DETERMINATION OF THE ROUGHNESS COEFFICIENT OF THREE SECTIONS OF 2-INCH POLYVINYL CHLORIDE PIPE

Prepared For
Longs Peak Engineering Co.
Berthoud, Colorado

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R. M. Haynie

Colorado State University Research Foundation
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LIST OF SYMBOLS

R_e = Reynolds Number = $\frac{VD}{\nu}$, Dimensionless.

V = Average velocity as computed from $\frac{Q}{A}$, ft/sec.

D = Inside diameter of pipe, ft.

Q = Measured discharge.

A = Cross-sectional area of pipe, ft^2.

f = Darcy-Weisbach resistance coefficient = $h_f \frac{LV^2}{2Dg}$, Dimensionless.

h_f = Measured head loss, ft.

L = Length of pipe between points at which h_f was measured, ft.

g = Acceleration of gravity = 32.2 ft/sec^2.

C = Hazen-Williams resistance coefficient = $\frac{V}{1.32\, R^{0.63}\, S^{0.54}}$ ft 1/2/sec.

R = Hydraulic radius of pipe = $\frac{A}{D}$, ft.

P = Perimeter of inside of pipe, ft.

S = Slope of energy gradient = $\frac{h_f}{L}$, ft/ft.

ν = Kinematic viscosity, ft^2/sec.

ACKNOWLEDGEMENTS

This study was performed under the supervision of Mr. S. S. Karaki, Research Engineer. E. A. Cecil, graduate student, assisted in the setting up and in running the tests and analyzing the data. Shop Supervisor, Mr. R. V. Asmus assisted in the installation of the piezometer connections.

INTRODUCTION

A laboratory study to determine the hydraulic roughness characteristics of a nominal 2-in. diameter rigid Polyvinyl Chloride pipe (hereafter labelled PVC pipe) was conducted at the hydraulics laboratory of Colorado State University. The study was conducted for the Longs Peak Engineering Company of Berthoud, Colorado

The ostensibly smooth-walled PVC pipes, upon examination, indicated internal wall roughness of varying sizes apparently created during or after the extruding process in its manufacture. The roughness appeared to be of varying heights in different lengths of pipes (30 ft. lengths) and produced corrugated ridges in the longitudinal direction of the pipes. Some of the ridges were circumferential, others terminated part of the way around the pipe, thus creating a heterogeneous roughness form inside the pipe. From observations by eye, there did not appear to be any reach in a given pipe length where the roughness was visibly greater than the average, although different pipe lengths were observed to have different heights of roughnesses. The absolute heights of the roughnesses could not be measured without cutting out circumferential portions of the pipe.

Three pipe lengths were tested and numbered 1, 2, and 3 in order of decreasing roughness as observed by eye. It was the purpose of this study to establish the hydraulic roughness coefficients of the test pipes in terms of the Hazen-Williams coefficient C as determined from the equation:

$$V = 1.32C\ R^{0.63}\ S^{0.54} \tag{1}$$

where

V = velocity in ft/sec

C = roughness coefficient

R = hydraulic radius in feet

S = slope of the hydraulic gradient in ft/ft

For purpose of information, the Darcy-Weisbach coefficient f in the equation

$$h_f = f\,\frac{L}{D}\,\frac{V^2}{2g} \tag{2}$$

is also provided. In Eq. (2),

h_f = head loss in feet

f = dimensionless resistance coefficient

L = pipe length in feet

D = pipe diameter in feet

V = average flow velocity in ft/sec

g = gravitational acceleration in ft/sec^2

The Darcy-Weisbach equation is generally superior to other empirical equations because it is a rational expression based upon known flow characteristics and fluid properties. It is just as easy to use as other equations and more accurate than some, although with data from specific tests, as is the case with the 2-in PVC pipe, any of the head loss equations should provide reasonably accurate determination of frictional head loss.

Test Apparatus

The PVC pipe was mounted level on a system of supports Water was supplied through the test pipes by a 4-in. turbine pump, and the discharge rate was measured by a venturi meter and a mercury manometer. The venturi meter was calibrated gravimetrically to within ± 1 per cent at the start of the study. The low discharges(below about 20 GPM) were measured gravimetrically during each test run since the venturi meter could not be used to measure the low range in flows.

Each of the three sections of pipe were fitted with piezometers located along the length of the pipe as shown in Figure 1. The piezometer holes in the PVC pipe were 0.098-in. in diameter and since the holes were drilled from the outside, the inside edges of the holes were smoothed off. Epoxy resin was used to fasten the piezometers to the pipes and allowed to dry for one day before tests were made. The piezometers were connected to a differential water manometer with Mayon tubing. The differential manometer was equipped with an air tank at the top end of the manometer tubes. The air tank was used as the means of increasing the pressure in the manometer tubes to balance the water pressure in the pipe thus making it possible to hold the water columns down in the tubes when the water pressure in the pipe was high.

The discharge end of the pipe was equipped with a Keystone valve. This valve was needed to regulate the water pressure in the pipe and insure the pipe flowing full at all discharges.

Test Procedures

The pump was started at a comparatively low discharge at the beginning of each test. The regulating valve on the lower end of the PVC pipe was then adjusted to get the pipe flowing full. The manometer lines were then "bled" of air by means of "Y"-connections in the lines. After the air had been removed from the manometer lines, air was forced into the air tank until the pressure in the manometer lines balanced the pressure in the pipe.

Differential head readings were then made between successive piezometer points.

Runs on each pipe were made for several evenly spaced discharges from approximately 5 GPM to 75 GPM. At each discharge the pressure differential between successive points in the pipe was read from the manometer.

From the pressure head differential readings at various discharges the roughness coefficients of the pipes were calculated. Both the Darcy-Weisbach "f" resistance coefficient and the Hazen-Williams "C" resistance coefficients were computed.

Results

The test results showed that the three pipes varied in roughness, but the roughness in a single pipe was fairly uniform as was evidenced by the differential readings between successive points on a pipe at a given discharge (see Table 1).

