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FINAL REPORT

HEATING OF FOOD IN MODIFIED ATMOSPHERES

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ABSTRACT

The first objective of the study was to design, build, test and deliver to NASA a test chamber for studying the heating characteristics in modified atmospheres of selected can items. The first part of the study was devoted to the design and assembly of the test chamber and accessory equipment.

A controlled DC power supply was utilized to provide power for heating the foods. A specially constructed resistant heater unit was molded to fit the 401 x 105 aluminum food cans which were used for the study. The heater temperature was controlled with a temperature controller unit that allowed selection of either proportional or on-off control.

Thermocouple probes were made for measuring the temperature inside the 401 x 105 cans of foods. A technique was developed for inserting the thermocouple probes into the food cans without allowing a change of the gas in the can. Another technique was developed for the precise location of thermocouples within the probes so that temperatures could be measured at precise locations in the food can.

Measurement of the food temperature was of primary interest since much of the study dealt with measurement of heating times required to achieve a given serving temperature. Temperatures inside the can varied with time and with location within the can, so the most meaningful temperature measurement was the mass average temperature of the food in the can.

It was desirable to be able to measure mass average food temperature using the minimum number of thermocouples. It was assumed that the mass average temperature could be measured by measuring the temperature at only one point in the food. Theoretical studies were conducted to determine the effect of various parameters on the location of such a point.

The theoretical studies were conducted using the assumption of ideal heating conditions and perfect insulation. Results of these tests indicated that it should be feasible to measure the mass average temperature within a narrow range of mass average temperatures by using only one thermocouple. The location of this point was independent of initial food temperature, heater temperature and the thermal properties of the food. It is expected that these results should also apply to the case of non-ideal heating conditions.

It was shown by the theoretical studies that food heating times were quite sensitive to small changes in heater temperature.

Experimental food heating tests were conducted to verify the results of the theoretical studies. Experimental temperature equilibration curves were also used to verify predictions of mass average temperature since the temperatures at several locations within the food converged to the mass average temperature after heater turn-off. Equilibration curves could only be used for estimating the mass average temperature at the time of heater turn-off. One thermocouple could be positioned in the food can to monitor the mass average temperature for the homogeneous food; however, for the heterogeneous food it was necessary to use the equilibration curve to estimate the mass average temperature.

Thermal conductivity for the two model foods was measured with a thermal conductivity probe. Measurements were made _in situ_ by inserting the thermal conductivity probe directly into the 401 x 105 food cans.

Detailed studies of convective and radiative heat transfer were conducted. Natural convection was of special interest since it can occur within the gravity of the earth but will not occur at zero gravity. Therefore if convection occurs during food heating tests on earth, these tests will not accurately reflect heating at zero gravity.

Highly viscous foods were used in the study to prevent convection within the food. The occurance of convective and radiative heat transfer was limited to heat transfer between the heater surface and the can surface. Mathematical analyses of radiation and convection between the heater and can showed that heat transfer by these means was insignificant primarily due to the small air space between the surfaces. Experimental tests also showed that convection and radiation were of insignificant magnitude and that almost all of the heat transferred from the heater to the food can was by conduction.

Food heating tests were conducted with two model foods; a Carnation turkey salad sandwich spread and frankfurter chunks in a sauce of water and agar. For the first series of tests comparing heating in five different atmospheres, the atmospheres were (1) air at atmospheric pressure, (2) air at 5 psia, (3) helium at 5 psia, (4) oxygen-nitrogen mixture at 5 psia and (5) oxygen-helium mixture at 5 psia. No significant differences in heating rates were caused by varying the atmosphere.

Initial food temperatures were varied in the next series of tests. Heating times were found to increase with decreasing initial temperatures. There were also differences in heating times between the two foods used.

Heating tests were conducted with varied heater control mode. Proportional control and on-off control were compared at the same heater watt density. No significant differences were obtained between the types of heater control.

In the food heating tests described above there were usually significant differences between food cans containing the same food item. Variations of $\pm$ 5 percent were not uncommon.

RECOMMENDATIONS

This study included the development of equipment for conducting heating tests to simulate heating of foods in space. Various heating tests with two model foods were conducted. The importance of this study is directly related to the need for providing wholesome, high quality food to astronauts working in a space environment. Food heating times must be known in order to coordinate meals with other mission activities and to prevent wasted time.

There are two other conditions which affect the food quality. Foods cannot be heated too slowly since this provides optimum growth conditions for microorganisms. Holding hot foods at serving temperatures for extended periods of time causes a deterioration in quality.

It is most desirable to heat foods quickly to the serving temperature followed by immediate consumption. To achieve this goal, heating times for those foods which will be served hot must be known. The effects of zero gravity and reduced cabin pressures require specially designed heating tests to predict these heating times.

The present study has increased the capability of NASA to predict food heating times in space. Radiative and convective heat transfer between the heater surface and can surface were found to be negligible. Heat transfer to the food is also not affected by differences in the surrounding atmosphere.

The heating rate is strongly affected by changes in the heater surface temperature. A small reduction in heater temperature can increase heating times quite significantly. Location of the heater temperature sensor is critical due to the temperature gradient in the heater. Placement of the sensor immediately adjacent to the heater surface would yield a higher heater surface temperature than placement of the sensor a short distance from the surface.

Techniques were developed for estimating the average food temperature in the food container during heating using a thermocouple probe inside the can. A thermal conductivity probe was utilized to measure the thermal conductivity of foods directly in the containers.

Not all questions regarding heating of foods in space were answered by the present study. As a result of the study several more information gaps can be pointed out. It is important that the heater tray used for testing is identical to the tray for which predictions are being made. The effect of contact between the heater and food can is one reason to use identical heating trays because poorer contact reduces the heating rate. Another reason is so that the temperature sensors will be similarly located since the heating rate is sensitive to the heater surface temperature, which is dependent on the precise temperature sensor location.

Heating rates in partially filled food cans will require a thorough study due to differences in total heat required and amount of heater surface in direct proximity to the food. Even more critical will be the manner in which food is distributed in a partially filled can. If the food forms a large droplet in the center of the can, heat transfer will be severely decreased due to poorer contact between the food and the heated surface. Frozen foods will add to the uncertainty in this situation because they would be fixed next to the can bottom during the freezing process on earth, but the food would be redistributed upon thawing to form a spheroid in the center of the can.

Natural convection will not occur in space due to zero gravity so most of the efforts concerning convection in this study were to eliminate it. However, subsequent to the initiation of this study, the concept of inducing forced convection in space by spinning the food cans was proposed. This concept merits more study since it should greatly increase heat transfer to the food.

The possibility of predicting heating times with a computer should be investigated. Thermal properties of the foods to be heated and the heater temperature must be known. Then a digital computer program can be developed which will predict the mass average temperature of the food and the temperature at any point within the food as a function of heating time, heater temperature and initial food temperature. The thermal properties of the foods and the heater temperatures can be measured experimentally.

Use of a computer program to predict heating times would greatly reduce the amount of experimental work required. A greater insight could be gained concerning the effect of various factors on heating rate.

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I. INTRODUCTION

Future space exploration missions are expected to be of longer duration than those conducted up to and including the Apollo missions. These extended missions may consist of interplanetary exploration or manning space stations near Earth. Extended missions will require (1) a greater food supply, (2) a wholesome and nutritionally sufficient selection of foods (3) foods of excellent appearance and taste, (4) more attention to safe storage requirements for retention of food quality, (5) convenience of preparation of food and (6) more attention to disposal of unconsumed food and containers.

Restrictions will exist in the forseeable future on weight at launch for space missions. However, food is so important for maintaining physical and mental condition of the personnel to assure successful completion of extended missions that better and more varied foods will be provided. It is anticipated that frozen foods will be included along with the presently available dehydrated, intermediate moisture, and thermally stabilized foods.

Food for consumption during space exploration must be safe biologically. This can be assured by adequate processing procedures before or after packaging and by adequate heating before consumption.

Convenience of preparing meals during space missions is a necessity to assure maximum and consistent quality of the prepared food as well as to minimize the time required by personnel. This becomes a critical factor because the personnel must be performing under increased stress conditions caused by their environment and their constant attention to the specific mission activities.

Many foods must be heated for optimization of acceptance. For maximum acceptibility the food temperature should be within an optimum temperature range which may vary with different types of foods.

A knowledge of heating times required to heat various food items to the desired temperature is necessary for future space missions. Food preparation times must be known in order to coordinate meal preparation and mission activities. The required heating times will be influenced by the type of food, storage temperature of the food, amount of food in the container, type of food container, the heater temperature, heater geometry and thermal properties of the heater assembly.

Heating food during space missions can cause some additional problems not experienced during heating on Earth. Aside from restricted space, minimum available time, and the absence of some equipment which could be used for the efficient cooking of food; the environment for cooking within a space vehicle is modified from that here on Earth. A reduced pressure of 5 psia may be used. At this pressure, water boils at a temperature of approximately 162 F. A food such as meat with a high moisture content would undergo rapid dehydration at 162 F, so the heater temperature would be maintained slightly lower than 162 F. Such a reduction in heater temperature would increase heating time. Microbial growth may then become an important consideration. In addition, some food items such as vegetables will deteriorate at temperatures above 140 F and may undergo significant reductions in quality.

Heating tests may be conducted on Earth to predict heating times in space; however, differences in heating times due to variations in gravity and atmosphere must be considered. For example, natural convective heat transfer may occur on or near the surface of the earth, but will not occur in zero gravity.

In 1970, a task force from the Food Science Institute at Purdue University made a comprehensive unsolicited research proposal to NASA to study problems associated with preparation of food in space including thermal properties, food heater power consumption, convenience, nutrition, and acceptance. After the submission of the above proposal, NASA contracted with contractor to conduct a more specific study on simulation of heating of foods in space.

The study plan followed for this investigation was the Revised Study Plan of September 29, 1970 and approved by NASA.

II. OBJECTIVES

The objectives of the study were as follows:

To design, build, test and deliver to NASA a test chamber to study the heating characteristics in modified atmospheres of selected can items.

To develop a program of experiments to optimize power consumption during heating of food items in modified atmosphere and isolate the separate effects of conduction, convection and radiation using two model food systems.

III. DEVELOPMENT OF EQUIPMENT

In order to achieve the objectives it was necessary to obtain or make various equipment. With the exception of the temperature measurement equipment, most of the equipment used was procured from commercial sources. Wherever possible equipment specifications were developed to insure maximum flexibility in equipment use. Only a cursory treatment of equipment is given in this section and a more detailed equipment description is contained in Appendix A.

A. Test Chamber

A test chamber was required so that heating could be accomplished at the various pressures and with different atmospheres.

1. Requirements.

The test chamber requirements were developed so that maximum flexibility existed in the number of possible uses.

a. Size.

A minimum inside dimension of 20 inches was chosen. This is larger than necessary for the heater assembly used but it allows for other heaters to be used or more than one heater assembly to be used at the same time.

b. Access.

The front end of the test chamber is covered by a door to allow for easy access to the inside of the chamber. Two 6-inch diameter glass observation ports are provided in the door.

2. Accessories.

a. Mechanical.

The accessories include a pressure gage, a manual vacuum - break valve, a pressure relief valve, a vacuum hose connection, a solenoid controlled gas inlet valve and extra 1/2-inch gas ports.

b. Electrical.

The electrical feed-throughs provide for 24 chromel-constantan thermocouple lead wires, 2 iron-constantan thermocouple lead wires and 14 600-volt, 5 amp, copper conductors. All of the electrical feed-throughs are standard 3/4 inch Conax connectors which may be replaced by other connectors if necessitated by future requirements.

B. Vacuum Pump.

The vacuum pump recommended has a 5.6 CFM capacity with an ultimate vacuum of 0.1 millitorr. It operates on 115 V, 60 Hz power and uses 13/16 inch I.D. vacuum tubing. It is expected that an absolute pressure of 5 psi. will be the lowest pressure required; however, this pump will also provide the capability of obtaining high vacuums.

C. Heater Assembly.

1. Heater unit.

The heater unit was designed for a 401 x 105 aluminum food can made by Central States Can Co., Massillon, Ohio. It was molded to fit the 401 x 105 can by Electro-Flex Heat, Inc. of Bloomfield, Connecticut. It consists of two separate heater units, a bottom heater and a side heater. The heater wires are surrounded by silicone rubber reinforced by fiberglass. A 1/4 inch layer of silicone foam rubber insulation was used next to the heater. One-half inch of neoprene foam rubber insulation backs up the silicone foam rubber.

2. Thermocouples.

Seven chromel-constantan thermocouples were molded into the heater unit when it was made. Additional thermocouples have been placed at the top surface of the heater to monitor and control the heater temperature. Chromel-constantan was selected due to its high voltage output per degree temperature change. In addition, chromel is more durable than copper and was more easily spot welded.

3. Heater lid.

The heater lid has 1/4 inch of silicone foam rubber backed by expanded polystyrene insulation. It is clamped on to the bottom of the heater assembly.

D. Power Supply.

1. Pilot amplifier and temperature controller.

The pilot amplifier and temperature controller unit provides a basic 28 volt DC power controlled by proportional or on-off modes of control. The voltage may be varied to change the watt density in the heaters.

The temperature controller utilizes an iron constantan thermocouple for its sensor. The controller is basically a proportional controller with proportional band and offset controls. For on-off heater control an auxiliary relay is added.

2. Auxiliary instrumentation.

Voltmeters are provided to indicate the voltage drop across each heater. A wattmeter is used to give the total power consumed by both heaters.

E. Temperature Measurement Equipment.

Thermocouples were used for all temperature measurements.

1. Thermocouple probe.

A probe containing two thermocouples is provided to measure the temperature inside the food cans. It consists of 20-gage stainless steel hypodermic tubing (0.81 mm O.D.) with insulated 0.051 mm O.D. chromel-constantan thermocouples placed inside. The thermocouple wires were insulated with a polyimide tubing (micro "ML" tubing made by Niemand Bros., Inc., Elmhurst, N.Y.) having an I.D. of 0.15 mm and wall thickness of 0.02 mm. The thermocouple junctions were made with an electric spotwelder prior to inserting the thermocouple wires in the insulation.

a. Provision of a seal between probe and can.

Several concepts to maintain a seal between the probe and the can lid were considered. The reason for providing such a seal was to allow for insertion of the probe into the food can without affecting the pressure inside the can.

A rubber disk glued to the top of the food can provides a simple solution. When a probe is inserted into a food can through the rubber disk, the rubber provides a seal between the probe and the lid so that the pressure inside the can is not changed.

Tests were conducted to check the seal between 20 gage hypodermic needle probes and the aluminum can lids under vacuum and pressure conditions. The can lids were clamped to the top of a 3 1/2-in. I.D. test chamber (see Figure III-1) which was connected to a vacuum/pressure pump and a pressure gage.

Rubber serum stoppers 7/8-in. in diameter and 3/16 in. thick were glued to the top of the can lids with Eastman 910 adhesive. The resulting pressure change in the chamber in each of five replications was less than 0.01 psi in five minutes. The seal was maintained even when the probes were removed.

Similar tests were performed with a pressure of 15 psig in the chamber. Again no significant pressure change occurred in each of five replications. There was a slight air leak when the probes were removed, but the seal was regained when the probe was reinserted into the same hole. The probes could be tilted 10-15 degrees from vertical without breaking the seal.

b. <u>Force required to puncture lid</u>.

Since the temperature measurement technique required the insertion of one or more probes through the can lids, it was of interest to measure the force required to do so.

Pointed 20-ga hypodermic needles were used for the probes. Using a universal testing machine, it was found that 11 to 14 lbs force is required to push the probes through the aluminum food can lids at moderate piercing speeds.

Tests were also carried out to determine the possibility of rupturing the can lid at the scored ring which is used for opening the can. A blunt-tipped 16-ga hypodermic needle was forced through the lid within 1/8 in. of the scored ring without tearing it. To simulate the simultaneous insertion of several probes a vertical force was applied to the center of the can lid with a 2 7/8 in. diameter plate. A 250 lb. force did not tear the ring. From these tests it was concluded that there is no possibility of damaging the scored ring by inserting probes.

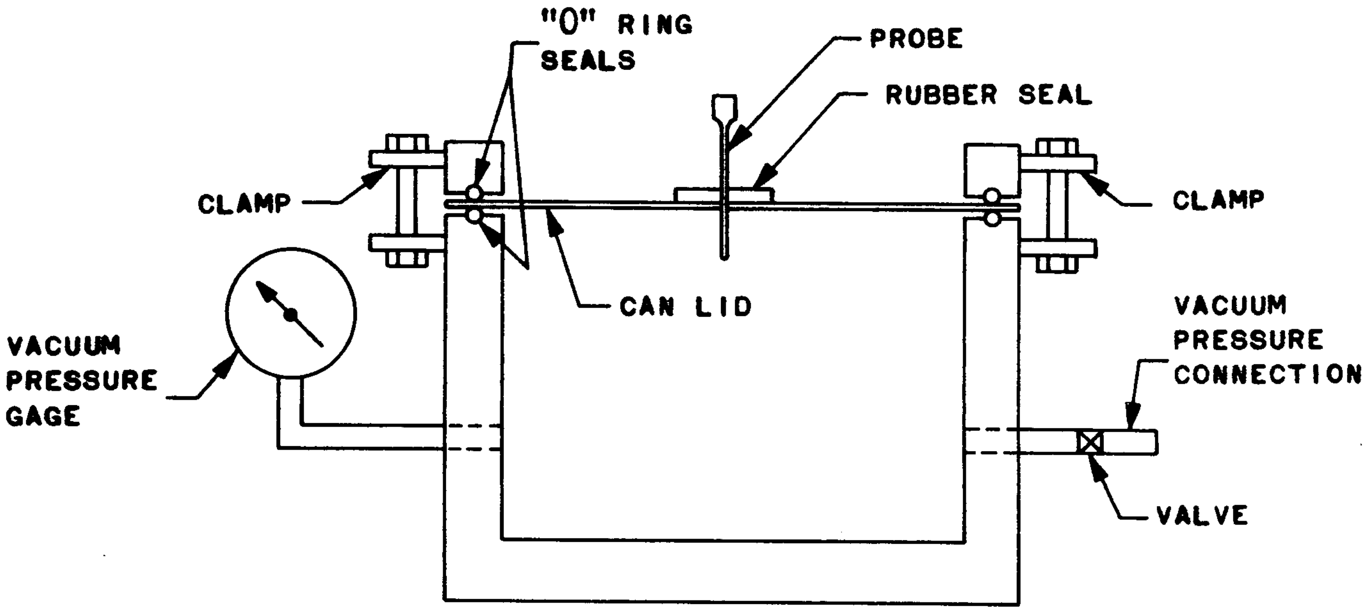


FIGURE III-1. CROSS SECTION OF TEST CHAMBER FOR CHECKING SEAL BETWEEN PROBE AND CAN LID.

c. <u>Error in probe due to axial heat flow</u>.

The thermocouple probes consist of stainless steel hypodermic tubing with insulated thermocouples inside. Since stainless steel is a better heat conductor than water or food materials, it was anticipated that axial heat conduction along the probe might cause error in the temperature measurements made with this probe. Tests were conducted to estimate the possible magnitude of this error.

A thermocouple probe consisting of a 20-ga stainless steel hypodermic needle was the basic probe tested. One probe contained a thermocouple 1/16 in. from the tip; this is the closest that a thermocouple can be located to the tip if the tip is made with a point of sufficient strength to penetrate the can lid. A second probe contained a thermocouple 1/2 in. from the tip. A similar probe was made using a 0.033 in. OD glass capillary tube having a thermal conductivity in the same range as that of water so that no appreciable axial heat conduction would occur in that part of the probe which is immersed in the water.

Temperature measurements were made with these probes in open-topped 401 x 105 aluminum cans containing water or petroleum jelly. The cans were heated on the bottom so that a linear steady state temperature gradient was established. One percent agar was added to the water to suppress convection. A 3 C/in. temperature gradient was established in the water. Petroleum jelly, a poorer heat conductor, was used to obtain a steeper temperature gradient of 6.5 C/in. Figure III-2 shows the results of a temperature measurement test in petroleum jelly.

Initial tests showed a very good correlation between temperatures measured by the glass probe and the stainless steel probes except within 1/8 in. to 3/16 in. of the top surface where in some cases even the glass probe tended to be cooled from 0.5 C to 1.5 C by the air above the heated medium.

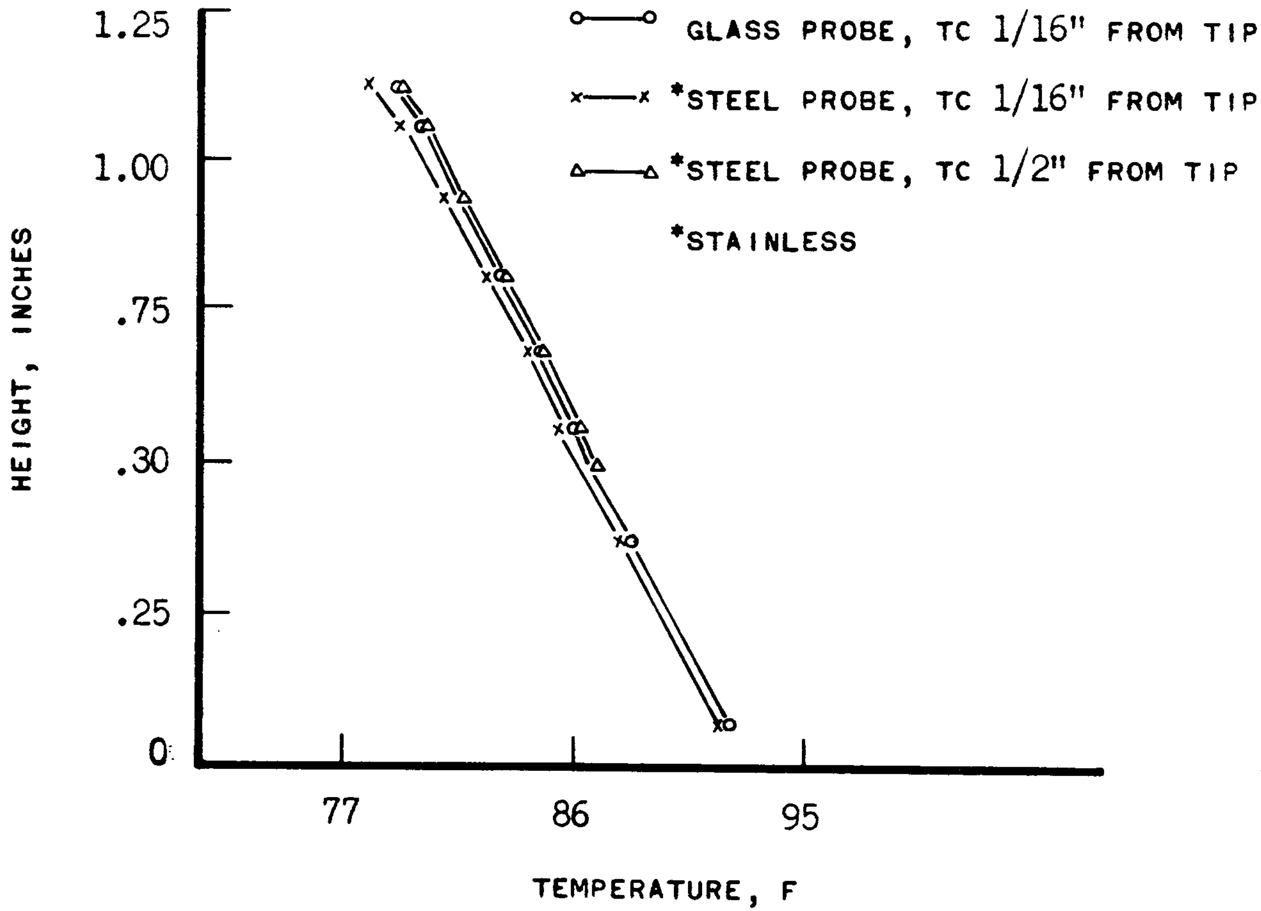


FIGURE III-2. TEMPERATURE MEASUREMENT WITH PROBES TO TEST AXIAL FLOW ERROR

Some of the differences in temperature may have resulted from inexact positioning of the thermocouples within the probes and inexact positioning of the probes in the cans. As shown in Figure III-2, a 1/16 in. error in thermocouple location would account for all of the temperature differences between the probes.

It was apparent from these tests that the error in temperature measurement due to axial heat flow in the probe was small. Probe construction techniques described below were designed to minimize this error.

d. Positioning thermocouples in probe.

A technique was devised which allowed for precise positioning of thermocouples within the probe and which compensated for any axial flow error.

A temperature gradient was established in a water-agar gel. The temperature gradient was accurately measured with the aid of a bare thermocouple junction supported by glass tubing to avoid axial conduction errors. This temperature gradient was plotted as in Figure III-3.

The hypodermic tubing was then placed in the gel with its tip resting on the bottom. A thermocouple which was continuously monitored was slid down inside the tubing until it indicated the temperature corresponding to the desired height as shown from the temperature plot in Figure III-3. Then Eastman 910 glue was poured into the tubing to fix the thermocouple at this location.

2. Recommended multipoint temperature recorder.

A Honeywell Electronic 16 multipoint temperature recorder was recommended. This item was not furnished by the contractor. The Electronic 16 recorder records up to 24 temperature points. The number of points recorded can easily be varied. The recommendation of this particular recorder does not imply that it is the only suitable recorder available.

IV. TEMPERATURE MEASUREMENT ANALYSIS

When heating cans of food in a 5 psia. atmosphere in space, there are two basic temperature restrictions. The maximum food temperature

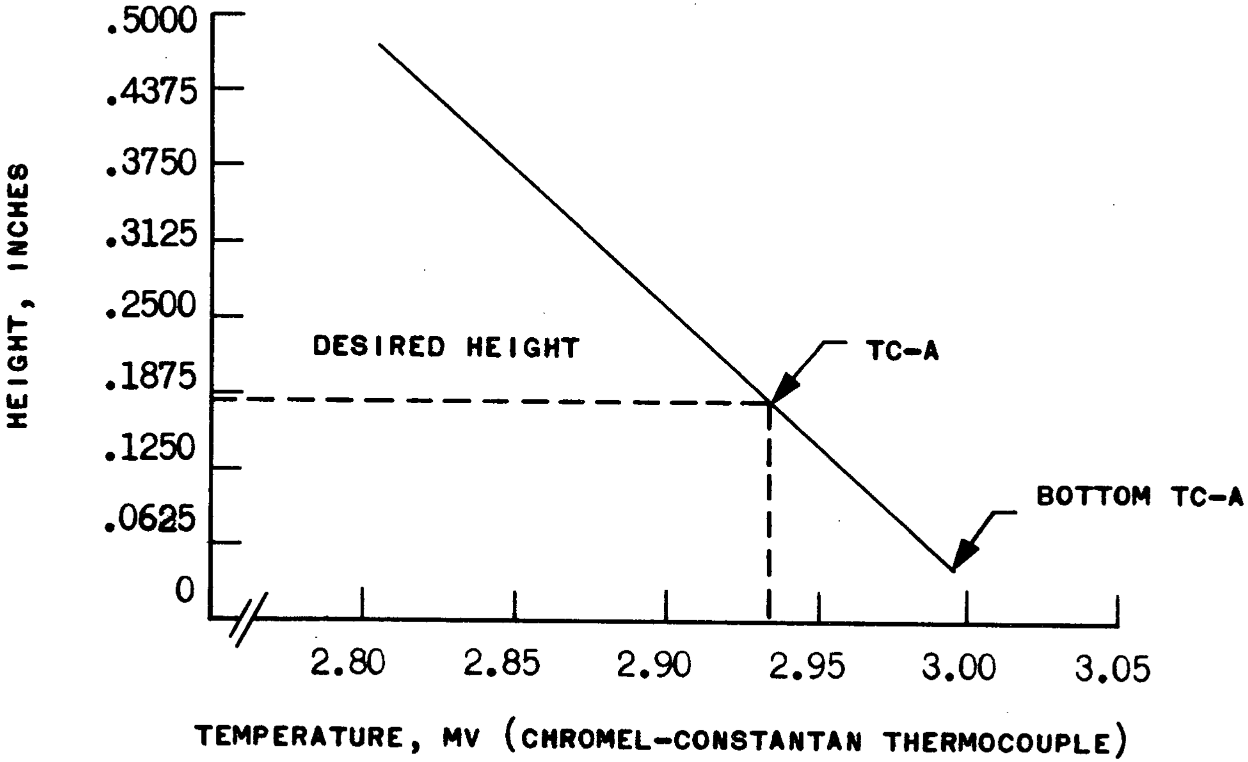


FIGURE III-3. POSITIONING THERMOCOUPLES IN PROBE DURING CONSTRUCTION must be less than the boiling point of the liquid in the food and the food must be hot enough for maximum acceptance. The maximum temperature used in this study was 159 F. This allows a margin of safety since the boiling point of water at 5 psia is about 162 F. The mass average temperature, which is defined as that temperature to which the food would equilibrate adiabatically, must be at least 149$\pm$6 F (SKYLAB food requirements) which keeps food above the pasteurization temperature (143 F) and gives a wide temperature variance for simplification of engineering design.

