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CONDENSATION OF FREON-12 IN 11-FINS-PER-INCH AND 19-FINS-PER-INCH COAXIAL COILS

Report No. 46

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OBJECTIVE

The objective of this investigation was to determine the relative performance of a series of six coaxial finned tube coils with Freon-12 condensing in the annulus of the coils.

ABSTRACT

The relative performance of three 11-fin-per-inch coaxial coils of various lengths and three 19-fin-per-inch coils of various lengths were individually determined in a five ton refrigeration system charged with Freon-12. Heat transfer and pressure performance curves are presented for 85, 115, and 135 psig. condensing pressures as a function of various condensing water flow rates.

I. SCOPE OF INVESTIGATION

The object of this investigation was to determine the relative performance of various finned tube coaxial coils when condensing Freon-12 in a five ton refrigeration application. The geometrical and physical features of these coils are described in Section II of this report.

The following aspects of comparison were considered:

1. Rates of heat removal with Freon-12 condensing in the annulus of the coils with variation in:

    a. cooling water flow rate,

    b. Freon-12 condensing pressures, and

    c. length of coil.

2. Pressure drop on freon side, and

3. Pressure drop on water side.

The experimentation was conducted in the condensing section of a five ton refrigeration system. Saturated or slightly superheated Freon-12 vapor was fed to the annulus of the coil where it was condensed on the finned side of the inner tube by means of water flowing inside the inner tube.

Many other factors which play an important role in the performance of the coils were not studied in this investigation. These are;

1. Outside shape of the coil (i.e., helical, spiral, slope per foot of length), and

2. Annulus cross sectional area, internal tube geometry, and external tube geometry.

A quantitative consideration of these factors was beyond the scope of the present study, since it would require a great number of different coils and more elaborate experimental equipment.

II. DESCRIPTION OF COILS

Coaxial coils fabricated with 11-fin-per-inch tubes and 19-fin-per-inch tubes inside of 18 gage 1-1/8 inch bare copper tube approximately twenty-five feet long were originally provided by Wolverine Tube. Preliminary studies indicated that the coils would have to be shortened in order to undertake the investigation. The coils were returned to Wolverine Tube for modification. Subsequently coils approximately 4 feet, 6 feet, and 12 feet long were received for investigation. Table I presents detailed information concerning the coils tested.

Figures 1, 2, and 3 show the 4 ft.-7 inch 5 ft.-11½ inch, and 11 ft.-10½ inch long 19-fin-per-inch coils. Figures 4, 5, and 6 show the 3 ft.-6½ inch, 6 ft.-0 inch, and 12 ft.-8 inch long 11-fin-per-inch coils studied in this investigation. Figures 7 and 8 show cross sections of the 11-fin-per-inch and 19-fin-per-inch coils.

III. DESCRIPTION OF APPARATUS

The equipment used in this investigation was originally fabricated by D. R. Robinson as a Trufin Fellow for his doctoral dissertation in finned tube heat transfer in 1949. The same equipment was later used by J. E. Myers in his doctoral dissertation research also as a Trufin Fellow. This apparatus, consisting essentially of a five ton compressor, a condenser, and an evaporator together with considerable auxiliary equipment, had to be modified in many ways to fit the investigation of the performance of the coaxial coils. In essence the coils studied replaced the original condenser used by Robinson and Myers. Figures 9, 10, and 11 show the equipment as modified for this investigation.

Three stream circuits were necessary for the measurements of the heat loads. The first and main circuit contained and handled the Freon-12. The other two circuits consisted of the evaporator water circulation system and the desuperheating and condensing water systems.

A. Freon Circuit.

The Freon circuit flow sheet is shown in Figure 12. The system consisted of the following units: the evaporator, the compressor and its accessories, the vapor liquid separator, the liquid Freon seal, the finned tube coaxial coils and an auxiliary condenser.

The Freon gas leaving the evaporator flowed through valve V_2 (see Figure 12) to the suction side of the compressor. The inlet suction pressure was measured by gage P_2. The Freon in passing through the compressor became contaminated with lubricating oil. The compressed gas was therefore passed through an oil separator. The oil separator was an Aminco Refrigeration Products Company type 820 F separator.

The compressed Freon gas after passing through the oil separator could be admitted through valve V_3 to the coaxial coil condensing system or through valve V_4 to the auxiliary condenser. The auxiliary condenser was seldom used. The vapor was desuperheated in a concentric pipe heat exchanger to a predetermined level.

All of the runs at a given inlet coil pressure were conducted at a constant inlet Freon temperature. At the inlet and outlet of the coil the temperature and pressure T_1, P_4 and T_2, P_5 were measured. The condensed Freon then passed to a liquid seal unit. This liquid seal was fabricated from a piece of 4 in. pipe about 14 in. long. It was fitted with a vent valve through which noncondensibles could be bled and a sight glass tube was provided along the side of the unit. The condensate then returned through a vapor liquid separator back to the evaporator.

The compressor used was a five ton carrier type 5F-30 model, operating three cylinders at 1750 rpm from a 5 hp drive. The unit was equipped with an automatic low and high pressure shut off switch, and an automatic oil safety switch which shut off the compressor whenever the difference between the oil pressure and suction pressure became less than about 45 psig.

The evaporator had a rectangular cross sectional shape. It measured 17-3/8 in. high by 7-14 in. wide by 39 in. long inside and was fabricated of 1/2 in. steel plate. It was fitted with a safety valve set to relieve at 150 psig, a pressure gage P_1, and three bull's eye sight glasses welded into the sides at three different levels. These windows were used to observe the Freon liquid level. A tube bundle of 16 gage 3/4 in. copper tubes was used in the evaporator. Through these tubes water was circulated to provide the necessary latent heat of evaporation and keep the evaporator pressure at a predetermined level. The auxiliary condenser was a water cooled multipass unit containing finned tubes.

Figure 9 shows the following units:

A. Coaxial Coil
B. Five Ton Compressor
C. Auxiliary Condenser
D. Vapor-Liquid Separation

Figure 10 shows the following units:

E. The Evaporator
F. Hot Water Surge Tank
G. Evaporator Water Recirculation Pump
H. Evaporator Tube Bank Exit Section
M. Evaporator Water Preheater

Figure 11 shows the following units:

I. Liquid Seal Unit
J. Condensing Water Pre-Heater
K. Oil Separator
L. Freon Vapor Desuperheater

B. Auxiliary Circuits

1. Evaporator Water Circuit.

The evaporator water circuit is shown in Figure 10. The heat of evaporation was provided by recirculated warm water. The circuit consists of a surge tank F, a pump G, and a pre-heater M.

The discharge from the pump was divided into two streams, one going to the evaporator and the other bypassed to the suction side of the pump for capacity control. The water was then returned to the surge tank. The pump took suction from the storage tank through a small stream heater.

2. Condenser Cooling Water Circuit.

Cooling water for the condensing coil was admitted from the main to a vertical heat exchanger (Unit J of Fig. 11) where it was preheated by means of steam to a constant temperature of 22°C. It was then admitted to the coil. Both the inlet and outlet temperatures were measured (T_1 and T_2 of Fig. 12). The rate of flow was determined by collecting and weighing the water in a weigh barrel for a certain period of time.

3. Freon Desuperheating Circuit.

Part of the Freon line at the inlet of the coil was jacketed and cooled by water coming from the water main. The flow rate of water required for the desired desuperheating was manually controlled by means of valves.

IV. PROCEDURE

A typical run consisted of operating the system under predetermined conditions such that the inlet Freon to the coaxial coil was entering at either 85, 115, or 135 psig. At the same time the condensing water flow rate was set at a predetermined value, always adjusting and holding the inlet water temperature at 22°C. The Freon was partially desuperheated before entering the coaxial coil.

In starting up, both water circuits were turned on and the coaxial coil inlet condensing water was adjusted to 22°C. The next step consisted of setting all valves in the Freon circuit following a sequence. The prescribed sequence prevented any liquid Freon from accumulating in the compressor crankcase and also prevented loss of oil from the crankcase into the Freon circuit. The compressor was started up and the pressure of the

Freon at the inlet of the coil was set at the prescribed level by valve V_2 of Figure 12. The pressure in the evaporator was held close to 50 psig by controlling the temperature and flow rate of the evaporator tube side water.

Measurements:

When the inlet water temperature to the coil read 22°C for the given water flow rate the following steps were taken.

The amount of superheat of the Freon vapor was reduced to approximately 5°C by controlling the rate of water flow in the desuperheater.

The water rate flowing through the coaxial coil was then measured using a weigh barrel. The inlet and outlet Freon and water temperatures and pressures were read. The pressure at the evaporator and the compressor outlet pressure were also recorded.

For a given water flow rate a series of runs at different condensing Freon pressures were taken. For these runs no adjustment of the inlet water temperature was needed. It was necessary, however, to readjust the Freon inlet temperature, and the pressure at the evaporator.

The condensing water flow rate was then changed and a new series of runs at different inlet Freon condensing pressures was taken.

V. RESULTS AND DISCUSSION OF RESULTS

The experimental method used followed closely, but not exactly for reasons mentioned below, the condenser water method described in Section 26 of the A.S.R.E. Standard Methods for Testing Mechanical Condensing Units, prepared and approved by the A.S.R.E. Council June 11, 1940 (A.S.R.E. Standard 14-41).

The following measurements were taken for each run:

1. Pressure of vapor refrigerant entering condenser coil,
2. Temperature of vapor refrigerant entering condenser coil,
3. Pressure of liquid refrigerant leaving condenser coil,
4. Temperature of liquid refrigerant leaving condenser coil,
5. Temperature of water entering condenser,
6. Temperature of water leaving condenser,
7. Weight of condenser cooling water per unit time,
8. Evaporator pressure.

Three or four consecutive measurements were taken after equilibrium was reached. Not all runs are listed in this report. As indicated earlier in this report, at the beginning of the experimentation period, runs were taken on smaple coaxial coils whose capacity exceeded the available capacity and load limit of the compressor. These coils were sent back and by request were cut to shorter lengths. Only the runs taken on these shortened coils are recorded in Table No. II. Only the arithmetic average of the four measurements of each run is recorded. The recorded pressures and temperatures include the necessary corrections determined by calibration of the thermometers and pressure gages.

The formula for calculation of the capacity of a condensing unit proposed by A.S.R.E. Standard 14-41 is

$$Q = \frac{(h_{g1} - h_{f1})}{(h_{g3} - h_{f3})} \left[W(t_2 - t_1) + Q_n\right] \qquad (1)$$

where:

h_{f1} = heat content of refrigerant liquid leaving condensing unit, in Btu. per lb.

h_{f3} = heat content of refrigerant liquid leaving the condenser, in Btu. per lb.

h_{g1} = heat content of refrigerant vapor entering condensing unit, under the conditions specified in the A.S.R.E. Standard Method of Rating Mechanical Condensing Units, in Btu. per lb.

h_{g3} = heat content of refrigerant vapor entering condenser, in Btu. per lb.

Q = condensing unit capacity, in Btu. per hr.

Q_n = heat loss from condenser to surrounding air, in Btu. per hr., $S\,U_a(t_c - t_a)$ approximately.

S = outside surface of condenser, in sq. ft.

U_a = air film heat transfer coefficient, in Btu. per hr. per sq. ft. per °F.

t_a = ambient temperature, in °F.

t_c = external surface temperature of condenser, in °F.

t_1 = condenser entering water temperature, in °F.

t_2 = condenser leaving water temperature, in °F.

W = flow of condenser cooling water, in lb. per hr.

The nomenclature used above in formula (1) follows exactly that specified in A.S.R.E. Standard 14-41. This formula was not used in calculating Q. Instead the heat load handled by the coil was calculated as follows:

$$Q = W(t_2 - t_1) \qquad (2)$$

The reason for this is that Equation 1 applies to the testing of a complete condensing unit. The correction coefficient factor in Equation 1 takes into account the difference in enthalpy of the liquid refrigerant leaving the condenser unit and that of the liquid refrigerant leaving the condenser proper. The investigation described in this report was concerned with the performance of coaxial coils. The results should be independent of the overall setup in which the coaxial coils may be used. This correction factor was therefore not required in this investigation.

It should be noted that the term Q_n was also not used. This term represents the rate of heat loss to the ambient air by convection and radiation from the outside surface of the coil. It can be estimated that under the most unfavorable conditions that could be encountered in the course of the experimentation, this heat loss represented at most 3 percent of the total heat capacity Q. As explained below, other factors affect the performance to a greater degree.

Figures 13 through 18 are plots of heat loads Q, in Btu per hour, versus condensing water flow rates, in pounds per hour, with Freon condensing pressure as the parameter. It should be noted that sometime during the experimentation the pressure gages measuring the inlet and outlet Freon pressures deviated from their original calibrations. The exact time at which this deviation developed could not be exactly determined. All of the coils were therefore tested again. Both the original and final data are tabulated in this report. The filled circles in the figures referred to above represent the original data while the unfilled circles represent the final data. The pressure parameters indicated on the final data curves is that measured after recalibrating the pressure gages. The old data curves are labeled with pressures obtained from the cross-plot curves, Q versus P, Figures 19 through 24, with parameters of water flow rate. This latter group of figures was prepared using only the final data. The dash lined curves on Figures 13 through 18 and 25 through 27 were obtained from reading values from the Q versus P cross plots (Fig. 19 through 24). Figures 25 through 27 are comparison curves for the short, medium, and long coils. The Freon pressure drop plots (Figs. 31 through 33) are also based exclusively on the final data.

In the summary of results Table II the outlet Freon pressure column was left blank in the case of the original data. The inlet Freon pressure column for the old data lists the pressures read off from the Q vs P curves by locating the measured Q and the corresponding measured flow rate curve and reading the inlet pressure on the abscissa.

A separate set of isothermal runs was taken to determine the pressure drop of the condenser water at different water flow rates. For low water rates the pressure drop was measured by means of a mercury manometer. For the higher water flow rates the inlet and outlet pressures were measured by means of calibrated pressure gages. Corrections were made for the static head difference. The data is tabulated in Table III. The pressure drop is plotted versus the water flow rates in Figs. 34 through 39.

Three particularly interesting and indicative plots are given in Figs. 28, 29, and 30. In these figures the heat loads Q are plotted versus the length of the six coaxial coils at what are considered to be representative water flow rates (50, 100, and 150 lbs. per minute) with Freon condensing pressure as the parameter.

Figure 25 indicates that the 19 fin-per-inch short coil is superior to the 11 fin-per-inch short coil. It should be noted, however, that the 19 fin-per-inch short coil is more than one foot longer than the 11 fin-per-inch coil. This figure must therefore be used with caution. The medium length coils are comparable in length. For high Freon condensing pressures the 11 fin-per-inch coil indicates superior performance. At high condensing water flow rates, however, the slope of the 11 fin-per-inch performance curve decreases faster than the corresponding 19 fin-per-inch curve and the curves cross. It is believed that differences in the Freon side cross sectional free flow area, geometrical deformations of the coil cross sections as a result of coiling of the tubes (Figures 7 and 8), finned tube geometry differences, and to some extent the shape of the coils all influenced the resulting performances of the coils. The precise mechanism which caused the curves to cross is unknown.

Figures 28, 29, and 30 indicate that there are definite coil length limitations beyond which the added length is not effective in condensing. It should be noted that any added length results mostly in supercooling of the condensate.

Figures 31, 32, and 33 indicate that there is no significant difference in the Freon pressure drops between 11 fin-per-inch and 19 fin-per-inch coils of the same length.

TABLE I

DESCRIPTION OF COAXIAL COILS

Coil No.	Length ft.	Tube No.	Material of Tube	Fins Per Inch	D_o	D_r	I.D.	A_o ft^2/ft	A_i ft^2/ft
73	4 ft. - 7 in.	196047-01	Copper	19	0.824	0.711	0.611	0.556	0.160
74	5 ft. - 11½ in.	196047-01	Copper	19	0.824	0.711	0.611	0.556	0.160
75	11 ft. - 10½ in.	196047-01	Copper	19	0.824	0.711	0.611	0.556	0.160
79	3 ft. - 6½ in.	60-115032-01	Copper	11	0.904	0.679	0.598	0.762	0.1565
77	12 ft. - 8 in.	60-115032-01	Copper	11	0.904	0.679	0.598	0.762	0.1565
78	6 ft. - 0 in.	60-115032-01	Copper	11	0.904	0.679	0.598	0.762	0.1565

TABLE II

SUMMARY OF TEST DATA

Run No.	Water Temperature In	Water Temperature Out	Water ΔT	H_2OΔT Corr.	Freon Temperature In	Freon Temperature Out	Freon Pressure In	Freon Pressure Out	Freon ΔP	Evap. Pres.	Water Rate #	Water Rate Sec.	Water Rate #/min.	Q
	°C	°C	°C	°C	°C	°C	Psi	Psi	Psi	Psi	#	Sec.	#/min.	Btu/hr.
Coil No. 79, Wolverine 60-115032-01, 11 fin/inch, 3 ft. 6½in.														
479	22.00	23.55	1.55	1.75	58.5	38.0	134	125	9	43	50	16.5	182	34,400
480	21.95	22.90	0.95	1.15	59.0	33.2	114	111	3	51	50	16.5	182	22,600
482	21.97	23.13	1.16	1.36	51.0	31.9	115	112	3	69	50	20.5	146	21,450
483	21.97	23.85	1.88	2.08	56.0	37.8	134.5	125	9.5	62	50	20.5	146	32,800
484	22.03	25.20	3.17	3.37	60.0	40.0	134.5	131	3.5	58	30	23.5	76.6	27,900
485	22.05	24.17	2.12	2.32	48.0	35.0	114	111	3	47	30	23.0	78.3	18,150
486	22.05	25.20	3.15	3.35	54.0	41.0	136	130	6	52	30	23.0	78.3	28,300
141	22.10	24.10	2.00	2.20	58.6	30.8	104			50	20	28.6	42	9,970
143	22.02	22.97	0.95	1.15	54.0	31.8	104			37.5	25	11.75	127.5	15,850
145	22.02	25.27	3.25	3.45	46.8	32.2	104			42	20	73.2	16.38	6,100
146	21.90	23.23	1.33	1.53	49.3	31.2	104			36	50	35.5	84.5	13,950
148	22.05	22.90	0.85	1.05	46.5	31.6	104			27	50	21.6	139	15,750
150	22.00	23.03	1.03	1.23	50.35	32.0	104			22	25	13.5	111.1	14,770
151	21.95	22.70	0.75	0.95	53.8	33.55	104			7	25	8.8	170.5	17,470
152	21.95	22.70	0.75	0.95	53.3	34.0	104			1.0	50	17.5	171.2	17,550
153	21.90	23.30	1.40	1.60	56.65	39.05	134			50	50	17.9	167.5	32,600
154	21.93	23.68	1.75	1.95	55.65	39.75	128			42	50	21.7	138.3	29,100
155	21.86	24.18	2.32	2.52	53.0	39.8	128			37	30	19.5	92.3	25,100
156	21.95	25.03	3.08	3.28	57.7	40.6	128			34	30	29.2	61.7	21,850
157	22.00	26.05	4.05	4.25	54.45	41.65	128			30	25	39.7	37.8	17,400
159	21.80	23.36	1.56	1.76	53.2	39.4	128			39	50	20.4	154	29,300
160	21.88	22.53	0.65	0.85	39.8	25.8	85	84	1	38.5	50	65.2	46.1	4,230
161	21.87	22.95	1.08	1.28	40.2	26.5	85	84	1	32	20	44.6	26.9	3,720
162	21.85	22.90	1.05	1.25	39.3	26.1	85	84	1	34	15	48.8	18.45	2,490
163	22.10	22.70	0.60	0.80	41.3	25.7	85	83.5	1.5	28.5	20	27.3	44	3,800

TABLE II (Continued)