In a plot of Hazen-Williams "C" vs discharge, for a composite of the three test pipes, nearly all the test points were contained in a band of $\pm$ 8 per cent on either side of a best fit line (Figure 2). In the plots of Hazen-Williams "C" vs Discharge for the individual pipes the test points formed rather satisfactory curves (Figures 3, 4, and 5). At the lowest discharge (5 GPM) for pipe number 2 the point was far out of line in relation to the other points because of an error in measurement, and was not considered when the curve was drawn. These three curves showed pipes 1 and 2 to be fairly similar in roughness and pipe 3 was somewhat smoother.

For the plots of Darcy-Weisbach "f" vs Reynolds number the resistance coefficients of pipes number 1 and 2 were nearly the same. However, the test point for the low discharge on pipe number 2 was not considered in the curve for this pipe. Pipe number 3 was shown to have a lower resistance coefficient than pipes 1 and 2 (Figures 6, 7, and 8).

In computing the Reynolds numbers, the actual diameters of the pipes were used. The diameter of each pipe was measured at 3 sections on each end. The average diameter of each pipe was found to be 1.939 inches. The nominal diameter of the pipes (2-in.) was used in computing the velocity of flow in the pipe for the plot of Flow Rate vs Head Loss in feet of water (Figure 9).

REFERENCE

Albertson, M. L., Barton, J. R., and Simons, D. B., Fluid Mechanics for Engineers, Prentice-Hall, Inc., New Jersey, 1960.

Table 1.--Of Measured and Calculated Data.
Actual Diameter = 1.939 inches. Cross Sectional Area = 0.0205 ft^2.
Hydraulic Radius, R, = 0.0403 ft. Water Temperature = 10.2°C.

Pipe No. 1

Q GPM	h_f ft/24 ft	S	V ft/sec	$V^2/2g$ ft	Re	C	f
16.30	0.204	0.0085	1.69	0.0443	19,600	127	0.031
7.96	0.0667	0.0028	0.87	0.0117	10,100	118	0.038
25.56	0.400	0.0167	2.78	0.1200	32,200	145	0.022
36.78	0.650	0.0271	4.00	0.2490	45,500	161	0.018
47.54	0.974	0.0406	5.17	0.4150	60,000	167	0.016
56.06	1.250	0.0520	6.10	0.5780	70,800	173	0.015
68.17	1.730	0.0721	7.41	0.8530	86,000	175	0.014

Pipe No. 2

61.89	1.720	0.0716	6.73	0.7040	78,200	160	0.016
70.41	2.030	0.0845	7.65	0.9100	88,700	166	0.015
42.16	0.875	0.0365	4.59	0.378	53,200	158	0.018
30.05	0.500	0.0208	3.27	0.1660	38,000	152	0.020
23.32	0.342	0.0143	2.54	0.1000	29,500	144	0.023
14.82	0.246	0.0075	1.61	0.0400	18,700	128	0.030
10.22	0.106	0.0044	1.11	0.0191	12,900	120	0.037
5.81	0.075	0.0031	0.63	0.0062	7,350	82	0.081

Pipe No. 3

30.05	0.442	0.0184	3.27	0.1667	38,000	161	0.0178
11.66	0.112	0.0047	1.27	0.0250	14,700	144	0.0303
38.57	0.683	0.0285	4.20	0.2740	48,700	164	0.0165
56.06	1.092	0.0455	6.10	0.5880	70,800	186	0.0125
63.24	1.590	0.0622	6.87	0.7330	79,700	170	0.0146
71.31	1.980	0.0825	7.75	0.9340	90,000	170	0.0143
8.97	0.063	0.0026	0.98	0.0148	11,350	140	0.0286
18.84	0.228	0.0095	2.05	0.0654	23,800	145	0.0235
4.94	0.033	0.0014	0.54	0.0045	6,230	108	0.0500
9.25	0.062	0.0026	1.00	0.0157	11,650	137	0.0268

