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PRELIMINARY EXPERIMENTS TO DETERMINE THE EFFECTIVENESS OF SCREEN WIRE EXTENDED SURFACES IN BOILING HEAT TRANSFER AUGMENTATION

by

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B. S., Kansas State University, 1970

9589

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

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INTRODUCTION

There is a continuing demand for higher heat transfer rates in heat exchangers of a given size. To achieve higher heat transfer rates from equipment designed for service in pool boiling for a given liquid one can either increase the effective area of the heat exchanger or alter the existing surface so the heat transfer will take place more rapidly.

Most of the recent work in pool boiling heat transfer enhancement has dealt with altering the existing surface to increase the active nucleation sites, and thus the heat transfer rate. Kuloor and Radhakrishman (1)* altered the existing surface by turning grooves on the outside of a copper cylinder on a lathe. A study of chemically etched, mechanically polished, and teflon coated surfaces was made by Nix, Vachon, and Hall (2). Hummel (3) has developed a patented method for surface preparation used to increase nucleation sites. The results of these works are adequately described and correlated by the results of Mikic and Rohsenow (4) and others who have done extensive work in developing equations for the heat transfer rate in terms of liquid properties and certain surface characteristics.

The application of the above work concerned with surface characteristic alteration to most practical heat exchanger design seems to have been of very little value. The problem of deposits on heat exchanger surfaces suggest that

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* Numbers in parentheses designate references in SELECTED REFERENCES.

a more realistic approach to the problem might be to forget about nucleation sites and concentrate on increasing the effective area of the heat exchanger through the use of some type of extended surface.

The object of this thesis, therefore, was to determine experimentally the effect on heat transfer rate of a class of extended surfaces that could be easily constructed and which could be applicable to heat exchanger use. These extended surfaces were made of copper screen wire which was attached to a copper cylinder.

The proper design and arrangement of extended surfaces for optimum heat transfer in a boiling liquid is unknown. Haley and Westwater (5) did a study on a single copper fin 1.207 inches long and .25 inches in diameter boiling in isopropyl alcohol. They cited a need for more study in the optimum shape for a fin in contact with a boiling liquid. Later Haley and Westwater (6) determined that, if the fins are spines of circular cross section, the optimum shape to minimize the volume of metal resembles a turnip. Cash, Klein, and Westwater (7) then did further work on a design they felt was a good approximation to the optimum spine. The results of the preceding work suggests the need not only for optimum fin design in various liquids, but also optimum fin spacing.

The use of the low-profile finned tubing for boiling surfaces in refrigeration equipment has been common. Myers and Katz (8) have reported experiments comparing plain tubes with finned tubes in bundles. Their finned tubes had nineteen nominal fins per inch and were .054 inches in height. Beurtheret (9) has used short stubby fins to cool large radio power tubes by rejecting heat to boiling water. Demauge, Douget, and Le France (10) have also done similar work on heat transfer from fins to a boiling liquid. References (9) and (10) were discussed by Haley and Westwater (5).

As one can see, screen wire can be sized to approximate the spacing and height of fins used in the studies of Myers and Katz when it is attached to a cylinder. When a screen mesh is used, fins not only run circumferentially but they also run in an axial direction. It is unknown whether or not a combination of axial and circumferential fins is better for heat transfer enhancement than the usual circumferential fins.

PART II

EXPERIMENTAL PROGRAM

The following section describes the test equipment used, the test section itself, and the procedure followed when taking data.

Test Apparatus

The apparatus used for the pool boiling experiment consisted of four major groups: the boiling unit, the power imput group, the temperature measurement group, and a safety ground. A schematic diagram of this entire assembly is shown in Fig. 1.

Included in the boiling unit was the boiler tank and insulation, the condenser, the supplementary heater, and the test section assembly.

The boiler tank was built from 28 guage galvanized iron. The height of the tank was 12 inches and the length and width were 15 and 10 inches, respectively. Centered in the large face of the tank was an 8 by 8 inch pyrex glass window for visual observation. Three inch thick styrofoam insulation was installed on the bottom and sides of the tank to reduce heat loss from the water.

The condenser, also made from 28 guage galvanized iron, served as a lid to the boiler tank. Copper tubing, .25 inch O.D., was coiled and soldered to the outside of the lid and thermal mastic was applied to reduce the thermal resistance between the coil and lid.

The supplementary heater was installed near the bottom of the boiler tank and centered. It was a commercial heater rated at 5 kilowatts at 240 volts and was used to maintain the pool water at saturation temperature.

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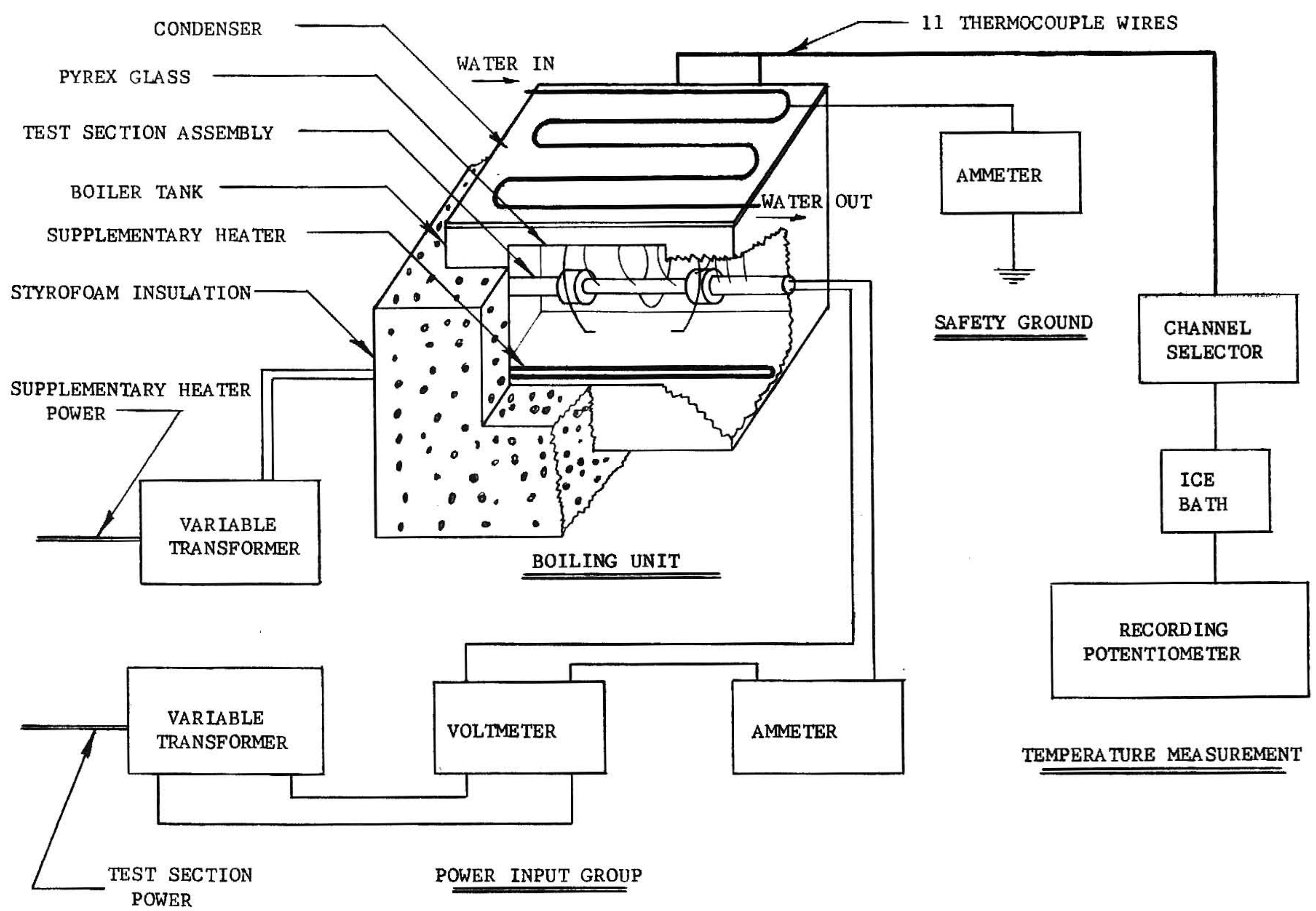

