THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE
ANN ARBOR, MICHIGAN

# ANNUAL REPORT FOR 1958

Report No. 50

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Project 1592

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WOLVERINE TUBE DIVISION
DETROIT, MICHIGAN

February 1959

## ABSTRACT

This report contains a summary of the operations of the research group and work completed during the year 1958. The status of the work of the project is reviewed and discussed.

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# INTRODUCTION

The Wolverine Tube heat transfer project at The University of Michigan Research Institute is entering its nineteenth year of operation. The project employed eight or nine men on a part-time basis during most of 1958. Equipment purchases took a larger than usual part of the project's funds during the first half of the year. For this reason it was necessary to postpone hiring replacements for several men who left the project during the summer and early fall months upon completion of their academic course work. As a result, at the end of 1958, the group was down to five men.

The research group always has more prospective investigations than can be handled simultaneously. The investigations which were carried out during the year were those which were given priority status as a result of conferences held with the Technical Manager, New Products Division of Wolverine Tube.

In January of 1958, the research group was working on the following investigations, with priority in the order presented.

1. Influence of thermal cycling on bond resistance.

2. Determination of the heat transfer and pressure drop characteristics of corrugated tubes in steam condensing.

3. Determination of the heat transfer and pressure drop characteristics of corrugated tubes in a liquid-liquid concentric pipe heat exchanger.

4. Investigation of the heat transfer and pressure drop performance of tube banks in a wind tunnel.

5. Investigation of the heat transfer and pressure drop performance of internal finned tubes.

6. Revision of the Williams-Katz report entitled "Performance of Finned Tubes in Shell and Tube Heat Exchangers".

7. Vibrational testing of bond resistance.

During the year considerable work was done on all the topics listed above except for the last item. A brief discussion of the research group personnel and activities is given below.

# PERSONNEL

At the beginning of the year the following personnel were employed on the project on a part-time basis. In 1958, all members of the project except the typist were graduate students in Engineering.

1. Marvin L. Katz
2. Dale E. Briggs
3. James R. Fleming
4. Byron S. Gottfried
5. Harry Hsiung
6. Robert H. Cherry
7. Henry C. Lim
8. J. David Hellums
9. Gordon D. Towell
10. Jean A. Storms (typist)

During the year there were a number of personnel changes. In January, Mr. Gottfried finished his studies for a master's degree and left the project for the Nuclear Power Division of Westinghouse in Pittsburgh, Pennsylvania. In June, Miss Storms accepted a full-time job in Los Angeles, California. Mrs. Ardis Vukas replaced Miss Storms as the project part-time typist. Mr. Hsiung changed his major to Nuclear Engineering and left the project in June for nuclear work. Mr. Fleming and Mr. Cherry left the project in July and September, respectively. Both men completed their work for masters degrees. Mr. Fleming entered the Army and Mr. Cherry accepted a Teaching Assistantship at Ohio State University. In September, Mr. Katz and Mr. Towell accepted fellowships here at The University of Michigan and left the project.

Two men were added to the project during 1958. In May, Mr. William H. McCarty joined the project on a part-time basis. Mr. McCarty has also worked part-time on the manuscript for the book, Heat Transfer Through Finned Tubes. In August, Mr. Thad D. Epps joined the project on a part-time basis. Both Mr. McCarty and Mr. Epps are candidates for masters degrees in Chemical Engineering.

At the end of 1958, the project consisted of the following personnel:

1. Dale E. Briggs
2. J. David Hellums
3. Thad D. Epps
4. Henry C. Lim
5. William H. McCarty
6. Ardis R. Vukas (typist)

## BOND RESISTANCE STUDIES

In 1958, extensive studies were made on the effect of thermal cycling on bond resistance. In January and February, an improved apparatus for steam cycling was constructed. Previously all cycling had been carried out two tubes at a time by manually alternating the flow of steam and water through the tubes. The new apparatus cycles four tubes at a time and is entirely automatic. Steam and water flows are alternated by solenoid valves controlled by a timing device. The new apparatus has permitted extensive cycling studies with a great saving in manpower. A picture of the apparatus is shown in Figure 1.