F I G U R E S

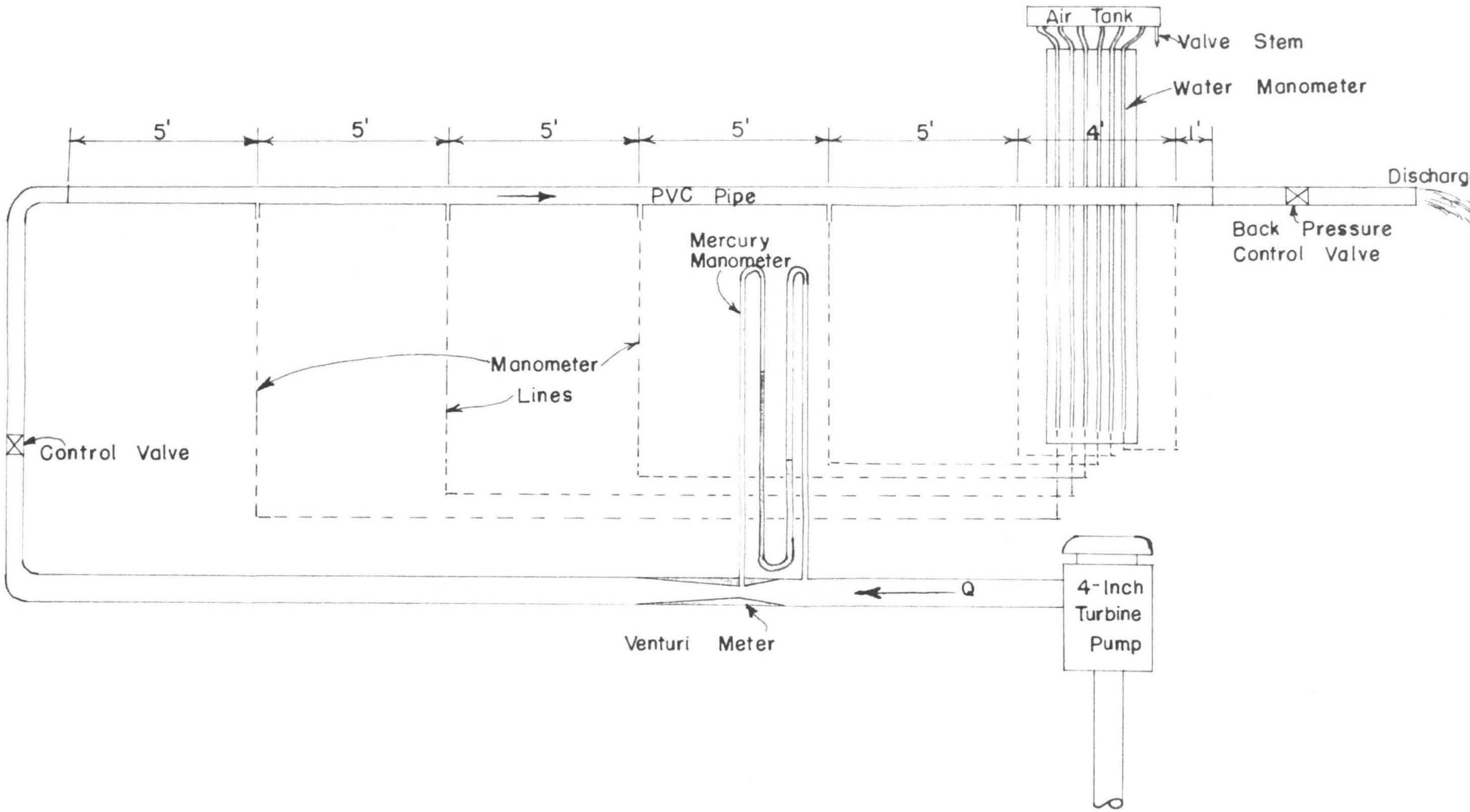


Fig. 1 SCHEMATIC OF TEST APPARATUS

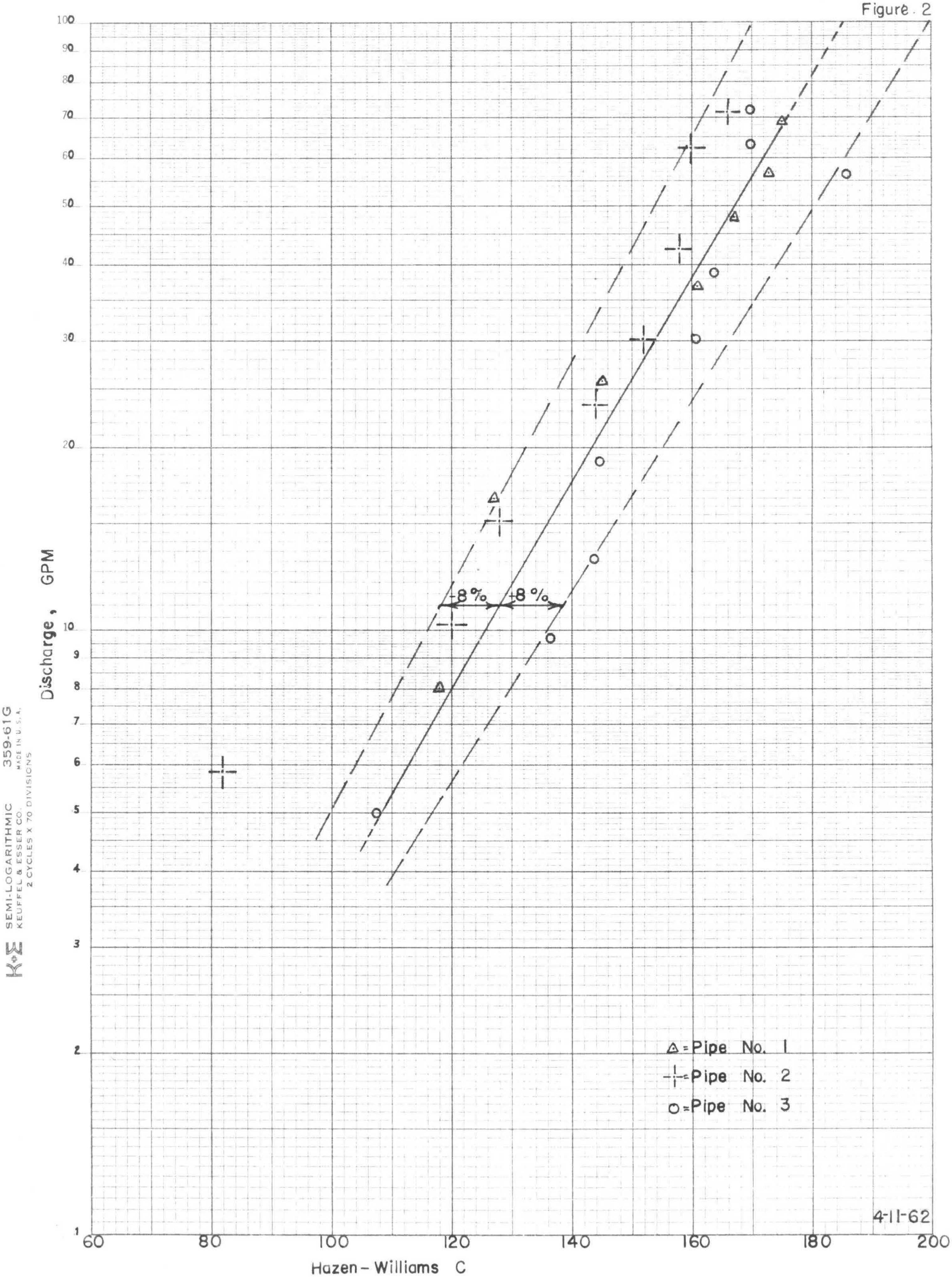


Figure. 2
Discharge, GPM
Hazen-Williams C
-8%
+8%
Δ = Pipe No. 1
-|- = Pipe No. 2
O = Pipe No. 3
4-11-62
SEMI-LOGARITHMIC 359-61G
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 CYCLES X 70 DIVISIONS