The maximum food temperature depends on the heater temperature and is located on the bottom food surface when the can is heated only from the bottom. Since the maximum temperature is confined to one plane, it would be simple to find the hottest point even if it varies with distance from the center of the can.

Determination of mass average temperature is more difficult since the temperature in the food will vary (1) with distance above the bottom surface, (2) with radius, and (3) with time of heating. It may be necessary to completely describe the temperature distribution in the food in order to calculate the mass average temperature.

Previous research with cooling of fruit has indicated that the temperature at a certain radius in the fruit was always the same as the mass average temperature of the entire fruit. Therefore it was hypothesized that there is one point in a 401 x 105 can of food which is always at the same temperature as the mass average temperature of all the food in the can.

A. Theoretical Analysis of Mass Average Temperature Measurement.

Theoretical analyses of heating with three different heater configurations under ideal conditions were made to provide information about the factors which influence mass average temperature. For the purpose of this analysis ideal heating conditions were assumed including constant thermal properties and homogeneity of the food and no convection. It was recognized that these assumptions are not always valid. Thermal properties of foods do vary with temperature and many foods are not homogeneous. Convection can occur in nonviscous foods; however, free convection cannot occur in space at zero gravity.

In spite of these limitations the ideal theoretical analysis will provide useful information concerning the measurement of mass average temperature.

A thermal diffusivity value for food of 0.73×10^{-4} ft.^{2}/min. was used except where otherwise noted. This is a typical value for meat.

1. Heating with bottom heater only.

The first heater configuration is heating from the bottom of the 401 x 105 can.

a. Analytical development.

Given an initial food temperature of 70 F and a heater temperature of 155 F, it is obvious that at any time after heating commences the mass average temperature of the food must be between 155 F and 70 F. And since it is impossible to have a discontinuity in the temperature profile from the bottom food surface to the top food surface, there will always be at least one point in the can which is at the same temperature as the mass average temperature of the entire can of food. It will be shown that, for ideal heating conditions described below, this point is stationary for all practical purposes and is not a function of heater temperature, initial food temperature, thermal properties of the food, or time (except for the early stages of heating when the mass average temperature is far below 135 F).

The analytical solution used is based on the physical situation shown in Figure IV-1 and the assumptions listed.

T_f - initial food temperature
k_f - thermal conductivity of food
C_{pf} - specific heat of food
ρ_f - density of food
T_s - bottom food surface temperature

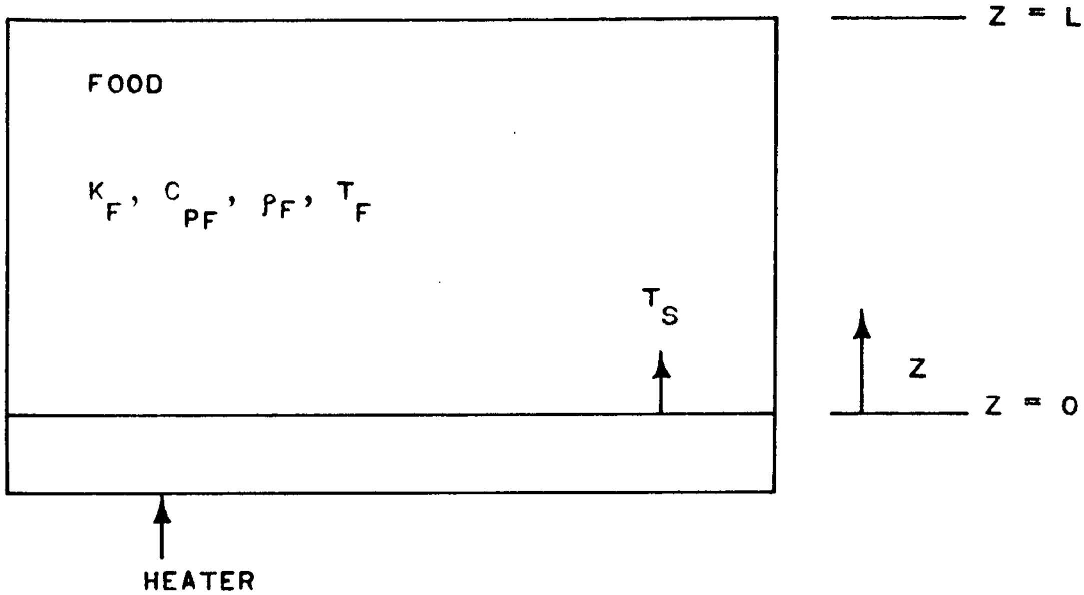


FIGURE IV-1. PHYSICAL SITUATION FOR THEORETICAL ANALYSIS

Assumptions:

1. T_f is uniform prior to heating
2. T_s is constant after heating is initiated.
3. The sides and top of the can are perfectly insulated.
4. Food properties are constant.

This is the same situation as an infinite flate plate initially at the temperature T_f, of thickness $H = 2L$, with both surfaces suddenly raised to T_s at time, $t = 0$. The heat conduction equation which describes the resultant heat transfer is:

$$\rho\, C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2} \text{ with boundary conditions} \tag{IV-1}$$

$$T(z = 0) = 0 \tag{IV-2}$$

$$T(t = 0) = T_f \tag{IV-3}$$

$$\frac{\partial T}{\partial z}(z = L) = 0 \tag{IV-4}$$

Its solution is

$$T = \frac{2T_f}{\pi} \sum_{n=1}^{\infty} \left(\frac{1 - \cos n\pi}{n}\right) \sin \frac{n\pi z}{H}\, e^{-\left(\frac{n\pi}{H}\right)^2 \alpha t} \tag{IV-5}$$

where $\alpha = \dfrac{k}{\rho C_p}$

and T is the temperature at location z at time t.

A digital computer program was used to calculate the mass average temperature of the food for various conditions. The food was "slided" into 50 layers of equal thickness. The temperature at the midpoint of each layer was calculated using equation (IV-5). The mass average temperature was calculated as the sum of all the temperatures of each layer divided by 50. The first 6 terms of equation 5 were used and only the first 2 terms contributed more than 0.01% of any temperature value. Typical temperature distributions are shown in Figure IV-2. The location of the mass average temperature is also shown.

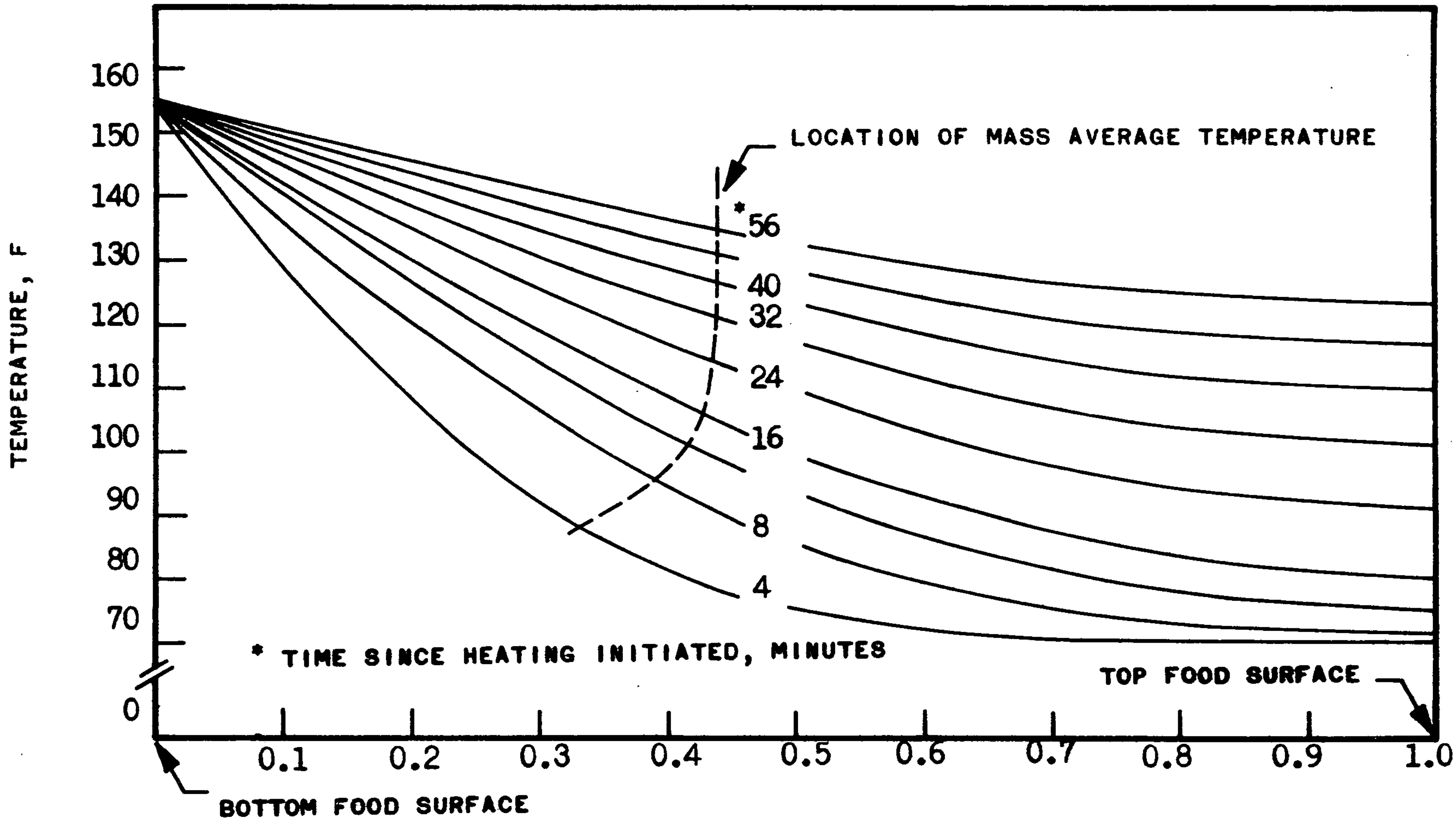


FIGURE IV-2. TEMPERATURE DISTRIBUTIONS IN CAN HEATED FROM BOTTOM ONLY

b. Results.

The effects of different variables on the mass average temperature will be discussed in succeeding paragraphs. Unless otherwise stated, L = 1.09 inches, which is equivalent to the 401 x 105 can completely filled.

Figure IV-3 shows the effect of heater temperature on the mass average temperature. Here heater temperature was defined as the temperature of the bottom surface of the food. Since a temperature drop between the heater and the bottom food surface is expected in the actual case, the effect of lower heater temperature or a temperature drop was studied. It can be seen that a temperature drop of 4 F increases heating time to a mass average temperature of 135 F by 15% and a temperature drop of 12 F increases heating time by 61%.

The effect of initial food temperature is shown in Figure IV-4. Changing the initial food temperature from 70 F to 32 F increased heating time by 30%.

It is apparent from Figure IV-5 that decreasing the total food depth decreases the required heating time.

Since different foods will be heated, the effect of the thermal diffusivity of the food was studied. Figure IV-6 shows its effect. Time is plotted on logarithmic scale since heating times were so long at low values of thermal diffusivity. An α of 1.05×10^{-4} ft^2/min was considered to be the maximum limit since that is the thermal diffusivity of pure water. A typical value for meat is 0.73×10^{-4} ft^2/min. The lower limiting value for foods would depend primarily on their moisture content or air content, with moisture enhancing diffusivity and air content decreasing it. A value below 0.5×10^{-4} ft^2/min would not normally be expected.

In Figure IV-2 it was apparent that the location of the point exhibiting the mass average temperature does depend on time during the first part of heating.

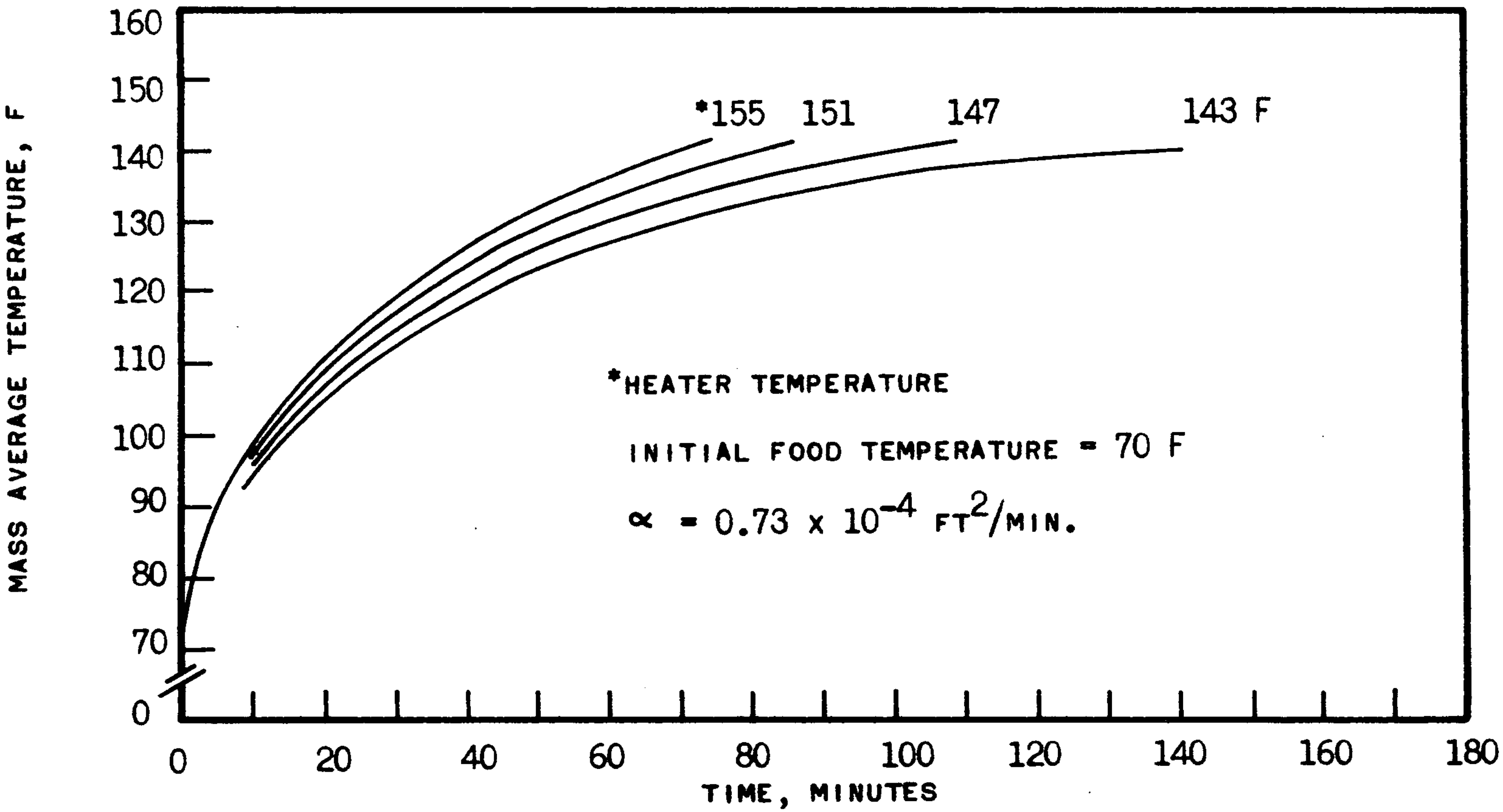


FIGURE IV-3. EFFECT OF HEATER TEMPERATURE ON MASS AVERAGE TEMPERATURE

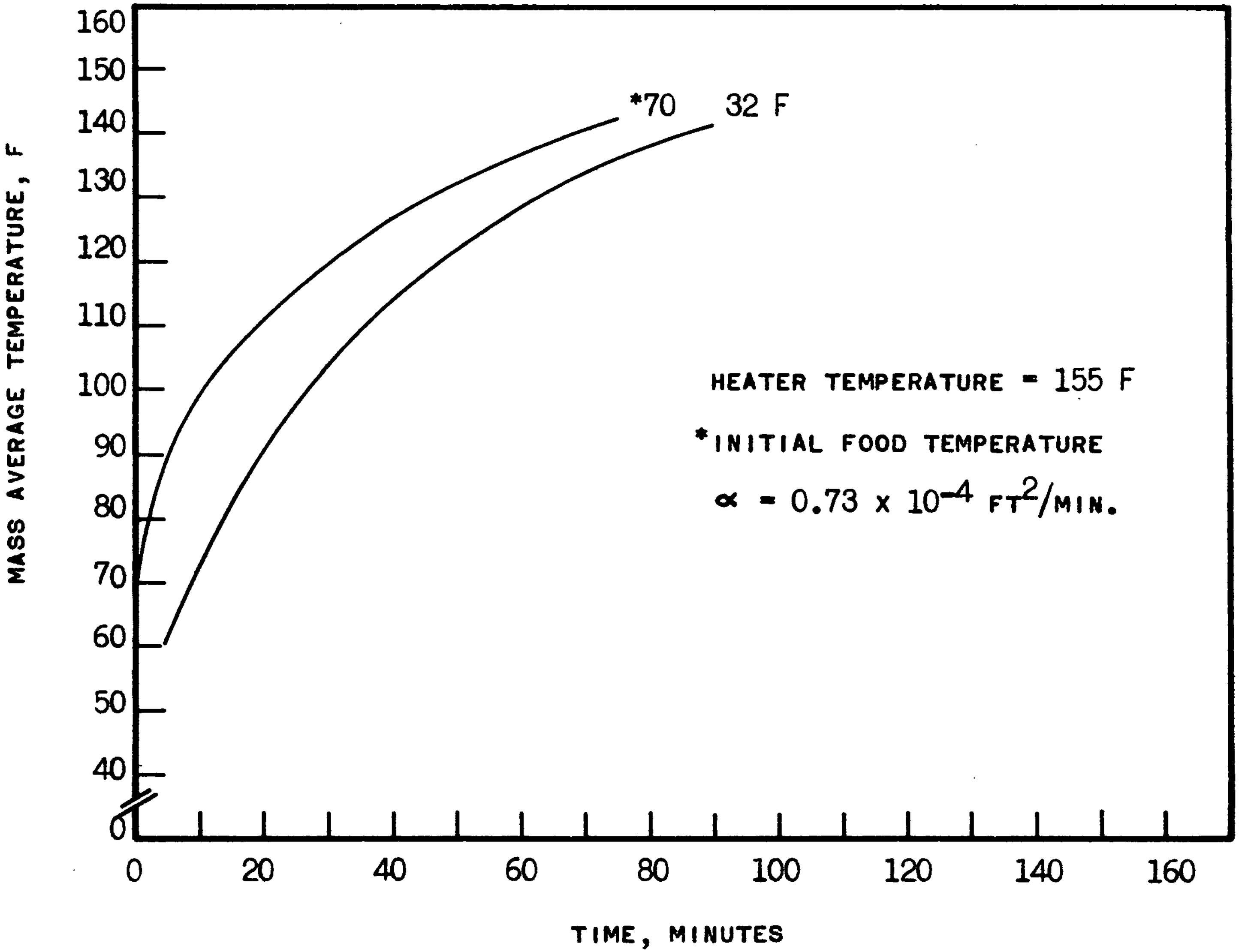


FIGURE IV-4. EFFECT OF INITIAL FOOD TEMPERATURE ON MASS AVERAGE TEMPERATURE

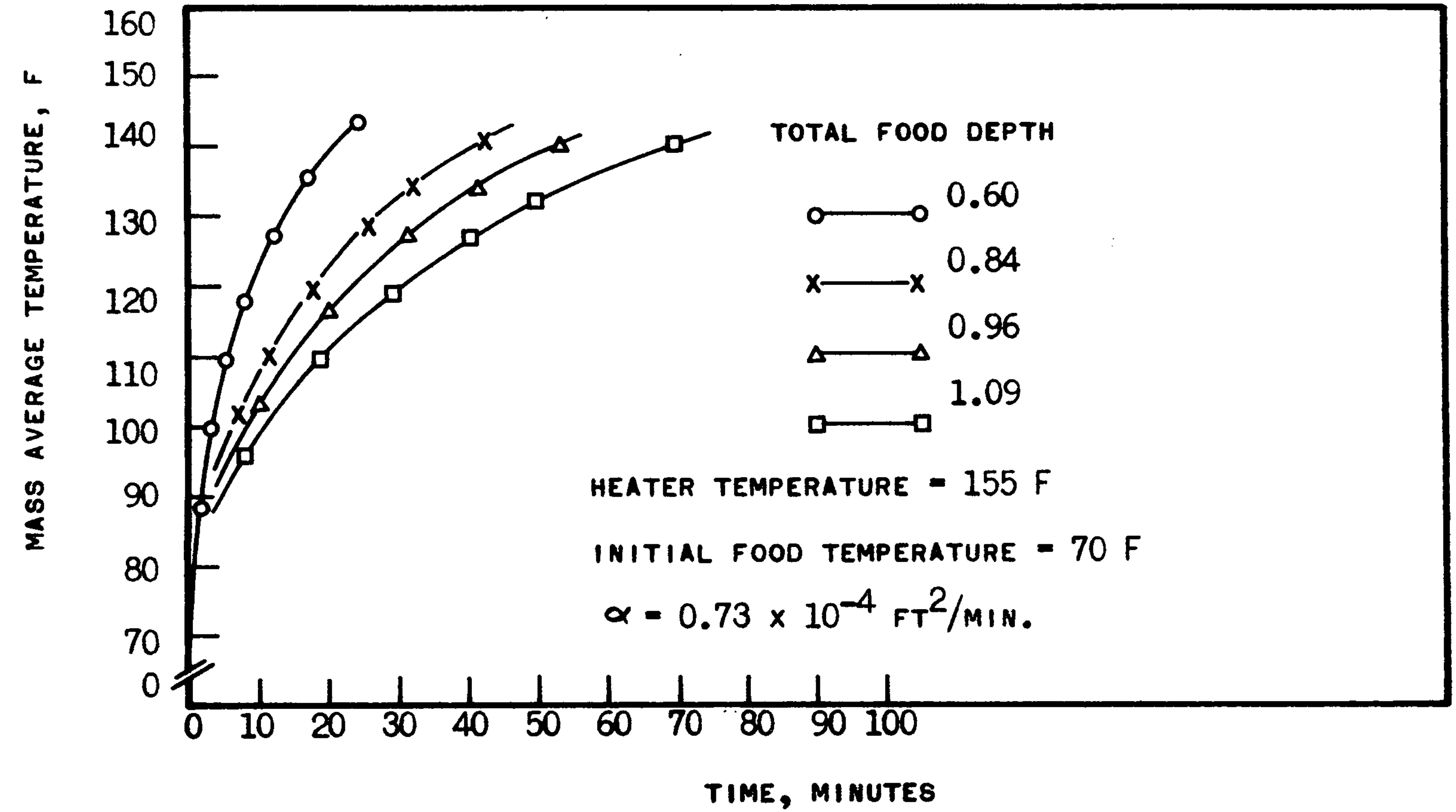


FIGURE IV-5. EFFECT OF TOTAL FOOD DEPTH ON MASS AVERAGE TEMPERATURE

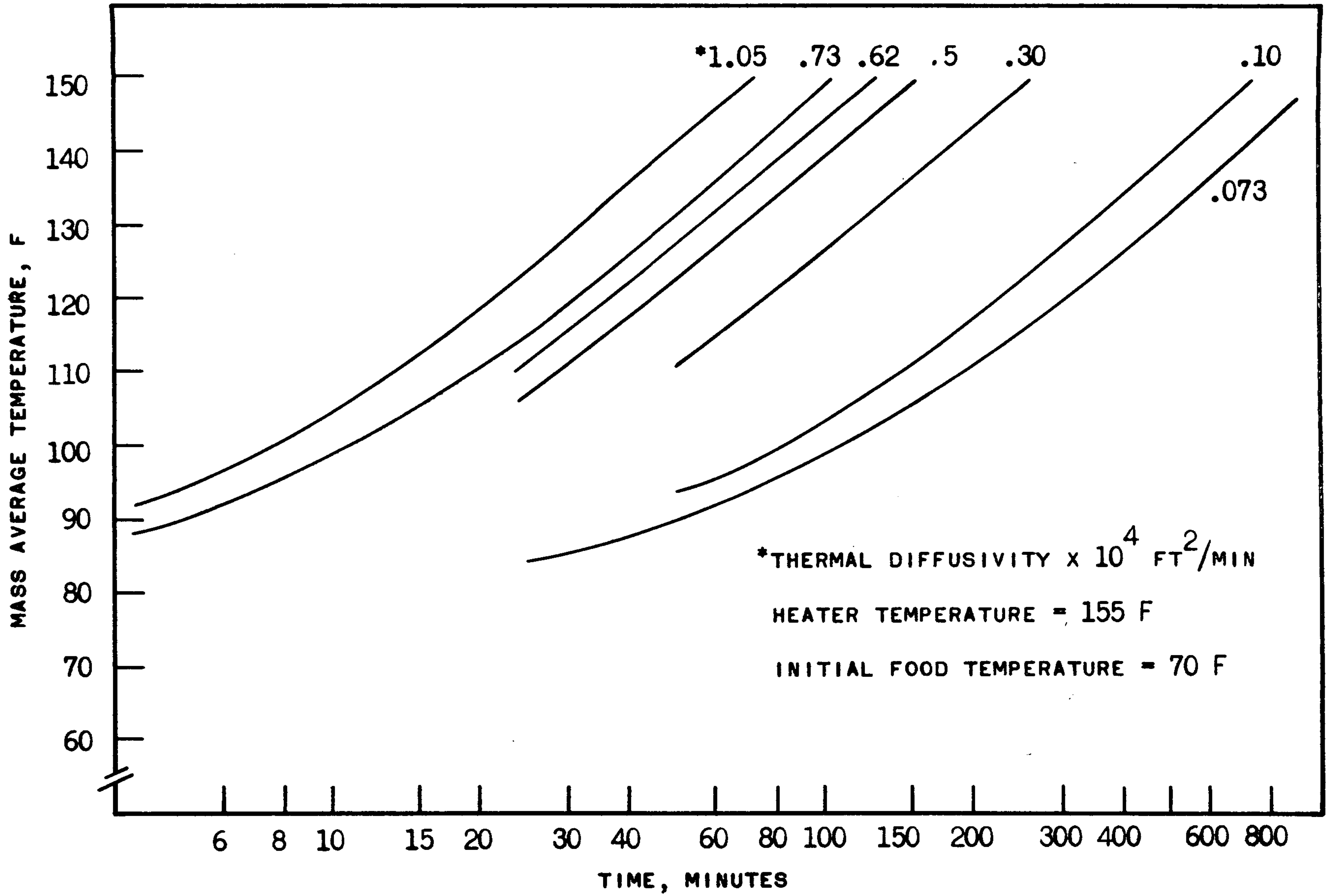


FIGURE IV-6. EFFECT OF THERMAL DIFFUSIVITY ON HEATING TIMES

Figure IV-7 shows the effect of time more clearly. The ordinate is the ratio of time to the total time required for the mass average temperature to reach 135 F. It can be seen that the location Z/L of mass average temperature approaches the value 0.44 asymptotically and has practically reached the value of 0.44 halfway through the heating time. The curve is the same for different values of thermal diffusivity.

Of particular interest is the location of the mass average temperature when it has the value of 135 F. Table IV-1 shows this location at different levels of the variables studied.

Table IV-1. Z/L for Mass Average Temperature of 135 F

Heater Temp., F	Initial Food Temp., F	ΔT	Thermal Diffusivity x 10^{-4}, ft^2/min	Total food depth, in.	Z/L
155	70	83	1.06	1.09	0.44
155	70	83	0.73	1.09	0.44
155	70	83	0.073	1.09	0.44
155	70	83	0.73	.96	0.44
155	70	83	0.73	.84	0.44
155	70	83	0.73	.60	0.44
143	70	83	0.73	1.09	0.44
155	70	83	0.73	1.09	0.44
143	32	111	0.73	1.09	0.44
155	32	123	0.73	1.09	0.44
143	-10	153	0.73	1.09	0.44
155	-10	165	0.73	1.09	0.44

It was concluded that for the ideal conditions assumed with bottom heating only, the mass average temperature can be measured with one thermocouple located at a height of 0.44 times total food depth.

