ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

ANNUAL REPORT FOR 1955

Edwin H. Young
Assistant Professor of Chemical and Metallurgical Engineering

Dennis J. Ward
Research Assistant

Project 1592

CALUMET AND HECLA, INCORPORATED
WOLVERINE TUBE DIVISION
DETROIT, MICHIGAN

January 1956

ABSTRACT

This report contains a summary of the operations of the research group and work completed during the year 1955. The status of the work of the project is reviewed and discussed. Recommendations as to the future research program are presented.

INTRODUCTION

The Wolverine Tube heat transfer project at the Engineering Research Institute is entering its sixteenth year of operation. In recent years, the scope of the project's research activities and its supporting budget have greatly expanded. The integral finned tube is rapidly becoming accepted by the various process industries.

The integral finned tube has definite heat transfer characteristics which can be used to advantage if used properly. The increased use and acceptance of the finned tube have resulted in the revealing of additional problems as a consequence of the field performance of the bimetal tube in certain applications. Also, misunderstandings have arisen concerning proper design procedures which should be followed. These situations have resulted in the expansion of the research project's activities.

As a result of the increased budget, additional graduate students have been added to the project group. A minimum of three problems have usually been worked on at one time. On occasion, four or more problems are handled simultaneously. The research group has always had in recent years an extensive list of research items far in excess of the number that could be handled at one time. In view of this situation, the research group has always operated on a policy of working closely with the sponsors of the project.

Priority lists established by Wolverine Tube have always been maintained in order to insure that current investigations were being carried out in the areas of most vital interest to the company. Normally, the priority lists were obtained by the project supervisor at the Finned-Tube Committee meetings which he had been invited to attend. The priority lists were often changed by Wolverine Tube in order to accommodate so-called "crash programs."

PROJECT STATUS AS OF JANUARY 1, 1955

On December 7, 1954, Mr. C. H. Kuthe and Mr. J. S. Rodgers visited The University of Michigan for a conference with Professor D. L. Katz and Professor E. H. Young. At this meeting the following priority list was put into effect:

1. Preparation of the lecture material and example designs for the "Opportunity Seminar" to be held in Houston, Texas.

2. Design of the U. S. Navy Freon-12 condensers.
3. Tankless hot-water heater investigation.
4. Bond-resistance investigation.
5. Investigation of bond resistance with cyclic operation.
6. All other items.

At the beginning of the 1955 year, the research group was actively working on the following items:

1. Preparation of lecture notes and charts for distribution at the "Opportunity Seminars."
2. Preparation of five example designs for presentation and distribution at the "Opportunity Seminars."
3. Freon-12 condenser designs for the U. S. Navy.
4. Preparation of the report entitled "The Investigation of Heat Transfer and Pressure Drop of 11-Fins-Per-Inch Tubes and Coils." This report constituted a summary of the first phase of the investigation of the performance of 11-fins-per-inch tubes in tankless hot-water heaters.

At the start of the year there existed a backlog of approximately twenty current items on the project work list. Included in this list were a number of important items such as:

a. Bond Resistance in Bimetal Tubes.—During 1954 the project group had completed an investigation entitled "The Effect of Root Wall Thickness on Bond Resistance" (Report No. 34). The group had also prepared a design of a concentric-pipe apparatus using steam and/or air with water for further studies of bond resistance. The design had been sent to the University Plant Department for fabrication.

b. The Influence of Cyclic Operation and Heat Flux on Bond Resistance.-Preliminary studies had been made to determine the type of testing equipment that would be required for this investigation. Arrangements had been made for borrowing a Speedomax or Micro-Max multipoint temperature recorder from the Engineering Research Institute for this study. Arrangements also had been made with the Chemical and Metallurgical Engineering Department for locating the test equipment where the hot flue gases could be safely conducted through the upper floors of the building and discharged through a roof vent. No actual research work had ever been started on this problem due to the position of this item in the priority lists.

c. Internal-Finned Tubes.—A paper investigation entitled "Pressure Drop and Heat Transfer Calculations for Monometallic and Bimetallic Tubes with Internal Fins of Various Geometries" (Memorandum No. 23) had been completed during 1954. No laboratory test data had been obtained on any internal-finned tubes.

d. Fouling of Tankless Hot-Water Heater Coils.
e. Aurora Gasoline Company Field Tests.
f. Boiling with Finned Tubes.
g. National Convection with Finned Tubes.