FIGURE 1. SCHEMATIC OF TEST APPARATUS

The test section assembly was installed 5 inches from the bottom of the boiler tank and centered. Fig. 2 shows the details of the test section assembly. The support tubes were 7/8 inch nominal copper tubing 4.5 inches long. The support tubes were countersunk 1/4 inches into the Micarta caps. The Micarta caps, which served to reduce end loss, were 2.0 inches in diameter and 1.5 inches long. The test section cylinder was inserted 0.5 inches into circular grooves in the Micarta caps. The test section heater was a commercial high-watt-density heater with a 2.5 kilowatt rating at 240 volts. It was 5/8 inches in diameter and 8.5 inches in total length; however, the heated section was only 4.5 inches in length. The space between the heater and the inside of the test section was taken up by three wraps of brass shim. The joints of support tube to boiler tank, support tube to Micarta caps and Micarta caps to test section were all sealed water tight with silicone rubber.

The power imput group consisted of two variable A.C. transformers, an ammeter, and a voltmeter. The variable transformer supplying the test section heater operated between 0-230 volts and 10 amperes; the transformer that supplied the supplementary heater had an operating capability of 0-280 volts and 28 amperes. The ammeter and voltmeter were used to measure the quantity of heat imput to the test section with a reading accuracy of $\pm$ .1 ampere and $\pm$ 1 volt. The temperature measuring sensors included eleven Chromel-Alumel thermocouples. Two were used to measure pool water temperature, four were attached to the support tubing and were used to check end losses and five were installed on the test section cylinder. The eleven thermocouples were hooked into the channel selector. A single ice water junction was used. The two leads from the ice bath were connected into the recording potentiometer.

The whole boiling unit was grounded through an ammeter so that one could tell if there was any current leakage to ground.