Although the above conclusion is based on ideal conditions, it is expected that these results are applicable to the non-ideal case. Since the insulation on top of the can is not perfect, there will be heat losses through the top of the can. This may change the location of the mass average temperature from 0.44 to a greater or lesser value but the thermal diffusivity of the food, total food

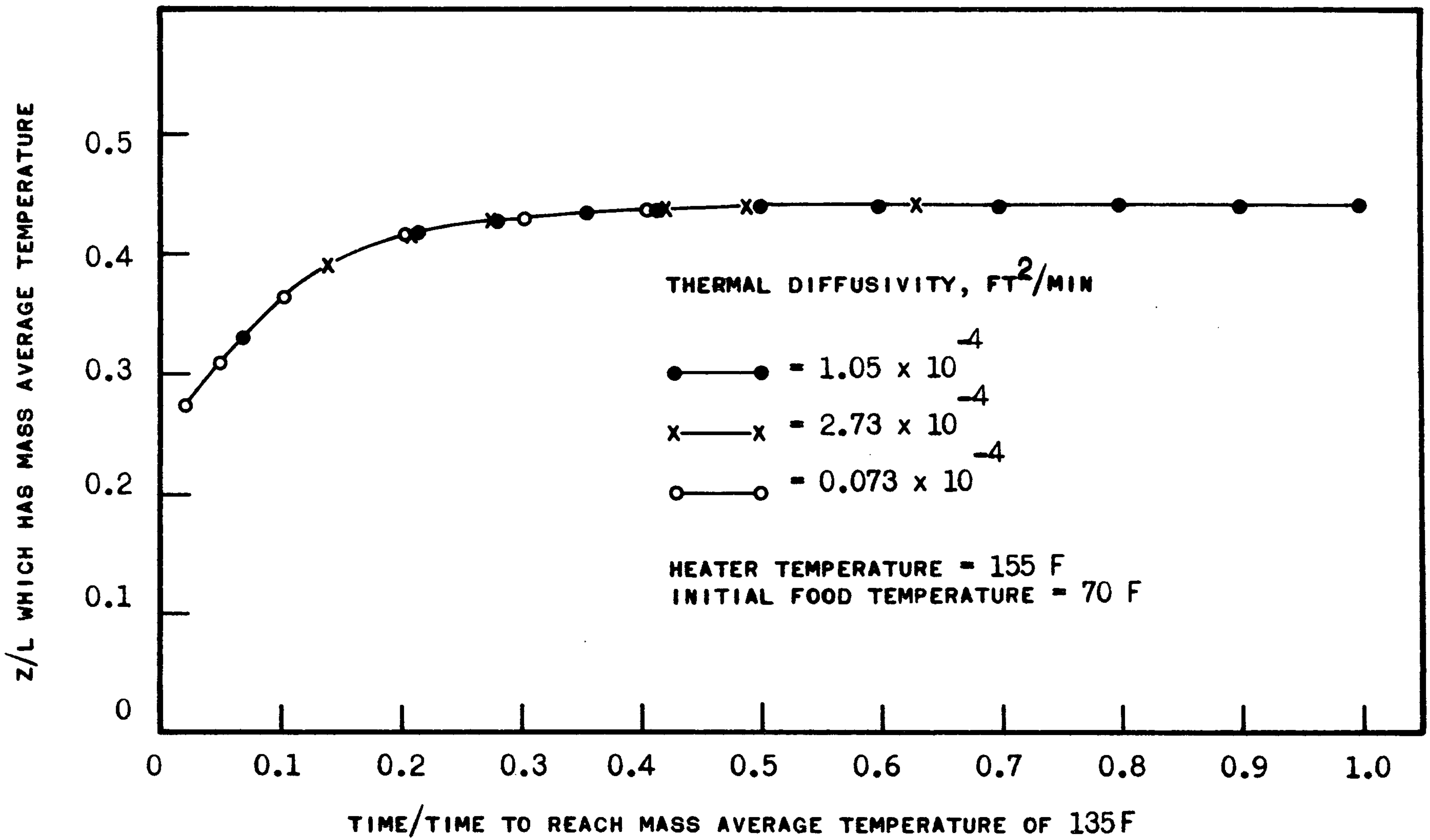


FIGURE IV-7. EFFECT OF TIME ON LOCATION OF MASS AVERAGE TEMPERATURE.

depth or difference between heater temperature and initial food temperature are not expected to affect the location of mass average temperature.

2. Heating with side heater only.

The model was a homogeneous finite cylinder perfectly insulated at both ends or an infinite cylinder which is heated from the radial direction only. Constant physical and thermal properties were assumed for the cylinder of food.as was done for the case with bottom heating only. The initial food temperature was assumed constant throughout the cylinder. The total volume was divided into twenty equal, concentric volumes. All combinations of four initial food temperatures (32 F, 50 F, 60 F, 70 F) and four surface temperatures (143 F, 147 F, 151 F, 155 F) were applied to calculate the temperature at the midpoint of the twenty divisions. The average temperature was calculated from the mean of the 20 temperatures and was shown to be equal to the theoretical average temperature.

The temperature distributions were plotted for 0 to 120 minutes in ten minute increments in Figures IV-8, IV-9, and IV-10. The graphs demonstrated that the average temperature could be measured at one point within the cylinder for time greater than and equal to 40 minutes. The point which is independent of initial food temperature and surface temperature, was 68.2% of the cylinder radius. For the 3.814 inch diameter can, it was at 1.300 inch from the center, concentric to the center.

a. <u>Analytical development</u>.

The heat conduction equation in cylindrical coordinates assuming constant properties is

$$\frac{\partial T}{\partial t} = k \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2}\right) \qquad \text{(IV-6)}$$

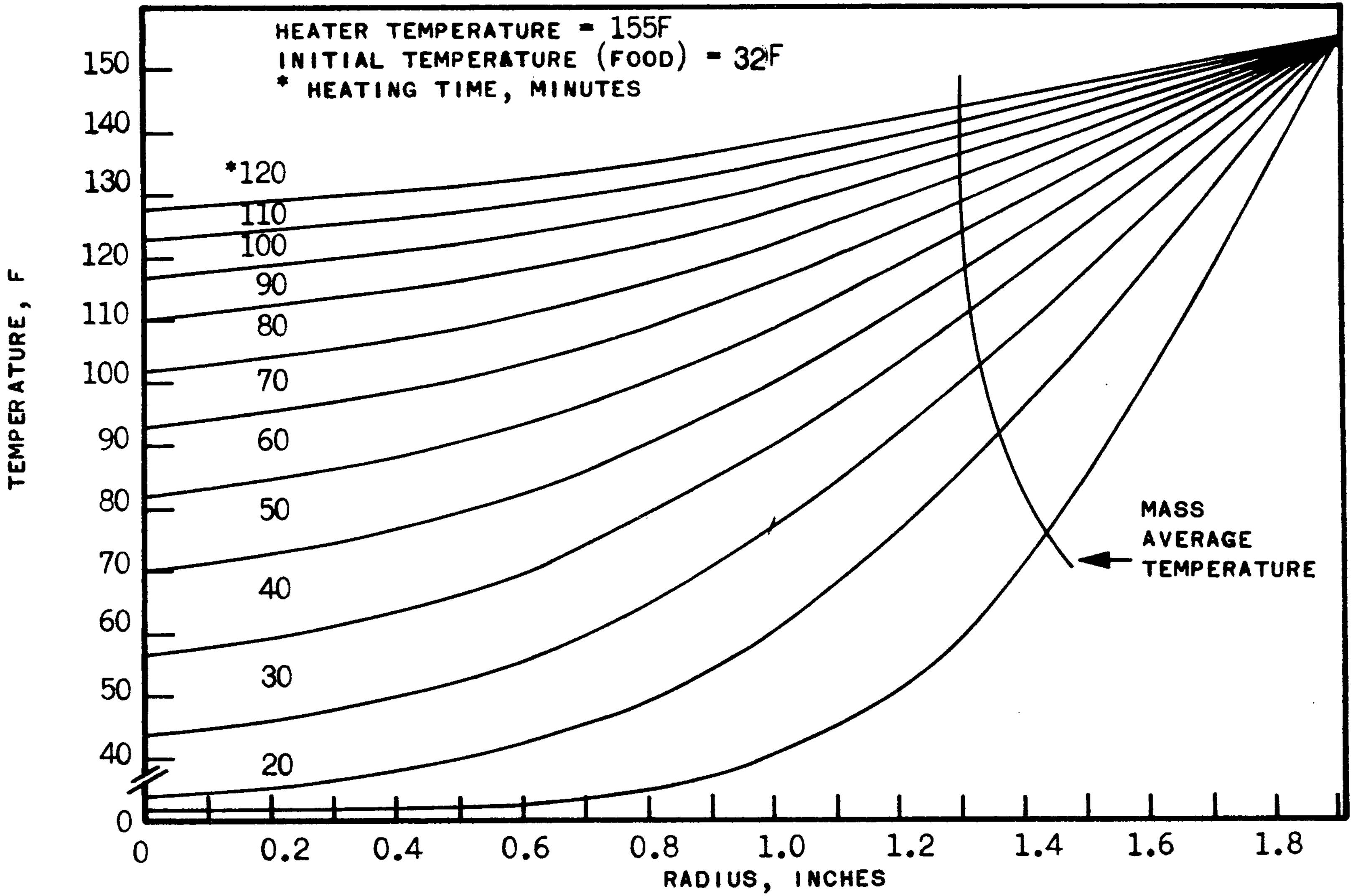


FIGURE IV-8. THEORETICAL TEMPERATURE DISTRIBUTIONS IN CAN HEATED FROM SIDES ONLY

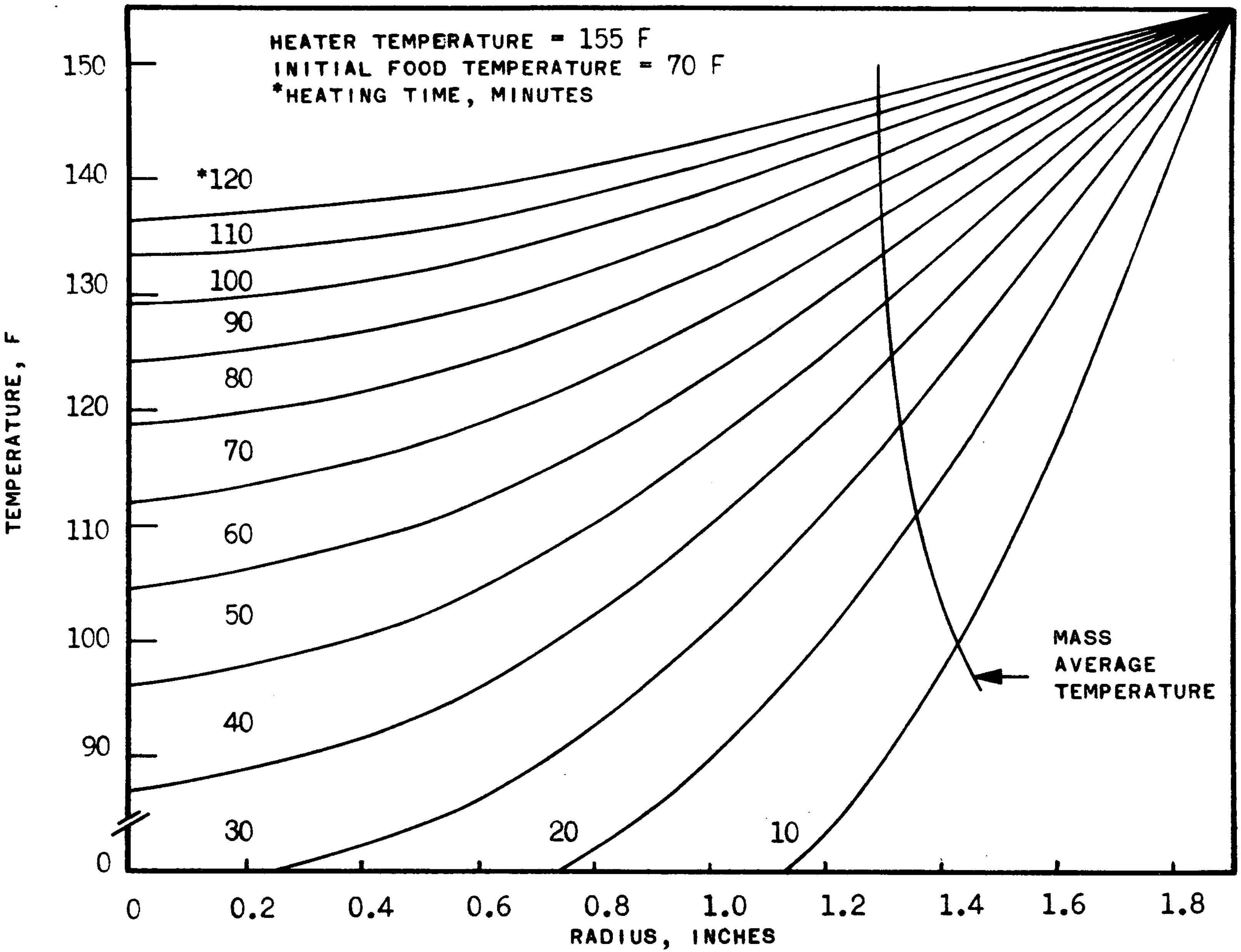


FIGURE IV-9. THEORETICAL TEMPERATURE DISTRIBUTIONS IN CAN HEATED FROM SIDES ONLY

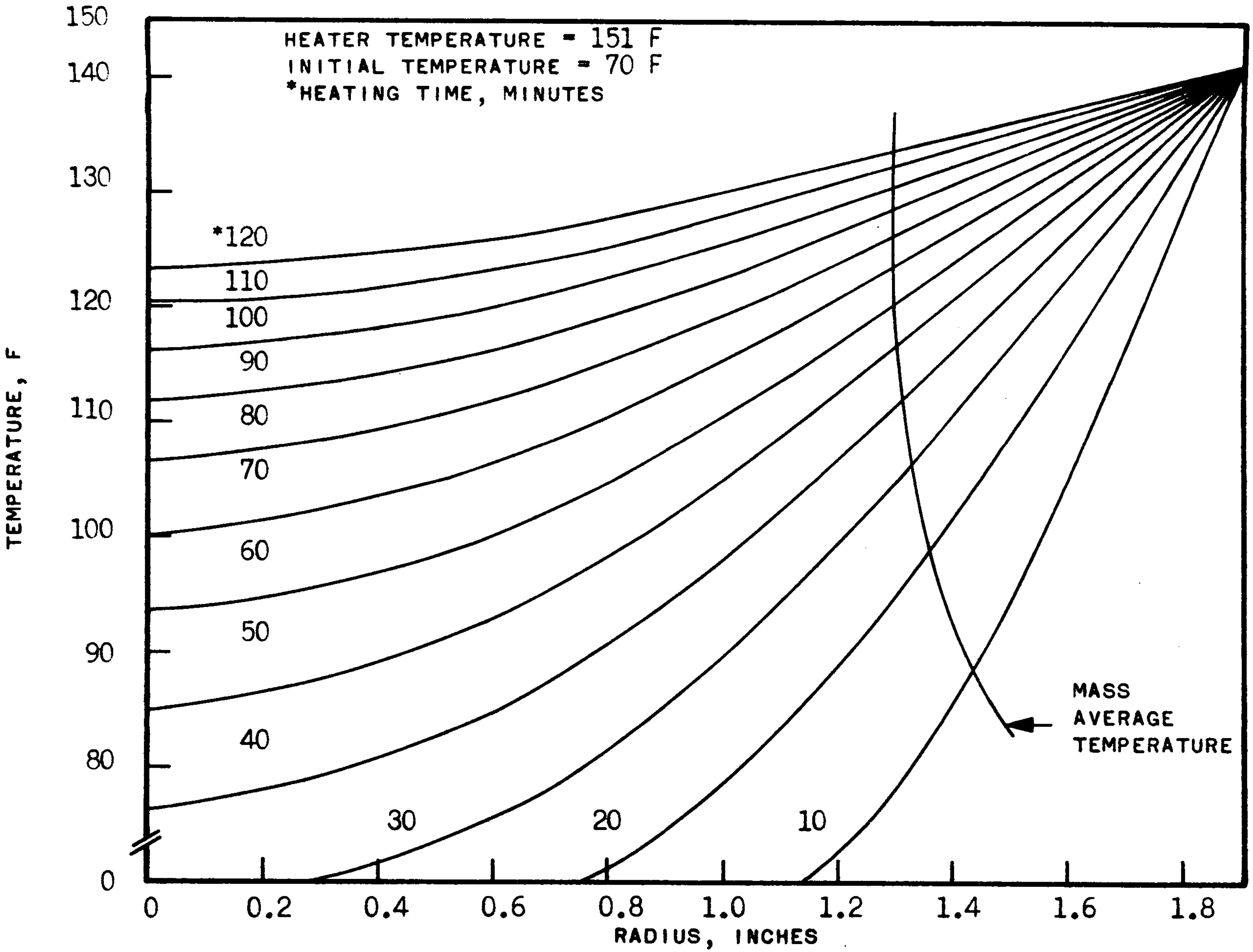


FIGURE IV-10. THEORETICAL TEMPERATURE DISTRIBUTIONS IN CAN HEATED FROM SIDES ONLY

Assuming no heat flow in the z direction and the temperature distribution is symmetrical about the center, this reduces to

$$\frac{\partial T}{\partial t} = k \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) \qquad \text{(IV-7)}$$

Let the initial temperature be given by $T = f(r)$ and the surface temperature equal a constant, zero

the Initial condition is $T = f(r)$ at $t \leq 0$

the Boundary condition is $T = 0$ at $r = a$ (IV-8)

for a cylinder $0 \leq r \leq a$

Assuming a solution of the form

$$T(r, t) = \exp(-k\,\alpha^2\, t)\, u(r) \qquad \text{(IV-9)}$$

and substituting equation IV-9 into equation IV-7, equation IV-10 is obtained.

$$\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} + \alpha^2 u\right) = 0 \qquad \text{(IV-10)}$$

This is Bessel's equation of order zero.

The solution to the partial differential equation takes the form

$$T(r, t) = A\, J_o(\alpha r) \exp(-k\,\alpha^2\, t) \qquad \text{(IV-11)}$$

where $J_o(x)$ is the Bessel Function of order zero of the first kind.

To satisfy the boundary condition, x must be the root of

$$J_o(\alpha a) = 0 \qquad \text{(IV-12)}$$

It is known that equation IV-12 has no complex roots or repeated roots and that it has an infinite number of real positive roots.

If $f(r)$, the initial temperature distribution, can be expanded in the series

$$f(r) = A_1 J_o(\alpha_1 r) + A_2 J_o(\alpha_2 r) + \ldots\ldots\ldots \qquad \text{(IV-13)}$$

The conditions of the problem will be satisfied by

$$T(r, t) = \sum_{n=1}^{\infty} A_n J_o(\alpha_n r) \exp(-k\,\alpha_n^2\, t) \qquad \text{(IV-14)}$$

For the case of constant initial temperature,

$$f(r) = V \tag{IV-15}$$

A_n simplifies to the following expression:

$$A_n = \frac{1}{a\alpha_n J_1(a\alpha_n)} \tag{IV-16}$$

The temperature function is

$$T(r_1 t) = \frac{2V}{a} \sum_{n=1}^{\infty} \exp(-k\alpha_n^2 t) \frac{J_o(r\alpha_n)}{\alpha_n J_1(a\alpha_n)} \tag{IV-17}$$

For the cylinder whose initial temperature is zero with its surface maintained at a constant, V

$$T(r_1 t) = V - \frac{2V}{a} \sum_{n=1}^{\infty} \exp(-k\alpha_n^2 t) \frac{J_o(r\alpha_n)}{\alpha_n J_1(a\alpha_n)} \tag{IV-18}$$

For the computer program, dimensionless variables were used:

$$a\alpha_n = \beta_n \text{ and } \frac{Kt}{\alpha^2} = M \tag{IV-19}$$

The temperature distribution becomes

$$\frac{T}{V} = 1 - 2 \sum_{n=1}^{\infty} \exp(-\beta_n^2 M) \frac{J_o(r\beta_n/a)}{\beta_n J_1(\beta_n)} \tag{IV-20}$$

where β_n, n=1, 2, 3, ... are the roots of

$$J_o(\beta) = 0 \tag{IV-21}$$

b. <u>Program development</u>.

Bessel's functions of the first kind of index n are given by

$$Jn(X) = \sum_{j=0}^{\infty} \frac{(-1)^j}{j!\Gamma(n+j+1)} \left(\frac{X}{2}\right) n+2j \tag{IV-22}$$

the zero order Bessel function is

$$J_o(x) = \sum_{j=0}^{\infty} \frac{(-1)^j}{j!\Gamma(j+1)} \left(\frac{X}{2}\right) 2j \tag{IV-23}$$

$$= 1 + \sum_{j=1}^{\infty} \frac{(-1)^{2j}}{j!\Gamma(j+1)} (\frac{X}{2}) \ (2j) \qquad \text{(IV-24)}$$

the first order Bessel function is

$$J \ (x) = \sum_{j=0}^{\infty} \frac{(-1)^{j}}{j!\Gamma(j+2)} (\frac{X}{2}) \ 1+2j \qquad \text{(IV-25)}$$

$$= \frac{X}{2} + \sum_{j=1}^{\infty} \frac{(-1)^{j}}{j!\Gamma(j+2)} (\frac{X}{2}) \ 1+2j \qquad \text{(IV-26)}$$

$$\Gamma(n) = e^{-t}t^{n-1}dt \qquad \text{(IV-27)}$$

$$\Gamma(n+1) = n! \ (n = 1, 2, 3, ...) \qquad \text{(IV-28)}$$

Equation (IV-24) was utilized for the computer subroutine to calculate the zero order Bessel Function. And Equation (IV-27) was used for the first order Bessel Function subroutine.

The gamma function was calculated using the system library routine RGAMMA - C3. For all terms of the Bessel Functions the gamma function was determined by equation (IV-28).

The Bessel Function subroutines were verified by two procedures. First, the roots of the function were used to prove that the alogarithim would calculate zero. Second, a table of function values for the argument from zero to nine was calculated and checked against a known source.

The first test was done only on the zero order Bessel Function using its first six roots. The subroutine calculated the first twenty terms of the series. The subroutine did obtain zero to four decimal places for the first three terms. For the final three roots, twenty terms of the series was insufficient to calculate zero. The program demonstrated that the magnitude of the argument is directly related to the number of terms in the series. For accuracy, the number of terms required is approximately twice the argument.

For the second test, the zero order and first order Bessel Functions were calculated with the arguments ranging from 0.00 to 8.99 in increments of 0.01.. The information was printed in tabular form and compared to Table I from The Theory of Bessel Functions by Watson (1948). The computer generated table was in exact agreement with Table I for the argument from 0.00 to 8.99.

The main Fortran program was developed around the dimensionless variable equation (IV-20). The individual independent parts of the equation were calculated and secondly combined to reduce the number of repetitious calculations. The program utilizes the first six roots of the zero order Bessel Function, twenty-position terms, and twenty-four time terms.

c. Results.

The transient temperatures for the twenty, equal-volume subdivisions were calculated by equation (IV-20). The transient temperatures are plotted in Figures IV-8, IV-9 and IV-10. The average temperature curve shows that the mass average temperature can be measured at one distinct point for each heating curve and time less than forty minutes. For time greater than or equal to forty minutes ($t \geq 40$ min.), the single point is located at 68.2% of the cylinder radius. For the 3.814 inch diameter can, the point would be at a radius of 1.30 inch from the center and concentric to the center.

The average temperature was calculated by first taking the mean of the twenty subdivision temperatures. Secondly, the average was calculated by the theoretical equation. The theoretical equation for the average temperature comes from the integration of the temperature multiplied by the area and the result divided by the total cross-sectional area.

$$T_{averg} = V \left[1 - \frac{2}{a^2} \int_0^{\alpha} r\, T\, d\, r \right] \qquad \text{(IV-29)}$$

$$= V \left[1 - \frac{4}{a^2} \sum_{n=1}^{\infty} \frac{1}{\alpha_n^2} \exp(-k\, \alpha_n^2\, t)\right] \qquad \text{(IV-30)}$$

In dimensionless variables this becomes:

$$T_{averg} = V\ [1 - 4 \sum_{n=1}^{\infty} \frac{1}{\beta_n^2} \ \exp\ (-\beta_n^2\ M)] \qquad \text{(IV-31)}$$

with β_n and T defined in equation (IV-19). The results show that the mean of twenty temperatures differs from the theoretical average by no more than two tenths (0.2) of a degree.

d. Limitations of the procedure.

The main program was tested by determining the temperature for the twenty points for times starting at one minute to sixty minutes in increments of one minute. The data showed that the program was accurate only for time greater than or equal to seven minutes ($t \geq$ min.). The limitation is due to using only the first six terms in the series of equation IV-20. The six terms are directly related to the first six roots of the zero order Bessel Function. For increased accuracy at smaller time values, more roots of the zero order Bessel Function which increases the number of terms in the series of equation (IV-20) are needed. By adding more terms, the number of computer calculations increases rapidly. The added zero order Bessel Function roots are larger number, which increases the number of terms needed in both Bessel Function subroutines and increases the number of terms used in calculating the transient temperature.

Five minutes was the smallest time used for the radial heating study. The calculated temperature oscillates slightly at the three inner cylinder subdivisions. For the graphs the oscillations were smoothed for the five minute heating curve.

e. Summary.

For a finite cylinder, perfectly insulated at both ends and heated only from the radial side, the mass average temperature can be measured at a single point. The point, which is independent of initial food temperature and heater temperature, is a distance of 68.2% of the radius from the center and concentric to the center. For the 3.814 inch diameter can the point was 1.30 inch from the center.

The average temperature calculated from the mean of the twenty subdivision temperatures was within two-tenths of a degree of the theoretically determined average temperature.

3. Heating with bottom and side heaters simultaneously.

Combining the heating from the bottom and sides represents a three dimensional study. The conditions assumed were: constant physical and thermal properties; constant initial temperature; a constant surface temperature along the sides and bottom; and a perfectly insulated top.

An analytical model of heat transfer radially and axially into a finite cylinder was developed. The cylinder of food was assumed to be a homogeneous, isotropic material. Initially the food was at a constant, uniform temperature and the top of the can was perfectly insulated. At some time, $t = 0$, the bottom and sides of the can were instantaneously raised to a constant heater temperature.

a. <u>Analytical development</u>.

The initial food temperature is called T_f and the heater temperature is T_s, and T is the food temperature during heating. The temperature is defined as θ where

$$\theta = T - T_f \qquad \text{(IV-32)}$$

Because the can is axially symmetric, the temperature varies only with the radius and the depth.

The energy equation takes the form

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \theta}{\partial r}\right) + \frac{\partial^2 \theta}{\partial z^2} = \frac{1}{\alpha}\frac{\partial \theta}{\partial t} \qquad \text{(IV-33)}$$

The can has a radius $r = a$ and a depth $Z = L$ and the thermal diffusivity of the food in the can is α. The sides and bottom are raised to the heater temperature at time, $t > 0$. See figure IV-11.

Mathematically, the assumed conditions take the following form:

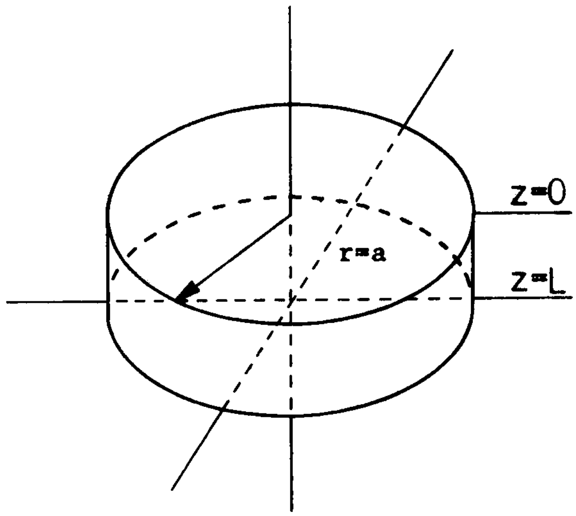


FIGURE IV-11. PHYSICAL SITUATION FOR CAN HEATED FROM BOTTOM AND SIDES.