In April, a 48-kw oil heating unit was installed. The research group fabricated a four-tube cycling unit in which tubes are heated to 600 °F by flow through the tubes of oil from the heating unit, and then cooled to 150 °F by flow of air through the annular areas. This apparatus is semi-automatically controlled and requires little manpower. Front and back views of the oil heating unit are shown in Figures 2 and 3. The hot oil tube cycling equipment is shown in Figure 4.

Bond resistance measurements in 1958 were all accomplished by use of the water-to-water heat exchanger previously described in Report Number 48. The exchanger and its auxiliary equipment are pictured in Figures 5 and 6, respectively. The tubes were cycled to 350 °F in the steam apparatus or to 600 °F in the oil apparatus and periodically tested for bond resistance using the water-to-water heat exchanger. The bond temperature in the water-to-water exchanger is about 130 °F.

The results of the bond resistance investigations were given in a paper delivered to the Symposium on Air Cooled Heat Exchange at the Annual Meeting, American Institute of Chemical Engineers, Cincinnati, Ohio, December 10, 1958. Mr. Marvin L. Katz received the "Presentation Award Certificate" for the "best presentation of a paper at the Annual Meeting of the A.I.Ch.E." The paper was entitled "The Effect of Thermal Cycling to 350 °F and 600 °F on the Heat Transfer Performance of Integral Finned Duplex Tubes" by Edwin H. Young and Marvin L. Katz.

## INVESTIGATIONS ON THE PERFORMANCE OF CORRUGATED TUBES

A concentric pipe water-to-water heat exchanger with a 9-foot test section was constructed in January. The exchanger was designed as a multi-purpose unit. Two shells of different sizes were fabricated to permit investigations on tubes of widely different diameter. Provision was made for measurement of pressure drop on both the tube and shell sides. The apparatus is complete with all necessary auxiliary equipment. A picture of the apparatus is shown in Figure 7.

During the first half of 1958, investigations were made on the performance of a plain copper tube, four 3/4-in. O.D. copper corrotubes, two 5/8-in. O.D. 70-30 cupro-nickel corrotubes, and two 5/8-in. O.D. 90-10 cupro-nickel corrotubes, all in the concentric tube apparatus. The 5/8-in. O.D. cupro-nickel corrotubes and two plain cupro-nickel tubes were also studied using the steam condensing apparatus. A picture of the steam condensing apparatus is given in Figure 8.

The results of the work on corrugated tubes were discussed with personnel of the United States Navy on two occasions during the year. The Navy is interested in corrugated tubes for use in reducing the size of shipboard condensers, and is conducting their own evaluation of Wolverine corrotubes.

In July, the priority of the corrotube investigation was lowered. After July, the only work done on corrotubes was in analysis of data taken earlier.

## INVESTIGATION ON THE PERFORMANCE OF FINNED TUBE BANKS

The doctoral research work of Dennis J. Ward, which was supported by Wolverine Tube, officially terminated on his graduation in January, 1958. Dr. Ward presented the results of this work at the American Institute of Chemical Engineers - American Society for Mechanical Engineers Second National Heat Transfer Conference in Chicago, on August 18, 1958, in a paper entitled, "Heat Transfer and Pressure Drop of Air in Forced Convection Across Triangular Pitch Banks of Finned Tubes".

In 1958, the research group extended the investigation begun by Dr. Ward on finned tube banks to include banks with wider ranges of the variables tube pitch and fin thickness. Additional data were obtained on the effect of turbulence and additional pressure drop studies were made. A picture of the wind tunnel used in this work is given in Figure 9.

All the data taken in 1958, together with Dr. Ward's data, were recorrelated. Improved correlations for predicting heat transfer and pressure drop performance of finned tube banks were developed.

## INVESTIGATIONS ON INTERNALLY FINNED TUBES

The concentric pipe apparatus used in the corrotube investigation was also used for studying the heat transfer and pressure drop characteristics of internally finned tubes.

A series of heat transfer and pressure drop studies were made on six internally finned tubes. Some of the tubes had straight longitudinal internal fins and the others had slightly spiral longitudinal internal fins. The tubes all had six internal fins of roughly the same size.

The main conclusions from this work and some typical data were reported to Wolverine in 1958 in the form of a letter report. Equipment modifications were begun which will make it possible to extend the study to Reynolds' numbers in the laminar flow and transition regions. In many, or perhaps most, applications of internally finned tubes, the tube side fluid is in laminar flow or in the transition region.