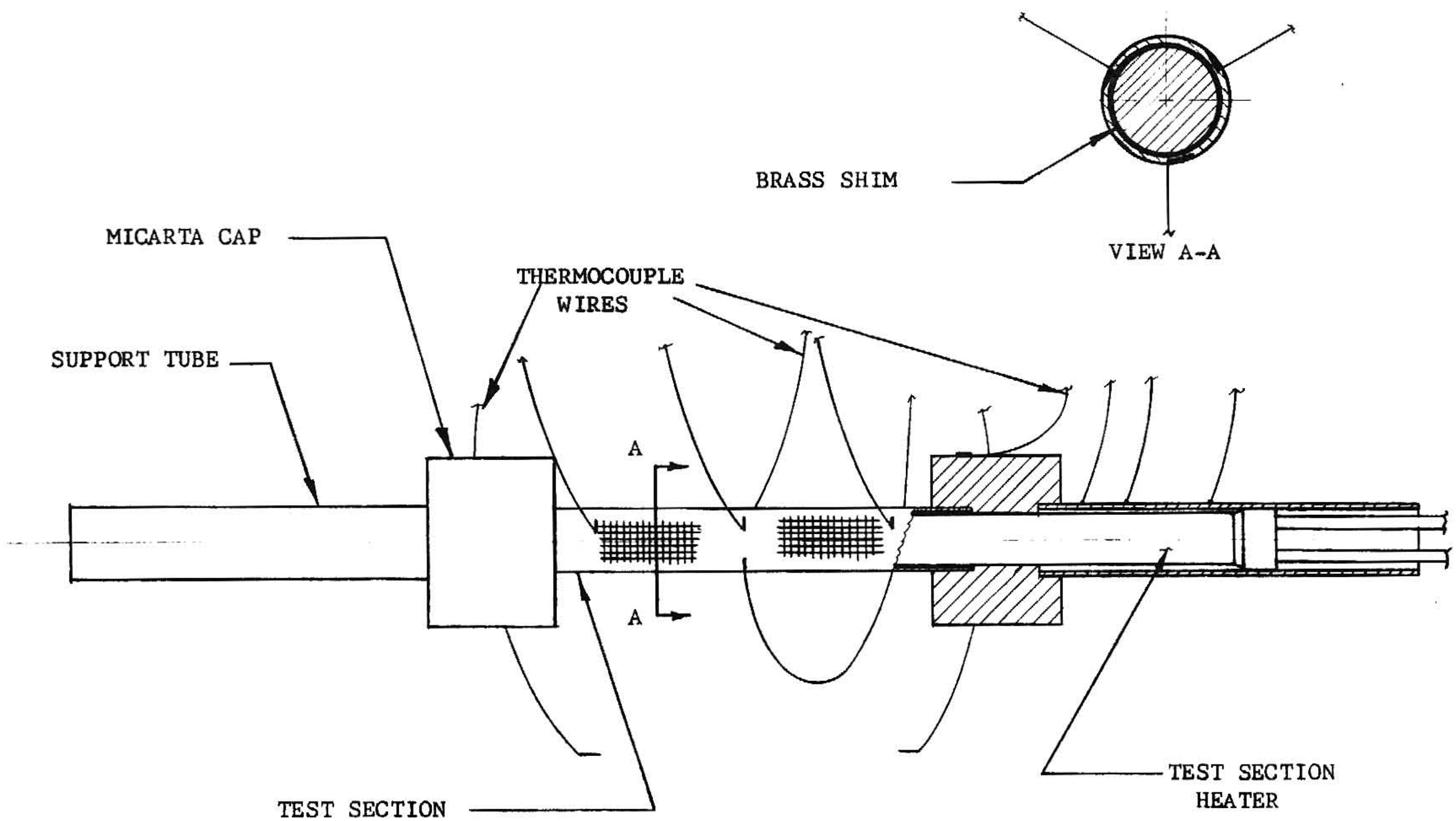

FIGURE 2. TEST SECTION ASSEMBLY

Test Section

For the test section it was decided that a 10 by 10, a 20 by 20 and a 30 by 30 (meshes to the inch) copper screen would be convenient to use for the evaluation of screen wire extended surfaces. The respective mesh wire diameters were .025, .016 and .013 inches. A 3/4 inch O.D. copper cylinder was chosen as a test surface to which the screens were soldered.

For the test section the copper tube was cut to a length of 5.4 inches. The active test section surface was 4.4 inches long and .5 inches of the cylinder on each end was inserted into the Micarta caps. The 4.4 inch test section surface was then turned on the lathe reducing the diameter by .004 inches. The copper tube was then heated and solder was liberally applied to the test section surface. The tube was then put back on the lathe and the excessive solder was machined until only a .002 inch thickness remained. Thus the outside diameter of the test section was again .75 inches. Four tubes in all were done using this procedure. One tube was to be run with just a solder test section surface, while the other three would each have a different mesh size screen attached to it.

The screen was attached to the tube by wrapping steel wire to secure the screen tightly to the tube. The tube was then heated with a hot air gun until the solder started to melt. The tube was then allowed to cool and the steel wire was removed leaving the screen attached to the tube. This procedure was followed with all three screens.

The thermocouple arrangement on the test section is shown in Fig. 2. The three thermocouples in the middle were 120° degrees apart and the outside ones were both 1.75 inches from the center ones. This thermocouple arrangement was used so that one could detect variations in temperature axially as well as circumferentially.

Each thermocouple was attached by sawing two small grooves perpendicular to the length of the tube with a jewelers saw. The two thermocouple wires were then peened into the two grooves and soldered to secure them. The thermocouple wires were then bent perpendicular to the surface. On the screen wire test section, a small patch of screen wire had to be removed first before the thermocouple wire was attached.

Experimental Procedure

The boiling tank was filled with distilled water to a level of 2 inches above the test section. The increase in pressure at the test section due to this was calculated to be only .01 inches of mercury. An ice bath was prepared with distilled water and the barometer was read.

The recording potentiometer was standardized with a Leeds and Northrup Millivolt Potentiometer. The reading accuracy of the recorder was ± .01 millivolts. The thermocouples were then calibrated in place and it was found that the variance was negligable.

After these preliminary steps were completed, the supplementary heater was turned on to a power level of approximately 4 kilowatts for the initial heat-up period. The water was brought to a rapid boil and then the power to the supplementary heater was reduced to .96 kilowatts to maintain pool saturation temperature. It remained at that power level throughout the experiment.

The test section heater was turned on and set for the lowest power level reading. After the water had been boiling from the test section for at least fifteen minutes, the first readings were taken. The power level was then turned up and the temperature was allowed to stabilize and instrumentation readings were taken; this took approximately ten minutes. Data was taken for at least five different power levels. The emf, voltage, and current indications were read and recorded onto the data sheet for all eleven thermocouples at each power level.

This procedure was followed for all of the test sections, except for a slight variation in one 30 by 30 screen mesh run. For this run the variable transformers were switched after the initial heat-up period. This was done to provide a higher test section power level from the larger transformer.

PART III

EXPERIMENTAL RESULTS

The following section outlines the results of the data and discusses the possibile errors of these results.

Results Of Data

The results of the experiment, a log-log plot of heat flux, q/A (Btu/hr-ft^2), versus superheat, delta T (^oF), are shown in Fig. 3. The heat transfer rate (q) was determined by the electrical power input to the cylinder test section. The area term (A) was simply the cylinder test section surface nominal area. Delta T was the average test section temperature minus the water saturation temperature. The average test section temperature was determined by using the following averaging formula:

$$T_a = \frac{2.5((T_2 + T_4 + T_5)/3.0) + (T_3 + s) + (T_1 + s)}{4.5}$$

where

$$s=((T_2 + T_4 + T_5)/3.0) - T_2$$

T_1 and T_3 are the temperatures measured at the right and left ends respectively of the test section (Fig.2). T_2 is the temperature measured at the center in line with T_1 and T_3. T_5 is on the bottom of the test section and T_4 is on the back side, both at the center of the test section. The saturation temperature was determined by averaging the readings of the two thermocouples in the water. For reference purposes, Fig. 3 shows the results of Vachon (11) and

Kuloor (1) as well as the Rohsenow equation. Vachon's data was obtained by using a stainless-steel strip with a 600 grit polished surface. Kuloor's experiment was done with a copper cylinder polished with 3/0 emery. Both experiments were done in boiling water. The Rohsenow equation is plotted using a C_{sf} of .013 which is the value given in Kreith (12) for a water-copper liquid-surface combination.

In Fig. 3 it is seen that the 30 by 30 test section surface provided the highest heat transfer rates of those specimens tested. For a 10 degree superheat, the smooth test section could accomodate a heat flux of 32,000 Btu/hr-ft^2, but the 10 by 10 could deliver about 50,000 Btu/hr-ft^2, the 20 by 20 approximately 70,000 Btu/hr-ft^2, and the 30 by 30 nearly 150,000 Btu/hr-ft^2. Therefore the heat transfer rate for the 30 by 30 test section surface was over four times as great as that of the smooth test section surface for a superheat of 10 degrees Fahrenheit.

To transfer 100,000 Btu/hr-ft^2 of heat, the 30 by 30 test section only required a superheat of 8 degrees. The 20 by 20 test section required nearly 12 degrees; the 10 by 10 required 14-15 degrees and the smooth test section needed a delta T of 17.5 degrees to transfer that amount of heat. This means that if a heat exchanger had smooth tubes, it might operate as much as 9 degrees Fahrenheit cooler and still transfer the same amount of heat if the smooth tubes were replaced by tubes with a 30 by 30 screen mesh wire attached.