(1) Constant initial temperature

for every r and Z $\theta = 0 \quad t \leq 0$ (IV-34)

(2) Perfectly insulated top

at $Z = 0 \quad \frac{\partial \theta}{\partial Z} = 0 \quad t > 0$ (IV-35)

(3) When the sides and bottom are raised to heater temperature

at $r = a \qquad \theta = (T_s - T_f) \quad t > 0$ (IV-36)

at $Z = L \qquad \theta = (T_s - T_f) \quad t > 0$ (IV-37)

(4) And for mathematical continuity

at $r = 0 \quad \frac{\partial \theta}{\partial r} = 0 \quad t > 0$ (IV-38)

The solution to the partial differential equation (IV-33) satisfying the above conditions is as follows:

$$\theta = (T_s - T_f) \left[1 - \frac{8}{\pi} \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} \frac{(-1)^m J_o(\frac{r\beta_n}{a})}{(2m+1)\, \beta_n\, J_1\, (\beta_n)} \cos\left(\frac{(2m+1)\, \pi Z}{2L}\right) \exp\left(- t \left[\frac{\beta_n^2}{a^2} + \frac{(2m+1)^2\, \pi^2}{4L^2}\right]\right) \right] \qquad \text{(IV-39)}$$

the β_n are the roots of

$$J_o\,(\beta) = 0 \qquad \text{(IV-40)}$$

The mass average temperature is developed from the integration of θ over the volume of the can.

$$\text{Mass Ave. } \theta = T_s - T_f \left[1 - \frac{2}{a^2 L} \int_o^L \int_o^a (\theta r)\, dr\, dZ\right] \qquad \text{(IV-41)}$$

$$\text{where } \theta = \frac{8}{\pi} \left[\sum_{m=0}^{\infty} \sum_{n=1}^{\infty} \frac{(-1)^m J_o\,(\frac{r\beta_n}{a})}{(2m+1)\, \beta_n\, J_1\, (\beta_n)} \cos\left(\frac{(2n+1)\, \pi Z}{2L}\right) \exp\left(- t \left[\frac{\beta_n^2}{a^2} + \frac{(2m+1)^2\, \pi^2}{4L^2} \right]\right) \right] \qquad \text{(IV-42)}$$

b. Results and discussion.

The digital computer was utilized to handle the complex mathematical equations. First the computer was used to determine the time for the food to reach a specified mass average temperature. The mass average temperature is defined as the temperature the food would equilibrate to if the heating stopped and the can was perfectly insulated. From the results listed in Table IV-2, the combination of side and bottom heating took 50% less time than the separate bottom or side heating to attain the same mass average temperature.

Second, the position of the points whose temperature is equivalent to the mass average temperature, was determined. For the bottom heating only, the mass average temperature is measured in a plane which is 44.0% of the depth from the bottom and parallel to the bottom. With radial heating only, the mass average temperature is located at 68.2% of the radius from the center and concentric to the center. In the combined heating case, the mass average temperature is located on a parabolic surface. The surfaces are sketched in Figure IV-12 for the mass average temperatures: 135, 140, 145 F.

The position or isothermal surface used for determining the mass average temperature is no longer simple. The surfaces obtained in the bottom heating or side heating cases were simple geometrically because the problem could be reduced to a one dimensional model. In the combined heating, the model has to be three dimensional. Therefore, the mathematics and physical perspective becomes more complicated.

Table IV-2. Heating Times for Bottom, Side and Combined Heating

Mass Ave. Temp.	Time Required		
	S+B	B	S
135 F	23.1 min	57 min	66 min
140 F	30.1	70	82
145 F.	39.9	------	106

S = Side Heating
B = Bottom Heating
S+B = Simultaneous Side and Bottom Heating

T_f = 70 F $\quad$ T_s = 155 F $\quad$ $\alpha = 0.73 \times 10^{-4}\ ft^2/min$

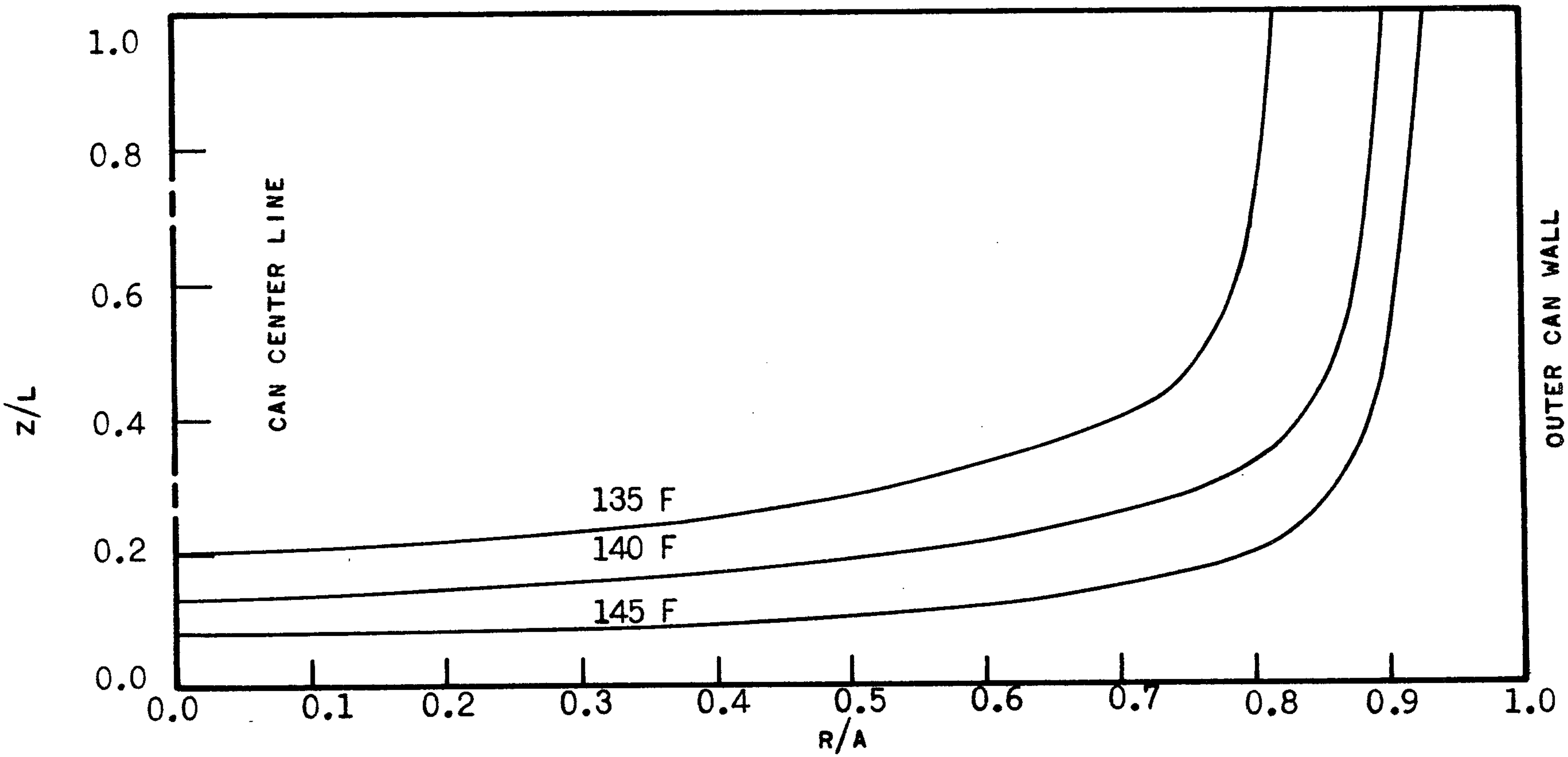


FIGURE IV-12. LOCATION OF SURFACES AT MASS AVERAGE TEMPERATURE

The mass average temperature can be calculated from the temperature at a point which is easily identified. A convenient point is the center of the can.

The graph in Figure IV-13 shows how the temperature at the center of the can is related to the mass average temperature at any time.

Dimensionless τ is the thermal diffusivity multiplied by time and divided by the depth of the food squared. θ is the measured temperature minus the initial temperature. The mass average θ is the mass average temperature minus the initial temperature.

An example calculation is as follows:

initial food temp = 70 F

heater temp = 155 F

center thermocouple = 119.7 F

time since the beginning of heating = 30 min

$$\text{Calculate } \tau = \frac{\alpha t}{L^2} = \frac{(0.0105)(30)}{(1.090)^2} = 0.265$$

Go to Figure IV-13 and set $\tau = 0.265$

$$\frac{\theta}{\text{Mass ave } \theta} = 0.71$$

$$\theta = T - T_o = 119.7 - 70 = 49.7$$

$$\text{Mass Ave } \theta = \frac{49.7}{0.71} = 70$$

$$\text{Mass Ave temp} = \text{Mass Ave } \theta + T_o$$

$$= 70 + 70$$

$$= 140 \text{ F}$$

Therefore, one thermocouple positioned at a convenient location is used to determine the mass average temperature versus positioning a thermocouple on the correct isothermal surface.

The combination of bottom and side heating reduced by more than 50% the time required to reach a specified mass average temperature. The mass average temperature of 135 F was attained in 231. minutes; 140 F in 30.1 minutes; and 145 F in 39.9 minutes.

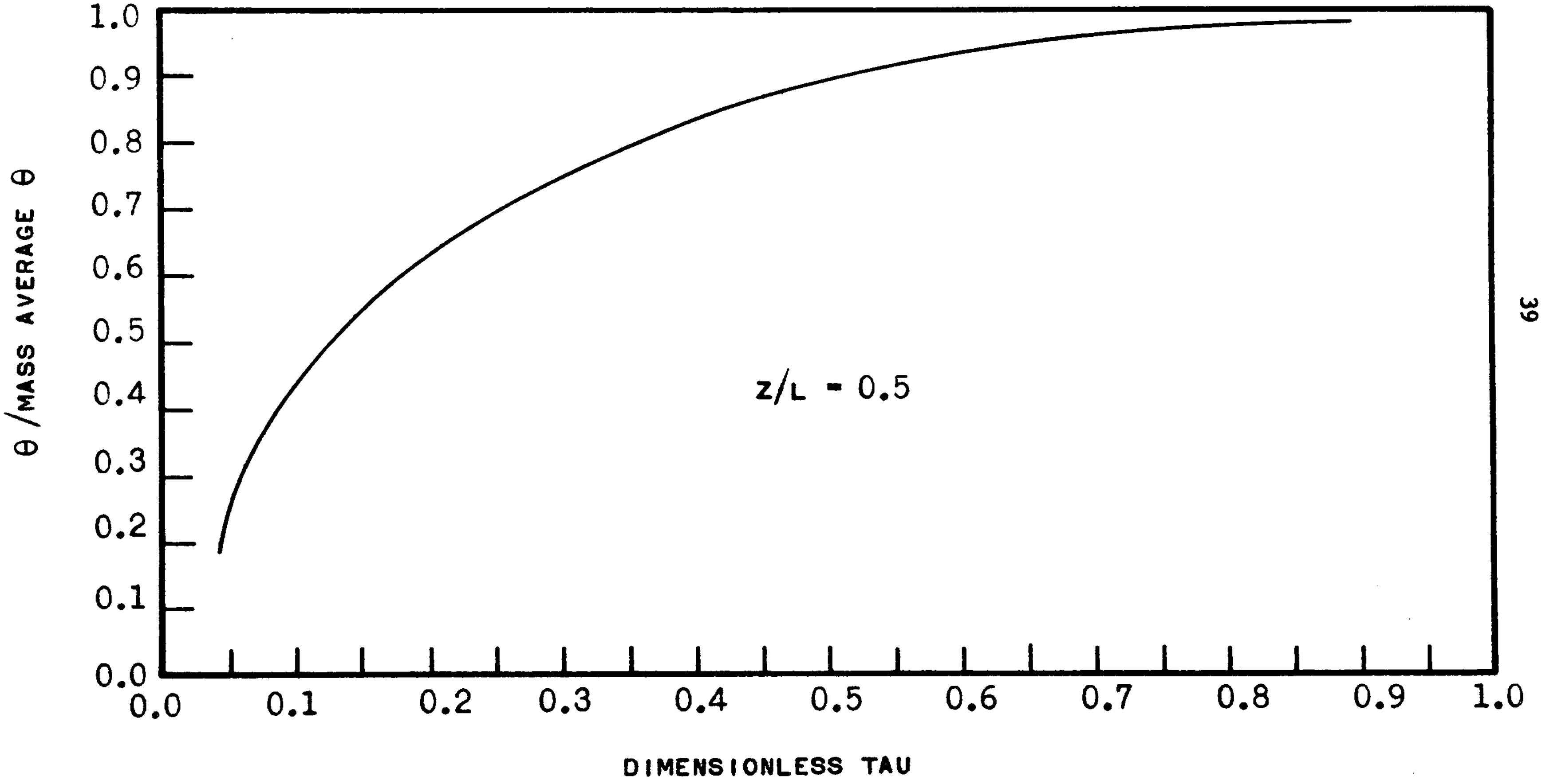


FIGURE IV-13. CORRELATION BETWEEN MASS AVERAGE TEMPERATURE AND ARBITRARILY MEASURED TEMPERATURE

4. Limitations of theoretical analyses.

The results of the theoretical analyses are limited because of the ideal conditions which were made to simplify the mathematical models.

a. Non-ideal insulation.

In reality the top surface of the can will not be perfectly insulated and some heat will be lost through this surface. The assumption of perfect insulation would tend to reduce the predicted heating times.

b. Variation in heater temperature.

Rather than having a constant, uniform heater temperature, the heater temperature increases at a finite rate after heating starts until it reaches the desired temperature. In subsequent heating tests this time varied from 15 to 50 seconds. In actuality there are also temperature variations across the heater surface due to imperfect heater construction and variations in insulation. In addition, there is a temperature drop between the heater surface and the food surface next to the can due to impeffect contact between the heater and the can. This would tend to decrease heating rates.

c. Constant thermal properties.

For temperatures above freezing thermal properties of foods do not vary greatly with temperature. Water which is the primary factor affecting thermal properties of most foods exhibits a 10% increase in thermal conductivity and an 11% increase in thermal diffusivity with a temperature increase from 70 F to 150 F. For the case of nonhomogeneous foods, differences in thermal properties among different constituents could influence the heat transfer.

The ideal analysis could not be used where freezing or thawing occur due to drastic changes in both thermal conductivity and thermal diffusivity which occur with the phase change.

5. Conclusions from theoretical analyses.

It is theoretically possible to measure the mass average temperature of the food in a 401 x 105 can of food by positioning one thermocouple at the proper location.

For heating from bottom and sides simultaneously the location which is at the same temperature as the mass average temperature is on a parabolic surface which moves closer to the heater with time.

The location of the mass average temperature is independent of the initial food temperature and the heater temperature.

The location of the mass average temperature is independent of the thermal properties of the food in the can.

The heating time depends more upon the heater temperature than the initial food temperature.

B. Experimental Analysis of Mass Average Temperature Measurement.

Following the theoretical analysis experimental heating tests were conducted for comparison with the theoretical analyses and to obtain information necessary for carrying out the heating tests with the two model food systems. The homogeneous food model was a commercially procured turkey salad sandwich spread made by Carnation. This food was not homogeneous on a microscopic level since it contained small particles of meat and relish; however, it could be considered homogeneous for heat transfer purposes because the particles were so small that they would be at a uniform temperature throughout.

The heterogeneous food model was frankfurter chunks in a sauce of water gelled with agar. Both food models are described in greater detail in section IV paragraph A.

1. Temperature gradients were obtained by making many temperature measurements at several locations within a can of the homogeneous food. These temperature data were also used to calculate a mass average temperature for the food in the can. Figure IV-14 shows the locations where temperature was measured. The can was divided radially into 5 elements of equal volume. A further division was accomplished with imaginary horizontal planes so that nine layers of equal volume were obtained. The temperature was then measured at the center of each of these 45 elements with a single thermocouple probe. It was inserted into each of

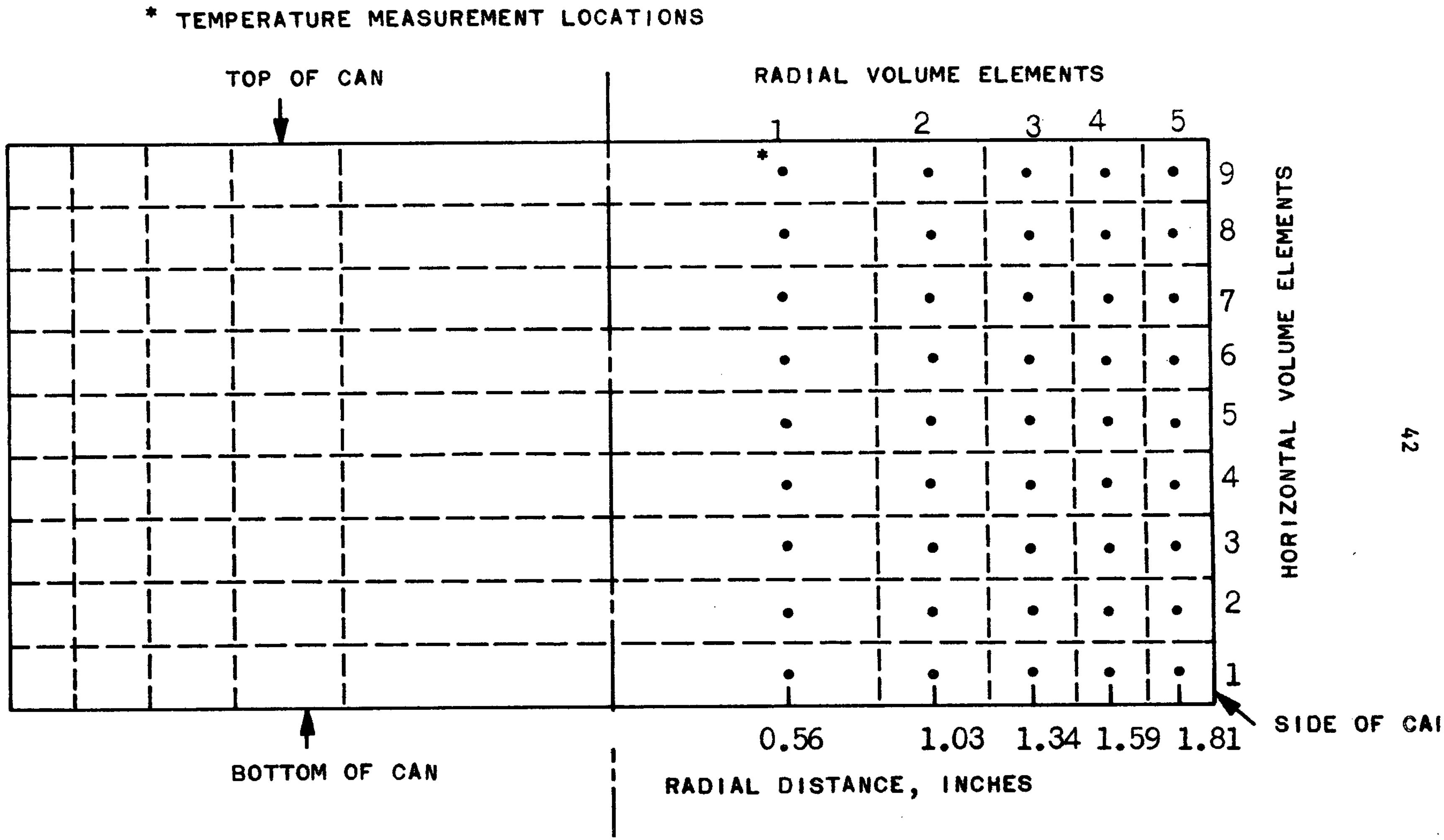


FIGURE IV-14. LOCATIONS IN FOOD CAN WHERE TEMPERATURES WERE MEASURED EXPERIMENTALLY five holes located at the appropriate radial distances. The temperature was measured at 1/8 inch vertical intervals starting 1/16 inch from the can bottom. Approximately five seconds were required per reading. Temperatures were also measured at the boundaries between the radial volume elements to describe the temperature gradients more thoroughly and to verify that the center temperature of these volume elements adequately portrayed the average element temperature.

It was found that the center of the can was not appropriate for measuring the average temperature of the center volume element since the center temperature was usually the maximum or minimum temperature within the element. Therefore, the temperature of the center element was measured at a radial distance approximately 2/3 of the radius of the element.

Temperature data were first plotted as shown in Figure IV-15 for each of the five radial distances. Then plots were made for temperature versus time for each radial location (Figure IV-16).

Typical temperature distributions for the three different heater configurations are shown in Figures IV-17, IV-18 and IV-19.

2. Mass average temperatures.

Mass average temperatures were determined by averaging the temperature of each of the volume elements at five minute intervals. Temperatures were obtained from the temperature versus time graphs. Figure IV-20 illustrates the mass average temperature as a function of time for the three heater configurations.

3. Equilibration studies.

Equilibration studies provided another means of determining mass average temperature. After heater turn-off the temperatures at all points within the can converge to the mass average temperature. This is shown in Figure IV-21. After the temperatures converge the temperature decreases with time since the can is not perfectly insulated, but loses heat to its cooler surroundings. Eventually the surface temperature decreases and the temperature throughout the can is no longer uniform.