CHANGE OF STATUS DURING THE YEAR

On January 19 Mr. Kuthe and Professor Young met with Mr. W. F. Roberts of the Happy Company of Tulsa, Oklahoma. At this meeting the subject of loose liners in bimetal tubes was discussed. The importance of "bond resistance" took on added significance. The Atlantic gasoline plant at Lovington, New Mexico, was not meeting production specifications due to the performance of several finned-tube heat exchangers. As a result of this meeting the University research group agreed to test sample tubes from the plant "jacket water cooler." Following this meeting the tubes were laboratory tested and an analysis was made of the Happy Company rating sheet. The results were summarized in a letter report dated February 9, 1955.

The first of the "Opportunity Seminars" was held at the Rice Hotel in Houston, Texas, on January 17 and 18.

On February 25, 1955, the research group attended the Finned-Tube Committee meeting at the Fort Shelby Hotel in Detroit, Michigan. At this meeting the research group at the University was discussed. Included in this discussion was the subject of bimetal cycling and the subject of fouling of 11-fins-per-inch tubes. As of this meeting the following priority list was put into effect:

1. U. S. Navy Freon-12 condenser program.
2. Tankless hot-water heater research investigation,
3. Bond-resistance testing.
4. Bond-resistance cyclic testing.
5. Boiling.
6. Natural convection.

On April 4 and 5 the second "Opportunity Seminar" was held in New York City at the Statler Hotel.

On April 14, 1955, a conference was held with Mr. E. C. Smith at the Hudson Engineering Company of Houston Texas, to discuss air testing of bimetal tubes for quality control. The air-testing device of Hudson Engineering Company was examined.

The University research group at that time was in the process of installing the concentric-pipe testing device referred to earlier for lab-

oratory testing of bond resistance. Wolverine Tube had the Hudson Engineering Company forward a blueprint of their air-test apparatus to the University research group. The research group then had a duplicate Hudson testing apparatus fabricated and proceeded to evaluate this device.

The jacket water cooler of the Atlantic gasoline plant at Lovington, New Mexico, was field tested by Professor Young and Mr. Ward of the project group on April 28 and May 2.

As a result of the seriousness of the poor performance of the Atlantic finned-tube units, the priority list was revised by Wolverine Tube, placing the analysis of the field test data first. This was followed by the bond-resistance air-testing program, using the Hudson type testing equipment and then by the program on bond-resistance cyclic testing.

The third "Opportunity Seminar" was held in Philadelphia, Pennsylvania at the Benjamine Franklin Hotel on May 25 and 26.

The fourth "Opportunity Seminar" was held in Chicago, Illinois, on June 13 and 14 at the Blackstone Hotel.

Due to inconsistencies in the calculated results of the Atlantic field test data, it was necessary to embark on an investigation of the performance of vane-type anemometers when used with small ducts. This investigation covered four- and six-inch ducts. As a result of the large experimentally determined duct correction factors, an improved method of analyzing the Hudson type air-test data was developed. Also, the Atlantic field test data were recomputed, taking into account the duct correction factors. This was followed by the preparation of a field test report including an analysis of four other Atlantic units that were not field tested.

On August 2, 1955, field tests of three units were started at the Aurora gasoline refinery.

