INVESTIGATION OF A THERMOELECTRIC REFRIGERATOR
WITH A
WATER-COOLED HEAT DISSIPATOR

BY

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ABSTRACT

In recent years, commercial thermoelectric refrigerators have been developed which use bismuth telluride elements to provide thermoelectric cooling. The purpose of this thesis was to investigate a prototype of a domestic thermoelectric refrigerator which employed water as the fluid coolant for the heat dissipator. It was felt that a water-cooled heat dissipator would provide a greater temperature difference between the heat absorber and room air than a natural convection heat exchanger. Unfortunately, the total resistance of the bismuth telluride element assembly was 0.18 ohms which was well above the maximum allowable value of 0.10 ohms. Because of the high resistance, the refrigeration unit would perform as a heater instead of a thermoelectric cooling unit. Although an experimental investigation could not be conducted to confirm the original premise of the thesis, a detailed soldering procedure for the element assembly was developed. The high resistance of the element assembly, which implied high junction resistance, was due to the poor condition of the elements themselves. Several elements had pits in their surfaces which formed air pockets of high resistance. The temperature difference is controlled for the most part by the junction resistance as poor junctions can contribute a resistance of 0.5 ohms in themselves. With new elements, it is felt that by employing the soldering techniques developed in this thesis the heat absorber can be cooled 80F below room air. Temperature differences of this magnitude are suitable for domestic thermoelectric refrigeration.

ACKNOWLEDGEMENTS

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NOMENCLATURE

A	cross sectional area of rectangular passages	ft.^{2}
C	coefficient for elbow losses	dimensionless
D	hydraulic diameter	ft.
f	friction factor	dimensionless
g	acceleration due to gravity	ft.^{2}/sec.
H_1	head of water level in constant head tank	ft.
H_2	head of water level in heat dissipator	ft.
k	thermal conductivity of water	BTU/hr.ft.F
L	length of rectangular passages	ft.
n	number of elbows	dimensionless
N_{Pr}	Prandtl number	dimensionless
N_{Re}	Reynolds number	dimensionless
P	wetted perimeter of rectangular passages	ft.
q	rate of heat transfer	BTU/hr.
t_s	wall temperature of heat dissipator	F
t_∞	temperature of fluid coolant	F
v	velocity	ft/sec.

Chapter 1

STATEMENT OF THE PROBLEM

For his master's thesis in 1960, John Edgar Evans, III, designed and built a prototype of a domestic thermoelectric refrigerator. This device used twelve bismuth telluride thermoelements, six thermoelectric couples, to cool 0.125 cubic feet of air space inside an insulated box.

Evans performed several extensive tests to evaluate the performance of his device. His refrigerator model was able to cool its heat absorber 39.5F below room temperature using a fan to simulate forced convection and no insulation on the heat absorber itself. Although this temperature difference may not be sufficient for commercial refrigeration where ice would have to be produced by a device operating in a room with a temperature as high as 80F, the addition of thermoelectric couples would enable the device to meet that performance requirement.

The problem undertaken in the present thesis was to evaluate and improve Evan's refrigerator. It was proposed to employ water cooling for the heat dissipator instead of the natural convection heat exchanger adopted by Evans. Since Evans had designed his refrigerator to be both a classroom demonstration model and a prototype of a domestic thermoelectric refrigerator, a method of heat dissipation which was easily portable had to be used. This condition ruled out a flow of water for cooling, and thus Evans employed room air as the heat sink for the device. Since these restrictions were not placed on the present thesis, it was felt that water cooling would improve the performance of a thermoelectric refrigerator by establishing a greater temperature difference between the heat absorber and the room. It was also felt that the overall coefficient of performance of the refrigerator would be increased. In addition, a compact water-cooled heat exchanger would occupy much less space than the fin arrangement used in natural convection and therefore would be much more suitable for domestic refrigeration.

In the solution of the problem, it was necessary to build an additional refrigerator model using many of Evans' components and modifying others. The present model would use the insulated box and the heat absorber built by Evans. The main feature of the new device was to employ a water-cooled heat exchanger as the heat dissipator. The flow of water would be circulated by means of a constant head tank which would employ tap water as the fluid coolant.

An experimental investigation of the device would be involved in which the model would be tested for peak current and temperature difference as a function of current. Peak current is the largest current which would be used in operating a commercial thermoelectric refrigerator. When the peak current is exceeded, both the temperature difference and the coefficient of performance decrease. The results obtained are to be compared with those of Evans to determine if water cooling has more merits than air cooling for use in the thermoelectric refrigeration.