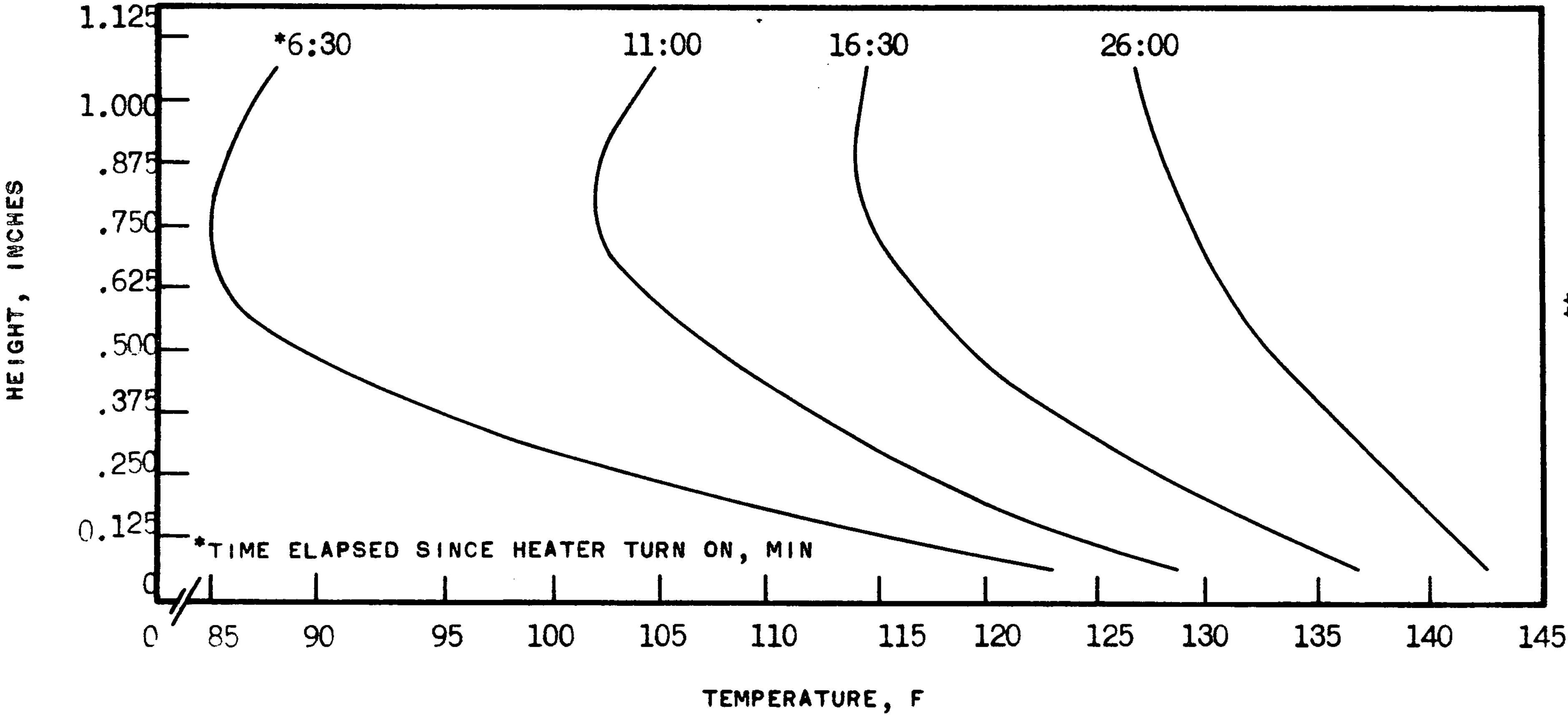


FIGURE IV-15. TEMPERATURE VERSUS HEIGHT AT A RADIUS OF 1.34 INCHES

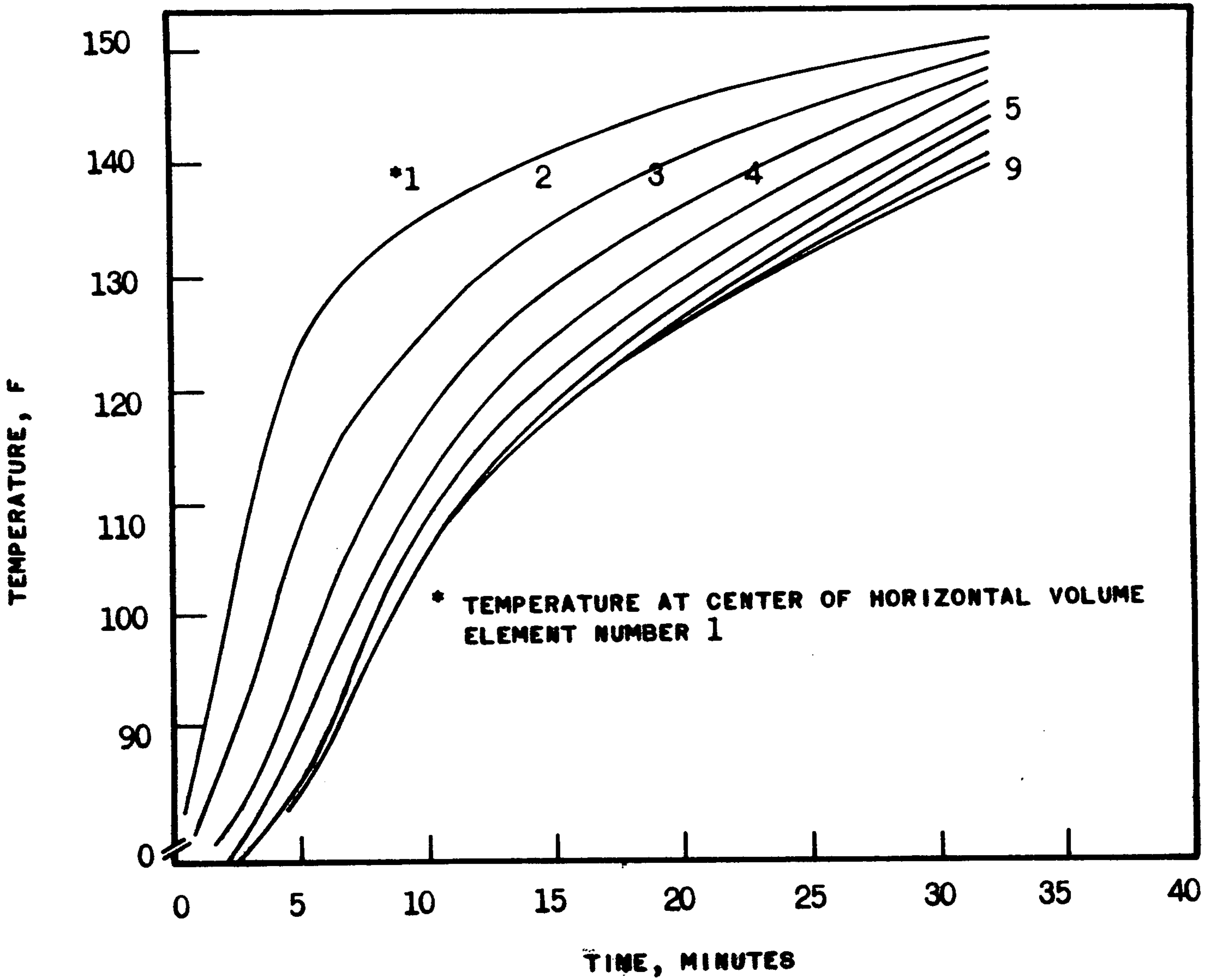


FIGURE IV-16. TEMPERATURE VERSUS TIME AT A RADIUS OF 1.34 INCHES

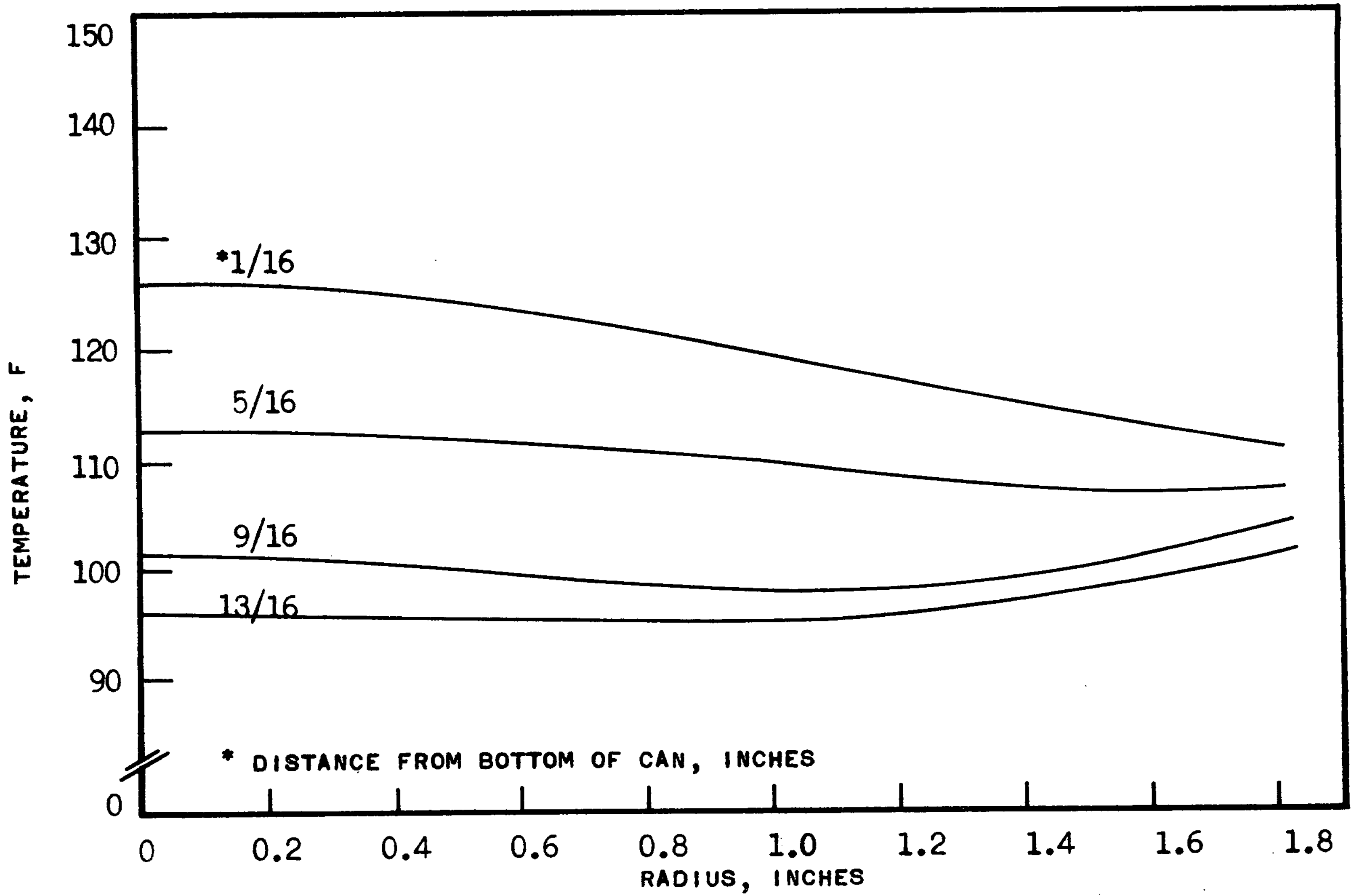


FIGURE IV-17. EXPERIMENTAL TEMPERATURE DISTRIBUTION FOR BOTTOM HEATER ONLY

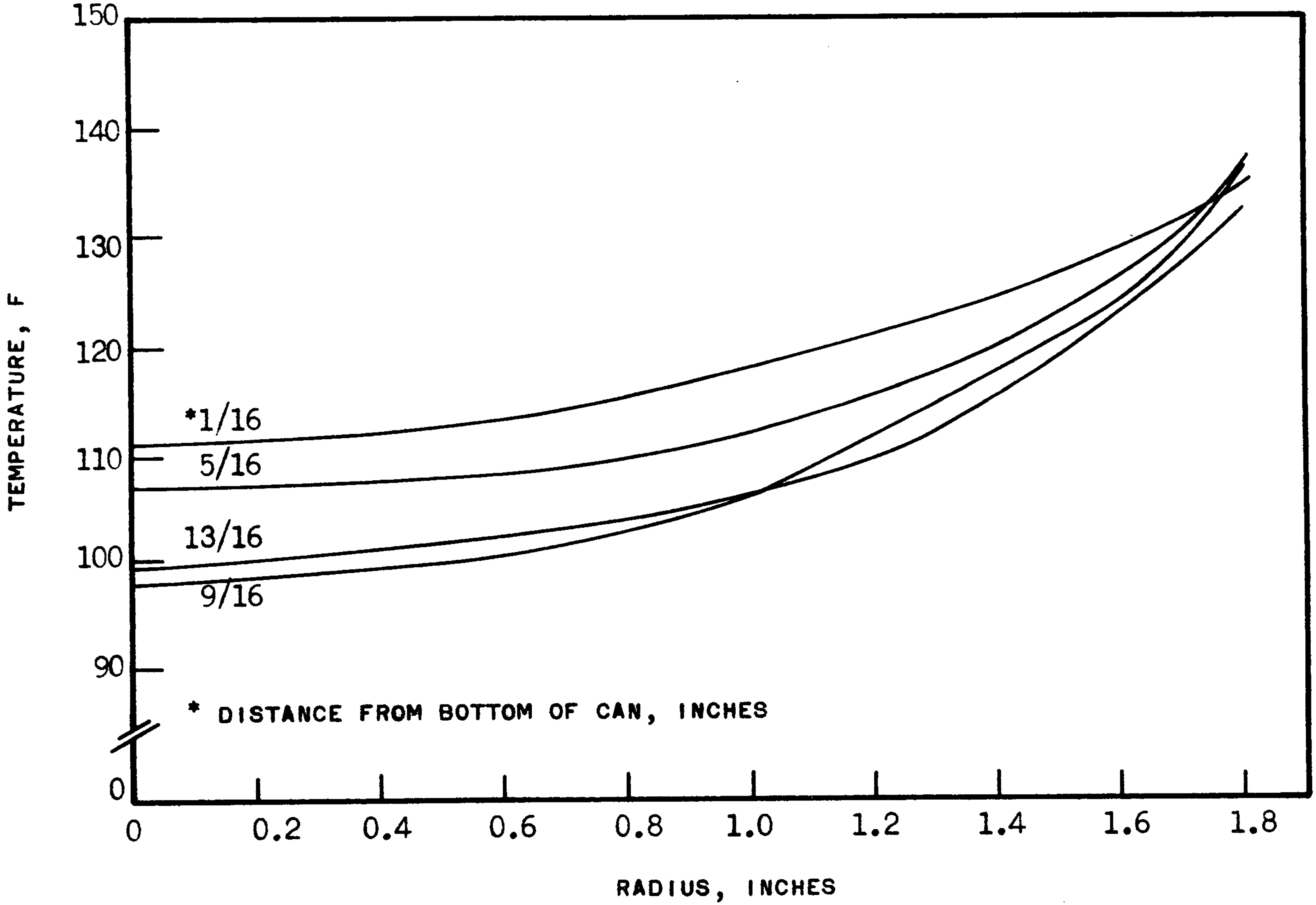


FIGURE IV-18. EXPERIMENTAL TEMPERATURE DISTRIBUTION FOR SIDE HEATER ONLY

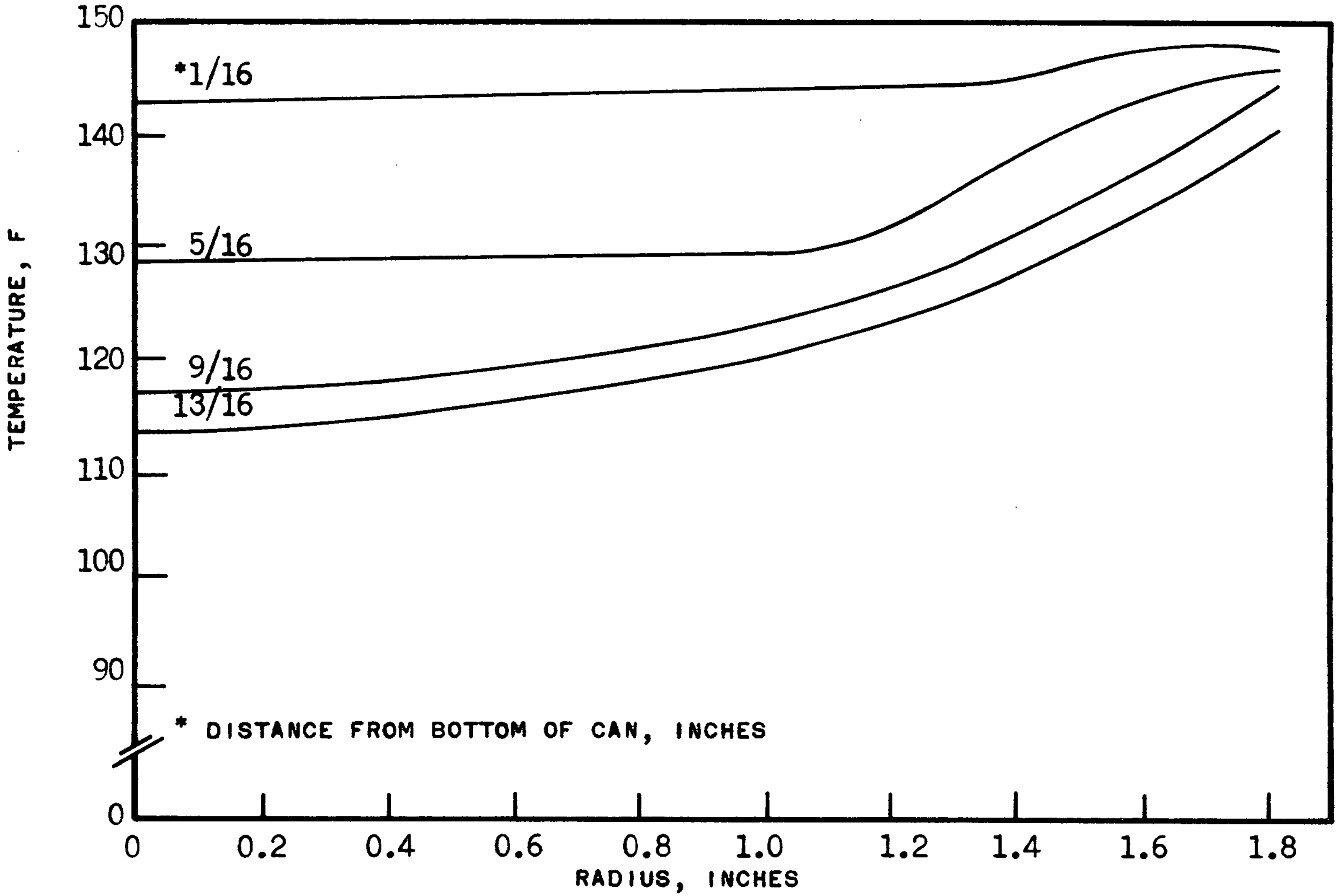


FIGURE IV-19. EXPERIMENTAL TEMPERATURE DISTRIBUTION FOR BOTTOM AND SIDE HEATERS

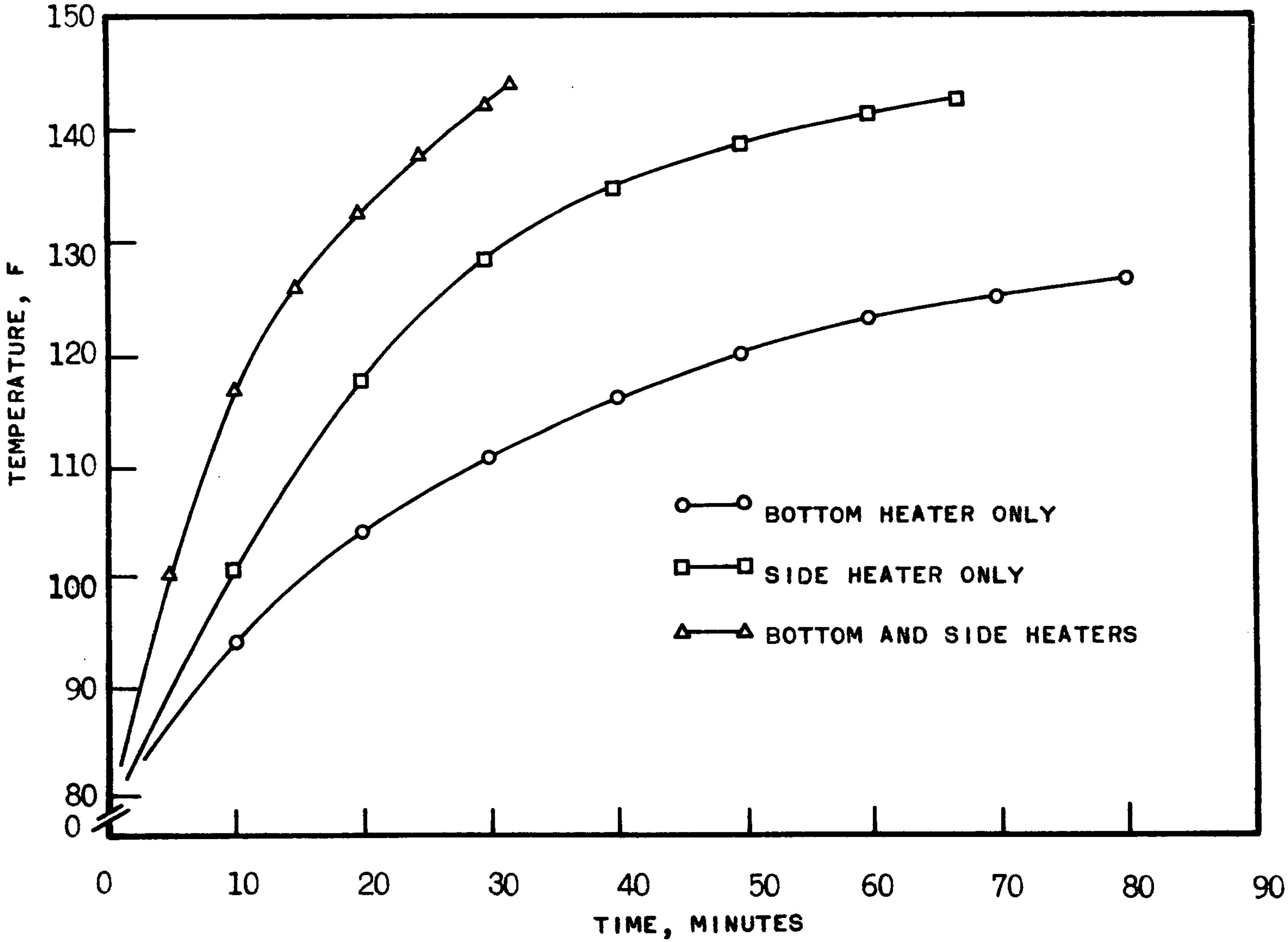


FIGURE IV-20. MASS AVERAGE TEMPERATURE VERSUS TIME AND HEATER CONFIGURATION

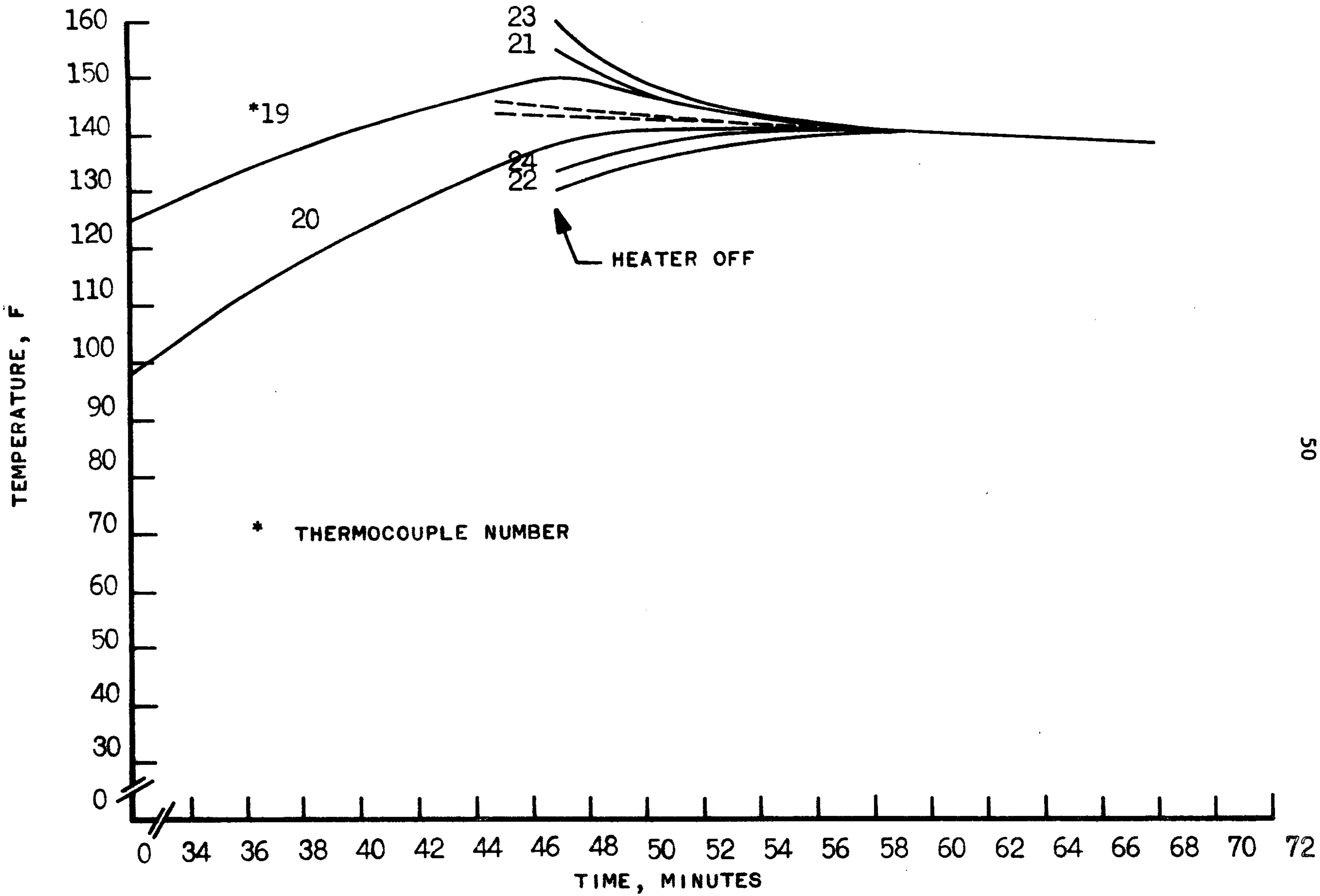


FIGURE IV-21. TEMPERATURE EQUILIBRATION AFTER HEATER TURN-OFF

Since the mass average temperature decreases with time after a uniform temperature is reached in the can, it must have been decreasing prior to the time of convergence also. An estimate of the mass average temperature at the time of heater turn-off was obtained by projecting the mass average temperature curve back to the time of heater turn-off. A straight line provides a reasonable estimate of the mass average temperature; however, the rate of temperature decrease is greatest at first when the temperature difference between the food and the ambient temperature is greatest so a more refined estimate would result from the projection of a slightly curved line as shown in Figure IV-21.

The vertical location of the point in the can which was at the mass average temperature was obtained using Figure IV-22.

Care must be exercised in estimating mass average temperature with a thermocouple located at the vertical location obtained using the above procedure. Since the theoretical analysis showed that the location exhibiting the mass average temperature changes with mass average temperature, this procedure is only valid within a limited temperature range.

There were also indications that the amount of contact resistance between the heater and the can affected the location exhibiting mass average temperature. These limitations may be overcome by utilizing the equilibration curve to estimate mass average temperature since it is not dependent upon the thermocouple height.

a. Heterogeneous foods.

When heating heterogeneous foods the equilibration curve must be used to estimate the mass average temperature at the time of heater turn-off. To demonstrate this procedure, frankfurter chunks in sauce, the heterogeneous food model, was heated. In one case the thermocouple was situated inside a chunk; for the second case the thermocouple was located in the sauce. The resulting temperature curves are shown in Figure IV-23. The sauce was at a higher temperature than the center of the chunk since

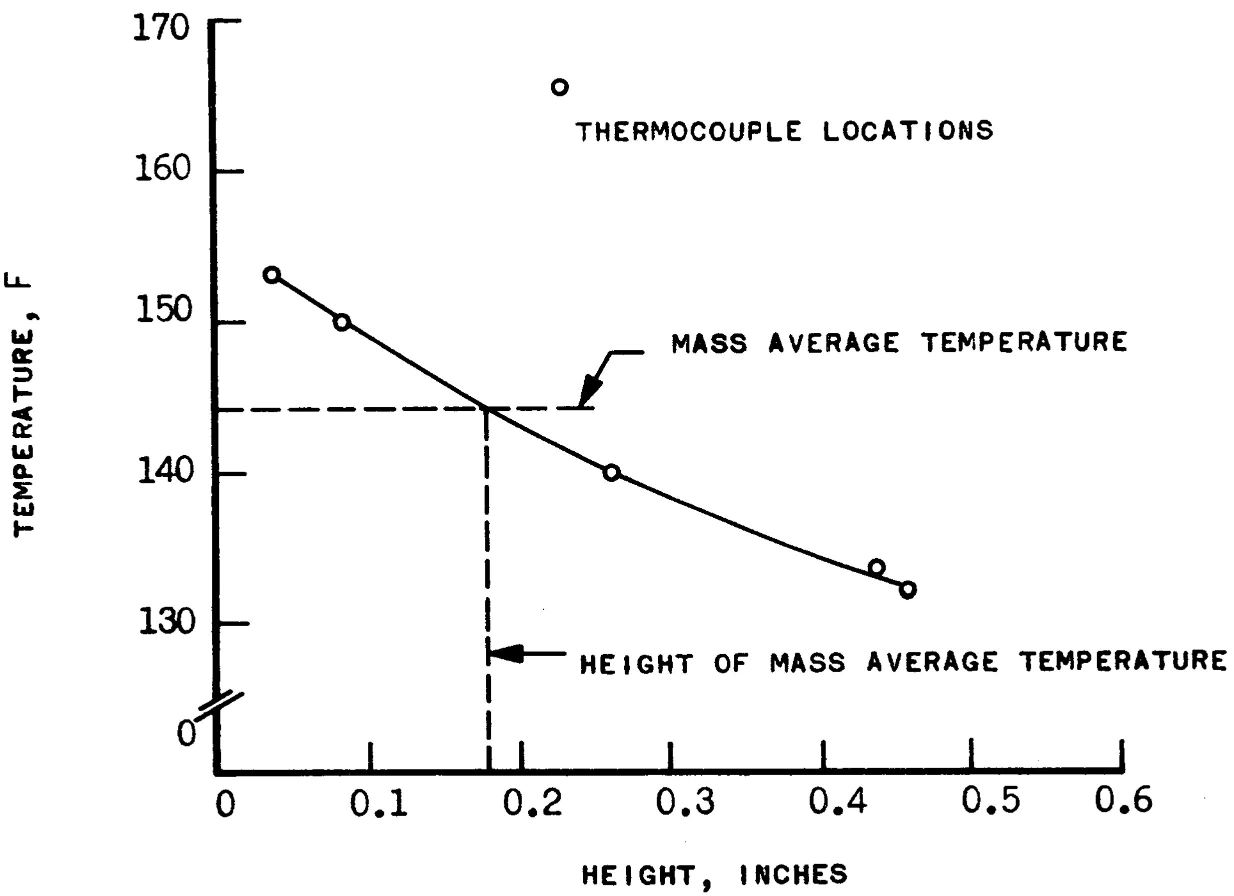


FIGURE IV-22. EXPERIMENTAL DETERMINATION OF LOCATION OF MASS AVERAGE TEMPERATURE

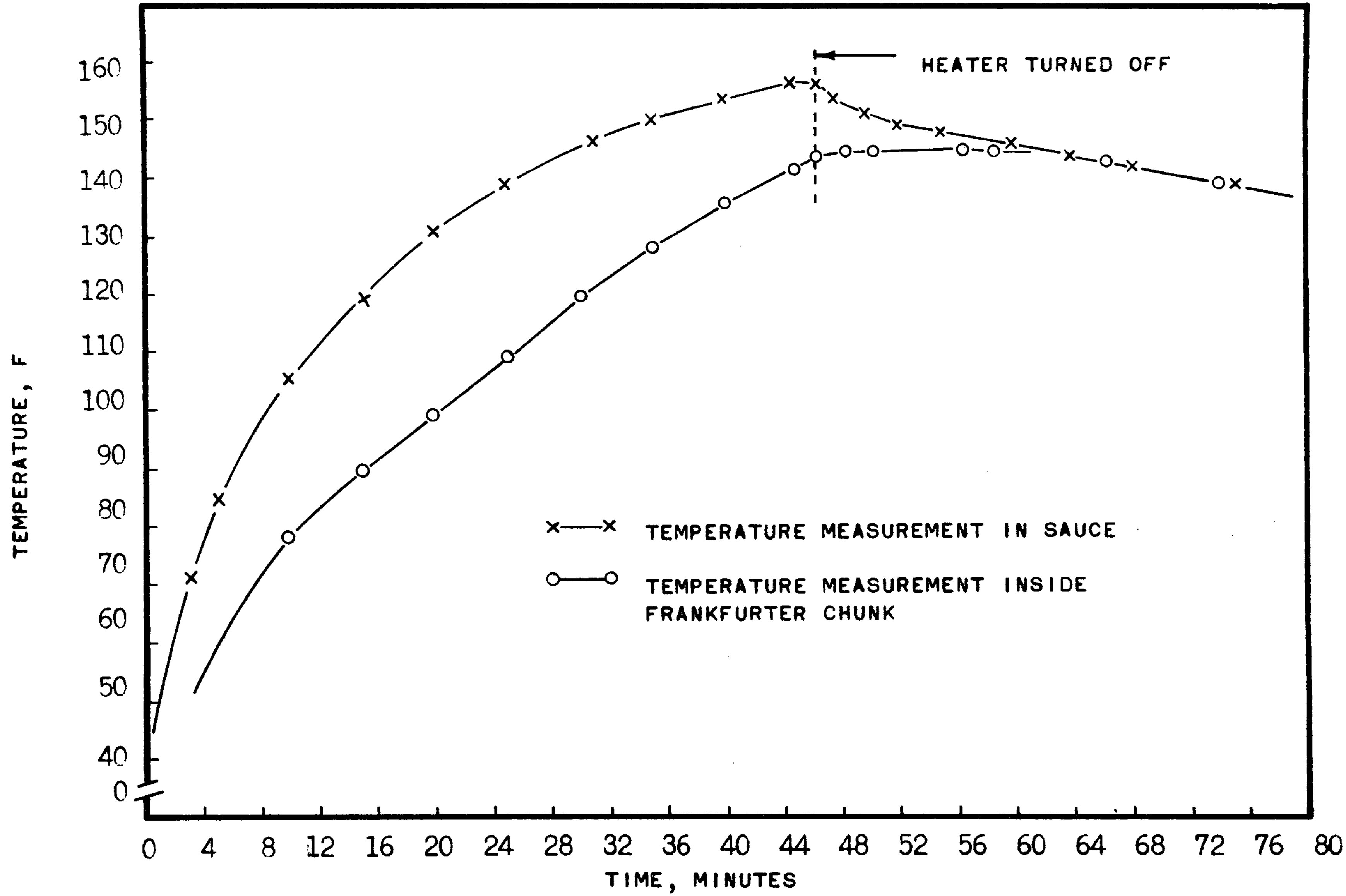


FIGURE IV-23. TEMPERATURE MEASUREMENTS IN A HETEROGENEOUS FOOD: FRANKS AND SAUCE the frankfurter is a poorer heat conductor. After the heater was turned off, the sauce cooled in a manner similar to the curve for homogeneous food but with a somewhat steeper temperature drop. The temperature in the chunk continued to rise or remained nearly constant since it was below the mass average temperature. The temperatures in the sauce and in the chunks converged to the mass average temperature. The mass average temperature at the time of heater turn-off can be estimated regardless of the thermocouple location by projecting back from the linear portion of the equilibrium curve.

b. Effect of heat content of heater.

