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BOILING OF FREON-114 IN A THREE-FOOT STRAIGHT TUBE EVAPORATOR

AUTHOR:

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BOILING OF FREON-114 IN A THREE-FOOT STRAIGHT TUBE EVAPORATOR

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A B S T R A C T

Experimental determinations of heat flux were made with Freon-114 flowing by natural circulation through a steam-heated vertical tube with and without swirl promoters. The heated length of the 7/8-inch outside diameter copper tube was 35 inches, the saturation temperature of Freon-114 at test-section flow exit 160°F., and the heat flux range from 7,000 to 70,000 Btu./hr./sq.ft. Heat flux measurements at specified conditions were compared to determine the degree of fouling and the effect of swirling flow on heat transfer efficiency.

Experimental data showed that the circulation of water-saturated Freon-114 at 200°F. for 2-1/2 hours did not produce sufficient steel corrosion products to foul the surface of the evaporator. Swirl promoters were effective in reducing dry-wall vapor binding at the higher heat loads. The 50 per cent increase in maximum heat flux observed was limited by the low liquid-to-vapor ratio of the bulk Freon leaving the evaporator. An increase in input flow to the evaporator by forced circulation or increased liquid head should produce an additional increase in maximum heat flux.

BOILING OF FREON-114 IN A THREE-FOOT STRAIGHT TUBE EVAPORATOR

INTRODUCTION

This report covers two series of tests run on a Freon evaporator containing a vertical copper tube having an outside diameter of 7/8 inch, heated externally for a length of 35 inches by steam condensing in a concentric jacket.

The first series of tests deals with the sensitivity of the heat-transfer surface to fouling when water-saturated Freon coolant is subjected to high temperatures. A decrease in heat-transfer efficiency had been noticed in some plant operations where these conditions had existed for short intervals. Also, laboratory experiments had shown that the combination of Freon, water, and high temperatures produced increased corrosion rates on steel samples.[1] The present work was designed to measure the rate of heat transfer through the wall of a copper tube before and after water-saturated Freon-114 was circulated through the test loop at temperatures up to 215°F.

The second series of tests run on this evaporator was designed to evaluate the use of helical strip and wire coil swirl promoters to increase heat transfer. The maximum over-all heat flux in the nucleate-boiling range is limited by dry-wall vapor binding in a portion of the tube, and the swirl promoter was placed in the Freon stream inside the tube to expedite the movement of the heavier liquid to the evaporator surface. Results from six different swirl promoters are compared with the open-tube data.

SUMMARY

Data for the boiling of Freon-114 with natural circulation inside a short vertical tube are presented as a basis for determining the degree of fouling of the heat-transfer surface, and the effect of swirling flow on the rate of heat transfer to a boiling liquid.

Circulating water-saturated Freon-114 through the test loop at temperatures up to 215°F. did not change the heat-transfer characteristics of the evaporator.

The use of swirl promoters increased the maximum heat flux approximately 50 per cent and caused a marked decrease in the liquid-to-vapor ratio at the exit of the evaporator. At the lower temperature differences across the Freon film, the heat flux was essentially unaffected by the use of swirl promoters.

PROCEDURE

Original Open Tube Tests

High temperature Freon-114 fouling studies were made using a natural circulation heat-transfer test loop. The vertical straight-tube evaporator with insulated steam shell was installed inside the heated enclosure containing the loop components. Air inside the enclosure was maintained at the Freon boiling temperature to minimize heat-loss corrections. Steel pipe was used to connect a high-pressure condenser to the evaporator in parallel with the test loop as shown in figure 1. Block valves protected the loop instrumentation during periods of high-pressure operation. The copper evaporator tube was 7/8-inch O.D. by 3/4-inch I.D. by 35 inches long. Five copper-constantan thermocouples were peened into the outside surface of the tube wall at the center of each 7-inch section of the tube. The average of these wall-temperature readings was used to determine the temperature differences across the Freon and the steam films. Heat transfer measurements were made at average temperature differences across the Freon film from 7 to 40°F. The Freon saturation temperature was maintained at 160°F. and the liquid head at 60 inches above the bottom of the evaporator.

Exposure to High Temperature

The high-pressure section of the loop consisting of steel pipe and steel condenser shell was exposed to water-saturated Freon-114 at elevated temperatures for a short period to see if corrosion products formed quickly and migrated to the evaporator surface to cause fouling. Approximately 10 cubic centimeters of water was placed in the loop with a small amount of Freon-114 present. An additional 3.3 liters of Freon-114 was added to fill the loop to the operating level. The amount of water required to saturate the Freon supply at 212°F. is 4 cubic centimeters. After circulating the Freon-water mixture for two hours at 200°F. with the steam shell pressure at 45 psia., the steam saturater was bypassed, and full steam-line pressure was used. The following conditions were used during a 30-minute period of circulating the mixture through the evaporator and the high-pressure section of the loop: steam shell pressure, 105 psia.; steam shell temperature, 330°F.; tube wall temperature, 315°F.; Freon feed temperature, 208°F.; and Freon outlet temperature, 215°F. The Freon-water mixture was removed from the loop and replaced with a normal supply of Freon-114 in preparation for heat-transfer tests to check for evidence of fouling.

Miscellaneous Test Conditions

Eleven tests were made at special operating conditions. These included subcooling of the Freon feed, reduction in liquid head, and reduced Freon saturation temperature.

Fabrication and Installation of Swirl Promoters

The helical strip swirl promoters were twisted to a given pitch by running a flat aluminum strip through a die. The aluminum wire coils were wound on a metal rod and stretched to the proper pitch and outside diameter. The swirl promoters reached the full length of the evaporator tube. Samples of both types are shown in figure 2. Each time the loop was opened to change the swirl promoters, it was evacuated to a pressure less than one millimeter of mercury before being refilled with Freon-114.

RESULTS

Original Open Tube Data

The heat-transfer coefficient for Freon-114 increased from 900 Btu./hr./sq.ft./°F. at a temperature difference across the Freon film of 7.3°F. to a peak value of 2400 Btu./hr./sq.ft./°F. at 13.5°F. At average Freon film temperature differences greater than 13.5°F., the coefficient decreased in the manner shown in figure 3 as the increase in the amount of film boiling caused vapor binding in the upper portion of the tube.

Figure 4 shows the relationship of heat flux to temperature difference across the Freon film for this evaporator within the limits of the operating conditions used in these tests. A maximum heat flux of 42,000 Btu./hr./sq.ft. was reached at a temperature difference across the Freon film of 30°F.

Operating at a 60-inch Freon liquid head, the liquid-to-vapor ratio leaving the evaporator ranged from a value of six to two and one-half, depending on the rate of heat transfer. The ratios observed at other operating conditions varied with liquid head, because of the change in total flow entering the evaporator (figure 5).

The apparent temperature differences across the Freon film used in these correlations were determined by subtracting the temperature of bulk Freon-114 at the evaporator exit from the average of five wall-temperature measurements. The difference between the bulk steam temperature and the average wall temperature was used as the temperature difference across the steam film. The wall temperature was reasonably uniform over the full length of the tube up to an average Freon film temperature difference of 10°F. For an average temperature difference across the Freon film of 30.4°F., the wall temperature at the top of the evaporator exceeded the temperature at the bottom by more than 40°F. A range of characteristic wall-temperature profiles is shown in figure 6.

The scatter in the plot of steam film coefficient versus temperature difference across the steam film (figure 7) is probably due to contaminants in the steam and sensitivity to small errors in temperature measurements.[2]

Open Tube Data Following Exposure to High Temperature

Results from tests following the brief exposure of the loop to water-saturated Freon-114 at elevated temperatures showed no appreciable fouling of the heat-transfer surfaces. Exposure time was limited to approximately two hours to simulate periods of abnormal plant conditions in order to determine the possibility of rapid fouling as opposed to a gradual loss in heat-transfer efficiency. Figure 4 shows the comparison of these data with the original heat flux measurements.

Miscellaneous Test Conditions

Results from eleven tests, 30 through 40, which incorporated variations in Freon feed subcooling, boiling temperature, and liquid head are listed in table 1 for comparison with other data. No major differences in total heat transfer were noted for reasonable variations in these conditions of operation.

The Effect of Swirling Flow on the Freon Film Heat-Transfer Coefficients for a Three-Foot Vertical Tube Evaporator

Even though a definite maximum heat flux for swirling flow was not established, all six swirl promoters tested at these conditions produced values at least 50 per cent greater than the maximum heat flux for vertical flow in the open tube. Heat flux was essentially unaffected at the lower temperature differences across the Freon film where nucleate boiling predominated over the full length of the tube. Figure 8 shows the effect of the different swirl promoters on heat flux within the limits of the conditions used in this investigation.

An indication of the relative efficiency of the various swirl promoters is shown in the plot of Freon film heat-transfer coefficient versus temperature difference across the film in figure 9. From 15- to 50-per cent increase in maximum Freon film heat-transfer coefficient was observed, depending upon the geometry of the swirl promoter used. The comparison plot of wall temperature profiles in figure 10 shows how swirling flow affected the dry-wall vapor binding and reduced the temperature difference across the Freon film in the upper portion of the evaporator.

The liquid-to-vapor ratio of the Freon leaving the evaporator was considerably reduced by the combined effects of increased evaporation, reduction in total flow resulting from increased frictional pressure drop, and increased impact surface for entrained liquid droplets (figure 11).

There was very little change in evaporator inlet and outlet pressures over the entire heat flux range for natural circulation with constant liquid head. The mass flow rate through the evaporator tube is controlled by an equilibrium condition in which the frictional pressure drop around the circulation loop is balanced by the difference in hydrostatic head existing between the saturated liquid in the return leg and the two-phase fluid in the evaporator tube. Pressure drop in the evaporator results from a combination of fluid acceleration, wall friction, and difference in hydrostatic head. The relative importance of these effects depends upon loop geometry and operating conditions.