## 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. A revision to this report was substantially completed during the past year. By use of the IBM 650 computer, it was possible to find an improved correlation for the original data without expending an inordinate amount of manpower. Figure 10 shows Mr. Thad D. Epps of the project group working with the IBM 650 computer. The results of this work are being prepared for publication as an UMRI report.

## OTHER ACTIVITIES

During the year the research group was active in a number of areas not covered under the main topics discussed above.

Professor Edwin H. Young and other members of the group participated in a large number of meetings with representatives of Wolverine Tube for the purpose of reporting results and planning of future project activities. Other meetings, in general, either were technical sessions on subjects of importance in the research program or were meetings with representatives of other organizations to discuss heat transfer through integral finned tubes, corrugated tubes, and related phenomena.

Professor Donald L. Katz, Chairman of the Department of Chemical and Metallurgical Engineering, and Professor Edwin H. Young, Project Supervisor, are co-authoring a book entitled *Heat Transfer Through Finned Tubes*. The book is to be published by John Wiley and Sons of New York. The preparation of the manuscript is being supported by a grant from Wolverine Tube.

During the year the research group carried out several minor investigations for Wolverine Tube. Most of these investigations consisted of analysis of data obtained by other organizations on various types of heat transfer equipment.

The research group receives many requests for copies of the reports and technical papers which have been published as a result of the research program. The requests are filled whenever possible.

Considerable use is made of the University IBM 650 digital computer. Whenever numerous trial-and-error calculations are required in correlating data, the computer can be used to great advantage. The project group does its own programming for the digital computer. Several of the project programs have been extensively used in correlating laboratory experimental data.

## CURRENT STATUS

At the end of the year the priority list for the research group was as indicated below. The revision of the Williams-Katz report is listed although that work was substantially completed.

1. Influence of thermal cycling on bond resistance.

2. Heat transfer and pressure drop characteristics of internally finned tubes.

3. Performance of finned tube banks in a wind tunnel.

4. Revision of the Williams-Katz report.

5. Heat transfer and pressure drop characteristics of corrugated tubes.

For the 1959 year there are a number of investigations which should be undertaken in addition to those on the current priority list. On October 30, 1958, a research planning meeting was held at the University. At that time, representatives of Wolverine Tube indicated interest in the following investigations.

1. Maximum tube wall operating temperature of Type L/C Trufin and the maximum bond resistance to be expected at this temperature. This investigation will require measurement of bond resistances over a wide range of temperature. The oil heating unit now being used will serve as the main item of equipment.

2. A revision of Dr. Dennis J. Ward's paper, "Heat Transfer and Pressure Drop of Air in Forced Convection Across Triangular Pitched Banks of Finned Tubes", including data on bond resistance.

3. Heat transfer and pressure-drop characteristics of Type S/T Trufin shell and tube exchangers in (a) gas cooling, and (b) with shell side liquids in longitudinal unbaffled flow.

4. Internal finned tube data on Trufin Type I/L tubes and on internal finned water-chiller tubes.

In addition to the above items are a number of fundamental heat transfer investigations involving finned tubes that the project group feel should be undertaken.