Since the heater is at a higher temperature than the food, some heat will be transferred from the heater to the can after the heater is turned off. An estimate of the amount of heat transferred in this manner was obtained as follows:

The insulation was at a higher temperature than the food but it could not transfer heat to the food because of the adverse temperature gradient. Figure IV-24 shows the heater and representative temperatures which existed during a typical heater test. After equilibration the food and the heater were at the same temperature. It was assumed that half of the heat lost by the heater was gained by the food and the other half flowed in the opposite direction. The following heat balance was made to determine the approximate magnitude of the temperature rise in the food caused by heat transfer from the heater after the heater was turned off.

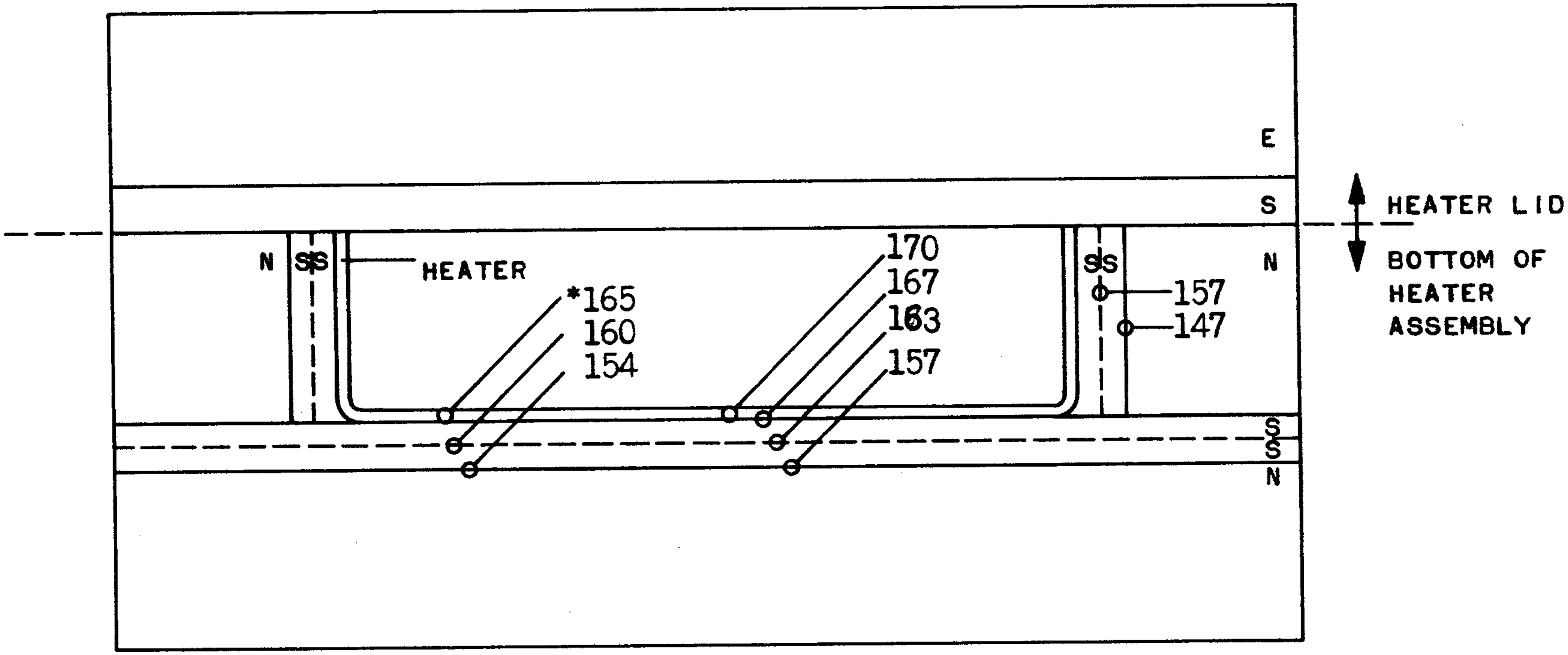
Heat lost by heater:

heater weight, W_h = 0.084 lbs.

specific heat of heater, C_p = 0.4 Btu/lb- F

temperature change, ΔT = 065-149 = 16 F

heat lost = $W_h C_p \Delta T$ 0.54 Btu



* TEMPERATURE IN F

E - EXPANDED POLYSTYRENE INSULATION
N - NEOPRENE FOAM INSULATION
S - SILICONE FOAM INSULATION

FIGURE IV-24. HEATER AND INSULATION TEMPERATURES FOR A HEATING TEST

Total heat gained by food = Total heat lost by heater ÷ 2 = $\underline{0.27}$ Btu

food weight, W_f = 0.488 lbs

specific heat of food, C_p = 0.84 Btu/lb- F

temperature change, ΔT = unknown

$$\Delta T = 0.27 \text{ Btu}/W_f C_p = 0.7 \text{ F}$$

Therefore it was concluded that the heat added to the food after the heater was turned off was negligible.

4. Measurement of thermal properties of foods.

In order to make meaningful comparisons between experimental and theoretical studies of heat transfer, the thermal properties of the foods used must be known. Thermal conductivities were measured. Specific heats were estimated from the water contents. Densities were measured. Thermal diffusivity was then calculated from the above properties:

$$\alpha = \frac{k}{\rho C_p}$$

where α is thermal diffusivity, ft^2/hr

k is thermal conductivity, Btu/hr-ft-F

ρ is mass density, lb/ft^3

C_p is specific heat, Btu/lb-F

a. <u>Moisture content</u>.

Moisture content was measured by determining the water loss after heating food samples in a 103 C oven to a constant weight. The moisture content of the turkey salad sandwich spread was 73% by weight, wet basis. The frankfurter chunks were 54% moisture and the sauce was 95% moisture.

b. <u>Density</u>.

Density was determined by weighing a known volume of each sample. The densities of turkey salad, frankfurter chunks and sauce were 68.3, 64.4, and 62.0, respectively.

c. Specific heat.

Specific heats were estimated from the moisture contents using the following equation:

$$C_p = 0.40 + 0.006\ (\%\ \text{water})\ \text{Btu/lb-F}$$

This equation was reported by Dickerson (1968) for estimating specific heats of fresh meats. Specific heat of a food is so strongly dependent upon its water fraction that the above equation provides a good (better than ± 5%) estimate for foods with high water contents.

d. Thermal conductivity.

Thermal conductivity measurements were made on each of the model foods used with a thermal conductivity probe developed by Sweat (1972). The probe used is shown in Figure IV-25. The one-inch length of the probe allowed for "in situ" thermal conductivity measurements to be made with the food in a 401 x 105 can (Figure IV-26).

The probe is similar to the thermocouple probes used for temperature measurement but it also contains a heater wire. A constant power is supplied to the heater wire in the probe while monitoring the temperature in the probe. The slope of the resulting temperature versus log (time) curve depends upon the thermal conductivity of the surrounding material. A thermal conductivity test requires only two minutes with the probe, and the calculation of the thermal conductivity is simple.

The thermal conductivities of the turkey salad and frankfurter chunks at 70 F were found to be 0.21 Btu/hr-ft-F, and 0.24 Btu/hr-ft-F, respectively. The value for water of 0.36 Btu/hr-ft-F was used for the sauce because of its high water content.

V. RADIATION AND CONVECTION TESTS

Although the primary mode of heat transfer from the heater to the food can is conduction, one of the objectives of this study was to separate and quantify the effects of radiation and convection heat transfer.

A. Analyses of Radiation and Convection Modes of Heat Transfer,

Primary analyses of heat transfer by these two modes of heat

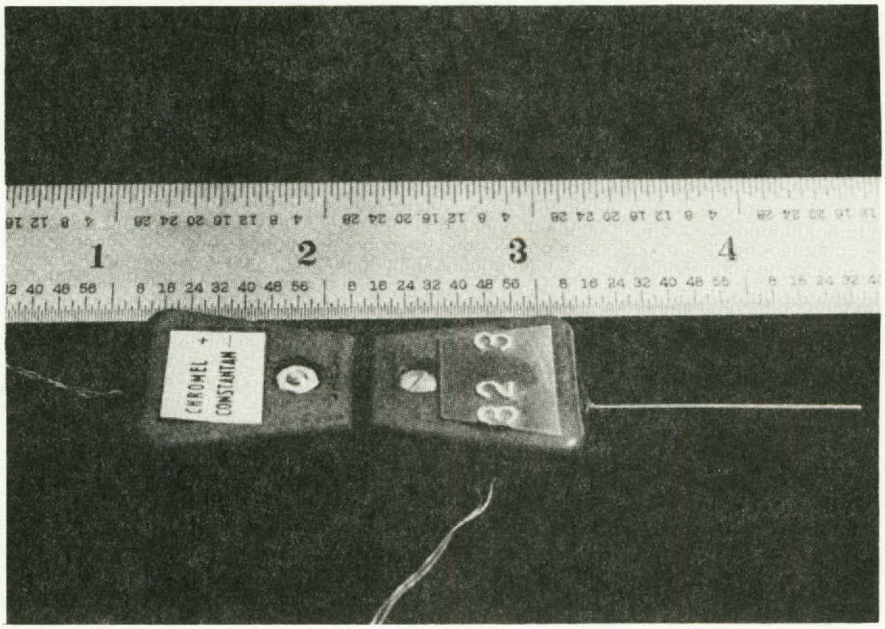


Figure IV-25. Thermal Conductivity Probe.

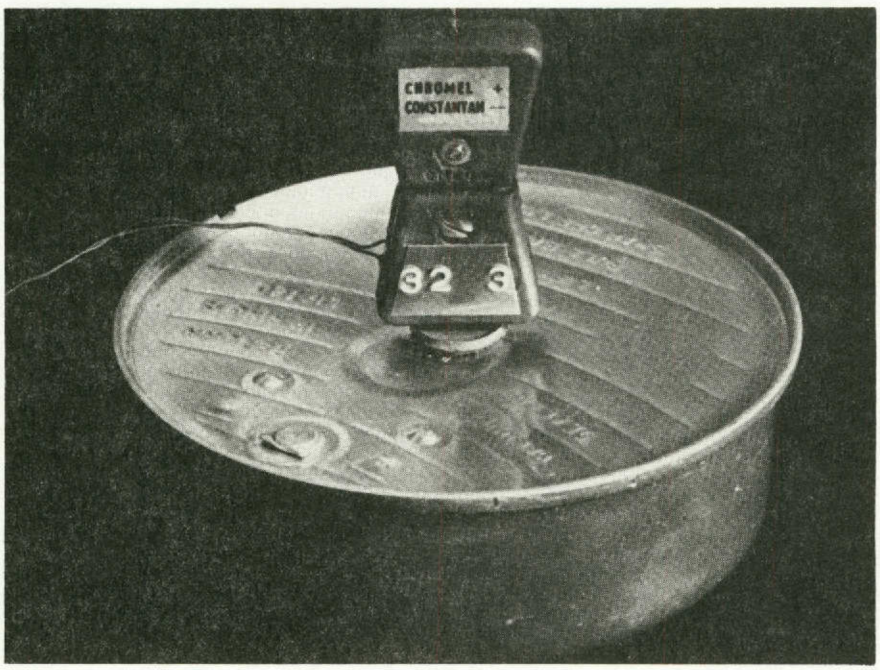


Figure IV-25. Thermal Conductivity Measurement of Food in Can.

transfer were undertaken to estimate the order of magnitude of the amounts of heat transfer which mihgt occur with each mode.

1. Radiation.

Radiation heat transfer occurs between two surfaces which are at different temperatures. The defining equation for radiation heat transfer, Q_{rad}, between two parallel surfaces of equal area is

$$Q_{rad} = \sigma AF(T_1^4 - T_2^4)/(1/\varepsilon_1 + 1/\varepsilon_2 - 1) \qquad \text{(V-1)}$$

where $\sigma = 1730 \times 10^{-12}$ Btu/ft^2-hr-R^4 (Stephan-Boltzman constant)

ε_1, ε_2 = thermal emissivities of surfaces 1 and 2

A = area of either surface, ft^2

T_1 = temperature of hotter surface °Rankine

T_2 = temperature of cooler surface, °Rankine

F = the configuration factor

Radiation is practically non-existent within the food container since there is direct contact between the food and the container and between adjacent food particles. Radiation heat transfer between the heater and the can surface is quite small due to the low absorptivity of heat by the aluminum can and because of the heater and can surfaces being at nearly the same temperature even if not in direct contact. Where there is direct contact between the two surfaces, they are at the same temperature so no net heat transfer due to radiation can occur. Since there is a pressure fit between the heater and can and since the heater is molded to fit the can, the space between these surfaces is extremely small.

An estimate of the radiation heat transfer was made using equation (V-1). The heater surface temperature was assumed to be 159 F and the can surface temperature was assumed to be 149 F for a temperature difference of 10 F, a very conservatively high assumption which would make the estimate probably much higher than the actual value. The heater surface area is approximately 25 square inches including the bottom and side heaters.

From emissivity data presented by Holman (1963) the emissivity of the aluminum can was estimated to be 0.1. The thermal emissivity of the heater surface was assumed to be 1, the emissivity value of a perfect radiator.

An F value of 1 was used since the two surfaces were so close together.

The heat transfer predicted by equation (V-1) is

$$Q_{rad} = 1730 \times 10^{-12} \frac{\text{Btu}}{\text{ft}^2\text{hr}^\circ\text{R}^4} \times \frac{25}{144}\ \text{ft}^2 \times 1 \times (619^4 - 609^4)/(1/1 + 1/.1 - 1) = 0.287\ \text{Btu/hr}$$

$$= 0.287\ \text{Btu/hr}$$

When a 401 x 105 can of turkey salad ($C_p = 0.84$, $W = 0.488$ lb) is heated from 70 F to 149 F in a period of 30 minutes, 64.7 Btu/hr is the average heat transfer rate.

Comparing the calculated radiation heat transfer rate with the average total heat transfer rate shows that radiation could account for at most only 0.44% of the total heat transfer. Additional calculations were made varying the food can surface temperature. Figure V-1 shows the effect of the temperature difference between the two surfaces on the percent of average total heat transfer contributed by radiation. It can be seen that even for a temperature difference of 45 F, radiation accounts for less than 2% of the total heat transferred.

Radiation is not directly dependent on the distance between the heater and the can; however, the distance between the heater and the can affects the temperature difference between the two surfaces and where there is direct contact, the temperature difference is zero.

Radiation heat transfer in a low pressure, zero gravity atmosphere is expected to be the same as the radiation heat transfer at normal atmospheric pressures and under the earth's gravity forces since radiation is independent of gravity and practically independent of the presence of an atmosphere.

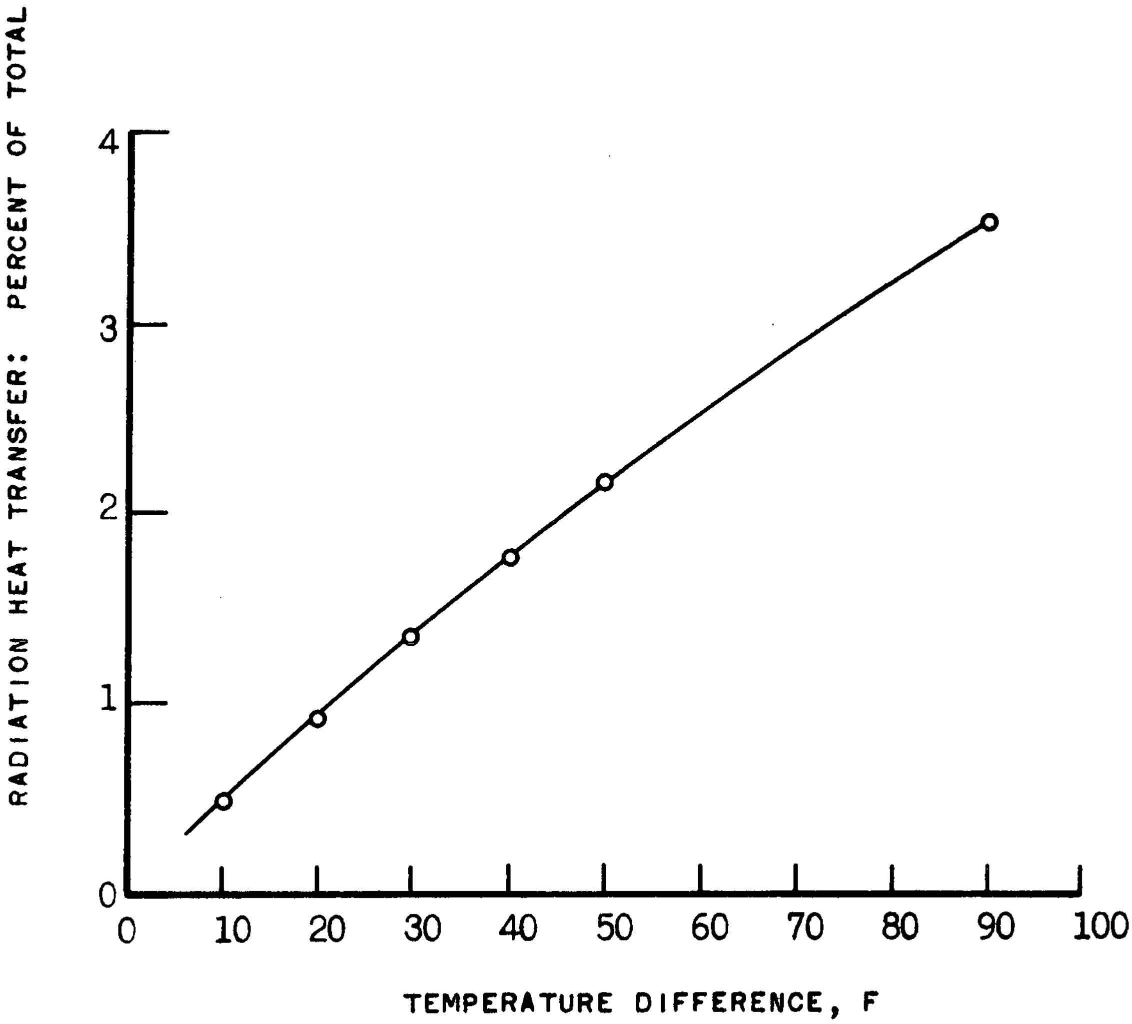


FIGURE V-1. EFFECT OF TEMPERATURE DIFFERENCE BETWEEN HEATER AND CAN ON RADIATION

2. Convection.

Natural convective heat transfer ocdurs in a non-zero gravity field when hot air rises due to a decrease in its density. Natural convection is negligible at zero gravity. Under the influence of the earth's gravity, convection may occur inside the food container and within air spaces which may exist between the heater surface and the can.

Convection can occur within the food cans only with non-viscous fluid foods which flow freely. For the viscous foods utilized in this study no convection occurred inside the cans.

Eckert (1959) stated that free convection will not occur between two horizontal surfaces if the product of the Prandtl-Grashof product is low, and that free convection patterns arise when the Prandtl-Grashof product is 1700. This product was calculated for typical heating situations utilizing helium or air at atmospheric pressure by using the following equation:

$$Pr\text{-}Gr = \frac{\nu}{\alpha} \times \frac{g\beta d^3\theta}{\nu^2} \qquad (V\text{-}2)$$

where ν = kinematic viscosity, ft^2/sec

α = thermal diffusivity, ft^2/sec

g = gravitational acceleration, ft/sec^2

β = coefficient of thermal expansion, 1/°F

d = vertical distance between surfaces, ft.

θ = temperature difference between surfaces, F

The distance between the heater and the can was assumed to be 0.01 inch for the calculations although the actual gap was expected to be less than this. A temperature difference of 89 F was selected since this is the maximum temperature difference when heating food at 70 F with a heater temperature of 159 F. Values of the other factors are listed in Table V-1 (McAdams, 1954).

Table V-1. Factors Used in Prandtl-Grashof Product

Factor	Air	Helium	Units
ν	0.18×10^{-3}	1.77×10^{-3}	ft^2/sec
α	0.905	9.36	ft^2/sec
g	32	32	ft/sec^2
β	1.79×10^{-3}	1.52×10^{-3}	1/°F
d	0.01	0.01	inch
θ	89	89	°F
Pr	0.72	0.686	none
Gr	0.091	0.80×10^{-3}	none

For air Pr-Gr is 0.066 and for helium Pr-Gr is 0.00055. These products are extremely small compared to the required product of 1700 for convection. An air gap of 1/4 inch still yields a Pr-Gr product less than 1700.

Jakob (1949) stated that convection will not occur between vertical surfaces when the Grashof number is less than 2000. In this case an air gap of 1/4 inch between the side heater and the food can side wall would still not allow convection to occur.

For decreased pressures, literature data were not readily available; however, an order of magnitude analysis was performed to see if there might be a drastic increase in the Pr-Gr product with lower pressures. The right hand side of equation (V-2) may be reduced to $\frac{g\beta d^3\theta}{\alpha\nu}$. The three factors remain constant when pressure is reduced. Eliminating these factors g, d^3 and θ and substituting $\frac{k}{\rho C_p}$ for α and $\frac{\mu}{\rho}$ for ν, the above expression becomes $\frac{\beta\rho^2 C_p}{k\mu}$ where μ is dynamic viscosity. It was reasoned that β and C_p would not be greatly affected by reduced pressure, ρ would decrease, k would decrease and μ would decrease with a reduction in pressure. Since both the numerator and denominator decrease in value, it does not seem possible that reduced pressures would increase the Prandtl-Grashof number to the extent that convection would occur.

It was concluded that convection would not be a significant factor in heater tests conducted in the earth's gravitational field at atmospheric pressures or at reduced pressures. It follows that neither radiation nor convection will cause differences between heater performance on earth at atmospheric pressures and heater performance in zero gravity at reduced pressures.

B. Experimental Tests.

In spite of the strong evidence developed above that radiation and convection heat transfer are insignificant, it was considered necessary to verify these conclusions experimentally with the heater and a model food.

1. Factorial experiment.

A 2 x 2 factorial experiment was conducted in which the factors were environmental pressure surrounding the can and presence or absence of diffuse black paint on the can bottom. The two pressure levels were atmospheric pressure (14.7 psia) and a vacuum of 29 inches of mercury.

The parameters analyzed were the time required for each of six thermocouples located in the can to reach 130 F and the temperature of each thermocouple after 50 minutes of heating. If there is a significant contribution to the overall heat transfer process by thermal radiation then the time required for a given temperature measurement location to reach 130 F should be significantly less for cans painted black than for unpainted cans since the painted cans had much greater heat absorption characteristics than unpainted cans. Also the temperature at a given location should be significantly higher after 50 minutes of heating for the painted cans. Similarly, for convection to make a significant contribution, the time to reach 130 F should be less for cans in an atmospheric pressure environment than for those in a vacuum and the temperatures at 50 minutes should be higher since there is not enough gas present to support convection heat transfer in a high vacuum.

a. Procedures.

Cans of Carnation turkey salad sandwich spread were heated in the heater unit with only the bottom heater from an initial temperature of 70 F. Temperature was measured with three thermocouple probes each containing two thermocouples. Proportional heater control was used.

For those tests conducted in a vacuum, the test chamber was evacuated to a vacuum of 29 inches of mercury. Tests were first conducted with unpainted cans, then the can bottoms were painted black and the tests were repeated. Two replications were donducted.

b. Results.

Table V-2 contains the temperatures reached by five of the thermocouples after 50 minutes of heating.

Table V-2. Thermocouple Temperatures After 50 Minutes.

Thermocouple		1	2	3	4	5	Ave.
No	Unpainted	136 F	125	135	126	137	134
Vacuum		140	129	140	131	140	
Vacuum	Unpainted	139	129	138	133	140	137
		142	131	141	132	142	
No	Painted	138	127	137	128	138	133
Vacuum		137	126	136	127	137	
Vacuum	Painted	140	129	138	129	140	137
		144	134	141	133	142	

A separate analysis of variance was conducted for each thermocouple. There was no significant difference ($p < .05$) between results for painted and unpainted cans so it was apparent that radiation heat transfer was insignificant. Some of the thermocouples showed a significant difference between a vacuum and no vacuum. For all thermocouples the tests conducted with a vacuum yielded temperatures an average of 2.5% higher than tests with no vacuum.

It was suspected that the results of the tests conducted with different pressure levels to test the effect of convection heat transfer were confounded by differences in contact between the heater and can due to expansion of the can in a vacuum. If the effects of convection were not confounded, then there is a paradox in the test results.

With a vacuum, convection is suppressed due to absence of gas. Therefore if convection is a significant mode of heat transfer, the tests with a vacuum should have yielded lower temperatures. However, the tests with a vacuum yielded higher temperatures. It was concluded that if convection heat transfer is significant, it was overshadowed by the effect of contact between the heater and can.

2. Can expansion.

Can expansion was measured at several levels of vacuum since it was suspected that vacuum caused better contact between the heater and can surfaces. Ames dial indicators were used to measure the distance moved by three points on the bottom and one point on the top of a 401 x 105 can of Carnation turkey salad sandwich spread at room temperature. Figure V-2 shows the expansion of the can as a function of the absolute pressure surrounding the can.

Since the bottom of the can expanded nearly 0.1 inch at the center, it was apparent that the can expansion due to a hard vacuum created better contact between the heater and can, thus increasing the rate of heat transfer.

It was also observed that the expansion of the can at 19 inches of mercury (5 psia) was only about 10% of that which occurred at a vacuum of 29 inches of mercury.

3. Radiation test.

A radiation test performed at a hard vacuum to eliminate any possible effects of convection and absorption of heat by the atmosphere.

a. Procedure.

Four cans of Carnation turkey salad sandwich spread were heated from 70 F with bottom and side heaters at a vacuum of 29.4 inches of mercury. The mass average temperature was measured with a thermocouple probe. Proportional heater control was used. The time for the mass average temperature to reach 149 F was the parameter analyzed.

Two replications were conducted with each can before the cans were painted on the bottom and sides with black

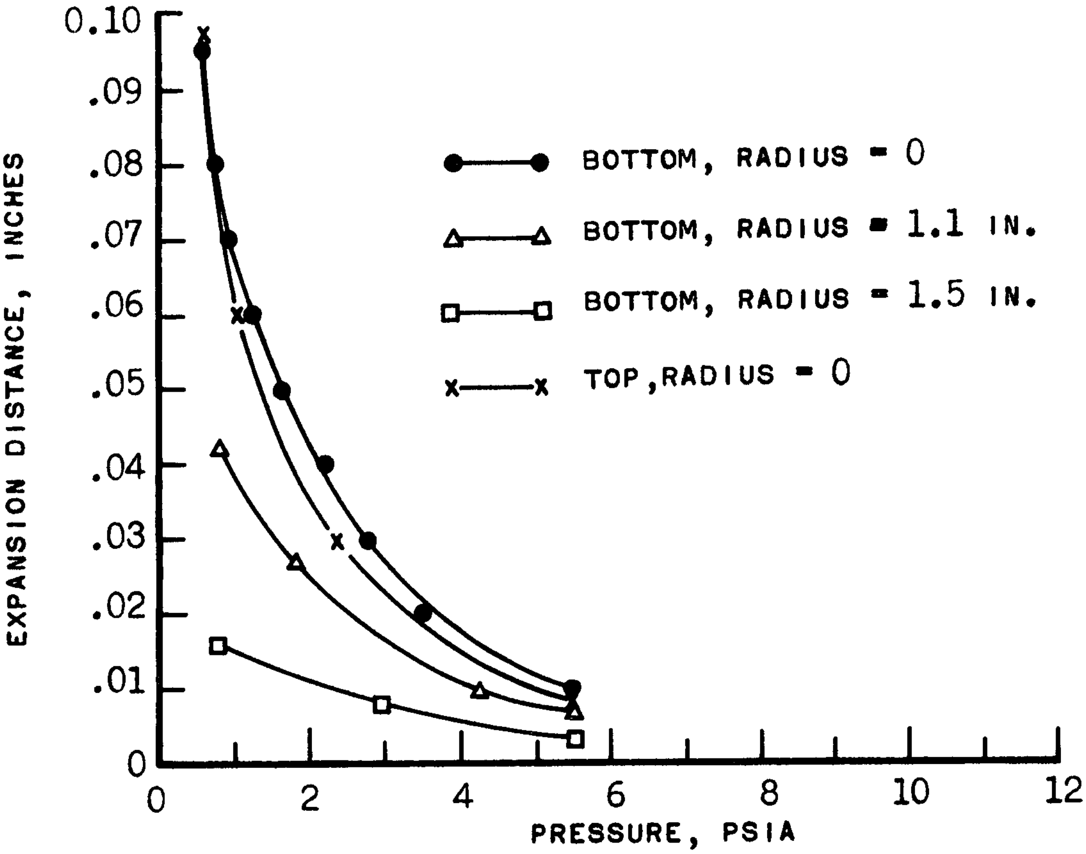


FIGURE V-2. EXPANSION OF 401 x 105 CAN IN A VACUUM paint. Then two more replications were conducted.

b. Results.