CONCLUSIONS

The conditions imposed on the loop during these studies were not sufficient to cause appreciable fouling of the evaporator surfaces.

Within the range of these experiments, subcooling of the Freon entering the evaporator reduced the amount of vapor leaving the evaporator but has very little effect upon the correlation of average heat flux versus apparent temperature difference across the Freon film in the nucleate boiling range. In one case, approximately one-third of the total heat transferred was required to bring the bulk Freon to the boiling temperature.

Swirling the flow of Freon-114 inside the evaporator tube produced heat-flux values at least 50 per cent greater than the maximum value observed for vertical flow in the open tube. For constant liquid head and a given temperature difference across the Freon film, the use of a swirl promoter produced a marked decrease in entrained liquid carry-over. The increase in maximum Freon heat-transfer coefficient and the average temperature difference across the Freon film at which it occurred for swirling flow were dependent upon the efficiency of the particular swirl promoter used.

REFERENCES

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2. McAdams, William H., Heat Transmission, Third Edition, New York, McGraw-Hill Book Company, Inc., 1954, p. 343

TABLE I

DATA FROM THE THREE-FOOT STRAIGHT TUBE EVAPORATOR

RUN NO.	STEAM TEMP., °F.	TUBE WALL TEMPERATURE, °F. Distance From Evaporator Inlet 3.5 in.	10.5 in.	17.5 in.	24.5 in.	31.5 in.	Average	BULK FREON TEMPERATURE, °F. Evap. Inlet	Evap. Outlet	Condenser Inlet	Condenser Drain	LIQUID HEAD Inches	FREON FLOW, lb./hr Total	Condensed Vapor	LIQUID-TO-VAPOR RATIO	WATER IN CONDENSER Flow, lb./hr.	Δt, °F.	EVAPORATOR HEAT LOAD, Btu./hr.	HEAT FLUX, Btu./hr./sq.ft.	Δt ACROSS STEAM FILM, °F.	STEAM FILM COEFFICIENT, Btu./hr./sq.ft./°F.	Δt ACROSS FREON FILM, °F.	FREON FILM COEFFICIENT, Btu./hr./sq.ft./°F.
ORIGINAL OPEN TUBE DATA																							
1	193.6	169.9*	169.9	171.2	172.3	181.2	172.9	159.8	159.6	157.5	156.5	59.5	1720	410	3.2	319.3	58.3	18,230	31,810	20.7	1318	13.3	2392
2	179.2	169.2*	169.2	169.8	170.5	170.8	169.9	160.7	160.5	159.1	158.0	60.5	1345	198	5.8	148.8	63.4	9,270	16,180	9.3	1492	9.4	1721
3	178.8	169.1*	169.1	169.9	170.5	170.6	169.8	160.7	160.4	159.1	158.0	60.5	1340	192	6.0	145.8	64.1	9,190	16,040	9.0	1529	9.4	1707
4	182.9	170.1*	170.1	171.0	172.1	173.3	171.3	160.4	160.4	159.0	158.0	59.0	1530	292	4.2	228.9	59.0	13,290	23,190	11.6	1715	10.9	2128
5	181.2	169.7*	169.7	170.7	171.2	172.2	170.7	160.5	160.3	158.9	158.2	63.5	1626	232	6.0	181.6	63.7	11,410	19,910	10.5	1626	10.4	1914
6	172.5	167.7*	167.7	168.3	168.5	168.3	168.1	160.0	160.2	158.8	158.1	65.0	980	94	9.4	56.0	88.9	4,910	8,580	4.4	1672	7.9	1086
7	174.6	167.6	168.0	168.8	169.1	168.8	168.5	160.0	160.3	158.7	158.0	59.0	950	139	5.8	82.6	79.0	6,420	11,210	6.1	1576	8.2	1367
8	190.3	170.6	171.3	172.3	173.6	180.7	173.7	160.7	160.6	159.0	157.0	59.0	1622	392	3.1	315.8	57.2	17,650	30,800	16.6	1592	13.1	2351
9	193.9	170.9	171.7	172.7	174.5	185.3	175.0	160.4	160.4	158.5	156.6	59.5	1711	446	2.8	358.2	55.3	19,290	33,660	18.9	1528	14.6	2306
10	197.7	171.1	171.8	172.7	174.5	190.5	176.1	160.2	160.1	158.2	156.1	58.5	1701	475	2.6	388.6	54.7	20,700	36,120	21.6	1434	16.0	2258
11	199.9	171.4	172.3	173.0	176.4	195.8	177.8	160.1	160.1	158.4	156.0	59.5	1785	490	2.6	400.0	55.3	21,510	37,540	22.1	1457	17.7	2121
12	217.3	173.7	174.1	186.0	205.7	213.2	190.5	160.4	160.1	158.5	157.5	60.5	1907	537	2.6	379.9	64.8	24,180	42,190	26.8	1350	30.4	1388
13	211.9	172.8	173.7	176.5	198.8	207.7	185.9	160.5	160.0	158.4	157.6	59.5	1850	529	2.5	369.2	65.5	23,780	41,504	26.0	1369	25.9	1602
14	209.0	172.3	172.9	174.4	189.8	202.4	182.4	160.5	160.1	158.2	157.6	57.5	1772	522	2.4	359.1	66.2	23,370	40,780	26.6	1315	22.3	1829
15	184.7	170.7*	170.7	171.2	171.9	171.9	171.3	160.0	160.3	159.0	155.7	60.0	1560	280	4.6	224.0	60.3	13,130	22,910	13.4	1467	11.0	2083
16	174.7	168.8*	168.8	169.4	169.6	168.6	169.0	160.1	160.1	158.9	154.5	60.0	1058	143	6.4	100.0	69.5	6,720	11,720	5.7	1764	8.9	1317
17	169.3	167.1*	167.1	167.8	168.0	167.1	167.4	160.0	160.1	158.5	153.7	60.5	485	72	5.7	59.0	66.2	3,770	6,590	1.9	2974	7.3	902
18	189.6	170.9	170.9	172.1	173.8	180.2	173.6	160.0	160.7	158.7	158.2	57.5	1524	369	3.1	247.0	69.1	16,780	29,280	16.0	1570	12.9	2270
19	186.3	170.3	170.6	171.5	172.6	177.6	172.5	160.8	160.5	159.1	158.6	60.0	1630	328	4.0	220.2	69.8	15,170	26,470	13.8	1645	12.0	2206
20	185.4	169.1	169.8	171.0	171.9	172.3	170.8	160.8	160.4	158.9	158.8	58.5	1403	238	4.9	158.8	72.2	11,320	19,770	14.6	1161	10.4	1901
21	181.2	169.9*	169.9	170.9	172.0	173.6	171.3	160.0	160.3	158.9	158.2	61.0	1550	265	4.9	186.3	68.4	12,560	21,920	9.9	1899	11.0	1992
22	175.6	168.5*	168.5	169.3	169.5	169.5	169.1	160.4	160.4	158.8	157.3	64.5	1275	136	8.4	79.0	87.1	6,750	11,770	6.5	1554	8.7	1353
23	174.2	168.5*	168.5	169.5	169.6	169.5	169.1	160.4	160.7	158.9	157.8	61.5	1160	137	7.5	78.3	88.6	6,810	11,880	5.1	1997	8.4	1414
24	172.0	167.7*	167.7	168.5	168.6	168.2	168.1	160.6	160.4	158.8	157.2	61.5	865	102	7.5	54.6	93.6	5,010	8,740	3.9	1940	7.6	1144
CHECK FOR FOULING AFTER EXPOSURE TO FREON-WATER MIXTURE																							
25	192.7	171.5*	171.5	172.3	174.0	182.8	174.4	160.1	160.4	158.8	158.4	61.0	1720	411	3.2	259.0	72.4	18,470	32,230	18.3	1511	14.0	2302
26	198.1	171.1*	171.1	171.9	173.6	180.7	173.7	159.9	160.0	158.3	158.1	60.5	1680	405	3.2	256.3	73.1	18,470	32,230	24.4	1133	13.7	2353
27	179.8	169.9*	169.9	170.8	172.0	172.4	171.0	160.4	160.3	158.7	158.6	58.5	1440	250	4.8	160.7	76.7	12,170	21,250	8.8	2071	10.7	1985
28	180.2	169.8*	169.8	170.9	171.5	172.6	170.9	159.9	160.4	158.9	156.9	61.5	1520	232	5.6	168.2	68.2	11,230	19,590	9.3	1807	10.5	1866
29	178.9	169.4*	169.4	170.5	171.1	171.9	170.5	159.9	160.3	158.7	156.8	60.0	1400	209	5.7	145.4	71.3	10,140	17,696	8.4	1807	10.2	1735
SUBCOOLED FREON FEED TO EVAPORATOR																							
30	178.9	169.5*	169.5	170.3	171.2	171.8	170.5	131.3	160.3	158.7	156.5	60.0	600	125	3.8	67.1	91.3	10,570	18,450	8.4	1885	10.2	1808
31	208.6	173.4*	173.4	174.4	184.6	202.4	181.6	146.0	160.0	158.4	156.6	61.5	1715	410	3.2	307.7	62.8	25,240	44,050	27.0	1400	21.6	2040
32	184.0	170.3*	170.3	171.2	172.2	174.5	171.7	138.0	160.1	158.9	157.3	56.0	870	186	3.7	123.7	74.9	14,170	24,740	12.3	1725	11.6	2132
33	181.6	162.8*	162.8	163.9	165.2	170.7	165.1	150.9	151.3	149.6	145.8	59.5	1620	355	3.6	300.0	56.7	16,440	28,700	16.5	1492	13.8	2080
34	182.1	170.3*	170.3	171.3	172.1	173.0	171.4	134.4	160.7	158.7	155.5	59.0	705	135	4.2	83.3	84.6	11,734	20,470	10.7	1642	10.7	1914
35	184.5	167.0*	167.0	167.8	169.4	176.0	169.4	155.6	155.8	154.1	152.1	60.0	1620	357	3.5	286.9	59.8	16,745	29,220	15.1	1660	13.6	2149
36	187.2	170.8	170.8	171.7	173.2	178.6	173.0	142.1	160.2	158.4	157.1	57.5	1155	235	3.9	176.7	66.6	17,060	29,770	14.2	1798	12.8	2326
37	192.7	171.4*	171.4	172.2	174.1	182.2	174.3	143.1	160.1	158.2	156.9	57.0	1263	292	3.3	221.8	63.7	19,510	34,050	18.4	1588	14.2	2398
REDUCED LIQUID HEAD																							
38	186.8	170.9*	170.9	171.6	173.2	180.2	173.4	159.9	160.4	158.8	156.0	55.0	1420	348	3.1	259.7	58.0	14,600	25,490	13.4	1631	13.0	1960
39	197.7	171.4*	171.4	172.5	174.3	182.5	174.4	159.6	160.4	158.6	156.3	45.0	1135	417	1.7	332.7	58.0	18,770	32,760	23.3	1211	14.0	2340
40	180.9	170.0*	170.0	170.8	172.0	174.0	171.4	159.5	160.3	159.2	157.3	24.0	409	268	0.5	202.5	61.2	12,140	21,190	9.5	1914	11.1	1909
HELICAL ALUMINUM STRIP SWIRL-PROMOTER, 3.5-INCH PITCH																							
41	183.7	170.8*	170.8	171.5	172.8	173.6	171.9	160.6	160.5	159.5	159.0	60.0	1040	317	2.3	271.1	54.0	14,460	25,230	11.8	1835	11.4	2214
42	194.4	172.1*	172.1	172.8	173.7	178.1	173.8	160.7	160.2	159.1	156.9	57.5	1005	513	1.0	505.6	45.0	22,170	38,690	20.6	1611	13.6	2845
43	176.5	169.2*	169.2	169.9	170.5	170.8	169.9	160.8	160.4	159.1	157.4	58.5	890	186	3.8	178.2	52.4	9,140	15,950	6.6	2073	9.5	1680
44	207.0	174.5*	174.5	174.5	177.2	181.1	176.4	160.4	160.4	159.7	156.8	63.0	1005	690	0.5	705.9	45.4	31,260	54,570	30.6	1530	16.0	3410
45	209.4	173.5*	173.5	174.8	176.5	180.8	175.8	158.4	159.8	159.0	152.9	58.5	980	717	0.4	1153.8	28.4	31,770	55,450	33.6	1416	16.0	3466
46	177.6	169.6*	169.6	170.3	171.0	171.4	170.4	160.2	160.2	159.0	155.8	61.5	1005	198	4.1	226.1	45.7	10,080	18,680	7.2	2095	10.2	1832
47	208.4	174.0*	174.0	174.4	177.0	183.3	176.5	160.1	160.1	158.8	156.6	63.0	1030	761	0.4	789.5	43.9	33,870	59,100	31.9	1589	16.4	3604
48	221.9	175.6*	175.6	177.5	181.6	197.6	181.6	159.8	160.0	158.4	156.0	64.0	1030	817	0.3	900.1	41.4	36,330	63,400	40.3	1350	21.6	2936
49	229.0	176.8*	176.8	178.1	183.6	208.4	184.7	159.6	160.0	158.5	156.3	56.5	921	832	0.1	909.1	41.4	36,800	64,220	44.3	1244	24.7	2600