All of the curves, except the 30 by 30 below 8 degrees superheat, appear to have a slope which is nearly the same as Vachon's. This slope is not quite as great as that from the Rohsenow equation. The slope of the 30 by 30 test section curve below 8 degrees superheat seems to correlate very close with the curve of Kuloor's experiment.

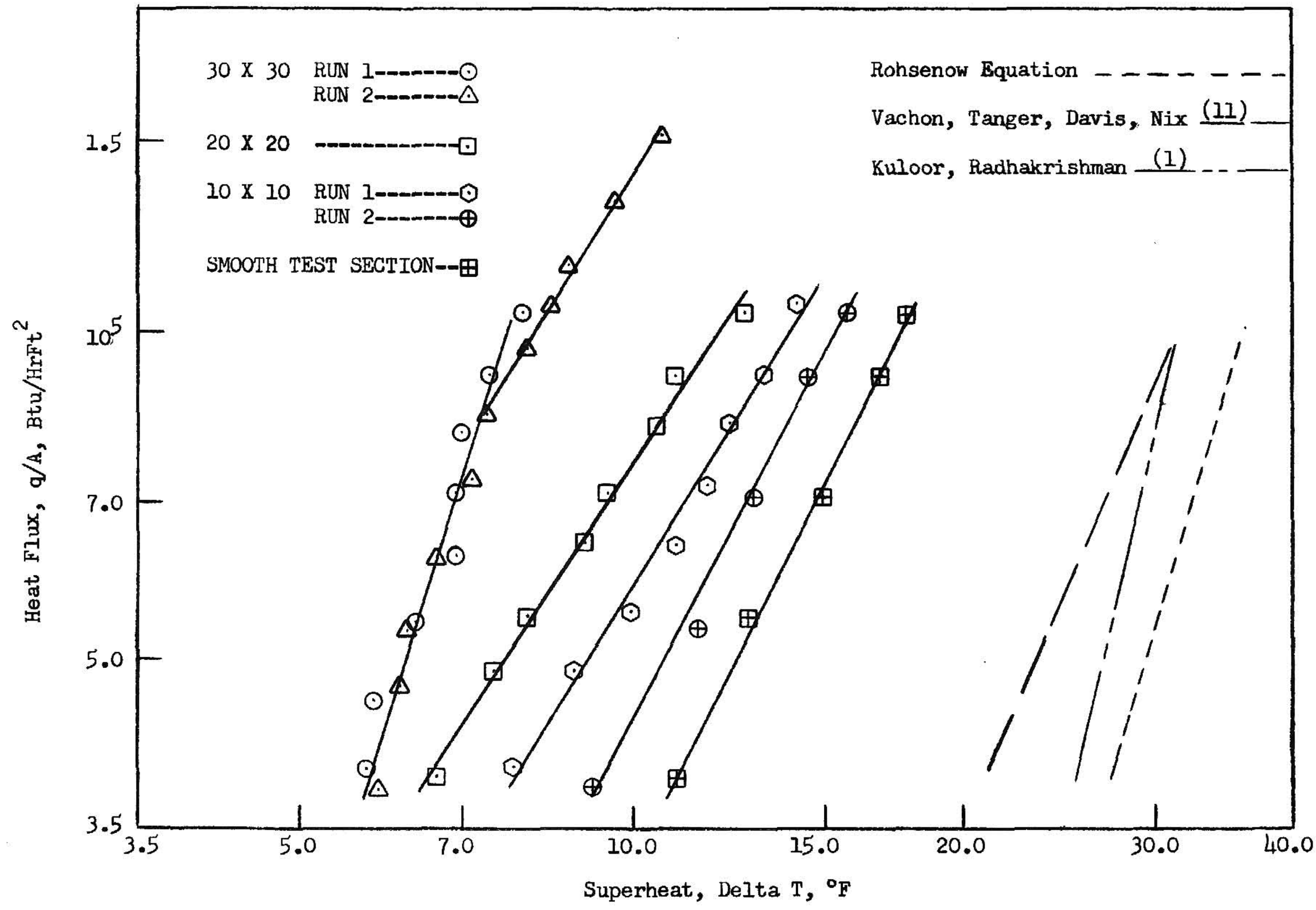

FIGURE 3. HEAT FLUX VERSUS SUPERHEAT FOR ALL TEST SECTIONS

The curves of Kuloor and Radhakrishman, those of Vachon, Tanger, Davis, and Nix and the Rohsenow equation in Fig. 3 are for reference only. Because of different water to surface characteristics, it would not be reasonable to expect exact correlation of the results to these curves.

For use in boiling computation it is convenient to also determine a boiling coefficient, h. This is particularly useful when dealing with finned tubes or tubes with extended surfaces. For this purpose boiling coefficient values were found by dividing the heat flux at a particular power level by the superheat, delta T, at that power level. Figure 4 shows the results on the log-log plot of h versus delta T.

The curves of Fig. 4 show that at a given superheat the boiling coefficient, h, is greater for the screen mesh test sections than it is for smooth test section. For example, at a superheat of 11 degrees, the curves show that the h of the 10 by 10 test section is 30-90% greater than the h of the smooth test section. The 20 by 20 screen mesh increased h by a factor of nearly 1.5 over that of the smooth cylinder for 11 degrees of superheat. The curve for the 30 by 30 test section shows that a 300% increase in h for a delta T of 11 degrees was found when that type of heat transfer surface was compared to the smooth surface.

One can also note that the slopes of the curves are nearly identical for all test sections for a superheat of greater than 10 degrees. The 30 by 30 test section has a greater slope when the superheat was less than 7 degrees, whereas run 1 of the 10 by 10 test section has a lesser slope when the superheat was less than 10 degrees. It is not known why these two curves had different slopes at low delta T values.

