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Progress Report

THE INVESTIGATION OF HEAT TRANSFER AND PRESSURE DROP OF 11 FINS PER INCH TUBES AND COILS

Report No. 35

EDWIN H. YOUNG
GAREN BALEKJIAN
DENNIS J. WARD
ALBERT J. PAQUETTE
STEVE G. GODZAK
MILTON MECKLER
MARVIN L. KATZ

Project 1592

WOLVERINE TUBE DIVISION
CALUMET AND HECLA, INC.
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ABSTRACT

This report contains a summary of all the heat transfer, and pressure drop test data obtained since April 1, 1954 and is presented in tabular and graphical form for six trombone-finned coils and six twenty-foot straight-finned tubes having eleven fins per inch, 1/8 and 3/16 inch fin heights, and varying root diameters.

The heat transfer tests were conducted with the trombone heater coils in a standard tankless hot water heater. Pressure drop test data were taken on both the trombone coils and the twenty-foot straight tubes.

No correlation of the heat transfer and pressure drop data is presented in this progress report because additional experimental data are required for such purposes.

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INVESTIGATION OF HEAT TRANSFER AND PRESSURE DROP OF ELEVEN FINS PER INCH TUBES AND COILS

INTRODUCTION

Finned-tube coils have found wide usage in both internal and external tankless hot water heaters. The conditions of heat transfer and fluid flow in these applications are such that external finned tubes may be used to definite advantage. This progress report covers a portion of an investigation of the heat transfer and pressure drop characteristics of eleven-fins-per-inch tubing having various fin heights and root diameters.

A standard tankless hot water heater test tank was fabricated in accordance with the Institute of Boiler and Radiator Manufacturers specifications.[1] This tank was used in the heat transfer and pressure drop measurements of the test coils. Separate twenty-foot tubes were used to obtain data on the effect of the internal grooves and the return bends of the test coil.

This progress report is divided into two sections. The first section deals with the heat transfer performance of the test coils and the second section covers the pressure drop investigations of the coils and the twenty-foot tubes.

Finned tubes having nominal root diameters of 1/2, 5/8, 3/4, and 7/8 inches and fin heights of 1/8 inch and 3/16 inch were investigated. The tube and coil characteristics are given in Tables I and II respectively. It should be noted that numbers have been assigned to the tubes and coils tested.

The heat transfer performance of a finned tube is related to the outside heat transfer area and mean overall temperature difference driving force by the following relationship:

$$Q = U_o A \Delta T \quad , \qquad (1)$$

[1]I.B.R. Testing and Rating Code for Indirect Storage and Tankless Water Heater Tested in Tank", The Institute of Boiler and Radiator Manufacturers. New York, New York, (1952).

where Q = Heat transferred, Btu per hour

U_o = Overall heat transfer coefficient, Btu/(hr)(°F)(ft^2) outside surface

A = Total outside heat transfer area, sq. ft.

T = Mean temperature difference, °F

The quantity of heat transferred in this investigation was readily determined by collecting a quantity of water passed through the test coil over a given time interval and measuring the temperature rise of the water collected. The outside area of the test coil was computed from the tube dimensions obtained from a camera enlargement of the tube cross section. Figure 1 shows a cross section of a 1/2 inch root diameter, 3/16 inch fin height tube. The ΔT temperature difference driving force was determined from temperature measurements of the tube side and fin side fluids. The overall coefficient was calculated by solving equation (1) for U_o.

The overall coefficient, in the absence of fouling is related to the individual coefficients by the following relationships:

$$\frac{1}{U_o} = \frac{1}{h_o} + r_m + \frac{1}{h_i}\left(\frac{A_o}{A_i}\right) \qquad (2)$$

where h_o = Outside film coefficient for a finned tube, Btu/(hr)(°F)(ft^2)

h_i = Inside film coefficient, Btu/(hr)(°F)(ft^2)

A_i = Inside tube surface area, ft^2/ft of tube length

A_o = Outside tube surface area, ft^2/ft of tube length

r_m = Resistance of the tube wall to heat transfer, (ft^2)(hr)(°F)/Btu

$$r_m = \frac{X_f \, A_o}{k_m \, A_m} \qquad (3)$$

where X_f = Root wall metal thickness, ft

$$A_m = \pi\left[\frac{D_r - D_i}{\ln \frac{D_r}{D_i}}\right], \quad ft^2/ft$$

D_r = Root diameter, ft

D_i = Inside diameter, ft

k_m = Metal thermal conductivity, (Btu)/(hr)(°F)(ft).

The outside film coefficient may be determined by extrapolating the inside water velocity to an infinite rate by means of a Wilson plot which reduces the inside film resistance to zero.

The fin side film coefficient h_o of equation (2) is uncorrected for fin efficiency. This coefficient may be corrected for fin efficiency by the following relationship:

$$h_o' = h_o \left(\frac{A_o}{A_e}\right) \qquad (4)$$

where h_o' = Fin side (outside) film coefficient corrected for fin efficiency. Btu/(hr)(°F)(ft^2 of outside equivalent area)

$$A_e = A_r + e_f A_f \qquad (5)$$

where A_r = Root area of tube, ft^2/ft
A_f = Fin area of tube, ft^2/ft
e_f = Fin efficiency[2]
A_e = Equivalent area, ft^2/ft.

In general the pressure drop of a fluid flowing inside a straight circular conduit is related to the fluid velocity, conduit length and inside diameter by the following relationship:

$$\Delta P = \frac{fLV^2\rho}{2g_c D_i} \qquad (6)$$

where ΔP = Pressure drop, lbs per ft^2
f = Moody friction factor[3]
L = Length of conduit, feet
ρ = Density of fluid, lbs/ft^3
g_c = Acceleration due to gravity, 32.2 ft lbs force per lb mass /sec^2
V = Bulk fluid velocity, ft/sec
D_i = Inside diameter, ft.

The Moody friction factor f in the above relationship is a function of the relative roughness of the inside tube wall and the Reynolds Number of the flowing fluid:

$$Re = \frac{DV\rho}{\mu} \qquad (7)$$

where Re = Reynolds Number, dimensionless
and μ = Fluid viscosity, lbs/foot second.

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[2] Gardner, K. A., Trans. A.S.M.E., 67 (No. 8), 625, (1945).

[3] Moody, L. F., Trans. A.S.M.E., 66, 671-684 (1944).

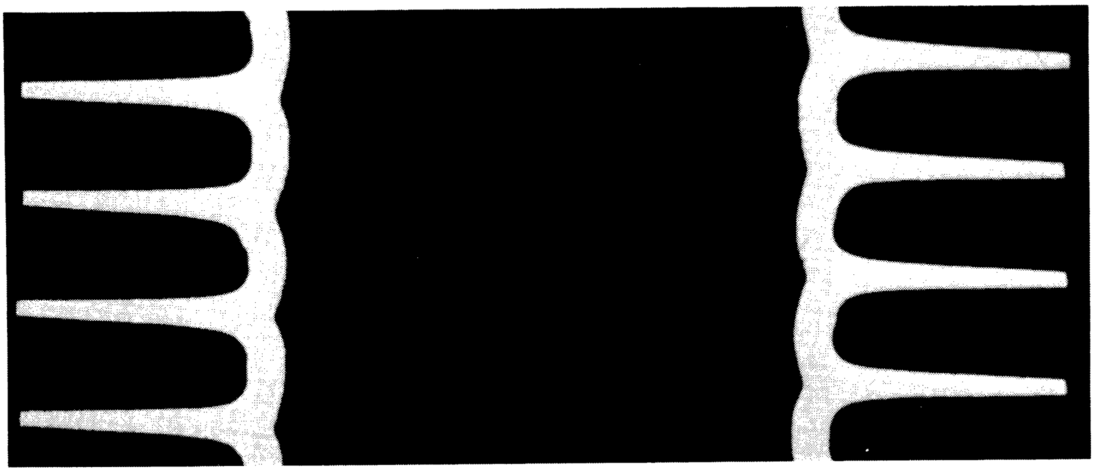

Fig. 1. Enlarged Photograph of a 1/2 Inch Root Diameter and 3/16 Inch Fin Height Tube

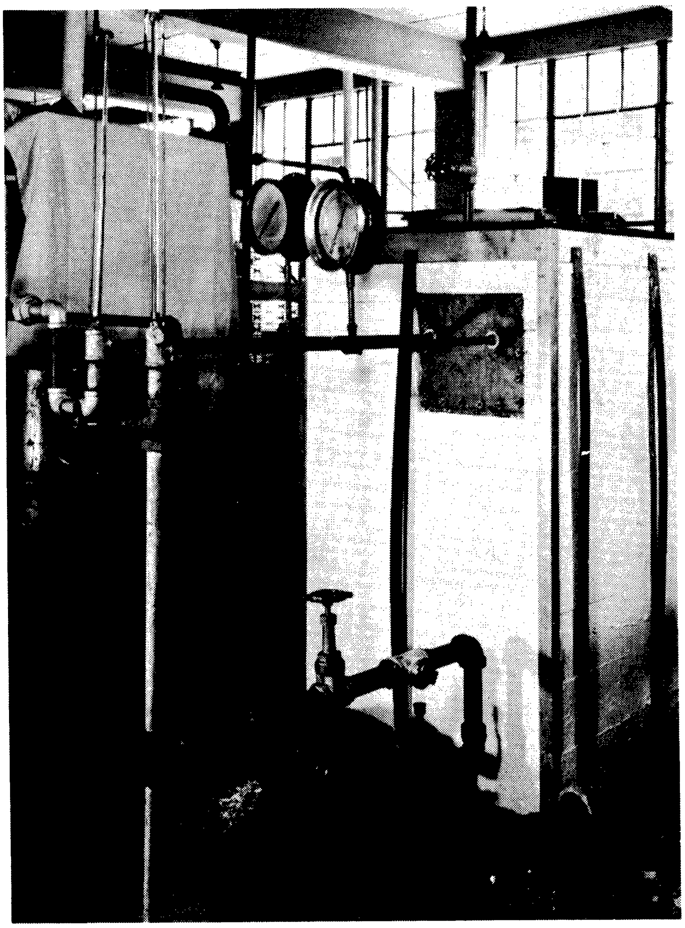

Fig. 2. Front View of Test Tank

TABLE 1

Tube Characteristics

Coil No.	D_o, inches	D_r, inches	D_i, inches	Mean Fin Thickness, inches	Fin Height inches	Fins/inch	A_o ft^2/ft	A_o/A_i
1	0.768	0.5199	0.4395	.01786	0.124	11.32	0.560	4.87
2	0.873	0.515	0.446	0.0182	0.1717	11.026	0.92	7.85
3	0.882	0.6407	0.5625	0.0137	0.1206	11.29	0.685	4.60
4	1.005	0.650	0.546	0.0186	0.1761	10.925	1.032	7.21
5	1.015	0.7664	0.672	0.018	0.136	11.03	0.7875	4.47
5A	1.015	0.7664	0.672	0.018	0.136	11.03	0.7875	4.47
6	1.133	0.8691	0.7804	.021	0.112	11.39	0.903	3.68
Plain	0.500	—	0.444	—	—	—	0.1310	1.125

TABLE 2

Coil Characteristics

Coil No.	A^{-2} ft. Total Outside	St.(No.)	U Bends	Length	Horizontal Pitch Inches	Vertical Pitch Inches	Copper Leads O. D.
1	14.59	20	19	26.81	1.08	1.86	0.50
1A*	14.40	20	19	26.20	1.08	1.86	0.50
2	24.60	20	19	26.96	1.005	2.20	—
3	18.77	20	19	27.31	1.14	2.18	0.50
4	26.33	20	19	25.39	1.005	2.625	0.875
5	22.66	20	19	21.6	1.015	2.73	0.935
5A	20.38	18	17	20.26	1.31	2.73	0.935
6	25.40	20	19	28.05	1.39	2.96	1.13
Plain	3.67	20	19	28.00	1.08	1.72	0.510

*Capacity Tests Only

APPARATUS

A. Coil Test Arrangement

Figure 2 shows a frontal view of the test tank with auxiliary pump, piping, gages, and thermometers. Figure 3 shows a top view of the test tank with the cover removed and a test coil in place. The vertical tank weir may be seen to the left of the test coil. During operation of the tank the water level is three inches above the top of the weir and the water flows by natural convection upward in the left chamber, horizontally to the right over the weir and downward over the test coil in the right chamber. The water then flows under the weir back into the left chamber where it is heated by a steam condensing coil and sparger. Figure 4 shows a schematic diagram of the test tank arrangement. The location of test coil, steam sparger, steam condensing coil and water flow control valves are indicated. The location of tank water thermometers T_a, T_b, and T_c supported by the tank cover plate are also indicated as are also pressure tap locations, P_1, P_2, and coil water thermometers T_1 and T_2.

Figure 5 shows one of the trombone type test coils with copper leads and piezometer rings for pressure drop measurements. Figure 6 shows a trombone test coil having copper leads for pressure drop measurements made externally to the test tank as shown in Figure 4.

B. Twenty-Foot Straight Tube Pressure Test Arrangement

The pressure drop tests arrangement for the twenty-foot long finned tubes is shown in Figure 7 and Figure 8. Figure 7 shows the water inlet section with calming section, thermometer, and pressure gage. To the right of the pressure gage may be seen two manometers, one filled with mercury and the other filled with carbon tetrachloride. These manometers were used for low flow rate pressure drop measurements. Figure 8 shows the downstream end of the test arrangement in which the downstream pressure gage and outlet thermometer can be seen. The weighing barrel and platform scale used to measure the water flow rate may be seen in the lower right-hand corner of the figure.

SECTION I

HEAT TRANSFER TESTS

Test Procedures

A. General

The test coils used in this investigation were fabricated into the desired trombone arrangement by the Wolverine Tube Division. The test coils were installed in the test tank described in an earlier section of this re-

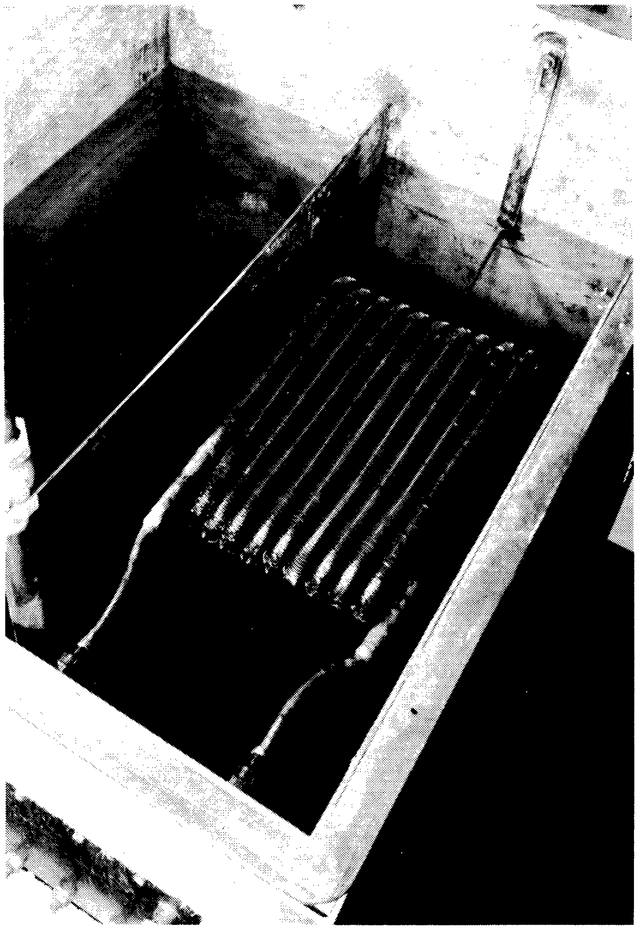

Fig. 3. Top View of Test Tank with Cover Removed
Showing a Test Coil in Place

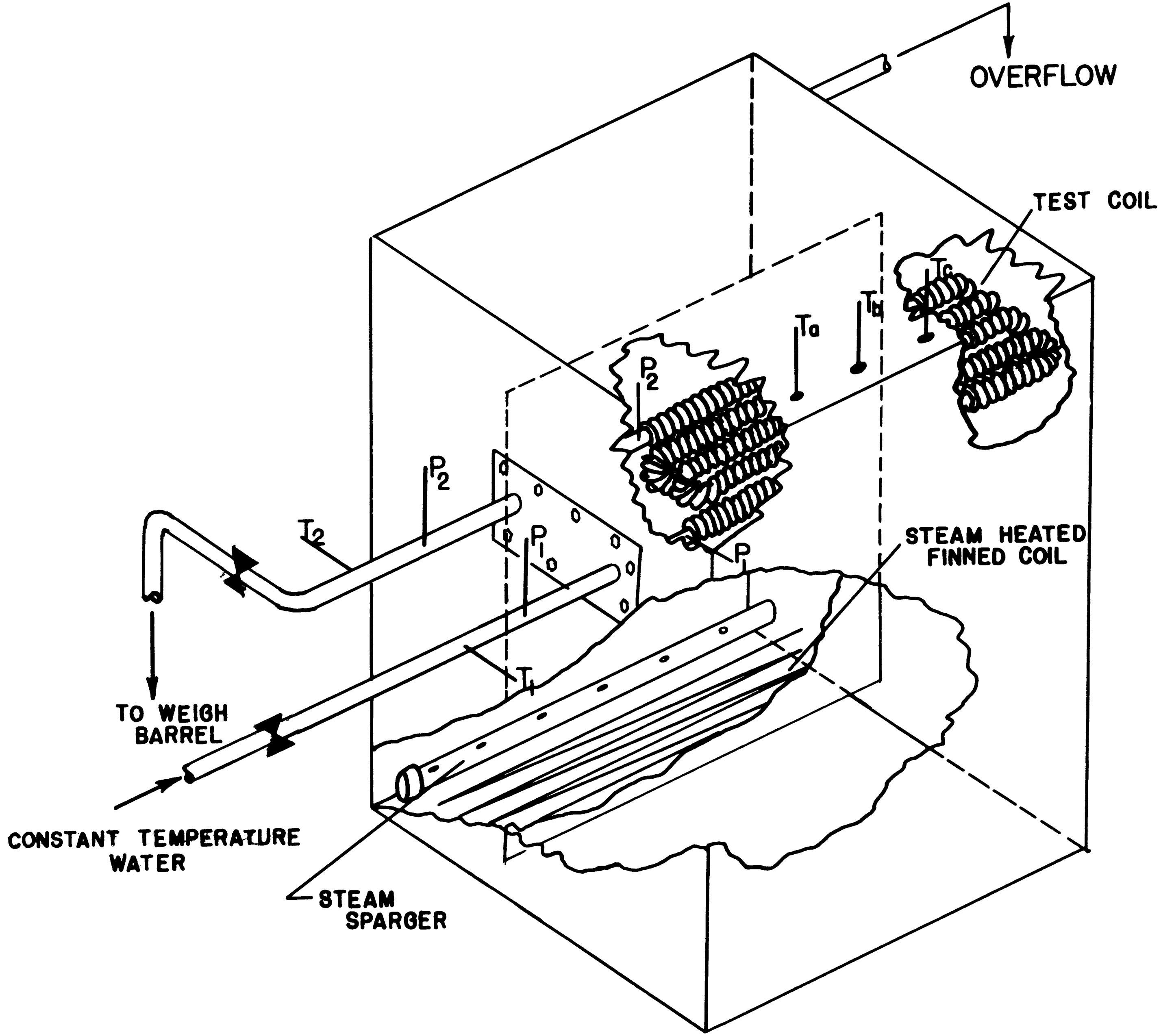

FIG. 4. SCHEMATIC DIAGRAM OF TEST TANK

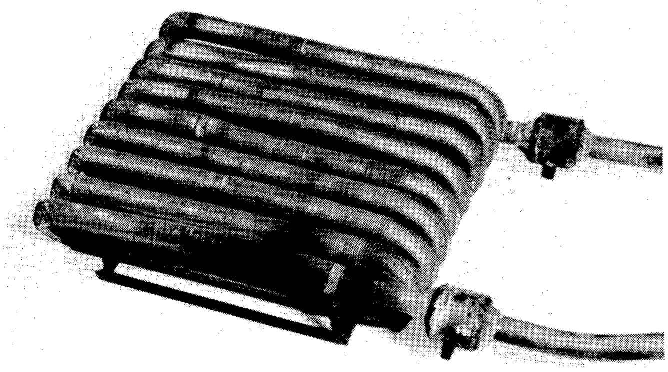

Fig. 5. Trombone Test Coil with Copper Leads and Piezometer Rings

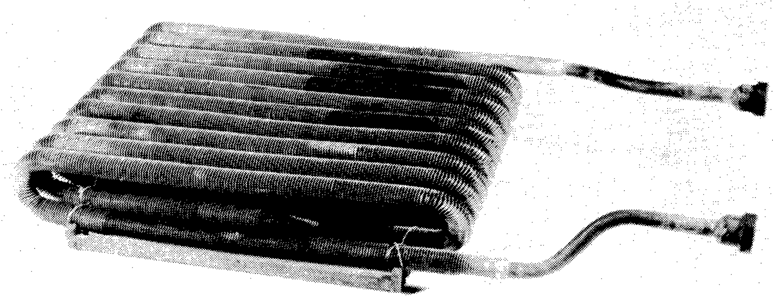

Fig. 6. Trombone Test Coil with Copper Leads for Attachment to Piezometer Rings Outside the Test Tank