Figure 3

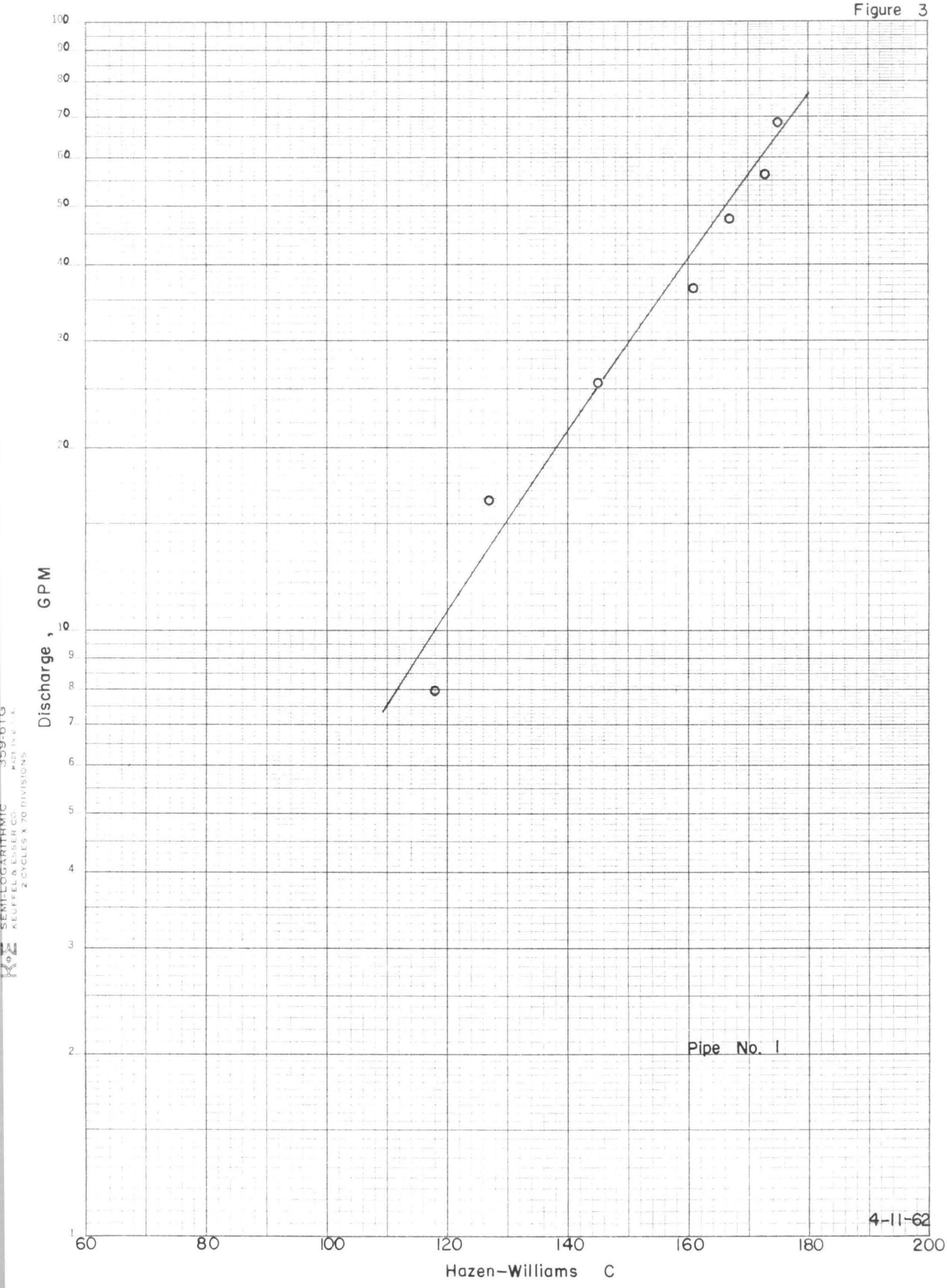
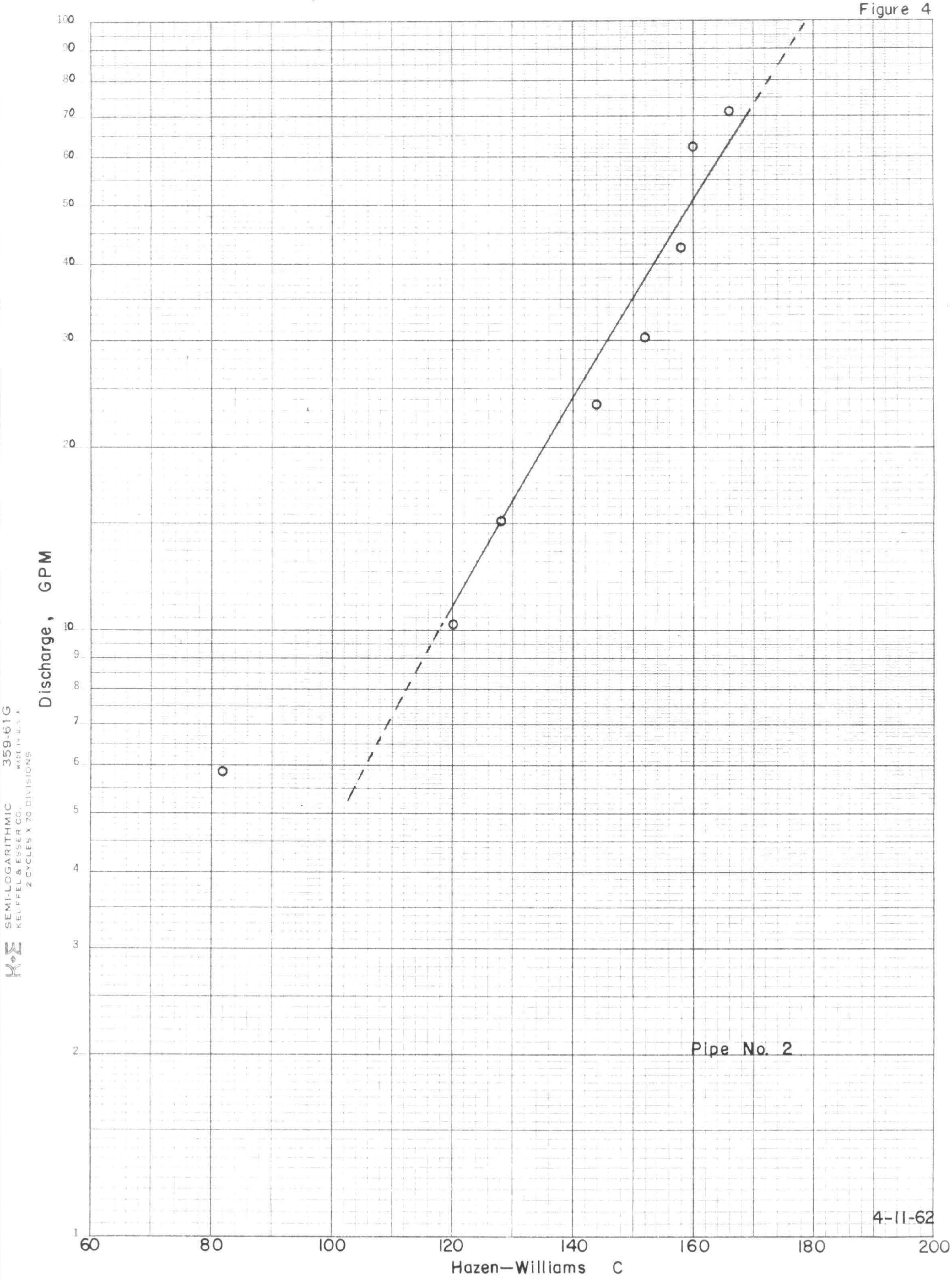