Chapter 2

THE HEAT DISSIPATOR

2.1 Design and Fabrication

The system utilized for heat dissipation consists primarily of a constant head tank and an aluminum heat exchanger which serves as the heat dissipator. Tap water is supplied continuously from the sink faucet through rubber tubing connected to the inlet of the constant head tank. The water level in the constant head tank is allowed to build up until it discharges through an overflow tap which is connected by rubber tubing to the inlet of the heat dissipator. The water then circulates through a series of rectangular passages in the heat dissipator and is finally discharged through the outlet into the sink. A continuous flow of water is maintained so that the temperature of the fluid coolant is kept as near as possible to that of tap water as the heat which is removed by the thermoelectric couples is dissipated to the heat dissipator. By circulating the water in this manner, the temperature difference between the hot and cold fluids and thus the capacity for heat dissipation is maximized to the greatest possible extent.

The heat dissipator, shown in Figure 1, was fabricated in the following manner. Ten rectangular passages, 1 in. in width and 1/2 in. in height, were milled in a solid piece of aluminum 5/8 in. x 11 in. x 11 in. Several screw holes were tapped in the 1/2 in. solid flange circumventing the passages to allow a top plate to be fastened to the base. A 1/8 in. x11 in. x 11 in. aluminum plate which was used as a top plate would be secured to the base by several flat heat machine screws after the gasket was inserted. Two holes were drilled and tapped in the solid flange so that conventional pipe taps could be inserted to serve as inlet and outlet taps. A gasket made of glarcol, a solid substance often used for radiator gaskets, was placed between the top plate and the base while clear glyptal was brushed along the gasket edges and deposited in the screw holes. The screws were screwed down tightly and the clear glyptal was left to harden.

The gasket and the clear glyptal were used as sealants to prevent leakage of the water through the sides and the countersunk screw holes of the heat dissipator. Any amount of leakage could wet the thermoelements and other electrical components of the refrigerator model and thus disrupt the experimental investigation. Thus, it was necessary that leakage be prevented. The heat exchanger was tested for leakage by forcing water under pressure through the inlet tap while the outlet tap was sealed. Several different gasket materials were tested before the heat exchanger was found to be adequately sealed.

2.2 Theoretical Analysis

Evans found that the rate at which heat was to be dissipated was 85 BTU/hr. Thus, the water-cooled heat dissipator must be able to accommodate at least 85 BTU/hr. as a primary design criterion.

The design of the heat dissipator was based on the following theoretical analysis. The difference in heads between the level of the water in the constant head tank and the level of water at the outlet of the heat dissipator is equal to the sum of the head losses. The head losses were composed of friction losses in the passages and losses in the elbows as the water circulates from one passage to another. The above is expressed in the following equation:

$$H_1 - H_2 = f \frac{L}{D} \frac{V^2}{2g} + m\, C \frac{V^2}{2g} \qquad (1)$$

The difference in heads reduced to the difference in the levels of the water whose height was assumed to be 3 ft. The coefficient for the elbow losses was assumed to be 2.0. The hydraulic diameter was calculated from the following equation:

$$D = \frac{4A}{P} = \frac{4\ (1/12)\ \ (1/24)}{2\ (1/12)\ +(2\ 1/24)} = \frac{1}{18}\ \text{ft.} \qquad (2)$$

A friction factor was assumed and the velocity was calculated by substituting values into the equation as shown below:

$$3 = (.02)\ \frac{\frac{(10)\ (10)}{12} \qquad V^2}{\frac{1}{18}\ (2)\ \ (32.2)} + \frac{(9)\ (2.0)\quad V^2}{(2)\ \ (32.2)} \qquad (3)$$

The Reynolds number was calculated from this velocity and checked to see if it corresponded to the value on the graph in Hunsaker and Rightmire, Fluid Dynamics. The velocity which satisfied these requirements was found to be 3.03 ft./sec.