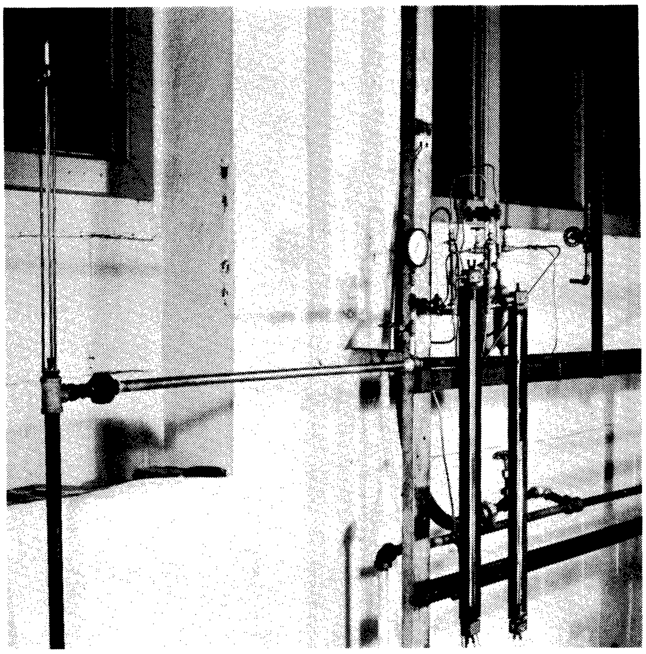

Fig. 7. Straight Tube Pressure Test Arrangement, Water Inlet Section

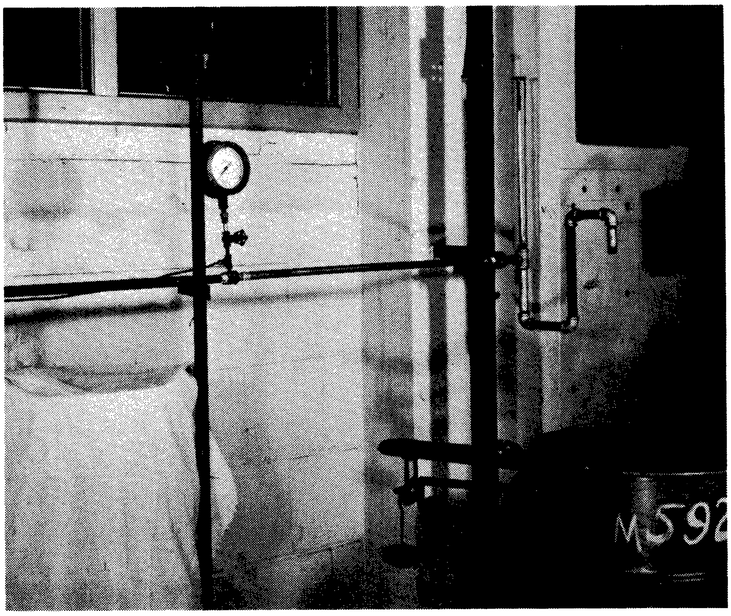

Fig. 8. Straight Tube Pressure Test Arrangement, Water Outlet Section

port. The five thermometers used in temperature measurements were calibrated against National Bureau of Standards thermometers to ±0.05°C. Three of the thermometers were installed in the tank cover directly above the coil to measure the temperature of the tank water going to the coil. Two thermometers were placed in the end of the calming section pipes leading to and coming from the coil being tested in order to measure the temperature rise of the water being heated. The calming sections consisted of two 3/8 inch steel pipes, three feet long each connected to the tank by means of pipe unions for external pressure measurements. A pressure gage attached by means of a piezometer ring was installed in the center of each of these pipes to measure the pressure drop occurring across the system. An auxiliary heat exchanger was used to preheat the coil water for the Wilson plot type of tests. A weighing barrel having a capacity of four hundred pounds of water and a stopwatch were used to determine the water flow rate through the coil. For one of the coils, coil No. 2, the calming pipes were replaced by copper tubing of the same diameter as the coil under test in order to determine the effect of the entrance conditions on the heat transfer capacity of the coil. The results of one of these tests are shown in Figures 9, 10, and 11. These Wilson plots were run at tank temperatures of 170°, 190°, and 210°F respectively. These figures show that the entrance conditions do not effect the heat transfer characteristics of the coils.

B. Coil Capacity Test Procedure

The test procedure used in obtaining data on the coil capacity runs were as follows:

The test tank was filled to the overflow pipe level and then heated and maintained at the desired temperature level by means of the steam sparger and heating coil indicated in Figure 4. Water was then introduced into the test coil and the flow rate adjusted to give a 100°F temperature rise. After allowing a sufficient time to insure steady state conditions, as determined by constant temperature levels, a test run was initiated.

A test run consisted of reading and recording the five thermometers and two pressure gages in succession while a known weight of water was being collected. The weight of water and the time required to collect it were recorded. Table 3 illustrates a typical capacity test run. A summary of all the capacity runs are tabulated in Tables 6 through 12 for the coils tested.

C. Wilson Plot Test Procedure

To obtain test data for the Wilson plot type of analysis, the tank was first filled to the overflow pipe level, then heated and maintained at the desired temperature level by means of the heating coil and sparger. Water was then introduced to the coil and the flow rate adjusted to give an average coil-water temperature of 121°F. Upon waiting a sufficient time to insure steady state conditions a test run was initiated.

A test run consisted of reading and recording in succession the two pressure gages and five thermometers while a predetermined weight of water was being collected. The weight of water collected and the time of collection were recorded.

TABLE 3

Data For Capacity Run No. 252

	Inlet Pressure Psi	Outlet Pressure Psi	T_a °C	T_b °C	T_c °C	(t_i) °C	(t_o) °C
	54.0	3.2	88.0	87.8	87.3	8.2	63.0
	54.0	3.2	88.0	87.5	87.6	8.2	63.3
	53.0	3.1	88.1	87.8	87.2	8.2	63.5
	53.0	3.2	88.2	87.8	87.4	8.2	63.7
	53.0	3.1	88.0	87.6	87.4	8.2	64.1
	54.0	3.2	88.0	87.8	87.2	8.2	63.0
	53.0	3.1	88.1	87.6	87.5	8.2	63.0
	53.0	3.1	88.0	87.8	87.7	8.2	64.4
	53.0	3.1	88.1	87.7	87.4	8.2	63.5
	53.0	3.1	88.4	87.9	87.1	8.3	63.7
avg	53.0	3.14	88.09	87.73	87.38	8.21	63.35

150 lbs of water collected

time for collection, 2 min. 44.7 sec.

Table 4 illustrates a typical Wilson plot test run. A summary of all the Wilson plot runs are tabulated in Tables 6 through 12 for the coils tested.

TABLE 4

Wilson Plot Run No. 276

	Inlet Pressure Psig.	Outlet Pressure Psig.	T_a °C	T_b °C	T_c °C	(t_i) °C	(t_o) °C
	47.5	2.6	88.8	88.5	88.0	29.2	69.5
	47.5	2.6	88.9	88.6	88.0	29.2	70.6
	47.5	2.6	88.8	88.5	88.1	29.3	70.9
	47.5	2.6	88.8	88.6	88.2	29.3	70.2
	48.0	2.7	88.7	88.5	88.0	29.3	70.0
	47.5	2.5	88.8	88.7	88.1	29.3	70.8
	47.5	2.6	88.8	88.5	88.0	29.3	70.9
	48.0	2.6	88.6	88.5	88.0	29.3	70.7
	47.5	2.6	88.8	88.5	87.9	29.3	70.9
	47.0	2.5	88.5	88.2	87.8	24.4	70.5
avg.	47.76	2.79	88.75	88.51	88.01	29.29	70.50

Water collected is 200 lbs.
Time of collection is 3 min 51.3 sec.

Test Results

A. Capacity Tests

A summary of all of the capacity test results are graphically presented in Figure 19. This figure clearly indicates the relative performance of the various tubes tested. The superiority of the 3/16-inch fin height over the 1/8-inch fin height is evident.

B. Wilson Plot Tests

Figures 12 through 18 are the Wilson Plot curves obtained from the test data. The intercepts of these plots, $\frac{10^4}{U_o A}$ are multiplied by the total outside area of the test coil and then substituted into equation (2) in which the term $\frac{1}{h_i}\left(\frac{A_o}{A_i}\right) = 0$ for the intercept. The value of h_o is then readily calculated. Table 5 presents a summary of the outside coefficients h_o and h_o' as calculated by this method and modified for fin efficiency by equation (4).

TABLE 5

Outside Coefficients Computed From Wilson Plot Intercepts

Coil No.	T_T, °F	h_o, Btu / hr-°F-ft^2(outside area)	h_o', Btu / hr-°F-ft^2 (equivalent area)
1	170.69	351	378
	192.16	427	476
	208.92	719	825
2	170.59	300	342
	190.37	403	480
	207.67	433	525
3	171.23	246	263
	189.19	340	373
	206.71	456	518
4	170.63	253	284
	189.58	344	403
	207.21	420	511
5	170.15	272	293
	188.98	337	370
	207.14	405	450
5A	171.16	263	282
	188.91	312	340
	206.44	405	450
6	171.30	236	248
	188.76	305	324
	207.33	385	415

C. Heat Transfer Performance

The variation in the overall heat coefficients, U_o, as a function of the coil water velocity are indicated in Figures 20 through 26 for coils tested.

SECTION II

Pressure Drop Tests

A. Coil Tests

Pressure drop measurements were made simultaneously with the heat transfer measurements on the test coils. Table 4 contains typical pressure drop measurements obtained in a test run.

The pressure drop measurements were obtained with two arrangements. In one case the piezometer rings were immediately adjacent to the finned section. In the other case the piezometer rings were located outside the test tank at a considerable distance from the finned section. Figures 27 through 31 give the pressure drop of the leads and test coil and the coil pressure drop obtained by subtracting the experimentally determined lead pressure drop from the overall pressure drop for the case of external piezometer rings. Also included in these figures are the experimentally measured pressure drop points for the case in which the piezometer rings are located immediately adjacent to the finned section. It was necessary to make both types of tests because of the difficulty of computing reliable corrections for the external pressure drop test arrangement. Figures 31 and 32 show the effect of the temperature level on pressure drop for coils 6 and 2 respectively.

Tables 6 through 15 summarize the pressure drop experimental data obtained on the test coils. Table 22 shows the experimental pressure drop due to the steel leads.

B. Twenty-foot Straight Tube Tests

Pressure drop measurements were made on twenty-foot long straight tubes in order to determine the relative roughness of the internal helical grooves of the tubes and the effect of the 180-degree return bends of the test coils. Tables 16 through 21 summarize the test data collected. Figure 33 presents a graphical summary of the data obtained. Figure 34 gives the calculated friction factors of these tubes based on a nominal inside diameter.

SUMMARY

No final correlations or conclusions can be made at the present time. This progress report summarizes all of the test data collected in the investigation to date. Additional experimental data are required to determine the influence of coil pitch, return bend radii, and coil shape on heat transfer and pressure-drop performance of finned tubes.

TABLE 6

COIL NO. 1.

D_r = 1/2 inch, FIN HEIGHT = 1/8 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED DATA

Run No.	Remarks	W_t, #/hr	Water Flow-Rate, Gallons/min	V_t, ft/sec	t_w, °F	Δt, °F	T_{avg}, °F	ΔT, °F	$Q \times 10^{-3}$, Btu/hr	U_o, $\frac{Btu}{hr\text{-}ft^2\text{-}°F}$	$\frac{10^4}{U_o A}$	$\frac{10^4}{(1+0.011t_w)\,W^{0.8}}$	$-\Delta P_t$*, #/in^2
99	Capacity Run	1300	—	5.51	—	98.80	172.06	—	128.1	—	—	—	—
100	"	2285	—	9.66	—	100.19	191.84	—	228.5	—	—	—	—
106	"	2959	—	12.51	—	98.81	201.65	—	293.9	—	—	—	—
107	"	2280	—	9.66	—	101.09	191.30	—	230.5	—	—	—	—
108	Wilson Plot Run	2892	5.78	12.26	122.18	63.90	191.68	69.50	102.5	182.0	3.76	7.21	49.50
109	"	2520	5.04	10.70	121.77	70.09	193.86	72.09	98.0	167.5	4.08	8.14	36.50
110	"	2185	4.37	9.27	122.50	74.18	191.53	69.03	90.0	160.5	4.26	9.02	28.00
111	"	1838	3.67	7.80	122.83	80.95	192.22	69.39	82.4	146.1	4.66	10.42	20.90
112	"	1435	2.87	6.09	123.73	90.67	191.86	68.13	72.1	130.0	5.25	12.55	12.40
113	"	1057	2.11	4.48	122.34	108.61	191.79	69.44	65.4	113.2	6.05	16.28	5.05
120	"	2905	5.88	12.32	122.22	92.99	208.67	86.45	151.0	214.0	3.20	7.16	48.50
121	"	2492	5.25	10.55	122.50	102.67	208.99	86.49	142.5	203.0	3.37	8.11	37.95
122	"	2135	4.32	9.05	122.36	111.91	208.80	86.44	133.0	189.0	3.62	9.17	28.25
123	"	1840	3.72	7.80	122.97	115.81	208.85	85.88	118.9	170.0	4.03	10.41	21.39
124	"	1290	2.61	5.47	122.20	132.52	208.87	86.67	95.0	135.0	5.07	13.78	10.45
125	"	991	2.01	4.21	122.70	90.70	209.32	86.62	80.0	113.9	6.02	16.99	3.00
126	"	2644	5.35	11.21	122.95	45.81	174.22	51.27	67.1	161.1	4.23	7.78	41.97
127	"	2400	4.86	10.20	122.85	47.38	172.80	49.95	63.2	156.0	4.40	8.40	35.53
128	"	2064	4.17	8.75	122.83	49.77	171.14	48.31	54.6	146.1	4.67	9.45	26.30
129	"	1770	3.58	7.50	122.36	57.82	172.96	50.60	56.7	139.5	4.95	10.80	19.20
130	"	1365	2.76	5.79	122.45	63.95	171.84	49.41	48.5	120.6	5.66	13.20	10.80
131	"	934	1.89	3.96	122.49	76.61	173.03	50.54	39.8	97.0	7.05	17.80	5.05
132	"	1061	2.15	4.50	121.44	72.76	172.31	50.87	42.9	103.5	7.09	17.40	7.00
133	"	1189	2.40	5.03	121.98	67.55	172.18	50.20	44.5	109.0	6.70	16.20	8.85
134	"	1560	3.16	6.61	122.56	57.65	171.90	49.34	50.0	124.2	6.26	14.70	15.57

* Includes Steel Leads

TABLE 7

COIL NO. 2

D_r = 1/2 inch   Fin Height = 3/16 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED DATA

Run No.	Remarks	W_t, #/hr	Water Flow Rate, Gallons/min	V_t, ft/sec	t_w, °F	Δt, °F	T_{avg}, °F	ΔT, °F	$Q\times10^{-3}$, Btu/hr	U_o, $\frac{Btu}{hr - ft^2 - °F}$	$\frac{10^4}{U_oA}$	$\frac{10^4}{(1+0.011t_w)\ W^{0.8}}$	$-\Delta P^*$, #/in^2
265	Wilson Plot Run	3082	6.20	8.8	122.32	45.47	170.22	47.90	139.0	119	3.41	6.91	48.69
266	"	2822	5.68	8.06	122.34	49.75	171.07	48.73	141.0	117	3.47	7.37	40.71
267	"	2588	5.20	7.39	122.41	52.24	171.14	48.73	135.2	113	3.60	7.89	34.36
268	"	2387	4.81	6.84	122.18	54.31	170.55	48.37	129.7	109.5	3.72	8.45	29.55
269	"	2260	4.55	6.46	122.23	55.84	170.51	48.28	126.0	106	3.83	8.77	26.64
270A	"	2067	4.14	4.16	122.82	58.64	170.13	48.31	115.3	102	3.99	9.50	23.20
270B	"	1845	3.72	5.30	122.50	63.40	170.90	48.70	117.0	98	4.15	10.40	19.80
271	"	1622	3.26	4.63	122.38	64.69	170.11	47.74	105.0	89.6	4.54	11.60	13.23
272	"	1392	2.80	3.98	122.13	70.81	170.96	48.83	98.5	82.4	4.94	13.07	9.86
273	"	1205	2.42	3.44	122.43	72.16	170.22	47.79	86.9	74.5	5.47	14.68	6.94
274	"	1055	2.12	3.01	122.32	76.88	170.87	48.55	81.1	68	5.98	16.32	5.21
275	"	852	1.72	2.44	121.68	80.89	170.44	48.76	68.9	57.5	7.07	19.40	3.05
276	"	3127	6.30	8.95	121.91	74.18	190.78	68.87	232.0	137.5	2.96	6.82	41.66
277	"	2863	5.75	8.16	122.36	76.66	190.42	68.06	219.5	131	3.10	7.26	38.23
278	"	2415	4.85	6.89	121.53	83.41	189.27	67.73	201.3	121	3.37	8.41	27.29
279†	"	2415	4.85	6.89	122.25	84.51	190.98	68.72	204.1	121	3.37	8.42	27.49
280	"	2790	4.35	6.18	121.77	87.91	190.06	68.29	245.2	113.5	3.59	9.20	22.16
281	"	1830	3.68	5.23	121.55	95.58	190.04	68.49	175.0	103.8	3.92	10.58	16.05
282	"	1440	2.90	4.12	122.49	105.30	190.72	68.24	151.8	90.4	4.50	12.70	9.86
283	"	1065	2.14	3.04	122.50	114.35	190.67	68.18	121.9	72.9	5.59	16.10	5.35
284	"	3110	6.25	8.87	121.10	98.87	207.68	86.58	307.0	144	2.82	6.84	44.50
285†	"	3150	6.34	9.00	122.11	98.17	208.27	86.06	305.7	141	2.79	6.74	45.17
286	"	3670	7.38	10.48	122.76	88.47	208.04	85.28	324.5	155	2.62	5.94	60.56
287†	"	3675	7.39	10.50	121.41	87.61	207.46	86.06	322.0	152.5	2.67	6.01	61.36
288	"	3515	7.08	10.05	122.99	87.55	206.49	83.50	308.0	150	2.71	6.13	56.21
289	"	2900	5.83	8.30	121.28	101.43	207.59	86.31	294.0	139	2.93	7.25	37.30
290	"	2360	4.75	6.75	122.27	111.33	207.81	85.54	262.6	125	3.26	8.50	25.27
291	"	2360	4.75	6.75	122.58	111.44	208.02	85.63	263.0	125.5	3.25	8.50	25.02
292	"	2860	5.75	8.17	122.13	50.04	170.69	48.56	131.1	120.0	3.39	7.30	38.31
293	"	1995	4.02	5.72	122.22	60.46	170.37	48.15	120.6	102	3.98	9.77	18.95
294	"	1049	2.11	3.00	121.50	78.53	170.67	49.18	82.3	68.5	5.95	16.90	4.97
251	Capacity Run	1904	—	—	94.01	101.36	170.38	76.37	192.8	—	—	—	—
252	"	3280	—	—	96.01	100.36	189.68	93.41	330.0	—	—	—	—
253	"	3670	—	—	98.49	101.56	197.01	98.52	372.0	—	—	—	—

† Check Run

* Includes Steel Leads

TABLE 7

COIL NO. 2

D_r = 1/2 inch   Fin Height = 3/16 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED DATA

Run No.	Remarks	W_t, #/hr	Water Flow Rate, Gallons/min	V_t, ft/sec	t_w, °F	Δt, °F	ΔT, °F	T_{avg}, °F	$Qx10^{-3}$, Btu/hr	U_o, $\frac{Btu}{hr - ft^2 - °F}$	$\frac{10^4}{U_oA}$	$\frac{10^4}{(1+0.011t_w) W^{0.8}}$	$-\Delta P^*$, #/in^2
397	Wilson Plot Runs	3464	6.92	9.81	122.16	66.96	66.37	188.53	231.9	142.0	2.86	6.28	43.30
398	"	2384	4.77	6.77	122.09	82.91	66.92	189.01	197.7	120.0	3.38	8.40	21.00
399	"	1837	3.67	5.21	122.00	91.78	66.56	188.56	168.6	103.0	3.95	10.44	13.00
400	"	1269	2.54	3.60	122.27	105.86	66.82	189.09	134.3	81.6	4.97	14.00	6.20
401	"	1538	3.08	4.37	121.68	97.96	66.60	188.28	150.7	92.0	4.42	12.01	9.30
402	"	2143	4.29	6.09	122.31	85.32	66.48	188.79	182.8	111.7	3.64	9.20	17.00
390	"	3302	6.60	9.36	122.34	45.05	48.82	171.16	148.8	124.0	3.28	6.51	40.36
391	"	2395	4.79	6.80	122.36	53.76	48.22	170.58	277.4	108.6	3.74	8.40	22.25
392	"	1840	3.68	5.13	121.69	63.67	49.32	171.01	117.2	965.0	4.21	10.40	13.04
393	"	1302	2.60	3.69	122.25	71.49	48.53	170.78	93.0	77.8	5.21	13.70	6.55
394	"	1017	2.03	2.88	121.77	80.49	49.08	170.85	81.9	67.7	6.00	16.76	2.94
396	"	363	.73	1.05	121.69	91.62	49.90	171.59	33.3	27.1	15.00	38.05	0.54
403	"	3400	6.80	9.65	121.60	91.66	85.23	206.83	311.6	149.0	2.73	6.40	41.70
404	"	2560	5.12	7.26	122.32	104.98	85.34	207.66	268.7	127.9	3.18	7.98	24.40
405	"	2790	5.58	7.94	122.02	100.64	84.18	206.20	280.8	136.0	2.99	7.46	28.60
406	"	3050	6.10	8.66	122.11	93.38	84.20	206.31	284.8	137.1	2.96	6.94	34.20

*Copper Leads

TABLE 8

COIL NO. 3

D_r = 5/8 inch, FIN-HEIGHT = 1/8 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED DATA