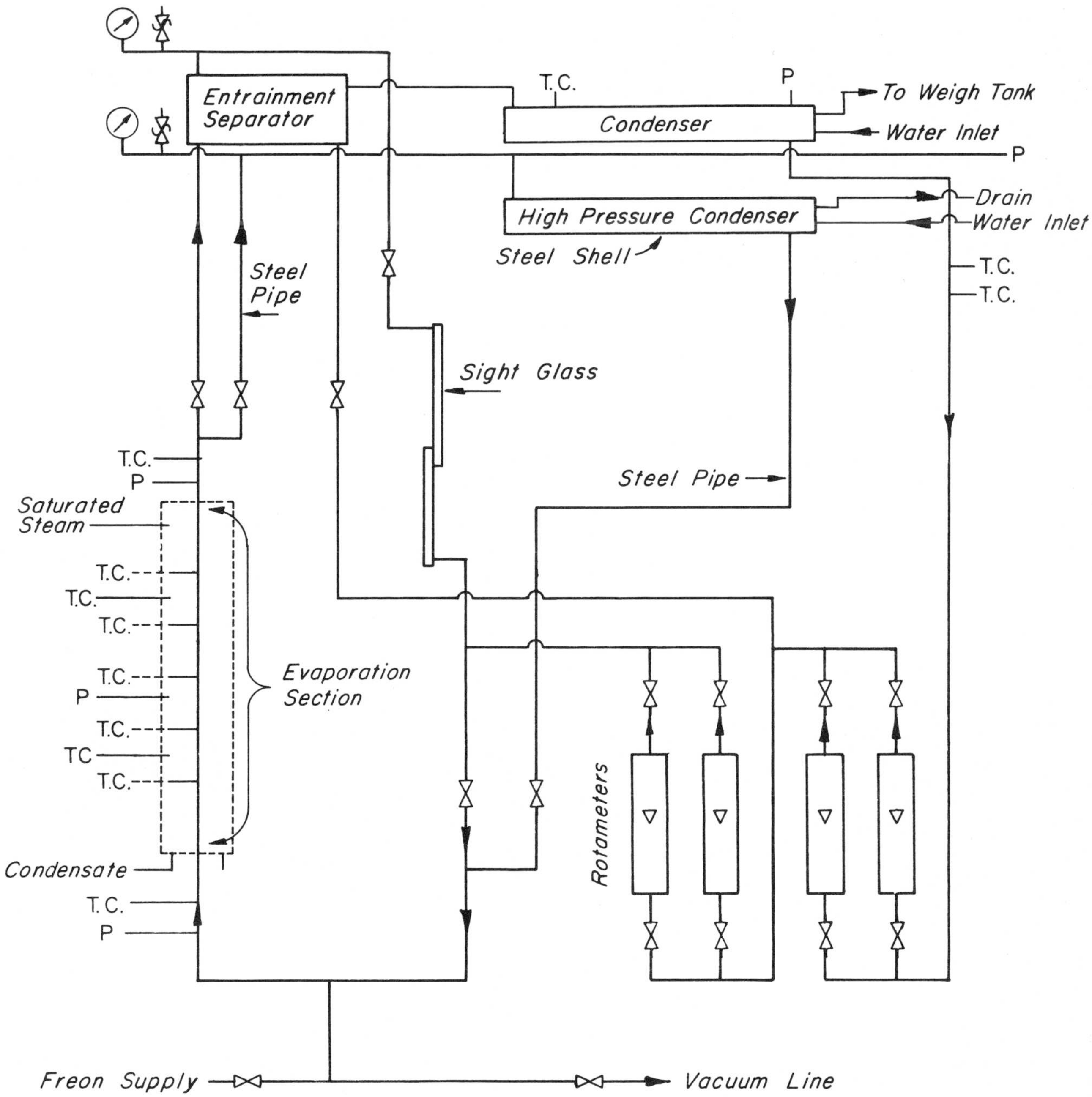
* The thermocouple at this point shorted out. The temperature at the 10-inch point was repeated to obtain the average wall temperature.

TABLE I (Cont.)