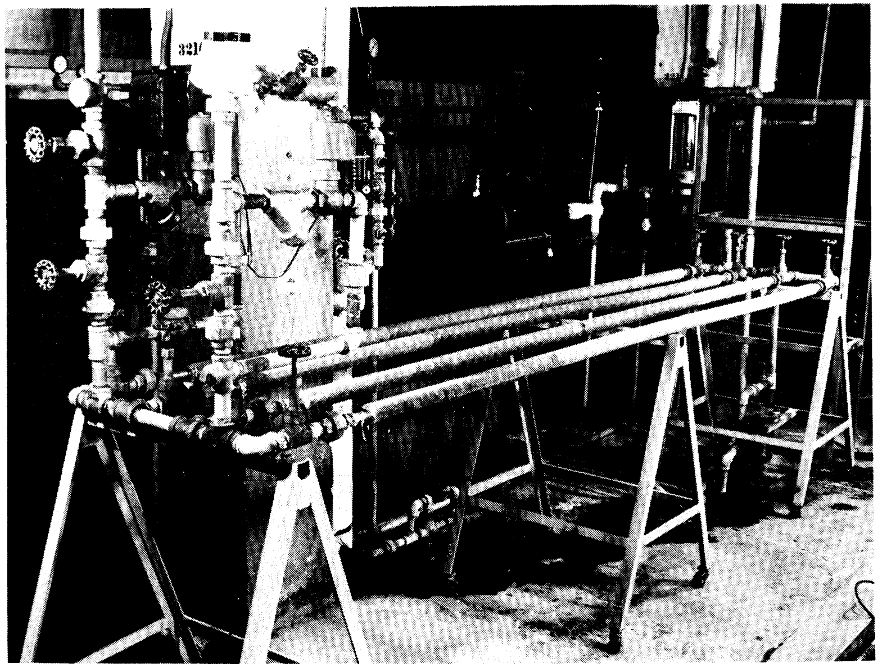

Figure 1. 350 °F Steam Cycling Apparatus with Control Valves and Timer.

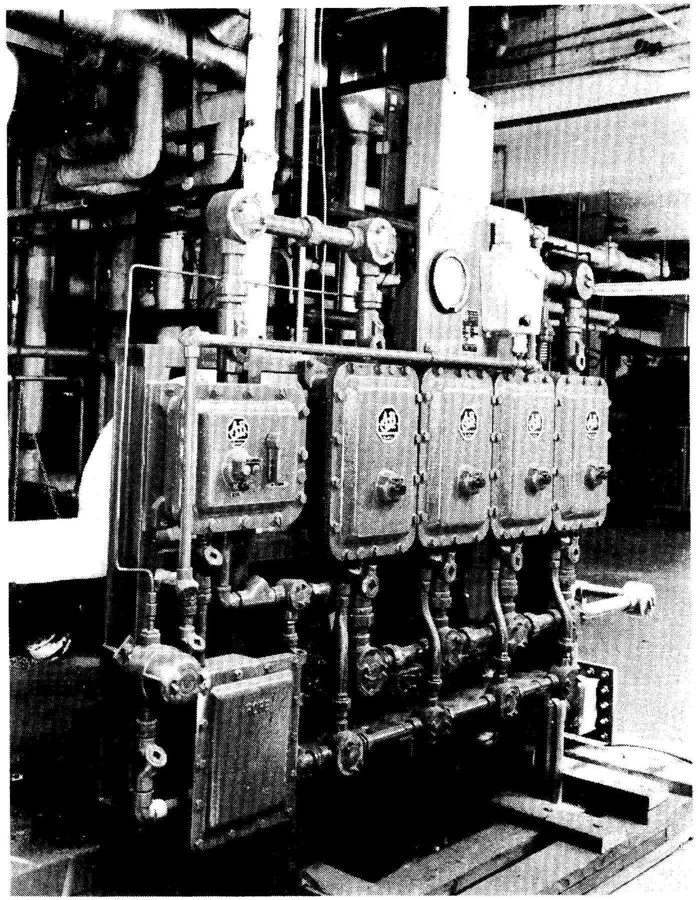

Figure 2. Control Panel of 48 Kilowatt Oil Heating Unit.