Run No.	Remarks	W_t, #/hr	Water Flow-Rate, Gallons/min	V_t, ft/sec	t_w, °F	Δt, °F	T_{avg}, °F	ΔT, °F	$Q \times 10^{-3}$, Btu/hr	U_o, $\frac{Btu}{hr - ft^2 - °F}$	$\frac{10^4}{U_o A}$	$\frac{10^4}{(1+0.011t_w)\,W^{0.8}}$	$-\Delta P^*$, #/in^2
139	Wilson Plot Run	3430	6.86	8.97	122.81	75.22	204.91	82.10	258.0	167.1	3.18	6.28	22.65
143	"	3800	7.60	9.94	122.32	84.24	206.56	74.61	320.0	179.0	2.98	5.83	27.15
144	"	3250	6.50	8.51	121.82	85.12	206.94	82.78	277.0	168.5	3.16	6.61	20.59
145	"	2770	5.54	7.25	122.07	90.43	207.61	85.54	250.2	155.9	3.42	7.45	13.48
146	"	2457	4.91	6.43	122.14	84.91	207.05	94.86	208.2	146.0	3.66	8.25	10.80
147	"	2125	4.25	5.56	122.63	84.56	207.19	101.50	179.8	136.0	3.92	9.22	7.85
148	"	1008	2.03	2.64	122.65	82.73	205.38	125.41	83.4	81.6	6.54	16.90	+
149	"	1650	3.30	4.32	122.36	114.34	206.96	84.60	188.8	119.0	4.49	11.31	5.00
150	"	1440	2.88	3.76	122.86	84.10	206.96	117.34	121.1	107.1	4.96	12.21	3.69
151	"	1359	2.72	3.56	122.68	84.82	207.50	122.18	115.0	104.0	5.12	13.10	3.30
152	"	3880	7.76	10.14	122.45	50.35	188.42	65.97	195.1	157.6	3.38	5.74	28.49
155	"	3690	7.38	9.65	122.67	66.51	189.18	50.58	245.7	150.0	3.56	6.00	26.24
156	"	3420	6.84	8.94	122.00	55.69	189.86	67.86	190.4	149.9	3.56	6.36	22.45
157	"	3060	6.12	8.00	122.68	66.76	189.45	59.92	204.0	146.0	3.64	6.92	17.92
158	"	2590	5.18	6.77	122.50	64.49	189.32	66.82	167.0	133.9	3.99	7.91	12.92
159	"	2310	4.62	6.04	122.18	66.94	189.12	69.41	154.4	128.0	4.18	8.60	9.55
160	"	1890	3.78	4.94	122.18	77.38	189.05	66.87	146.1	116.5	4.58	10.20	6.63
161	"	1580	3.16	4.13	122.32	66.94	189.27	84.31	105.8	106.1	5.02	11.75	4.55
162	"	1158	2.32	3.02	122.63	94.64	189.07	66.44	109.6	88.2	6.04	15.05	1.74
163	"	3320	6.64	8.67	122.11	49.79	171.90	35.86	165.3	127.2	4.18	6.45	21.05
164	"	2850	5.70	7.45	122.32	48.51	170.83	38.29	138.2	120.5	4.43	7.30	14.99
165	"	2330	4.66	6.10	121.64	45.49	171.52	49.88	106.0	113.1	4.70	8.60	10.50
166	"	1930	3.86	5.05	122.86	47.99	170.85	48.47	92.5	103.5	5.14	10.10	7.10
167	"	1600	3.20	4.18	122.83	54.47	171.66	48.83	87.0	95.5	5.59	11.59	5.06
168	"	1275	2.55	3.34	122.07	48.58	170.65	60.05	62.0	85.0	6.27	13.90	3.10
213	Capacity Run	1160	—	3.04	102.57	101.48	176.32	125.00	118.0	—	—	—	—
214	"	2145	—	5.61	100.91	100.39	189.51	138.80	215.0	—	—	—	—
215	"	3265	—	8.54	100.93	101.18	206.35	156.10	330.0	—	—	—	—

+Not Readable

*Includes Steel Leads

TABLE 9

COIL NO. 4

D_r = 5/8 inch, FIN HEIGHT = 3/16 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED DATA

Run No.	Remarks	W_t, #/hr	Water Flow-Rate, Gallons/min	V_t, ft/sec	t_w, °F	Δt, °F	ΔT, °F	T_{avg}, °F	$Q \times 10^{-3}$, Btu/hr	U_o, $\frac{Btu}{hr - ft^2 - °F}$	$\frac{10^4}{U_oA}$	$\frac{10^4}{(1+0.011t_w) W^{0.8}}$	$-\Delta P^*$, $\#/in^2$
176	Wilson Plot Run	4780	9.62	13.25	121.69	78.48	85.39	207.09	375.1	167.50	2.27	4.83	32.42
177	"	4375	8.80	12.15	122.23	79.83	83.93	206.09	349.2	157.60	2.40	5.17	26.70
178	"	4055	8.15	11.28	122.20	87.41	85.41	207.61	354.4	157.80	2.41	5.75	23.18
179	"	3540	7.12	9.85	122.09	98.35	86.53	208.61	348.2	152.90	2.49	6.09	17.56
180	"	2165	4.35	6.03	122.83	116.28	84.40	207.23	251.7	113.60	3.34	9.50	6.50
181	"	2701	5.43	7.50	121.95	104.89	84.42	206.37	283.3	127.60	2.98	7.64	10.38
182	"	2554	5.13	7.10	122.13	109.46	85.32	207.45	279.6	122.70	3.10	7.95	9.65
183	"	1055	2.12	2.93	122.43	111.19	65.57	188.01	117.3	67.98	5.58	16.30	1.98
184	"	1260	2.53	3.50	122.23	105.71	67.16	189.39	133.2	75.28	5.05	14.00	2.44
185	"	1710	3.44	4.75	121.91	94.91	67.30	189.21	162.3	91.53	4.15	11.00	4.35
186	"	2125	4.27	5.91	122.00	89.23	68.44	190.44	189.6	105.20	3.62	9.25	6.63
187	"	2600	5.23	7.23	121.89	82.21	68.02	189.91	213.7	118.10	3.21	7.90	10.20
188	"	3025	6.08	8.41	122.00	76.54	68.60	190.60	231.5	128.40	2.96	6.97	13.55
189	"	3340	6.71	9.28	121.78	71.19	68.18	189.97	237.8	132.50	2.86	6.47	16.90
191	"	4815	9.68	13.40	122.20	54.14	66.87	189.07	246.2	148.70	2.56	4.76	33.29
192	"	4230	8.50	11.76	122.22	59.92	67.41	189.63	253.5	142.80	2.68	5.35	26.11
193	"	3850	7.74	10.70	122.14	42.12	48.51	170.65	162.2	127.00	2.99	5.75	21.03
194	"	3480	7.00	9.67	121.50	44.50	49.55	171.05	154.9	118.90	3.20	6.30	17.64
195	"	3010	6.05	8.37	121.33	47.03	48.83	170.17	141.6	110.90	3.42	7.00	13.61
196	"	3250	6.52	9.03	122.40	48.46	47.77	170.17	157.5	121.00	3.15	3.62	12.79
197	"	2680	5.38	7.45	121.93	51.12	48.85	170.78	137.0	106.30	3.56	7.70	10.47
198	"	2310	4.65	6.42	122.49	55.40	49.28	171.77	128.0	98.75	3.85	8.60	7.98
199	"	1990	4.00	5.43	122.04	59.49	48.94	170.98	118.4	91.91	4.13	9.72	5.66
200	"	1410	2.84	3.92	122.45	64.64	46.96	169.41	91.1	73.68	5.15	12.90	2.63
201	"	1510	3.04	4.20	122.45	65.47	48.24	170.71	98.9	78.23	4.86	12.25	3.05
204	Capacity Run	1960	—	5.45	93.65	100.22	77.15	170.85	196.4	—	—	—	—
205	"	1875	—	5.21	93.70	100.37	77.00	170.62	188.2	—	—	—	—
206	"	2920	—	8.12	95.00	101.74	90.40	185.40	297.0	—	—	—	—
207	"	3080	—	8.57	95.20	101.63	92.05	187.36	313.0	—	—	—	—
208	"	4565	—	12.70	94.50	99.81	108.20	202.87	455.6	—	—	—	—

* Includes Steel Leads

COIL NO. 5, TABLE 10

D_r = 3/4 inch, FIN HEIGHT = 1/8 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED DATA

Run No.	Remarks	W_t, #/hr	Water Flow-Rate, Gallons/min	V_t, ft/sec	t_w, °F	Δt, °F	T_{avg}, °F	ΔT, °F	$Q \times 10^{-3}$, Btu/hr	U_o, $\frac{Btu}{hr - ft^2 - °F}$	$\frac{10^4}{U_o A}$	$\frac{10^4}{(1+0.011t_w) W^{0.8}}$	$-\Delta P^*$, #/in^2
216	Capacity Run	1630	—	3.02	102.00	101.54	185.14	83.14	165.3	—	—	—	—
217	"	2180	—	4.02	101.48	101.18	193.10	91.62	220.7	—	—	—	—
218	"	3205	—	5.90	102.60	100.82	206.35	103.75	322.5	—	—	—	—
219	"	3185	—	5.85	101.57	100.44	205.92	104.35	320.0	—	—	—	—
220	Wilson Plot Run	4825	9.65	8.90	122.43	47.11	188.87	66.44	227.3	119.5	2.93	4.76	17.24
221	"	4340	8.68	8.00	122.72	50.96	189.05	66.33	221.2	115.2	3.01	5.19	14.23
222	"	3940	7.88	7.26	121.98	52.81	189.03	67.05	208.1	107.8	3.23	5.62	11.41
223	"	3580	7.16	6.60	122.16	56.02	188.73	66.56	200.5	104.8	3.32	6.10	9.78
224	"	3185	6.37	5.87	122.13	59.04	189.21	67.09	188.0	97.2	3.57	6.68	7.94
225	"	2915	5.83	5.38	121.73	62.64	189.19	67.46	182.6	93.7	3.70	6.90	6.51
227	"	2600	5.20	4.80	121.23	67.39	189.00	67.77	175.2	90.0	3.86	7.90	5.07
228	"	2240	4.48	4.13	122.02	71.17	188.92	66.91	159.4	82.6	4.20	8.90	3.92
229	"	1935	3.87	3.56	122.16	76.55	189.25	67.09	148.1	77.0	4.52	10.90	2.90
230	"	1480	2.96	2.73	122.43	82.06	188.51	66.08	121.4	64.0	5.42	12.35	2.04
231	"	4000	8.00	7.38	122.16	32.89	170.08	47.92	131.6	95.1	3.65	5.48	13.05
232	"	3640	7.28	6.71	121.86	36.04	170.29	48.42	131.2	94.0	3.69	6.00	9.13
233	"	3190	6.38	5.89	121.91	38.32	170.64	48.73	122.2	87.1	3.98	6.68	7.93
234	"	2907	5.81	5.36	122.11	40.14	169.95	47.84	116.7	84.6	4.09	7.22	5.56
235	"	2585	5.17	4.77	122.04	43.49	170.19	48.15	112.4	81.2	4.28	7.90	4.33
236	"	2215	4.43	4.08	122.16	47.07	170.08	47.92	104.3	75.5	4.60	8.94	2.98
237	"	1985	3.97	3.66	122.95	51.68	170.22	47.27	102.6	75.3	4.62	9.76	2.44
239	"	1639	3.27	3.02	121.71	55.12	170.31	48.60	90.3	64.5	5.38	11.49	1.34
240	"	1165	2.33	2.15	121.71	61.87	169.57	47.61	72.1	52.5	6.61	15.04	0.52
241	"	5415	10.83	10.00	122.34	60.01	207.28	84.94	325.0	133.0	2.62	4.35	21.74
242	"	5020	10.04	9.25	121.86	61.72	206.96	85.10	309.8	126.5	2.74	4.63	18.74
243	"	4637	9.27	8.54	122.14	63.85	206.38	84.24	296.0	122.0	2.84	4.93	16.18
244	"	4140	8.28	7.64	122.14	70.67	207.61	85.28	292.6	119.0	2.91	5.40	13.00
245	"	3830	7.66	7.05	122.05	73.75	207.00	84.94	282.5	115.0	3.02	5.73	10.90
246	"	3455	6.91	6.36	121.96	76.00	206.64	89.96	262.6	107.3	3.23	6.25	9.19
247	"	2877	5.75	5.30	121.96	84.42	208.13	86.17	242.9	97.9	3.55	7.18	6.57
248	"	2480	4.96	4.57	121.44	90.90	206.56	85.12	225.4	92.0	3.77	8.18	5.14
249	"	2115	4.23	3.90	121.95	96.08	207.18	85.23	203.2	82.7	4.20	9.28	3.80
250	"	1900	3.80	3.50	121.90	102.24	207.86	85.95	194.3	78.5	4.43	10.10	3.21

*Includes Steel Leads

TABLE 11

COIL NO. 5A

D_r = 3/4 inch, Fin Height = 1/8 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED RESULTS

Run No.	Remarks	W_t, #/hr	Water Flow Rate Gal/Min.	V_t, ft/sec	$t_{w\,ave}$, °F	Δt_w °F	ΔT, °F	T_T, °F	$Qx10^{-3}$, Btu/hr	U_o, Btu / hr-ft²-°F	$\frac{10^4}{U_oA}$	$\frac{10^4}{(1+.011t_w)V^{0.8}}$	$-\Delta P_t$,* #/in²
338	Wilson Plot Run	7360	14.72	13.60	122.11	32.51	66.88	188.99	239.3	176.0	2.79	3.45	15.26
339	"	7300	14.60	13.60	122.27	32.74	66.76	189.03	239.0	175.5	2.80	3.46	15.17
340	"	6825	13.65	12.60	122.00	34.34	66.67	188.67	241.3	172.5	2.85	3.62	12.52
341	"	6480	12.96	12.00	122.20	35.10	66.33	188.53	227.4	168.2	2.92	3.81	11.40
342	"	5998	12.00	11.09	122.00	38.12	67.03	189.03	228.6	167.0	2.94	4.07	9.80
343	"	5410	10.82	10.00	122.14	40.25	67.21	189.36	217.8	160.8	3.06	4.40	8.07
344	"	4410	8.82	8.15	121.60	47.20	66.90	188.50	208.2	153.0	3.21	5.21	5.54
345	"	3380	6.76	6.25	122.27	53.35	66.74	189.01	187.1	137.6	3.57	6.44	3.33
346	"	2810	5.62	5.20	122.25	61.56	66.69	188.94	187.3	127.2	3.86	7.44	2.32
347	"	2140	4.28	3.95	121.40	67.40	67.40	188.80	144.2	110.0	4.46	9.25	1.27
348	"	1460	2.92	2.70	122.43	81.14	66.78	189.21	118.5	87.1	5.64	12.56	0.64
263	"	745	1.49	1.38	123.00	130.40	83.00	205.88	97.1	57.5	8.55	21.40	0.18
264	"	834	1.67	1.54	122.68	130.77	86.04	208.72	108.8	62.2	7.90	19.65	0.24
373	"	6300	12.60	11.65	122.38	23.42	48.45	170.83	266.0	149.5	3.29	3.90	10.80
374	"	5475	10.95	10.10	122.32	26.95	49.05	171.37	147.6	147.5	3.33	4.37	8.24
375	"	4700	9.40	8.10	122.11	28.65	48.76	170.87	282.2	135.8	3.62	4.91	6.27
376	"	4100	8.20	7.58	122.14	31.39	48.33	170.47	128.7	130.5	3.76	5.49	4.88
377	"	3740	7.48	6.90	122.14	36.99	49.55	171.70	138.3	137.2	3.58	5.92	3.64
378	"	2699	5.39	4.98	122.32	41.35	48.38	170.71	111.6	113.0	4.35	7.70	2.14
379	"	2125	4.25	3.92	121.96	47.09	49.82	171.79	100.1	99.0	4.97	9.35	1.45
380	"	1070	2.14	1.98	122.58	62.01	48.58	171.16	66.4	66.5	16.09	7.33	0.32
381	"	652	1.30	1.20	122.22	72.14	49.36	171.57	47.0	46.8	10.50	23.80	0.11
382	"	7310	14.62	13.50	121.98	44.80	83.92	205.92	327.5	192.0	2.56	3.46	14.21
383	"	6410	12.82	11.85	121.66	49.50	84.65	206.31	317.3	184.5	2.66	3.83	11.05
384	"	5160	10.32	9.55	122.47	58.14	84.15	206.62	300.0	175.0	2.81	4.57	7.33
385	"	4020	8.04	7.44	122.00	67.34	84.67	206.67	270.7	157.0	3.13	5.59	4.45
386	"	2735	5.47	5.05	121.86	82.89	84.60	206.46	226.7	131.3	3.74	7.61	2.21
387	"	1720	3.43	3.17	122.23	102.49	84.44	206.67	176.3	102.3	4.80	11.00	0.90
260	Capacity Runs	978	—	1.80	101.70	101.36	75.56	177.26	99.0	—	—	—	—
261	"	1940	—	3.57	98.92	101.07	93.55	192.47	196.0	—	—	—	—
262	"	3060	—	5.64	97.48	100.80	109.70	207.18	308.0	—	—	—	—
349	"	740	—	1.36	99.37	100.98	103.00	170.20	74.6	—	—	—	—
351	"	1969	—	3.63	99.50	101.00	91.49	191.00	262.0	—	—	—	—
352	"	3197	—	5.89	95.54	100.50	109.28	204.82	321.0	—	—	—	—
353	"	3176	—	5.84	95.39	101.14	110.45	205.84	320.0	—	—	—	—

*Copper Leads

TABLE 12

COIL NO. 6

D_r = 7/8 inch, Fin Height = 1/8 inch

SUMMARY OF EXPERIMENTAL AND CALCULATED RESULTS

Run No.	Remarks	W_t, #/hr	Water Flow Rate, Gallons/min	V_t, ft/sec	t_w, °F	Δt, °F	ΔT, °F	T_{avg}, °F	$Qx10^{-3}$, Btu/hr	U_o, $\frac{Btu}{hr - ft^2 - °F}$	$\frac{10^4}{U_oA}$	$\frac{10^4}{(1+0.011t_w) W^{0.8}}$	$-\Delta P^*$, #/in^2
295	Wilson Plot Run	3730	7.46	5.00	121.82	39.01	49.14	170.96	145.7	116.5	3.38	5.63	10.36
296	"	3320	6.64	4.46	121.96	41.13	48.96	170.92	136.8	110.0	3.58	6.50	8.22
297	"	—	—	—	—	—	—	—	—	—	—	—	—
298	"	2855	5.71	3.83	121.68	45.95	49.72	171.41	131.1	104.0	3.79	7.30	6.62
299	"	2180	4.36	2.92	122.25	51.71	49.46	171.72	112.8	91.1	4.32	9.05	4.15
300	"	1798	3.59	2.41	122.61	56.05	48.87	171.48	101.0	81.4	4.84	10.22	2.20
301	"	4550	9.10	6.10	122.36	51.50	65.48	187.84	234.3	141.5	2.78	5.06	13.08
302	"	4050	8.10	5.44	122.25	56.75	68.22	190.47	229.9	132.5	2.97	5.54	10.03
303	"	3820	7.64	5.14	122.32	56.95	65.93	188.26	217.6	130.0	3.03	5.77	9.06
304	"	3230	6.46	4.34	122.07	62.59	66.04	188.11	202.3	120.5	3.27	6.65	6.86
305	"	2805	5.61	3.77	122.04	67.75	66.49	188.53	190.0	112.9	3.49	7.43	5.11
306	"	2370	4.74	3.18	122.07	73.37	66.94	189.01	173.8	102.0	3.86	8.53	3.98
307	"	1655	3.31	2.22	122.04	84.58	66.83	188.87	140.1	82.4	4.78	11.38	2.21
308	"	722	1.44	0.97	121.71	107.35	67.25	188.96	77.5	45.5	8.65	22.04	0.63
309	"	5750	11.50	7.71	121.46	61.11	84.65	205.39	351.7	164.8	2.39	4.04	20.60
310	"	5890	11.78	7.90	122.49	64.10	85.37	207.86	378.0	174.1	2.26	3.97	22.26
311	"	5290	10.58	7.10	122.00	68.11	86.18	208.18	360.1	164.8	2.39	4.38	18.34
312	"	4800	9.60	6.44	123.26	72.81	84.94	208.20	349.4	161.1	2.44	4.75	14.43
313	"	4810	9.62	6.46	122.04	72.09	86.26	208.29	346.6	158.5	2.48	4.75	14.47
314	"	4110	8.22	5.51	121.69	76.68	85.86	207.55	315.0	144.8	2.72	5.50	10.74
315	"	3740	7.48	5.02	121.96	81.14	85.19	207.16	303.8	140.5	2.80	5.90	8.42
316	"	3200	6.40	4.30	122.14	86.89	85.25	207.39	278.0	128.8	3.06	6.66	6.56
317	"	2700	5.40	3.62	121.57	93.31	85.32	206.89	252.0	111.8	3.53	7.73	4.59
318	"	2110	4.22	2.83	121.41	102.60	85.01	206.42	216.3	100.5	3.92	9.30	3.07

