DEPARTMENT OF CHEMICAL AND METALLURGICAL ENGINEERING
Heat Transfer Laboratory
The University of Michigan
Ann Arbor, Michigan

ANNUAL REPORT FOR 1961

Report No. 53

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Project 1592

CALUMET AND HECLA, INCORPORATED
WOLVERINE TUBE DIVISION
DETROIT, MICHIGAN

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UMR 1012

ABSTRACT

This report contains a summary of the operations of the research group and work completed during the year 1961. The status of the work of the project is reviewed and discussed.

INTRODUCTION

The Wolverine Tube heat transfer project within the Department of Chemical and Metallurgical Engineering at The University of Michigan is in its twenty-second year of operation. During the past year the project usually employed three or four men. Of these, one was normally employed on a full-time basis and the others were graduate students working part-time. Part-time secretarial help was also employed. The project's laboratory facilities are located in the Fluids Building on the North Campus of the University as indicated in Figure 1. The project director maintains an office in the East Engineering Building where many of the files are kept.

During 1961, there were many more prospective investigations listed than could be handled simultaneously or could be completed. The investigations were, therefore, undertaken in accordance with the current priority status set as a result of conferences held with the Director of Research and Development Division and Director of Operations Division of Wolverine Tube. The prospective projects were separated into two categories. One consisted of projects requiring laboratory facilities and the others consisted of projects requiring the use of technical information available in the literature to effect a desired design or analysis of heat transfer data in an effort to abstract information of value to Wolverine Tube.

In January 1961, the equipment (laboratory) projects in order of priority were:

1. High temperature bond resistance measurements of Type L/C tubes at various tube wall temperatures.

2. The effects of cycling on high temperature bond resistance of Type L/C tubes at various tube wall temperatures.

3. The wind tunnel investigation of the performance of Loktfin tubes.

4. The investigation of internal fin configurations on boiling refrigerant coefficients.

5. The performance of Type S/T tubes in large shell and tube heat exchangers. Liquid and gas cooling. The effect of longitudinal (unbaffled) flow.

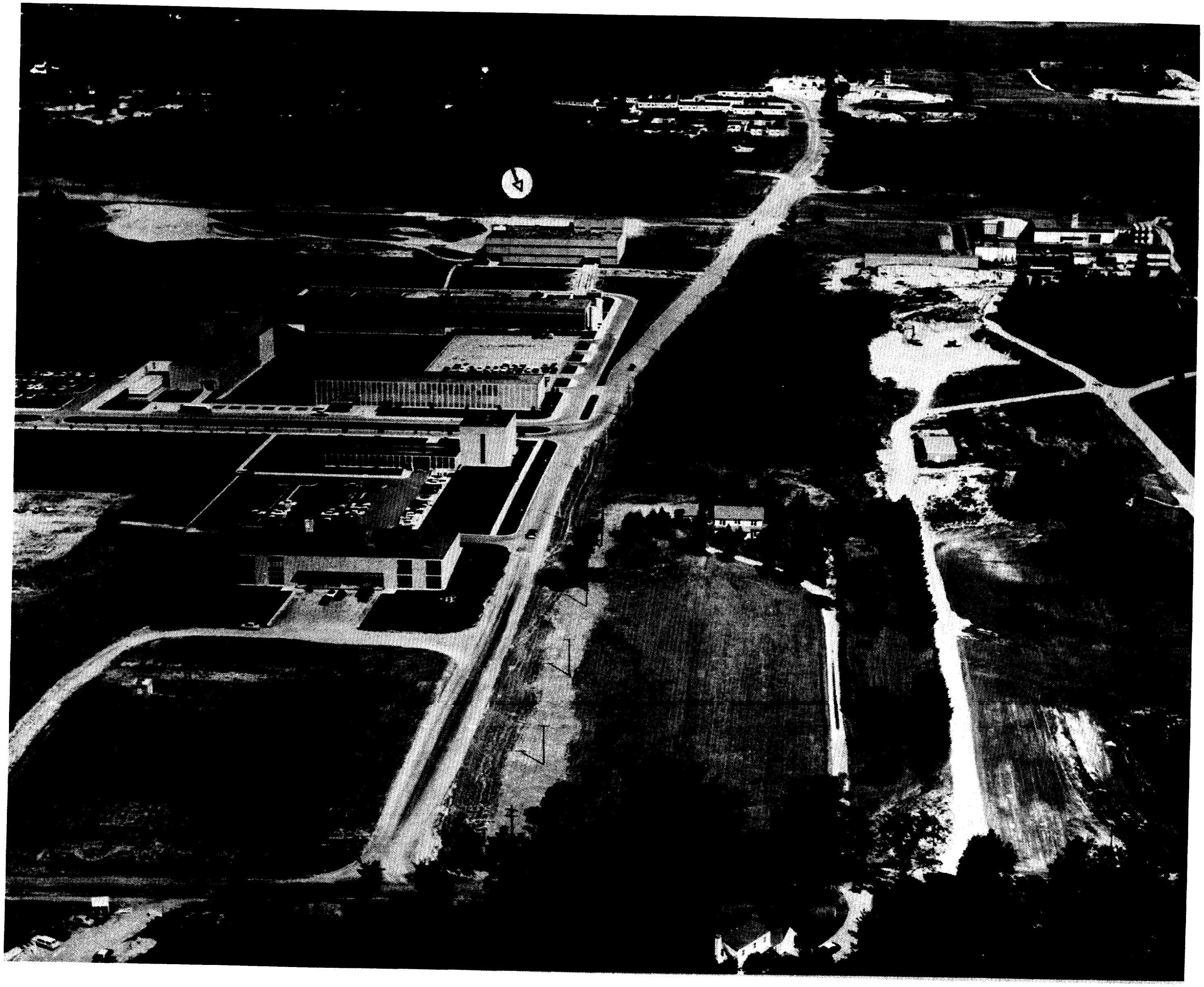

Figure 1. View of the North Campus of the University of Michigan. The Fluids Building is Indicated by an Arrow. The Aeronautical Laboratory, Phoenix Laboratory with the Ford Nuclear Reactor and the Automotive Laboratory are Shown.

Non-laboratory studies in order of priority were:

1. Optimum fin height for refrigerant condensing.

2. Revision of the Ward-Young air cooling correlation to include data obtained on additional banks of tubes.

3. Revision of the Williams-Katz report on the performance of Type S/T tubes in shell and tube heat exchangers. Re-correlation using IBM 704 computer.