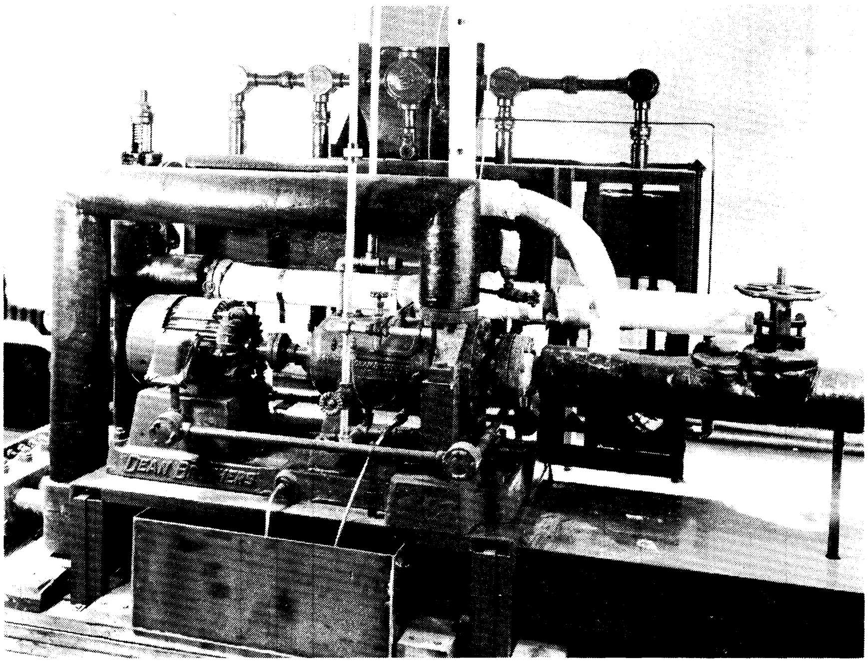

Figure 3. Back View of 48-kw Electric Heating Unit Showing Oil Circulating System.

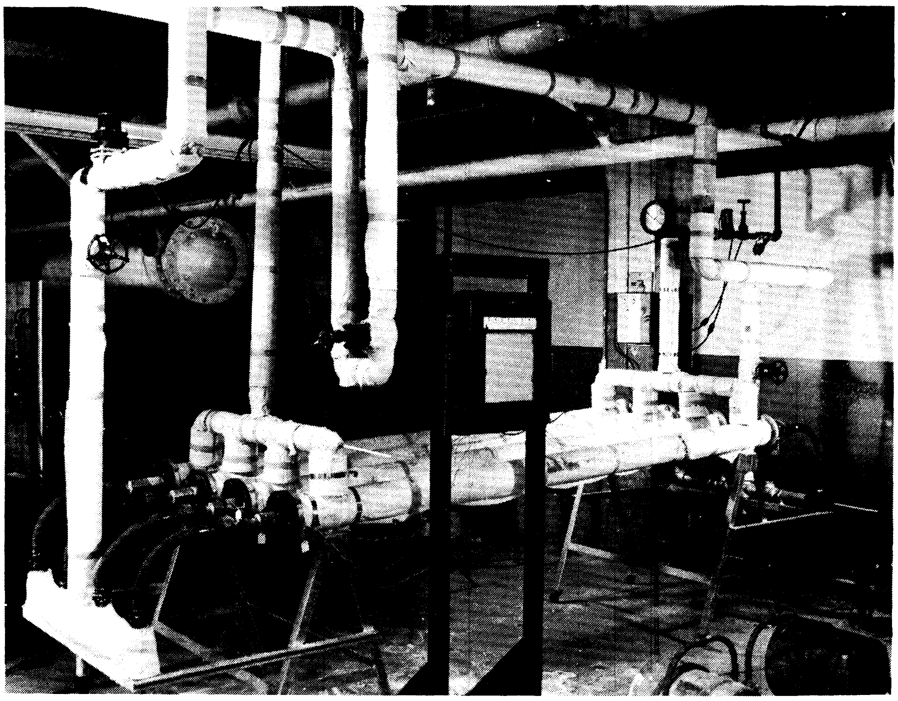

Figure 4. 600 °F Oil Cycling Apparatus with Temperature Recorder.

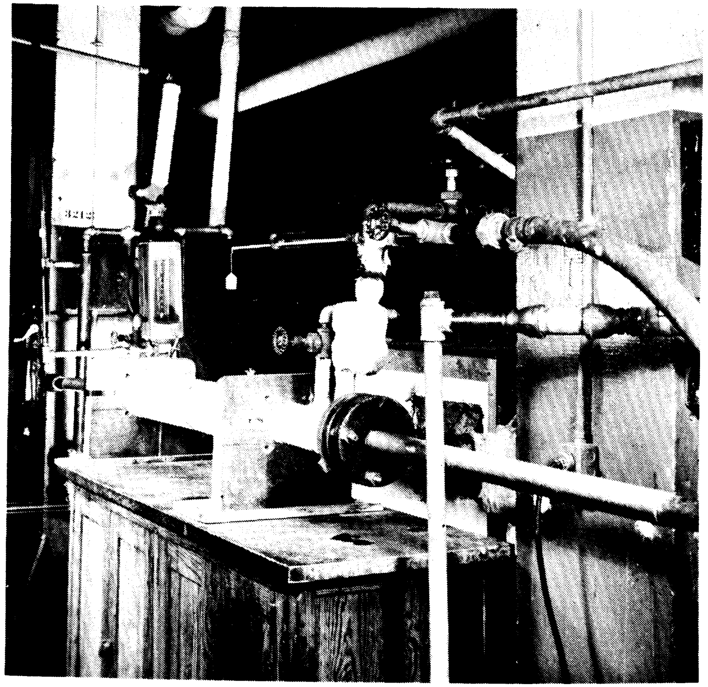

Figure 5. Bond Resistance Apparatus Test Section.