DATA FROM THE THREE-FOOT STRAIGHT TUBE EVAPORATOR

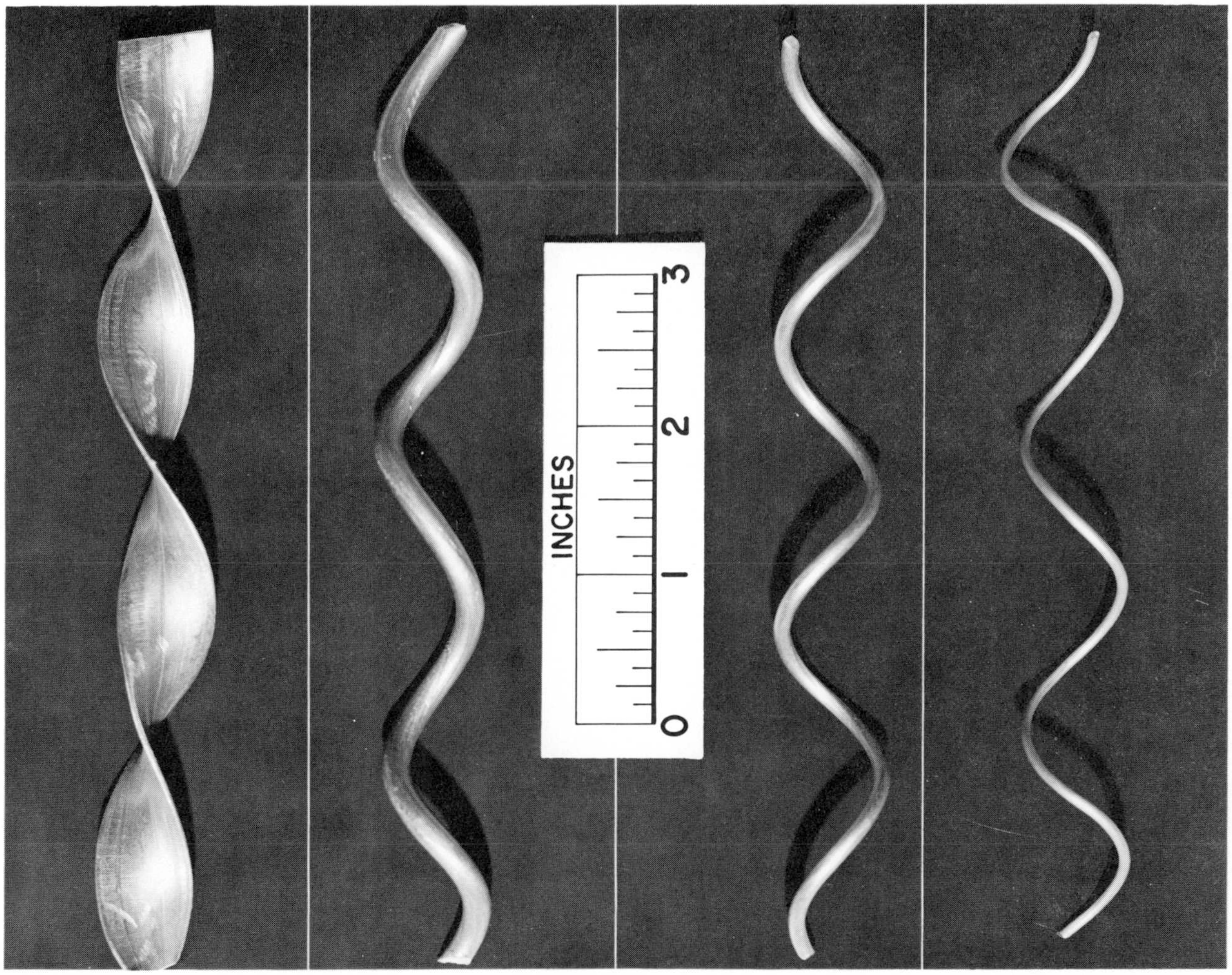
RUN NO.	STEAM TEMP., °F.	TUBE WALL TEMPERATURE, °F. Distance From Evaporator Inlet 3.5 in.	10.5 in.	17.5 in.	24.5 in.	31.5 in.	Average	BULK FREON TEMPERATURE, °F. Evap. Inlet	Evap. Outlet	Condenser Inlet	Condenser Drain	LIQUID HEAD Inches	FREON FLOW, lb./hr. Total	Condensed Vapor	LIQUID-TO-VAPOR RATIO	WATER IN CONDENSER Flow, lb./hr.	Δt, °F.	EVAPORATOR HEAT LOAD, Btu./hr.	HEAT FLUX, Btu./hr./sq.ft.	Δt ACROSS STEAM FILM, °F.	STEAM FILM COEFFICIENT, Btu./hr./sq.ft./°F.	Δt ACROSS FREON FILM, °F.	FREON FILM COEFFICIENT, Btu./hr./sq.ft./°F.
HELICAL ALUMINUM STRIP SWIRL-PROMOTER, 6-INCH PITCH																							
50	181.2	170.4*	170.4	171.1	172.0	173.4	171.5	160.3	160.4	159.6	158.4	59.0	1120	287	2.9	240.0	54.5	12,910	22,520	9.7	1992	11.1	2029
51	193.4	172.4*	172.4	173.1	174.2	177.2	173.9	161.2	160.5	158.9	157.6	62.0	1262	501	1.5	422.5	50.4	20,750	36,220	19.5	1593	13.4	2703
52	203.2	173.7	173.7	174.3	177.2	184.8	176.7	160.8	160.4	158.9	157.2	65.5	1220	651	0.9	669.2	44.3	28,920	50,480	26.5	1634	16.3	3097
53	213.8	174.9*	174.9	175.2	178.4	189.6	178.6	160.7	160.3	159.0	156.9	61.5	1075	750	0.4	825.8	40.9	32,890	57,400	35.2	1400	18.3	3137
54	221.7	175.0*	175.0	176.4	180.2	201.2	181.6	160.3	160.2	158.8	156.4	61.0	1040	817	0.3	973.0	38.2	36,180	63,130	40.1	1351	21.4	2950
0.112-INCH DIAMETER ALUMINUM WIRE COIL, 1.9-INCH PITCH																							
55	194.4	172.5*	172.5	173.2	175.0	178.4	174.3	159.3	160.4	159.3	157.7	60.0	1186	469	1.5	390.2	53.5	20,600	35,950	20.1	1534	13.9	2586
56	189.8	171.7*	171.7	172.5	173.9	176.2	173.2	159.3	160.4	159.1	157.9	57.0	1130	398	1.8	321.4	55.3	17,560	30,650	16.6	1584	12.8	2394
57	208.4	174.6*	174.6	174.7	177.7	186.0	177.5	160.4	160.6	159.1	156.8	65.0	1154	700	0.7	714.3	45.5	31,760	55,440	30.9	1539	16.9	3280
58	212.4	175.0*	175.0	175.0	177.6	191.2	178.8	160.2	160.1	159.2	156.6	59.0	1030	761	0.4	814.6	43.2	34,360	59,970	33.6	1531	18.7	3207
59	223.6	176.3*	176.3	176.0	178.6	192.4	179.9	160.0	160.2	158.9	156.5	58.5	1020	805	0.3	873.9	42.5	36,270	63,300	43.7	1242	19.7	3213
60	230.2	177.2*	177.2	176.8	183.2	205.2	183.9	160.1	160.3	159.0	156.6	59.0	1005	844	0.2	955.4	40.7	37,970	66,260	46.3	1228	23.6	2808
OPEN TUBE TESTS TO CHECK ORIGINAL DATA																							
61	186.8	171.2*	171.2	172.1	173.4	176.4	172.9	160.4	160.5	159.2	158.1	63.0	1551	322	3.8	283.4	52.9	14,760	25,750	13.9	1589	12.4	2077
62	198.4	173.1*	173.1	173.9	176.5	190.0	177.3	161.0	160.5	159.5	157.9	61.5	1571	479	2.3	435.5	49.0	20,870	36,420	21.1	1482	16.8	2168
63	204.1	173.7*	173.7	174.9	183.7	200.0	181.2	160.9	160.6	159.0	157.9	61.0	1580	501	2.2	472.4	47.9	22,150	38,660	22.9	1448	20.6	1877
64	228.7	181.2*	181.2	208.3	220.7	225.6	203.4	161.2	160.8	159.2	158.0	--	1634	535	2.1	514.3	46.8	23,550	41,100	25.3	1393	42.6	965
0.188-INCH DIAMETER ALUMINUM WIRE COIL, 2-INCH PITCH																							
65	193.8	172.4*	172.4	173.1	174.4	177.4	173.9	160.3	160.4	159.2	157.8	66.5	1168	479	1.4	410.3	52.7	21,260	37,100	19.9	1600	13.5	2750
66	206.4	174.1*	174.1	174.4	176.9	185.2	176.9	160.6	160.4	159.1	157.1	60.0	923	701	0.3	706.7	45.2	31,190	54,420	29.5	1582	16.5	3298
67	220.0	176.1*	176.1	176.1	180.0	201.2	181.9	160.4	160.3	158.9	156.7	61.0	923	800	0.2	887.3	41.2	35,690	62,280	38.1	1402	21.6	2883
68	230.0	176.9*	176.9	177.6	183.2	208.8	184.7	160.2	160.2	159.0	156.2	61.5	910	855	0.1	1005.7	39.1	38,250	66,760	45.3	1264	24.5	2725
69	201.2	173.4*	173.4	173.8	175.6	179.7	175.2	160.5	160.3	158.9	157.2	76.5	1186	646	0.8	621.9	46.8	28,460	49,660	26.0	1638	14.9	3333
70	206.9	174.0*	174.0	174.3	177.0	184.2	176.7	160.9	160.2	159.0	157.6	60.5	933	700	0.3	717.1	45.2	31,680	55,310	30.2	1571	16.5	3352
71	206.8	174.1*	174.1	174.6	179.7	190.0	178.5	160.7	160.6	159.3	158.2	44.0	792	646	0.2	606.1	47.9	28,510	49,750	28.3	1508	17.9	2779
72	208.2	174.3*	174.3	174.9	181.6	196.8	180.4	160.4	160.5	159.4	158.5	28.0	635	623	0	552.2	49.5	26,940	47,020	27.8	1451	19.9	2363
73	208.4	173.6*	173.6	174.8	189.6	202.8	182.9	160.0	161.0	164.0	158.6	19.0	540	512	0	465.7	51.5	23,710	41,380	25.5	1392	21.9	1890
0.070-INCH DIAMETER ALUMINUM WIRE COIL, 1.8-INCH PITCH																							
74	194.0	172.8*	172.8	173.2	175.6	179.2	174.7	159.2	160.4	159.0	156.4	64.0	1307	507	1.6	485.2	47.7	22,700	39,620	19.3	1760	14.3	2770
75	185.2	170.9*	170.9	171.6	172.7	174.5	172.1	159.8	160.3	158.8	156.8	59.5	1220	310	2.9	270.7	52.4	13,890	24,240	13.1	1587	11.8	2054
76	205.4	174.1*	174.1	174.5	177.2	184.8	176.9	159.9	160.4	159.2	156.0	62.5	1186	679	0.8	734.7	42.5	30,420	53,080	28.5	1597	16.5	3217
77	211.0	174.9*	174.9	175.1	178.8	188.4	178.4	159.4	160.4	158.8	155.2	63.5	1153	766	0.5	895.5	39.8	34,670	60,500	32.6	1591	18.0	3361
78	222.4	176.2*	176.2	176.6	180.8	197.6	181.5	158.8	160.4	159.2	154.8	60.0	1030	863	0.2	1097.7	36.4	38,880	67,860	40.9	1423	21.1	3216
79	231.8	177.2*	177.2	177.6	186.8	213.6	186.5	158.8	160.4	159.2	154.8	60.5	1002	875	0.2	1139.4	35.8	39,770	69,400	45.3	1314	26.1	2659
0.070-INCH DIAMETER ALUMINUM WIRE COIL, 4-INCH PITCH																							
80	183.0	170.5*	170.5	171.2	172.4	173.6	171.6	160.3	160.3	159.1	155.9	61.5	1375	287	3.8	265.9	51.5	13,310	23,240	11.4	1748	11.3	2056
81	193.8	172.1*	172.1	173.1	174.2	180.4	174.4	159.9	160.2	158.8	155.6	60.5	1355	463	1.9	440.1	47.3	20,270	35,380	19.4	1564	14.2	2491
82	205.6	174.0*	174.0	174.4	180.0	187.2	177.9	160.2	160.2	159.0	156.6	57.0	1186	618	0.9	598.0	47.5	27,750	48,420	27.7	1500	17.7	2736
83	207.2	174.0*	174.0	174.4	178.4	188.8	177.9	160.0	160.2	158.8	156.6	60.5	1250	647	0.9	622.8	47.0	28,590	49,900	29.3	1461	17.7	2819
84	219.7	176.0*	176.0	176.1	186.3	198.4	182.6	157.6	159.9	158.6	153.2	61.0	1186	761	0.6	973.0	36.5	34,820	60,770	37.1	1405	22.7	2677
85	229.6	178.0*	178.0	178.8	187.6	204.4	185.4	156.0	159.2	158.2	152.4	60.5	1135	839	0.4	1168.7	33.8	38,880	67,860	44.2	1317	26.2	2590
OPEN TUBE TESTS TO CHECK ORIGINAL DATA																							
86	208.1	174.4*	174.4	175.2	192.4	205.0	184.3	160.0	160.4	158.9	157.2	72.0	1600	501	2.2	420.6	53.6	22,120	38,610	23.8	1391	23.9	1597
87	208.6	174.4*	174.4	175.8	194.0	205.2	184.8	160.4	160.4	158.8	157.5	60.5	1452	501	1.9	414.8	54.0	21,950	38,300	23.8	1380	24.4	1570
88	208.8	174.4*	174.4	175.8	194.5	205.9	185.0	160.4	160.4	159.1	158.0	44.5	1055	497	1.1	404.5	55.4	22,040	38,470	23.8	1386	24.6	1564
89	208.7	174.4*	174.4	176.4	201.2	206.8	186.6	160.0	160.1	159.6	158.6	18.0	572	457	0.3	358.6	56.5	20,560	35,880	22.1	1393	26.5	1354

