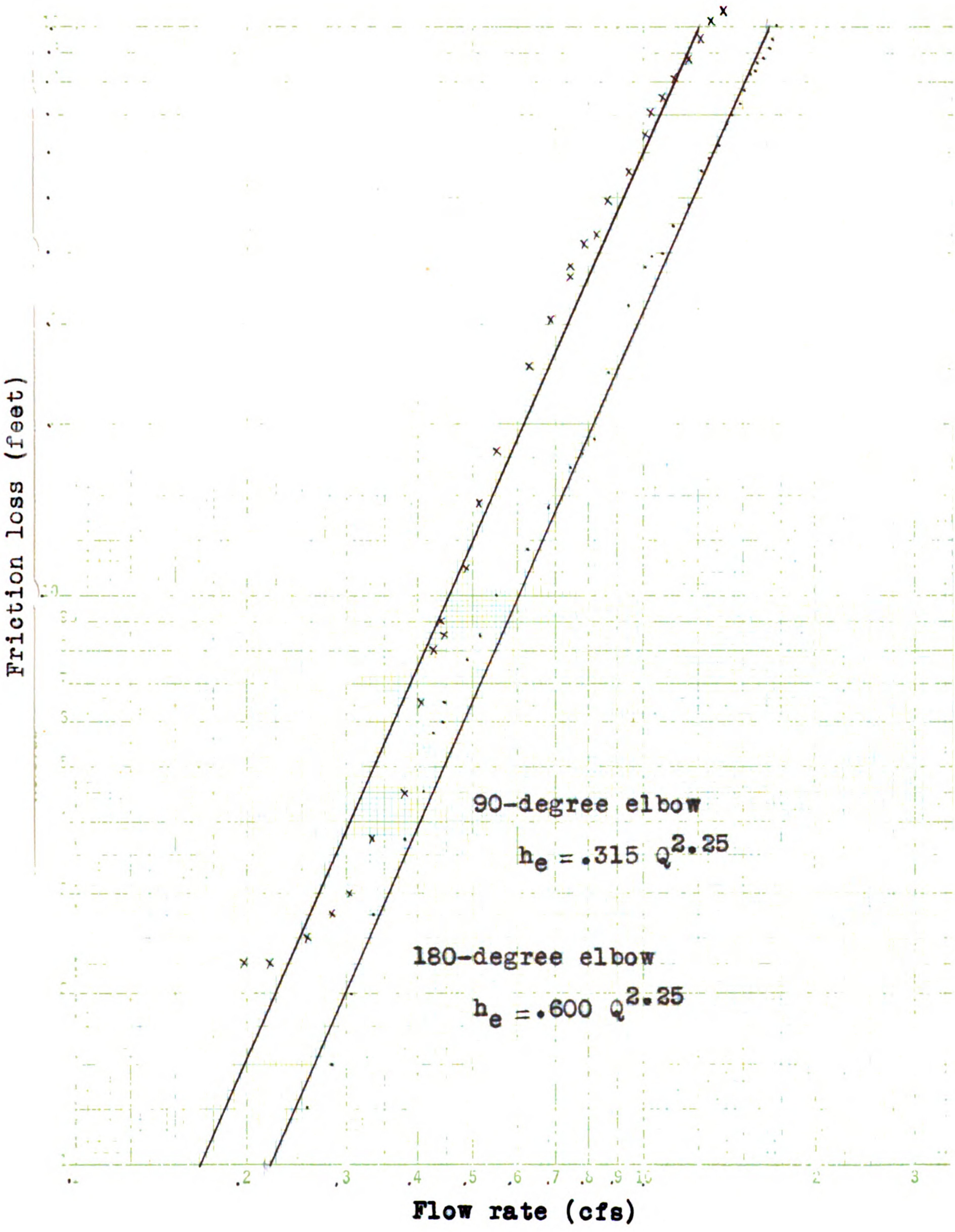
As it was determined for couplers, K_e value is:

$$h_e = K_e \frac{V^2}{2g} = KQ^{2.25} \qquad K_e = 2.281\ KQ^{.25}$$ so:

Fig. 16 Head loss vs. flow rate (90-degree and 180-degree elbows).