In the work of Myers and Katz (8), a boiling coefficient based on an effective total exposed outside surface area, rather than just nominal cylinder

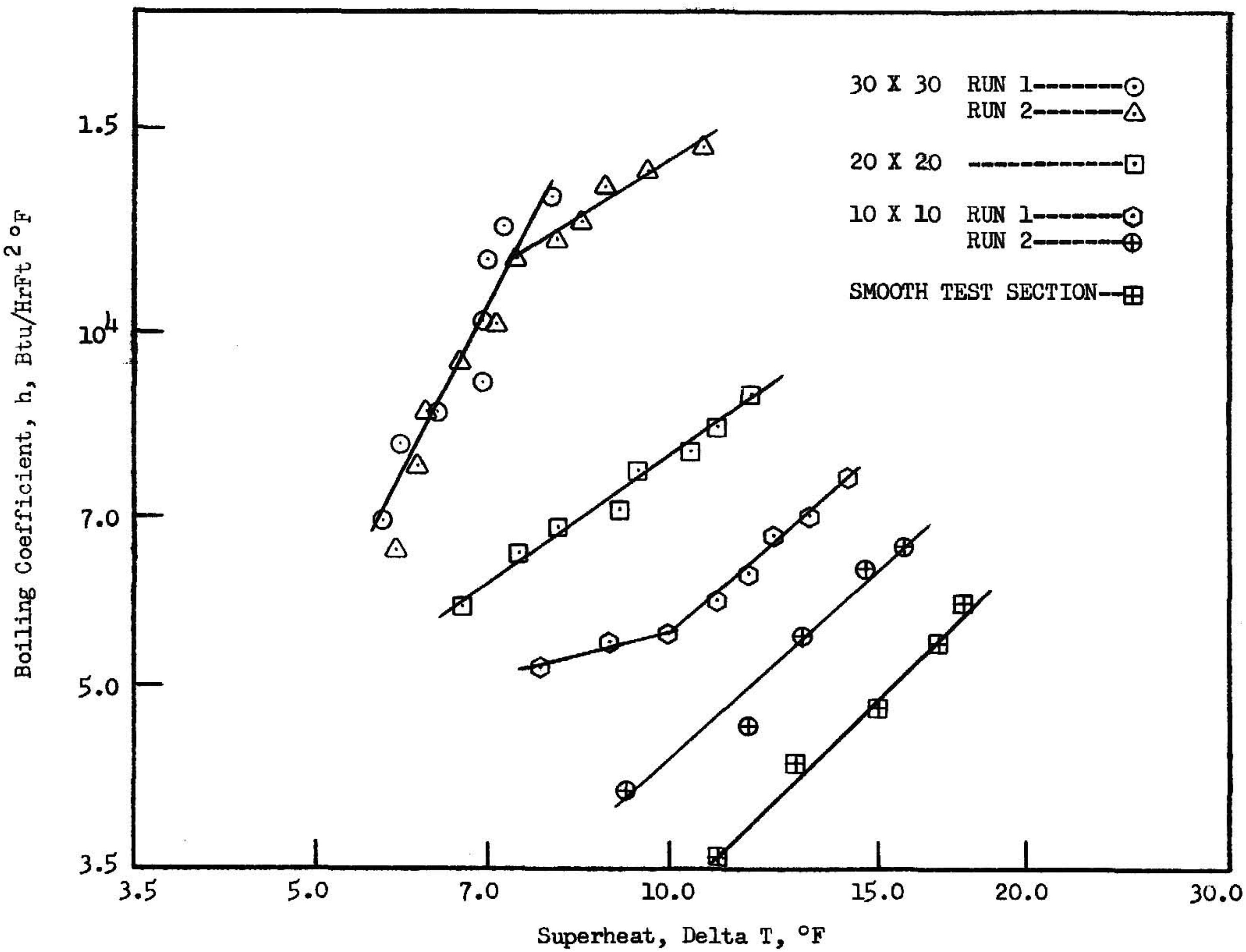

FIGURE 4. BOILING COEFFICIENT VERSUS SUPERHEAT FOR ALL TEST SECTIONS

area, was computed. To compute an effective boiling coefficient, one needs a screen-cylinder effective area.

The total effective area was computed by taking the sum of the effective screen area and the effective cylinder area. The effective screen area was found by computing the entire screen area and subtracting off the area believed to be below the solder surface. The effective cylinder area was found by subtracting the cylinder area believed to be covered by the solder-screen combination from the total cylinder area. The computer program used to calculate effective area is shown in Appendix A.

Figure 5 shows a log-log plot of effective boiling coefficient, h', versus delta T. Figure 5 shows a tendency for the curves of the screen wire test sections to stack up on the smooth test section curve. If one omits the curve of the 10 by 10 run 2, the results stack up on the plain test section curve within a range of $\pm$ 5 degrees.

One might think that if a true effective area were found, the results of Fig. 5 should show all of the curves lying more closely to the smooth test section curve. Myers and Katz (8) showed that this reasoning is not true. They found when working with tubes in bundles that up to a certain point tubes with fins actually had a higher heat transfer rate per effective area than plain tubes did. However, they did not explain why this phenomena occurred. The 30 by 30 screen mesh, shown in Fig. 5, also shows this trend.

The relative location of the 30 by 30, 20 by 20, 10 by 10, and smooth pipe test section results with respect to each other in Figs. 3 and 4 seems logical. The reason being because the total effective area available for heat transfer is something greater than nominal pipe area for the screen mesh runs. The 30 by 30 test section has the largest effective area followed by the 20 by 20 and then the 10 by 10.