On August 5, 1955, a conference was held in Mr. J. S. Rodger's office between Professor Young, Mr. Kuthe, Mr. Grimm, Mr. Walters, Mr. Dasher, and Mr. Rodgers. At this meeting the subject of "testing" as a part of the project research program was discussed. It was felt that the University research group was spending too much time in testing-type activities and not enough time in research activities. The status of the research group's current investigations were reviewed. The meeting ended with the understanding that the following priority list was to be adhered to:

1. Aurora field tests to be continued on schedule.
2. Preparation of the report on the Atlantic field tests.
3. Tankless hot-water heater fouling tests on 11-fins-per-inch tubes.
4. Continuation of bond-resistance air-test investigation.
5. Cyclic-testing effect on bond resistance.

On August 16 a finned-tube task-force meeting was held at The University of Michigan. Dr. Katz, Professor Young, and Mr. Ward represented the University research group. Wolverine Tube was represented by Messrs. Walters, Rodgers, Kuthe, Dasher, Wright, and Grimm. At this meeting it was agreed by all concerned that Wolverine Tube should establish their own testing laboratories in order to free the project group for investigating urgent research problems. The problem of "optimum fin height and thickness" was discussed. As a part of the bond-resistance investigation, a "numerical analysis" of the temperature distribution in the root metal of an all-aluminum, high-fin tube was to be made.

The fifth "Opportunity Seminar" was held on September 12 and 13 in Tulsa, Oklahoma. The sixth "Opportunity Seminar" was held in Los Angeles, California, on September 15 and 16. The seventh seminar wa held in Cleveland, Ohio, on October 19 and 20.

Professor Young participated in a series of meetings over a three-day period (November 1-3) at the Wolverine Tube, Decatur, Alabama, plant. A verbal presentation of the results of the Atlantic field tests was given to representatives of Wolverine Tube and of the Happy Company. The suitability of the Hudson type air-test apparatus for quality control was also discussed at these meetings. The final report on the Atlantic tests (Report No. 38) was presented in person to Wolverine Tube at a meeting at the Detroit plant on December 9, 1955. At this meeting the report was reviewed and summarized.

Field test data were obtained on three units at the Aurora Gasoline Company plant on eighteen different occasions during the last five months of 1955. During this period a number of conferences were held with representatives of the refinery. The purpose of the tests was to obtain fouling-rate data on low-fin tubes.

PROJECT STATUS AS OF DECEMBER 31, 1955

At the end of the year the project was actively working on the following items:

1. Aurora field tests.
2. Fouling of tankless hot-water heater coils.
3. Evaluation of Hudson air test appratus.
4. Modification of existing apparatus for investigating the performance of coaxial coils.

SUMMARY OF LETTER REPORTS, MEMORANDA AND TECHNICAL REPORTS
FORWARDED TO WOLVERINE TUBE IN 1955

1. Example designs and calculations for the heat transfer seminars. Originals dated January 27, 1955.

a. Shell and tube gas-cooler design.
b. Liquid-liquid heat-exchanger design.
c. Total-condenser designs
d. Partial-condenser design.
e. Fin-efficiency notes.
f. Partial-condenser notes.
g. Gas-phase condensation notes.
h. Fin-efficiency and its application notes.

2. Recorrelation of pressure-drop data given in the Katz-Williams report to conform to the Donohue "Centroid-to-Centroid Distance" preparation of revised friction-factor plots. Preparation of "j"-factor plots for 19-fins-per-inch tubes.

3. One hundred fifteen letters and approximately 475 sets of reprints of technical articles published on project work prepared for distribution at seminars and by Technical Sales Office.

4. Letter report concerning the Happy Company tubes and rating sheets. Report of bond resistance obtained from the test apparatus. February 9, 1955.

5. Memorandum No. 22, reissue of "Performance of Trufin 195042-01 Tubes in Freon-113 Evaporation of Trane Centravac Refrigeration Unit." (Appendix giving calculations added.) February 10, 1955.

6. Letter report on internal fouling as a function of length. February 18, 1955.

7. Report No. 35, "The Investigation of Heat Transfer and Pressure Drop of 11 Fins-per-inch Tubes and Coils." February 25, 1955.