COIL NO. 2 TABLE 13

D_r = 1/2 inch Fin Height = 3/16 inch

PRESSURE DROP WITH 75 AND 100°F WATER. COPPER LEADS AND MANOMETER

Run No.	Remarks	W_t, #/hr	Water Flow Rate, Gallons/min	t_w, °F	ΔZ, in. Hg.	$-\Delta P$, #/in^2
199	Pressure Drop	437	0.88	74.97	17.00*	0.36
200	"	476	0.95	75.22	25.68*	0.54
201	"	568	1.14	75.29	2.58	1.17
202	"	729	1.46	75.29	4.23	1.92
203	"	825	1.65	74.39	5.38	2.44
204	"	923	1.85	74.21	6.75	3.06
205	"	1044	2.09	73.85	8.71	3.94
206	"	1177	2.36	73.67	11.04	5.00
207	"	1310	2.62	73.40	13.83	6.26
208	"	1427	2.86	73.31	16.73	7.57
209	"	1593	3.19	73.24	21.05	9.53
210	"	1716	3.44	72.91	24.29	11.00
211	"	2021	4.05	72.86	—	15.68
212	"	334	0.67	98.92	0.74	0.33
213	"	525	1.05	99.00	2.04	0.92
214	"	680	1.37	99.43	3.55	1.61
215	"	867	1.74	99.55	5.95	2.69
216	"	1000	2.01	100.08	7.92	3.59
217	"	1157	2.33	99.75	10.94	4.95
218	"	1303	2.62	99.99	14.06	6.36
219	"	1454	2.92	100.09	17.54	7.94
220	"	1603	3.22	99.88	20.94	9.48
221	"	1746	3.51	99.61	25.97	11.75
222	"	1879	3.78	99.52	30.20	13.67
223	"	1997	4.02	99.50	—	16.73
224	"	2205	4.43	99.50	—	19.60
225	"	2423	4.87	99.61	—	24.04
226	"	2680	5.39	99.41	—	29.30
227	"	2903	5.84	99.19	—	32.36
228	"	3115	6.27	99.88	—	36.80

*Inches CCl_4

COIL NO. 5A

TABLE 14

D_r = 3/4 inch

Fin Height = 1/8 inch

PRESSURE DROP WITH 100°F WATER. COPPER LEADS AND MANOMETER

Run No.	Remarks	W_t, #/hr	Water Flow Rate, Gallons/min	t_w, °F	ΔZ, in. Hg.	$-\Delta P$, #/in^2
354	Pressure Drop	1179	2.37	99.66	0.59	0.26
355	"	1353	2.72	99.46	1.03	0.47
356	"	1673	3.36	99.02	1.63	0.74
357	"	2048	4.12	100.11	2.63	1.19
358	"	2300	4.62	99.86	3.54	1.60
359	"	2544	5.12	100.21	4.40	1.99
360	"	2929	5.89	99.51	5.89	2.67
361	"	3260	6.56	99.67	7.64	3.46
362	"	3503	7.05	100.05	8.99	4.07
363	"	3700	7.43	99.60	10.02	4.54
364	"	4024	8.09	99.05	11.49	5.20
365	"	4242	8.53	99.74	12.71	5.75
366	"	4504	9.06	99.54	14.09	6.75
367	"	4790	9.63	99.64	15.63	7.08
368	"	5097	10.25	100.30	17.25	7.81
369	"	5408	10.88	99.47	19.24	8.71
370	"	5705	11.47	100.40	21.22	9.61
371	"	6459	12.99	99.64	26.54	12.01
372	"	6870	13.82	99.82	29.44	13.33

COIL NO. 6

TABLE 15 $D_r = 7/8$ inch Fin Height = 1/8 inch

PRESSURE DROP WITH 100 AND 122°F WATER. COPPER LEADS AND MANOMETER

Run No.	Remarks	W_t, #/hr	Water Flow Rate, Gallons/min	t_w, °F	ΔZ, in. Hg.	$-\Delta P$, #/in^2
240	Pressure Drop	1204	2.42	99.45	0.70	0.32
241	"	1477	2.97	100.45	1.07	0.48
242	"	1732	3.48	100.06	1.43	0.65
243	"	1974	3.97	99.57	1.83	0.83
244	"	2340	4.71	99.66	2.48	1.12
245	"	2915	5.86	99.01	3.73	1.69
246	"	3523	7.09	99.77	5.37	2.41
247	"	4063	8.17	99.45	6.88	3.12
248	"	4649	9.35	99.77	8.89	4.02
249	"	5260	10.58	99.95	11.11	5.03
250	"	5725	11.51	100.02	13.03	5.90
251	"	6190	12.45	99.72	15.12	6.84
252	"	6623	13.32	99.93	17.00	7.69
253	"	7120	14.32	99.91	19.58	8.86
254	"	7469	15.02	100.02	—	9.65
255	"	7479	15.04	99.84	21.45	9.71
256	"	8114	16.32	99.46	24.87	11.26
257	"	8340	16.77	99.66	26.34	11.93
258	"	1317	2.66	121.26	0.87	0.39
259	"	2060	4.16	120.96	1.88	0.85
260	"	2703	5.46	121.96	3.14	1.42
261	"	3424	6.92	121.96	4.90	2.22
262	"	4070	8.23	121.01	6.73	3.05
263	"	4696	9.59	121.77	8.76	3.96
264	"	5169	10.45	120.92	10.54	4.77
265	"	5800	11.72	121.86	12.95	5.86
266	"	6280	12.69	121.33	14.95	6.77
267	"	6680	13.50	121.68	16.90	7.65
268	"	7070	14.29	121.66	18.64	8.44
269	"	7582	15.32	120.76	21.08	9.55
270	"	8155	16.48	121.10	24.16	10.94
271	"	8484	17.14	121.33	25.88	11.72

TABLE 16

STEEL LEAD PRESSURE DROP AT 100°F AND 122°F

Run No.	Water Flow Rate, #/hr	$-\Delta P$, $\#/in^2$	t_w, °F
411	5291	11.74	122.16
412	4911	10.18	121.98
413	4525	8.66	121.77
414	3727	5.85	122.23
415	2704	3.12	122.32
416	1941	1.63	121.89
417	1180	0.64	122.23
418	5035	10.85	100.02
419	4452	8.42	99.91
420	3538	5.29	99.99
421	2731	3.19	99.81
422	2013	1.72	100.09
423	920	0.41	99.91

TABLE 17

SUMMARY OF EXPERIMENTAL DATA FOR STRAIGHT TUBE NO. 1

Root Diameter 1/2 inch
Fin Height 1/8 inch
Nominal Inside Diameter 0.4395 inch

Length 19.69 ft.
Average Water Temp. 69.88 °F

Run Number	Average Water Temperature, °F	Water Flow Rate, #/hr.	$-\Delta P$, #/in^2	Reynold's Number, Re	Friction Factor, f	$-\Delta P$/100 ft of Tubing, #/in^2
90	76.94	37.70	0.0104	538.	0.113	0.053
91	75.27	99.85	0.0214	1426.	0.033	0.109
92	73.99	135.54	0.0349	1936.	0.029	0.177
93	73.06	176.95	0.0718	2528.	0.035	0.365
94	72.28	215.76	0.105	3082.	0.035	0.533
95	71.64	266.27	0.157	3804.	0.034	0.797
96	71.33	323.35	0.228	4619.	0.034	1.16
97	71.13	358.48	0.282	5121.	0.038	1.43
98	70.61	416.55	0.383	5951.	0.034	1.95
99	70.18	466.93	0.473	6671.	0.033	2.40
100	69.76	524.78	0.579	7497.	0.032	2.94
101	68.63	554.60	0.674	7923.	0.034	3.42
102	68.14	928.18	1.76	13260.	0.031	8.94
103	67.86	1241.4	3.20	17735.	0.032	16.2
104	67.62	1530.0	4.47	21859.	0.029	22.7
105	66.96	1852.8	6.31	26471.	0.028	32.0
106	67.75	2173.7	8.37	31055.	0.027	42.5
107	67.73	2322.0	9.89	33174.	0.028	50.2
108	67.48	2490.3	11.46	35579.	0.028	58.2
109	67.66	2686.6	13.42	38383.	0.029	68.2
110	67.33	3363.5	21.26	39594.	0.029	108.0
111	67.49	3810.9	27.02	54446.	0.029	137.2
112	67.46	4131.6	32.10	59028.	0.029	163.0
113	68.57	4505.1	38.00	64364.	0.029	193.0
114	68.95	4780.6	43.60	68300.	0.029	221.4
115	69.17	5074.0	48.30	72492.	0.029	245.3
116	69.55	5434.0	54.50	77636.	0.028	276.8
117	72.01	5819.0	61.70	83136.	0.028	313.4

TABLE 18

SUMMARY OF EXPERIMENTAL DATA FOR STRAIGHT TUBE NO. 2

Root Diameter 1/2 inch
Fin Height 3/16 inch
Nominal Inside Diameter 0.446 inch

Length 19.81 ft.
Average Water Temp. 68.21 °F

Run Number	Average Water Temperature, °F	Water Flow Rate, #/hr.	$-\Delta P$, $\#/in^2$	Reynold's Number, Re	Friction Factor, f	$-\Delta P$/100 ft of Tubing, $\#/in^2$
62	73.42	44.2	0.0092	666	0.078	0.046
63	71.70	93.4	0.0176	1374	0.034	0.089
64	70.38	150.0	0.0343	2174	0.025	0.173
65	69.52	200.2	0.0778	2862	0.032	0.393
66	68.99	219.6	0.105	3121	0.036	0.528
67	69.05	261.1	0.158	3714	0.038	0.798
68	68.56	302.0	0.212	4267	0.038	1.07
69	68.56	343.6	0.277	4858	0.039	1.40
70	68.57	391.3	0.362	5532	0.039	1.83
71	68.53	489.7	0.455	5931	0.043	2.30
72	68.34	505.2	0.591	7121	0.038	3.00
73	68.68	764.2	1.32	10821	0.037	6.65
74	68.41	985.7	1.94	13900	0.033	9.79
75	68.19	1205.6	3.26	16955	0.037	16.46
76	67.93	1423.3	4.64	19948	0.038	23.43
77	67.91	1676.7	6.35	23512	0.038	32.07
78	67.90	1890.8	8.18	26457	0.038	41.29
79	67.75	2073.7	9.88	28984	0.038	49.86
80	67.49	2238.8	11.55	31163	0.038	58.31
81	67.29	2400.0	13.51	33322	0.039	68.19
82	67.26	3145.8	23.57	43661	0.039	119.0
83	67.39	3566.7	31.30	49720	0.041	158.0
84	67.30	3904.6	39.50	54257	0.039	182.2
85	69.39	4093.4	56.50	58515	0.039	199.4
86	68.15	4861.9	51.29	68307	0.040	285.2
87	67.75	4618.5	46.79	64546	0.040	258.9
88	67.70	4362.1	40.29	60934	0.041	236.2
89	67.90	4154.7	36.09	58158	0.039	203.4

TABLE 19

SUMMARY OF EXPERIMENTAL DATA FOR STRAIGHT TUBE NO. 3

Root Diameter 5/8 inch
Fin Height 1/8 inch
Nominal Inside Diameter 0.5625 inch

Length 19.79 ft.
Average Water Temp. 68.45 °F

Run Number	Average Water Temperature, °F	Water Flow Rate, #/hr.	-ΔP, #/in²	Reynold's Number, Re	Friction Factor, f	-ΔP/100 ft of Tubing, #/in²
35	69.81	195.8	0.016	2236	0.022	0.081
36	68.44	317.1	0.065	3556	0.034	0.328
37	68.11	404.2	0.101	4514	0.033	0.510
38	68.45	486.2	0.147	5452	0.033	0.743
39	68.51	557.3	0.190	6252	0.033	0.960
40	68.53	620.0	0.246	6973	0.034	1.243
41	68.33	717.8	0.314	8050	0.032	1.587
42	68.28	798.9	0.375	8951	0.031	1.895
43	68.14	927.8	0.490	10379	0.030	2.476
44	69.99	1377.0	1.01	15796	0.028	5.103
45	69.54	1839.0	1.76	20979	0.028	8.893
46	69.41	2293.0	2.69	26109	0.027	13.59
47	69.47	2659.0	3.56	30306	0.027	17.99
48	69.29	3172.0	5.02	36067	0.026	25.37
49	69.30	3582.0	6.40	40720	0.026	32.34
50	69.25	3946.0	7.71	44840	0.026	38.95
51	69.30	4293.0	9.10	48806	0.026	45.98
52	69.38	4589.0	10.46	52241	0.026	52.85
53	69.25	4870.0	11.82	55340	0.026	59.72
54	69.39	5094.0	12.83	57980	0.026	64.83
55	67.09	6771.0	23.81	74633	0.027	120.3
56	66.58	6605.0	22.56	72275	0.027	114.0
57	66.80	7178.0	26.15	78796	0.027	132.1
58	66.49	7291.0	27.68	79884	0.028	139.8
59	66.31	7931.0	31.27	86471	0.026	158.0
60	66.75	8490.0	35.47	93167	0.026	179.2
61	67.77	8831.0	37.78	98254	0.026	190.9

TABLE 20

SUMMARY OF EXPERIMENTAL DATA FOR STRAIGHT TUBE NO. 4

Root Diameter 5/8 inch
Fin Height 3/16 inch
Nominal Inside Diameter 0.546 inch

Length 19.77 ft.
Average Water Temp. 68.00 °F

Run Number	Average Water Temperature, °F	Water Flow Rate, #/hr.	$-\Delta P$, #/in^2	Reynold's Number, Re	Friction Factor, f	$-\Delta P$/100 ft of Tubing, #/in^2
118	71.94	74.8	0.0057	909	0.047	0.029
119	70.21	247.3	0.0246	2937	0.018	0.124
120	69.85	287.4	0.0486	3396	0.027	0.246
121	69.62	358.8	0.0811	4226	0.029	0.410
122	69.39	432.6	0.118	5078	0.029	0.598
123	69.06	517.2	0.168	6048	0.029	0.850
124	68.92	600.2	0.229	6998	0.029	1.159
125	67.87	688.3	0.288	7910	0.028	1.456
126	67.64	778.1	0.366	8577	0.028	1.854
127	67.42	867.9	0.452	9914	0.027	2.284
128	67.35	949.2	0.535	10828	0.027	2.707
129	66.97	1285.1	0.934	14583	0.026	4.722
130	66.74	1826.4	1.85	20659	0.025	9.372
131	66.81	2219.5	2.74	25130	0.025	13.84
132	66.94	2713.6	4.07	30779	0.025	20.56
133	66.81	3132.5	5.40	35846	0.025	27.32
134	66.90	3656.1	7.42	41450	0.025	37.51
135	66.99	4085.6	9.28	46382	0.023	46.92
136	66.90	4486.0	11.22	50865	0.025	56.75
137	67.05	4796.8	12.92	54497	0.026	65.35
138	67.06	5166.9	14.71	58700	0.025	74.40
139	67.12	5830.0	19.14	66322	0.026	96.81
141	68.52	6832.2	26.10	79224	0.026	132.0
142	67.75	7312.5	30.00	83898	0.026	151.7
143	68.13	7819.5	34.50	90197	0.026	174.5

TABLE 21

SUMMARY OF EXPERIMENTAL DATA FOR STRAIGHT TUBE NO. 5

Root Diameter 3/4 inch
Fin Height 1/8 inch
Nominal Inside Diameter 0.672

Length 19.85 ft.
Average Water Temp. 68.07 °F

Run Number	Average Water Temperature, °F	Water Flow Rate, #/hr.	-ΔP, #/in²	Reynold's Number, Re	Friction Factor, f	-ΔP/100 ft of tubing, #/in²
144	71.19	189.6	0.0097	1846	0.035	0.049
145	70.61	341.3	0.033	3299	0.036	0.166
146	69.58	461.2	0.056	4395	0.034	0.284
147	69.22	598.6	0.096	5679	0.034	0.484
148	68.97	812.6	0.166	7691	0.032	0.837
149	68.38	953.2	0.226	8948	0.032	1.13
150	68.34	1160.2	0.312	10881	0.030	1.57
151	67.75	1299.6	0.383	12096	0.029	1.93
152	67.68	1434.3	0.460	13334	0.029	2.31
153	67.66	1588.0	0.550	14758	0.028	2.75
154	67.82	1354.6	0.402	12616	0.028	2.02
155	67.66	2214.0	0.974	20585	0.025	4.91
156	67.51	3046.7	1.76	28264	0.024	8.87
157	67.39	3862.7	2.71	35749	0.023	13.6
158	67.28	4812.8	4.00	44500	0.022	20.1
159	67.33	5663.9	5.38	52383	0.021	27.1
160	66.67	6275.4	6.51	57545	0.021	32.8
161	66.87	6896.5	7.75	63435	0.021	39.0
162	67.19	7377.0	8.87	68094	0.021	44.7
163	66.67	7923.7	10.0	72678	0.020	50.4
164	67.32	8238.0	10.8	76202	0.020	54.3
165	68.38	9382.0	13.5	88068	0.019	68.2

TABLE 22

SUMMARY OF EXPERIMENTAL DATA FOR STRAIGHT TUBE NO. 6

Root Diameter 7/8 inch
Fin Height 1/8 inch
Nominal Inside Diameter 0.7804 inch

Length 19.79 feet
Average Water Temps. 68.40°F and 99.69°F

Run Number	Average Water Temperature, °F	Water Flow Rate, #/hr.	-ΔP, #/in^2	Reynolds Number, Re	Friction Factor, f	-ΔP/100 ft of tubing #/in^2
166	70.77	159.2	0.0059	1329	0.063	0.030
167	69.44	353.9	0.014	2898	0.032	0.071
168	69.06	487.3	0.035	3974	0.040	0.179
169	68.67	755.2	0.069	6128	0.033	0.349
170	68.58	885.8	0.092	7176	0.032	0.465
180	68.49	1051.1	0.124	8508	0.030	0.626
181	68.38	1249.5	0.170	10102	0.030	0.859
182	68.18	1424.6	0.214	11481	0.029	1.08
183	68.09	1574.9	0.253	12675	0.028	1.28
184	68.27	1763.3	0.320	14225	0.027	1.62
185	68.16	1970.3	0.380	15871	0.027	1.92
186	67.87	2160.0	0.447	17324	0.026	2.26
187	67.87	2344.7	0.514	18808	0.025	2.59
188	67.91	2478.2	0.566	19906	0.025	2.86
189	67.91	2588.7	0.615	20788	0.025	3.11
190	68.14	3227.5	0.901	26000	0.024	4.55
191	68.05	4681.4	1.78	37671	0.022	8.99
192	67.93	5825.5	2.63	46785	0.021	13.28
193	67.96	6886.0	3.59	55328	0.021	18.14
194	67.75	7831.8	4.51	62763	0.021	22.79
195	67.32	8619.3	5.40	68681	0.020	27.29
196	69.37	9457.1	6.32	77407	0.020	31.93
197	68.99	10388.0	7.51	84638	0.019	37.95
229	99.70	2017.2	0.38	23887	0.025	1.92
230	99.64	3134.1	0.86	37057	0.024	4.35
231	99.50	4752.5	1.70	56134	0.020	8.59
232	98.40	5909.4	2.52	69380	0.019	12.73
233	100.33	6691.4	3.29	79753	0.020	16.62
234	99.90	7552.4	4.00	89587	0.019	20.21
235	100.04	8366.4	4.74	99358	0.018	23.95
236	98.96	9071.0	5.59	106632	0.018	28.25
237	100.04	9836.0	6.48	1168105	0.018	32.74
238	100.11	5376.3	2.14	63968	0.020	10.81
239	99.95	4147.5	1.33	49227	0.021	6.72