Several new projects of higher priority than those mentioned above were added to the project work list during the year. Work on these projects were coordinated with existing projects depending on Wolverine Tube's needs.

PERSONNEL

At the beginning of the year, the following personnel were employed on the project on a part-time basis:

1. Dale E. Briggs (one-half time)
2. I. Lin Chow (full time)
3. William E. Johnson (one-half time)
4. Ian M. Sommerville (full time)
5. Ardis R. Vukas (typist, one-quarter time)

Messrs. Briggs, Johnson, and Sommerville were graduate students in Chemical Engineering. Mr. Chow was a graduate student in Mechanical Engineering. Because of their full-time employment, Mr. Sommerville and Mr. Chow were on limited academic programs.

Several personnel changes occurred during the year. Mr. W. E. Johnson left the project on February 15, 1961, and accepted an assistantship in the Department of Chemical and Metallurgical Engineering. Mr. I. Lin Chow left the project on February 25, 1961, and accepted an assistantship in the Department of Mechanical Engineering. These two reductions in project personnel were necessitated by project budget limitations.

The project director, Professor E. H. Young, was granted a sabbatical leave for the fall semester, 1961-1962, and has taken a leave of absence from the project from September 13, 1961, to February 3, 1962. Professor Young is collaborating with Professor Donald L. Katz in completing a manuscript entitled Heat Transfer Through Finned Tubes. Mr. Dale E. Briggs was appointed acting director of the project during Professor Young's absence.

Mr. Ian M. Sommerville resigned and left the project on December 1, 1961, to accept a position involving heat transfer research work with the Missile and Space Vehicle Department of General Electric at Valley Forge, Pennsylvania.

At the end of 1961, the following persons were employed on the project:

1. Dale E. Briggs (one-half time)
2. Ardis R. Vukas (typist, one-quarter time)

LABORATORY INVESTIGATIONS

Bond Resistance Studies

In 1961, the bond resistance characteristics of Types L/C and W/H tubes were studied. The Type L/C tube investigation consisted of measuring the bond resistances of 2-inch O.D. Type L/C bimetallic tubes with aluminum fins and steel liners at high temperatures. The Type W/H tube investigation consisted of measuring the bond resistances of 1-inch O.D. Type W/H duplex "leak-detector" tubes at wall temperatures of about 130 °F.

Beginning in January, bond resistance data were taken on three Type L/C tubes using the concentric pipe, counter-current hot oil bond resistance equipment shown in Figure 2. By varying the oil flow rates and temperatures, bond resistance data were obtained for various combinations of liner and average fin temperatures. It was possible to vary the liner temperature from about 175 °F to 490 °F and to vary the average fin temperature from about 155 °F to about 390 °F. In all runs the liner temperature was higher than the fin temperature. The bond resistance of a tube at a fixed set of oil flow rates and temperatures was determined from the difference in the actual measured overall heat transfer coefficient and the calculated overall heat transfer coefficient predicted from tube-side and annulus-side heat transfer correlations. The correlations were obtained in 1960 using a 2-inch O.D. monometallic Type L/C tube of the same overall dimensions as the bimetallic tubes. All the data were processed using the IBM 704 computer. A typical computer output sheet giving the tabulated values of temperatures, flow rates and bond resistances are shown in Table 1. When all the data had been processed, the computed values of bond resistances were plotted versus the liner temperatures and compared to the bond resistances predicted using the procedure presented by Gardner and Carnavos in their paper, "Thermal Contact Resistance in Finned Tubing." The equations presented in the paper were found to be adequate in predicting the bond resistance of Type L/C tubes over the range of conditions studied. A report was submitted giving the results of the comparison. A second report was then prepared and submitted giving the anticipated bond resistances of Type L/C tubes as a function of the inside heat transfer coefficient, inside fouling resistance, tube-side fluid temperature, air-side coefficient, and air temperature.