The rate of heat transfer was calculated by assuming that the mode of heat transfer was that of conduction through a flat plate. Heat transfer through the passage walls was neglected. The rate of heat transfer was calculated by using equation 7.40 in Giedt, Heat Transfer.

$$q = .664 \; k \, N_{Pr}^{1/3} \sqrt{N_{Re}} \; (t_s - t_o) \qquad (4)$$

The temperature difference was assumed to be I F. This value and other pertinent values were substituted as in the following equation:

$$q = (.664)(.339)(8.00)^{1/3} \sqrt{\frac{(3.03)(\frac{10}{12})}{(.514)(10^{-5})}} \; (61-60) \qquad (5)$$

The rate of heat transfer was found to be 315 BTU/hr. which is well in excess of the 85 BTU/hr. required. Thus a considerable factor of safety is introduced by employing this type of heat dissipator.

2.3 Formation of a Thermal Contact Which Is Not Also an Electrical Contact

It was decided that in the present model there would be no electrical contact between the elements and the heat exchangers. A good thermal contact, of course, was required. Two methods that could be used for obtaining the thermal contact without the electrical contact are:

1) An aluminum heat exchanger, which has been anodized to prevent the electrical contact, could provide the thermal contact between the hot junction surface and the heat dissipator.

2) A sheet of mica could provide the thermal contact between the cold junction surface and the heat absorber. This also could be used in place of anodizing to provide the thermal contact between the hot junction

surfaces and the heat dissipator.

Anodizing is a coating of aluminum oxide which has a sufficiently large dielectric strength to prevent electrical breakdown at the voltages encountered in a thermoelectric refrigerator. Although it is not a good heat conductor, it is deposited in layers so thin that the temperature difference across it will not be large. Evans states that a coating 0.0005 in. thick and one square foot in surface area would require 0.00197F in temperature drop for the transfer of 75 BTU/hr.

Mica has a very large dielectric strength so that it could be used in extremely thin sheets. A sheet 0.001 in. thick can be used to facilitate handling. Evans states that a sheet of mica 0.001 in. thick provides a temperature difference of 0.0144F.

The present model would be built using two pieces of mica 0.001 in. thick to prevent electrical conduction between the heat exchangers and the elements. It was found that the heat dissipator could not be anodized because the anodizing bath would attack and partially disintegrate the flat head machine screws and the brass pipe taps. Silicone lubricant would be placed on both sides of the mica to minimize the thermal contact resistance.

Chapter 3

PREPARATION OF THE REFRIGERATION UNIT

3.1 Fabrication of the Bismuth Telluride Thermoelements

A most versatile material for use in thermoelectric refrigeration is the impurity semiconductor, often made from bismuth telluride. If a small amount of an impurity of valence n+1 is added to a crystal of an element whose valence is n, there will be an extra electron per impurity atom beyond the number required to fill the valence band. At low temperatures each of these extra electrons will move about one of the donor impurity ions in response to the additional positive charge on these ions. Thermal energy at room temperature is sufficient to raise some of the extra electrons to the conduction band and so produce semiconductivity. An n-type semiconductor, as described above, involves conduction by negative carriers, namely electrons. If the impurity element has a valence of n-1, rather than n+1, the electrons are localized and cannot conduct electricity, but the holes they create in the valence band act as a positive carriers. The term p-type semiconductor applies in this case.

A thermoelectric couple consists of an n-type semiconductor and a p-type semiconductor connected electrically in series, which means that thermally they are in parallel. When a current is passed through the couple, the cold junction on the heat absorber absorbs heat while the hot junction on the heat dissipator dissipates heat. Theoretically, as current is applied the electrons wander to the positively charged holes which quantum mechanically can be interpreted as a change in energy levels. This change must be absorbed by the overall vibrational energy of the crystal which causes a temperature difference to result. The cooling is the phenomenon which takes place at the cold junction.

The p-type bismuth telluride thermoelements were made by vacuum casting a 1 cm. diameter cylinder from a melt containing stoichiometric proportions of Bi_2Te_3 to which a 1% excess of Bi had been added as a doping element. The n-type elements were cast with a 0.08% excess of I_2 added for doping.

When Evans' refrigerator model was disassembled, it was found that one of the solder junctions was broken. One of the thermoelements had been split axially and another was in poor condition. Therefore, it was necessary to reassemble the apparatus and replace the two damaged thermoelements.

Ten of the twelve elements were found to be in good condition. The thermoelectric power of these thermoelements was measured with an Alpha meter which consists of a heated probe connected to a microammeter. When the probe is placed on a thermoelectric material, the heat energy from it creates either electrons or positively charged holes in the material and the resulting current flow is measured. The surface film was removed from the sample by a sandblaster. It is important that surface and oxide impurities be removed for the thermoelectric power measurement because this is primarily a surface measurement. The thermoelectric power of these elements was within 5% of the values recorded by Evans. Since the thermoelectric power of these elements did not change very much, it was assumed that the values for the resistivities were approximately the same.