Run No.	Water Temperature In	Water Temperature Out	Water ΔT	$H_2O \Delta T$ Corr.	Freon Temperature In	Freon Temperature Out	Freon Pressure In	Freon Pressure Out	Freon ΔP	Evap. Pres.	Water Rate #	Water Rate Sec.	Water Rate #/min.	Q
	°C	°C	°C	°C	°C	°C	Psi	Psi	Psi	Psi	#	Sec.	#/min.	Btu/hr.
Coil No. 78, Wolverine 60-115032-01, 11 fin/inch, 6 ft.														
206	22.01	23.32	1.31	1.48	57.6	32.2	108			51	50	17.3	173.5	27,750
207	22.00	23.70	1.70	1.87	57.4	32.5	108			43	50	47.0	138	27,950
208	22.00	23.25	1.25	1.42	47.85	31.65	108			33	50	16.3	184	28,200
209	21.98	23.43	1.45	1.62	48.75	31.9	108			38	50	19.5	154	27,000
210	22.08	23.63	1.55	1.72	48.75	32.0	108			42	50	21.5	139.5	25,950
211	21.90	23.65	1.75	1.92	48.25	32.0	108			45	50	26.4	113.5	23,600
212	21.90	24.40	2.50	2.67	48.0	33.0	108			49	50	40.5	74	21,400
213	22.08	25.28	3.20	3.37	54.8	33.4	108			55	30	41.0	44	16,000
215	22.05	24.95	2.90	3.07	57.35	35.3	128			37	50	24.0	125	41,400
216	22.03	25.63	3.60	3.77	55.4	36.2	128			44	50	32.8	91.5	37,300
217	22.00	26.55	4.55	4.72	57.0	37.55	128			40	30	30.2	59.6	30,400
218	22.10	28.40	6.30	6.47	52.75	39.35	128			41	20	40.7	29.4	20,550
221	22.05	24.70	2.65	2.82	51.30	33.3	108			30	30	27.1	66.5	20,500
222	22.00	26.30	4.30	4.47	54.4	37.2	128			24	50	45.0	66.6	32,200
223	21.97	22.51	22.54	0.72	35.3	25.6	80			58	20	25.6	47	3,650
224	21.95	22.50	0.55	0.72	37.4	25.7	80			45	30	27.4	65.7	5,100
225	22.03	22.33	0.30	0.47	40.1	25.4	80			38	30	18.4	98.0	4,960
226	22.02	22.75	0.73	0.90	39.1	24.9	80			42	20	43.9	27.4	2,660
332	21.98	24.33	2.35	2.50	61.7	35.0	136	113	23	23	50	16.6	181	48,900
333	21.99	23.39	1.40	1.70	49.4	32.3	116	105	11	40	50	16.6	181	33,300
334	21.95	22.30	0.35	0.55	40.3	25.0	86	85	1	39	50	21.2	141.5	8,400
335	22.00	23.90	1.90	2.10	52.6	33.2	116	106	10	36	50	21.3	141	32,000
336	22.00	24.85	2.85	3.05	58.6	35.7	136	114	22	31	50	21.0	142.5	47,000
337	22.05	26.00	3.95	4.15	58.0	27.3	136	118	18	28	50	30.2	99.4	44,500
338	22.05	24.50	2.45	2.75	51.4	33.7	116	108	8	38.5	50	30.0	100	29,700
339	22.00	22.40	0.40	0.60	41.5	26.6	86	84	2	36	50	30.1	99.5	6,430
340	22.03	22.93	0.90	1.10	38.5	26.7	86	84	2	42	20	21.6	55.5	6,590
341	21.99	25.59	3.60	3.75	59.2	35.2	117	113	4	38	20	21.9	54.9	22,200
342	22.00	27.50	5.50	5.70	58.5	39.1	136	125	11	35	20	21.5	55.8	34,400
343	21.95	29.70	7.75	7.95	64.0	41.0	137	130	7	41	10	28.8	20.8	17,900
344	22.00	27.00	5.00	5.20	59.8	36.1	116	115	1	42	10	29.2	20.6	11,550
345	22.05	23.20	1.15	1.35	38.7	26.5	86	86	0	29	10	28.5	21.1	3,080
346	22.05	24.60	2.55	2.75	49.9	33.8	117	109	8	60	30	18.3	98.3	29,200
347	22.00	25.90	3.90	4.10	55.8	37.1	137	118	19	47	30	18.6	96.8	42,800
350	22.00	24.55	2.55	2.75	50.6	34.0	117	109	8	46	30	18.5	97.3	28,900
351	22.00	22.50	0.50	0.70	41.5	26.6	86	86	0	54	30	18.7	96.3	7,280

TABLE II (Continued)

Run No.	Water Temperature In	Water Temperature Out	Water ΔT	H_2OΔT Corr.	Freon Temperature In	Freon Temperature Out	Freon Pressure In	Freon Pressure Out	Freon ΔP	Evap. Pres.	Water Rate #	Water Rate Sec.	Water Rate #/min.	Q
	°C	°C	°C	°C	°C	°C	Psi	Psi	Psi	Psi	#	Sec.	#/min.	Btu/hr.
Coil No. 77, Wolverine 60-115032-01, 11 fin/inch, 12 ft. 8 in.														
259	22.10	23.98	1.88	2.08	50.4	25.05	115			47.5	50	19.1	157	35,200
260	22.00	24.43	2.43	2.63	50.5	25.1	115			40	50	24.5	122.5	34,800
262	22.11	25.70	3.59	3.79	55.6	26.5	115			77	40	31.8	75.5	30,900
263	21.91	27.19	5.28	5.48	51.8	28.1	115			44	40	57.1	42.0	24,900
264	22.00	24.61	2.61	2.81	53.75	24.65	135			63	70	26.0	161.5	49,000
265	21.95	25.50	3.55	3.75	57.1	25.4	135			47	60	29.9	120.5	48,900
266	21.91	26.61	4.70	4.90	53.2	26.2	135			38	50	34.7	86.5	45,700
267	22.12	28.52	6.40	6.60	55.2	28.2	135			31	30	31.4	57.3	40,800
268	20.05	31.65	9.60	9.80	57.5	32.8	135			70	20	42.6	28.15	29,900
269	22.33	24.93	2.60	2.80	54.3	25.2	135			70	50	18.4	163	49,200
270	21.90	25.30	3.40	3.60	54.45	25.15	135			64	70	33.3	126	49,000
278	22.00	24.92	2.92	3.12	59.6	25.1	135			36	50	20.3	148	49,700
279	22.00	25.50	3.50	3.70	63.0	25.3	135			32	50	24.5	127.5	48,800
398	22.00	22.60	0.60	0.80	39.2	24.0	85	76.5	8.5	72	50	19.0	158	13,600
399	21.95	22.65	0.70	0.90	38.7	23.9	85	77	8	67	50	20.3	148	14,400
400	22.10	24.10	2.00	2.20	52.0	24.9	113.5	78	35.5	55	50	20.0	150	35,600
403	22.05	25.00	2.95	3.15	54.2	25.0	135	82	53	55	50	20.5	146.5	49,700
404	22.00	25.65	3.65	3.85	55.0	25.3	135	81	54	63	50	26.2	114.6	47,600
405	21.98	24.58	2.60	2.80	50.9	25.4	115.5	80	35.5	69	50	26.4	113.8	34,400
406	22.05	23.00	0.95	1.15	43.6	24.0	86	77.5	8.5	46	50	26.2	114.6	14,300

TABLE II (Continued)

Run No.	Water Temperature In	Water Temperature Out	Water ΔT	$H_2O\Delta T$ Corr.	Freon Temperature In	Freon Temperature Out	Freon Pressure In	Freon Pressure Out	Freon ΔP	Evap. Pres.	Water Rate #	Water Rate Sec.	Water Rate #/min.	Q
	°C	°C	°C	°C	°C	°C	Psi	Psi	Psi	Psi	#	Sec.	#/min.	Btu/hr.
Coil No. 73, Wolverine 196049-01, 19 fin/inch, 4 ft. 7 in.														
441	21.75	23.65	1.90	2.10	58.0	38.0	135	116.5	18.5	53	50	15.6	192.5	43,600
442	22.10	23.30	1.20	1.40	54.0	34.4	114.5	97	17.5	54	50	15.7	191.5	29,000
443	22.10	24.60	2.50	2.70	58.5	25.0	135	121	14	52	50	23.5	127.7	37,200
444	22.10	23.80	1.70	1.90	53.0	35.0	114.5	110	4.5	60	50	23.6	127.2	26,100
445	22.00	25.20	3.20	3.40	60.0	40.2	135	126	9	53	20	13.8	87.0	31,900
446	22.00	24.20	2.20	2.40	53.0	35.5	114.5	110	4.5	55	20	13.8	87.0	22,600
447	22.00	25.20	3.20	3.40	60.0	39.5	130	122	8	51	30	21.0	85.7	31,500
448	22.00	24.20	2.20	2.40	53.0	35.0	110	108	2	55	30	21.0	85.7	22,200
449	22.00	25.10	3.10	3.30	61.0	39.4	130	121	9	50	30	21.0	85.7	30,500
450	22.00	25.20	3.20	3.40	58.5	40.6	135	126	9	52	30	19.6	91.9	33,800
451	22.00	24.20	2.20	2.40	50.0	35.8	115	107	8	57	30	19.8	91.0	23,600
452	22.00	23.40	1.40	1.60	41.5	32.2	100	100	0	59	30	20.1	89.6	15,500
453	22.00	25.90	3.90	4.10	54.6	41.6	135	130	5	53	30	27.2	66.3	29,200
454	22.00	24.65	2.65	2.85	49.7	36.2	115	113.5	1.5	58	30	27.0	66.7	20,500
455	22.00	23.80	1.80	2.00	44.0	32.0	100	100	0	46	30	27.0	66.7	14,400
456	22.00	22.80	0.80	1.00	42.65	27.0	86	86	0	50	30	27.0	66.7	7,200
457	22.00	22.90	0.90	1.10	37.0	26.0	86	86	0	46	30	38.0	47.4	5,630
458	21.97	24.19	2.22	2.42	50.4	32.2	100	100	0	58	30	38.2	47.1	12,300
459	22.00	25.10	3.10	3.30	51.3	36.8	115	114.5	0.5	63	30	38.1	47.2	16,900
460	22.00	26.70	4.70	4.90	55.0	42.2	135	131	4	54	30	38.6	46.6	24,700
462	22.00	24.25	2.25	2.45	55.9	38.6	135	120	5	36	50	19.6	153	40,500
464	22.00	23.50	1.50	1.70	48.8	34.8	115	111	4	42	50	19.6	153	28,100
465	22.00	23.00	1.00	1.20	50.0	32.0	100	100	0	44	50	19.6	153	19,800

TABLE II (Continued)

Run No.	Water Temperature In	Water Temperature Out	Water ΔT	H_2OΔT Corr.	Freon Temperature In	Freon Temperature Out	Freon Pressure In	Freon Pressure Out	Freon ΔP	Evap. Pres.	Water Rate #	Water Rate Sec.	Water Rate #/min.	Q
	°C	°C	°C	°C	°C	°C	Psi	Psi	Psi	Psi	#	Sec.	#/min.	Btu/hr.
Coil No. 74, Wolverine 196049-01, 19 fin/inch, 5 ft. 11½ in.														
227	22.02	23.40	1.38	1.58	51.80	31.5	108			38.5	50	17.5	171.5	29,300
228	22.00	23.60	1.60	1.80	51.0	32.0	108			36	50	20.8	144.2	28,050
229	22.00	23.87	1.87	2.07	50.5	32.1	108			34	50	24.5	122.5	27,400
230	22.00	24.20	2.20	2.40	49.5	32.7	108			32	30	19.0	94.7	24,600
231	21.98	25.18	3.20	3.40	50.3	33.8	108			45	20	24.7	48.6	17,850
232	22.05	26.75	4.70	4.90	50.9	34.7	108			51.5	10	34.1	17.6	9,300
233	22.10	25.07	2.97	3.17	57.03	35.9	128			51	50	26.1	115	39,400
234	21.90	24.12	2.22	2.42	56.4	34.3	128			49	50	17.5	171.5	44,800
235	21.90	24.50	2.60	2.80	56.1	35.2	128			49	50	25.1	139.5	42,200
236	21.90	25.52	3.62	3.82	53.85	36.95	128			51	22	15.0	88.	36,300
237	22.08	26.67	4.59	4.79	57.35	38.6	128			52	30	32.4	55.6	29,000
238	22.10	28.15	6.05	6.25	54.5	40.0	128			60	20	44.3	27.1	18,250
239	22.10	23.10	1.00	1.20	32.6	25.1	83			45	20	31.65	37.9	4,900
240	22.00	22.70	0.70	0.90	41.35	25.0	83			30	30	25.5	70.6	6,860
241	22.00	22.50	0.50	0.70	38.42	25.1	83			55	30	16.3	110	8,320
242	22.00	22.45	0.45	0.65	40.5	35.0	83			39	50	24.3	123	8,640
466	22.00	25.00	3.00	3.10	55.0	36.8	135	113.5	21.5	47	50	21.8	137.5	46,000
467	22.00	24.10	2.10	2.20	53.0	33.5	114	104	10	57	50	21.8	137.5	32,600
468	22.10	24.00	1.90	2.00	51.0	32.0	114.5	102	12.5	62	50	18.3	164	35,400
469	21.90	24.60	2.70	2.80	57.0	35.8	135	111	24	59	50	18.0	166.7	50,400
470	21.90	23.20	1.30	1.40	56.0	31.0	100	97	3	66	50	18.1	166	25,100
471	21.90	24.50	2.60	2.70	59.0	35.6	134.5	110	24.5	54	50	17.3	173.5	50,500
473	22.07	26.97	4.90	5.00	51.0	38.0	135	125	10	49	50	50.5	59.4	32,000
474	22.07	25.62	3.55	3.65	45.0	34.3	115	111	4	50	50	50.2	59.8	23,550
475	21.98	24.62	2.64	2.74	42.0	30.8	101	100	1	50	50	50.0	60.0	17,750
476	22.10	25.80	3.70	3.80	56.0	33.0	135	121	14	35	50	31.1	96.5	39,600
477	22.10	24.65	2.55	2.65	48.0	30.1	114	97	17	36	30	18.6	96.9	27,700
478	22.10	23.90	1.80	1.90	34.0	23.7	102	100	2	41	50	31.1	96.5	19,800

TABLE II (Concluded)

Run No.	Water Temperature In	Water Temperature Out	Water ΔT	$H_2O \Delta T$ Corr.	Freon Temperature In	Freon Temperature Out	Freon Pressure In	Freon Pressure Out	Freon ΔP	Evap. Pres.	Water Rate #	Water Rate Sec.	Water Rate #/min.	Q
	°C	°C	°C	°C	°C	°C	Psi	Psi	Psi	Psi	#	Sec.	#/min.	Btu/hr.
Coil No. 75, Wolverine 196049-01, 19 fin/inch, 11 ft. $10\frac{1}{2}$ in.														
407	22.04	28.24	6.20	6.40	59.0	31.1	135	97	38	52	30	30.7	58.7	40,600
408	21.95	26.50	4.55	4.75	51.0	29.1	115	92	23	52	30	31.5	57.2	29,900
409	21.98	23.56	1.58	1.78	44.0	25.1	85	80	5	56	30	31.4	57.4	11,020
410	22.05	23.00	0.95	1.15	43.0	24.4	85	80	5	52.5	50	31.0	96.8	12,000
411	21.95	24.85	2.90	3.10	55.0	26.8	114	86	28	43.5	50	30.7	97.8	32,800
412	22.00	26.05	4.05	4.25	57.8	28.1	135	89	46	39	50	31.0	96.8	44,400
413	22.02	24.07	2.05	2.25	47.6	25.8	100.5	84	16.5	42	50	31.0	96.8	23,550
414	21.98	23.50	1.52	1.72	47.4	25.4	100	81.5	18.5	42	50	21.7	138	25,700
415	22.05	24.25	2.20	2.40	52.0	26.2	114.5	86	28.5	39	50	22.0	136	35,400
416	22.05	25.03	2.98	3.18	56.6	26.7	135	85	50	34	50	22.2	135	46,500
417	22.05	24.10	2.05	2.25	59.5	25.9	134.5	82	52.5	32.5	50	15.0	192	46,700
418	21.97	24.05	2.08	2.28	58.3	25.8	135	82	53	48	50	15.6	192	47,300
419	22.02	23.55	1.53	1.73	53.5	25.6	115	81	34	64	50	15.6	192	35,900
420	22.00	32.00	10.00	10.20	54.8	37.2	135	116	19	65	10	24.6	24.4	26,900
421	22.00	29.53	7.53	7.73	49.9	34.0	115.5	105	10.5	66	10	24.9	24.1	20,100
422	21.95	26.90	4.95	5.15	51.0	30.3	100	93	7	68	10	24.9	24.1	13,400
423	22.05	24.45	2.40	2.60	48.0	25.7	85	82	3	53	10	25.7	23.3	6,560
424	21.95	23.00	1.05	1.25	50.7	24.7	100	80	20	62	50	15.6	192	25,900
425	22.00	22.47	0.47	0.67	48.6	24.2	85	78	7	45	50	15.7	191	13,800

TABLE III. CONDENSING WATER PRESSURE DROP

Water Temp.	Pressure Gauge Reading inlet	outlet	Manometer Reading left	right	ΔP Corr.	Water Rate		
°C	Psi	Psi	in. Hg	in. Hg	Psi	#	Sec.	#/min.
Coil No. 73, Wolverine 196049-01, 19 fin/inch, 4 ft. 7 in.								
7.8	45.9	30.8			13.9	50	15.3	196
7.8	46.2	31.3			13.7	50	15.4	195
7.8	57.0	48.5			7.3	50	22.1	136
7.6	30.3	16.6			12.6	50	16.2	185
7.6	24.3	13.4			9.8	50	18.0	166.5
7.6			- 3.8	+ 4.3	3.69	50	30.9	97
7.65			- 8.4	+ 8.6	7.75	50	20.5	146.5
7.65			-10.0	+10.1	9.15	50	19.0	158
7.65			- 5.6	+ 6.0	5.28	50	25.7	117
7.65			- 2.0	+ 2.5	2.05	50	42.6	70.4
7.7			- 1.2	+ 1.75	1.34	50	53.9	55.6
Coil No. 74, Wolverine 196049-01, 19 fin/inch, 5 ft. 11½ in.								
8.2	37.0	20.6			15.2	50	14.4	208
8.1	32.1	17.8			13.2	50	15.4	195
8.05	24.4	13.6			9.7	50	18.0	167
8.0	26.3	14.5			10.7	50	17.1	175.5
8.0	21.5	11.9			8.5	50	18.5	162
8.0			- 9.0	+ 9.2	8.31	50	19.9	151
8.0			- 7.7	+ 8.0	7.17	50	21.9	137
7.8			- 5.95	+ 6.35	5.62	50	24.9	120.5
7.8			- 4.6	+ 5.1	4.44	50	28.3	106
7.7			- 3.1	+ 3.65	3.1	50	34.2	87.7
8.0			- 2.0	+ 2.6	2.12	50	42.3	70.9
8.05			- 1.1	+ 1.7	1.3	50	55.5	54
Coil No. 77, Wolverine 60-115032-01, 11 fin/inch, 12 ft. 8 in.								
8.5	55.5	13.2			41.1	50	17.9	167.5
8.4	53.5	11.3			41.0	50	19.5	154
8.4	44.8	10.5			33.1	50	20.1	149
8.35	44.3	9.1			34.0	50	21.6	139
8.35	32.5	7.6			23.8	50	23.8	126
8.4	25.4	5.9			18.4	50	26.9	111.5
8.5	18.6	4.3			13.2	50	31.7	94.6
8.5			+10.8	- 9.7	9.37	50	38.7	77.5
8.55			+ 7.9	- 7.1	6.86	50	45.5	66
8.6			+ 6.05	- 5.25	5.17	50	52.1	57.5
8.7			+ 4.6	- 3.8	3.85	50	62.0	48.4

TABLE III (Continued)

Water Temp.	Pressure Gauge Reading inlet	outlet	Manometer Reading left	right	ΔP Corr.	Water Rate		
°C	Psi	Psi	in. Hg	in. Hg	Psi	#	Sec.	#/min.
Coil No. 75, Wolverine 196049-01, 19 fin/inch, 11 ft. 10½ in.								
7.4	42.5	17.0			24.3	50	15.7	191
7.5	31.5	12.5			17.9	50	18.6	161
7.5	36.0	14.4			20.5	50	17.2	174
7.7	30.2	12.0			17.1	50	19.0	158
7.65	25.2	10.2			13.9	50	20.8	144
7.7	22.2	9.0			12.1	50	22.2	135
7.7			-11.3	+11.5	10.4	50	24.5	122.5
7.7			- 9.2	+ 9.6	8.55	50	27.5	109
7.7			- 7.3	+ 7.7	6.81	50	31.1	96.5
7.75			- 4.8	+ 5.3	4.58	50	39.0	77
7.8			- 3.8	+ 4.4	3.71	50	43.7	68.6
7.8			- 2.35	+ 2.95	2.39	70	77.8	54
7.9			- 1.45	+ 2.15	1.62	50	68.5	43.8
Coil No. 78, Wolverine 60-115032-01, 11 fin/inch, 6 ft.								
7.9	45.5	16.5			27.8	50	15.8	190
7.85	46.5	16.8			28.5	50	16.5	182
7.85	46.5	17.0			28.3	50	15.8	190
7.8	42.7	15.4			26.1	50	16.5	182
7.8	40.5	14.7			24.6	50	17.0	176.5
7.8	35.0	12.6			21.3	50	18.0	167
7.85	30.0	10.9			18.0	50	20.0	150
7.9	21.7	8.2			12.4	50	23.5	128
7.9			-11.3	+11.4	10.3	50	26.3	114
8.0			- 7.0	+ 7.4	6.6	50	33.5	89.5
8.0			- 8.7	+ 9.0	8.1	50	30.3	99.2
8.05			- 5.7	+ 6.2	5.45	50	37.1	80.9
8.1			- 3.2	+ 3.8	3.21	50	48.8	61.5
8.1			- 4.0	+ 4.5	3.9	50	44.0	68.1
8.3			- 2.2	+ 2.8	2.3	50	57.9	51.9
8.5			- 1.25	+ 1.9	1.46	50	74.8	40.1

TABLE III (Concluded)

Water Temp.	Manometer Reading left	Manometer Reading right	ΔP Corr.	Water Rate		
°C	in. Hg	in. Hg	Psi	#	Sec.	#/min.
Coil No. 79, Wolverine 60-115032-01, 11 fin/inch, 3 ft. 6½ in.						
7.8	-13.8	+13.9	12.6	50	19.5	154
7.7	-11.7	+11.9	10.75	50	20.5	146.5
7.7	-10.4	+10.7	9.6	50	22.4	134
7.7	- 8.0	+ 8.4	7.46	50	25.0	120
7.7	- 6.2	+ 6.7	5.88	50	28.6	104
7.7	- 4.4	+ 5.0	4.28	50	33.7	89
7.75	- 2.9	+ 3.6	2.96	50	40.9	73.4
7.8	- 1.8	+ 2.5	1.96	50	50.8	59
7.9	- 1.15	+ 1.95	1.41	50	60.1	49.9
8.0	- 0.6	+ 1.4	0.91	50	76.6	39.2

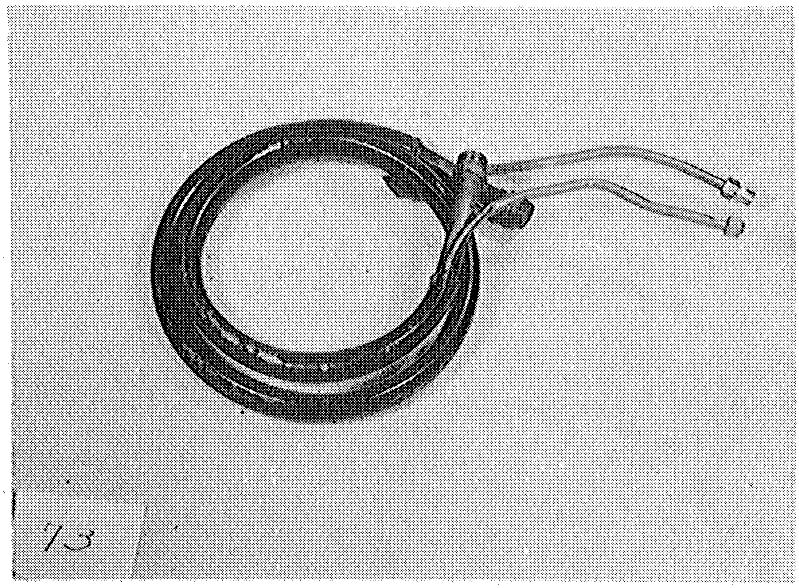

Fig. 1. 4'-7" long 19-fin-per-inch coaxial coil.