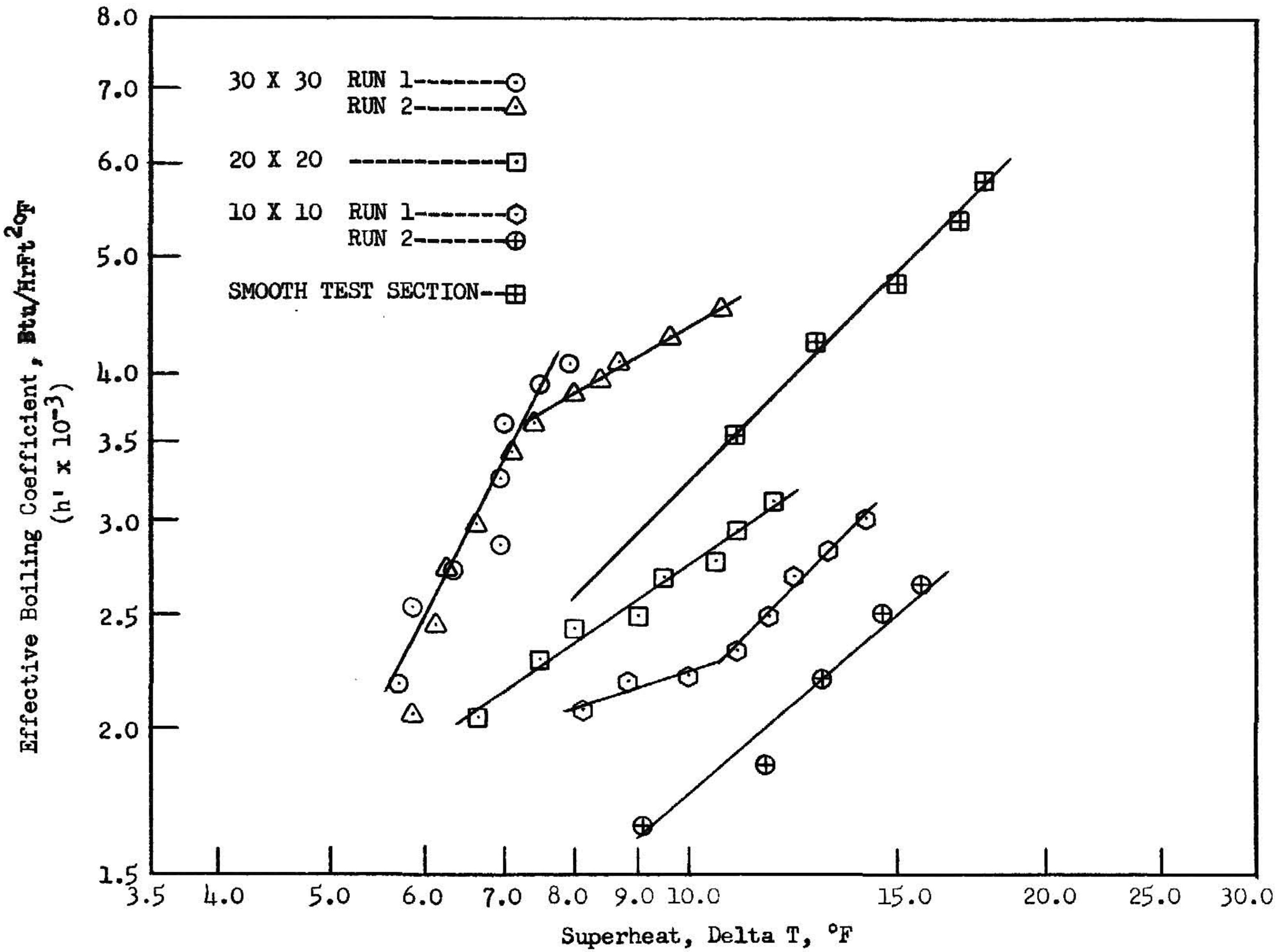

FIGURE 5. EFFECTIVE BOILING COEFFICIENT VERSUS SUPERHEAT FOR ALL TEST SECTIONS

Discussion of Possible Errors

The variance in the two 10 by 10 test section runs seems large. It should be noted however that, for a given heat flux, separation between the curves is only about 2 degrees. Such a difference could be attributed to a difference in boiling water purity. A variance between runs might also occur because of a difference in conduction patterns in the cylinder. Since the test section was assembled and disassembled between runs, different conduction patterns might have occurred because of varying differences in heater-test section contact resistance. Water purity and contact resistance are further discussed in Part IV.

The heat transfer from areas other than the test section area was computed to be less than .5% of the total power imput. In data reduction, the heat transfered from the test section area was assumed to be the same as the total power imput to the test section heater.

One must be cautious, however, when drawing definite conclusions about the results of the data. As one can see from the reduced data shown in Appendix B, the average test section temperature, T_a, is highly influenced by the method of temperature averaging used.

For example, if this equation was used:

$$T_a = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5.0}$$

the results of a heat flux versus delta T plot moves the 30 by 30 test section curves nearly 3 degrees to the right of the 30 by 30 curves in Fig. 3. The 10 by 10 curves move approximately 2.5 degrees to the right, the 20 by 20 curve moves 1 degree to the left, and the smooth test section curve moves about 1.5 degrees to the left of their respective curves in Fig. 3.

A question also arises about the location of the curve of the smooth test section run. One check run was made with a different smooth test section. It was constructed by coating the surface with solder and then wiping the surface until it was smooth and shiny. After attaching the thermocouples, all excessive solder was ground off flush with the cylinder surface. Aluminum dust was used as packing between heater and test cylinder, instead of using brass shim. The results of this run showed that the smooth test section curve lay between the 30 by 30 runs and the 20 by 20 run in Fig. 3.

It is felt that a combination of things caused almost a seven degree spread in the two smooth test section curves. A different surface would certainly cause a shift, however, it would seem that a smoother surface should have a poorer instead of a better heat transfer rate. It would seem, therefore, that the type of packing and the thermocouple attachment method had a greater influence on the results than did differences in solder surface characteristics for this case.

The 20 by 20 test section was also run with a thermal mastic packing. The results of this data was a curve that lay one to three degrees to the right of the 20 by 20 curve that is given in the results (Fig. 3). From this one could conclude that the type of packing (brass shim, aluminum dust, or thermal mastic) definitely did have an influence on the thermocouple readings.

PART IV

CONCLUSIONS AND RECOMMENDATIONS

The results of the experiments as presented show that screen wire extended surfaces appear particularly useful in boiling heat transfer augmentation. However due to the lack of confidence in some of the data, the following reflections on the experiment are presented and recommendations for an extended, more precise, evaluation are made.

If a cylinder were used in a further study of this topic, it would be better to design the test section so that the thermocouples could be attached through the inside of the cylinder. One does not know how the presence of the thermocouples on the outside effects the boiling phenomena. This better design would do away with any doubt about the disturbance of the boiling surface.

It would also be wise to have the test section cylinder wall at least 1/16 inch thick so deformation would not take place so easily. Deformation is undesirable, especially where the thermocouple is attached, because it may cause non-representative readings due to variations in thermal contact resistance. Tang and McDonald (13) found differences when they measured temperature along the longitudinal axis of a cylinder. They attributed this to variations in the thermal contact resistance generated at the interface between a spacer and an outer cylinder.

The degree of water purity is another facet of the experiment that needs refining. An abstract of an article from Institution of Mechanical Engineers-Proceedings (14) tells the effect of adding certain additives to pure water.

It notes that considerable increases in critical heat flux were obtained by addition of powdered graphite and precipitated silica . These increases were attributed to the presence of a surface film containing these additives.

The galvanized boiling tank also added certain additives to the boiling water of the experiment. It was thought that the high water temperature produced a reaction with the galvanized coating releasing impurities into the boiling water and forming a surface film on the test section.

The extent of the variation in the data due to the impure water is not precisely known. It would be advisable, however, in future experiments to have a container, such as glass, that will not add impurities to the boiling water. It would also be advantageous to start with water as pure as possible and wash the water-contact surfaces before every run. Vachon (11) used deionized degassed water and washed with sodium hydroxide, acetone, and distilled water.

An improved screen attachment technique also needs to be devised. To fully utilize the screen extended surface, every mesh point should be in solid contact with the cylinder but at the same time none of the screen "holes" should be filled with solder. The test section screens used in this experiment had some places where the screen was not in solid contact, and other places where the solder ran and filled the screen mesh "holes". An improved process of attaching the screen, whereby a uniform pressure over the entire screen area is applied in conjunction with a more carefully regulated temperature for heat-up, needs to be devised.