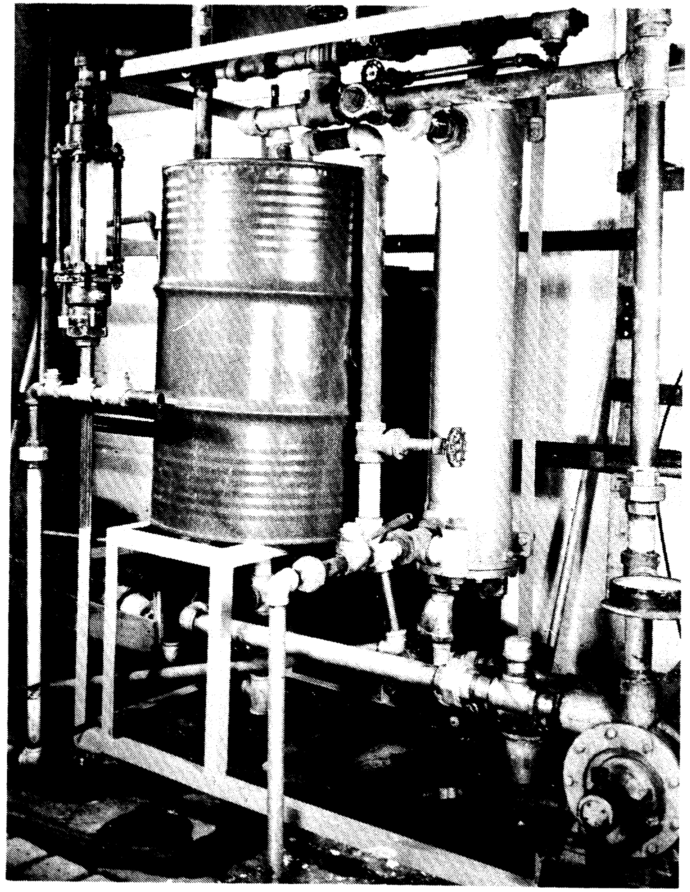

Figure 6. Hot Water Supply System for the Bond Resistance Apparatus.

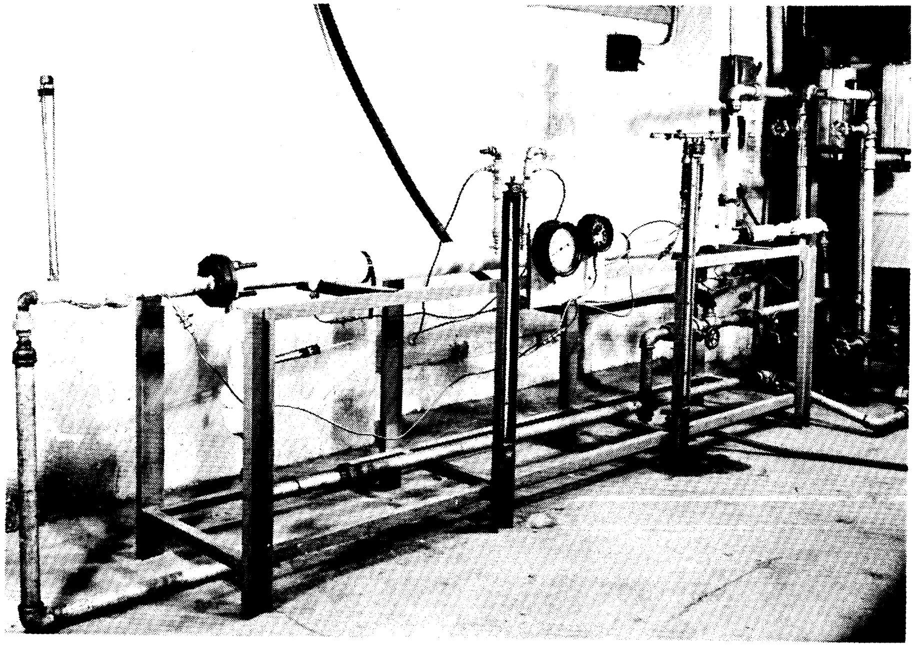

Figure 7. View of Concentric Pipe Exchanger Showing Auxiliary Manometers, Rotameters, and Pressure Gages.