8. Report No. 36, "Investigation of Heat Transfer Performance of a Series of U. S. Navy Freon-12 Condensers." March 14, 1955.

9. Report No. 36 (reissued after revision), "Investigation of Heat Transfer Performance of a Series of U. S. Navy Freon-12 Condensers." May 31, 1955.

10. Letter report on Atlantic Gasoline Plant jacket-water-cooler Test Results. June 28, 1955.

11. Letter report on calibration of thermometers for Wolverine Tube. September 29, 1955.

12. Letter report of air-test run nos. 1-186. September 15, 1955.

13. Letter report on tankless hot-water-heater fouling tests. October 4, 1955.

14. Letter report of air-test run nos. 187-321. October 5, 1955.

15. Letter report on Aurora fouling tests. November 7, 1955.

16. Letter report on tankless hot-water-heater fouling tests (Wilson plots). November 7, 1955.

17. Letter report on numerical analysis of the temperature distribution in the root of a fin. November 7, 1955.

18. Letter report on book Compact Heat Exchangers by Kays and London. December 19, 1955.

19. Report No. 37, "Investigation of the Performance of Vane-Type Anemometers in a Four-Inch Duct." December 21, 1955.

20. Report No. 38, "Analysis of the Performance of Five Forced-Air Cooling Units at the Denton Oil Field Plant of the Atlantic Refining Company." December 9, 1955.

21. Report No. 39, "Investigation of Heat Transfer Performance of a Series of U. S. Navy Freon-12 Condensers" (letter of transmittal December 21, 1955).

DISCUSSION

During the past year the efforts of the research groups were spread over a large number of activities. The size of the group was substantially increased. On occasions, due to the heavy pressure from Wolverine Tube on certain priority items, too many items were worked on at one time. The result of spreading the efforts too thinly was to introduce inefficiency into the operations. Men were pulled off research projects to work on "crash" items, with the end result of slowing down the progress being made in the more important fields of investigation.

RECOMMENDATIONS

A. OPERATIONS

In order to insure that definite progress is continually being made on the fundamental items of major importance to the sponsors of the project, it is recommended that the following method of operation be adopted for 1956:

1. The research group to be divided into three sections.
2. Two of the sections to be definitely assigned to research investigations of major importance, with the understanding that the work will not be interrupted until a report has been issued.
3. The third group to be kept available to:
   a. handle "crash" programs.
   b. work on "service-type" problems.
   c. assist the other two groups.

If there are more problems for the third group than this group can handle at one time, Wolverine Tube is to determine which items are the most important and the order in which this group is to work on them. The members of the first two groups are not to be pulled off their projects in order to work on "crash programs."

In essence, the operational problem consists of providing a proper balance between research and nonresearch-type activities such that Wolverine Tube will most greatly benefit from the group's operations.

B. TESTING

It is felt that too much of the group effort was spend on "testing" and nonresearch activities. This problem was discussed at the Finned-Tube Task-Force Meeting held in Ann Arbor on August 16, 1955. Following this meeting a letter dated August 18 was forwarded to Wolverine Tube, containing the following statements:

"It is strongly recommended that the testing phase of our work be taken over by Wolverine Tube. There are two important reasons for this recommendation.

"1. There are a number of fundamental questions or problems of such an urgent nature that it is imperative that we devote our fullest efforts towards their solution.
"2. The abilities of the masters and doctorate level project per-

sonnel should be used to Wolverine Tube's best advantage. It is believed that the use of this available talent in routine testing is a wasteful procedure.

"A certain amount of testing is obviously necessary in our research work but a distinction should be drawn between routine testing and research testing. Also a certain amount of nonresearch activities such as some of the memorandum work is good for the project in that new insights into the field application problems are essential."

It is our understanding that Wolverine Tube has agreed that the University research group should be relieved of routine-type test work.

It is therefore strongly recommended that Wolverine Tube proceed with the establishment of testing facilities so as to relieve the research group of this type of work.