100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
Discharge , GPM
60
80
100
120
140
160
180
200
Hazen-Williams C
Pipe No. 1
4-11-62
SEMI-LOGARITHMIC 359-61G
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 CYCLES X 70 DIVISIONS

Figure 4



Discharge, GPM
Hazen—Williams C
Pipe No. 2
4-11-62
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
60
80
100
120
140
160
180
200
K+E SEMI-LOGARITHMIC 359-61G
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 CYCLES X 70 DIVISIONS

Figure 5

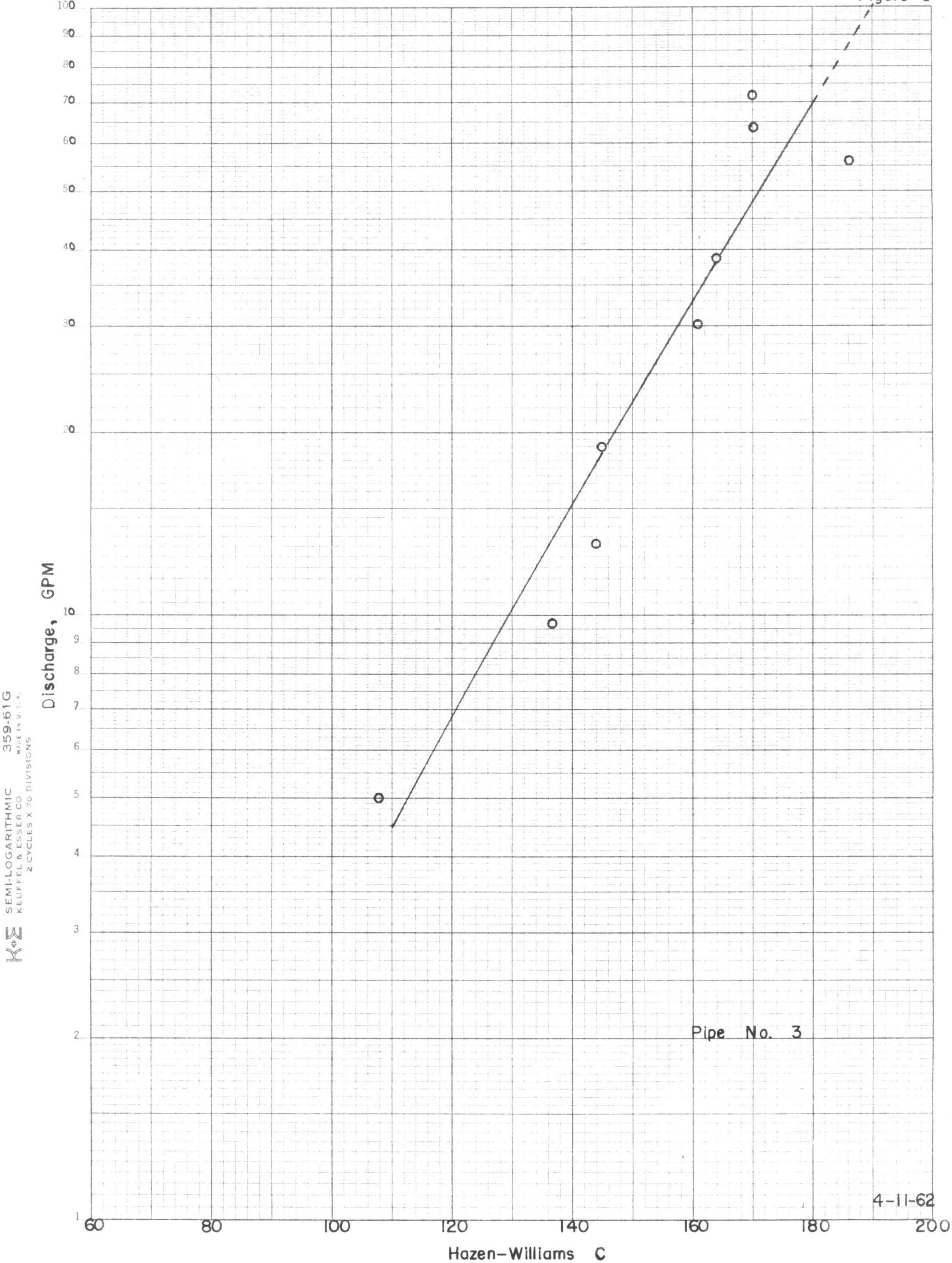