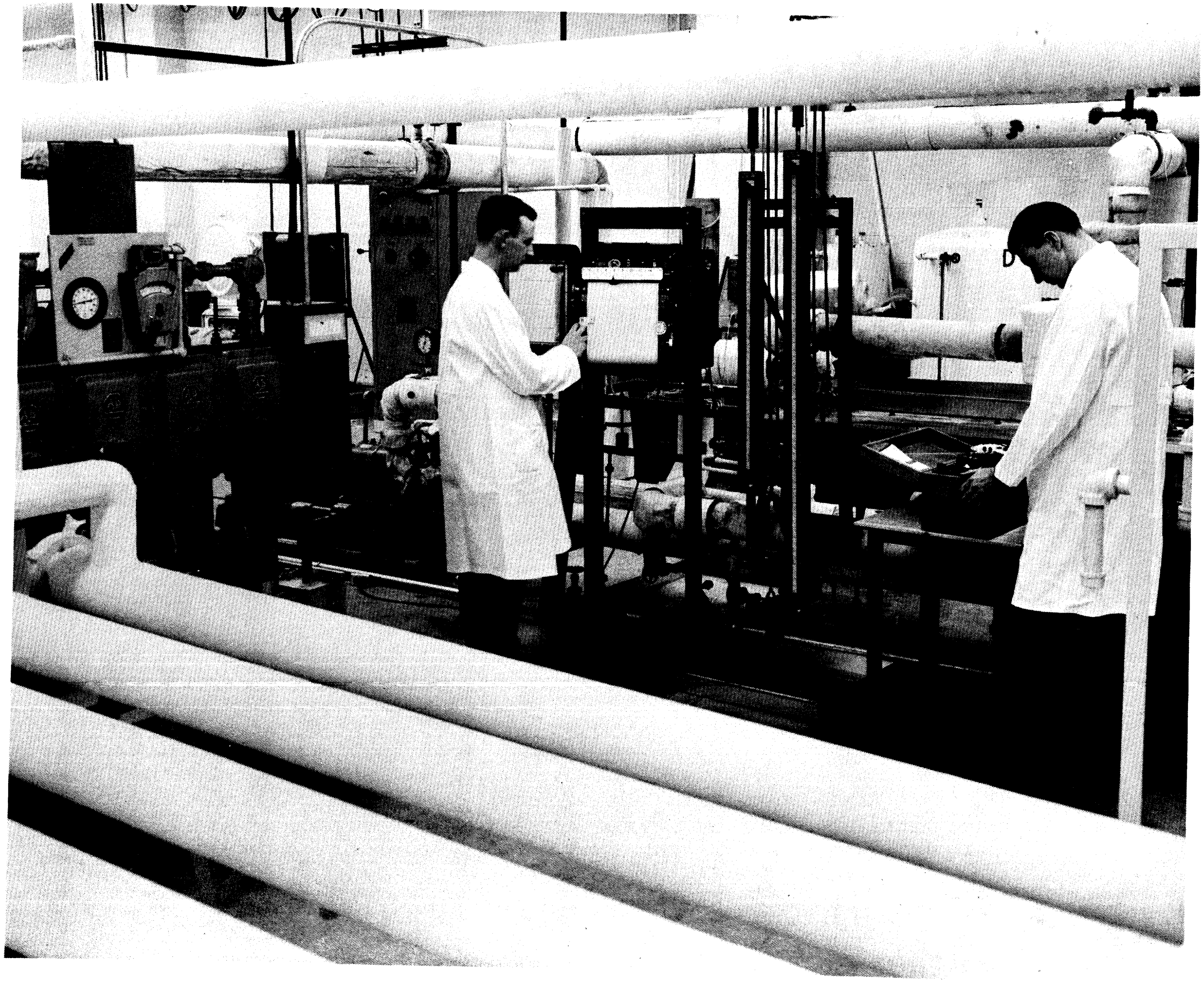

Figure 2. A View of the High Temperature Bond Resistance Equipment with Mr. J. G. Lavin on the Left and Mr. D. E. Briggs Taking Heat Transfer Data.

BOND RESISTANCES FOR TUBE 462 NUMBER OF RUNS IS 5

FIRST RUN NUMBER IS 6 , LAST RUN NUMBER IS 17

RUNS	TUBE	TEMP	XAO	XAI	XAB	RMT	CI
5	462	0	17.3830	1.1350	1.3600	0.37740E-02	0.30250E-01

CO	POWER	RMO	RMI	AMI	AMO
0.33500E-01	0.80000	0.23700E-03	0.36100E-04	1.24800	1.42800

NO	K	L	M	NN	O	P	Q
1	0.38925000E-00	0.44750000E-03	-0.	-0.	-0.	-0.	-0.
2	0.34400000E-00	0.46333332E-03	-0.	-0.	-0.	-0.	-0.
3	0.67977499E-01	-0.19774999E-04	-0.	-0.	-0.	-0.	-0.
4	0.71699999E-01	-0.20999999E-04	-0.	-0.	-0.	-0.	-0.
5	0.99823005E-03	0.25712574E 01	-0.69221853E 03	0.11250699E 06	-0.10177819E 08	0.46051075E 09	-0.79607078E 10
6	-0.19719001E 01	0.12289596E 04	-0.19496695E 06	0.18438552E 08	-0.70568714E 09	-0.	-0.
7	-0.25903068E 01	0.19983570E 04	-0.34916238E 06	0.48629483E 08	-0.38561749E 10	0.12372172E 12	-0.
8	0.62218542E-01	0.15559641E 03	-0.31062931E 05	0.42424545E 07	-0.32040986E 09	0.12080298E 11	-0.17491806E 12

DIAS	AFS	AFT	DIAT	AFIN	AROOT
0.41700E-01	0.30400E-01	0.37600E-02	0.69300E-01	16.14300	1.24000

RUN	TSIF	TSOF	TTIF	TTOF	W SHELL	W TUBE	Q SHELL	Q TUBE
1	202.740	203.900	258.270	255.340	25400.	9440.	14150.	12806.
2	302.170	305.840	415.410	408.860	19400.	10650.	37400.	37317.
3	300.950	306.850	474.340	463.670	19050.	9540.	59035.	57136.
4	351.200	355.710	530.610	517.580	22600.	7280.	55796.	55666.
5	373.030	378.830	547.770	539.710	21700.	14550.	70164.	69887.

RUN	Q AVG	PER DEV	LMTD	UO	RE SHELL	RE TUBE	TWALLI	TBONDI	TBONDO	TROOT	RFIN
1	13478.	4.985	53.480	14.498	11176.	23727.	219.605	217.046	210.718	210.378	0.52037E-02
2	37358.	0.110	108.124	19.877	15590.	90498.	360.825	353.731	323.619	322.675	0.50852E-02
3	58086.	1.634	165.094	20.240	15301.	108766.	392.327	381.297	334.541	333.072	0.50979E-02
4	55731.	0.117	170.605	18.792	22582.	105409.	443.085	432.501	379.218	377.809	0.47289E-02
5	70026.	0.198	167.808	24.006	23665.	227401.	488.421	475.123	408.096	406.326	0.47105E-02

RUN	HI	HO PRIME	UO CORR	UO EXP	LINER TEMP	FIN TEMP	BOND TEMP	BOND RESISTANCE	DEL T
1	319.216	256.492	16.433	14.498	218.326	206.033	213.882	0.635411E-03	-12.293
2	641.492	277.629	27.521	19.877	357.278	310.911	338.675	0.109333E-02	-46.367
3	667.426	275.306	28.208	20.240	386.812	314.735	357.919	0.109185E-02	-72.077
4	606.126	348.749	27.294	18.792	437.793	361.501	405.860	0.129679E-02	-76.292
5	1115.279	352.741	39.917	24.006	481.772	385.916	441.609	0.129909E-02	-95.856

Table 1. Data and Results Calculated by IBM 704 Digital Computer for Bond Resistance of Type L/C Tubes.

The Type W/H tube bond resistance investigation was started in October 1960, and completed in March 1961. Inside and annulus heat transfer correlations were obtained for a 1-inch O.D. Type W/H monometallic copper finned tube using modified Wilson plots. The Wilson plot data were processed with an IBM 704 digital computer. Table 2 shows the tabulated computer output results for the determination of the inside heat transfer coefficient of the monometallic tube by the modified Wilson plot technique. The plotted computer results are shown in Figure 3. Bond resistance data were then taken on six 1-inch O.D. Type W/H duplex "leak-detector" tubes produced by Unifin Tube Company. Three tubes had copper fins and copper liners and three tubes had copper fins and cupro-nickel liners. The data were taken with the heat flux in both directions using the low temperature bond resistance equipment shown in Figure 4. An analysis of the processed data revealed that the bond resistance was negligible at wall temperatures of 155°F and below. Wall temperatures of 155°F were the highest obtainable with the equipment. A letter report was prepared giving the results of the investigation.