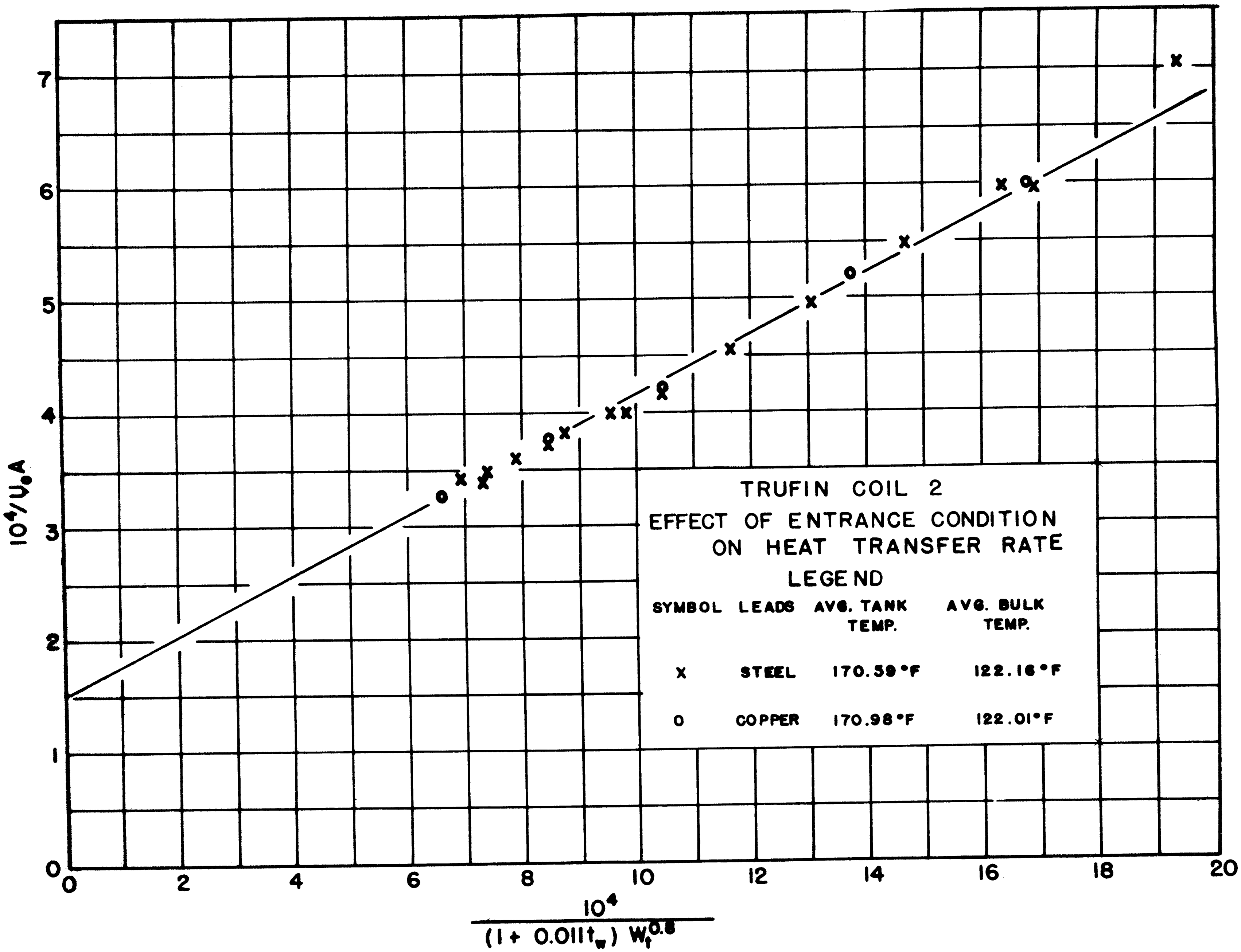

FIG. 9 . WILSON PLOT OF COIL 2

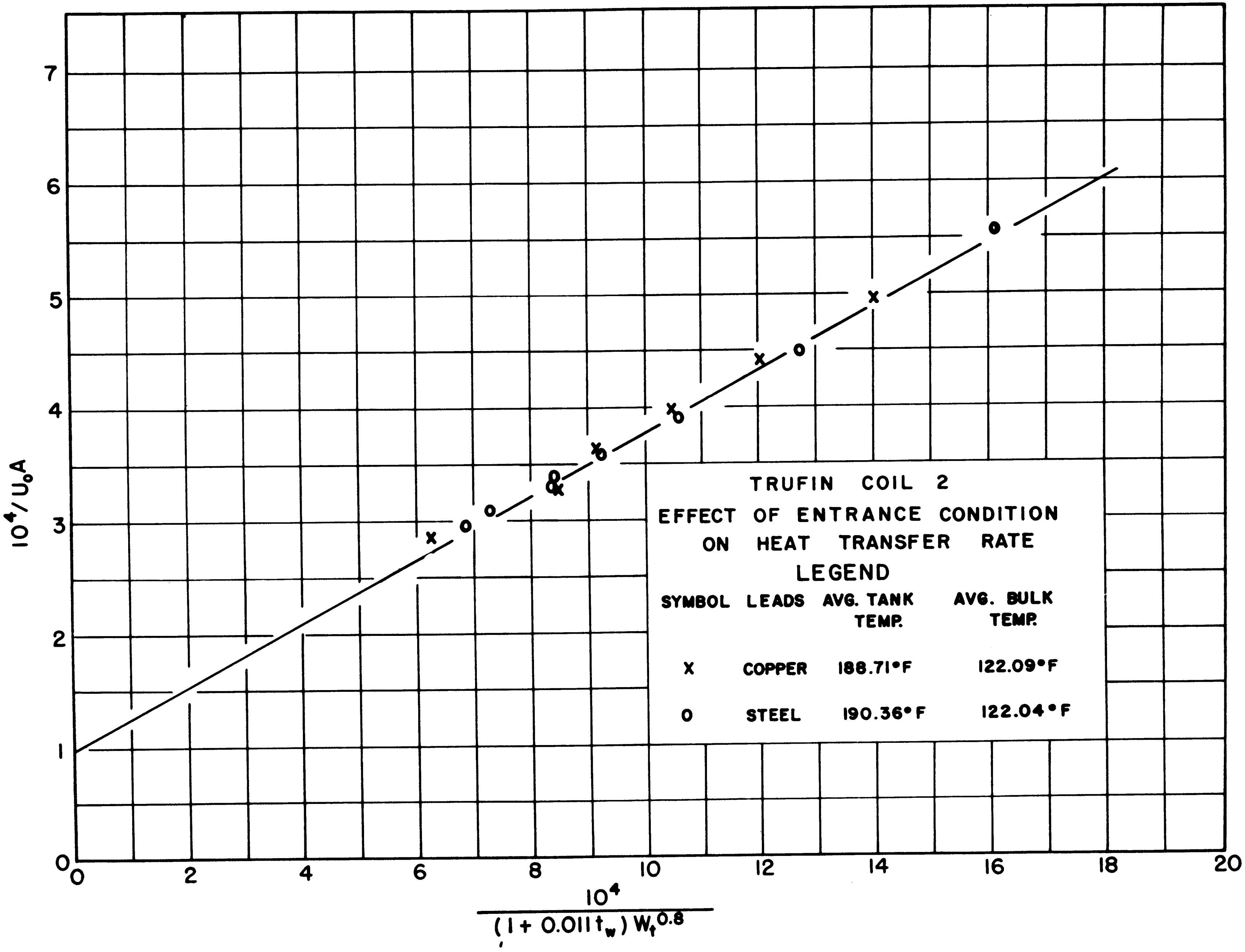

FIG. 10. WILSON PLOT OF COIL 2

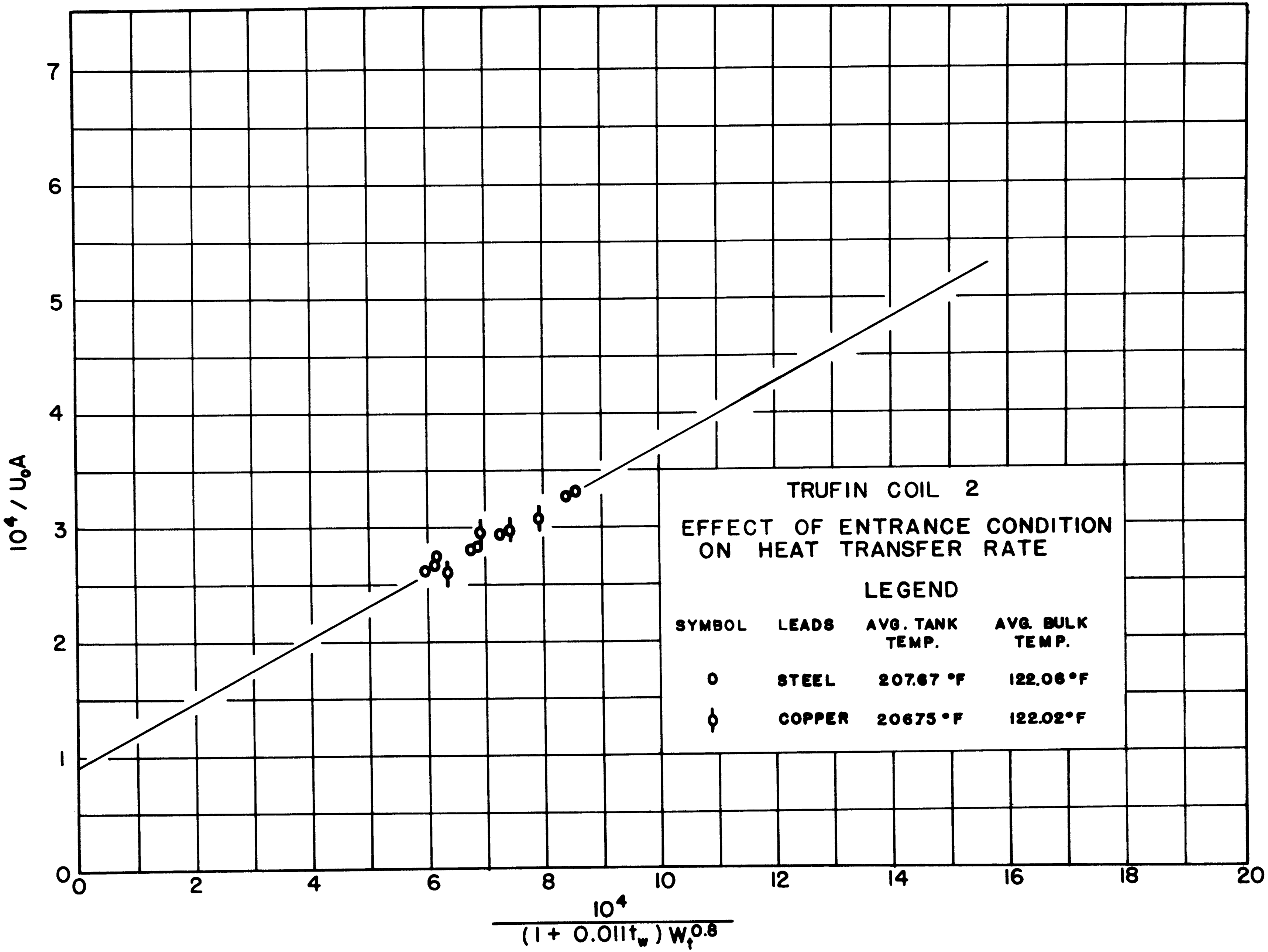

FIG. 11 . WILSON PLOT OF COIL 2

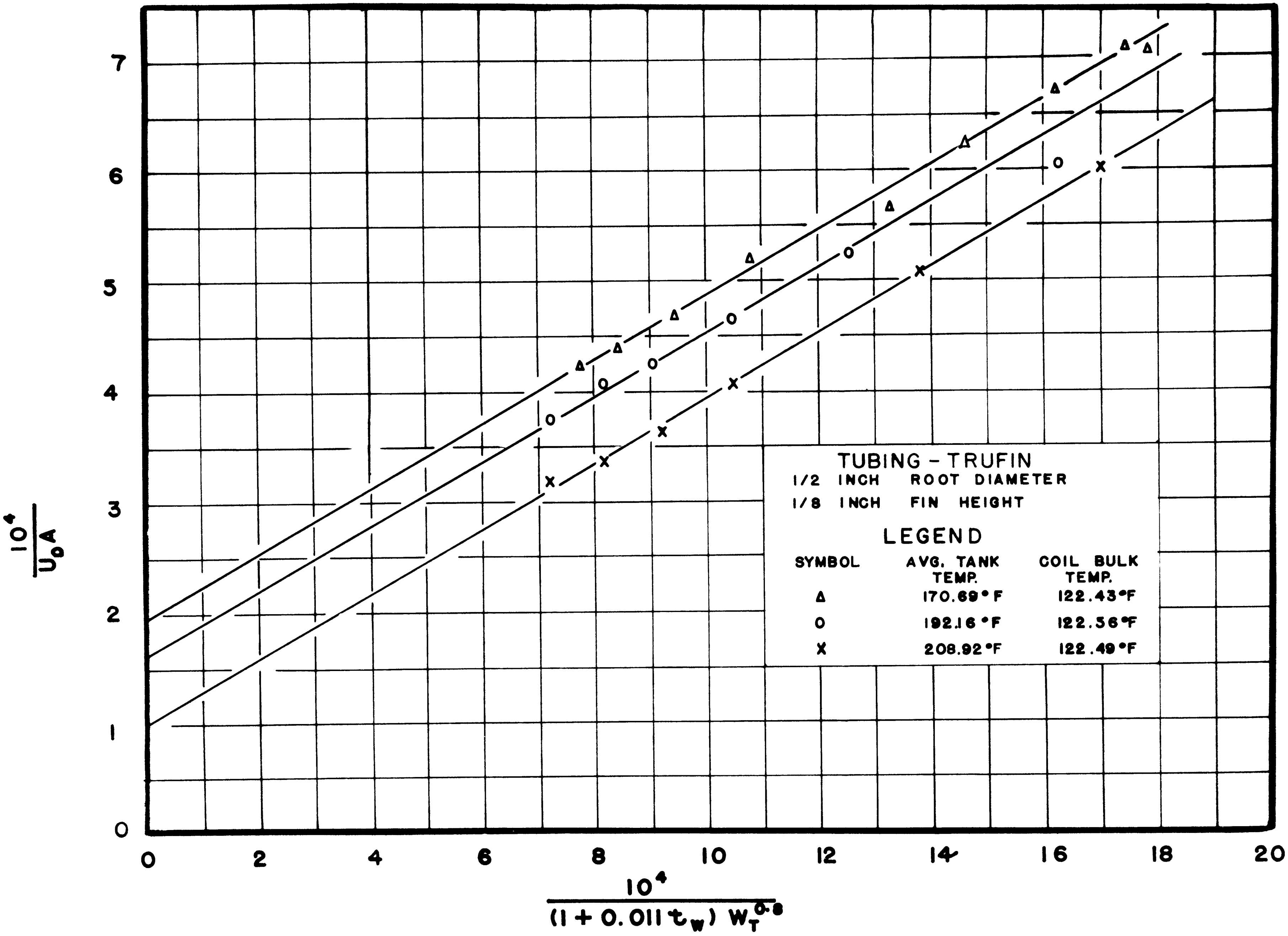

FIG. 12 . WILSON PLOT OF COIL 1

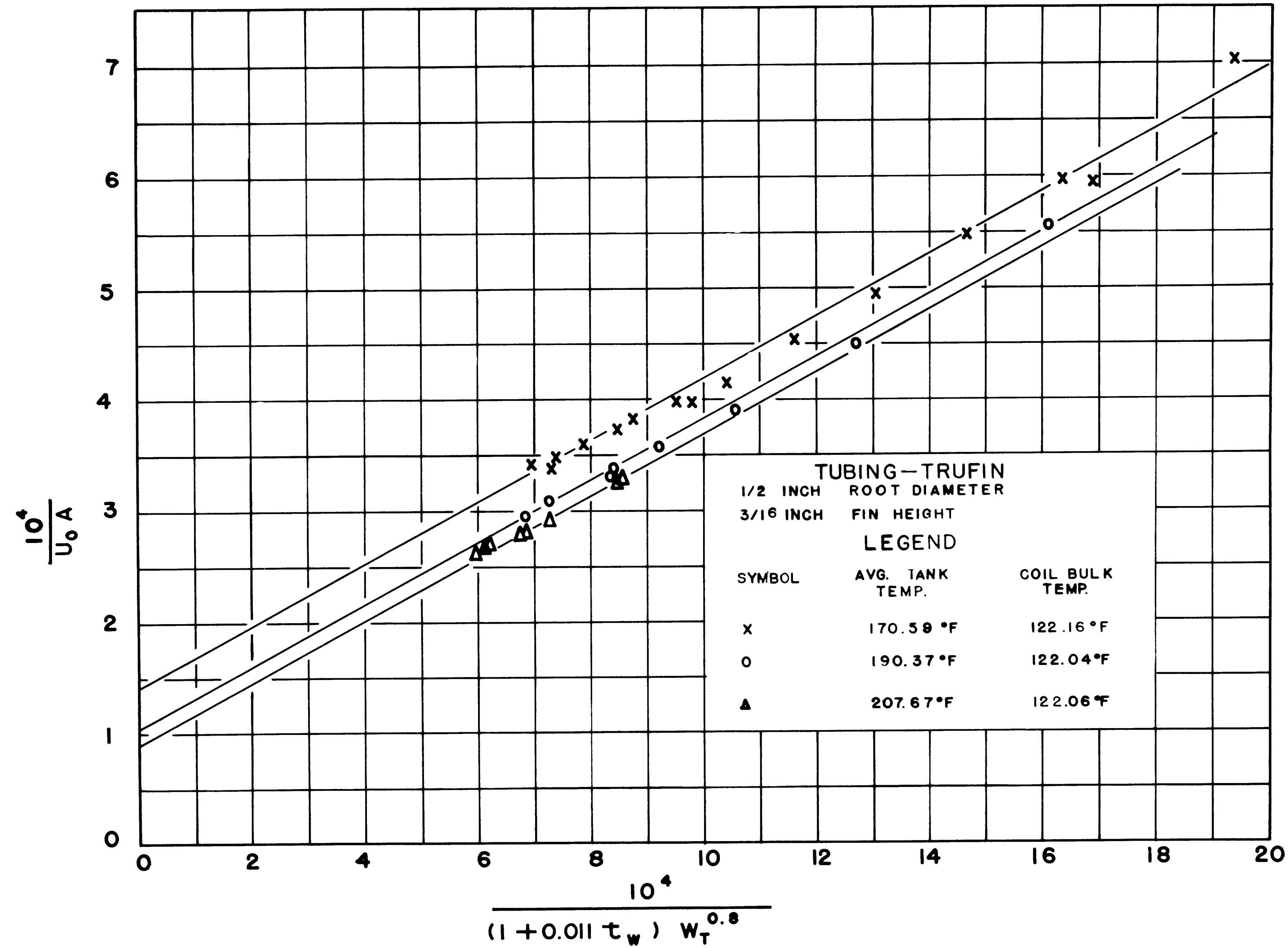

FIG.13. WILSON PLOT OF COIL 2

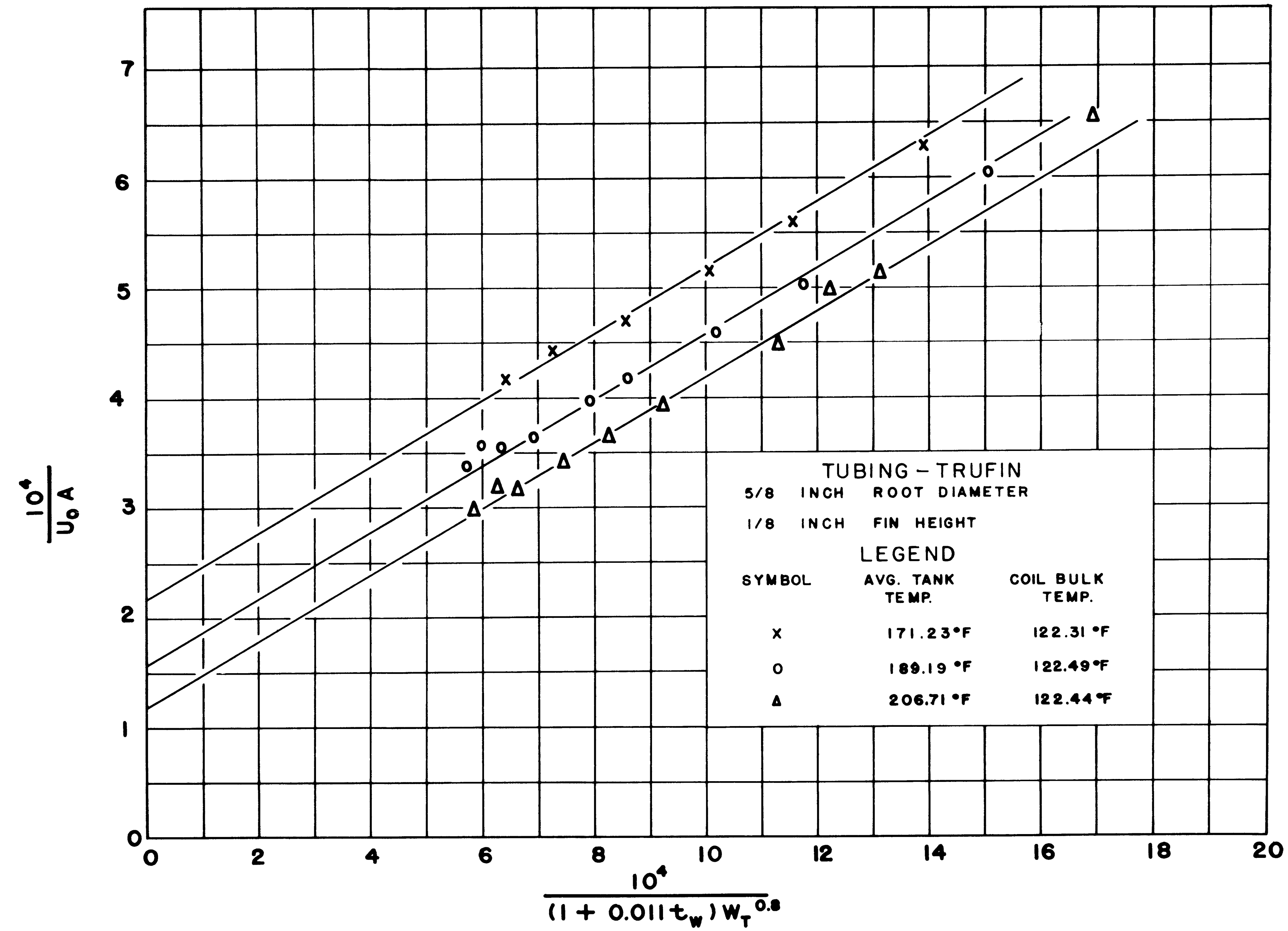

FIG.14. WILSON PLOT OF COIL 3

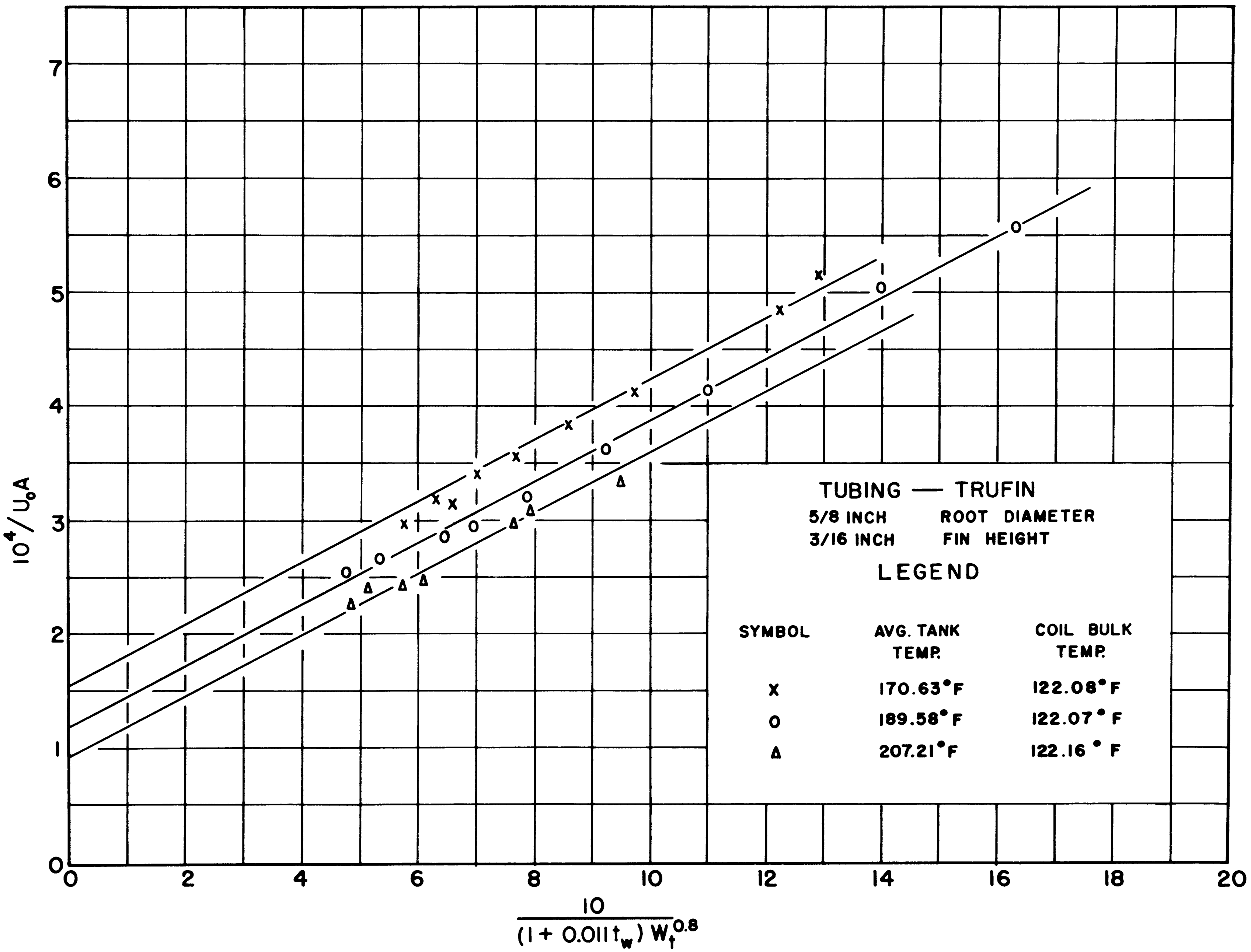

FIG. 15 . WILSON PLOT OF COIL 4

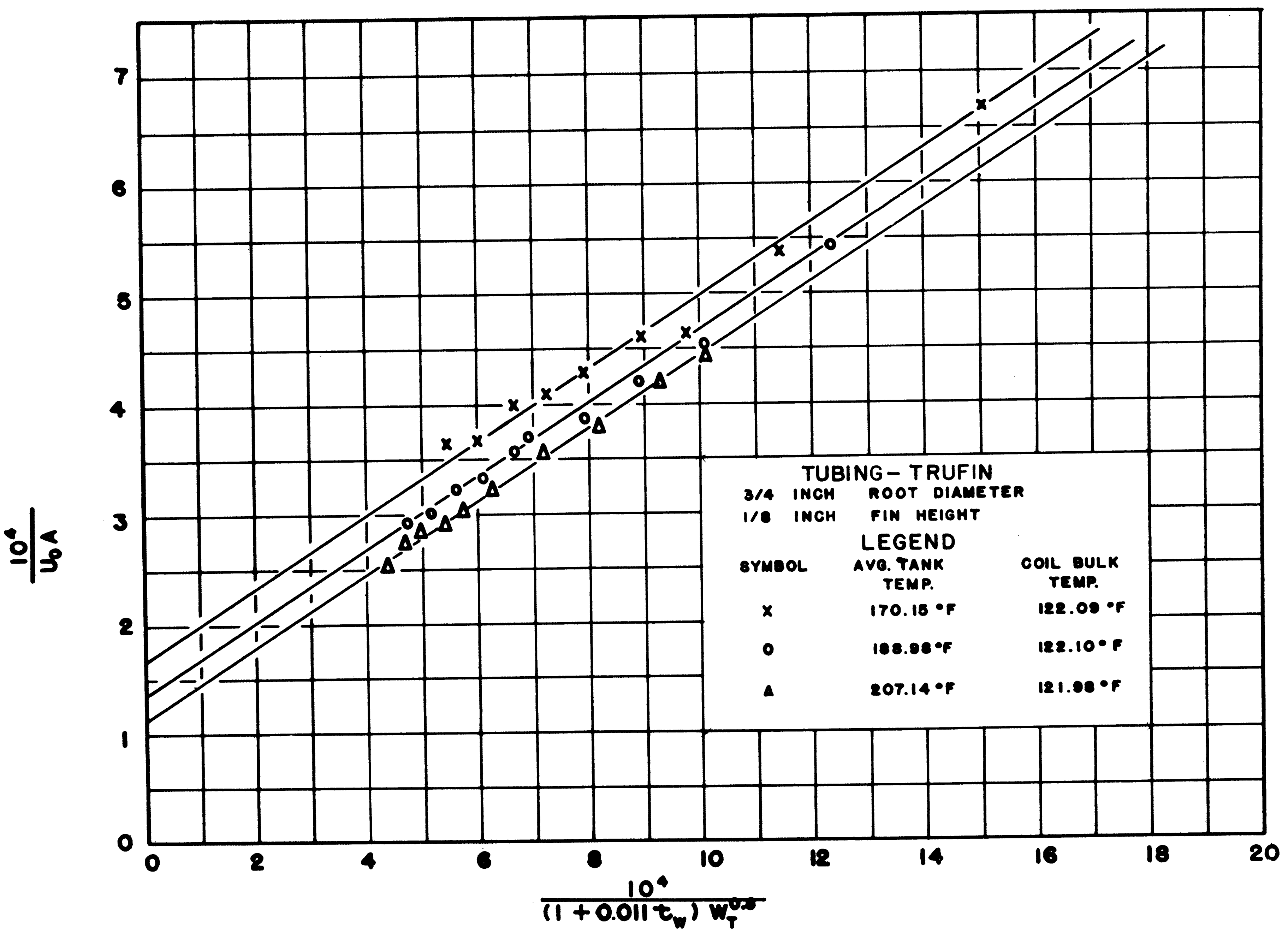