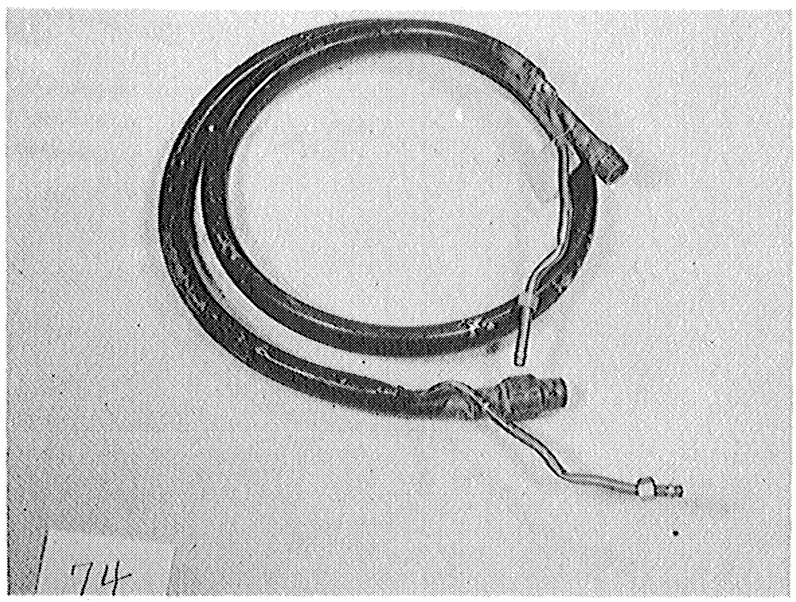

Fig. 2. 5'-11-1/2" long 19-fin-per-inch coaxial coil.

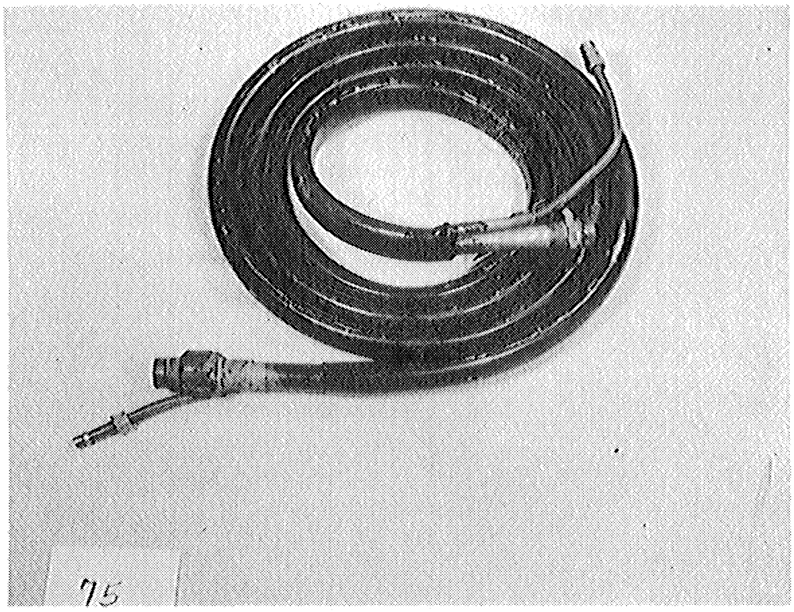

Fig. 3. 11'-10-1/2" long 19-fin-per-inch coaxial coil.

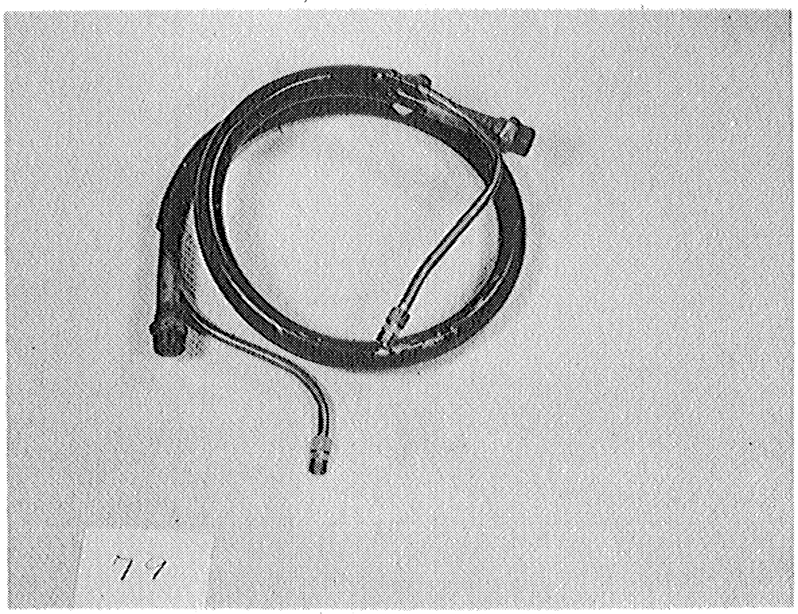

Fig. 4. 3'-6-1/2" long 11-fin-per-inch coaxial coil.

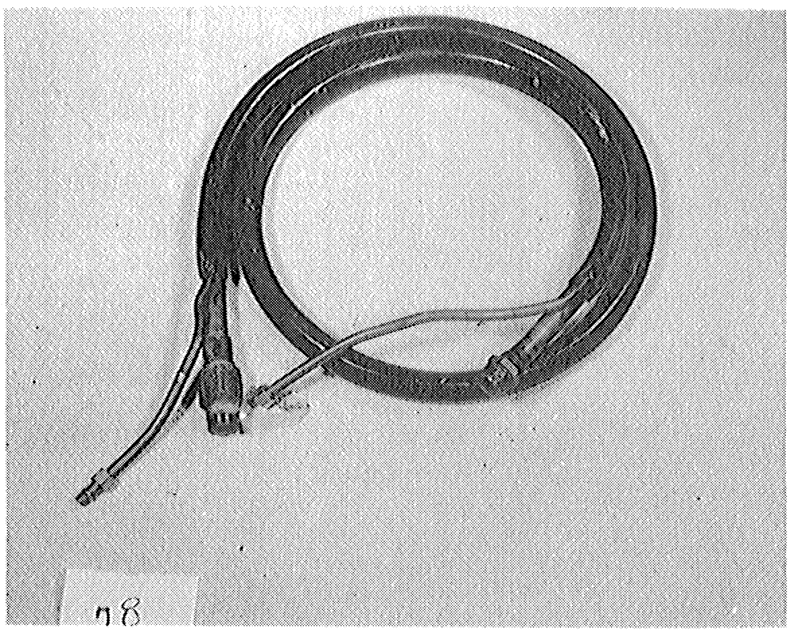

Fig. 5. 6'-0" long 11-fin-per-inch coaxial coil.

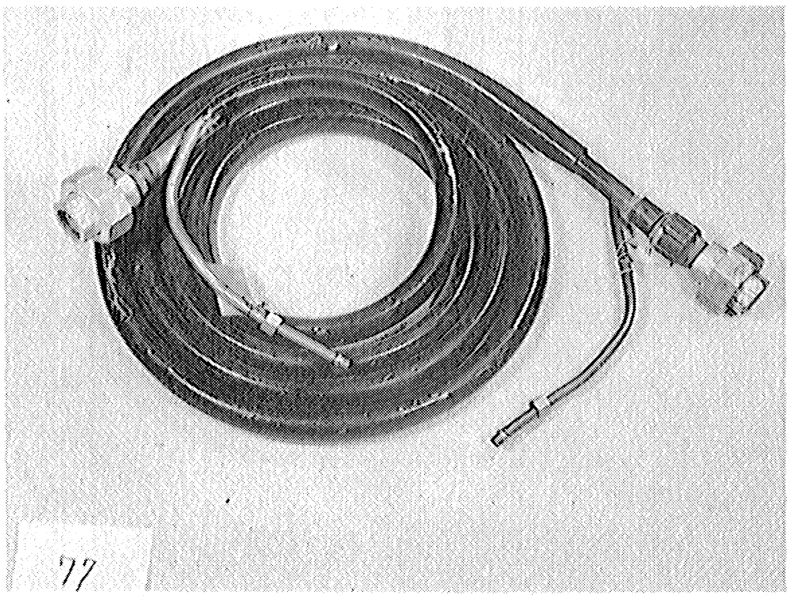

Fig. 6. 12'-8" long 11-fin-per-inch coaxial coil.

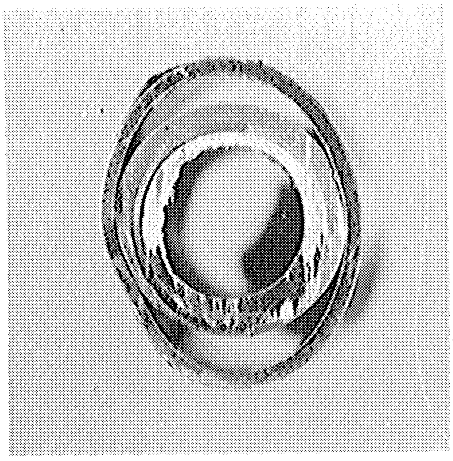

Fig. 7. Cross-sectional view of the 11-fin-per-inch coil.

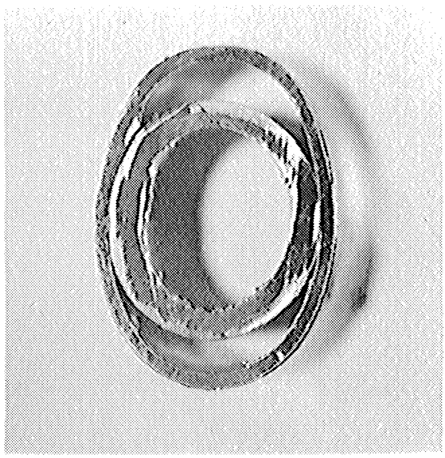

Fig. 8. Cross-sectional view of the 19-fin-per-inch coil.

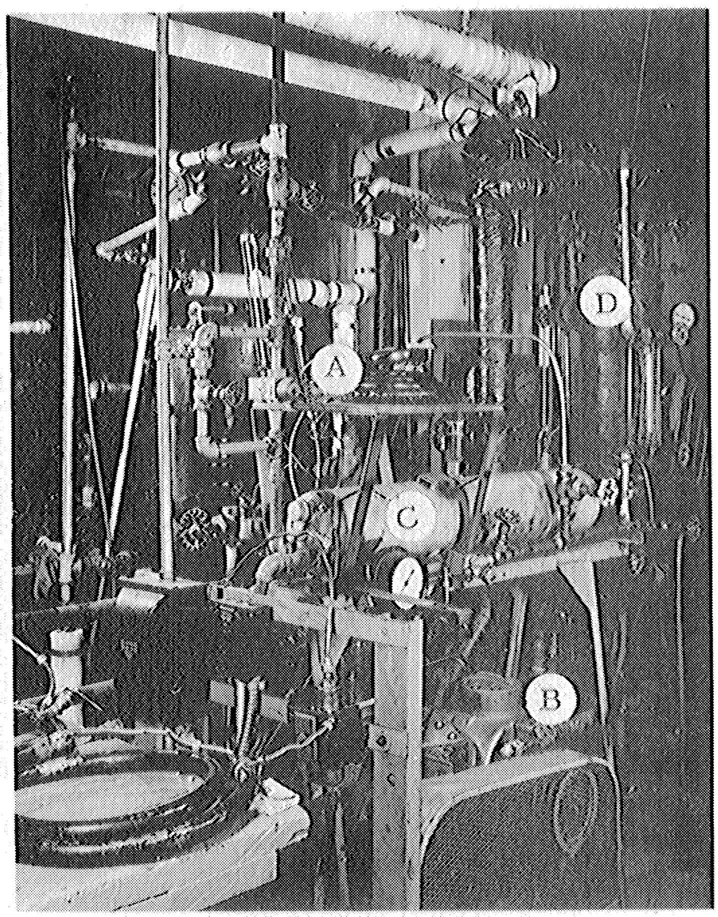

Fig. 9. Compressor and condensing section.

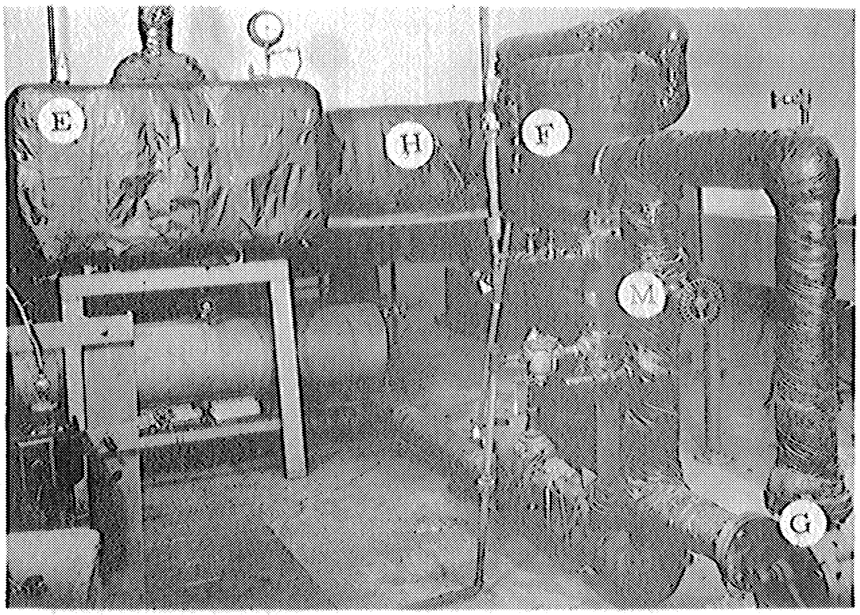

Fig. 10. Freon-12 evaporator and evaporator water system.

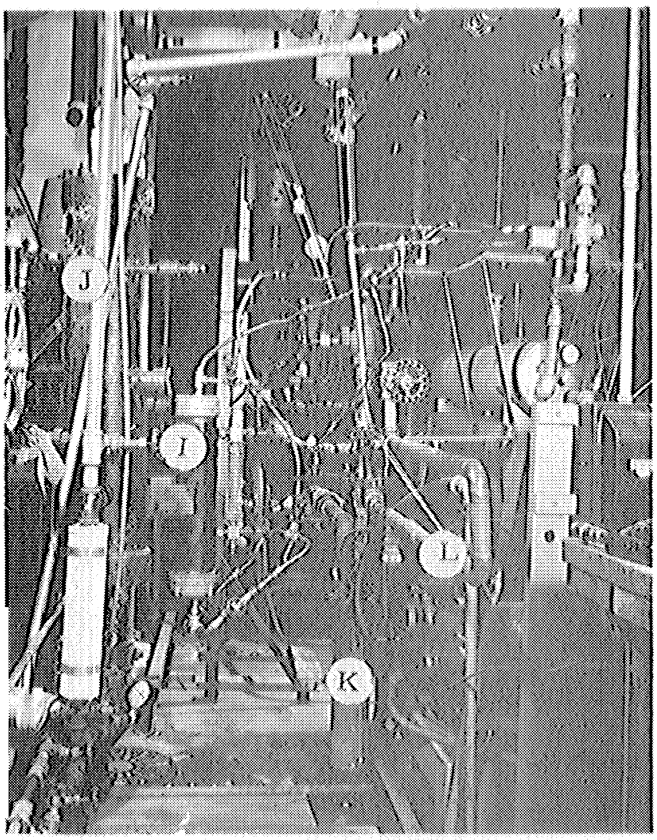

Fig. 11. View of the liquid seal and the desuperheater.

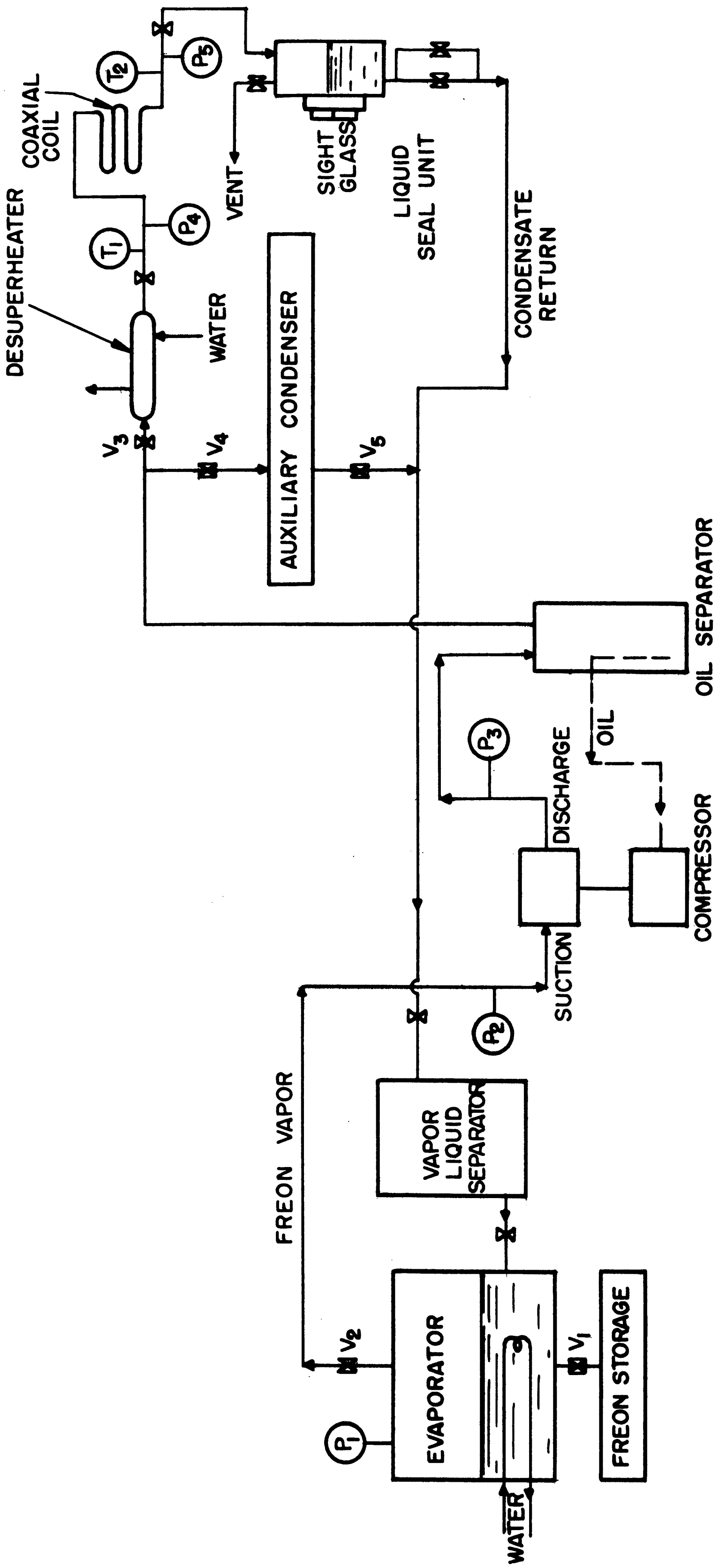

Fig. 12. Freon circuit.