In future studies it might also be desirable to analyze the results of screen wire extended surfaces attached to various tubes with different diameters. This would help determine whether or not the increase in heat transfer rate is solely attributable to an increase in effective area.

Since the thermocouple attachment seems to be somewhat of a problem in cylinders, one might also want to consider some other type of geometry. It is felt that the effect of screen wire extended surfaces could be examined just as well from a flat horizontal surface. Chatterjee and Lyon (15) have done studies on surface effects in nucleate boiling of oxygen from a flat horizontal surface. The design they used incorporated a relatively large slab of metal with a high thermal conductivity (i.e. silver, copper). One thermocouple was attached near the test section surface by drilling in diagonally from an adjacent side. Another thermocouple was attached a known distance directly below the first. The thermocouple near the surface gave a representative test section temperature, and the heat flux could be calculated directly by knowing the difference in the two thermocouple readings, the thermal conductivity of the slab, and the distance between the thermocouples.

The horizontal surface would also make the job of attaching the screen easier. A more uniform pressure could be applied to the screen when attaching it to a flat surface.

In future studies it may be advantageous to use other types of screen wire. Perhaps a screen with a different weave pattern would be desirable. A study of a rectangular rather than a square mesh might also be beneficial. It is hoped that this preliminary study will induce the interest and lead to a further study of screen wire extended surfaces.

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APPENDIX

APPENDIX A

COMPUTER PROGRAM FOR CALCULATING EFFECTIVE AREA OF SCREEN-CYLINDER COMBINATION

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C      PROGRAM FOR CALCULATING AEFF FOR SCREEN-CYLINDER COMBINATION
C      CALL THE SOLDER THICKNESS Y (IN INCHES)
C      DIA=DIAMETER OF WIRE IN INCHES
C      PTNUM=NUMBER OF MESH POINTS
C      R=RADIUS OF WIRE IN INCHES
C      PIPLEN=LENGTH OF PIPE
C      SIZE=THE MESH SIZE
C      RBAR IS 3 TIMES R
   100 FORMAT (1H ,2F10.1,2E13.5)
   101 FORMAT (1HO,3E13.5)
       DIA=0.016
       R=DIA/2.0
       PTNUM=4200.0
       PIPLEN=4.438
       SIZE=20.0
       Y=0.002
       RBAR=3.0*R
       RBARMY=RBAR-Y
       THETA1=ARCOS(RBARMY/RBAR)
       A1=(RBAR**2.0)*THETA1
       A2=RBAR*SIN(THETA1)*RBARMY
       A3=A1-A2
       EQUIVL=A3/Y
       THETA2=ARCOS((R-Y)/R)
       TWTHET=THETA2*2.0
       W=2.0*R*SIN(THETA2)
       VOLDIS=R*EQUIVL*((R*TWTHET/2.0000)-(W*SIN(THETA2)/2.0))
       VOLW=VOLDIS/4.0
       AREAW=VOLW/EQUIVL
       RSQD=R**2.0
       THETA3=3.1417/2.0-THETA2
       DO 1 I=1,120
       APIE=RSQD*THETA3/2.0
       ABR=RSQD*2.0*SIN(THETA3/2.0)*COS(THETA3/2.0)/2.0
       D=R*COS(3.1417/2.0-THETA3-THETA2)-W/2.0
       E=R-Y-R*SIN(3.1417/2.0-THETA3-THETA2)
       ASHAD=D*E/2.0+ABR-APIE
       IF(ASHAD.LE.AREAW)GO TO 4
     1 THETA3=THETA3-3.1417/360.0
     4 BETA2=THETA2*180.0/3.1417
       BETA3=THETA3*180.0/3.1417
       WRITE(6,100) BETA2,BETA3,ASHAD,AREAW
       Q=W+4.0*D
       ASUBP=Q*EQUIVL*PTNUM/144.0
       ASUBS=DIA*TWTHET/2.0*EQUIVL*PTNUM/144.0
```

APPENDIX A

COMPUTER PROGRAM FOR CALCULATING EFFECTIVE AREA OF SCREEN-CYLINDER COMBINATION (CON'T)