FIG. 16. WILSON PLOT OF COIL 5

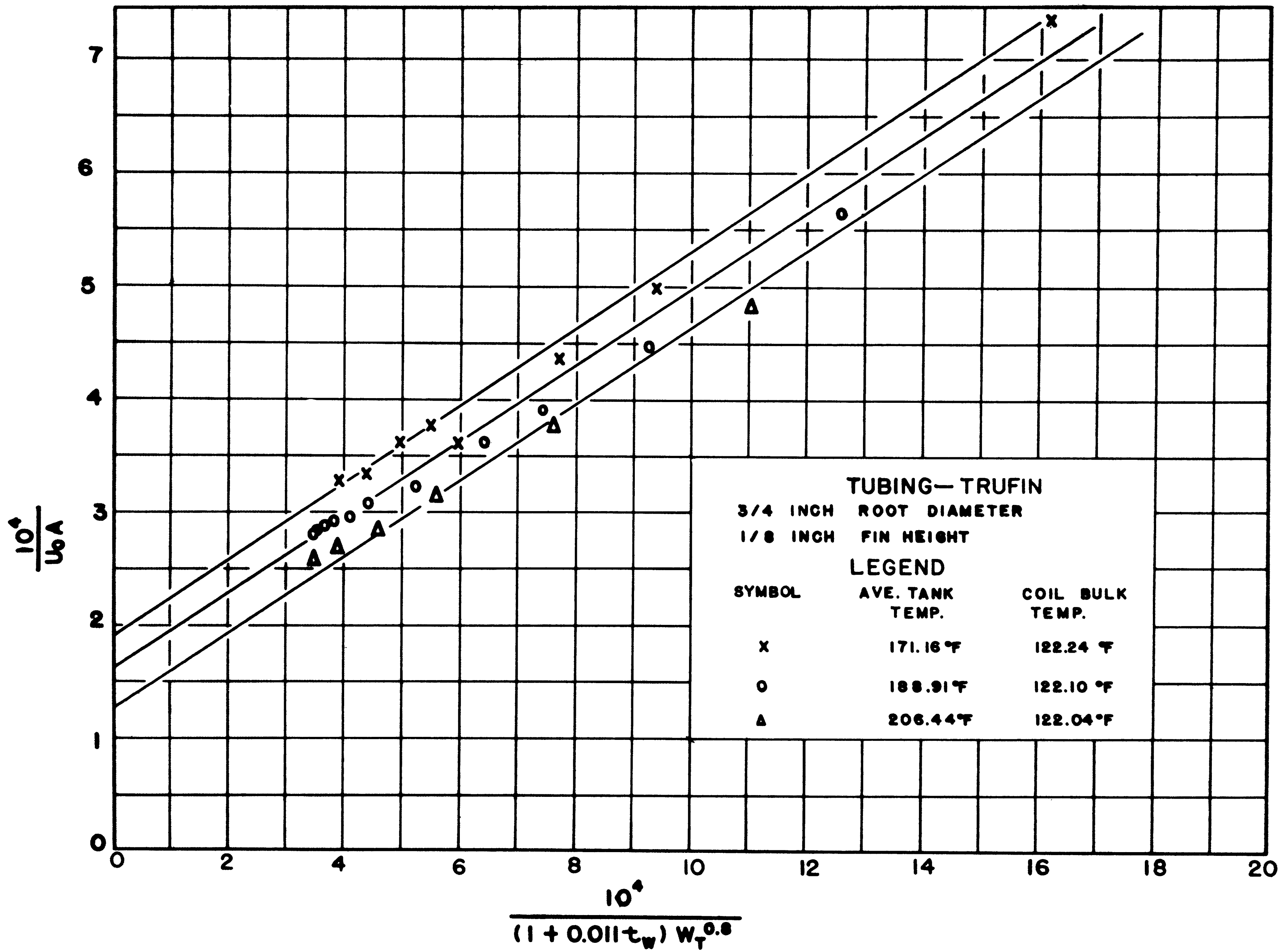

FIG. 17 . WILSON PLOT OF COIL 5 A

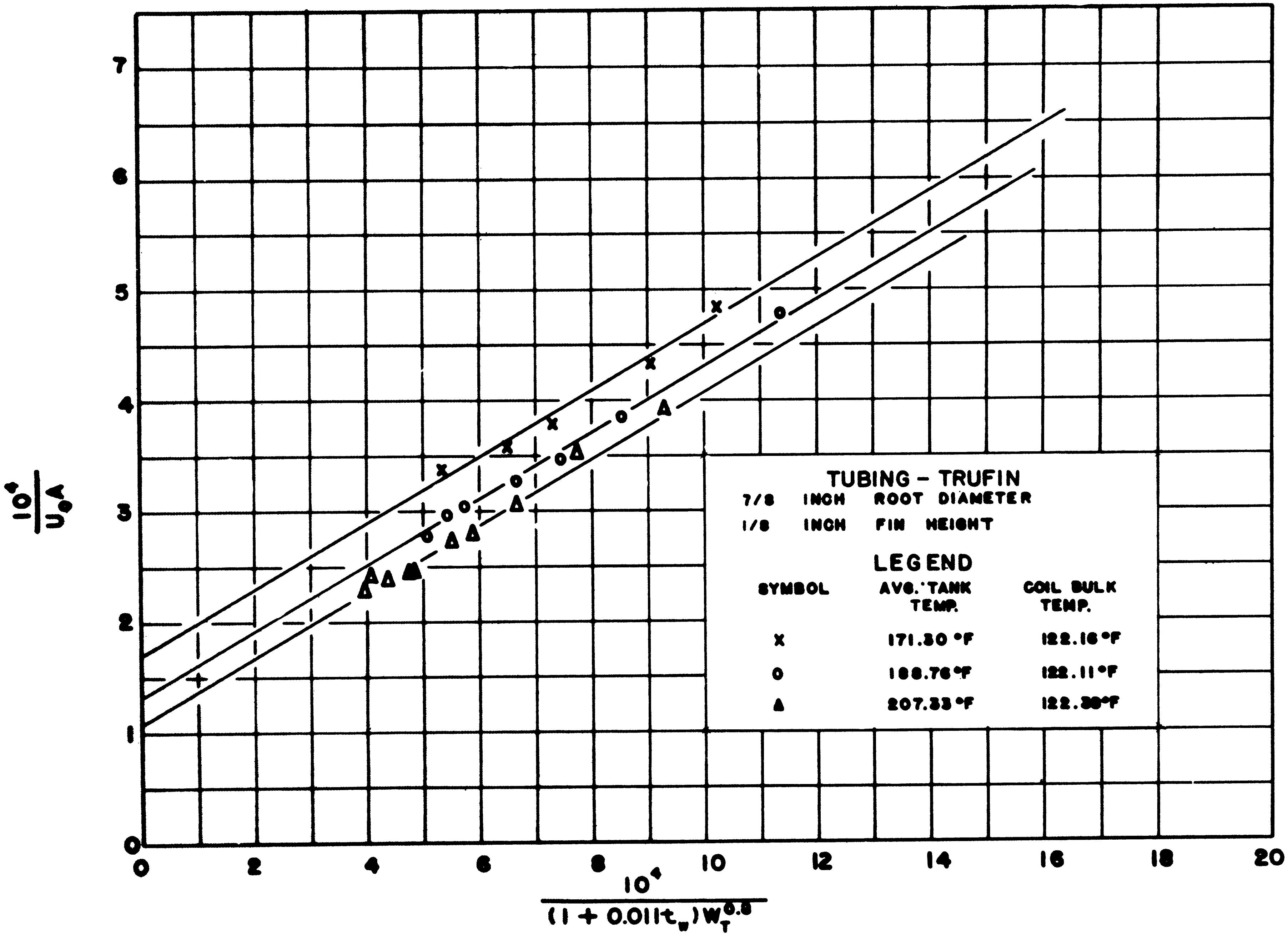

FIG. 18 . WILSON PLOT OF COIL 6

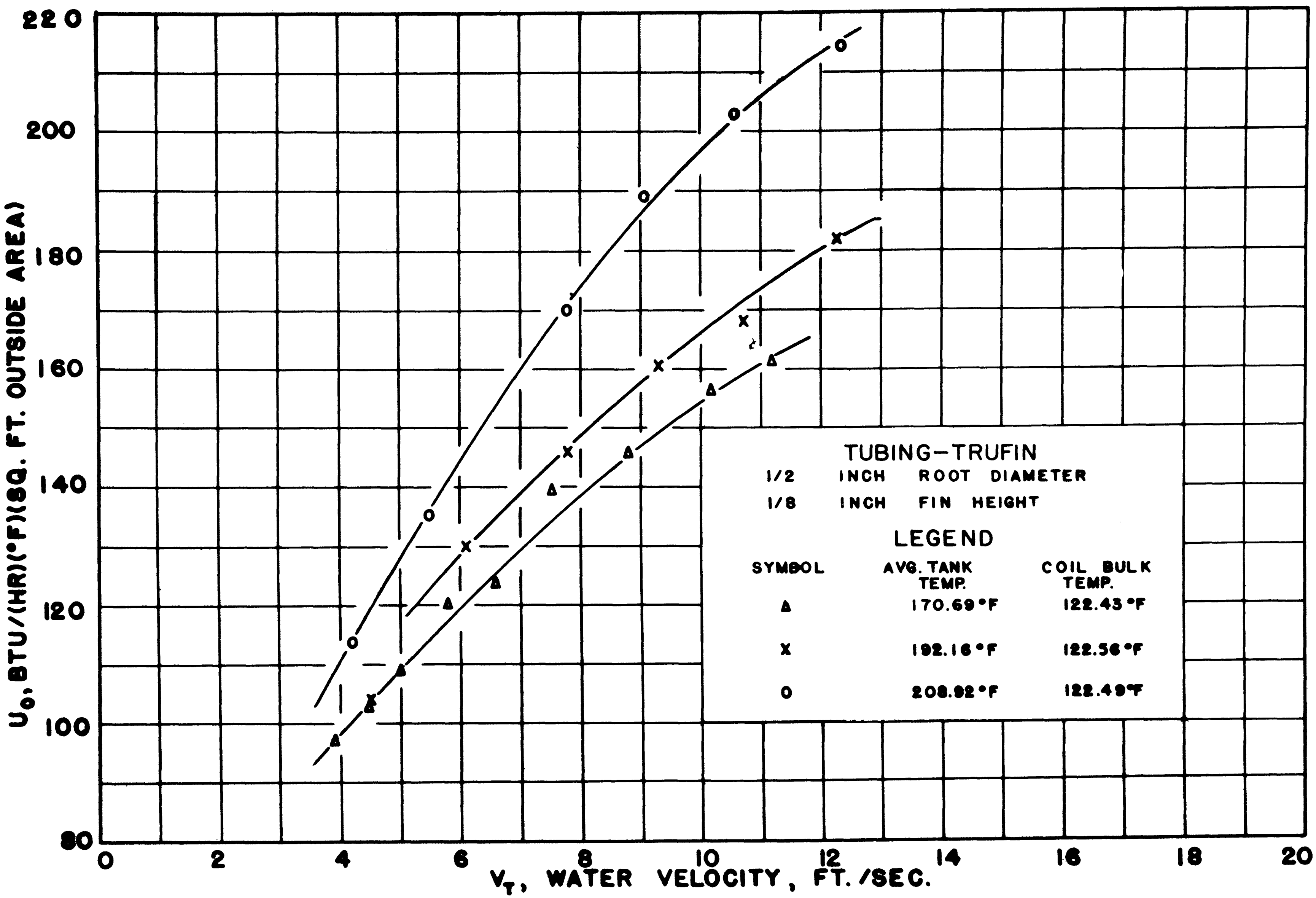

FIG. 20. VARIATION OF OVERALL COEFFICIENT WITH WATER VELOCITY INSIDE COIL 1

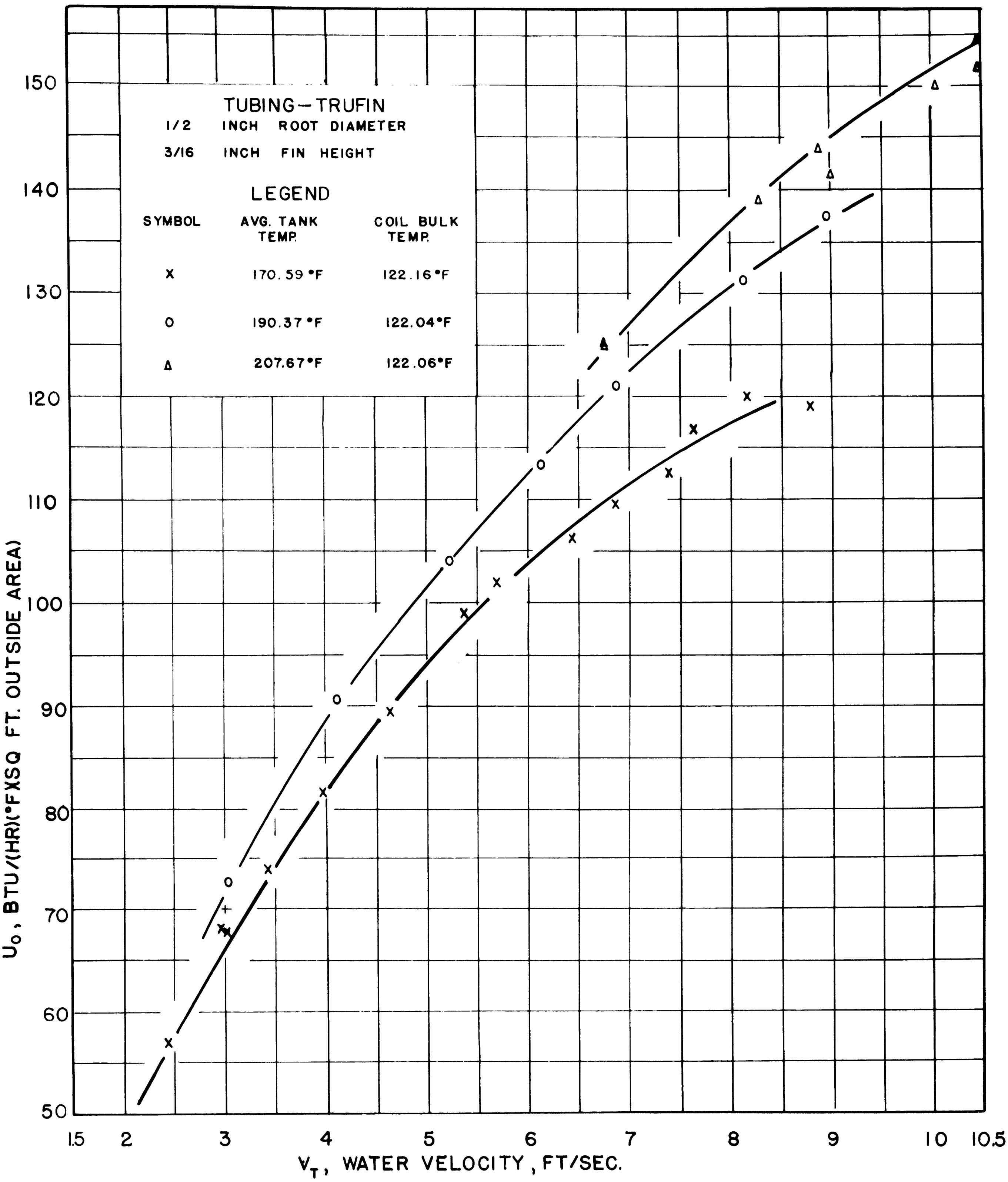

FIG. 21 . VARIATION OF OVERALL COEFFICIENT WITH WATER VELOCITY INSIDE COIL 2

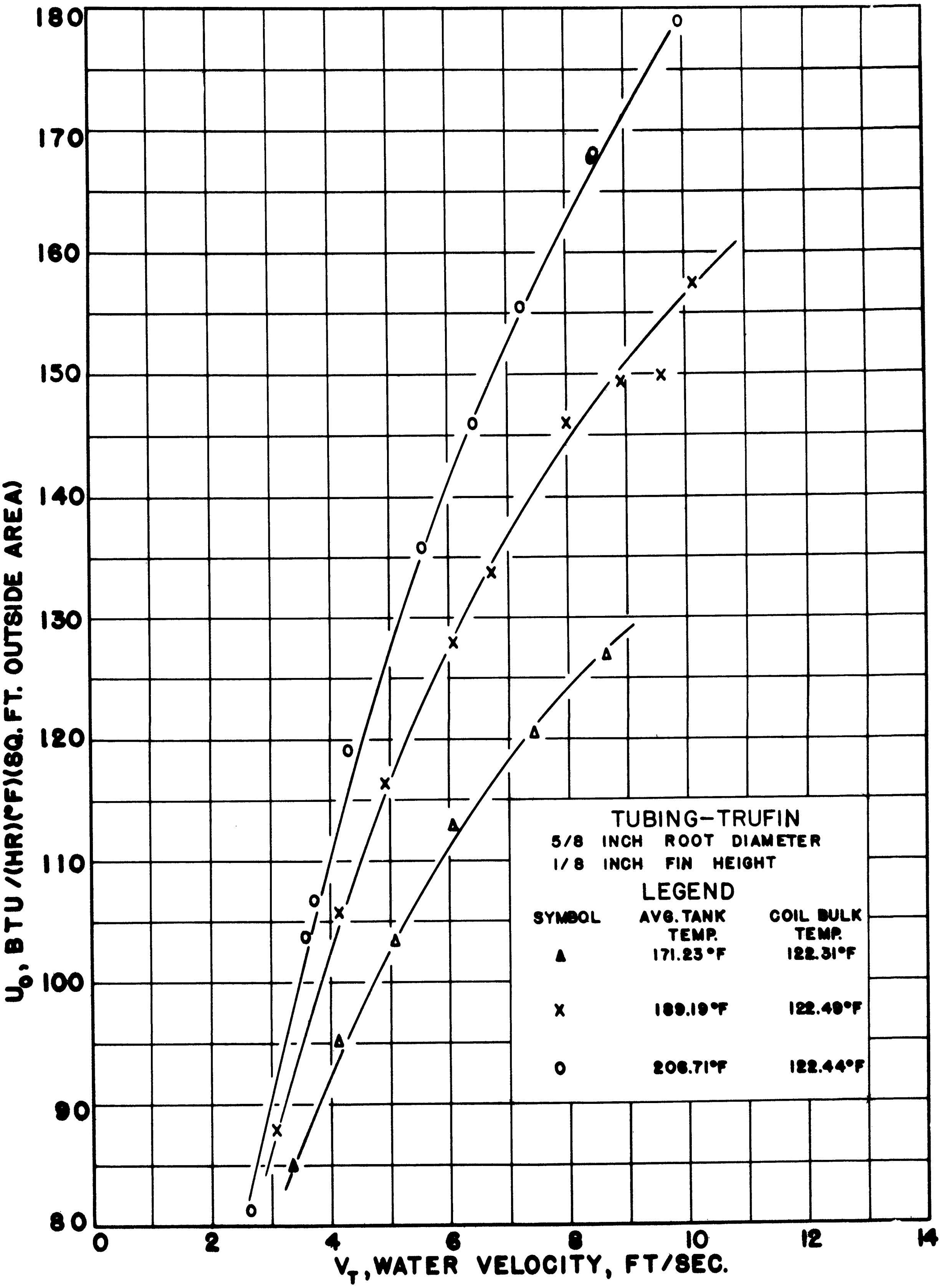

FIG.22. VARIATION OF OVERALL COEFFICIENT WITH WATER VELOCITY INSIDE COIL 3

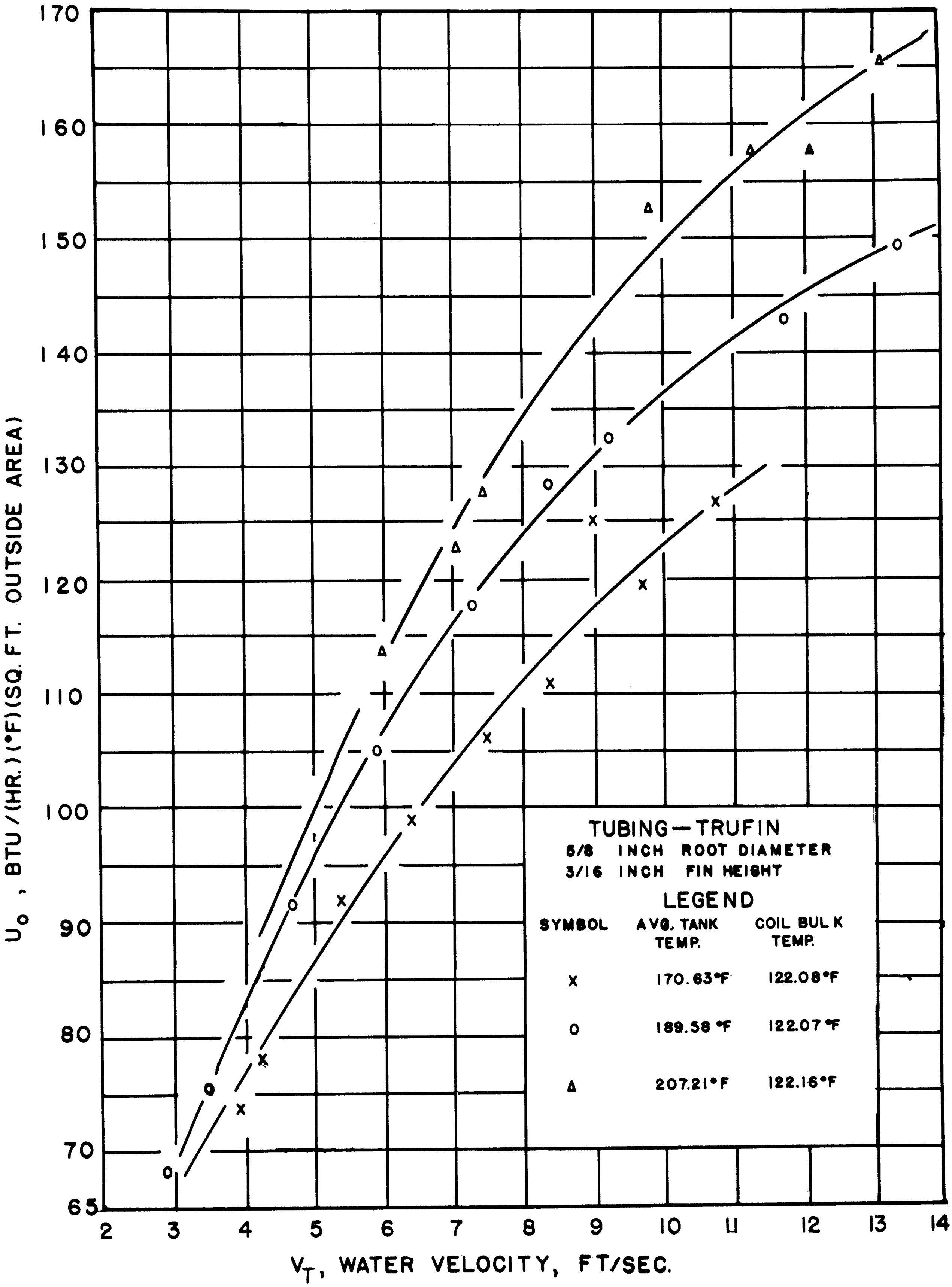