* The thermocouple at this point shorted out. The temperature at the 10-inch point was repeated to obtain the average wall temperature.



TEST LOOP SCHEMATIC DIAGRAM

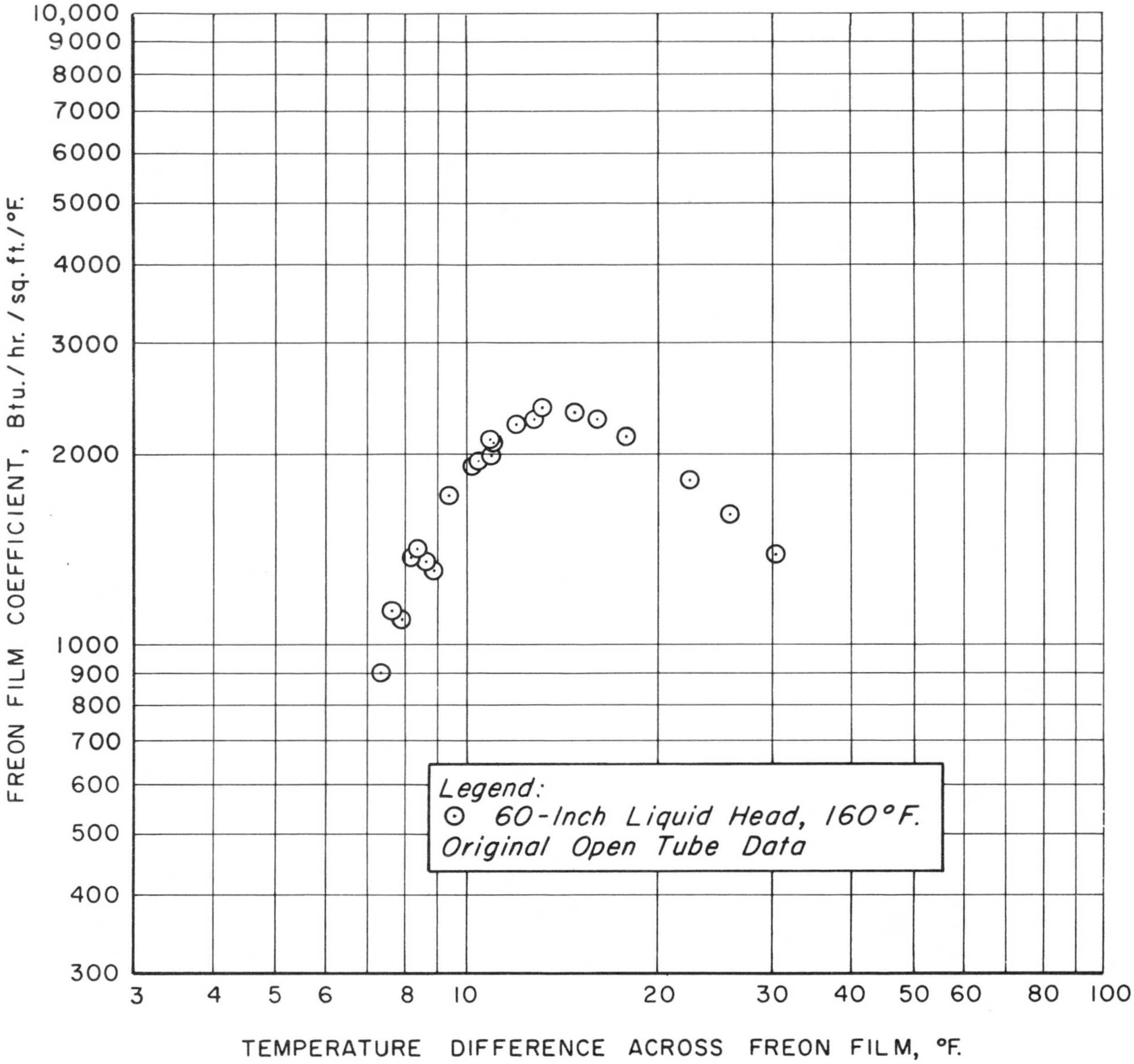
FIGURE 1



0.040-INCH THICK STRIP 3.5-INCH PITCH | 0.188-INCH DIA. WIRE 2.0-INCH PITCH | 0.112-INCH DIA. WIRE 1.9-INCH PITCH | 0.070-INCH DIA. WIRE 1.8-INCH PITCH