Elements 2 and 12 were replaced with new n-type elements. The thermoelectric power and resistivity of these elements were measured. The resistivity was measured by passing a known alternating current through each and recording the potential difference between two probes. With the current, voltage, cross-sectional area, and distance between probes the resistivity was calculated.

Later, two more thermoelements, elements 7 and 8, were damaged and two others, elements 1 and 2, were stolen or misplaced. These four elements were replaced and the thermoelectric power and resistivity of these elements were recorded. The final values of thermoelectric power, resistivity, and geometry for the elements are recorded in Table 1.

3.2 Preparation of the Jigs and Connector Pieces

The cold junction connector pieces were made by cutting 1/8 in. copper sheet into 1 3/8 in. x 2 3/4 in. rectangular drapes and rounding the corners and edges of them to prevent their puncturing the mica sheet. These are used to conduct the current from element to element and also to conduct heat between the elements and the heat exchangers.

The hot junction connector pieces used were those of Evans. These were made by soldering with lead tin solder two copper cylinders to rectangular drapes similar to the ones mentioned above. The use of cylinders enabled the heat exchangers to be separated by a distance greater than the element length which decreased the heat leak between the dissipator and absorber. In other words, the additional spacing allowed insulation to be deposited around the elements to reduce the heat leak. However, the weight of the copper cylinders would contribute to greater stresses which could disrupt the junctions. This was compensated for by potting the assembly with lockfoam which is described in a later section.

The flexible current leads were removed from Evans' model and soldered to the two small hot junction connector pieces. Each current lead consisted of four strands of 1/4 in. diameter cable shielding which was very flexible. The other ends of the cables would be passed through holes in the insulated box and bolted to the box after assembly was completed.

Two jigs were made by Evans from 1/2 in. aluminum plate, and the hot junction connector pieces were bolted to one of these jigs. The jig which held the cold junction connector pieces had four dowel pins which fit into holes in the other jig for purposes of locating. After the hot junction connector pieces were secured to the jig, the exposed ends of the cylinders were milled so that they all lay in the same plane and were as smooth as possible. These pieces remained attached to the jig until the final soldering of the elements.

3.3 Soldering Procedure

Before the elements were soldered to the cold junction connector pieces, the area where each element was to be located was cleaned and nickel plated. The nickel plate on the copper was to prevent a decrease in thermoelectric power so that copper could not diffuse into the bismuth telluride.

The elements were also cleaned by sandblasting, nickel plated on both ends, and then tinned with indium tin solder using as cool an iron as possible. They were then located by eye with the help of lines marked on the copper plates.

The soldering of the first element on each connector piece was not difficult. The copper rectangular drape was heated with a 150 watt soldering iron. After the spot where the element would go was tinned, the element was placed down securely and water was splashed on it to accelerate the cooling process.

The first element was protected by a wet tissue while the second element was soldered to the connector piece. The second element was soldered in a similar manner as the first. After all the cold junctions were fabricated, the connector pieces were bolted to the jig.

The exposed ends of the copper cylinders were cleaned, nickel plated, and tinned with indium tin solder. The jig containing these pieces was placed on a hot plate and the temperature was monitored with the aid of a thermocouple. It was necessary to hold the temperature near 275F so that the indium tin solder would melt without melting the lead tin solder which was used to solder the copper cylinders to their rectangular drapes. When the temperature reached the proper value, the jig containing the cold junction connector pieces was located by the dowel pins into the holes of the other jig. Since this assembly cooled slowly, the jig containing the elements was located with care. The apparatus was then allowed to cool and the soldering was checked.

After this attempt the soldering assembly still in the jigs was given to the machinist for further work. When the machinist removed the jigs, he discovered that several of the junctions were broken. Since it was possible that the machinist did not exercise sufficient care in removing the jigs and had applied sufficient force to break the junctions, it was decided to reassemble the apparatus and have the author remove the jigs himself. The soldering procedure was repeated and the jigs were removed. However, some of the junctions still did not hold and it was evident that improper techniques were employed in the soldering procedure.