The results are given in Table V-3 and the analysis of variance is found in Table V-4.

Table V-3. Time to Reach 149 F Mass Average Temperature

Can	7	8	9	10
Unpainted	29.7 min.	27.0	28.2	27.5
	27.0	25.5	28.7	27.7
Painted	29.0	29.0	28.7	25.0
	30.0	28.0	29.0	26.5

Table V-4. ANOVA for Radiation Test

source	df	SS	MS	F	
Paint	1	0.951	0.95	1.1	not significant
Can	3	13.558	4.52	5.1	significant at 5% level
PxC	3	9.016	3.01	3.4	significant at 10% level
Error	8	7.085	0.89		
Total	15	30.610			

The heating curves for one of the cans used are shown in Figure V-3.. The temperature plotted is that of the thermocouple positioned to measure the mass average temperature at 149 F.

The results verified the previous conclusion that radiation heat transfer is not significant since increasing the heat absorption characteristics of the can with black paint did not increase the heat transfer.

It is noted that there was a statistically significant difference between cans at the 5% level.

4. Convection tests.

Convection tests were conducted to verify the previous analysis that convection heat transfer is insignificant.

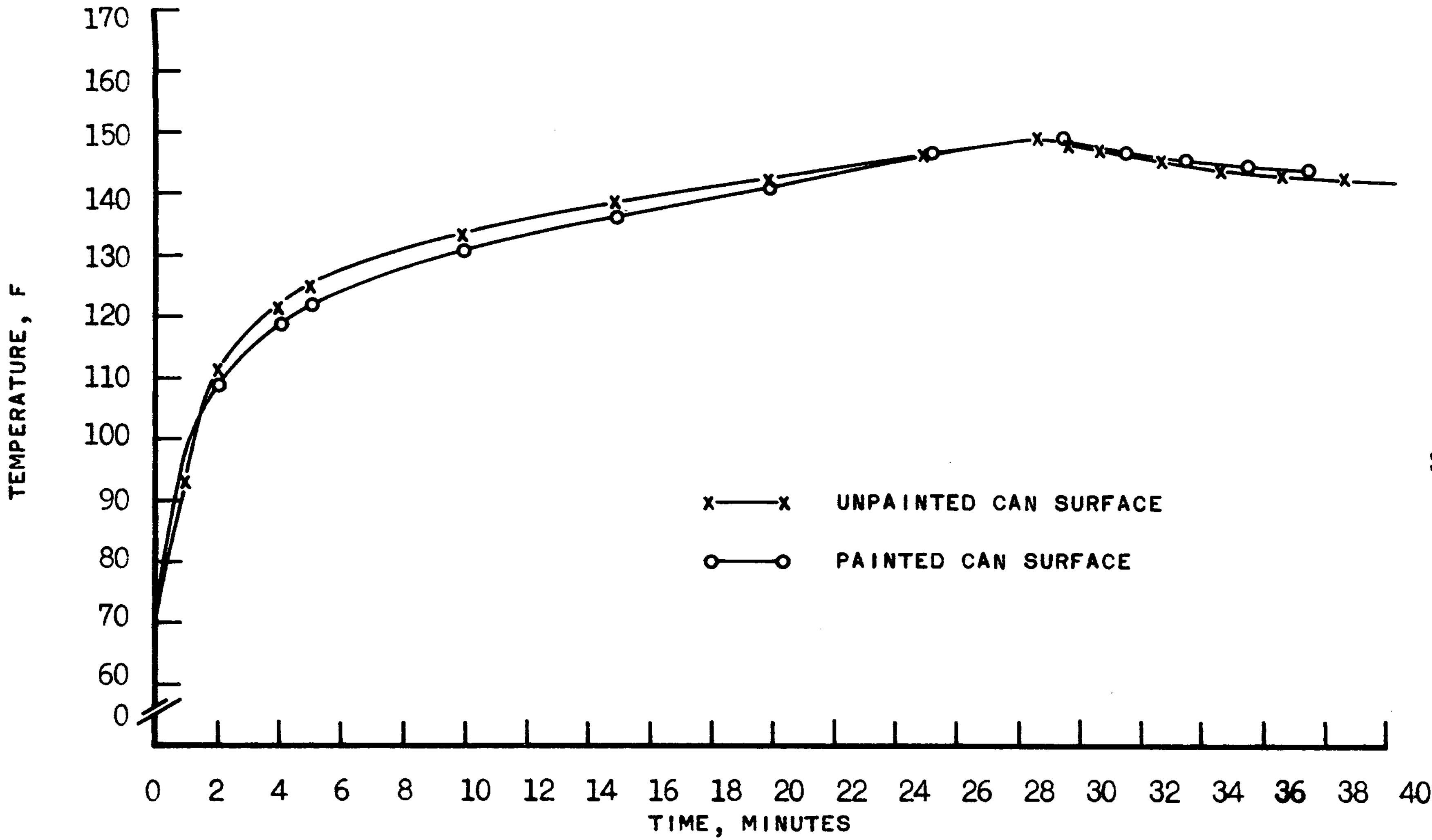


FIGURE V-3. HEATING CURVES FOR RADIATION TESTS

a. Varied test chamber pressure.

The first tests were performed with test chamber pressure as the variable. Atmospheric pressure was one pressure level and a vacuum of 29.4 inches of mercury was the other.

(1) Procedure. Four cans of Carnation turkey salad sandwich spread were heated from 70 F with bottom and side heaters in the proportional control mode. The time required for the mass average temperature to reach 149 F was the parameter analyzed. The mass average temperature was measured with a thermocouple probe.

One test was conducted at each pressure level with each can. Pressure level and can number were randomized for this test sequence.

(2) Results. Table V-5 contains the results in minutes required to attain a mass average temperature of 149 F.

Table V-5. Results of Convection Test; Time to Reach 149 F Mass Average Temperature

Can	7	8	9	10
Vacuum	28.0	29.7	27.0	28.4
No Vacuum	34.5	32.5	30.5	36.0

Table V-6 contains the analysis of variance for the above test.

Table V-6. ANOVA for Convection Test; Variable Pressure

Source	df	SS	MS	F	
Pressure	1	52.02	52.02	19.4	significant
Can	3	19.905	4.30	1.6	not significant
Error	3	8.03	2.68		
Total	7	72.955			

Although this test was quite limited, it seemed clear that there was a substantial difference between pressure levels. As in a previous test described in paragraph VB1, the vacuum increased rather than decreased the heat transfer.

Figure V-4 shows a comparison between heating tests with and without a vacuum for one can. The temperature measured by the thermocouple positioned to measure mass average temperature at 149 F is plotted for both tests. The power consumed by the heater is also plotted, illustrating two points which show that there was better contact between the heater and can: (1) The power level dropped off sooner with no vacuum. Since the heater temperature reached the set point more quickly, the heater was not transferring as much heat to the can. (2) The total power consumed with no vacuum was less, also due to poorer contact between the heater and can.

b. Variable heater orientation.

Another approach was required to eliminate convection without varying pressure. Since free convection will not occur between two horizontal surfaces when the upper surface is hotter than the lower (Eckert, 1959(, the heater orientation was turned upside down to eliminate convection at the bottom heater surface.

(1) Procedure. One treatment was with the heater in its normal orientation while the other treatment was with the heater upside down so that the heater surface would be on top. Three cans of Carnation turkey salad were heated from 70 F with bottom and side heaters in the proportional control mode. The chamber pressure for all tests was 5 psia. The parameter analyzed was the temperature in the center of the can at a depth of 0.18 inches at the end of 25 minutes of heating. Two replications were conducted with normal orientation and one test with upside down orientation. The

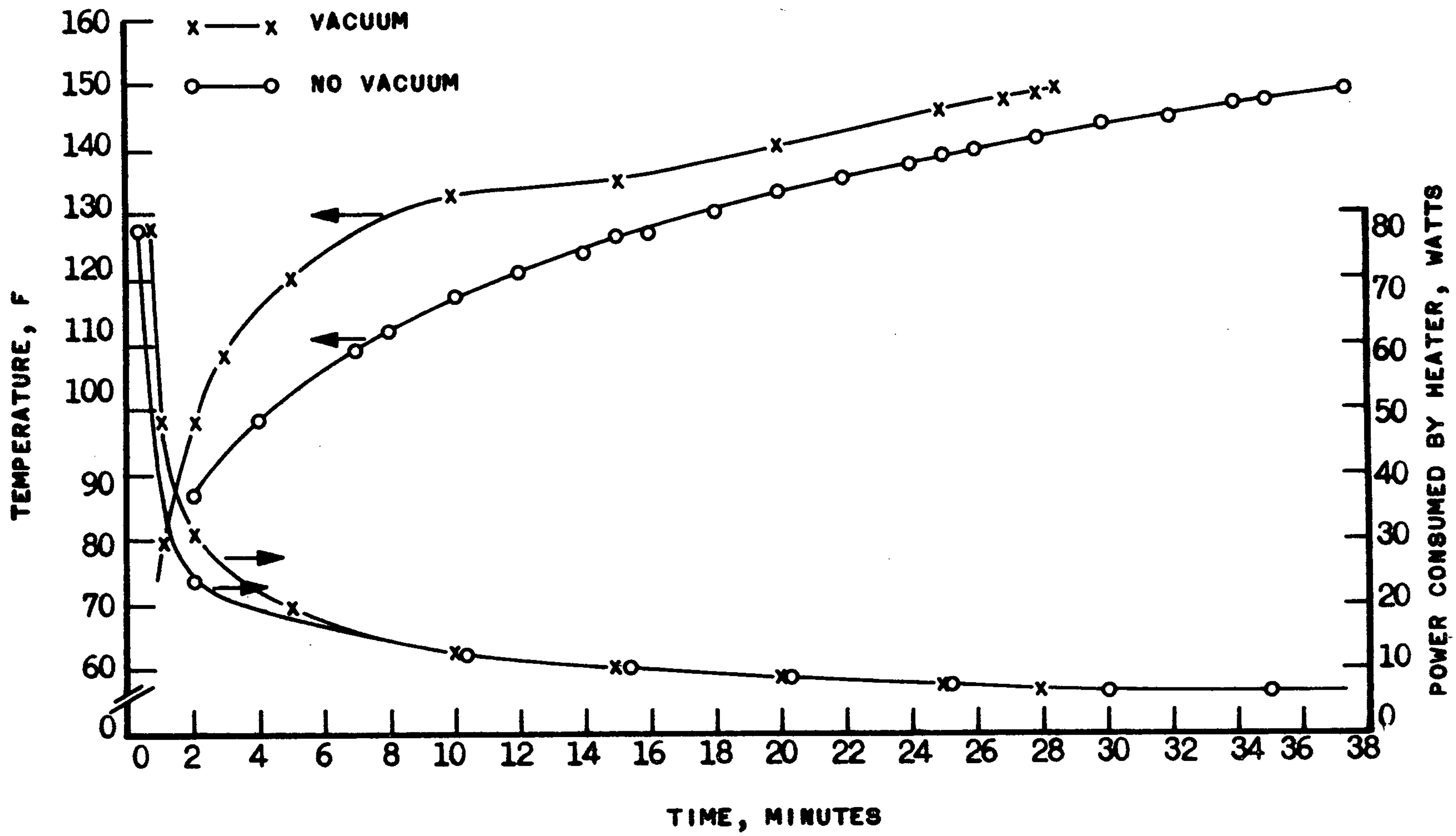


FIGURE V-4. HEATING TESTS WITH AND WITHOUT VACUUM other procedures were the same as those described in paragraph 4a above.

(2) Results of the convection test with variable heater orientation are shown in Table V-7. The analysis of variance is contained in Table V-8.

Table V-7. Results of Convection Test; Varied Heater Orientation

Can	11	12	13
Normal orientation	*155.9	150.9	155.4
	153.2	151.1	154.8
Upside down	151,7	147.6	157.0

*Temperature in °F after 25 minutes of heating

Table V-8. ANOVA for Convection Test; Varied Heater Orientation

Source	df	SS	MS	F	
Orientation	1	4.2450	4.24	1.4	not significant
Can	2	52.9335	26.4	8.7	significant at 5% level
Error	5	15.1415	3.03		
Total	8	72.3200			

It was concluded that convective heat transfer was of insignificant magnitude with the heater used and with 401 x 105 cans.

VI. TESTING OF MODEL FOODS

Experimental tests were conducted to determine heating times to attain 149 F and to check the effect of certain factors on heating times.

A. Food Items Used.

A homogeneous food and a heterogeneous food were used to represent the two basic types of food from a heat transfer viewpoint. Commercially procured Carnation turkey salad sandwich spread was the homogeneous item. The heterogeneous fodd was frankfurter chunks in a sauce of water and agar. A list of the properties of each food is given in Table VI-1.

Table VI-1. Properties of Model Foods

Property	Turkey Salad	Franks	Sauce
Weight in can, lb	0.488	0.21	0.23
Mass density, lb/ft^3	68.3	64.4	62.0
Specific heat, Btu/lb-F	0.84	0.72	1.0
Thermal conductivity, Btu/hr-ft F	0.21	0.24	0.36
Thermal Diffusivity, ft^2/hr	0.00366	0.00518	0.00581
Percent water	73.3	54.1	95

All meat frankfurters were obtained commercially and cut into chunks having length equal to diameter. Eleven chunks having a total weight of approximately 0.21 lb were placed in each can. One chunk was placed at the center of the can so that a thermocouple placed at the center of the can would be inside the chunk. The sauce consisted of water with 5 percent agar (by weight) to maintain a gel at temperatures of at least 160 F. A small amount of iodine was added to prevent bacterial growth. The cans were completely filled so that very little air space existed in the cans. Lids were put on while the contents were at 150 F to create a vacuum in the cans at room temperature.

The Carnation turkey salad sandwich spread was obtained in 401 x 105 pull-top aluminum cans each containing 0.488 lb. of sandwich spread. The meat pieces were relatively small with a few having maximum lengths of approximately 0.25 inches. Little or no void space was contained in the can.

B. Equipment.

The equipment used is described in detail in Appendix A. A Leeds and Northrup Speedomax G multipoint temperature recorder was utilized to monitor temperatures. A Stokes Model 146H vacuum pump was used.

C. Tests With Varied Atmosphere.

Although it has been shown that convection is not significant, the use of different atmospheres may cause differences in heating because of differences in heat conduction through the gases. The thermal conductivity of helium is 5.6 times that of air and 5.7 times that of nitrogen. Therefore tests were conducted with various atmospheres to determine what effects different atmospheres would cause. Carnation turkey salad sandwich spread was used for these tests.

1. Procedure.

The food heating test procedures outlined in Appendix D were followed. Initial food temperature was 70 F. Proportional heater control was used with the heater temperature set at 159 F. The heater was turned off at the end of 25 minutes for all tests. The parameter analyzed was the temperature of the upper probe thermocouple at the end of 25 minutes.

a. Tests at atmospheric pressure.

After the can was placed in the heater, (See Appendix C, paragraph B5) a hard vacuum was obtained in the chamber. Then dry air was fed into the chamber through the solenoid operated gas inlet valve until atmospheric pressure was reached.

b. Tests at 5 psia.

The procedure was the same as above with the following exception. After a hard vacuum was obtained in the chamber, the appropriate gas was fed into the chamber through the gas inlet valve until a chamber pressure of 5 psia was reached.

2. Results.

The results are given in Table VI-2. The analysis of variance for these tests is shown in Table VI-3.

Table VI-2. Results of Tests with Varied Atmosphere

Atmosphere	Can 11	Can 12	Can 13
Air, atmospheric pressure	*152.5	147.2	156.4
Air, 5 psia	155.9	150.9	155.4
70% O_2 - 30% N_2, 5 psia	153.6	151.9	155.1
70% O_2 - 30% He, 5 psia	152.7	152.4	151.9
Helium, 5 psia	156.1	153.0	153.4

*Temperature, F, of upper probe thermocouple after 25 minutes of heating.

Table VI-3. ANOVA for Tests with Varied Atmospheres

Source	df	SS	MS	F	
Atmosphere	4	11.33	2.83	0.66	
Can	2	34.37	17.19	3.98	Significant at 10% level
Error	8	4.32			
Total	14	80.28			

The interaction was treated as error. The variation due to atmosphere was insignificant; however, there were significant differences between cans at the 10% level.

The results of these tests indicated that there was a relatively small amount of heat transferred through the gas since the helium atmosphere did not improve the heat transfer and since there was insignificant variation between atmospheres. It was concluded that most of the heat was transferred by direct contact between the heater surface and the can surface. Heating curves for two varied atmosphere tests are illustrated in Figure VI-1.

D. Tests with Varied Initial Food Temperatures.

Initial food temperature was varied for heating tests with both types of food studied.

1. Procedure.

Three cans of frankfurter chunks and sauce and three cans of Carnation turkey salad sandwich spread were heated from initial temperatures of 0 F, 32 F and 70 F using the proportional control heater mode with heater temperature set at 159 F. Air at 5 psia was the atmosphere in the test chamber. The time required to obtain a mass average temperature of 149 F was determined for each test.

2. Results.

Results are presented in Table VI-4. Heating time increased with decreasing initial food temperature. Heating times were greater for the heterogeneous food. Heating curves for turkey salad and frankfurters and sauce are contained in Figures VI-2 and VI-3, respectively.

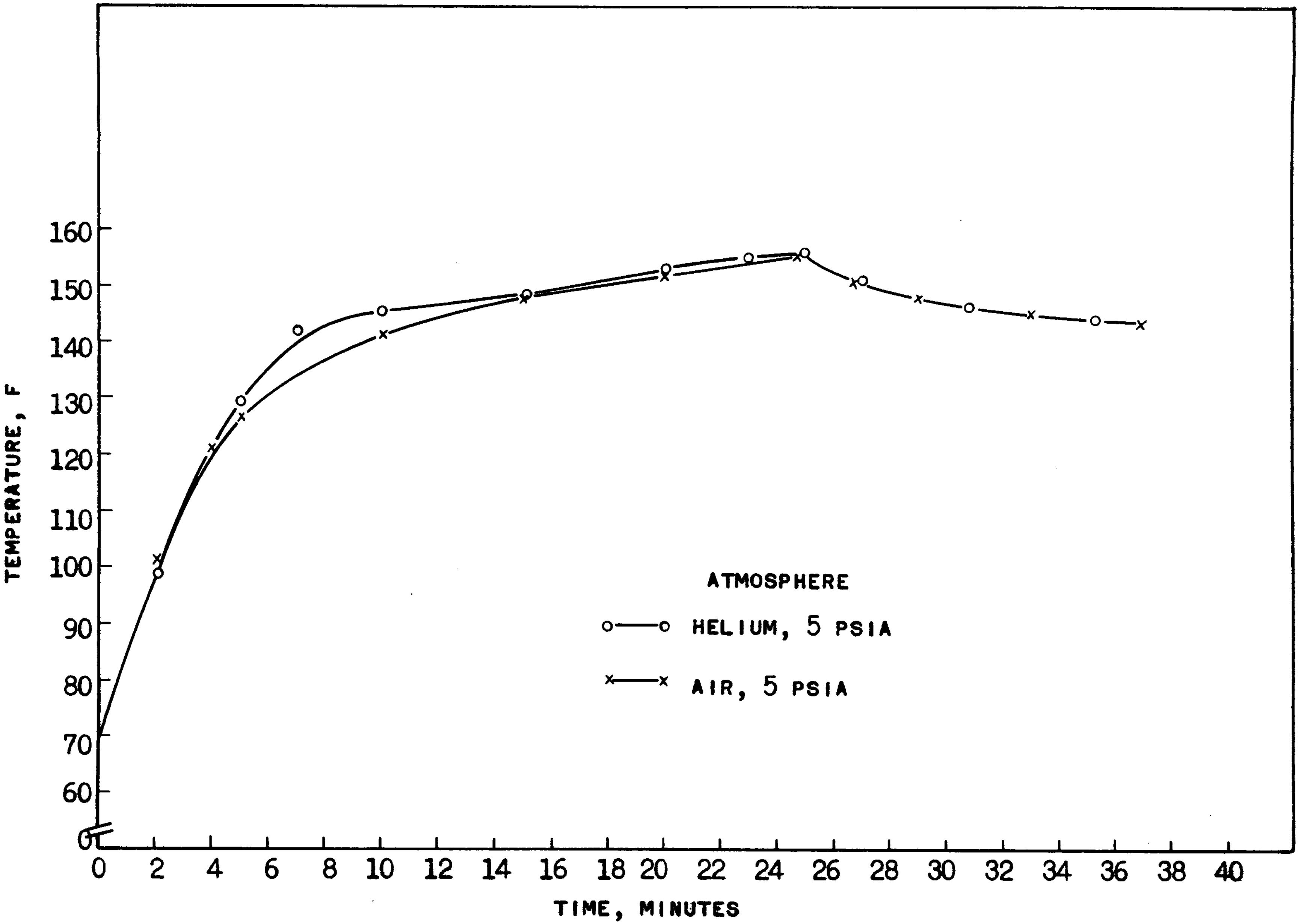


FIGURE VI-1. HEATING CURVES FOR VARIED ATMOSPHERE TESTS

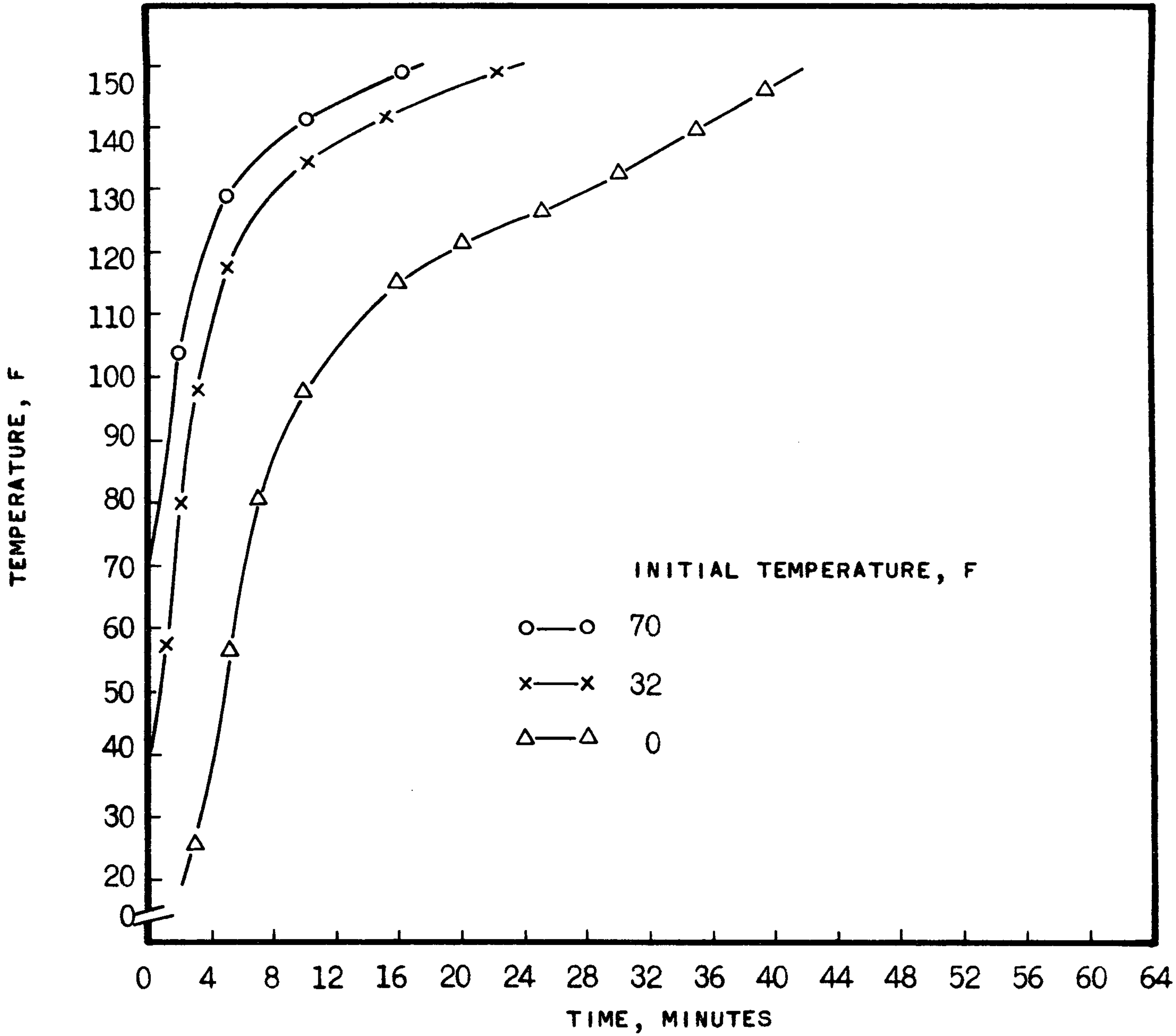


FIGURE VI-2. EFFECT OF INITIAL TEMPERATURE ON HEATING TIME FOR HOMOGENEOUS FOOD.