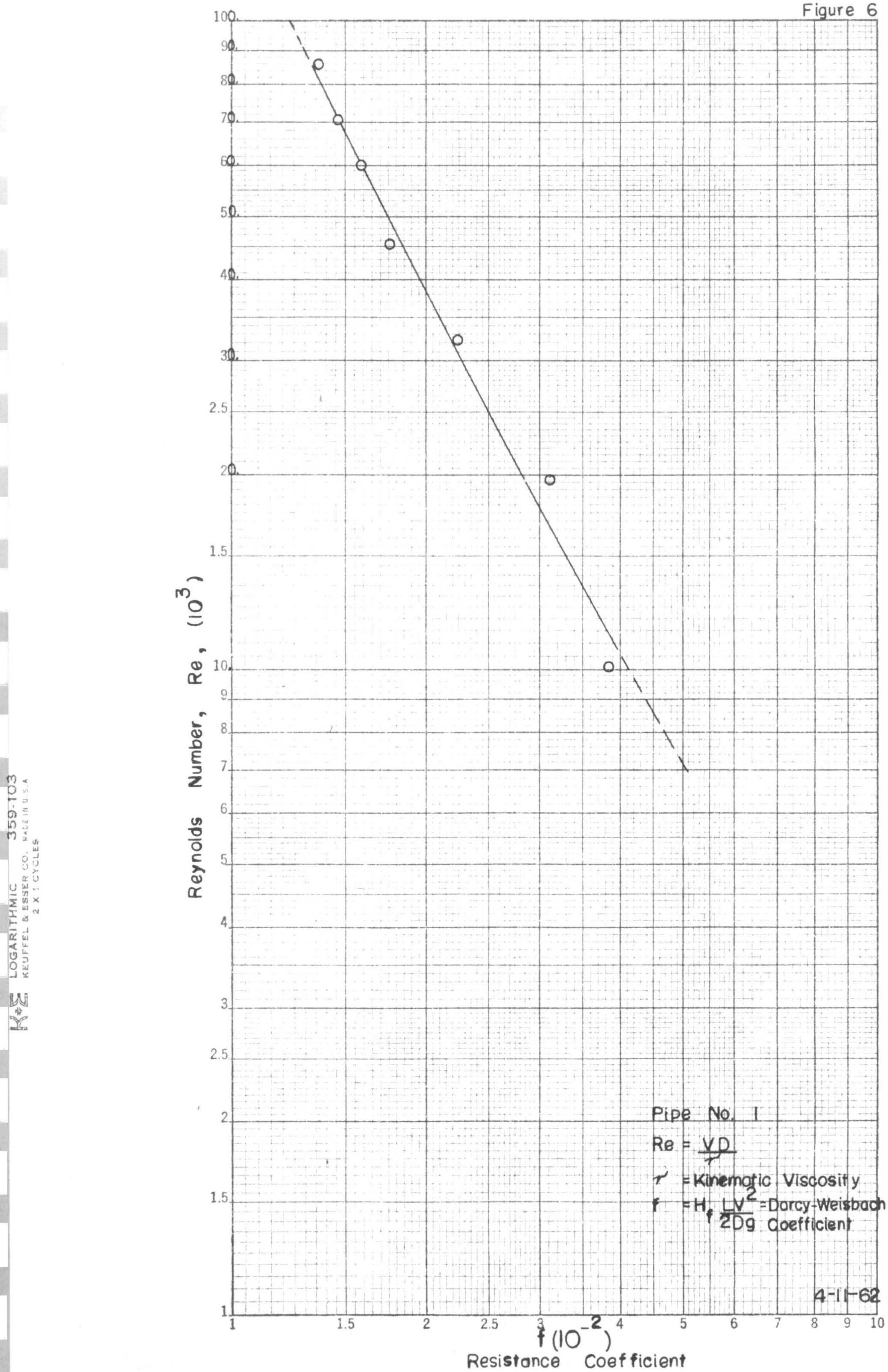

100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
Discharge, GPM
60
80
100
120
140
160
180
200
Hazen-Williams C
Pipe No. 3
4-11-62
SEMI-LOGARITHMIC 359-61G
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 CYCLES X 70 DIVISIONS

Figure 6



Reynolds Number, Re, (10^3)
f (10^{-2})
Resistance Coefficient
Pipe No. I
$Re = \frac{VD}{\nu}$
ν = Kinematic Viscosity
$f = H_f \frac{LV^2}{2Dg}$ = Darcy-Weisbach Coefficient
4-11-62
LOGARITHMIC 359-103
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 1 CYCLES