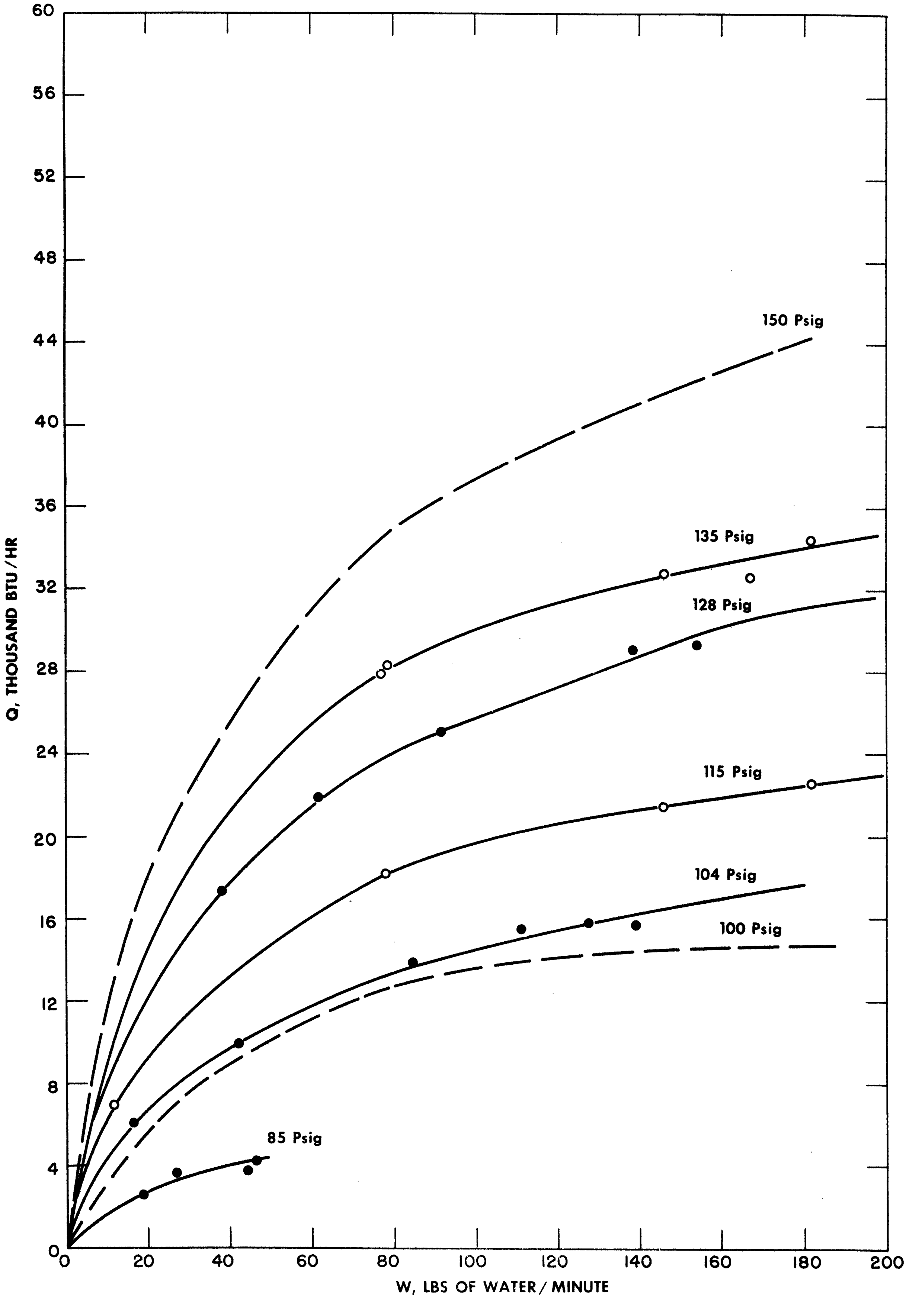

Fig. 13. Heat transfer performance of coil No. 79 (11 fins/inch - 3'-6-1/2" long).

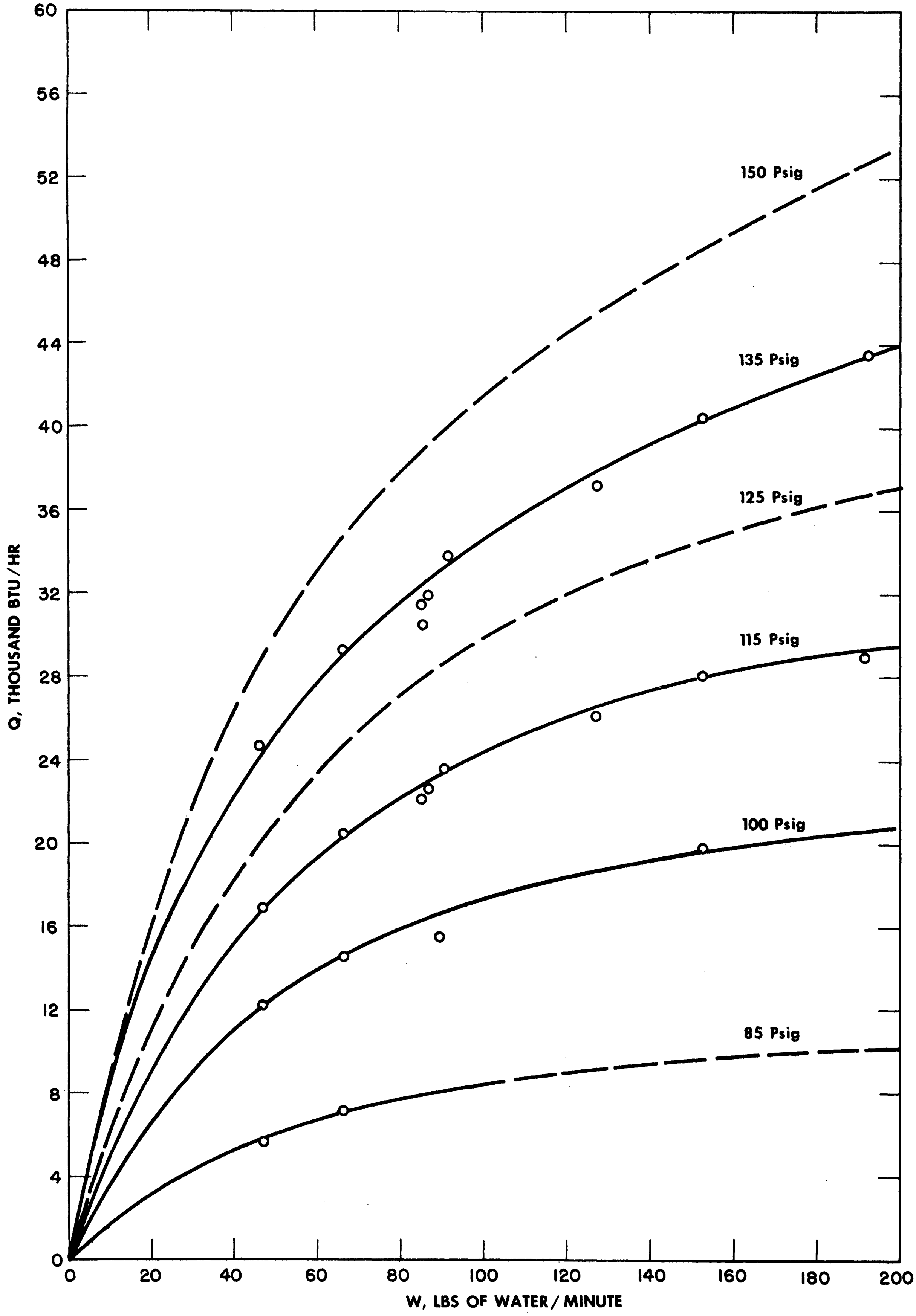

Fig. 14. Heat transfer performance of coil No. 73 (19 fins/inch - 4'-7" long).

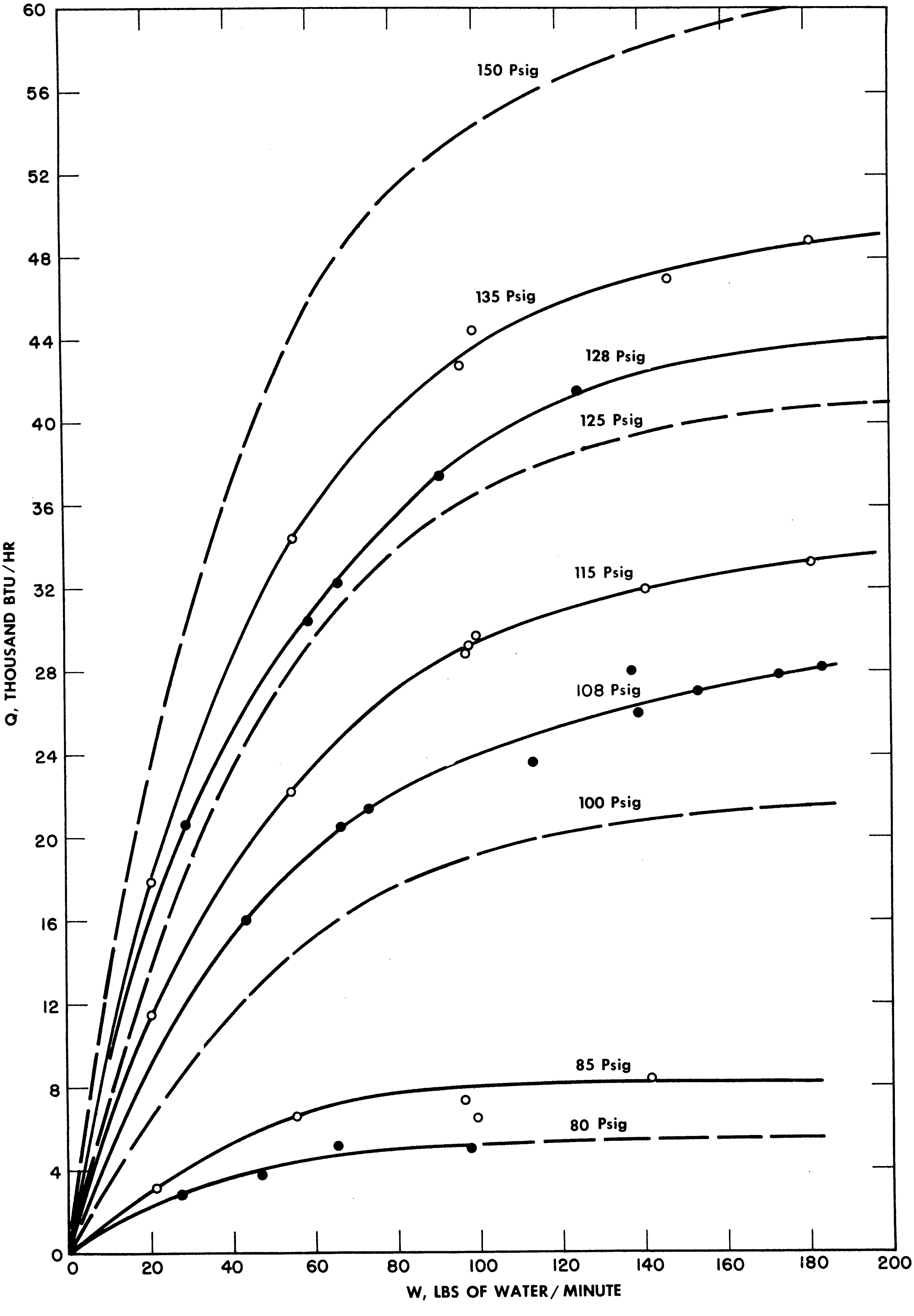

Fig. 15. Heat transfer performance of coil No. 78 (11 fins/inch - 6'-0" long).

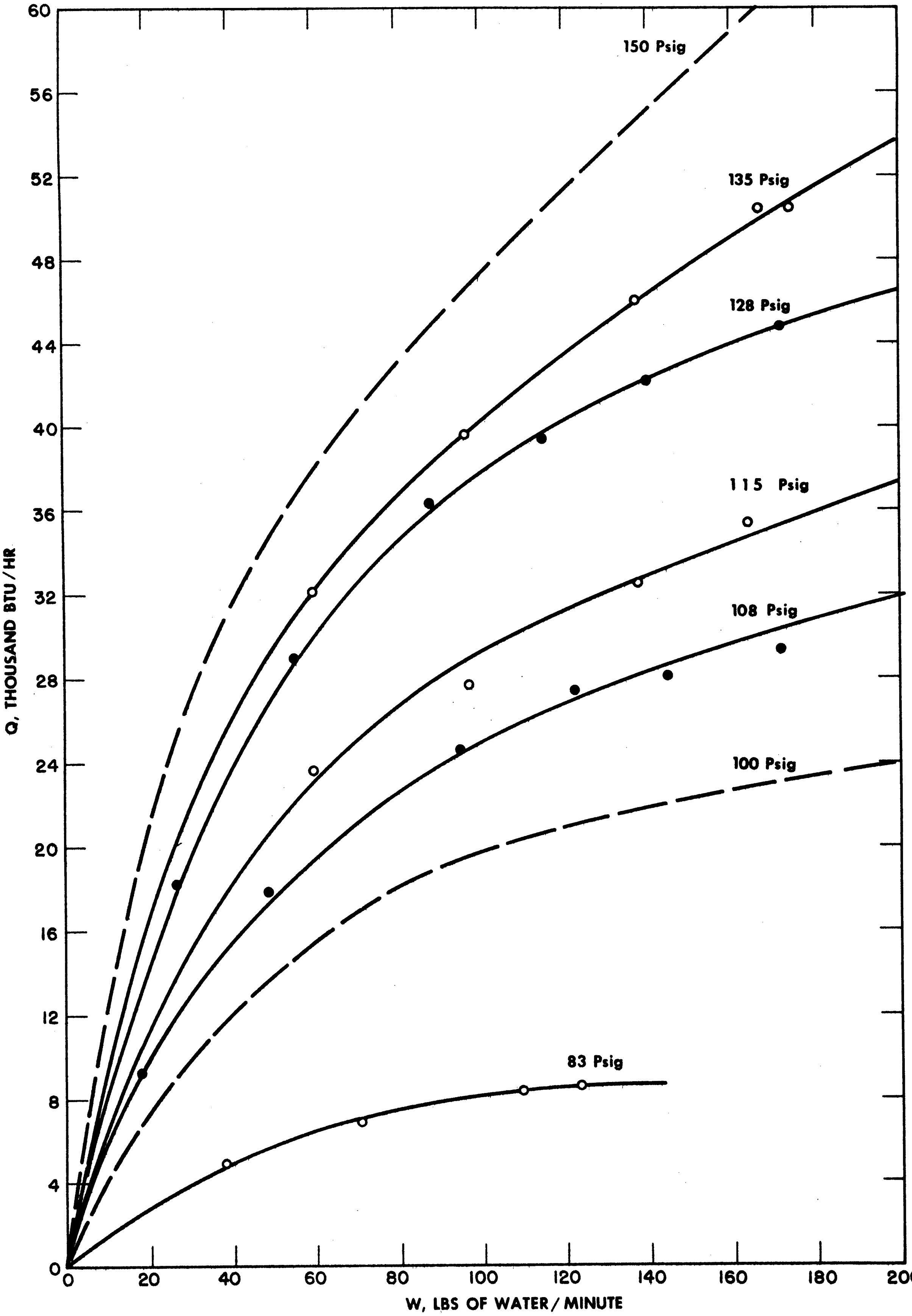

Fig. 16. Heat transfer performance of coil No. 74 (19 fins/inch - 5'-11-1/2" long).

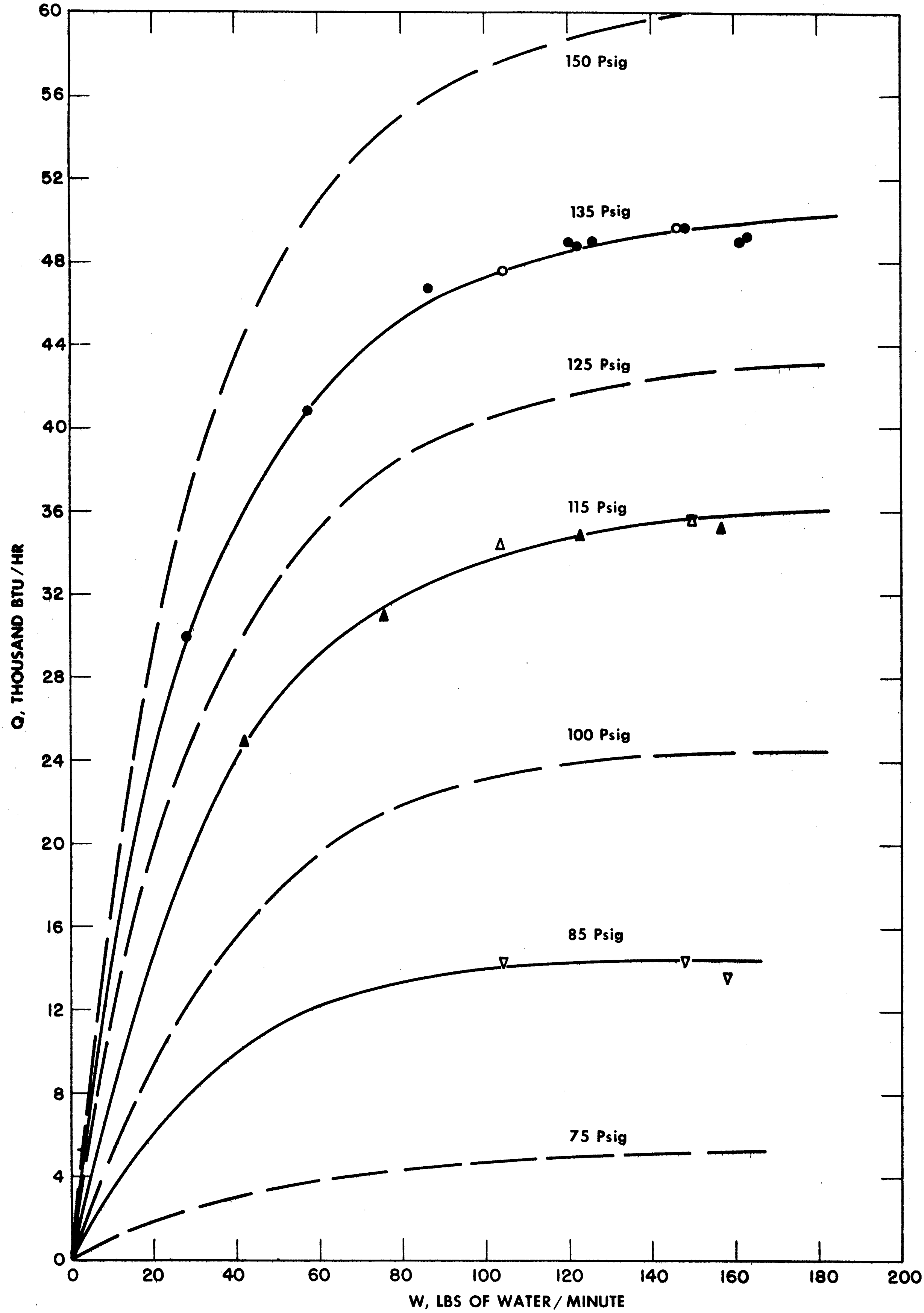

Fig. 17. Heat transfer performance of coil No. 77 (11 fins/inch - 12'-8" long).