FIG.23. VARIATION OF OVERALL COEFFICIENT WITH WATER VELOCITY INSIDE COIL 4

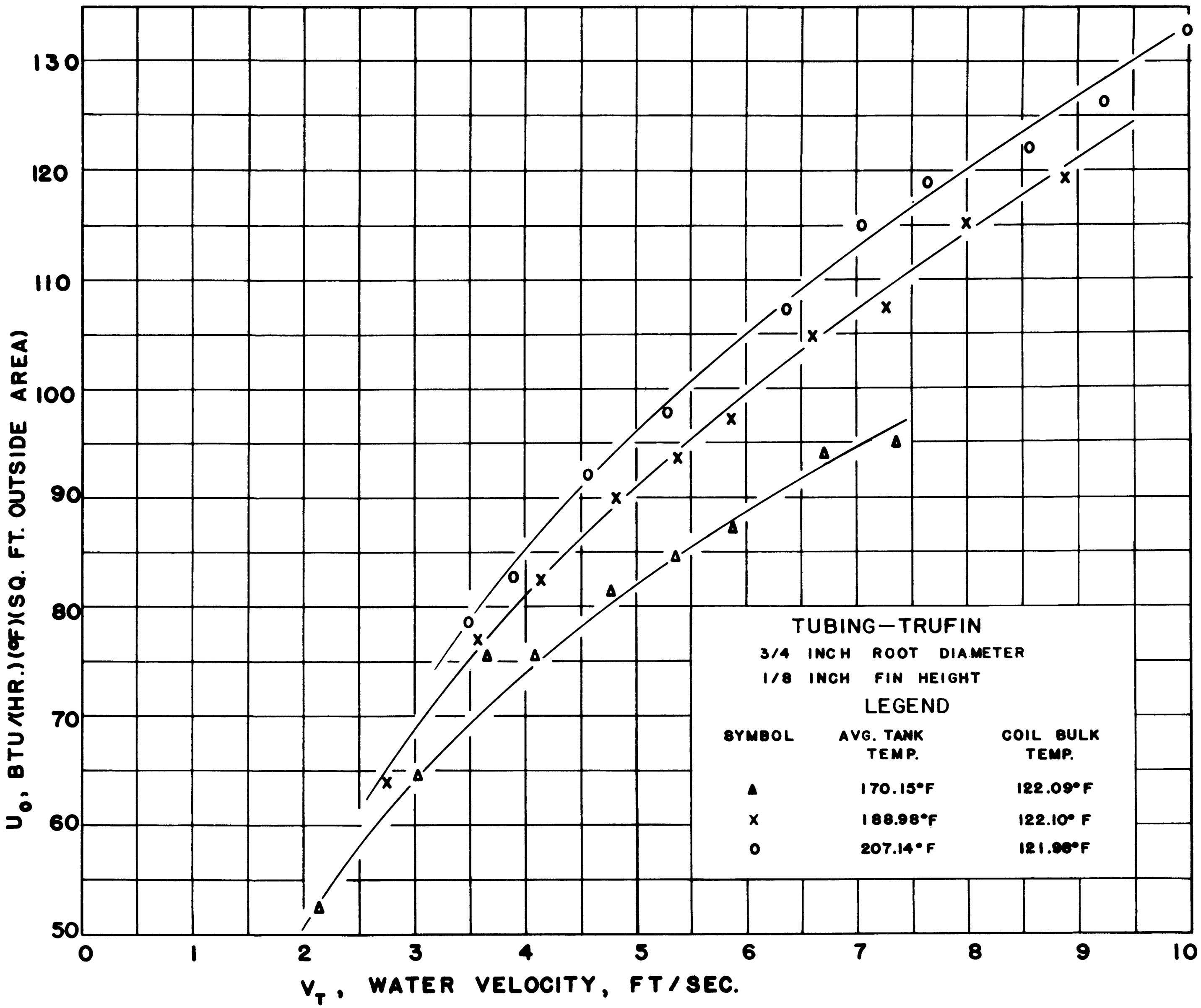

FIG. 24 . VARIATION OF OVERALL COEFFICIENT WITH WATER VELOCITY INSIDE COIL 5

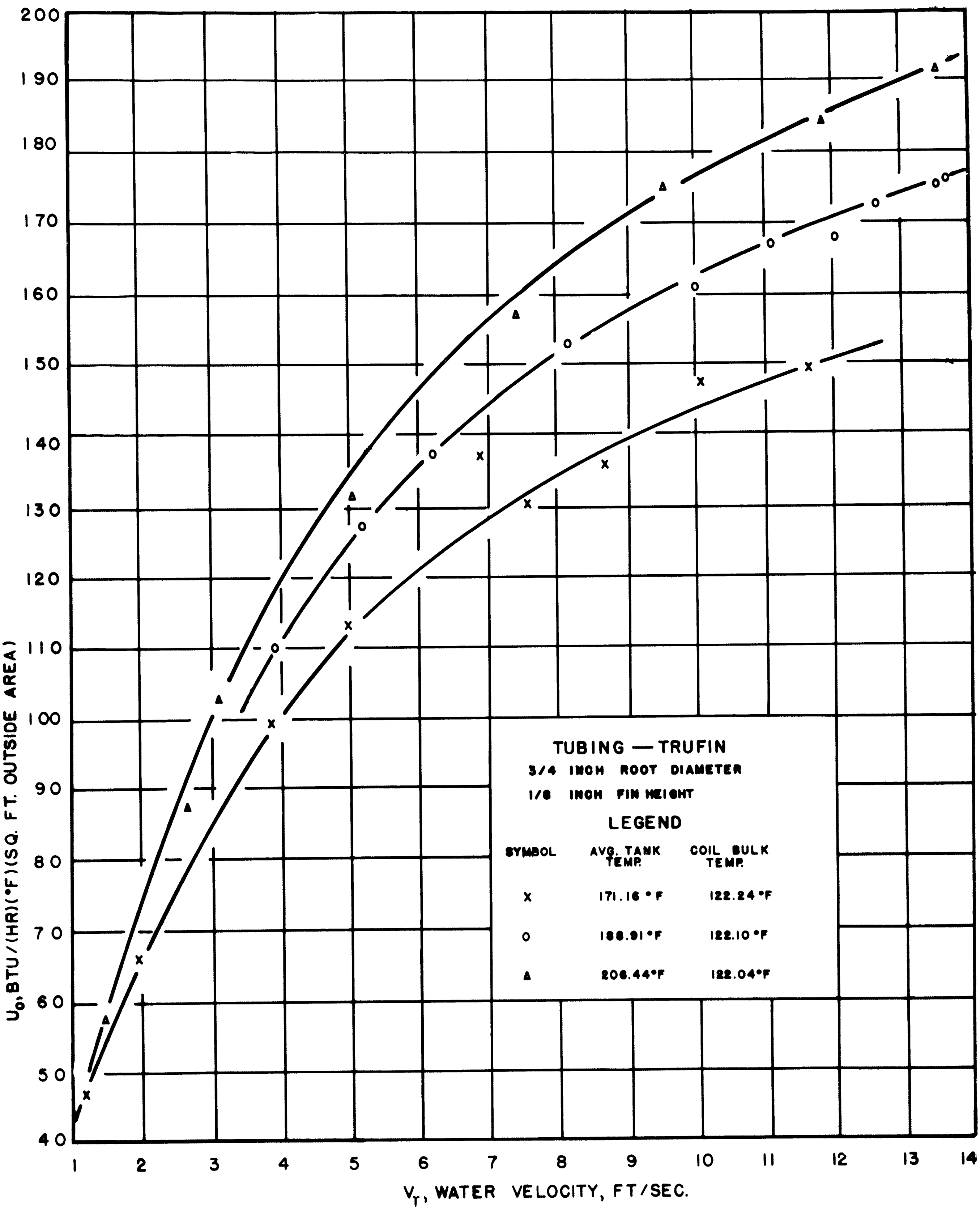

FIG25. VARIATION OF OVERALL COEFFICIENT WITH WATER VELOCITY INSIDE COIL 5A

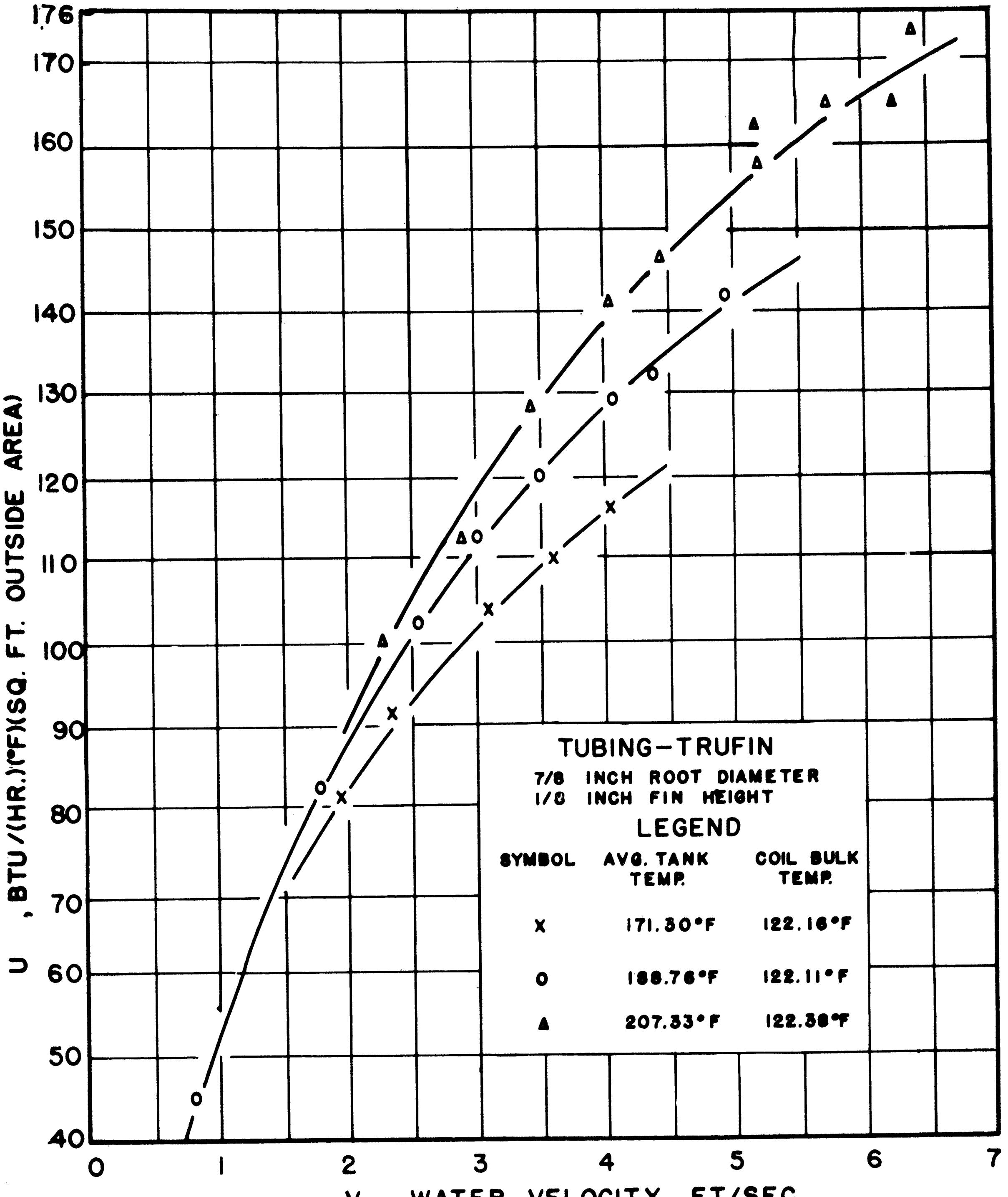

FIG.26 VARIATION OF OVERALL COEFFICIENT WITH WATER VELOCITY INSIDE COIL 6

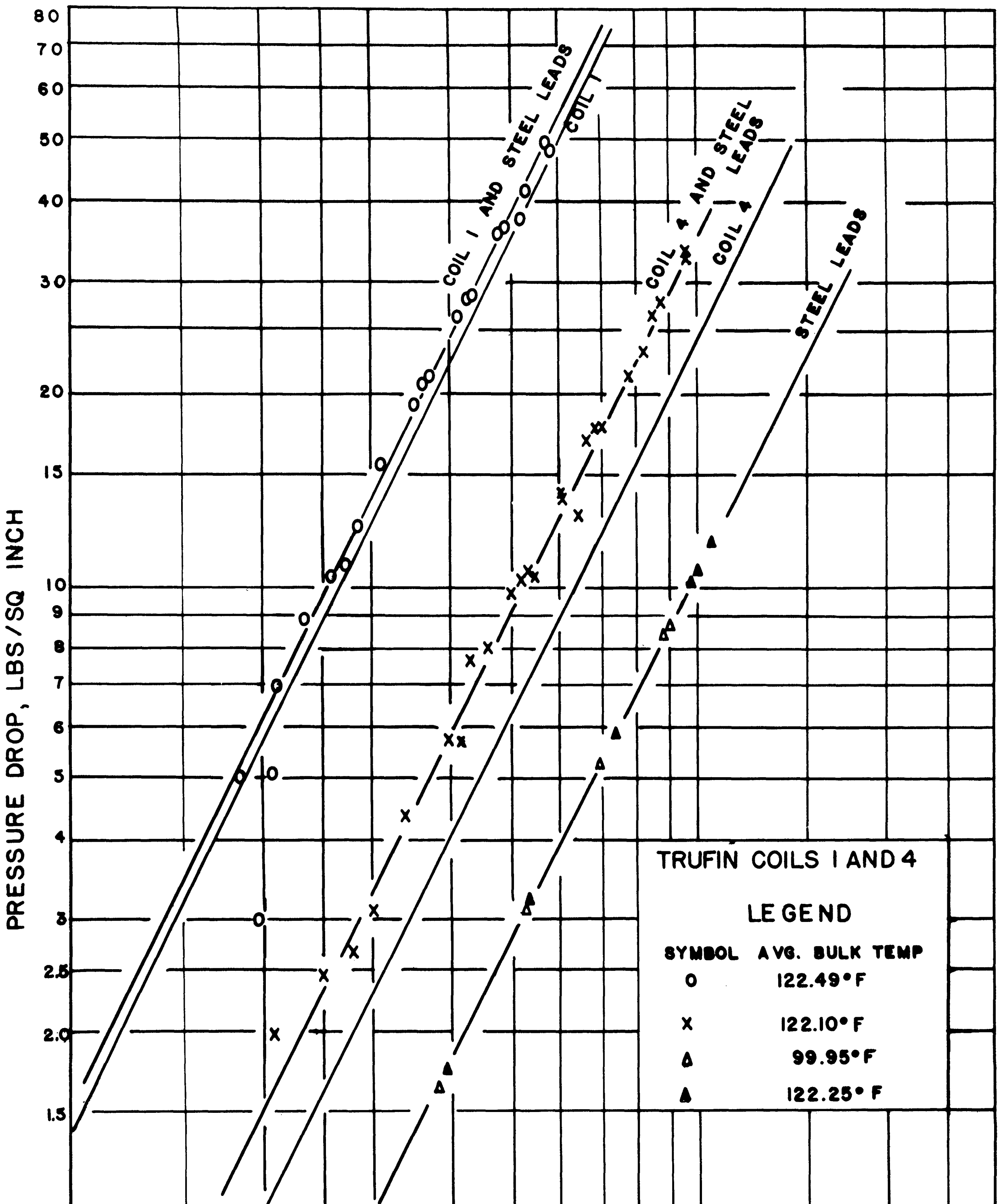

FIG.27. VARIATION OF PRESSURE DROP WITH WATER FLOW RATE INSIDE COILS 1 AND 4