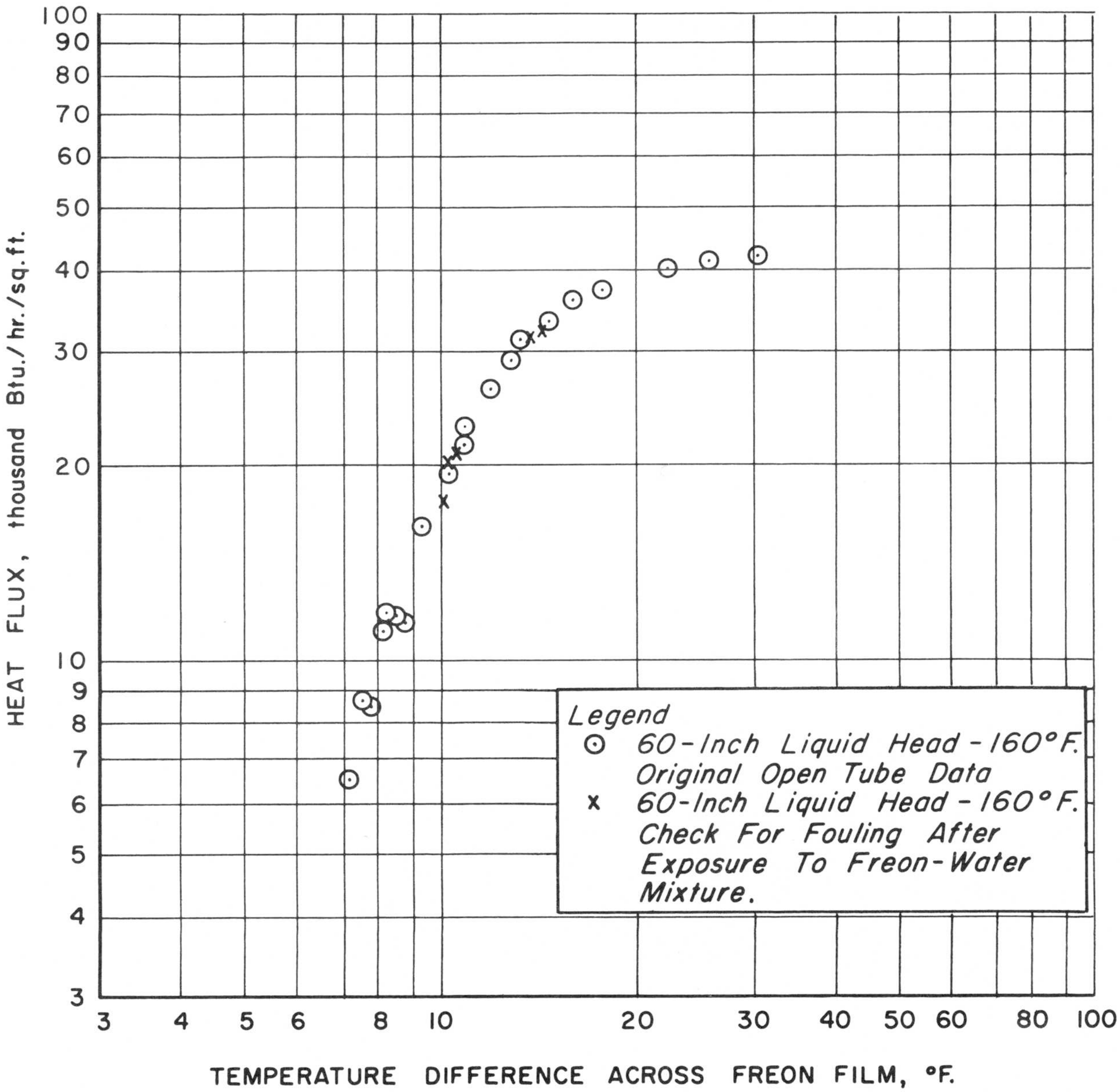
PHOTOGRAPHS OF HELICAL-STRIP AND WIRE-COIL SWIRL PROMOTERS

FIGURE 2



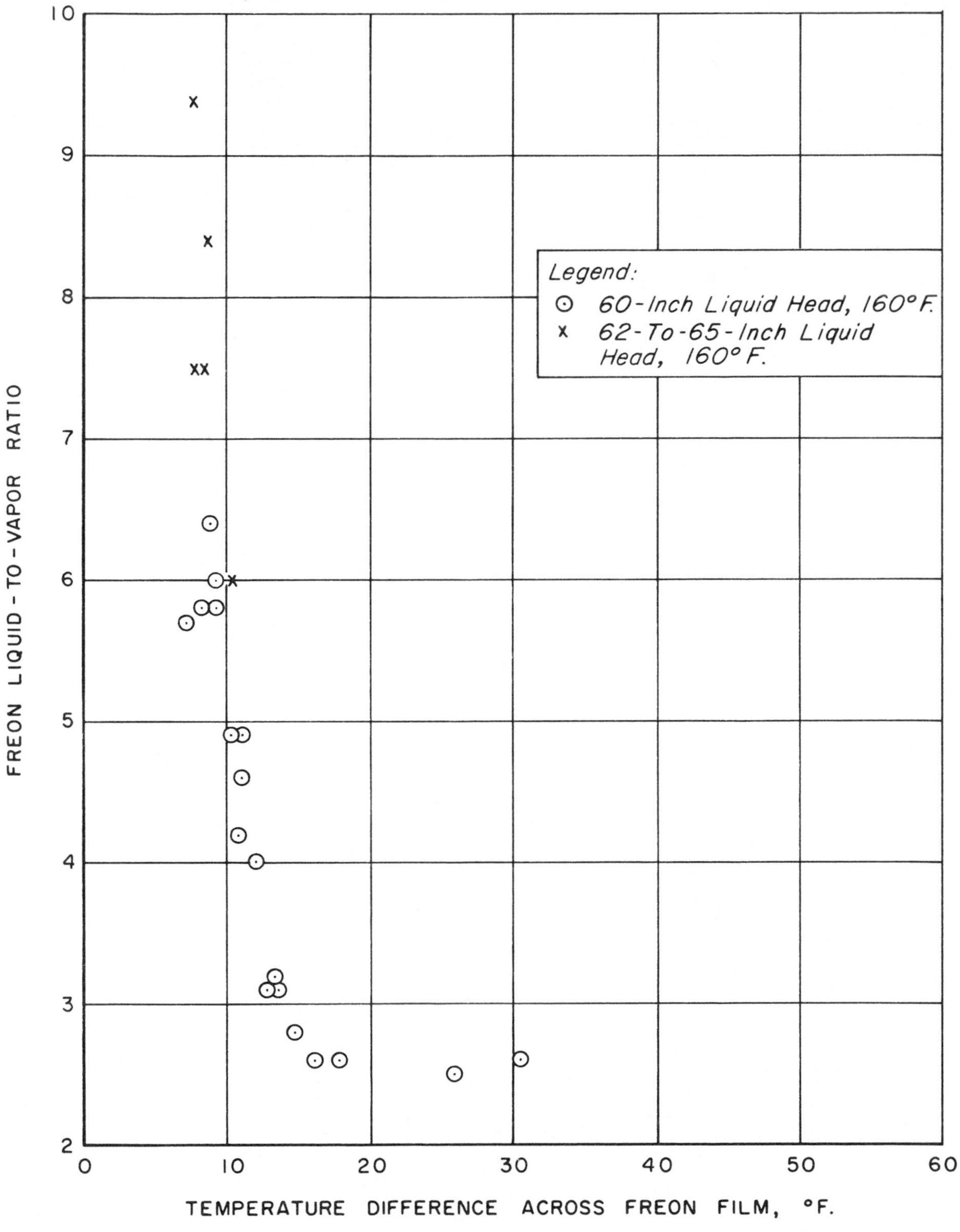
FREON FILM COEFFICIENT VS. TEMPERATURE DIFFERENCE ACROSS FREON FILM

FIGURE 3



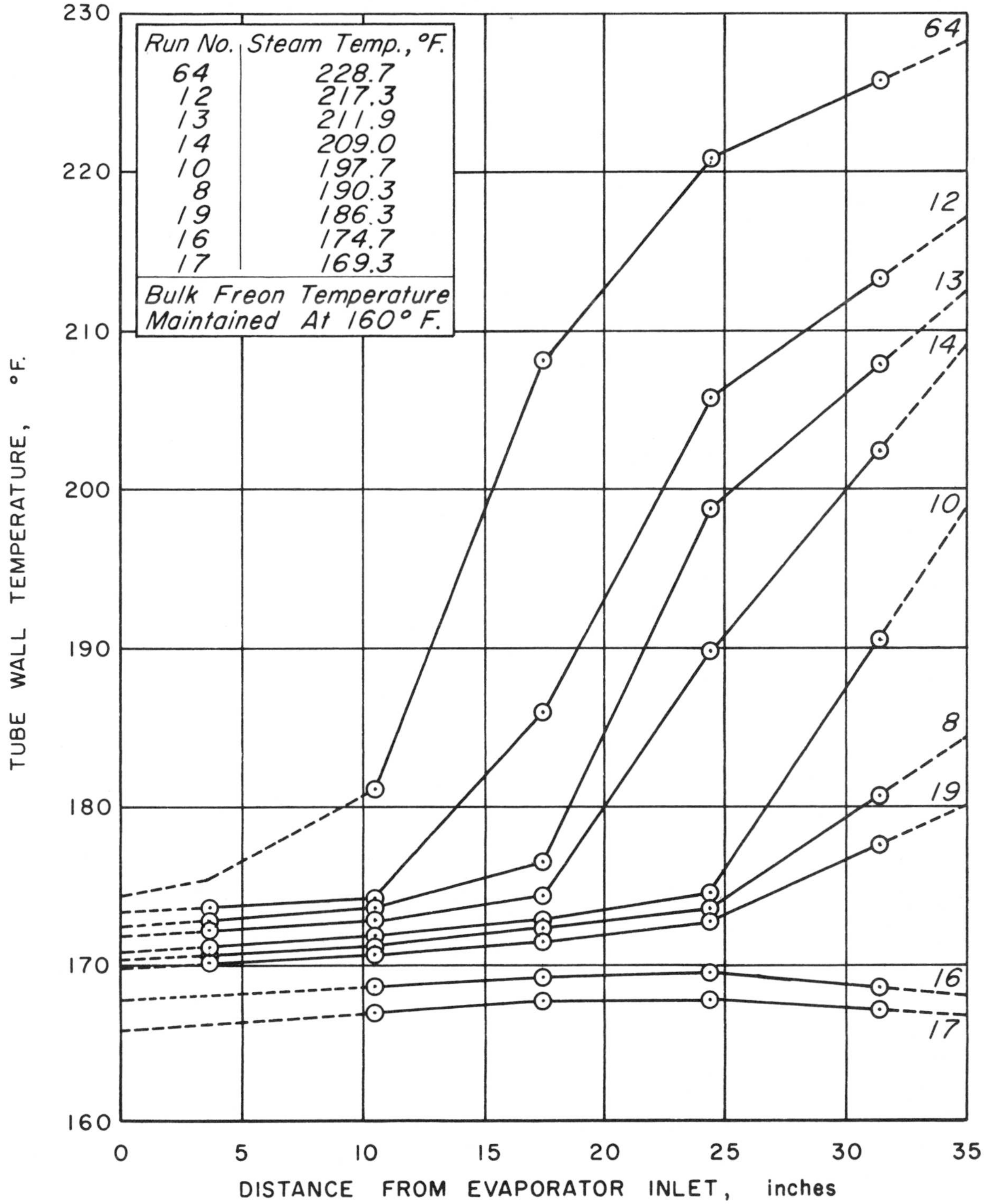
HEAT FLUX VS. TEMPERATURE DIFFERENCE ACROSS FREON FILM

FIGURE 4