Wind Tunnel Investigation

Four different wind tunnel tube banks were studied in the wind tunnel during the year. The studies involved taking heat transfer and pressure drop data for each bank, analyzing the data, and developing air side heat transfer and pressure drop correlations. The first tube bank studied contained six rows of 2-1/4-inch O.D. Loktfin tubes on a 2-7/16-inch equilateral triangular pitch. The second tube bank contained six rows of 2-3/4-inch O.D. monometallic aluminum tubes on a close triangular pitch. The tubes, which were similar to Wolverine Type L/C, were produced by Imperial Chemical Industries Limited in England. The third tube bank contained six rows of 2-inch O.D. Type L/C finned tubes with admiralty liners on a 2-3/16-inch equilateral triangular pitch. Figure 5 gives the air side heat transfer correlation obtained for that tube bank. A tube bank containing six rows of 2-inch O.D. wrap-on fin tubes on a 2-3/16-inch equilateral triangular pitch was the fourth bank studied. Figure 6 shows a view of the wind tunnel.

WILSON PLOT DETERMINATION OF THE INSIDE HEAT-TRANSFER COEFFICIENT FOR TUBE 478 , NUMBER OF RUNS IS 8

FIRST RUN NUMBER IS 25 , LAST RUN NUMBER IS 32

SHELL SIDE FLUID IS WATER

TUBE SIDE FLUID IS WATER

RUNS	TUBE	TEMP	ITER	XAU	XHI	XAM	Rm	C1
8	478	1	10	3.8900	0.6960	0.8360	0.4490E-04	0.2800E-01

NO	K	L	M	NN	O	P	Q
1	0.10124896E 01	-0.46678063E-03	0.58540867E-05	-0.32721741E-07	0.72640616E-10	-0.	-0.
2	0.10124896E 01	-0.46678063E-03	0.58540867E-05	-0.32721741E-07	0.72640616E-10	-0.	-0.
3	0.30377927E-00	0.25267360E-03	0.92050520E-05	-0.75847219E-07	0.17507457E-09	-0.	-0.
4	0.30377927E-00	0.25267360E-03	0.92050520E-05	-0.75847219E-07	0.17507457E-09	-0.	-0.
5	0.13164107E-03	0.95188121E-01	-0.45460416E 02	0.11863807E 05	-0.16322078E 07	0.10831812E 09	-0.25943214E 10
6	-0.21968737E 01	0.54722744E 03	-0.41363282E 05	0.16141324E 07	-0.24764542E 08	-0.	-0.
7	-0.21968737E 01	0.54722744E 03	-0.41363282E 05	0.16141324E 07	-0.24764542E 08	-0.	-0.
8	-0.	-0.	-0.	-0.	-0.	-0.	-0.

DIAS	HFS	HFT	DIAT
0.35500E-01	0.80000E-02	0.15220E-02	0.44000E-01

RUN	TSI	TSO	TTI	TTO	W SHELL	W TUBE
1	78.130	73.080	28.910	44.850	7630.	2350.
2	79.130	72.640	30.150	43.450	7630.	3650.
3	78.860	71.780	31.070	42.840	7630.	4470.
4	79.830	71.740	29.710	40.790	7630.	5380.
5	79.420	70.720	30.140	39.920	7630.	6550.
6	79.870	70.470	29.780	38.910	7630.	7600.
7	80.200	70.370	29.600	38.390	7630.	8250.
8	80.620	70.390	30.070	38.360	7630.	9100.

NOTE - INPUT DATA TEMPERATURES ARE IN CENT.

RUN	TSIF	TSOF	TTIF	TTOF	W SHELL	W TUBE	Q SHELL	Q TUBE
1	172.634	163.544	84.038	112.730	7630.	2350.	69497.	67350.
2	174.434	162.752	86.270	110.210	7630.	3650.	89318.	87283.
3	173.948	161.204	87.926	109.112	7630.	4470.	97427.	94595.
4	175.694	161.132	85.478	105.422	7630.	5380.	111336.	107175.
5	174.956	159.296	86.252	103.856	7630.	6550.	119715.	115173.
6	175.766	158.846	85.604	102.038	7630.	7600.	129349.	124752.
7	176.360	158.666	85.280	101.102	7630.	8250.	135269.	130378.
8	177.116	158.702	86.126	101.048	7630.	9100.	140779.	135631.

RUN	Q AVG	PER DEV	LMTD	UO	RE SHELL	RE TUBE	PR SHELL	PR TUBE
1	68423.	-1.568	69.243	254.026	37285.	40284.	2.358	4.655
2	88300.	-1.153	70.175	323.469	37422.	62473.	2.349	4.663
3	96011.	-1.475	68.971	357.855	37146.	76735.	2.368	4.647
4	109255.	-1.904	72.930	385.112	37373.	89378.	2.352	4.824
5	117444.	-1.934	72.068	418.927	37024.	108352.	2.376	4.847
6	127051.	-1.809	73.485	444.459	37073.	124054.	2.373	4.922
7	132824.	-1.841	74.318	459.443	37129.	133743.	2.369	4.960
8	138205.	-1.863	74.308	478.121	37237.	148161.	2.361	4.936

Table 2. Modified Wilson Plot Data and Results Calculated by IBM 704 Digital Computer for the Inside Heat Transfer Coefficient Correlation of a Type W/H Tube.

AFTER 5 ITERATIONS, INTERCEPT IS 0.66249789E-03 , CI IS 0.02753470

RUN	FUNCTION A	FUNCTION B
1	0.77555337E-04	0.34823599E-02
2	0.54619736E-04	0.26398243E-02
3	0.46460582E-04	0.23441367E-02
4	0.40618311E-04	0.21424740E-02
5	0.34832286E-04	0.19335658E-02
6	0.31117090E-04	0.17959251E-02
7	0.29230589E-04	0.17226507E-02
8	0.26975557E-04	0.16382903E-02

RUN	TSAV	TWALL O	TWALL I	TTAV
1	168.089	152.436	148.761	98.384
2	168.593	148.970	144.228	98.240
3	167.576	146.296	141.140	98.519
4	168.413	143.875	138.007	95.450
5	167.126	140.687	134.380	95.054
6	167.306	138.745	131.922	93.821
7	167.513	137.793	130.659	93.191
8	167.909	137.036	129.613	93.587

RUN	HI PRIME	RFIN IN	HI	HO PRIME	RFIN OUT	HO	NU SHELL	NU TUBE
1	1951.477	-0.	1951.477	1477.265	0.1867E-03	1157.871	135.906	237.254
2	2758.729	-0.	2758.729	1492.203	0.1864E-03	1167.407	137.236	335.468
3	3236.638	-0.	3236.638	1487.745	0.1865E-03	1164.565	136.914	393.422
4	3688.628	-0.	3688.628	1458.943	0.1871E-03	1146.130	134.193	450.413
5	4290.837	-0.	4290.837	1452.706	0.1872E-03	1142.122	133.728	524.263
6	4791.103	-0.	4791.103	1454.971	0.1871E-03	1143.579	133.921	586.494
7	5093.378	-0.	5093.378	1463.457	0.1870E-03	1149.027	134.684	624.106
8	5511.871	-0.	5511.871	1466.989	0.1869E-03	1151.292	134.976	674.970