After much discussion with soldering experts, the following modifications were applied to the soldering procedure on the third attempt. First of all, the copper rectangular drapes were cleaned more thoroughly with emory cloth and a polishing wheel. Secondly, the elements were cleaned by filing with a very fine file. It was felt that in sandblasting fine sand particles could become impregnated in the crystal and possibly an oxide film was formed. It is imperative that the surface of the element be as clean as possible so that the solder will adhere properly. Thirdly, lead tin solder would be used to solder the elements to the copper drapes. It is possible that the heat from the hot plate was sufficient to melt some of the indium tin solder forming the cold junction and thus disrupt the junction between the element and the copper drape. Finally, in soldering the hot and cold junction pieces together the temperature would be raised to 300F so that all the solder would melt uniformly. The cold junction pieces would be left on the cylinders at this temperature for at least ten minutes so that both surfaces would be hot enough and the solder would flow correctly.

In the third attempt the detailed procedure is described as in the following. The copper drapes were cleaned thoroughly with an emory cloth and a polishing wheel. The area where each element was to be located was cleaned again with an emory cloth and nickel plated. This area was tinned with lead tin solder using a very large iron, and the film of solder was kept to a minimum thickness. The elements were filed on top and bottom to a very smooth surface and nickel plated. One surface of each element was tinned with lead tin solder with a very large iron after applying a small amount of sulfuric acid to make the surface as clean as possible. By doing this, it was readily seen that the solder adhered very well to the surface of the element. In the first two attempts, a good adherence was not achieved which probably affected the results considerably.

The copper drape was heated with the large iron near the area where first element was to be located until the solder melted. The element was then placed down securely, held there while heat was applied for a short time so that the solder tinned on the element would melt and fuse together with the solder tinned on the copper drape, and then allowed to cool. The first element was protected with a wet tissue while the second element was soldered in a similar manner as the first. The top surface of each element was tinned with indium tin solder after applying a small amount of sulfuric acid to make the surface as clean as possible. The cold junction connector pieces were then bolted to their jig. Excellent junctions resulted from this procedure with no excess of solder surrounding the element and thus affecting the quality of the contact.

The exposed ends of the copper cylinders were retinned by placing the jig containing them on a hot plate and controlling the temperature near the melting point of indium tin solder. Indium tin solder was then deposited on the exposed ends of the copper cylinders in a thin film. The tinned ends of the cylinders were thoroughly cleaned with acetone to dissolve impurities. The tinned surfaces of the elements were also thoroughly cleaned with acetone.

The jig containing the hot junction connector pieces was placed on a hot plate and heated until the temperature reached 300F. When the temperature reached the proper value, polyflux was brushed onto the tinned surfaces of the elements and the jig containing these cold junction connector pieces was located by the dowel pins into the holes of the other jig. The soldering assembly was held at 300F for ten minutes so that the solder could melt uniformly and then the assembly was allowed to cool. The junctions appeared to be intact but the quality of these junctions had to be determined by measuring the overall resistance of the circuit.

The resistance was measured by exciting the circuit with an alternating current of 0.020 amperes and measuring the voltage across the flexible current leads. Fibre washers were used to hold down the copper plates and the screws were insulated from the copper plates by placing small strips of cardboard in between. Continuity was checked before the final soldering. The voltage across the current leads was found to be 0.0036 volts. Thus, the resistance was found to be 0.18 ohms. This was almost twice as much as the maximum allowable value of 0.10 ohms. Evans' value of resistance was 0.0189 ohms. This meant that the apparatus would effectively act as a heater instead of producing cooling.

The high value of resistance is probably due to one or two poor contacts. A very poor contact can have a resistance of 0.50 ohms by itself. These poor contacts were probably due to the condition of the elements themselves. Most of the elements had been used throughout all last year and had been through two unsuccessful attempts in the present thesis. Several elements had small pits in their surfaces due to constant use and the impregnation of sand particles during sandblasting. The solder would not adhere to these pits and would flow over them leaving air pockets. It is these air pockets that is responsible for the high resistance.

Unfortunately, it was too late to obtain new elements and make another attempt. Thus, the thesis was concluded at this point. However, I would recommend that the next student doing a thesis on thermoelectric refrigeration obtain all new elements and follow the procedures discussed previously very carefully. I would also suggest that he first work with only one couple and measure its resistance so that he can determine if six similar couples will have a resistance within the allowed value.