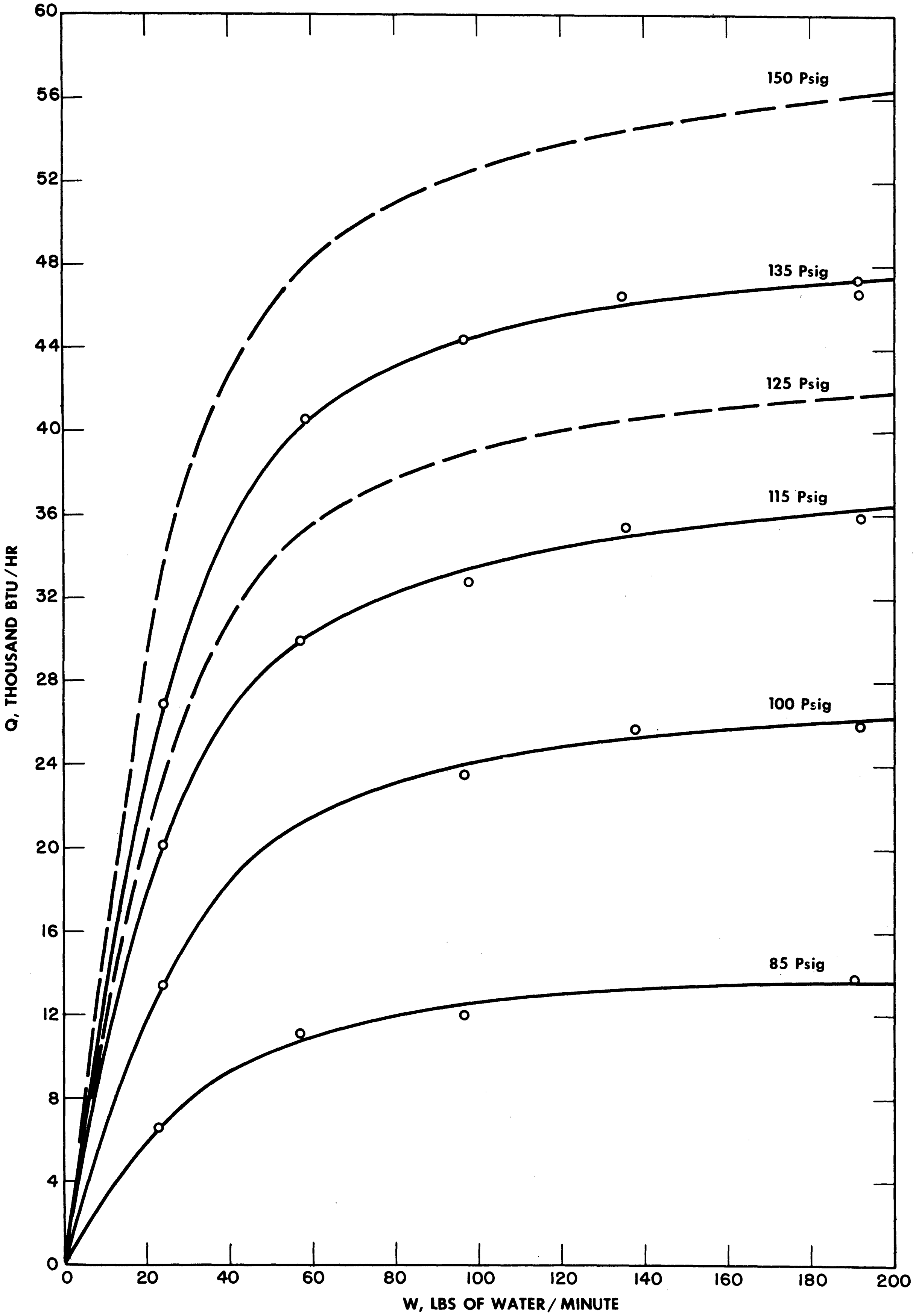

Fig. 18. Heat transfer performance of coil No. 75 (19 fins/inch - 11'-10-1/2" long).

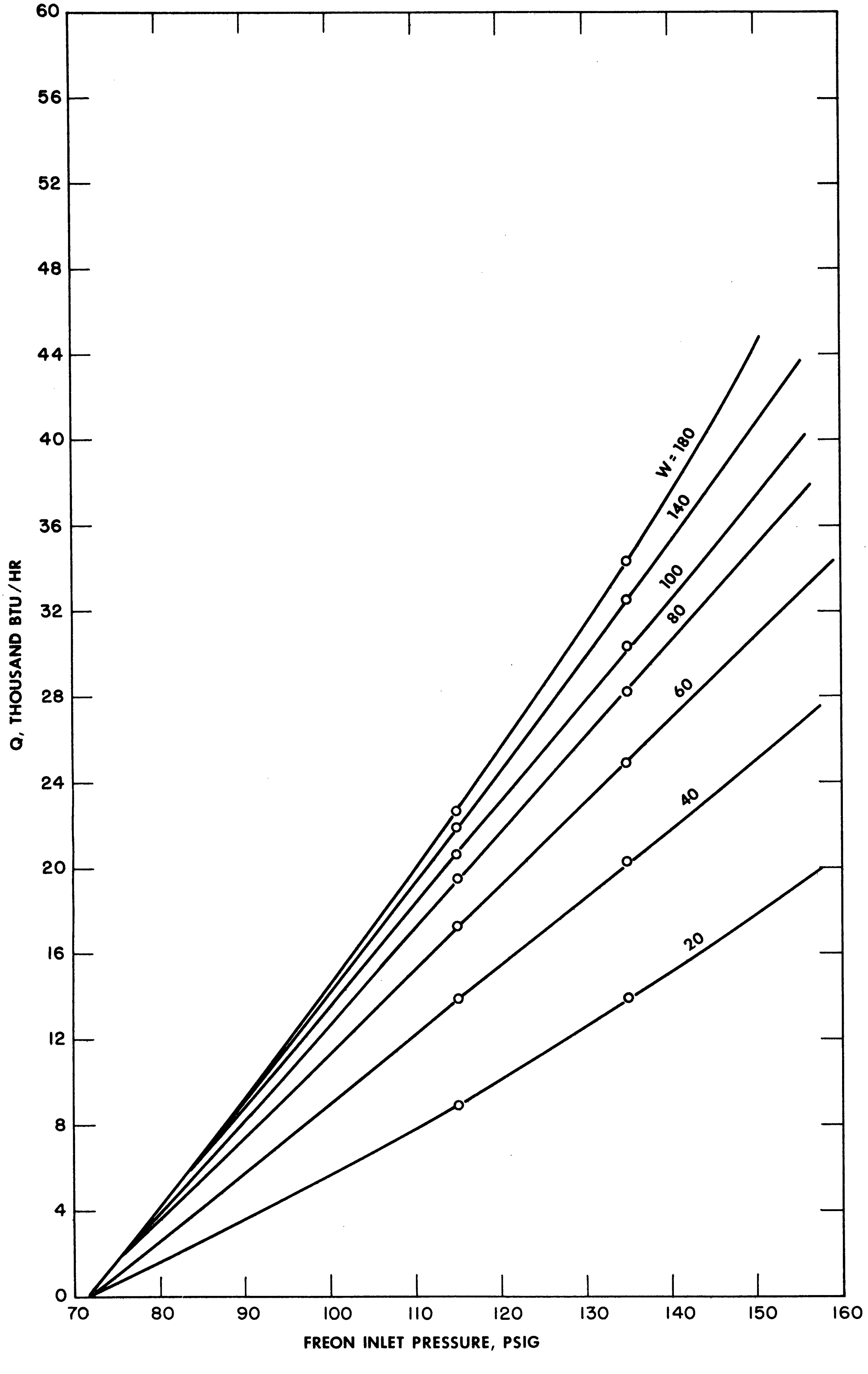

Fig. 19. Heat transfer performance cross-plot for coil No. 79.

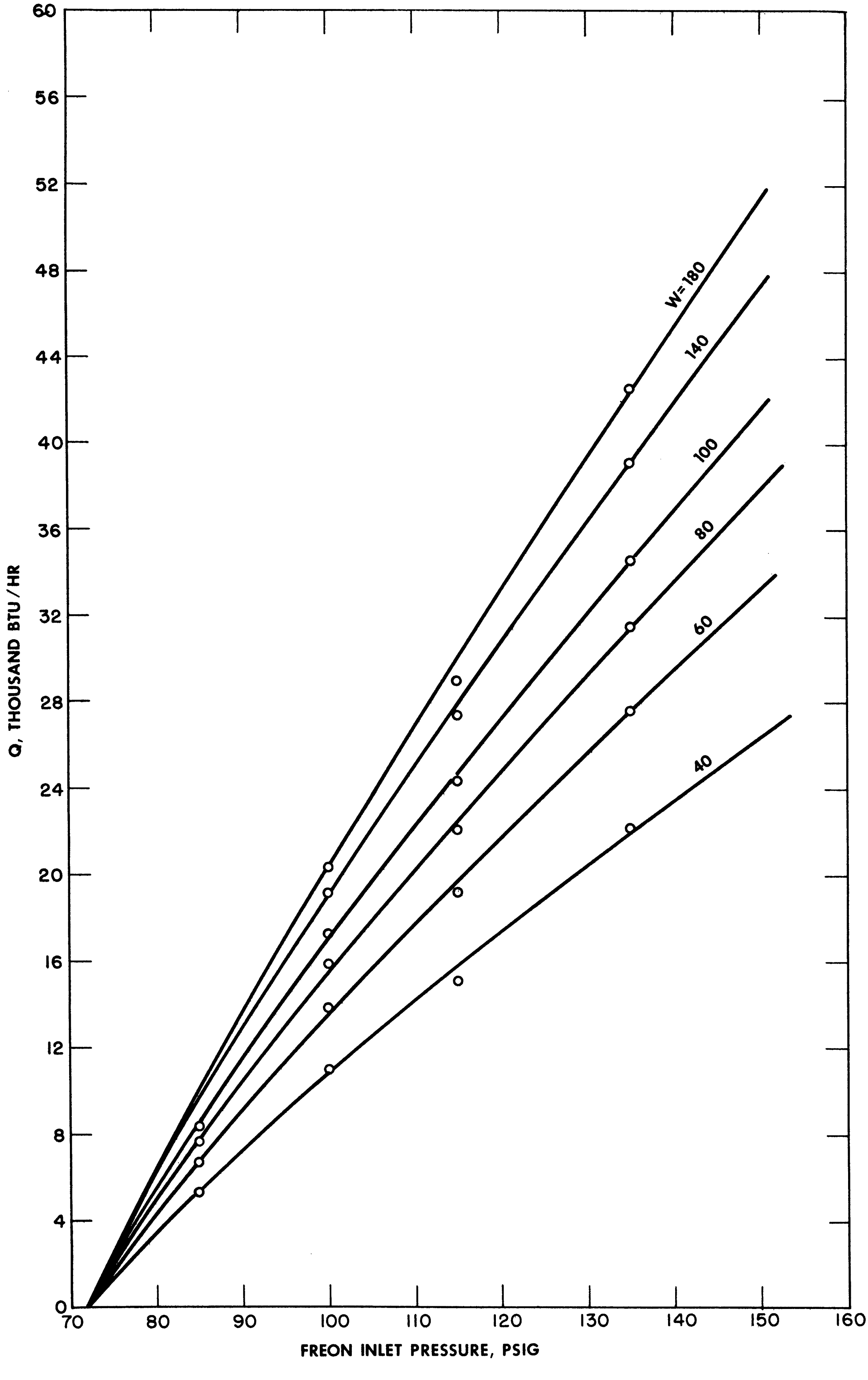

Fig. 20. Heat transfer performance cross-plot for coil No. 73.

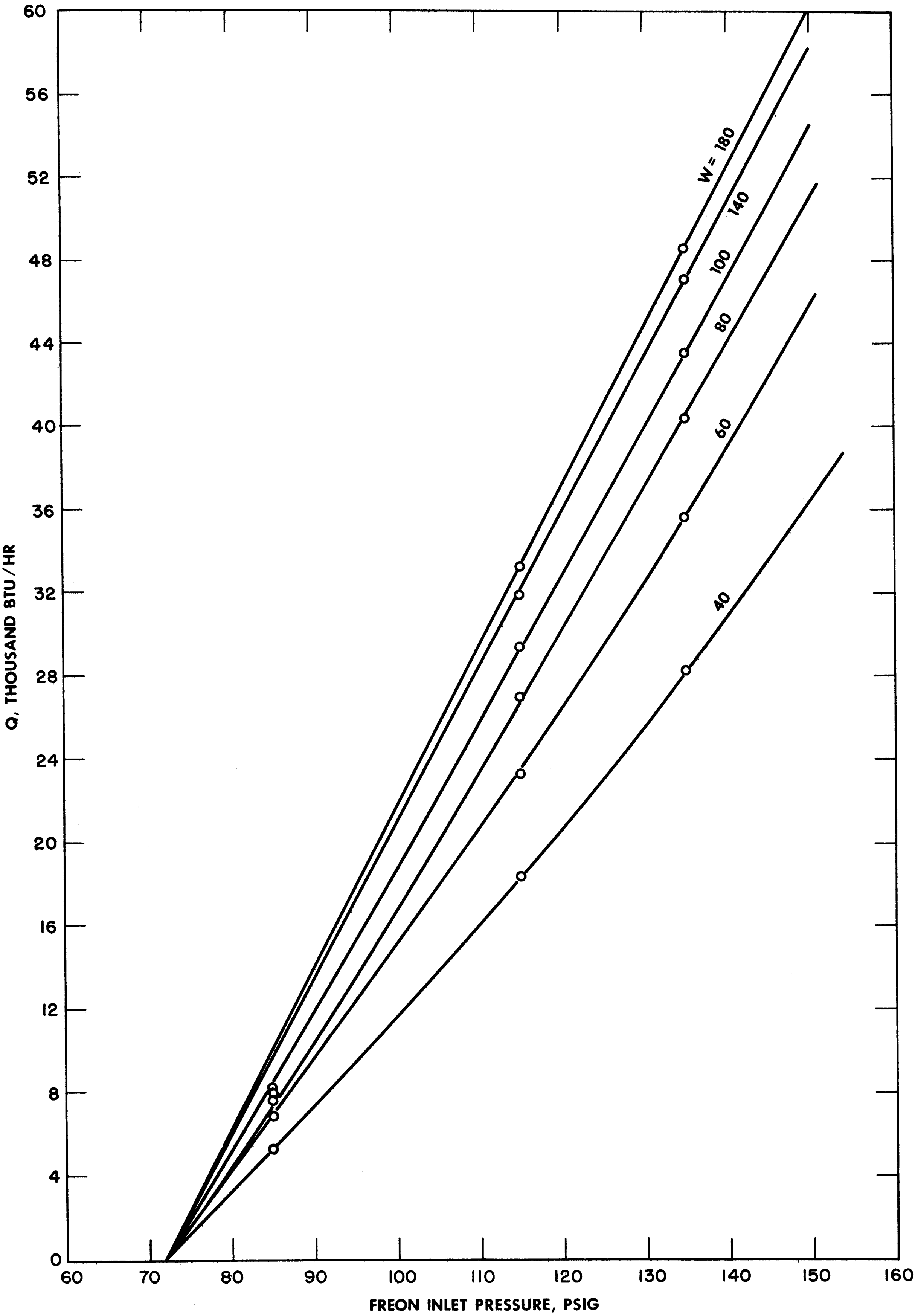

Fig. 21. Heat transfer performance cross-plot for coil No. 78.

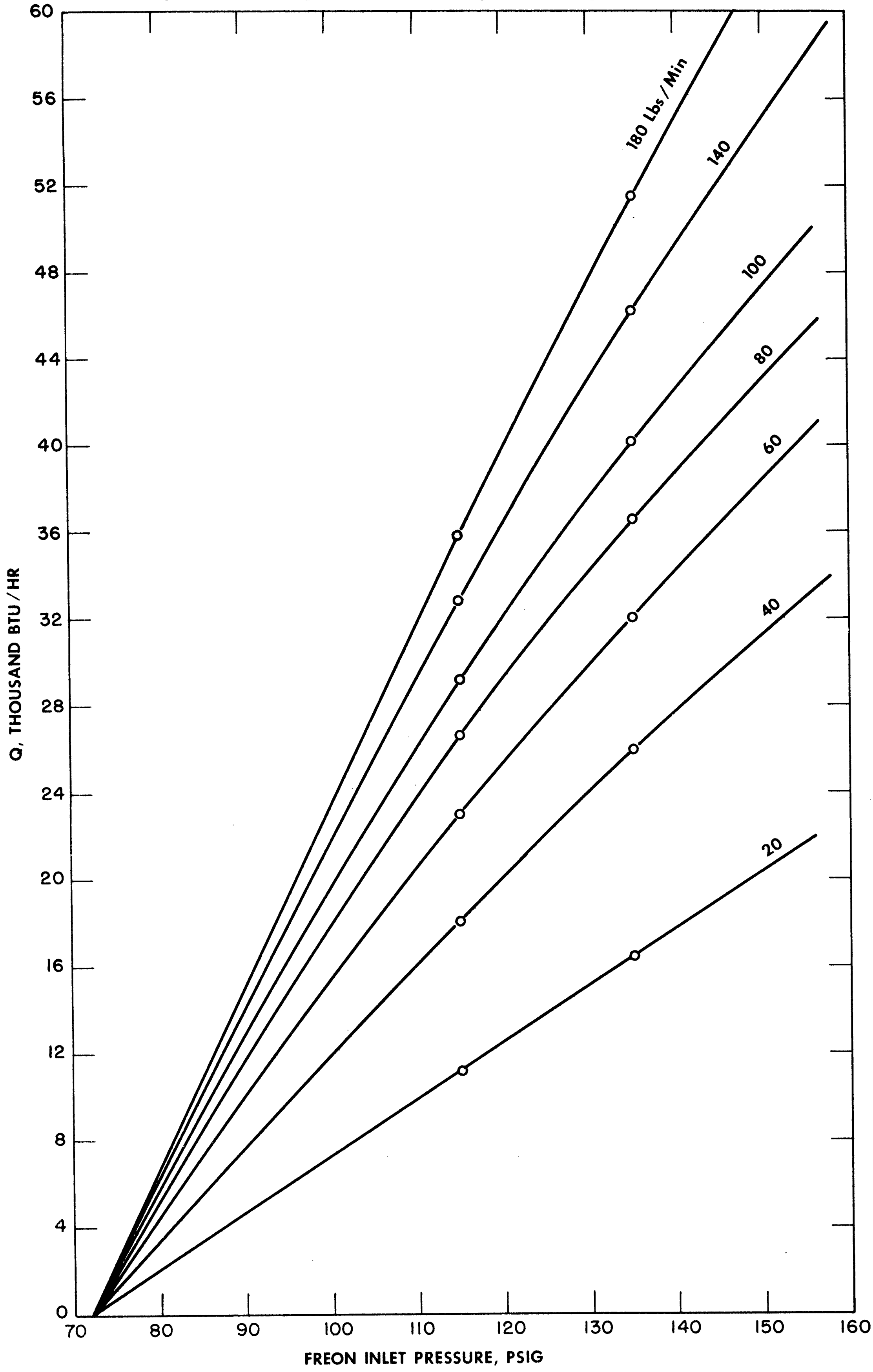

Fig. 22. Heat transfer performance cross-plot for coil No. 74.

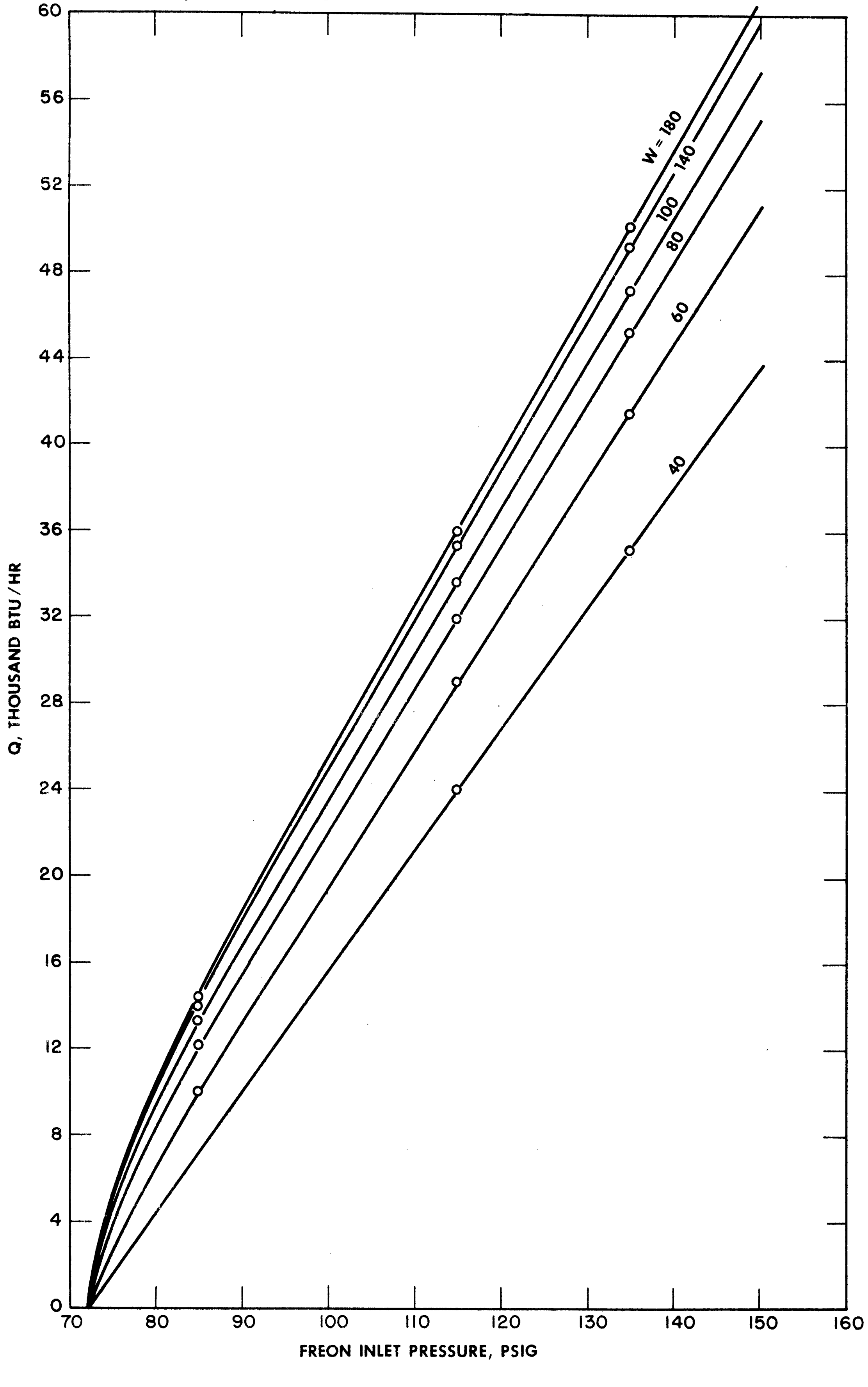

Fig. 23. Heat transfer performance cross-plot for coil No. 77.