VISCOSITIES LB/FT-HR

RUN	VISC. SHELL	VISC SH WALL	VISS/VISSW	VISC. TUBE	VISC TU WALL	VIST/VISTW
1	0.9081	1.0230	0.8876	1.6864	1.0536	1.6006
2	0.9048	1.0519	0.8601	1.6890	1.0952	1.5421
3	0.9115	1.0752	0.8477	1.6840	1.1238	1.4985
4	0.9059	1.0970	0.8258	1.7402	1.1544	1.5074
5	0.9145	1.1269	0.8115	1.7476	1.1912	1.4671
6	0.9133	1.1457	0.7971	1.7711	1.2174	1.4548
7	0.9119	1.1552	0.7894	1.7833	1.2312	1.4484
8	0.9093	1.1628	0.7820	1.7756	1.2427	1.4288

WILSON PLOT CONSTANT EQUALS 0.02753470 , INTERCEPT EQUALS 0.66249789E-03

Table 2. (cont.)

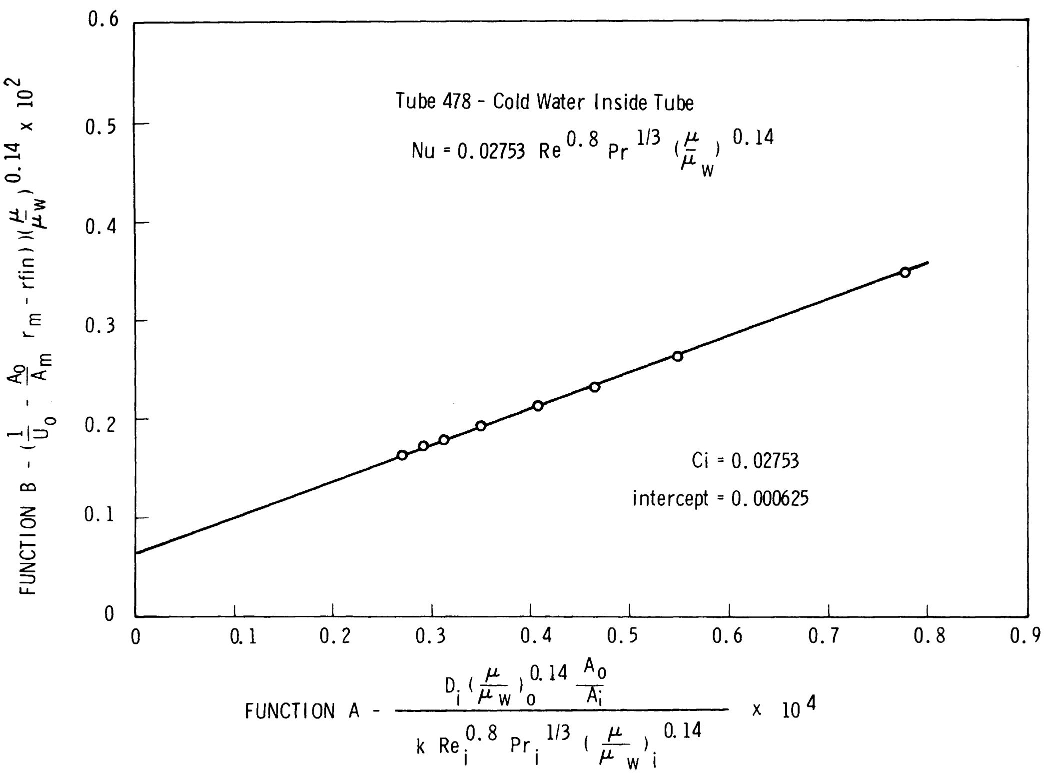

Figure 3. Modified Wilson Plot for Inside Heat Transfer Coefficient - Type W/H Tube.

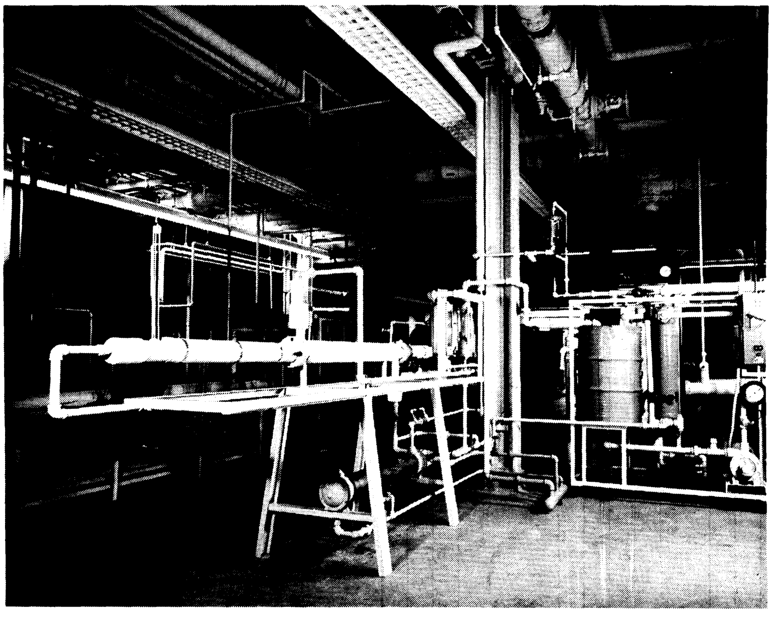

Figure 4. Low Temperature Bond Resistance Measuring Equipment Located in the Fluids Building.