Chapter -4-

MOUNTING THE HEAT DISSIPATOR

If the soldering assembly is successful, the problem still remains of handling the apparatus without breaking any of the junctions. This problem can be solved by potting the soldering assembly with lockfoam while it is still in the jigs. Lockfoam is self-curing and rigid, and it will adhere to everything except silicone lubricant. Thus, before the connector pieces are bolted to the jigs the surfaces of the jigs can be coated with a thin layer of silicone lubricant. After soldering, the sides of the jigs can be blocked off with masking tape and the lockfoam can be poured in and left to set. The jigs can now be removed and the handling of the apparatus is facilitated.

The heat dissipator must be mounted so that its surface comes into contact with the copper rectangular drapes of the hot junction surfaces. Six pieces of 3/4 in. nylon rod which were fabricated to support the heat dissipator can be turned to the proper lengths by measuring the distance between the two jigs containing the soldered elements and subtracting the thickness of the aluminum bars, rubber washers, and mica sheet discussed in the following paragraph. A hole was drilled and tapped along the axis of each nylon rod so that they can be screwed to the heat absorber. A rubber washer can be placed on each rod so that any discrepancy in the measured distance would be taken up by the rubber washers.

A thin coat of silicone lubricant can be placed on the heat absorber; the mica sheet located; and a second coat of lubricant placed on the mica . The six nylon rods can then be screwed into position and a rubber washer placed on each. The element assembly can then be removed from the jigs and the cold junction connector pieces placed on the heat absorber. Two aluminum bars 3/4 in. in width can be screwed to the nylon rods by flat head machine screws in countersunk holes. A thin coat of silicone lubricant can be placed on the heat dissipator; the mica sheet located; and a second coat of lubricant placed on the mica. The heat dissipator can then be located on the hot junction connector pieces and screwed to the two aluminum bars. Thus, the mounting is secure and the heat dissipator is supported by the nylon rods so as not to exert any compressive force on the element assembly.

The heat dissipator can be secured to the sides of the insulated box by angle pieces so that there is no sidewards motion. Santocel insulation is deposited in the insulated box to reduce heat leak. The top of the insulated box can be covered with a plywood top with two holes allowing the rubber tubing to be secured to the outlet and inlet taps. Thus, the refrigerator model is ready for testing.

Chapter 5

METHOD OF TESTING

5.1 Testing apparatus

Although no actual tests were carried out on the refrigerator model because of the high resistance of the element assembly, the method of testing will be described briefly as a reference for those doing future work in this area. The general objective is to record temperature differences as a function of current.

The proposed method of excitation for the refrigerator model was to use a motor-generator set. An available set required an AC source of 2.3 amperes at 220 volts for the motor and produced DC currents up to 45.6 amperes at 6.5 volts. The current ripple factor, the ratio of the amplitude of the alternating current component to the direct current component, was approximately 8.5 % which was within the 10% limit which produces no effect on the thermoelectric cooling.

The current from the motor-generator set was controlled by changing the circuit resistance. Evans built a device whose resistance could be varied between 1.00 and 0.151 ohms and which would carry from 7.5 to 45 amperes. This consisted of seven one ohm resistors which were connected at one end to a bus bar and at the other end to switches which were connected to another bus bar. As each switch was closed, the resistance of the resistor board decreased because another resistor was placed in parallel. A two ohm resistor was placed in parallel with each one ohm resistor so that finer adjustments could be made.

5.2 Placement of the Thermocouples

Thermocouples can be used as temperature sensors and a potentiometer used to measure the resulting potential difference. The reference junction is placed in melting ice contained in a thermos bottle. A selector switch is used to place one thermocouple at a time in the circuit with the potentiometer and the reference junction.

Thermocouple 1 is bolted to one fin of the heat absorber and thermocouple 4 to the heat dissipator. Thermocouple 2 is placed on a cold junction connector piece and thermocouple 3 on a hot junction connector piece. Thermocouple 5 inside the refrigerator and thermocouple 6 outside it are used to measure the air temperature. Thermocouple 7 is placed between the aluminum foil and the inside masonite wall in the insulated box of the refrigerator.

Temperatures can be recorded at specified time intervals for different values of current. The temperature difference and peak current of the model can be determined and the effectiveness of the refrigerator model interpreted.