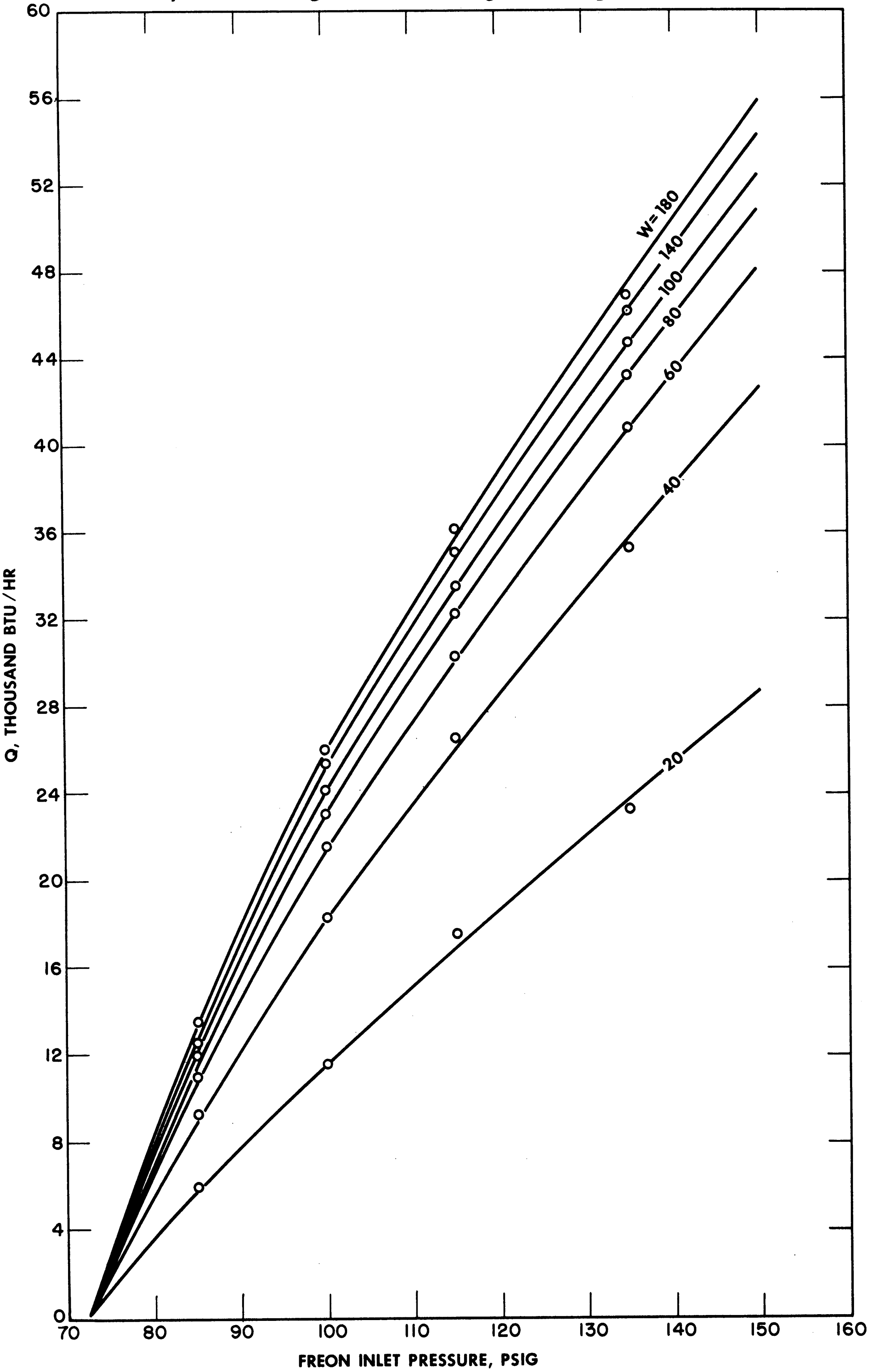

Fig. 24. Heat transfer performance cross-plot for coil No. 75.

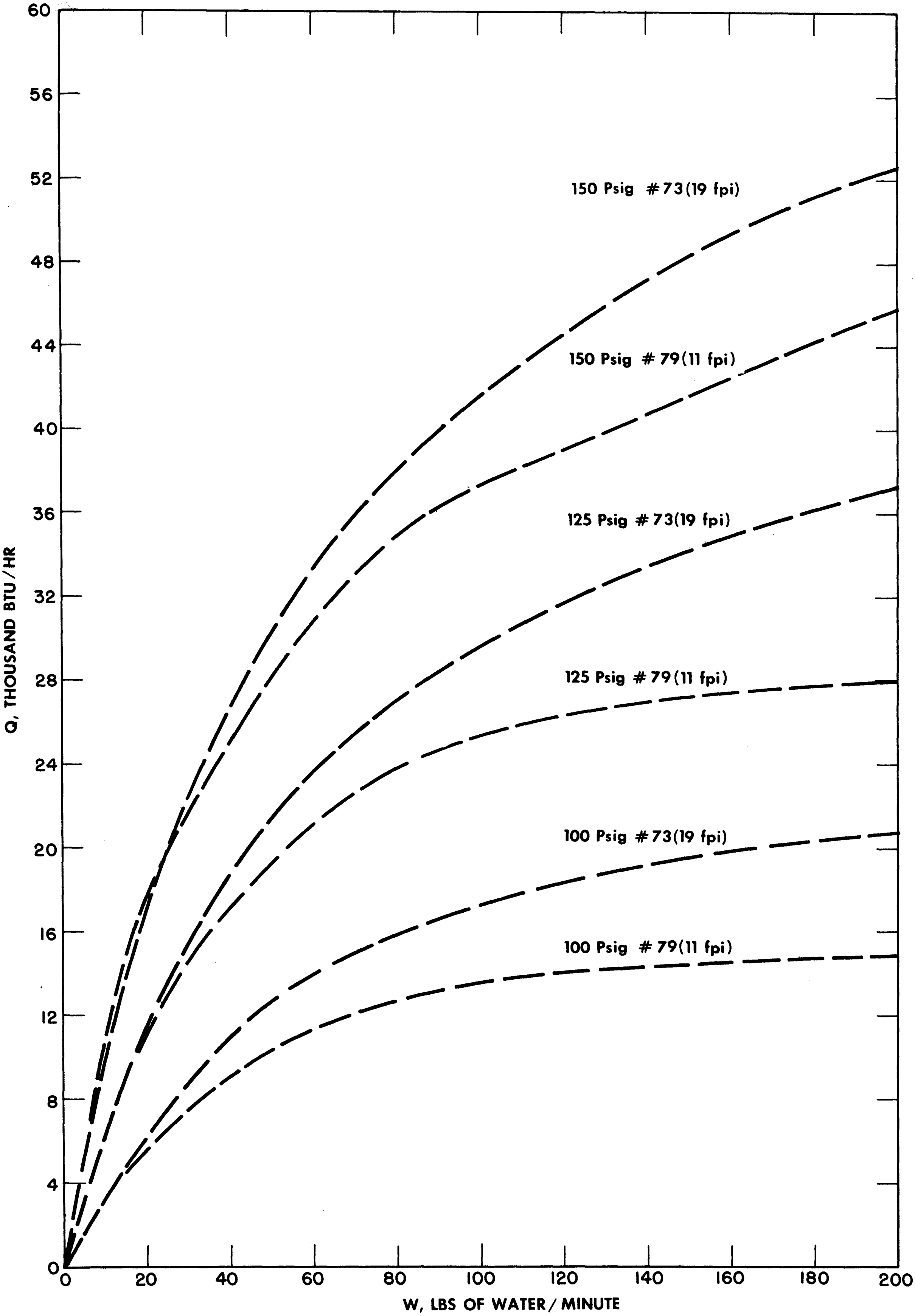

Fig. 25. Summary of performance of four-foot coils.

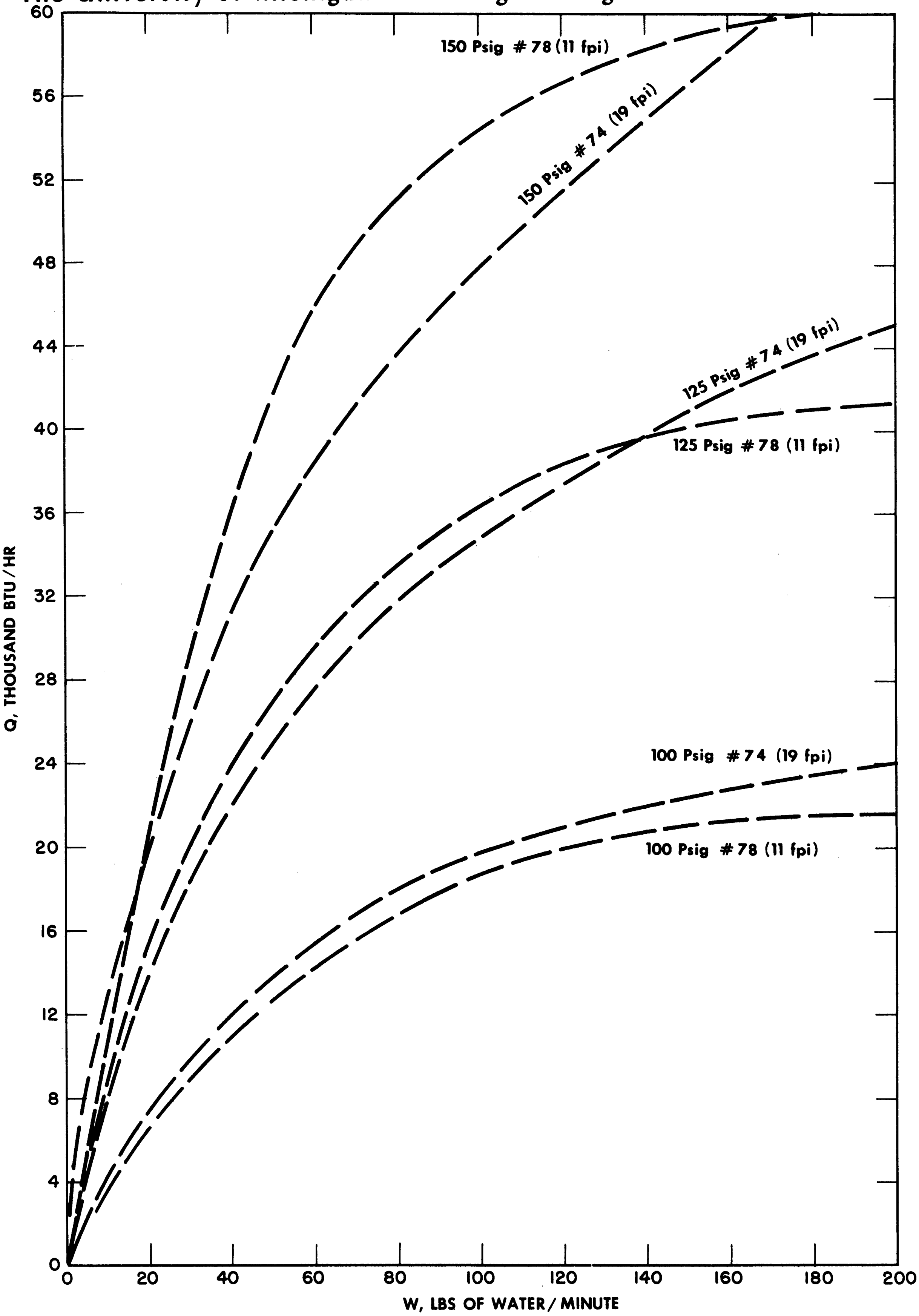

Fig. 26. Summary of performance of six-foot coils.

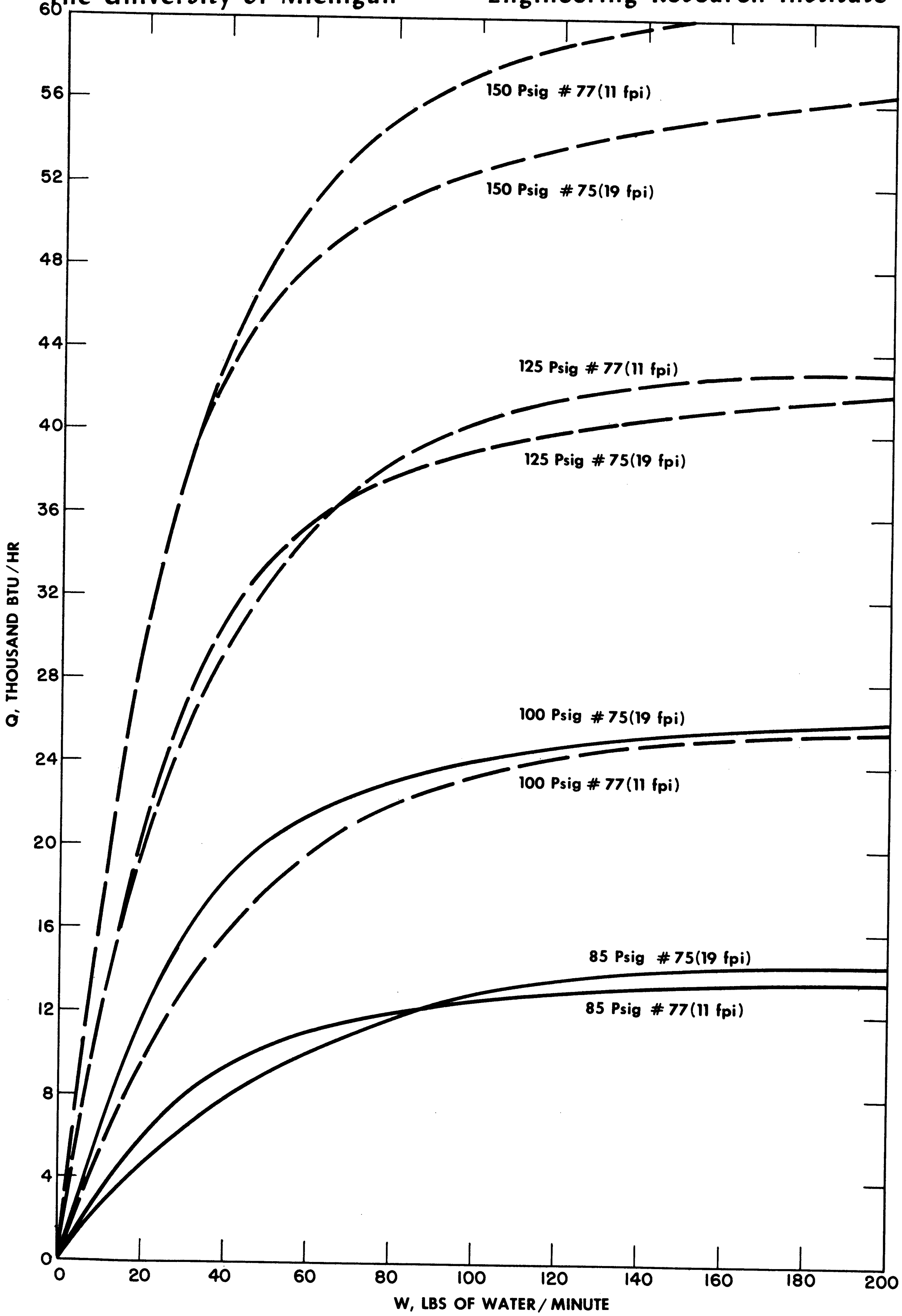

Fig. 27. Summary of performance of twelve-foot coils.

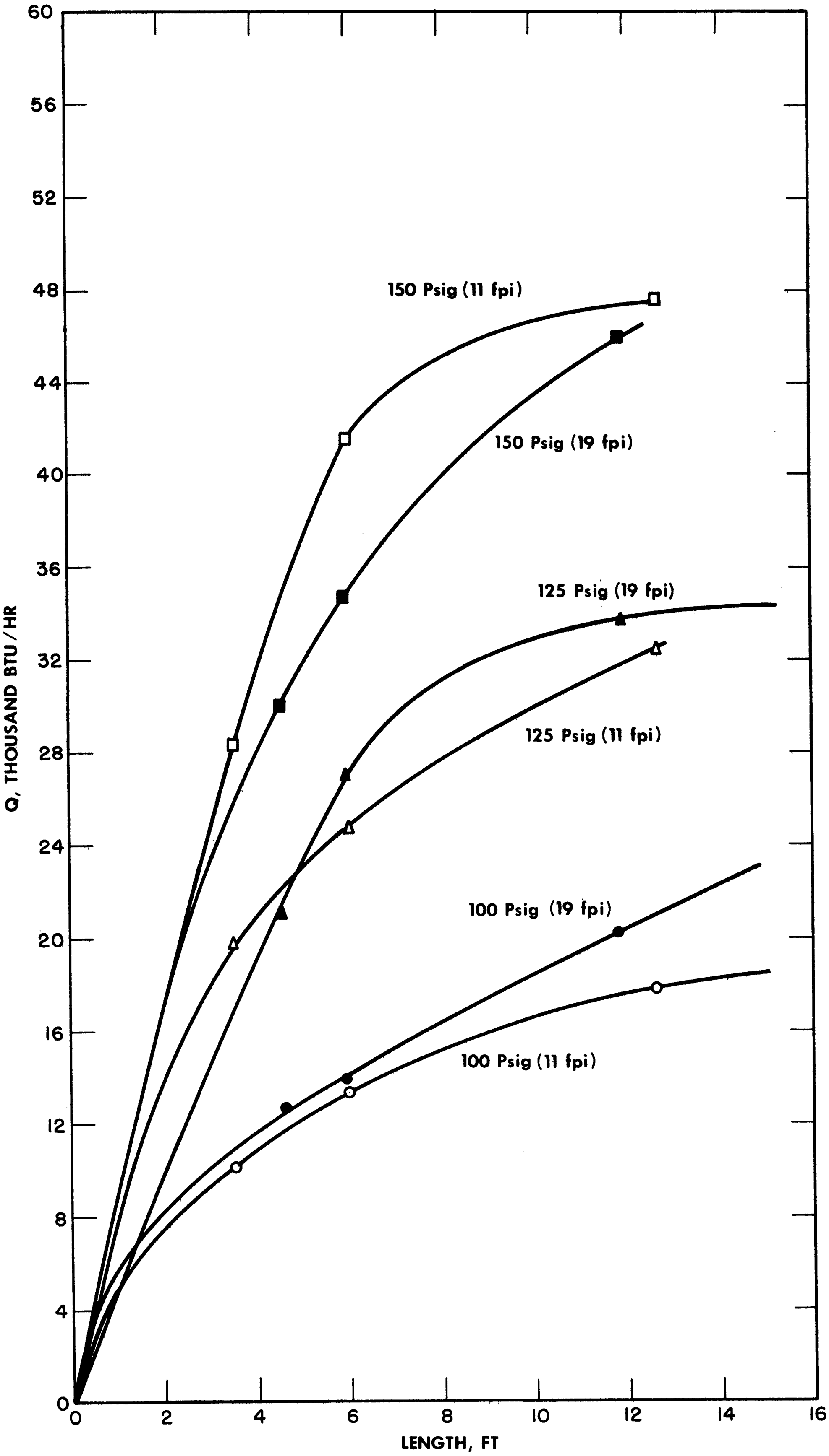

Fig. 28. Effect of length of coil on heat load with a constant water flow rate of 50 lbs. per minute.