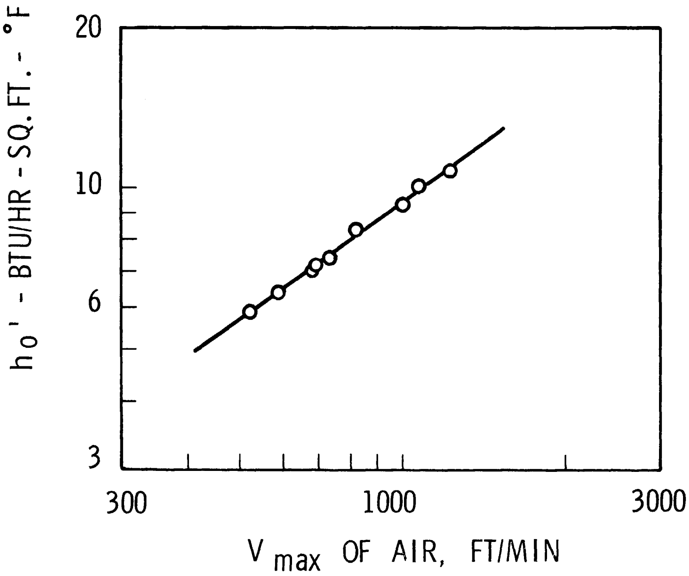

Figure 5. Air Film Heat Transfer Coefficient for Bank No. 17 - 6 Rows of 2 Inch O.D. L/C Tube on a 2-3/16 Inch Triangular Pitch.

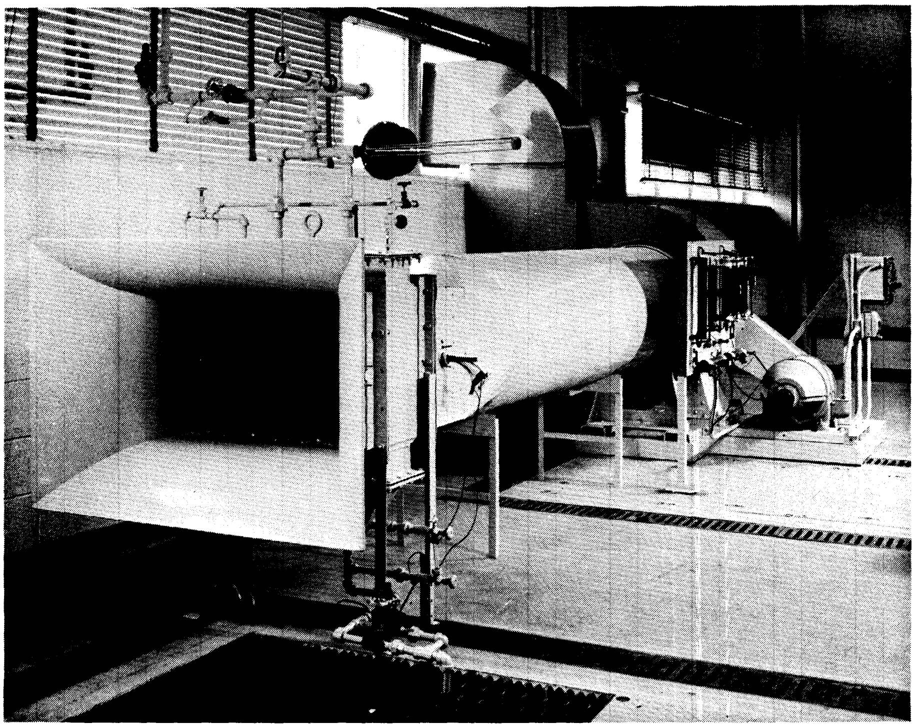

Figure 6. Wind Tunnel for Studying Air Film Heat Transfer Coefficients of Banks of Finned Tubes.

Revision of Report on Performance of Finned Tubes in Shell and Tube Heat Exchangers

Report No. 25, entitled "Performance of Finned Tubes in Shell and Tube Heat Exchangers" by R. B. Williams and Professor D. L. Katz, was issued in 1951. Preliminary plans were made to expand the scope of the original report by utilizing a 10-inch shell and a 16-inch shell provided by Aurora Gasoline Company and a 10-inch shell and a 13-inch shell provided by The Griscom-Russell Company. The laboratory work was not begun during the year.

THEORETICAL INVESTIGATIONS AND CALCULATIONS

Boiling Refrigerants

This investigation was initiated after some boiling refrigerant studies were made in a commercial sized water chiller heat exchanger containing plain tubes with Strubing inserts. These data on refrigerant 22 were analyzed using the correlation of Bo Pierre presented in his paper, "The Heat Transfer Number of Boiling Freon-12 in Horizontal Tubes" and the boiling heat transfer coefficients were compared to those obtained in plain tubes. Data on a tube with a star insert were also analyzed. These data for refrigerant 12 in three water chillers were used to compare the boiling refrigerant heat transfer coefficients of the tubes with star inserts with those for plain tubes.

The second phase of this study was the preliminary design of a boiling refrigerant system which would be used to obtain integral boiling refrigerant heat transfer data on single and multiple tube arrangements. The project was never completed because of the anticipated capital investment required for the program. Mr. J. G. Lavin, the recipient of the Wolverine Trufin Fellowship at The University of Michigan for the years 1960-1962, is conducting a laboratory investigation in this field. The project expects to extend the work to other tubes and other arrangements at the completion of the doctoral thesis by Mr. Lavin.

Direct Fired Water Heaters

Performance data for several directed fired water heaters using integral finned tubing were analyzed. The results were used to evaluate a new direct fired water heater design containing helical coils of Type W/H tubes.

Thermoelectric Plate Fin Units

An investigation was completed for the determination of the heat transfer characteristics of fin plate thermoelectric units when used with air in forced convection. The heat transfer correlations required in this investigation were obtained from the literature. Curves were prepared giving the anticipated heat transfer rates as a function of the air velocity between the fins.

Steam Condensing Data Analysis

The U. S. Naval Engineering Experiment Station data on corrugated tubes were analyzed. Modified Wilson plot techniques were used to obtain the inside heat transfer coefficients for the corrugated tubes. Figure 7 shows a typical Wilson plot. The steam condensing coefficients were determined by a differencing procedure. Using the inside and condensing heat transfer coefficients obtained, an economic evaluation was made comparing corrugated tubes of various metals with plain tubes of the same metal in low pressure steam condensing applications. A report was submitted entitled "Wilson Plot Analysis of U. S. Navy Corro-Tube Steam Condensing Data."

Economic Evaluation of Various Air Cooling Tubes

A report entitled "Economic Evaluation of Various Air Cooling Tubes" was prepared and written in which six typical finned tubes used in air cooling were evaluated on an economic basis when cooling n-pentane from 250°F to 150°F.

Natural Convection Heat Transfer Coefficients for Plate Fins

An investigation was undertaken to determine the optimum fin spacing and fin thickness for plate fin units used in dissipating heat from a particular thermoelectric module arrangement by natural convection. The investigation was completed using available literature on natural convection from closely spaced heated plates. A conference was held at Wolverine Tube to discuss the significance of the results.