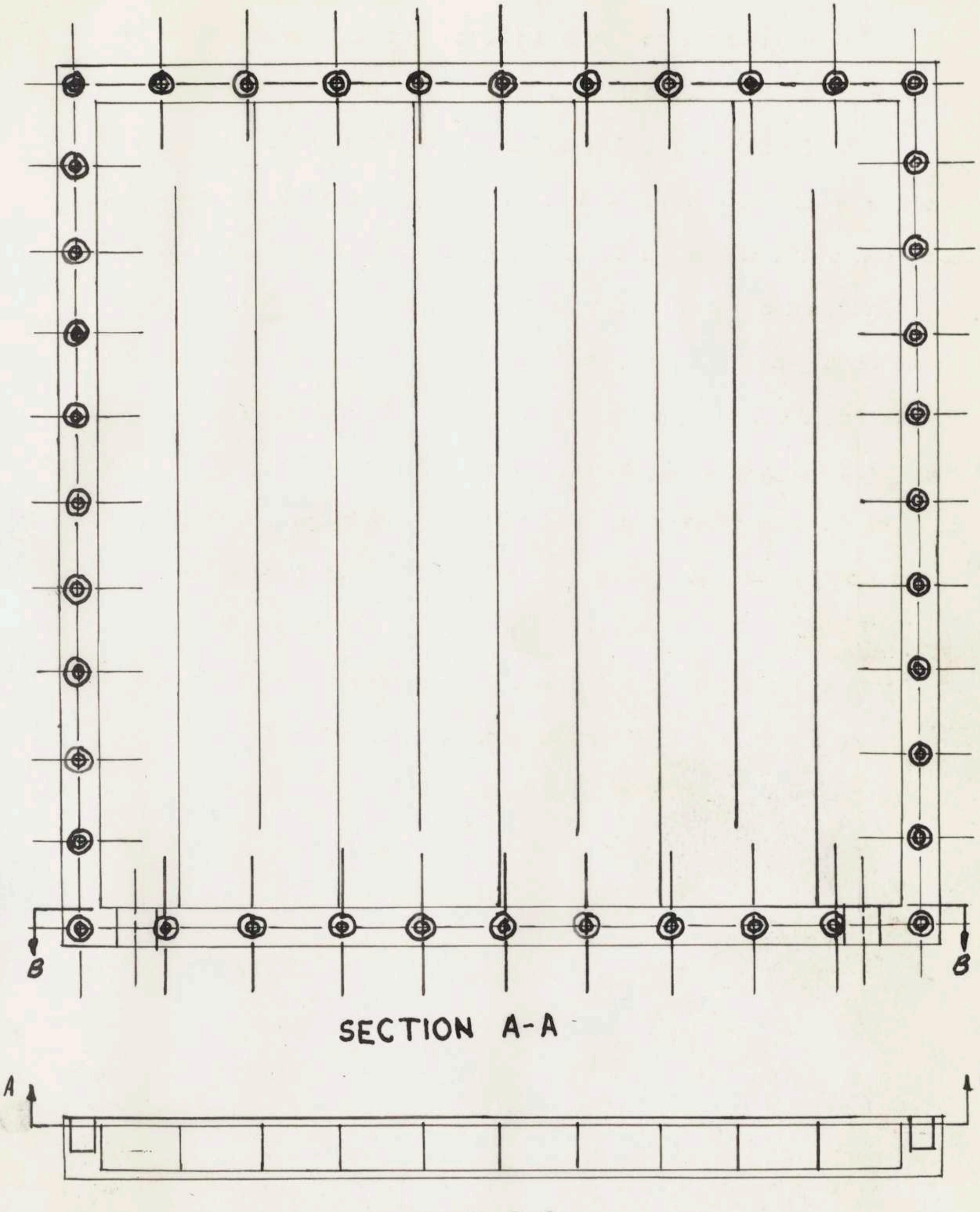

FIGURE 1

TABLE I

Element length = 0.395 in. = 1.005 cm.

Element Number	Thermoelectric Power in microvolts/C	Resistivity in milliohm - cm.	Area cm^2
1	180 (p)	1.25	0.95
2	150 (n)	0.49	0.44
3	190 (p)	1.35	0.93
4	145 (n)	0.47	0.44
5	180 (p)	1.25	0.88
6	145 (n)	0.47	0.44
7	180 (p)	1.25	0.88
8	150 (n)	0.49	0.44
9	170 (p)	1.15	0.88
10	145 (n)	0.55	0.47
11	170 (p)	1.12	0.91
12	145 (n)	0.47	0.44

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