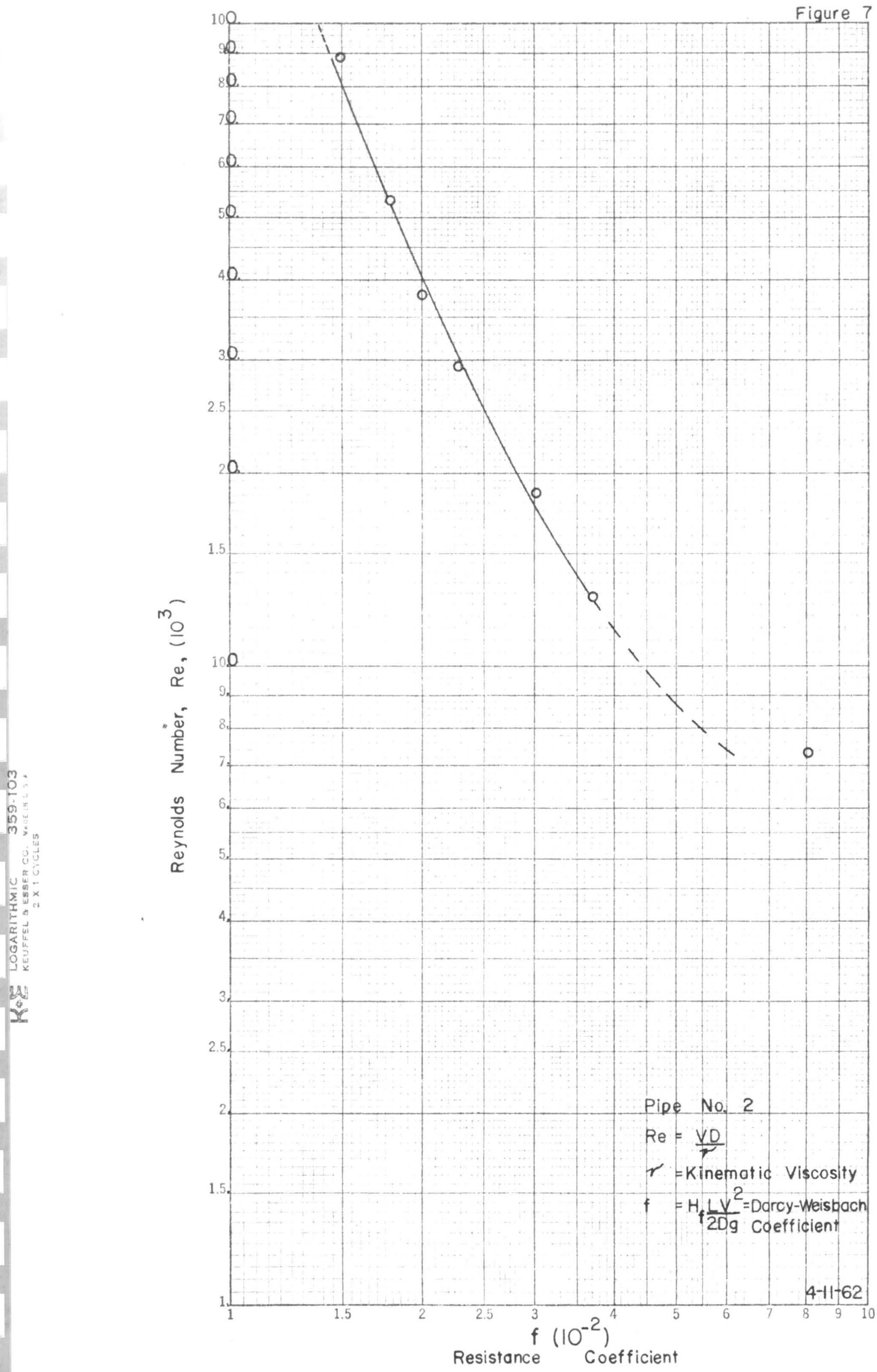
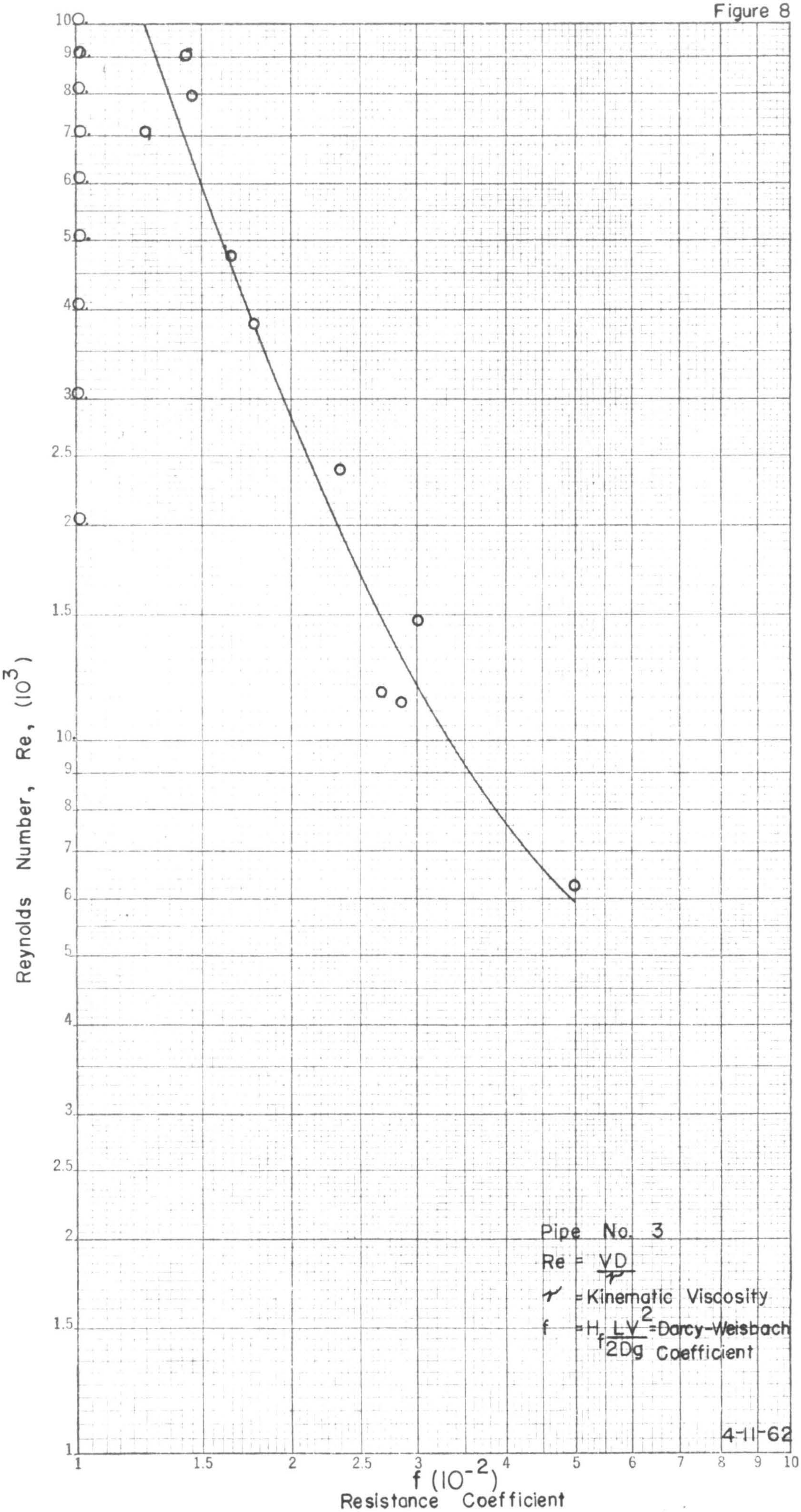