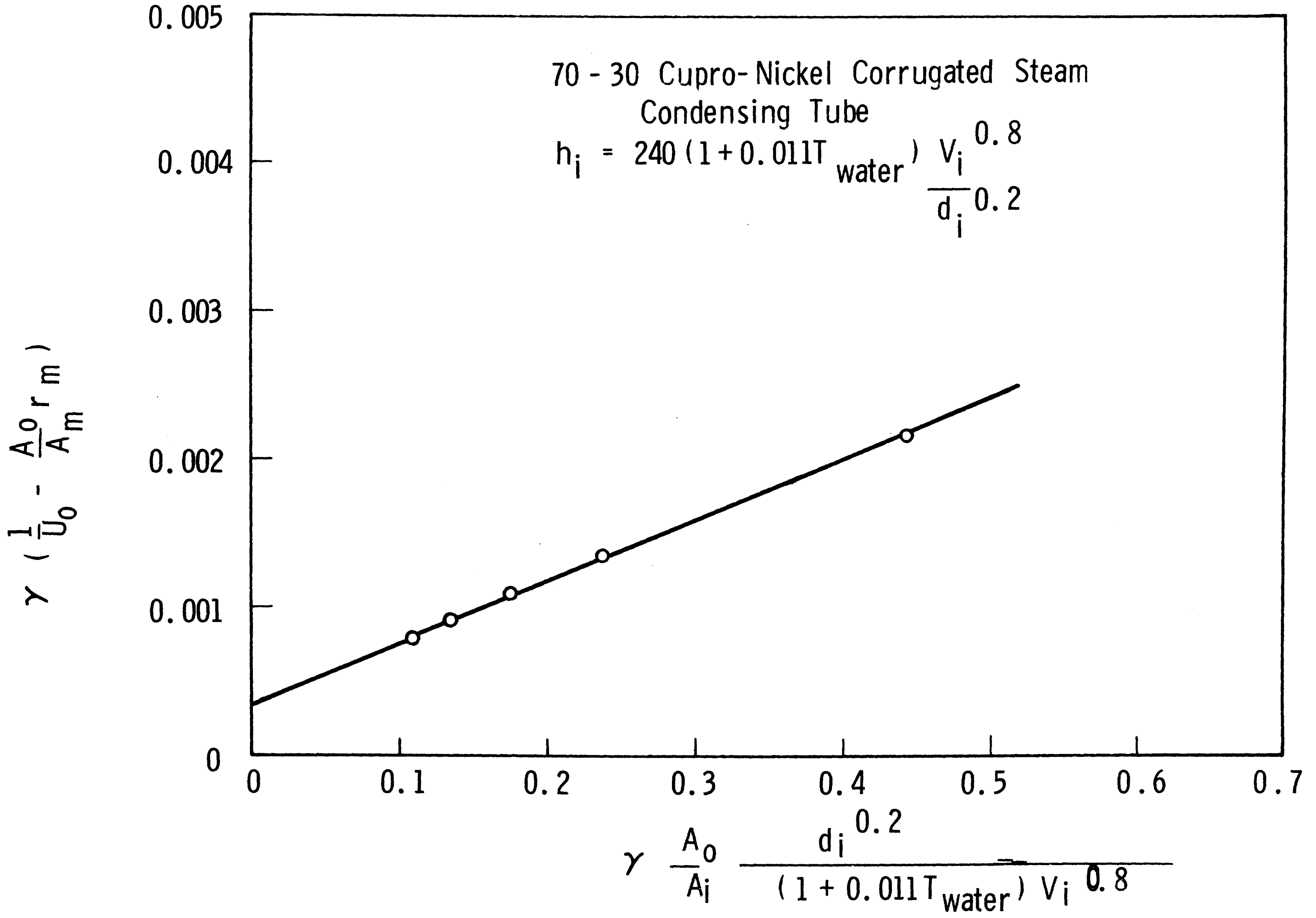

Figure 7. Modified Wilson Plot for Inside Heat Transfer Coefficient - 70-30 Cupro-Nickel Corrugated Tube.

Fin Efficiencies

The fin efficiencies of internal transverse fins were determined. These will be used in the evaluation of the Wolverine Tube concentric pipe data on various internal tube configurations.

Internal Integral Turbulence Promotors

A report was prepared and submitted entitled, "Evaluation of Various Internal, Integral Turbulence Promotors for Low Pressure Steam Condensing Applications." The report was based on Günther Grass's data from his paper entitled "Improvement of Heat Transfer on Water by Artificial Roughening of the Surfaces in Reactors or Heat Exchangers." An economic comparison was made between Grass's tubes and plain tubes when condensing equal amounts of low pressure steam at equal rates of power expenditure. The data of Kemeny and Cyphers printed in their paper "Heat Transfer and Pressure Drop in an Annular Gap with Surface Spoilers" were also analyzed and an addendum to the above report prepared and submitted.

OTHER ACTIVITIES

Many special projects were performed for Wolverine Tube during the past year. One of these projects was the processing of Wolverine's concentric pipe heat exchanger data. The University replaced the IBM 704 computer with an IBM 709 computer as shown in Figure 8. IBM 709 digital computer programs were written and existing programs were altered to do modified Wilson plot analysis of the data. The results obtained for Wolverine Tube are similar to those shown in Table 2 and Figure 3. The project also served in an advisory capacity for the Wolverine Tube concentric pipe exchanger program. Project personnel further assisted Wolverine Tube in the areas of plate fin heat transfer, steam condensing, and other projects.

In July 1961, Mr. R. E. Metrey, Code 651, U. S. Navy, Bureau of Ships, Washington, D. C., spent approximately one week with the project group. Mr. Metrey spent his time working with project personnel on the wind tunnel and the concentric pipe heat exchanger. Conferences on many additional subjects were held with him. Mr. D. M. Mellen of Wolverine Tube spent a similar period with the project in August 1961.

During the year project personnel reviewed heat transfer literature and the heat transfer papers presented at technical meetings. Information pertinent to the project's present or anticipated future needs were placed in the project's files. Similar information of importance to Wolverine Tube's work was forwarded to Wolverine Tube.

A close liaison was maintained by Professor E. H. Young between the research project and the Bureau of Ships, Navy Department, Washington, D. C. and the U. S. Naval Engineering Experiment Station, Annapolis, Maryland. Professor Young participated in conferences at the Bureau of Ships with Mr. D. F. Grimm of Wolverine Tube on March 22, 1961, and September 13, 1961.