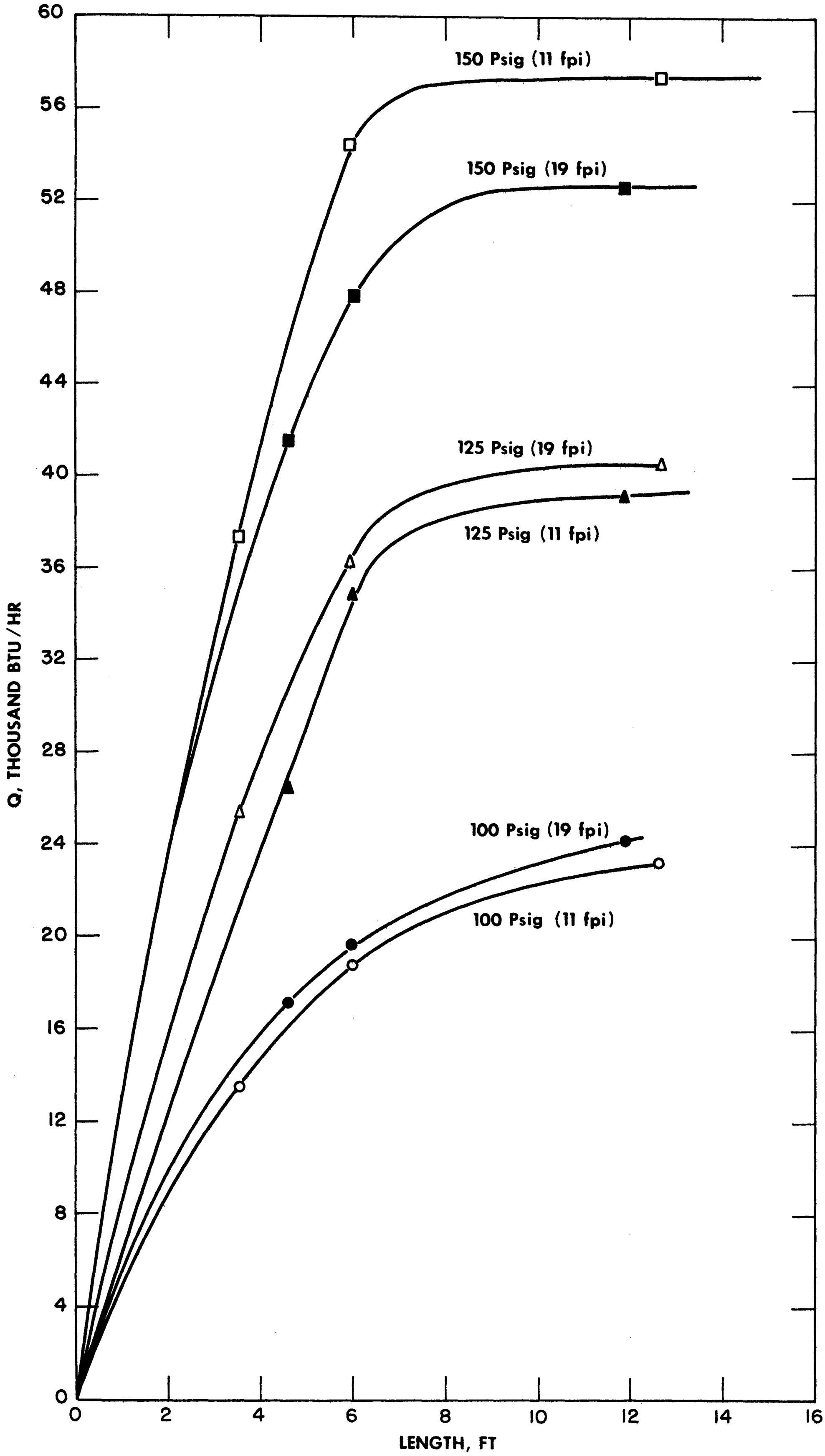

Fig. 29. Effect of length of coil on heat load with a constant water flow rate of 100 lbs. per minute.

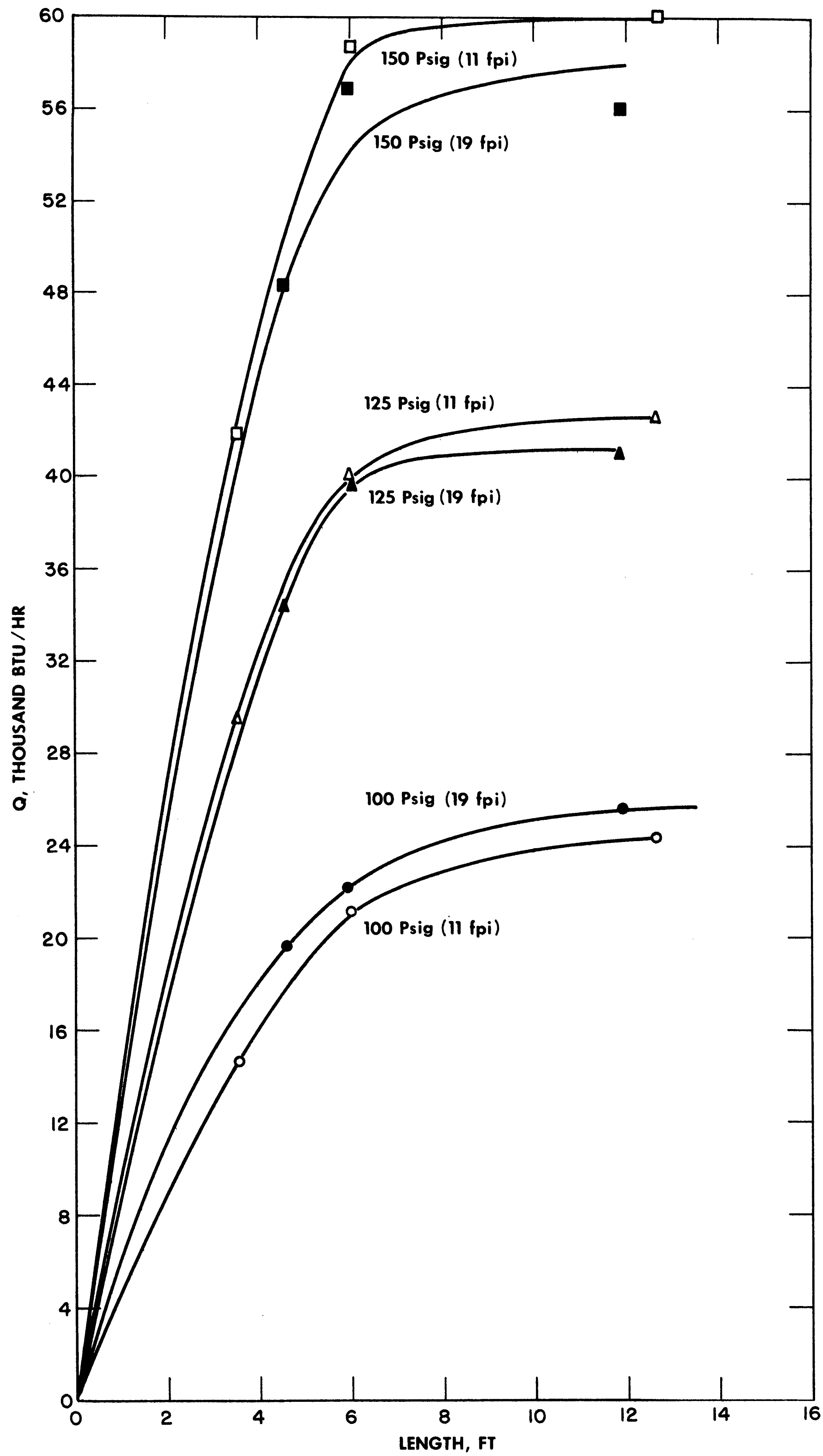

Fig. 30. Effect of length of coil on heat load with a constant water flow rate of 150 lbs. per minute.

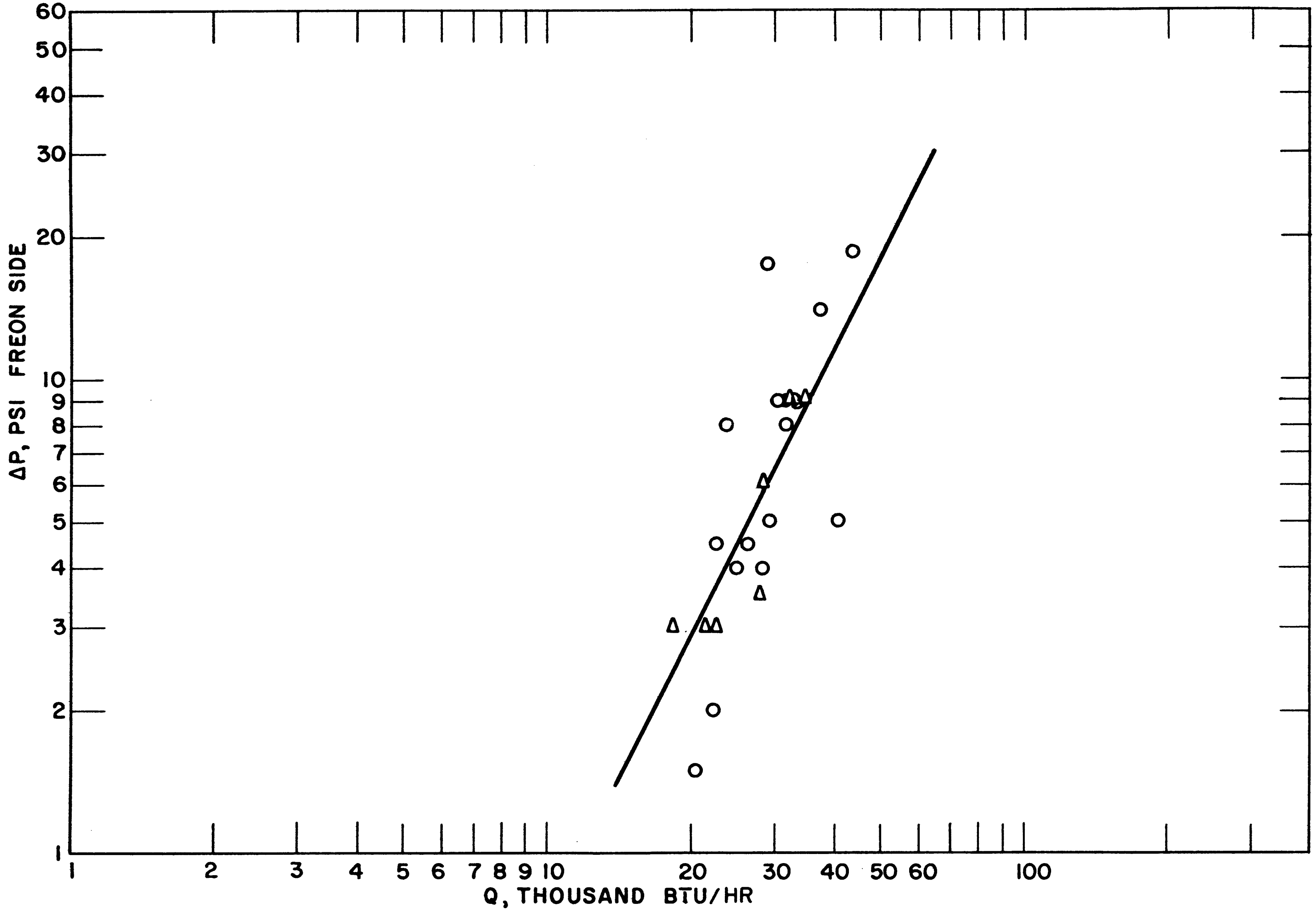

Fig. 31. Summary of pressure drop data for the four-foot coils.
[O coil No. 73 (19 fins/inch)]
[Δ coil No. 79 (11 fins/inch)]

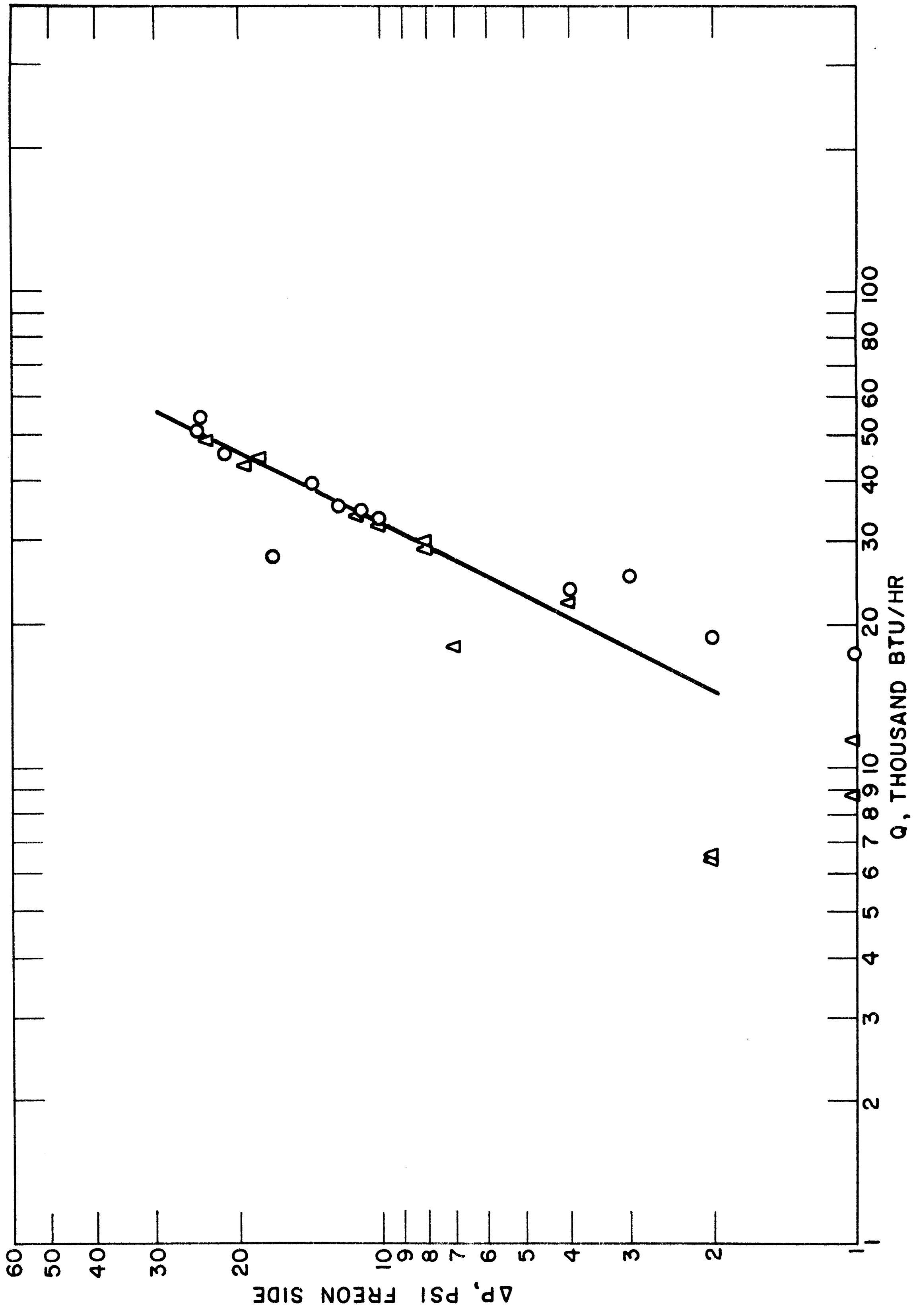

Fig. 32. Summary of pressure drop data for the six-foot coils.
[O coil No. 74 (19 fins/inch)]
[Δ coil No. 78 (11 fins/inch)]

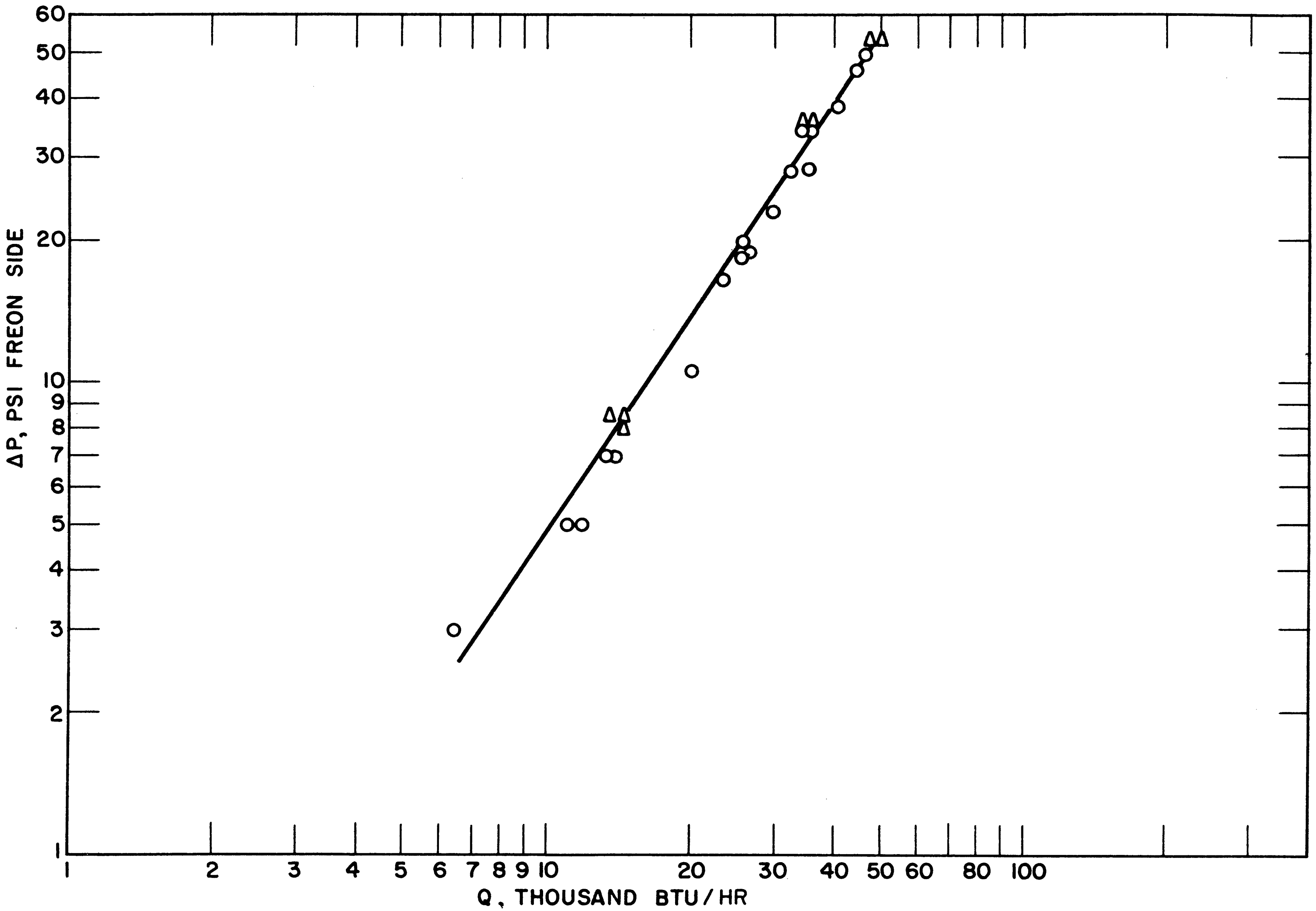

Fig. 33. Summary of pressure drop data for the twelve-foot coils.
[O coil No. 75 (19 fins/inch)]
[Δ coil No. 77 (11 fins/inch)]

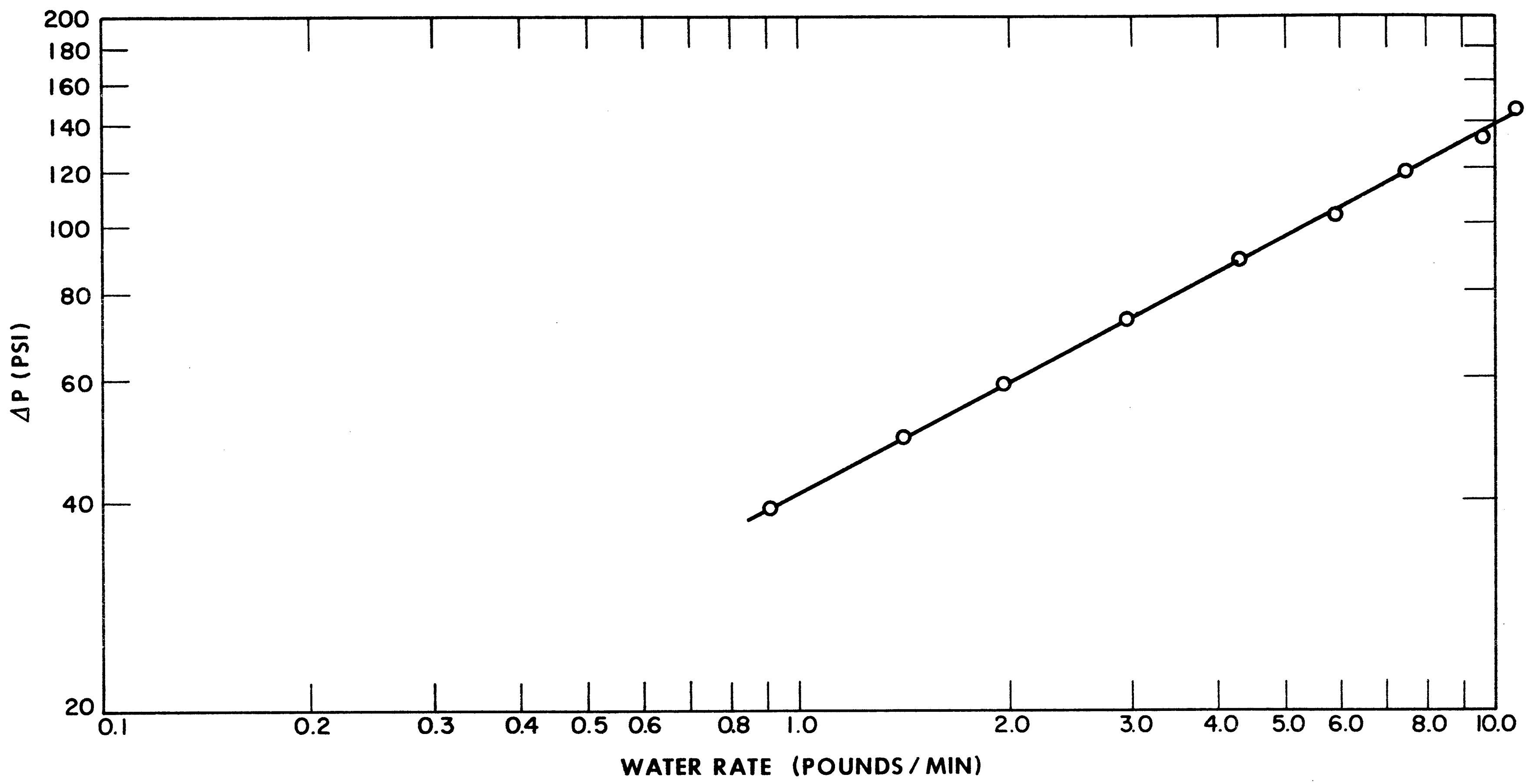

Fig. 34. Water side pressure drop for coil No. 79 (11 fins/inch - 3'-6-1/2" long).