<u>Fig. 16</u> **Head loss vs. flow rate (90-degree and 180-degree elbows).**



For 90 -degree elbow (piez. 7-8) ... $K_e = .718\ Q^{.25}$ (18)

For 180-degree elbow (piez. 3-4) ... $K_e = 1.368\ Q^{.25}$ (19)

Table 12 gives values for K_e according to equations (18) and (19).

<u>Table 12</u> Loss of head h_e and loss coefficient K_e for elbows.

Disch. (cfs)	Disch. (gpm)	90° h_e (feet)	180° h_e (feet)	90° K_e	180° K_e
.1	45	.00177	.00337	.4041	.7696
.2	90	.00842	.01605	.4805	.9152
.3	135	.02098	.03996	.5318	1.013
.4	180	.04006	.07632	.5712	1.088
.5	225	.06621	.12612	.6041	1.151
.6	270	.0997	.1900	.6322	1.203
.7	315	.1411	.2689	.6572	1.251
.8	360	.1906	.3631	.6795	1.294
.9	404	.2485	.4733	.6998	1.333
1.0	449	.3150	.6000	.7185	1.368
1.1	494	.3902	.7434	.7355	1.401
1.2	539	.4750	.9048	.7524	1.433
1.3	584	.5685	1.083	.7673	1.462
1.4	629	.6709	1.278	.7807	1.487
1.5	674	.7843	1.494	.7950	1.514
1.6	719	.9072	1.728	.8083	1.540
1.7	764	1.039	1.980	.8203	1.563
1.8	809	1.181	2.250	.8315	1.584
1.9	853	1.335	2.544	.8438	1.607
2.0	898	1.499	2.856	.8549	1.628

CONCLUSIONS

1. The friction factor determined for new six-inch diameter aluminum tubing is in agreement with that presented in the literature for smooth tubing. Its equation for 100-foot length of tubing $h_f = 1.471\ Q^{1.881}$ if written in the form of the general equation of pipe flow becomes:

$$h_f = .000281 \frac{L}{d^{1.14}} V^{1.881}$$

This equation is based on the result of experiments on only one size diameter and so its practical value is limited.

2. The friction loss in 100-foot length of six-inch diameter aluminum tubing, plus the head loss in couplers set at 20-foot intervals (5 couplers in 100 feet) can be expressed by the following equations:

Pipe without coupler	$h_f = 1.500\ Q^{1.92}$
Pipe with coupler well set and in alignment with the tubing	$h_L = 1.649\ Q^{1.92}$
Pipe with coupler in vertical offset, but in alignment with the tubing (Position 1)	$h_L = 1.662\ Q^{1.92}$
Pipe with coupler in vertical offset and at 3-degree deflection in horizontal (Position 2)	$h_L = 1.836\ Q^{1.92}$
Pipe with coupler in vertical offset and at 6-degree deflection in horizontal (Position 3)	$h_L = 1.885\ Q^{1.92}$

3. The head loss in each coupler can be written:

Coupler well set and in alignment with the tubing .... $h_c = .0298\ Q^{1.92}$

Coupler in vertical offset, but in alignment with the tubing (Position 1) .... $h_c = .0324\ Q^{1.92}$

Coupler in vertical offset and at 3-degree deflection in horizontal (Position 2)........ $h_c = .0672\ Q^{1.92}$

Coupler in vertical offset and at 6-degree deflection in horizontal (Position 3)........ $h_c = .0770\ Q^{1.92}$

4. The loss coefficient K_c for couplers in the equation $h_c = K_c \frac{V^2}{2g}$ was determined as being:

Coupler well set and in alignment with the tubing................ $K_c = .0679 Q^{-.08}$

Coupler in vertical offset, but in alignment with the tubing (Position 1).................. $K_c = .0739 Q^{-.08}$

Coupler in vertical offset and at 3-degree deflection in horizontal (Position 2)........ $K_c = .153\ Q^{-.08}$

Coupler in vertical offset and at 6-degree deflection in horizontal (Position 3)........ $K_c = .176\ Q^{-.08}$

5. The head loss in 90-degree and in 180-degree elbows can be expressed:

For 90-degree elbow (Piezometers 7-8).. $h_e = .315\ Q^{2.25}$

For 180-degree elbow (Piezometers 3-4). $h_e = .600\ Q^{2.25}$

6. The loss coefficient K_e for elbows was determined

and its value is:

For 90-degree elbow (Piezometers 7-8). $K_e = .718\ Q^{.25}$

For 180-degree elbow (Piezometers 3-4). $K_e = 1.368\ Q^{.25}$

SUMMARY

1. Extruded aluminum tubing and couplers have been used extensively in portable sprinkler-irrigation systems in recent years. Recognizing the need for further research on the hydraulic characteristics of aluminum tubing, couplers, and elbows, the Perfection Sprinkler Company of Ann Arbor, Mich., made available to the Agricultural Engineering Department the 6-inch diameter of new aluminum pipe, couplers, and elbows used in this experiment. Investigations were made in the Spring of 1950 in the Hydraulic Laboratory of the Agricultural Engineering Department of Michigan State College.

2. The experiment was divided into two parts. The first part was the determination of the friction losses in the tubing and the head losses in couplers when the longitudinal pipe alignment was straight in all planes. The second part was the determination of the friction losses in couplers due to varying degrees of poor alignment of connecting sections of tubing through the coupling as follows: position 1 - coupler out of alignment in the vertical plane using the maximum amount of vertical displacement within the coupler; position 2 - tubing vertically displaced as in the coupler of position 1 and in addition a three (3) degree deflection from true alignment through the coupler in the horizontal plane; position 3 - identical to position 2 except the

angle of deflection was increased to six (6) degrees, the maximum allowed by the test coupling.

The experiment includes also the determination of the head losses in 90-degree and in 180-degree elbows.

3. A differential manometer filled with carbon tetrachloride was used to determine the pressure differences between two piezometers. The piezometers were set in such a way as to give the friction loss in pipe, the head loss in couplers, the head loss in couplers and pipe, and the head loss in elbows. The rate of flow was measured by a Cipolletti weir.

4. Results of investigations on friction loss in pipe and head loss in couplers when the longitudinal pipe alignment was straight in all planes are in good agreement with those presented in literature for smooth tubing and sprinkler-pipe couplers.

5. Results of experiments with couplers out of alignment in the vertical plane by using the maximum amount of vertical displacement within the coupler (position 1) gave only a slightly higher value for the head loss coefficient as compared with the head loss coefficient for coupler when the longitudinal pipe alignment was straight in all planes. The same occurred when the head loss coefficient for 3-degree horizontal displacement (position 2) is compared with that for 6-degree deflection from true alignment (position 3).

However, the 3-degree deflection (position 2) gave a relatively much greater value for the head loss coefficient as compared with that in position 1.

6. The loss coefficient value for the 180-degree elbow was found to be almost twice as great as the loss for the 90-degree elbow.

LITERATURE CITED

1. Christiansen, J. E. Irrigation by Sprinkling. California Agr. Exp. Sta. Bul 670. 1942.
2. Daugherty, R. L. Hydraulics. 4th ed. New York: McGraw Hill Book Co., 1937.
3. Freeman, J. R. Experiments upon the Flow of Water in Pipes and Pipe Fittings. New York: American Society of Mechanical Engineers, 1941.
4. Gibson, A. H. Hydraulics and its Applications. 4th ed. New York: Constable and Company Ltd., 1930
5. King, H. W., Wisler, C. O., and Woodburn, J. G. Hydraulics. 5th ed. New York; John Wiley and Sons, Inc., 1948.
6. Le Conte, J. N. Hydraulics. 1st ed. New York: McGraw Hill Book Co., Inc., 1926.
7. Olson, H. M. The Determination of the Friction Factor for New and Used Aluminum Tubing and Head Loss in Sprinkler-Pipe Couplers. Thesis. Utah State A.C., 1950.
8. Russel, G. E. Hydraulics. 5th ed. New York: Henry Host and Co., 1948.
9. Unwin, W. C. A Treatise on Hydraulics. 1st ed. London: Adam and Charles Black, 1907.
10. Vennard, J. K. Elementary Fluid Mechanics. 2nd ed. New York: John Wiley & Sons, 1947.
11. Weston, E. B. Loss of Head Due to Friction of Water in Pipes. 3rd ed. New York: D. Van Nostrand Co., 1903.