Professor E. H. Young and other members of the research group participated in a total of 42 meetings with representatives of Wolverine Tube for the purpose of reporting results and planning future project activities. Conferences were held with representatives of several other companies concerning project activities or project experience in certain areas. Professor Young, Mr. Briggs and Mr. Sommerville met with a representative of the Airtemp Division of Chrysler Corporation on January 26, 1961. On April 11, 1961, Professor Young held meetings with representatives from American Standard and General Electric in Louisville, Kentucky. On July 26, 1961, Professor Young visited The Griscom-Russell Company at Massillon, Ohio.

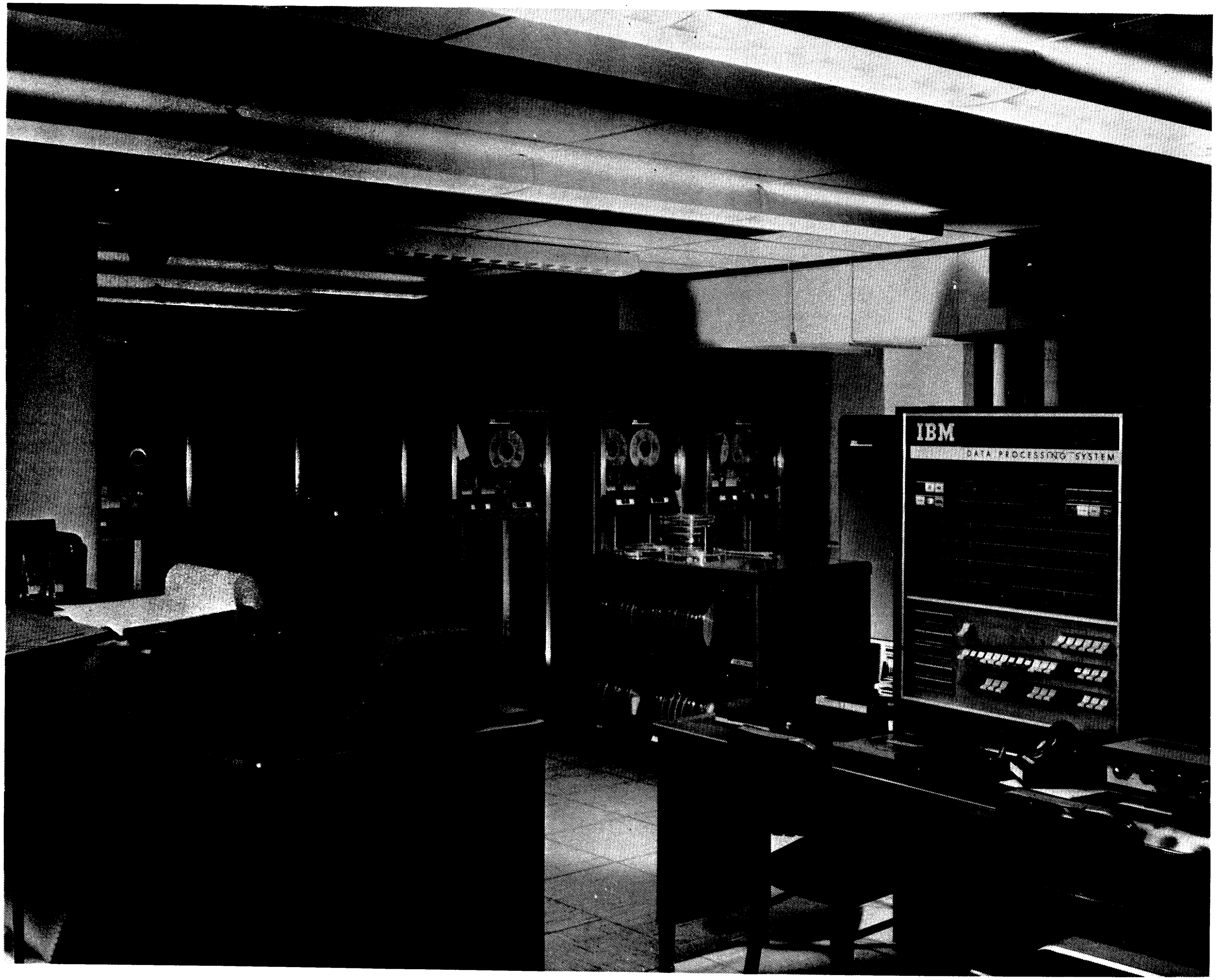

Figure 8. View of the IBM 709 Digital Computer at The University of Michigan

Project personnel also attended important heat transfer conferences. Mr. Briggs attended heat transfer symposia at the ASHRAE Semi-annual meeting and the International Heating and Air-Conditioning Exposition in Chicago, Illinois, on February 13, 1961. Professor Young participated as Symposium Chairman of the Heat Transfer Symposium at the Joint Chemical Engineering Congress in Cleveland, Ohio, on May 8-9, 1961. Mr. Sommerville also attended the symposium.

Professor Young remained active on the ASME Atmospheric Cooling Equipment Code Committee and attended meetings on April 4-5, 1961, in Houston, Texas, and Baytown, Texas, and on November 29, 1961, in New York, New York.

The research project received many requests for copies of the reports and technical papers which have been published as a result of the research program. The requests were fulfilled whenever possible.

CURRENT STATUS

The current priority list established by Wolverine Tube divided the project activities into two categories. One consisted of projects requiring laboratory facilities and the other consisted of non-laboratory investigations. At the end of 1961 the current priority list of projects was:

Equipment (laboratory) projects in order of priority

1. Study of the heat transfer characteristics of boiling refrigerants and investigation of internal fin configurations on boiling refrigerant heat transfer coefficients.
2. Determination of the optimum fin height and fin spacing for refrigerant condensing.
3. Investigation of the steam condensing characteristics of titanium tubes.
4. Investigation of the steam condensing characteristics of corrugated tubes.
5. Determination of the air film heat transfer and pressure drop correlations for banks of finned tubes using the wind tunnel.
6. Study of the performance of Type S/T tubes in large shell and tube heat exchangers. Liquid and gas cooling. The effect of longitudinal (unbaffled) flow.
7. Study of natural convection heat transfer from plate fins and finned tubes.

Non-laboratory studies in order of priority

1. Revision of the Ward-Young air cooling correlation to include data obtained on additional banks of tubes.
2. Revision of the Williams-Katz report on the performance of Type S/T tubes in shell and tube heat exchangers. Re-correlation using IBM 709 computer.