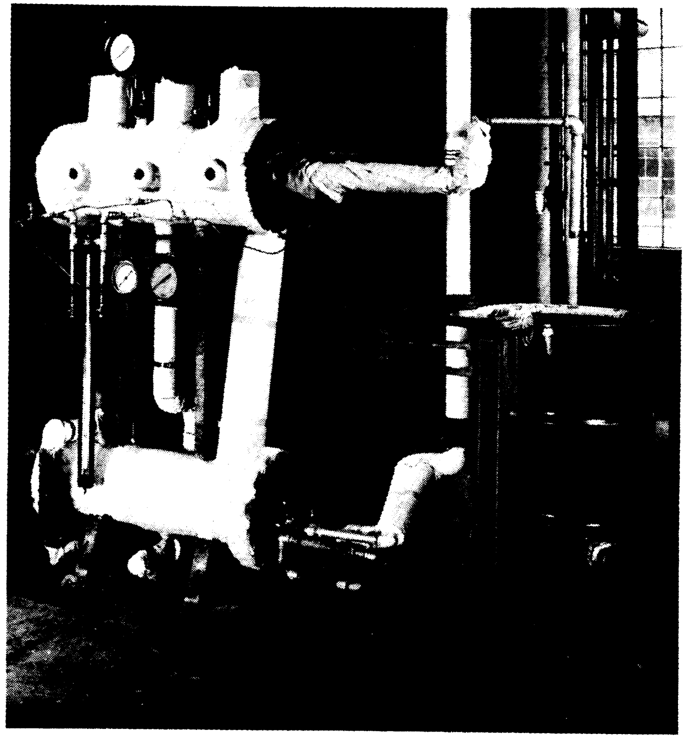

Figure 8. Steam Condensing Apparatus. The Upper Portion is the Condensing Section and the Lower Portion is the Reboiler.

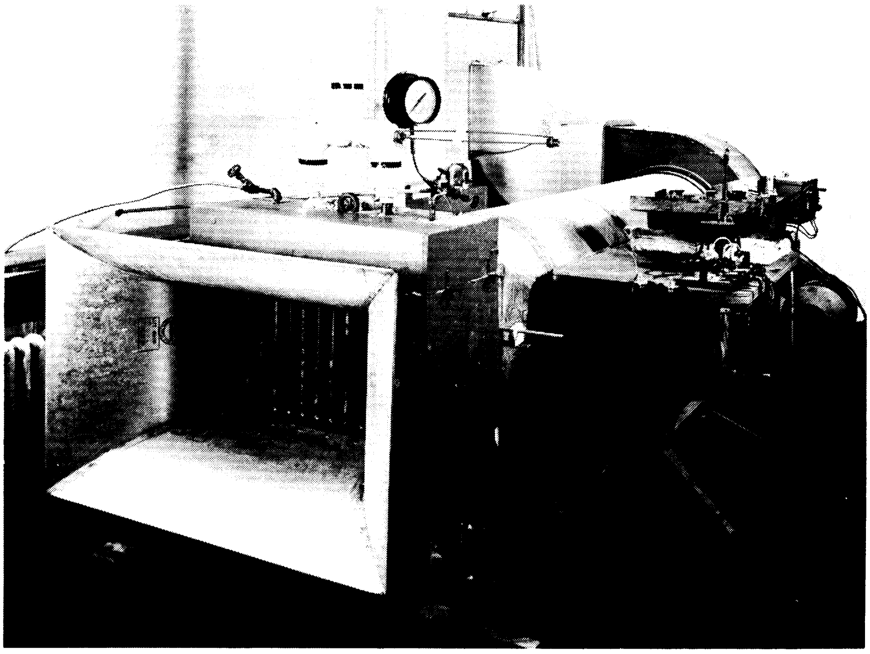

Figure 9. Overall View of Wind Tunnel with Tube Bank Installed.

Figure 10. Console and "Read-Punch" Unit of The University of Michigan IBM 650 Digital Computer.