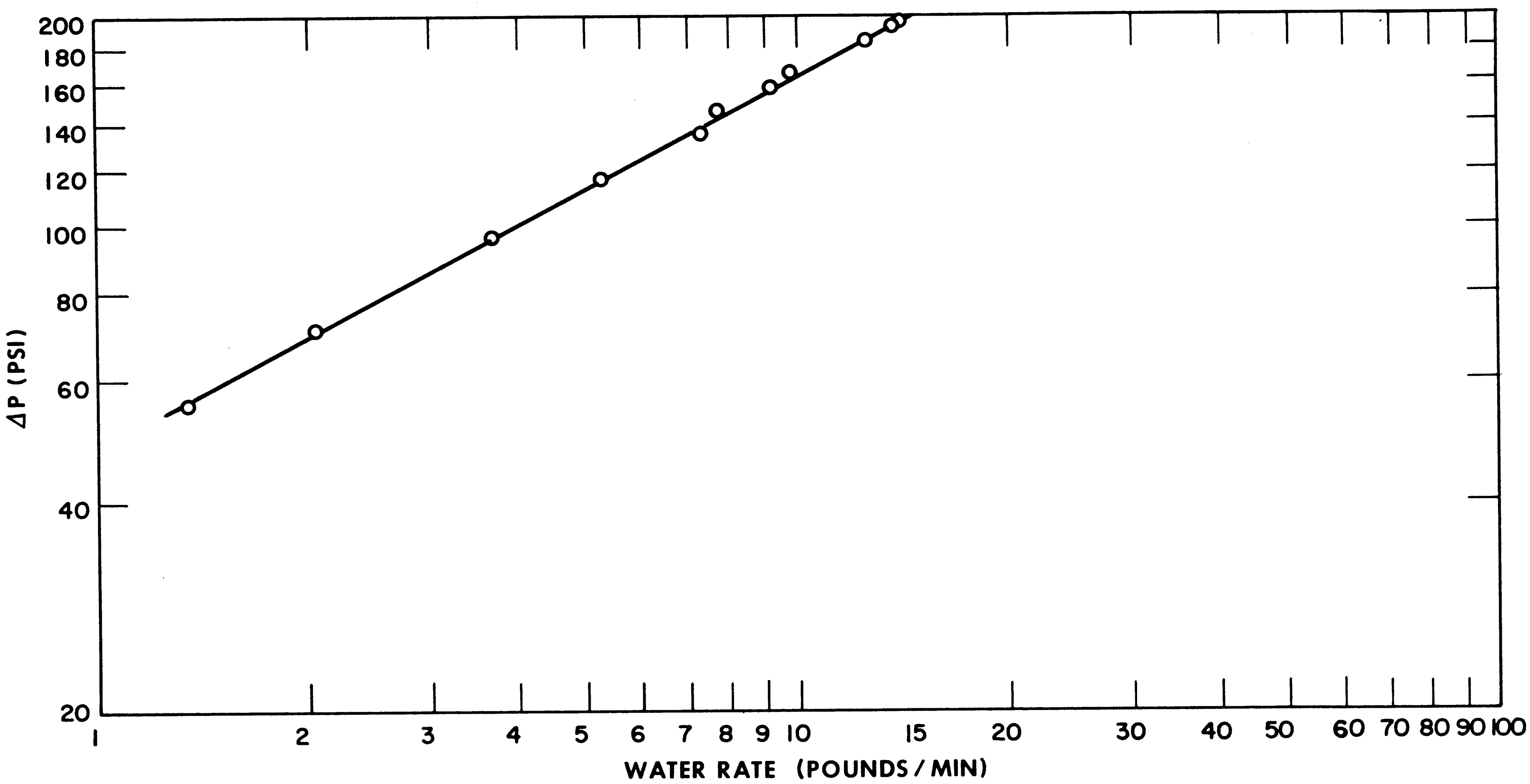

Fig. 35. Water side pressure drop for coil No. 73 (19 fins/inch - 4'-7" long).

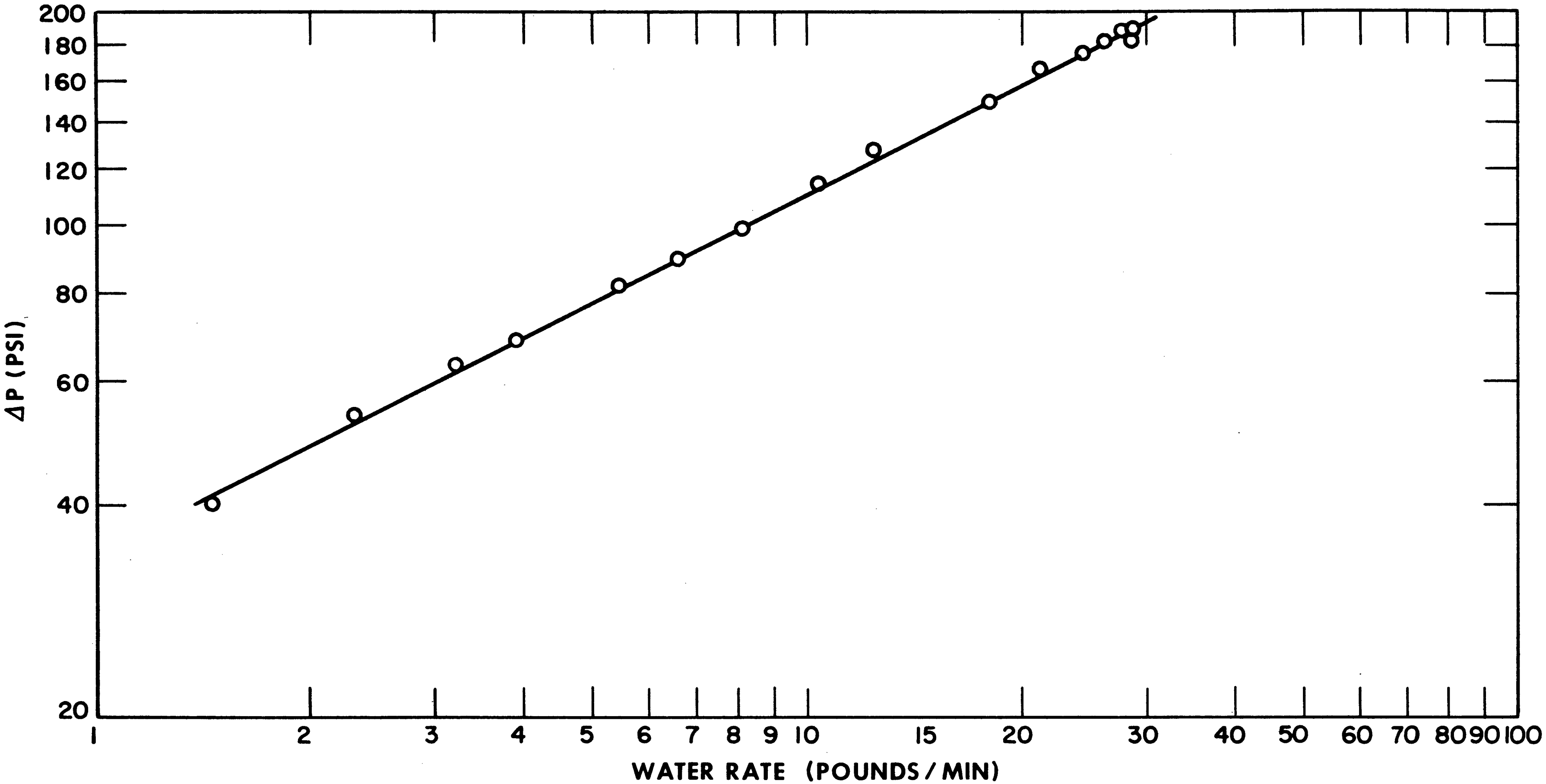

Fig. 36. Water side pressure drop for coil No. 78 (11 fins/inch - 6'-0" long).

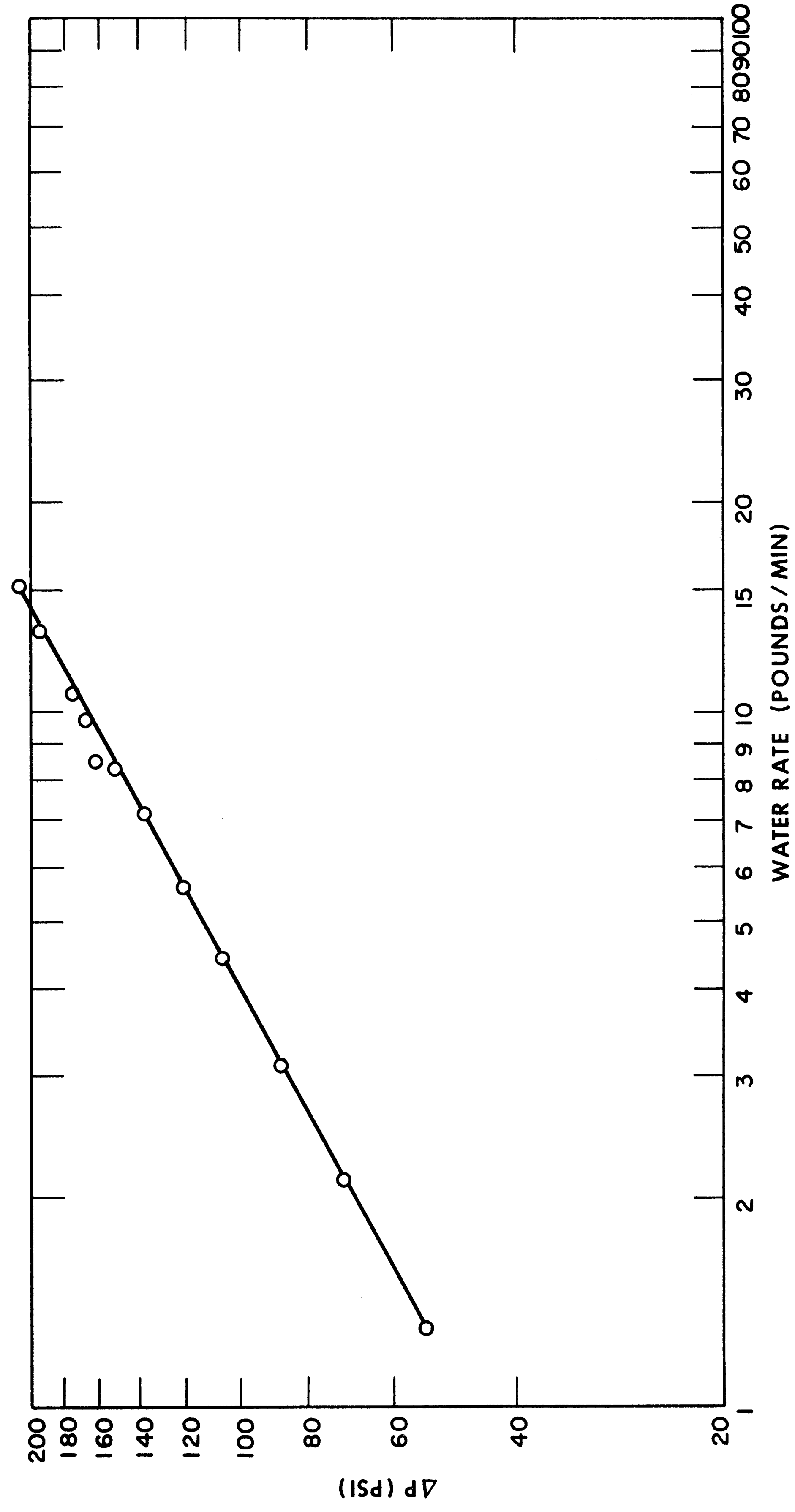

Fig. 37. Water side pressure drop for coil No. 74 (19 fins/inch - 5'-11-1/2" long).

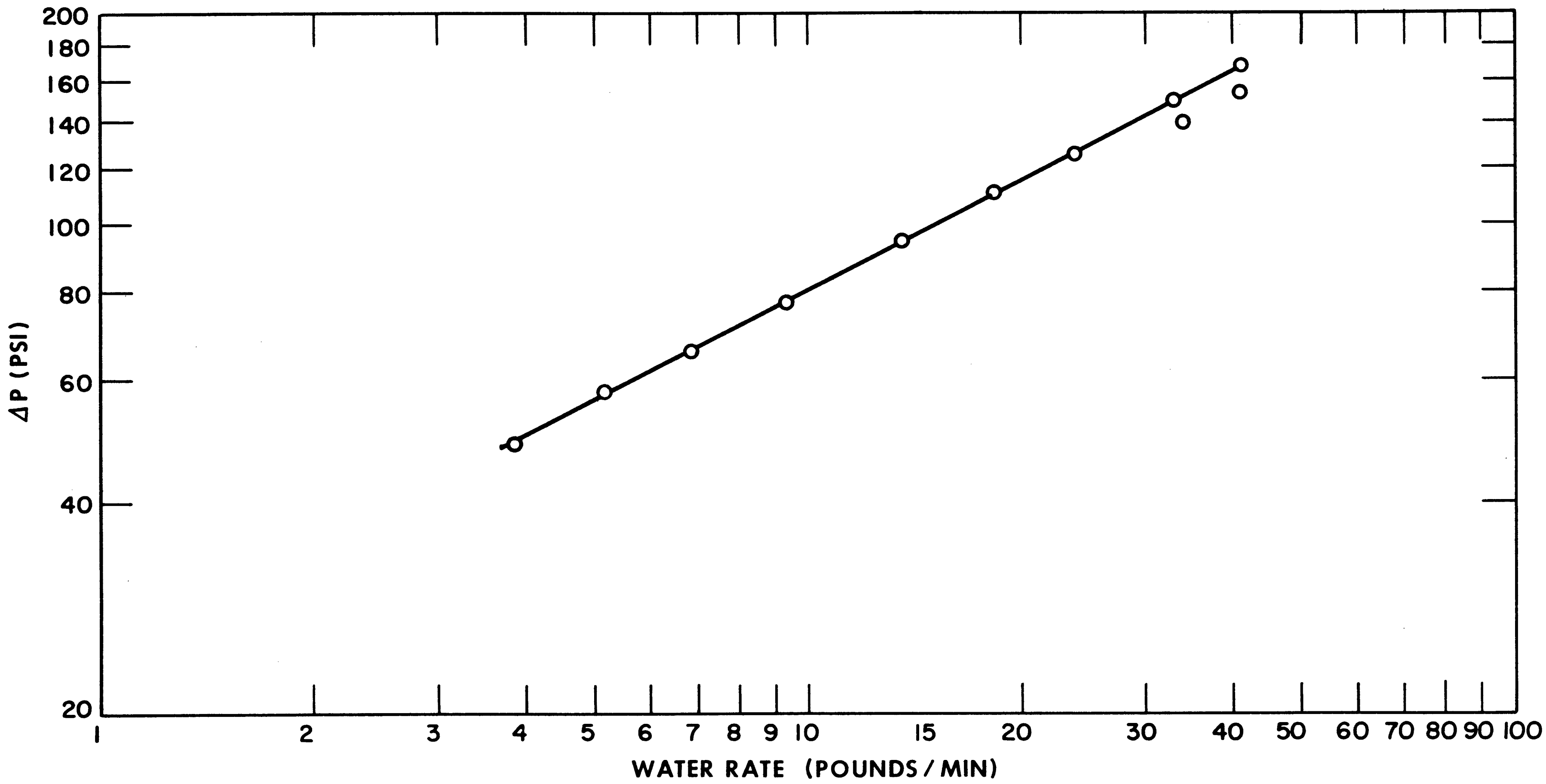

Fig. 38. Water side pressure drop for coil No. 77 (11 fins/inch - 12'-8" long).

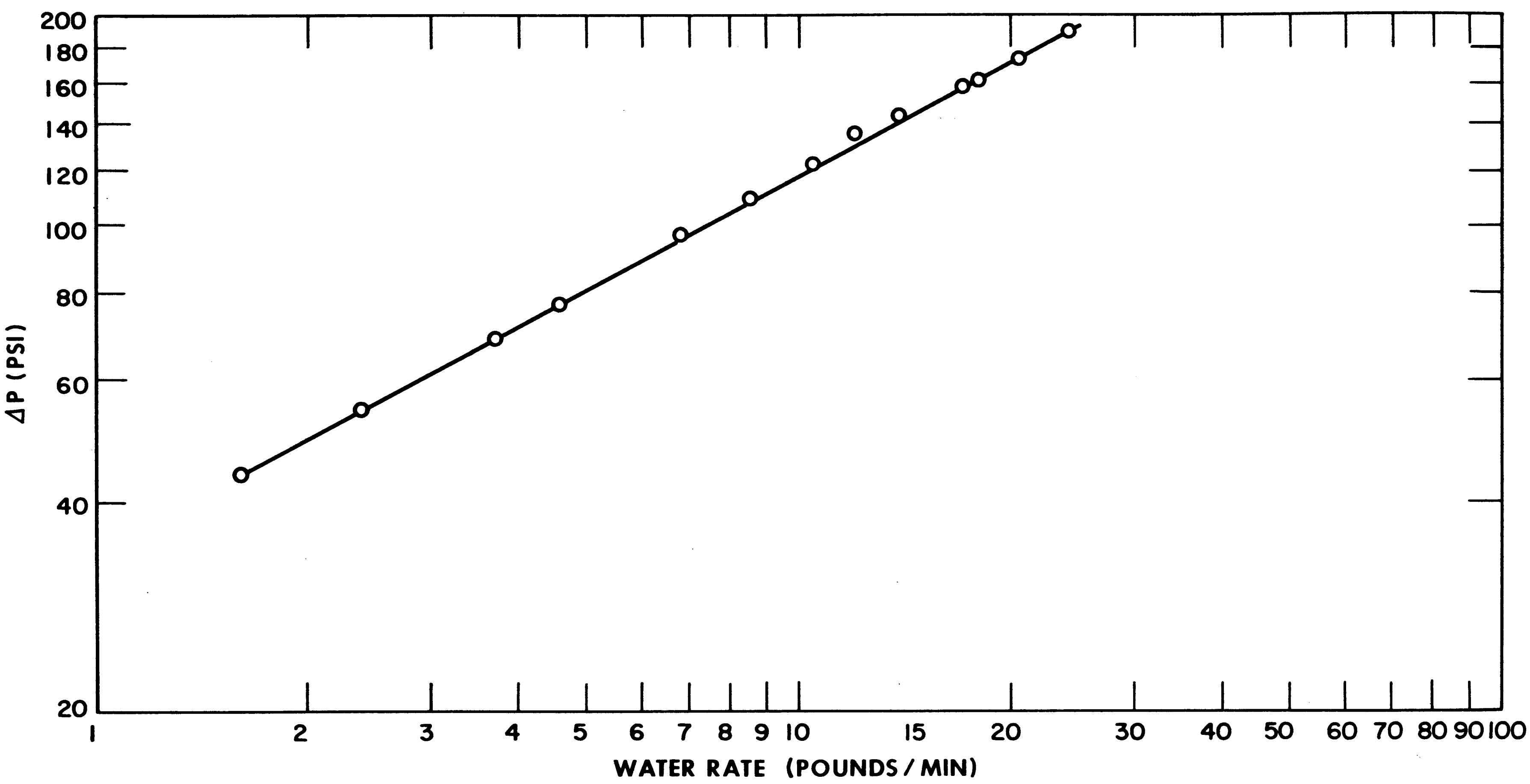

Fig. 39. Water side pressure drop for coil No. 75 (19 fins/inch - 11'-10-1/2" long).