```
      ATP=0.75*3.1417*PIPLEN/144.0
      C=2.0*3.1417*ATP
      ATS=C*SIZE*DIA
      AEFFS=ATS-ASUBS
      AEFFP=ATP-ASUBP
      AEFFT=AEFFP+AEFFS
      WRITE(6,101) AEFFP,AEFFS,AEFFT
      STOP
      END
```

APPENDIX B

REDUCED DATA

Current (amperes)	Voltage (volts)	Test Section Temp. (°F) 1	2	3	4	5	Support Tube Temp. (°F) 6	7	8	Water Temp. (°F) 9	10
					30 X 30 Run 1						
5.90	142.0	214.1	221.1	220.2	213.2	216.3	209.8	209.4	209.4	209.4	209.4
6.50	152.0	214.5	222.0	220.7	213.6	216.7	210.2	209.8	209.8	209.8	209.8
7.00	164.0	215.0	222.8	221.1	214.1	217.6	210.6	210.2	210.2	209.8	209.8
7.50	177.0	215.4	223.2	221.6	214.1	218.5	210.6	210.2	210.2	209.8	209.8
8.00	190.0	215.7	224.1	221.6	214.3	218.9	210.6	210.2	210.2	209.8	209.8
8.50	202.0	215.9	225.0	221.1	214.5	219.4	210.6	210.2	210.2	209.8	209.8
9.00	215.0	216.5	226.3	221.6	214.5	220.2	211.1	210.2	210.2	209.8	209.8
9.60	231.0	216.7	222.6	223.0	214.8	221.1	211.1	210.2	210.2	209.8	209.8
					30 X 30 Run 2						
5.90	136.0	216.3	218.9	218.0	214.1	219.8	212.8	211.9	211.5	211.5	211.1
6.55	152.5	216.8	219.8	218.5	214.1	220.4	212.8	211.7	211.1	211.1	211.1
7.00	162.0	217.2	220.4	218.9	214.1	221.1	212.8	211.9	211.5	211.3	211.3
7.55	175.0	217.2	221.1	219.4	214.3	221.8	213.0	211.9	211.5	211.3	211.1
8.15	190.0	217.8	222.0	220.0	214.3	222.6	212.8	211.7	211.5	211.3	211.1
8.75	205.0	218.2	222.8	220.9	214.3	223.4	213.2	211.9	211.9	211.5	211.5
9.30	220.0	218.9	223.9	222.0	214.5	224.3	213.2	211.7	211.3	211.5	211.3
9.70	230.0	218.9	224.3	222.4	214.5	225.0	213.6	211.9	211.7	211.3	211.3
10.20	243.0	219.6	225.5	223.4	214.5	225.9	213.4	211.9	211.7	211.5	211.5
10.85	258.0	220.2	226.6	224.8	214.5	226.8	213.8	212.1	211.7	211.3	211.3
11.70	278.0	221.1	227.9	226.1	214.5	228.5	213.6	211.9	211.3	211.3	211.1
					Smooth Test Section						
5.90	140.0	221.1	217.6	217.6	218.9	222.0	209.4	209.4	209.4	209.4	209.4
7.00	165.0	222.8	219.4	219.4	220.2	225.0	210.2	209.8	209.8	209.4	209.8
8.00	189.5	225.9	220.7	221.6	222.4	226.8	210.2	209.8	209.4	209.4	209.8
9.00	215.0	228.5	221.6	222.8	223.2	229.0	210.6	209.8	209.8	209.4	209.8
9.60	228.0	229.4	222.0	223.7	224.1	229.9	210.6	209.8	209.8	209.8	209.8

APPENDIX B

REDUCED DATA (CON'T)

Current (amperes)	Voltage (volts)	Test Section Temp. (^{o}F) 1	2	3	4	5	Support Tube Temp. (^{o}F) 6	7	8	Water Temp. (^{o}F) 9	10
					20 X 20						
5.90	142.0	220.2	218.9	216.8	218.9	215.4	211.5	211.1	210.6	211.1	211.1
6.50	157.0	219.8	218.9	216.3	217.6	215.0	209.8	209.4	209.4	209.4	209.4
7.00	166.0	222.8	221.1	218.0	220.7	216.3	211.9	211.5	211.1	211.1	211.1
7.50	181.0	223.7	222.4	218.9	221.1	217.6	211.9	211.1	211.1	210.6	211.1
8.00	190.0	225.5	222.8	218.9	220.0	217.6	211.9	211.5	211.5	211.1	211.1
8.50	205.0	225.9	224.1	220.2	222.8	218.9	211.9	211.5	211.5	211.1	211.1
9.00	214.5	227.7	224.6	220.2	223.2	218.9	212.4	211.5	211.5	211.1	211.1
9.60	229.5	229.0	225.9	220.7	224.6	219.0	212.4	211.5	211.5	211.1	211.1
					10 X 10 Run 1						
5.90	144.0	215.9	217.2	215.4	217.6	225.0	211.9	211.5	211.5	211.5	211.5
6.50	157.0	216.8	218.0	215.9	218.5	226.8	211.9	211.9	211.9	211.5	211.5
7.00	167.5	217.2	218.0	216.3	218.9	228.5	211.9	211.9	211.5	211.5	211.1
7.50	180.0	217.6	218.5	216.8	219.8	230.3	211.9	211.9	211.5	211.1	211.5
8.00	192.0	218.0	218.9	217.2	220.2	232.0	212.4	211.9	211.9	211.5	211.5
8.50	205.0	218.5	219.4	217.2	220.7	233.4	212.8	211.9	211.9	211.5	211.5
9.00	210.7	218.9	219.8	217.6	220.7	235.5	212.8	211.9	211.9	211.5	211.5
9.70	233.0	219.4	220.2	218.0	221.6	237.3	212.8	212.4	211.9	211.5	211.5
					10 X 10 Run 2						
5.80	137.0	214.5	216.8	214.5	214.5	225.0	209.8	209.8	209.8	208.9	208.5
7.00	163.0	215.9	216.3	215.0	215.9	229.0	210.2	209.8	209.8	208.5	208.5
8.00	188.0	216.8	218.0	215.4	216.8	232.0	210.6	210.2	209.8	208.5	208.5
9.00	229.0	218.0	218.9	216.8	218.5	235.1	210.6	210.6	210.2	208.9	208.9
9.60	229.0	218.5	218.5	217.2	219.4	236.9	211.1	210.6	210.2	208.9	208.9

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Dr. R. L. Gorton for his guidance in the building of the test apparatus and his assistance in the operation of the experimental equipment. His suggestions during the preparation of this thesis are gratefully appreciated.

I am also thankful for the time spent and hard work extended by my wife, Linda, who typed this thesis.

VITA

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Master of Science

Thesis: PRELIMINARY EXPERIMENTS TO DETERMINE THE EFFECTIVENESS OF SCREEN WIRE EXTENDED SURFACES IN BOILING HEAT TRANSFER AUGMENTATION

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PRELIMINARY EXPERIMENTS TO DETERMINE THE EFFECTIVENESS
OF SCREEN WIRE EXTENDED SURFACES IN BOILING
HEAT TRANSFER AUGMENTATION

by

ROBERT EARL HENNING

B. S., Kansas State University, 1970

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

ABSTRACT

To achieve higher heat transfer rates from equipment designed for service in pool boiling for a given liquid one can either increase the effective area of the heat exchanger or alter the existing surface so the heat transfer will take place more rapidly. Most of the recent work has dealt with altering the existing surface to increase active nucleation sites. However, the problem of deposits on heat exchanger surfaces suggest that a more realistic approach to the problem might be to forget about nucleation sites and concentrate on increasing the effective area of the heat exchanger through the use of some type of extended surface.

Low-profile finned tubing has been used for boiling surfaces in refrigeration equipment. Short stubby fins have also been used to cool large radio power tubes by rejecting heat to boiling water. It was thought that screen wire attached to a boiling surface would be a very close approximation to the type of extended surfaces used in boiling heat transfer. The object of this thesis, therefore, was to determine experimentally the effect a copper screen wire had on heat transfer rate when it was attached to a copper cylinder.

To accomplish the desired objective, four different test sections were constructed. A 10 by 10, a 20 by 20, and a 30 by 30 mesh screen wire was attached to each of three different cylinders with solder for three of the test sections. The fourth test section was a bare cylinder with a solder coating. The heat transfer rate from each test section to a pool of boiling water was measured.

The results of the experiments show that screen wire extended surfaces appear particularly useful in boiling heat transfer augmentation. It was found that the 30 by 30 test section provided the highest heat transfer rates, followed by the 20 by 20 test section. All screen wire test sections had higher heat transfer rates than the smooth test section, with the 30 by 30 having a heat flux approximately four times that of the smooth test section.

However, due to the lack of confidence in some of the data, and due to the fact that different types of test sections should be tested, an extended, more precise, evaluation was suggested.