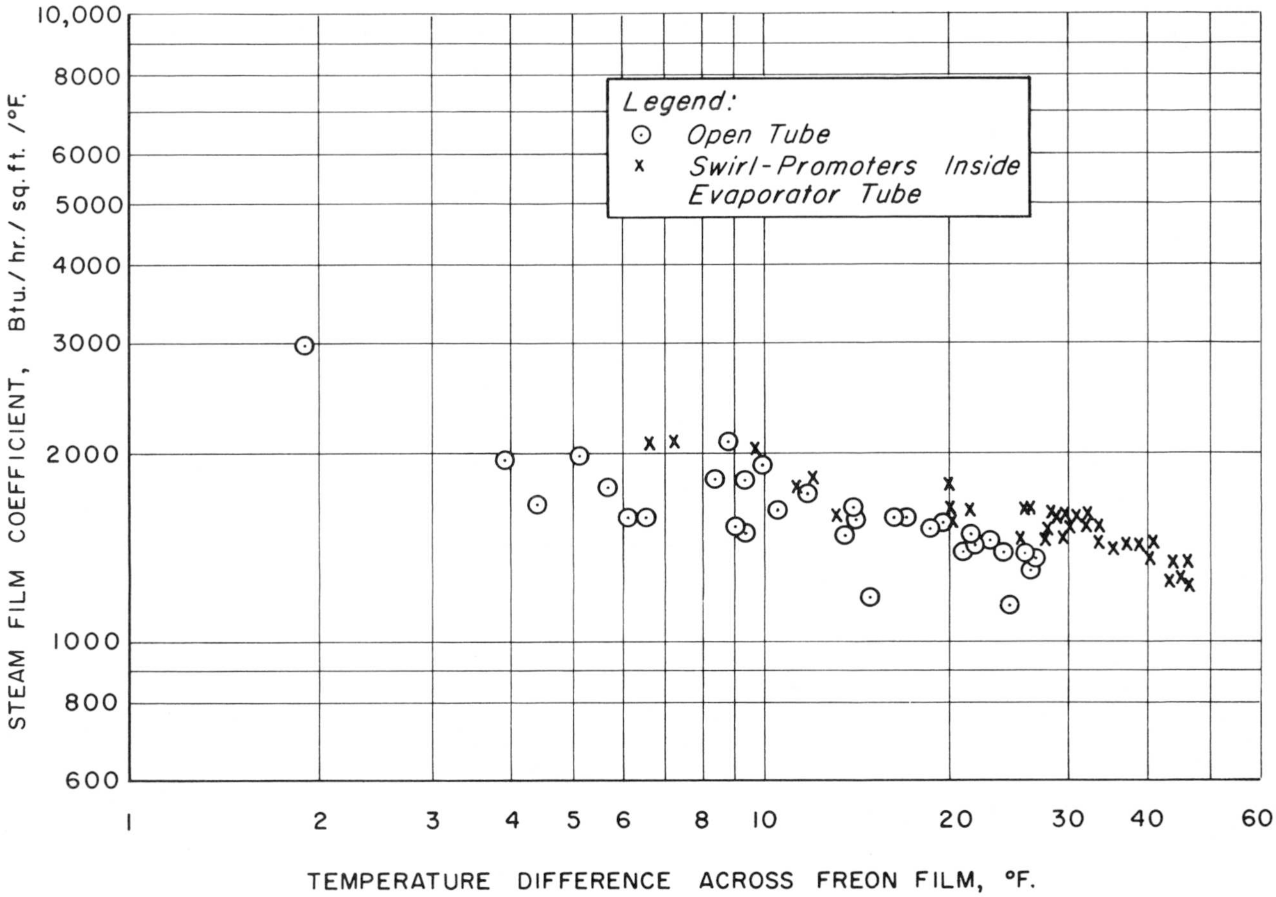
FREON LIQUID-TO-VAPOR RATIO
VS.
TEMPERATURE DIFFERENCE ACROSS FREON FILM

FIGURE 5



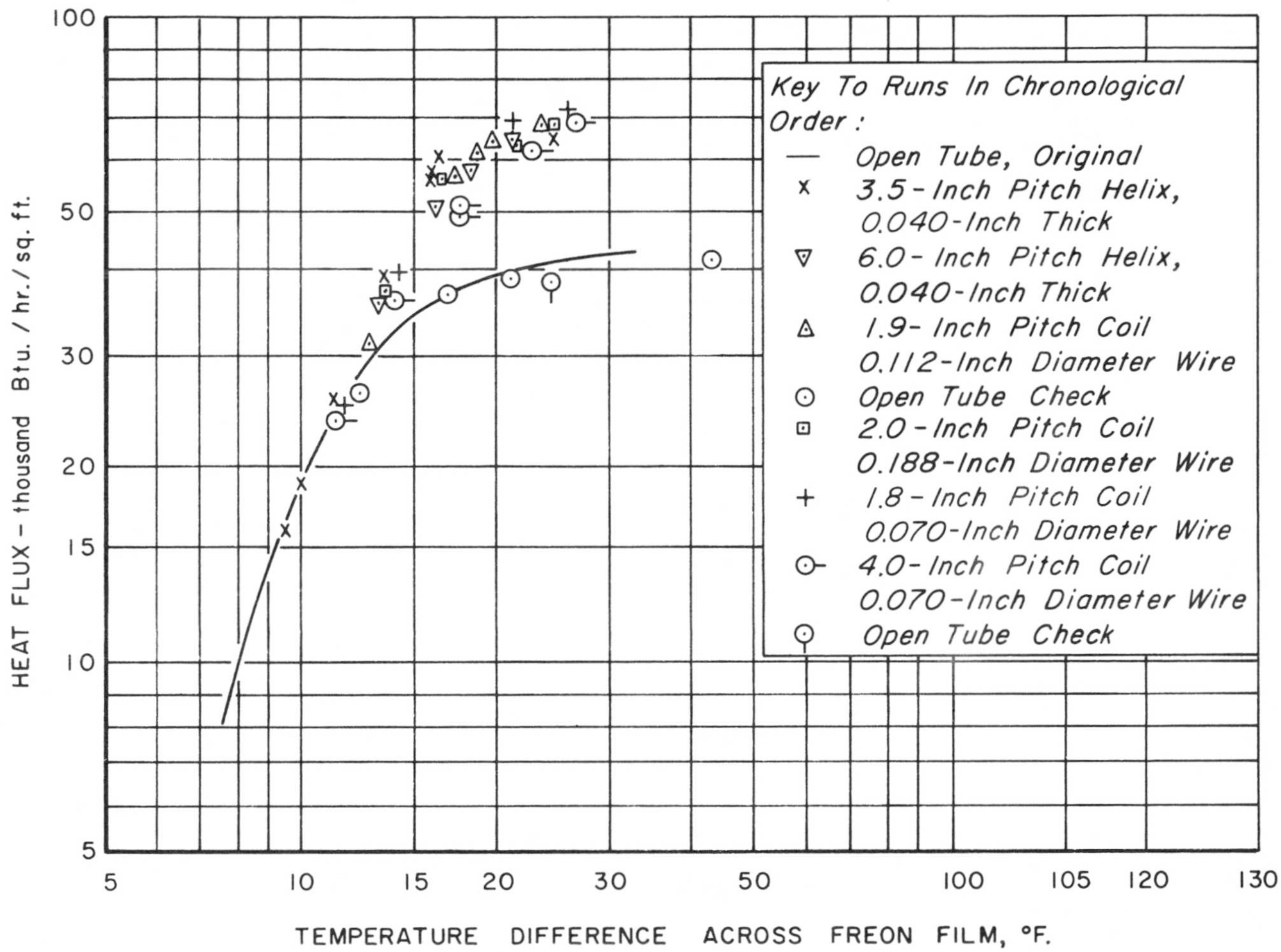
TUBE WALL TEMPERATURE
VS.
DISTANCE FROM EVAPORATOR INLET

FIGURE 6



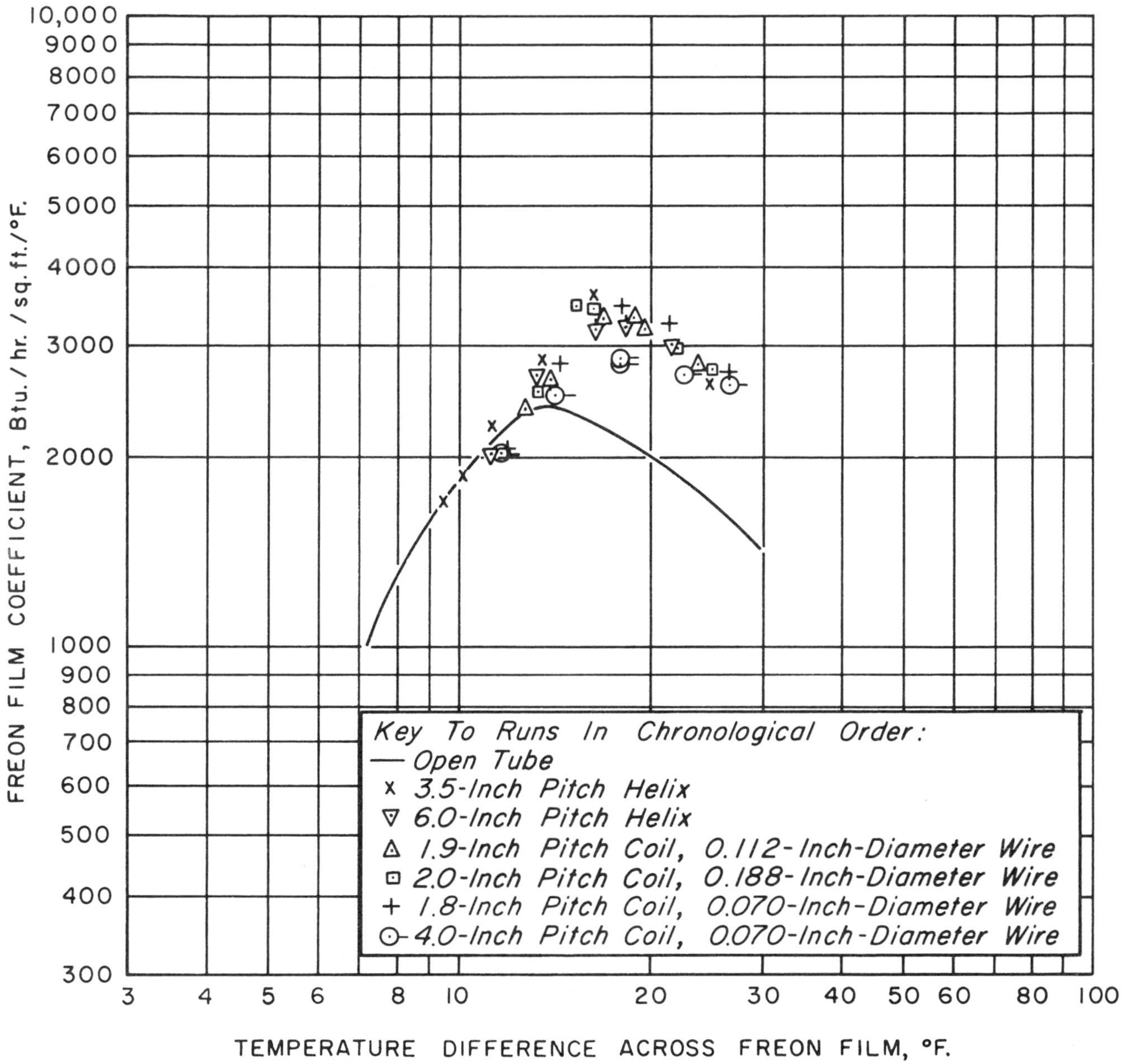
STEAM FILM COEFFICIENT VS. TEMPERATURE DIFFERENCE ACROSS STEAM FILM

FIGURE 7



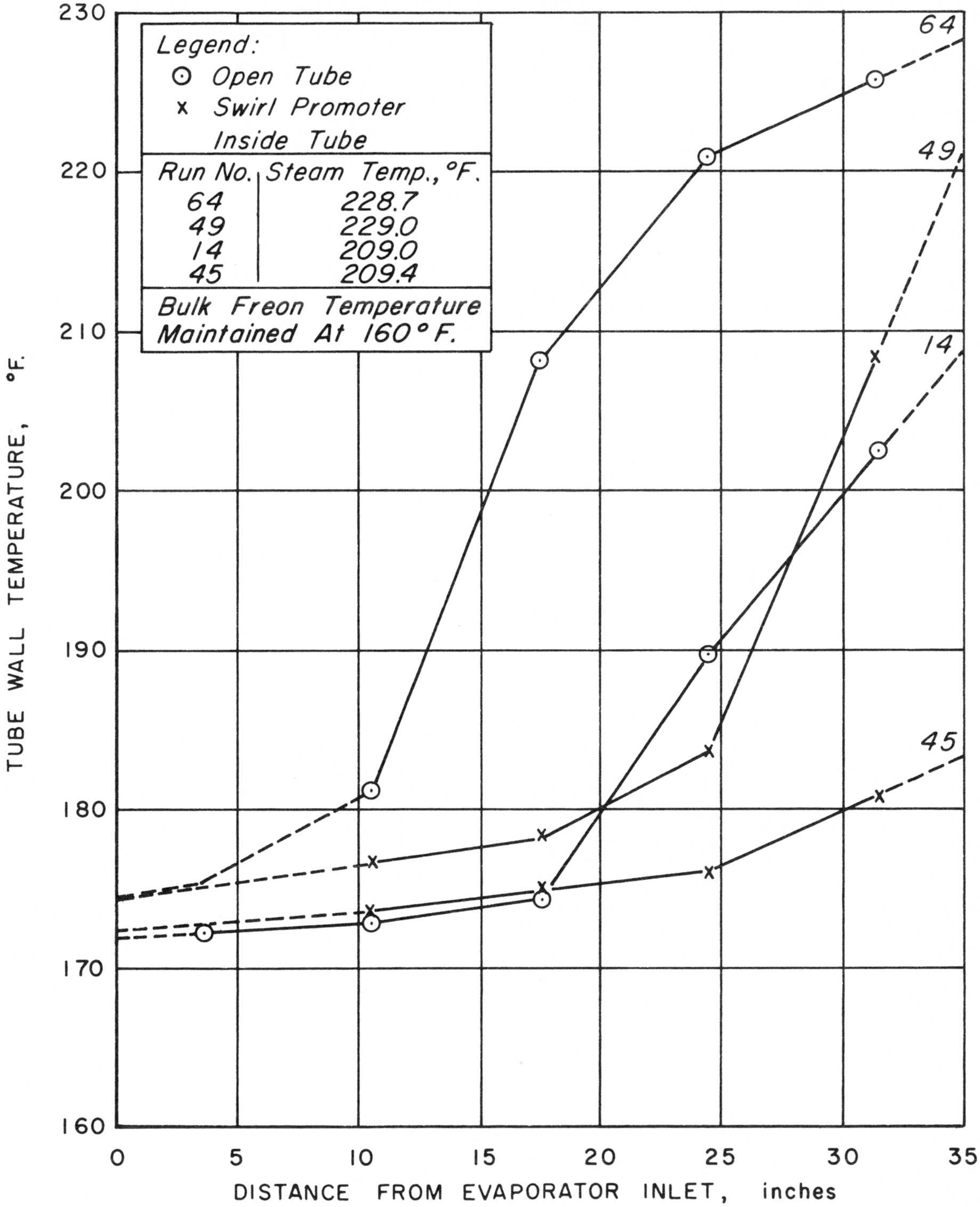