Figure 7
Reynolds Number, Re, (10^3)
f (10^{-2})
Resistance Coefficient
Pipe No. 2
Re = VD/ν
ν = Kinematic Viscosity
f = $H_f \frac{LV^2}{2Dg}$ = Darcy-Weisbach Coefficient
4-11-62
K&E LOGARITHMIC 359-103
KEUFFEL & ESSER CO.
2 X 1 CYCLES

Figure 8


Reynolds Number, Re, (10^3)
100
90
80
70
60
50
40
30
2.5
20
1.5
10
9
8
7
6
5
4
3
2.5
2
1.5
1
1
1.5
2
2.5
3
4
5
6
7
8
9
10
f (10^{-2})
Resistance Coefficient
Pipe No. 3
Re = VD/ν
ν = Kinematic Viscosity
f = H_f LV²/2Dg = Darcy-Weisbach Coefficient
4-11-62
LOGARITHMIC 359-103
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 1 CYCLES

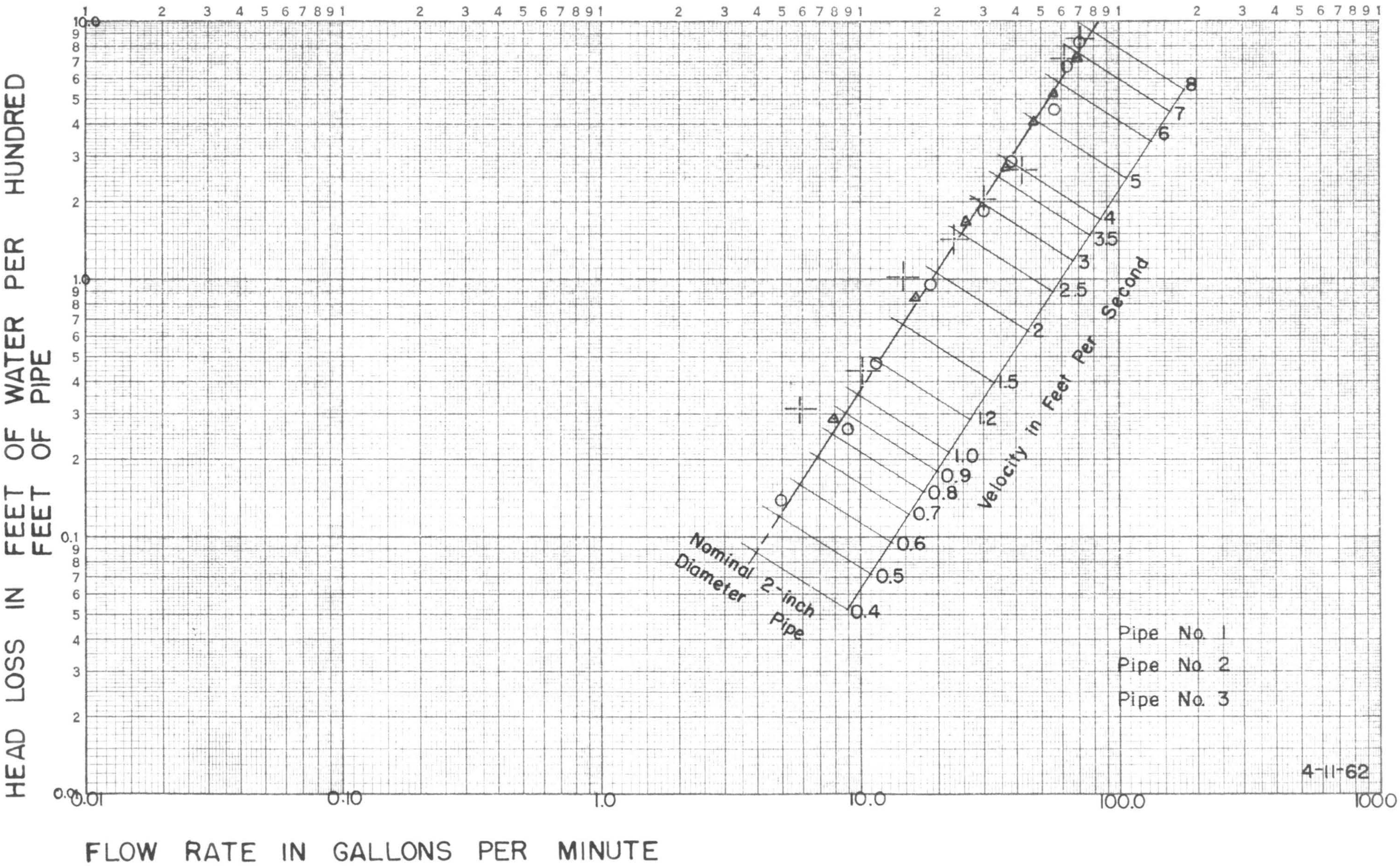

HEAD LOSS IN FEET OF WATER PER HUNDRED FEET OF PIPE
FLOW RATE IN GALLONS PER MINUTE
0.01
0.10
1.0
10.0
100.0
1000
10.0
1.0
0.1
0.01
Nominal 2-inch Diameter Pipe
Velocity in Feet Per Second
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.5
2
2.5
3
3.5
4
5
6
7
8
Pipe No. 1
Pipe No. 2
Pipe No. 3
4-11-62

Figure 9