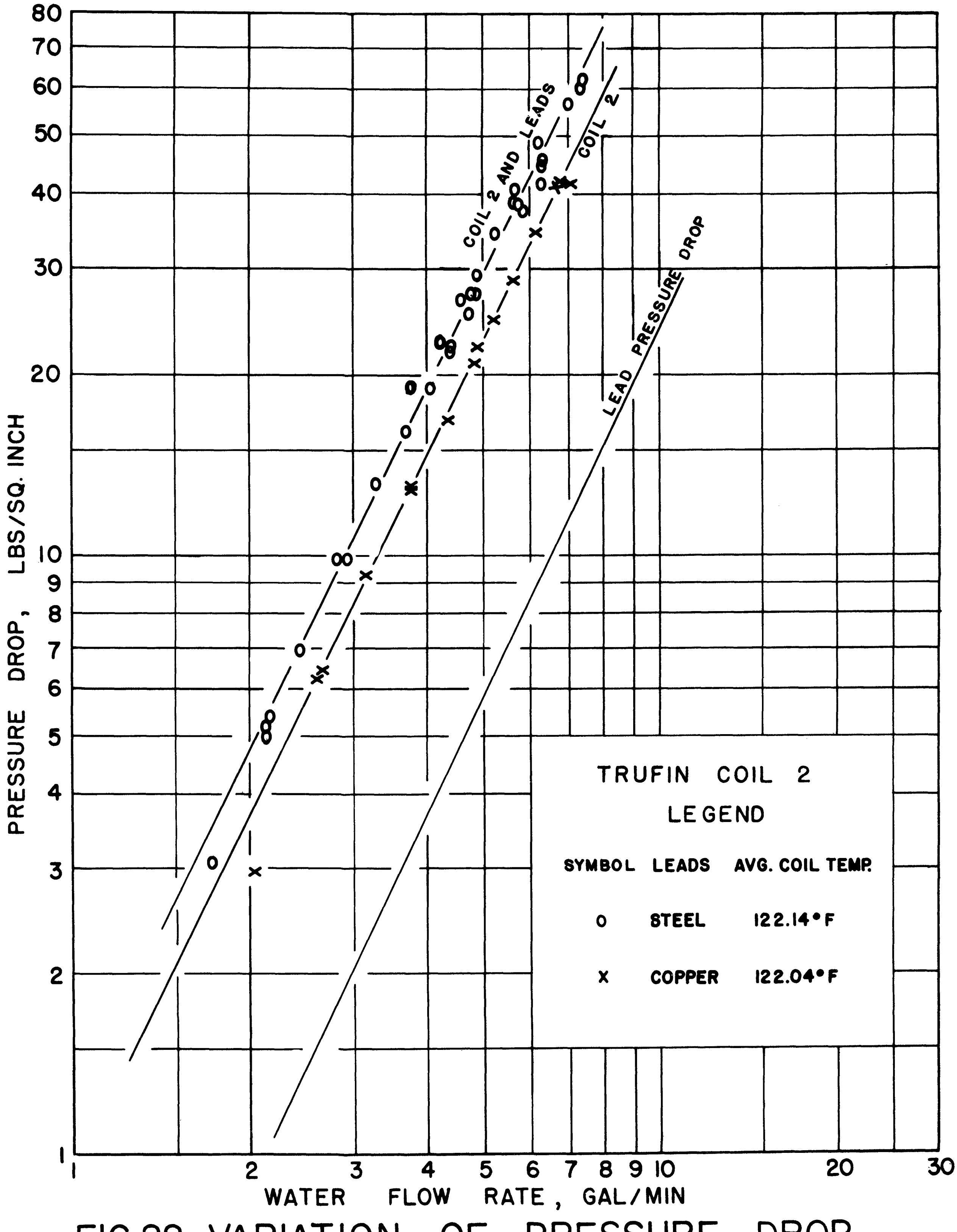

FIG.28. VARIATION OF PRESSURE DROP WITH WATER FLOW RATE, COIL 2

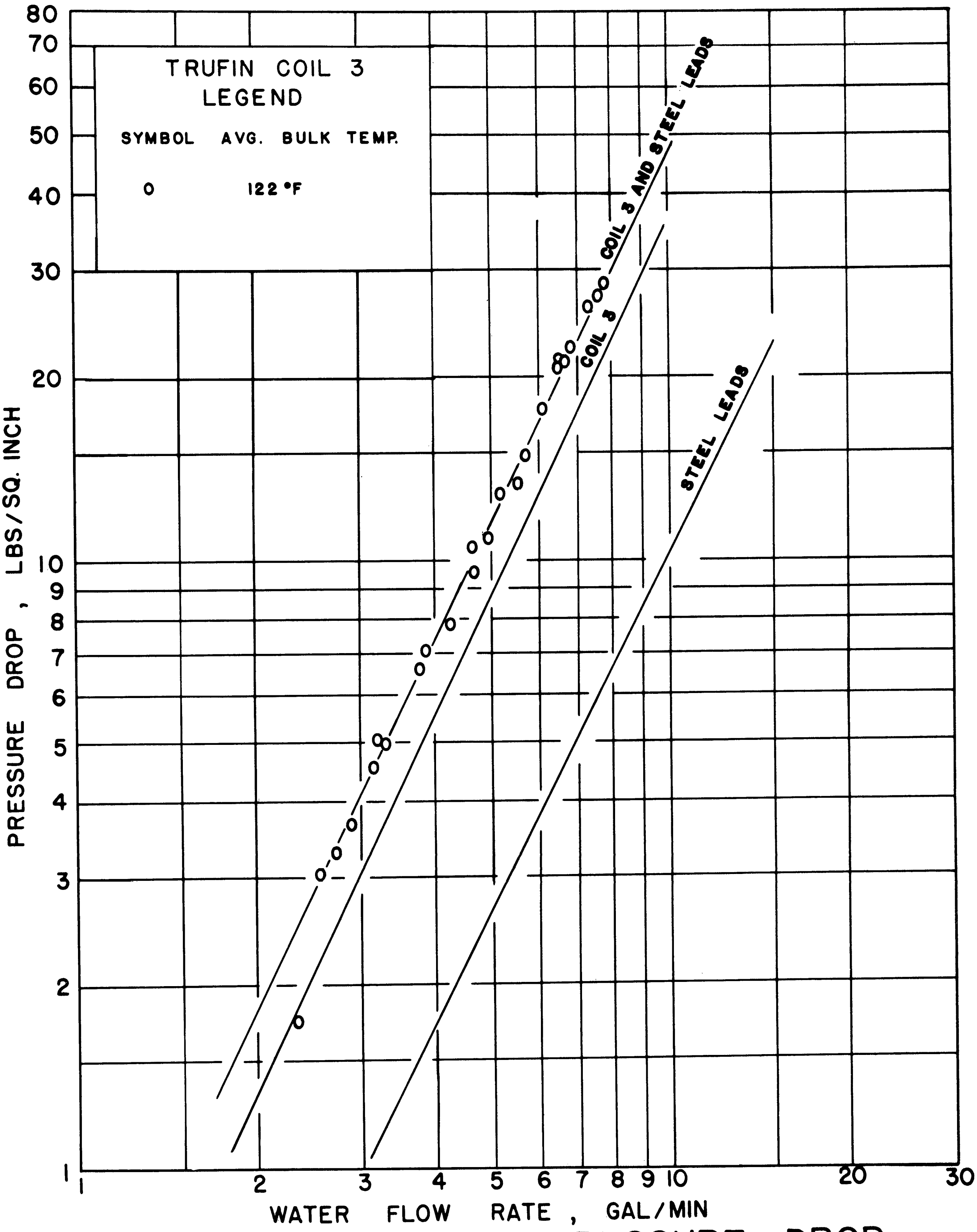

FIG.29. VARIATION OF PRESSURE DROP WITH WATER FLOW RATE COIL 3

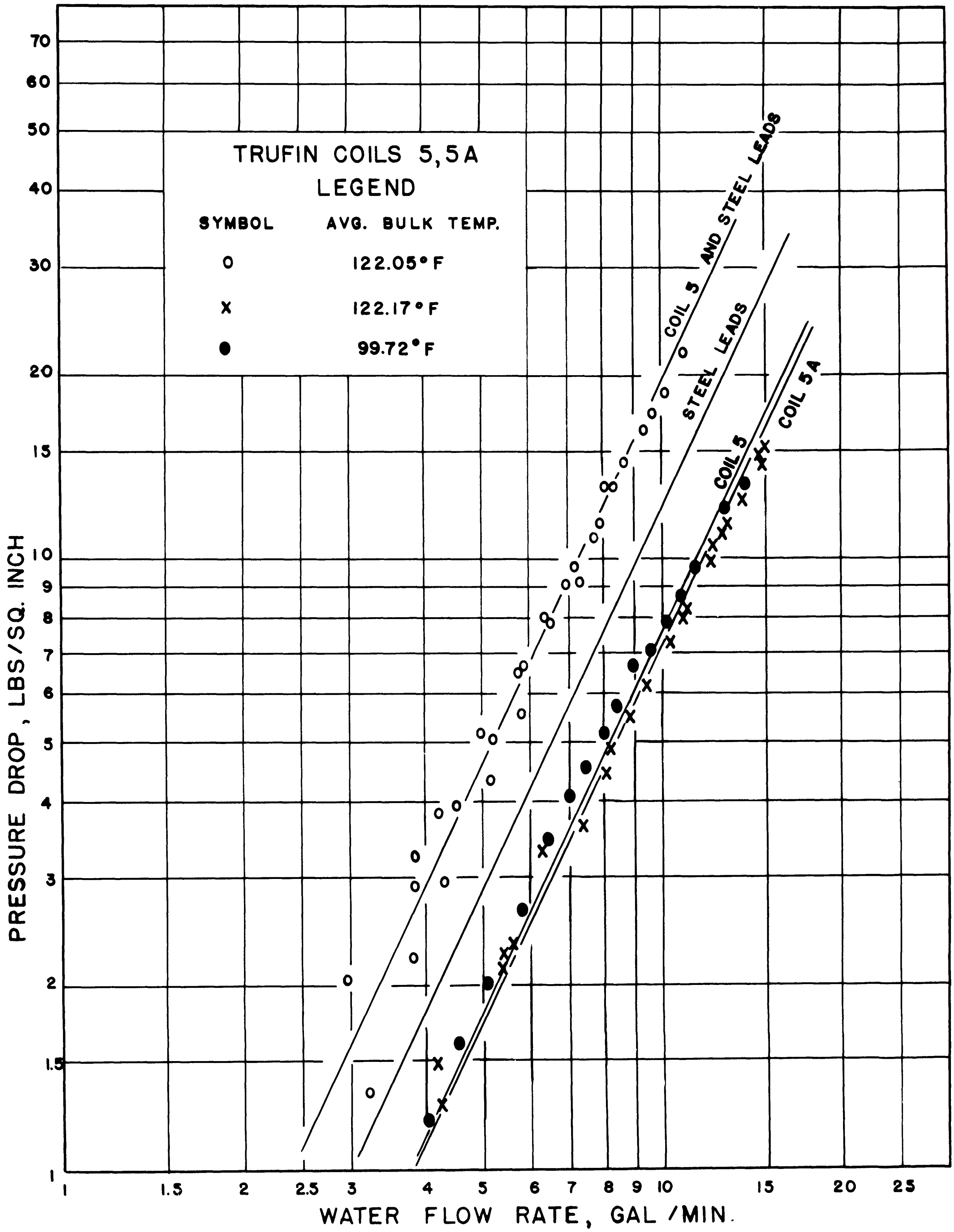

FIG. 30. VARIATION OF PRESSURE DROP WITH WATER FLOW RATE INSIDE COILS 5 AND 5A

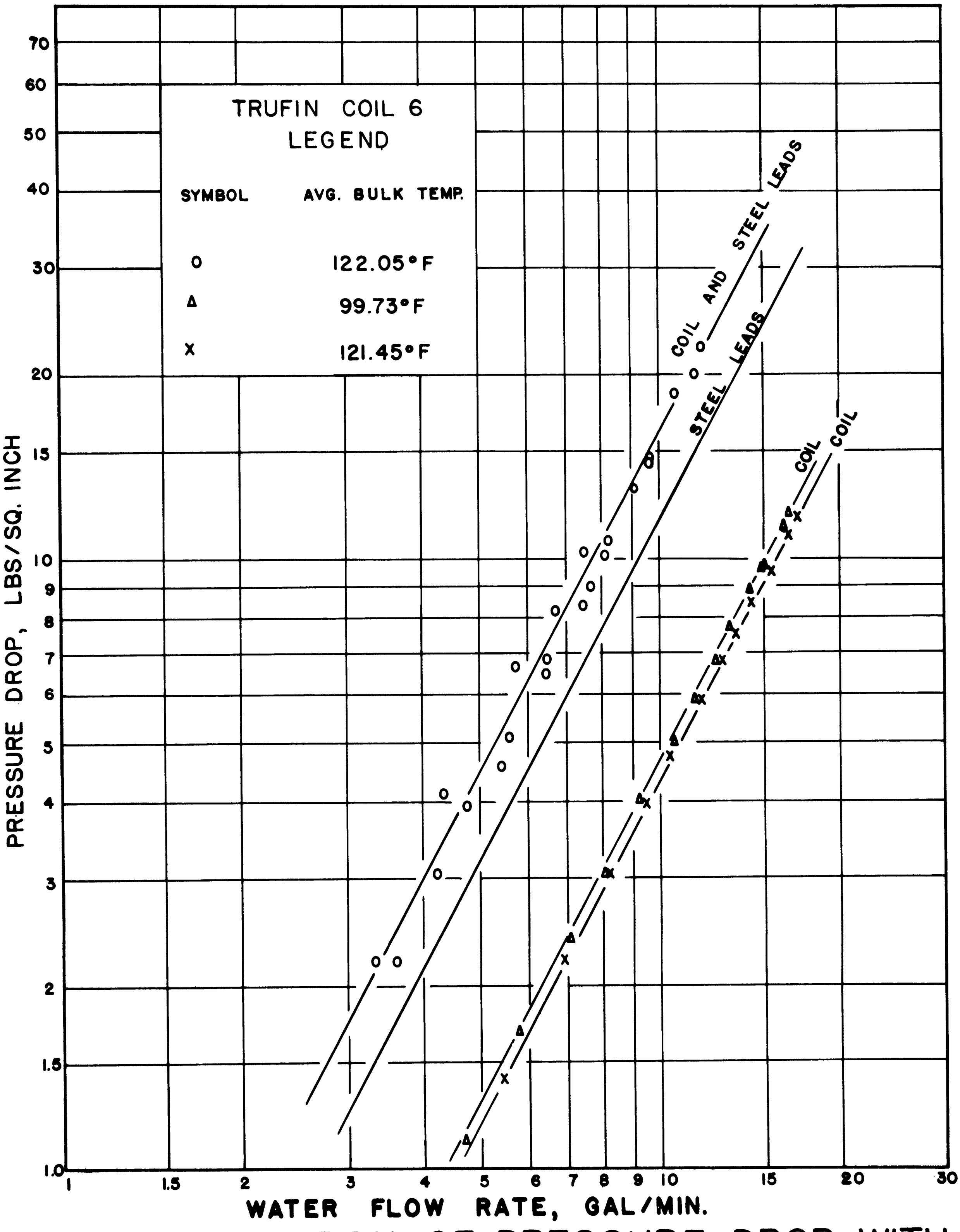

FIG.31. VARIATION OF PRESSURE DROP WITH WATER FLOW RATE INSIDE COIL 6

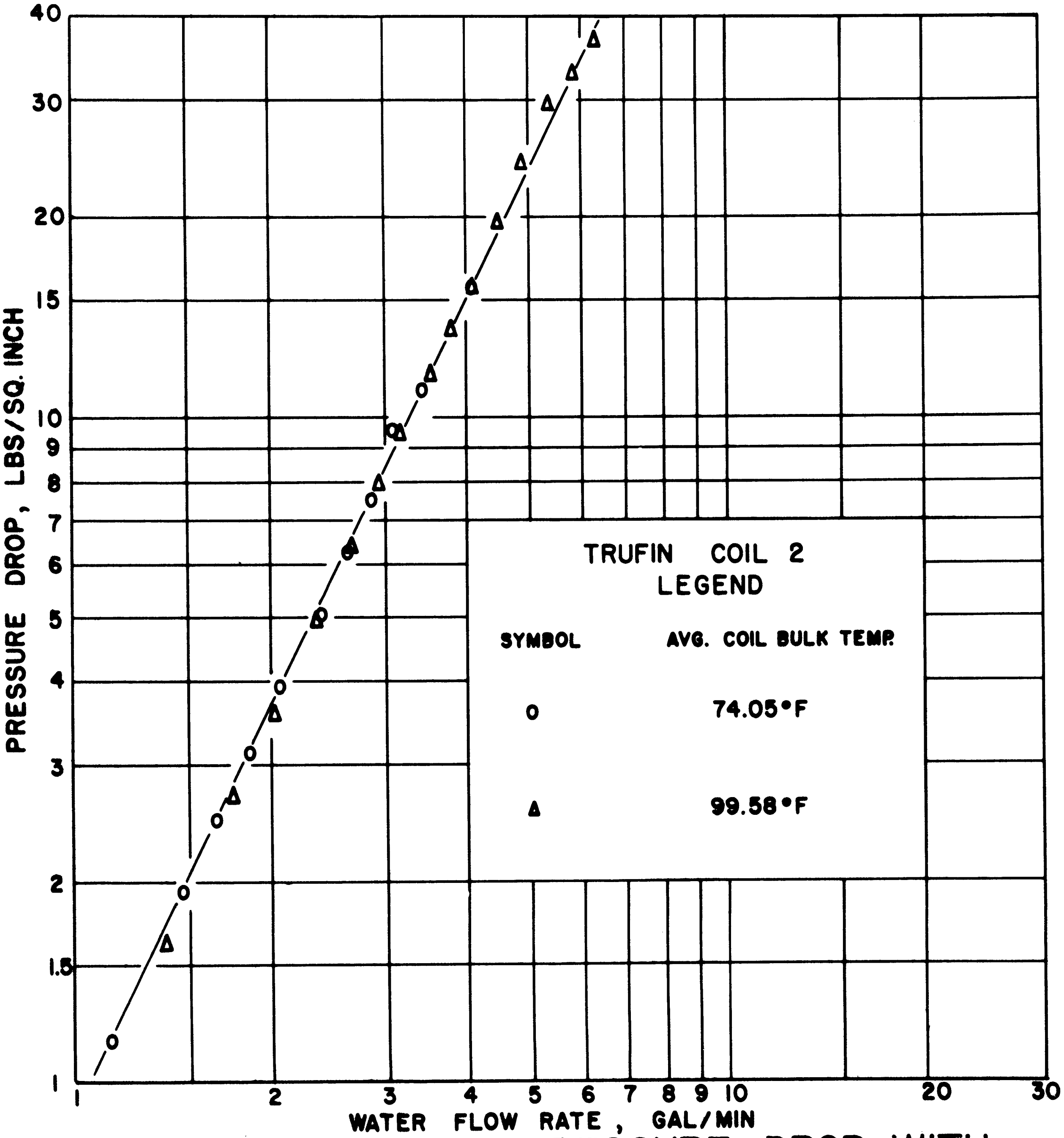

FIG.32. VARIATION OF PRESSURE DROP WITH WATER FLOW RATE INSIDE COIL 2