HEAT FLUX VS. TEMPERATURE DIFFERENCE ACROSS FREON FILM

FIGURE 8



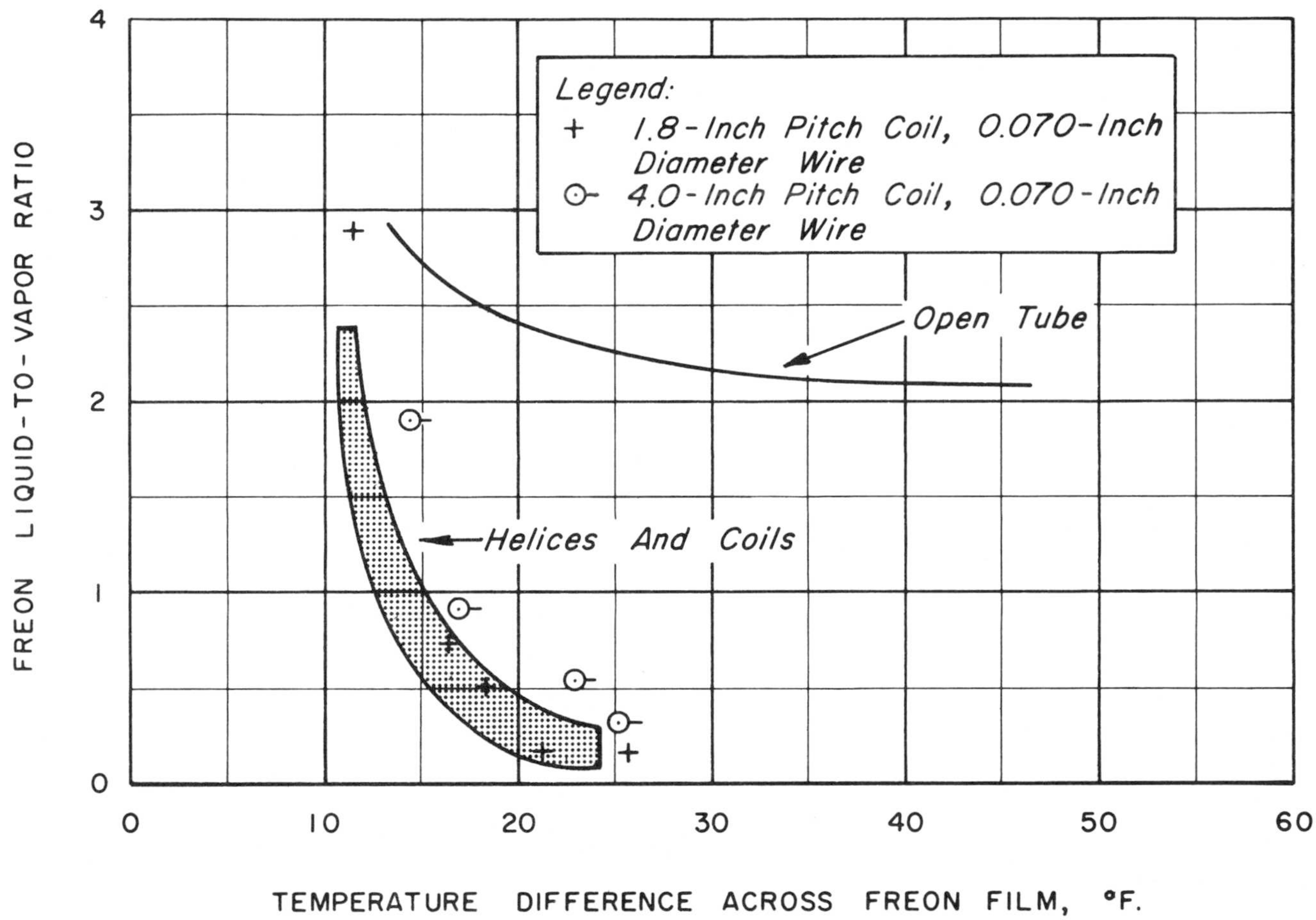
FREON FILM COEFFICIENT VS. TEMPERATURE DIFFERENCE ACROSS FREON FILM

FIGURE 9



TUBE WALL TEMPERATURE
VS.
DISTANCE FROM EVAPORATOR INLET

FIGURE 10



FREON LIQUID-TO-VAPOR RATIO

VS.

TEMPERATURE DIFFERENCE ACROSS FREON FILM

FIGURE 11