C. FUTURE PROJECT WORK

A critical examination of many of the items that have not as yet been worked on indicates that a major investigation involving flow of fluids past finned tubes should be undertaken. The studies in the flow of fluids through (a) the shell side of liquid-liquid heat exchangers, (b) the air side of air-blast coils, (c) the natural-convection side of tankless hot-water heaters, (d) the tank side of storage-tank heaters, (e) the air-side flow in baseboard, natural—convection heaters, (f) the shell side of shell and tube gas coolers, and other applications have much in common.

Various items that should be investigated are summarized below.

1. Shell and Tube Investigations.—

a. Liquid-Liquid. An investigation of the relative performance of 19 fins-per-inch tubes (Type S/T), laid out on a square pitch arrangement rotated 45°, to plain tubes of the same arrangement should be undertaken. Also, data should be obtained on the equilateral triangular pitch arrangement without the shell-circle arrangement.

b. Gas Cooler. The use of Type S/T low-finned tubes in shell and tube gas coolers represents an ideal application for this tube. Relative pressure-drop and heat transfer data for finned and plain tubes in identical shell arrangements with gas flow are needed.

c. Partial Condensers. Low-finned tubes of Type S/T can be used to definite advantage in partial condenser applications. A laboratory investigation for measuring experimental coefficients with plain and finned tubes in identical shell arrangements should be undertaken.

d. Katz—Williams Report. This report on the performance of finned tubes in shell and tube heat exchangers was written in January, 1951. The report has been in continual demand but is currently out of print. An extensive list of requests for the report is on file at the University. The nomenclature used in the report is different than the standardized nomenclature that was prepared in 1954. In order to utilize this information for simultaneous heat and mass transfer applications (partial condensers), j-factor curves have been prepared. Also, the pressure drop data have been recomputed and recorrelated to conform with Donohue's method of analysis. The report should be completely rewritten, including the above three items, and then reissued.

2. High-Fin Forced-Air Units.—The correlation report (Report No. 30) contains test data on bimetal tubes with the bond resistance left in the data. The current studies of bond resistance indicate that a study of air-side coefficients should be made, including proper allowance for bond resistance. Further studies of the influence of tube arrangements and tube geometries on the air-side coefficient should also be made. Such a study is necessary in order to determine optimum fin heights and fin spacings.

3. Boiling.—Further studies of boiling coefficients are needed, particularly in the field of water chillers. Finned tubes can be used to definite advantage in such applications.

4. Bond-Resistance Tests.—

a. An improved testing device with considerably greater sensitivity is badly needed for quality control in the production of bimetal tubes.

b. Studies to determine the effect of cyclic operation on the bond resistance of bimetallic tubes should be undertaken as soon as possible.

5. Natural-Convection Heat Transfer.—

a. An investigation for determining the performance of finned tubes in storage-type tankless water heaters should be undertaken. Data suitable for design purposes should be obtained.

b. Studies of the heat transfer from finned tubes to air by natural convection should also be undertaken. An investigation of this nature, using baseboard-type heaters was initiated in 1953, but was discontinued due to the pressure of other important investigations. Data of this type would be of great value in preparing a natural-convection correlation.

c. The results of (a) and (b) above should be combined and correlated to obtain a generalized correlation for natural convection.

6. Internal-Finned Tubes.—Laboratory investigations of the heat

transfer and pressure-drop characteristics of internal-finned tubes have never been made. Such investigations should include heat transfer and pressure-drop measurements in the following applications:

a. Boiling.
b. Condensing.
c. Liquids in forced convection.

7. Fouling of Finned Tubes in Shell and Tube Units.—Two of the heat exchangers used in the Katz-Williams investigations could be used for a pilot-plant study of shell-side fouling in one or more refinery applications. The two units of identical tube layout, but with finned tubes in one unit and plain tubes in the other unit, could be tied into an existing process stream paralled with an existing commercial heat exchanger. Fouling-rate studies of the two types of tubes could be obtained and compared. It is recommended that this type of investigation be undertaken.