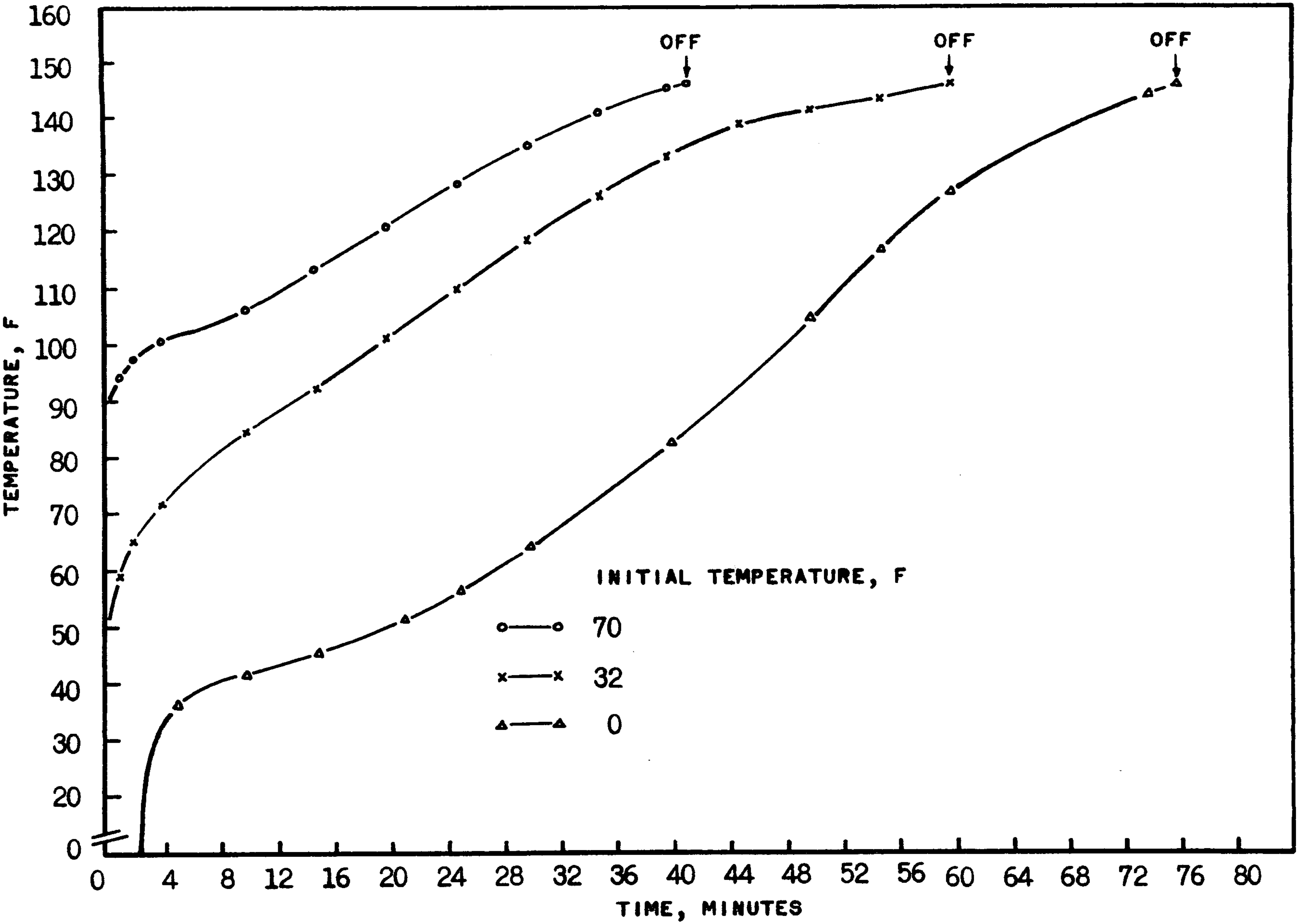


FIGURE VI-3 EFFECT OF INITIAL TEMPERATURE ON HEATING TIME FOR HETEROGENEOUS FOOD

Table VI-4. Results of Tests with Varied Initial Temperature

Type Food	Initial Temp., F	Can 14	Can 15	Can 16
Turkey salad	70	*22.0	26.5	27.0
Turkey salad	32	30.0	38.0	39.0
Turkey salad	0	53.0	52.0	66.0
		Can 20	Can 21	Can 22
Frankfurters	70	44.0	44.5	38.0
Frankfurters	32	49.0	62.0	51.0
Frankfurters	0	56.5	70.0	68.0

* Heating time to mass average temperature of 149 F.

E. Tests with varied heater control mode were conducted to compare heating with proportional control to heating with on-off control.

1. Procedure.

Three cans of Carnation turkey salad sandwich spread were heated from 70 F for 25 minutes at atmospheric pressure. For proportional heater control the heater temperature set point was 159 F and the heater voltage was 28 volts across each heater. For the on-off control mode the heater voltage was 28 volts for two replications and 20 volts for the third set of tests. The heater temperature cycled between 157 and 159 F. The parameter analyzed was the temperature of the upper probe thermocouple after heating for 25 minutes.

2. Results.

The results are presented in Table VI-5.

Table VI-5. Test Results with Varied Heater Control Mode

Control Mode	Heater Voltage	Can 11	Can 12	Can 13
Proportional	28	*153.1	152.2	153.5
Proportional	28	155.9	150.9	155.4
On-Off	28	145.6	148.3	157.7
On-Off	28	155.8	151.2	155.2
On-Off	20	157.8	150.5	155.8

* Temperature of upper probe thermocouple after heating for 25 minutes.

An analysis of variance for the 28 volt tests only is given in Table VI-6. There was no significant difference between proportional control and on-off control at 28 volts. The tests conducted with on-off control at 20 volts did not appear to be significantly different from the 28 volt tests.

Table VI-6. ANOVA for Tests with Varied Heater Control Mode

Source	df	SS	MS	F	
Control Mode	1	4.28	4.28	0.4	
Can	2	46.58	23.3	2.1	not significant at 10% level
CxC	2	17.42	8.71	0.8	
Error	6	66.00	11.00		
Total	11	134.28			

A comparison of heating curves for the three different heater treatments is given in Figure VI-4. Note that the proportional control heater test produced a higher initial temperature but the differences in temperature between the curves diminished with time.

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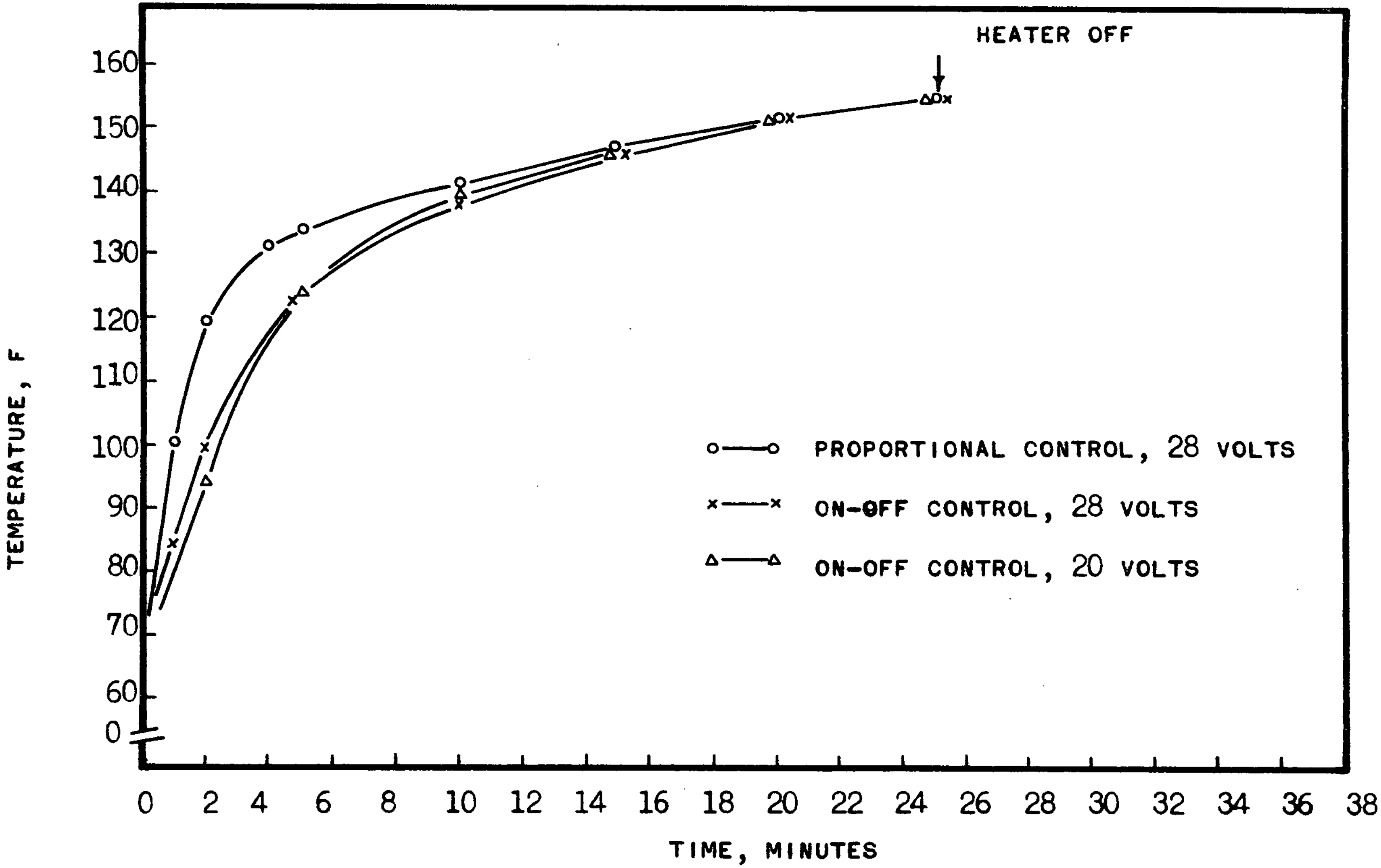


FIGURE VI-4. EFFECT OF HEATER CONTROL MODE ON HEATING TIME

APPENDIX A. EQUIPMENT DESCRIPTION

A. Test Chamber.

The test chamber shown in Figure A-1 is a Stokes Model 338B-0 Vacuum Shelf Dryer without shelves. Figure A-2 shows the food heater. The inside dimensions of the test chamber in inches are: 30 x 28 x 20.

1. Specifications.

The Stokes Model 338B-0 is fabricated entirely of welded carbon steel. It is designed for vacuum only with standard service to 100 microns. It is supplied with two 6-in diameter sight glasses in the chamber door. The chamber is sealed by use of a neoprene "O" Ring gasket contained in a machined groove in the door. Standard equipment includes a manually operated vacuum break valve, dial vacuum gage and pressure relief valve. The basic chamber is as shown in Stokes drawing No. 338-1-461 (Figure A-3) without shelves.

2. Modifications.

a. Four 1/2 inch gas ports were added to the chamber, two on the left side and two on the back. b. Three Conax TG-20-16 transducer glands with 3/4 inch NPT mounting threads were added on the right side to feed through 24 chromel-constantan thermocouple leads. c. Two Conax PL-18-8 power lead pressure seals with 3/4 inch NPT mounting threads were added on the right side to feed through 14 600-volt, 5 amp, silver plated copper wires and 2 iron-constantan thermocouple leads. d. A solenoid operated gas inlet valve was mounted in one of the rear gas ports for use when filling the chamber with gas other than room air. e. A manually operated valve was added to the vacuum line between the chamber and the vacuum pump. This allows the vacuum pump to be isolated from the system when a vacuum is to be held in the chamber for long periods of time. f. One thermocouple and power lead connector panel (Figure A-4) was mounted on the inside of the chamber to provide inside terminals for all of the thermocouple and power lead feed throughs. (1) The thermocouple connections are Omega miniature thermocouple connectors; black for iron-constantan and reddish brown for chromel-constantan. The thermocouple numbers on the

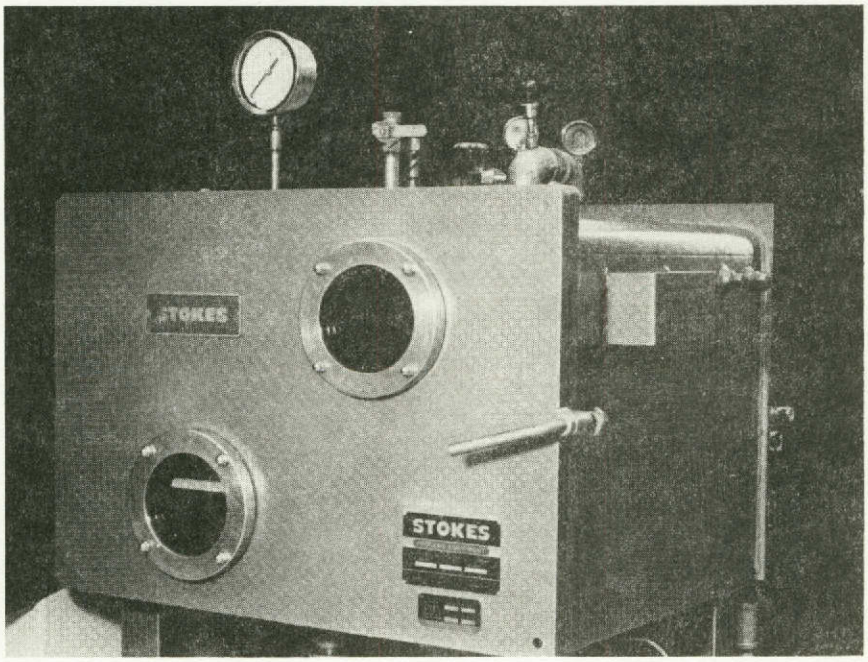


Figure A-1. Test Chamber

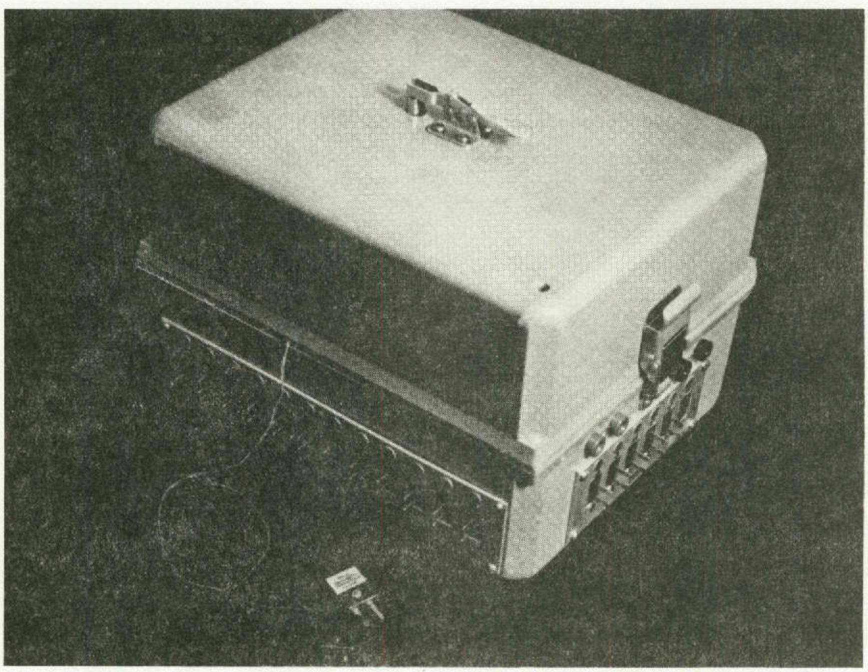
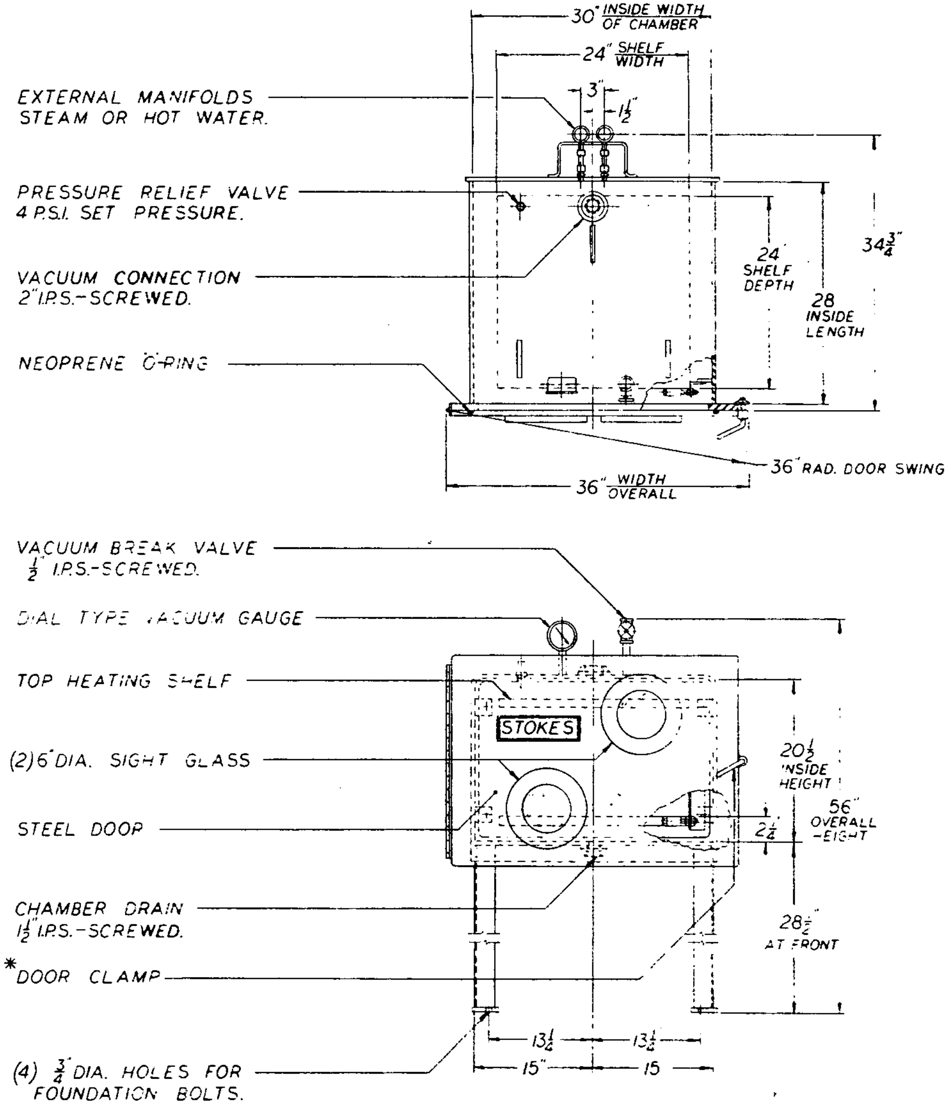
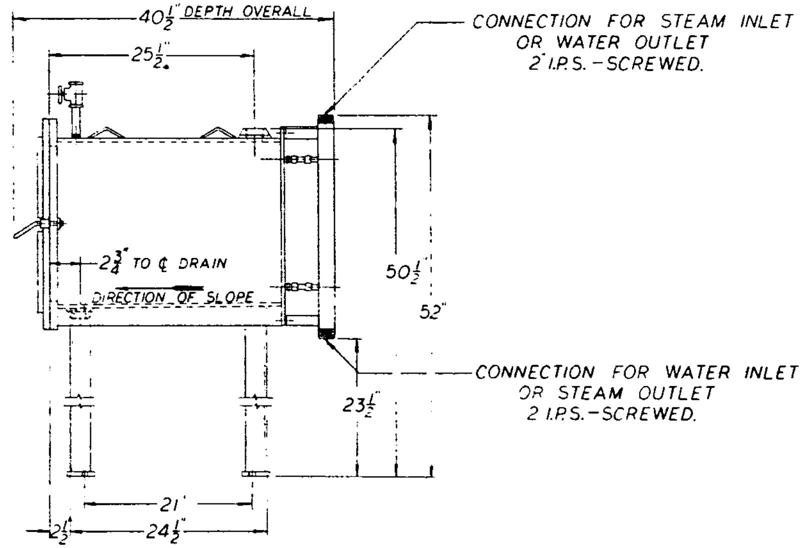


Figure A-2. Heater Assembly.





NOTES:

CHAMBER IS DESIGNED FOR VACUUM SERVICE ONLY-STANDARD SERVICE TO 100 MICRONS.

SHELVES ARE CONSTRUCTED FOR MAX. STEAM WORKING PRESSURE OF 50 P.S.I. IN ACCORDANCE WITH THE CURRENT A.S.M.E. CODE FOR UNFIRED PRESSURE VESSELS.

STANDARD CONSTRUCTION—WELDED CARBON STEEL.

*WHEN USED AS IMPREGNATOR ADDITIONAL DOOR CLAMPS REQ'D.

*NO INTERNAL PRESSURE-FLOODED CHAMBER ONLY.

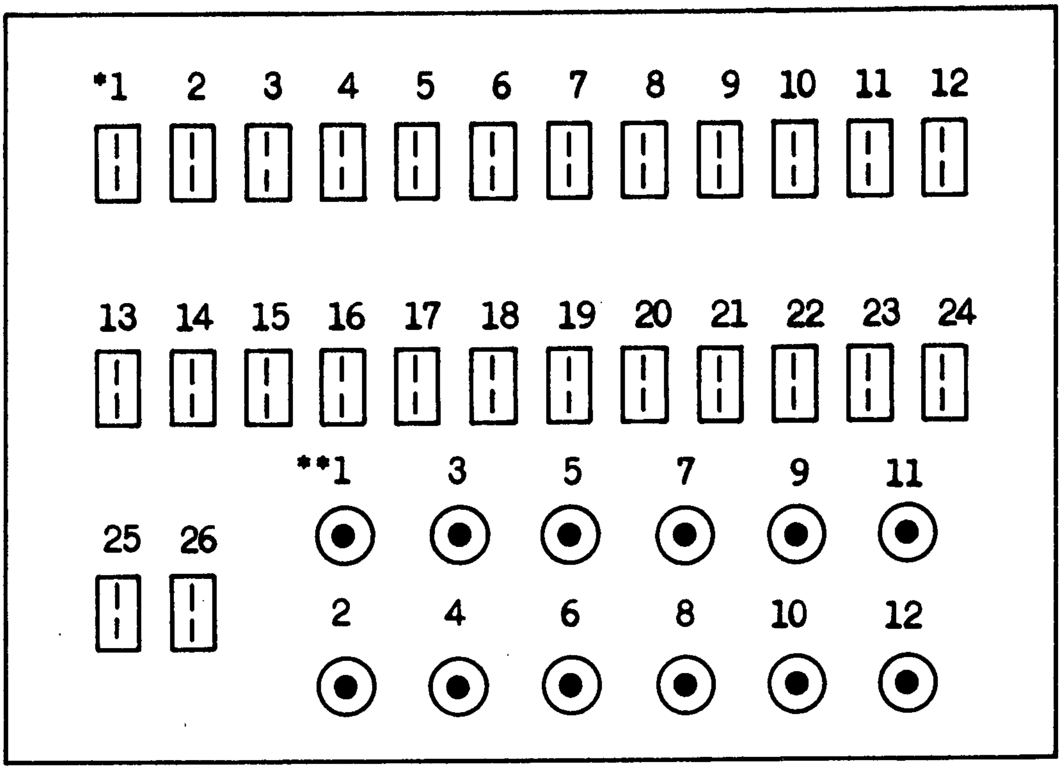
MODEL	NO. OF USABLE SHELVES	CLEARANCE BETWEEN SHELVES	NET WEIGHT LBS.
338B-1	1	16.300"	1280
338B-2	2	7.600"	1370
338B-3	3	4.800"	1460
338B-4	4	3.300"	1550
338B-5	5	2.500"	1640
338B-6	6	1.900"	1730

MODEL 338-B VACUUM SHELF DRYER OR *IMPREGNATOR

F.J. STOKES CORPORATION
PHILADELPHIA 20, PA., U.S.A.

DWG. NO. 338-1-461

Figure A-3. Model 338 B Vacuum Shelf Dryer.



* THERMOCOUPLE LEADS
** POWER LEADS

FIGURE A-4. THERMOCOUPLE AND POWER LEAD CONNECTOR PANEL.

panel correspond with the numbers on the outside ends of the thermocouple wires. (2) The power lead terminals are banana jacks for power leads 1-12. No terminals are supplied for leads 13 and 14. g. Work shelf. A formica covered work shelf is provided in the test chamber.

B. Heater.

The heater assembly is pictured in Figure A-2.

1. Heater element.

The basic heater element was made by Electro-Flex, Inc., Bloomfield, Connecticut. It consists of a bottom heater element and a side heater element, electrically separate, but bonded together into one heater unit. The heater was molded to fit a 401 x 105 aluminum can. The heater wires are contained in silicone rubber reinforced with fiberglas.

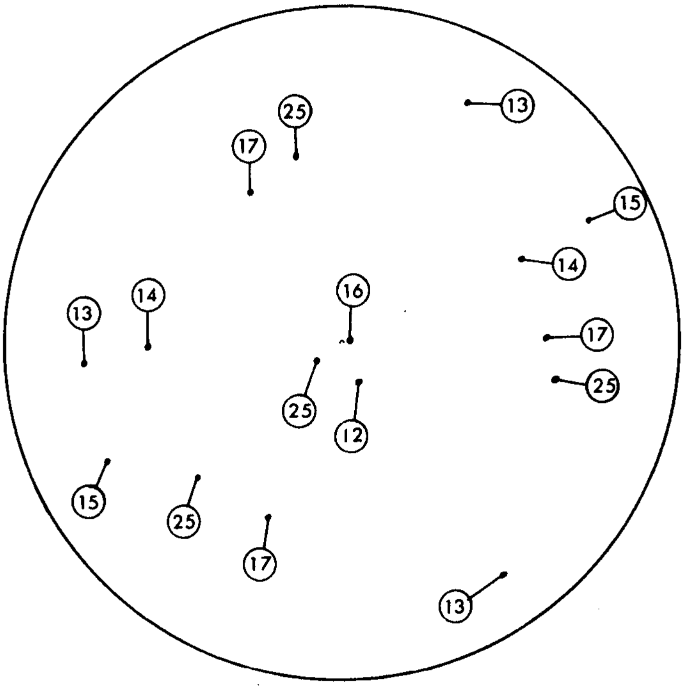
2. Thermocouples.

Seven chromel-constantan thermocouples were molded within the heater when it was made. Locations of these thermocouples are indicated in Figure A-5. Additional chromel-constantan thermocouples were threaded into the bottom and side heaters, located as shown in Figure A-5, with the thermocouple junctions placed at the surface of the heater facing the can. There are also six iron-constantan thermocouples threaded into the heater surface which monitor the heater temperature for the temperature controller. These iron-constantan thermocouples are all connected in parallel. All thermocouples are connected to the thermocouple connectors in side and end connector panels. The thermocouples are numbered in Figure A-5 to correspond with the connector to which they are connected. Several pairs of thermocouples are connected in parallel.

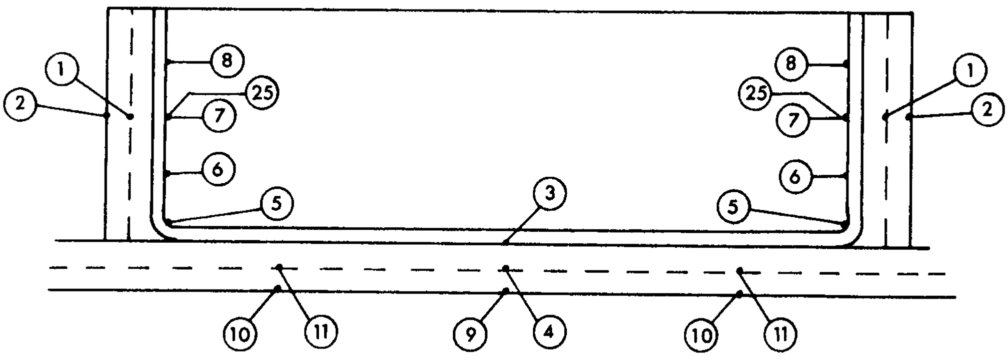
3. Remainder of heater assembly.

The remainder of the heater assembly consists of the plastic base and lid, the insulation and the heater terminals. The insulation is illustrated in Figure IV-24.

The heater lid is fastened to the bottom of the heater assembly with fasteners. The thermocouple probes are placed in the center of the 401 x 105 food can through the hole in the lid. A toggle clamp is positioned near the hole in the lid to hold the thermocouple probe down against the bottom of the can.



TOP SURFACE OF BOTTOM HEATER



CROSS SECTION OF HEATER

FIGURE A-5. LOCATIONS OF THERMOCOUPLES IN HEATER

The heater terminals are color coded banana jacks. The side heater terminals are green and the bottom heater terminals are black.

C. Controls.

Most of the controls are located in a separate control box which may be located on a table adjacent to the test chamber. The front control panel (Figure A-6) contains all of the controls and gages except for the manually operated vacuum break valve and vacuum inlet valve, multipoint temperature recorder controls and the chamber pressure gage.

1. Heater temperature controller and power supply. The heater temperature is controlled by a Barber Colman Model 537G-00319 Precision Controller. Power is supplied by a Barber Colman Model 610A-10 Pilot Amplifier.

a. Temperature controller.

The temperature controller requires a temperature input from an iron-constantan thermocouple. The temperature set point is variable. There is a proportional band adjustment on the controller. For a complete description of the controller, see Barber Colman Instruction Manual $\frac{1252}{1N7-6}$ which is supplied with the test chamber.

(1) For proportional control, the controller output is fed directly to the pilot amplifier. The output of the pilot amplifier varies with the signal from the controller.

(2) For on-off control, the controller output is switched to a Barber Colman Model 861A Auxiliary Control Relay which provides on-off control of the heater. In this mode the pilot amplifier receives a constant input from a 24-volt DC power supply and provides a constant output voltage. See Barber Colman Instructions $\frac{1502}{1N1-2}$ for a description of the Auxiliary Control Relay.

b. Pilot Amplifier.

The Model 610A-10 Pilot Amplifier provides DC power. Its output may be controlled by the input signal which is connected to it. Potentiometers are provided for varying the output voltage of the pilot amplifier in either control mode. Barber Colman Instruction Manual IN 1318-1A, which was pro-

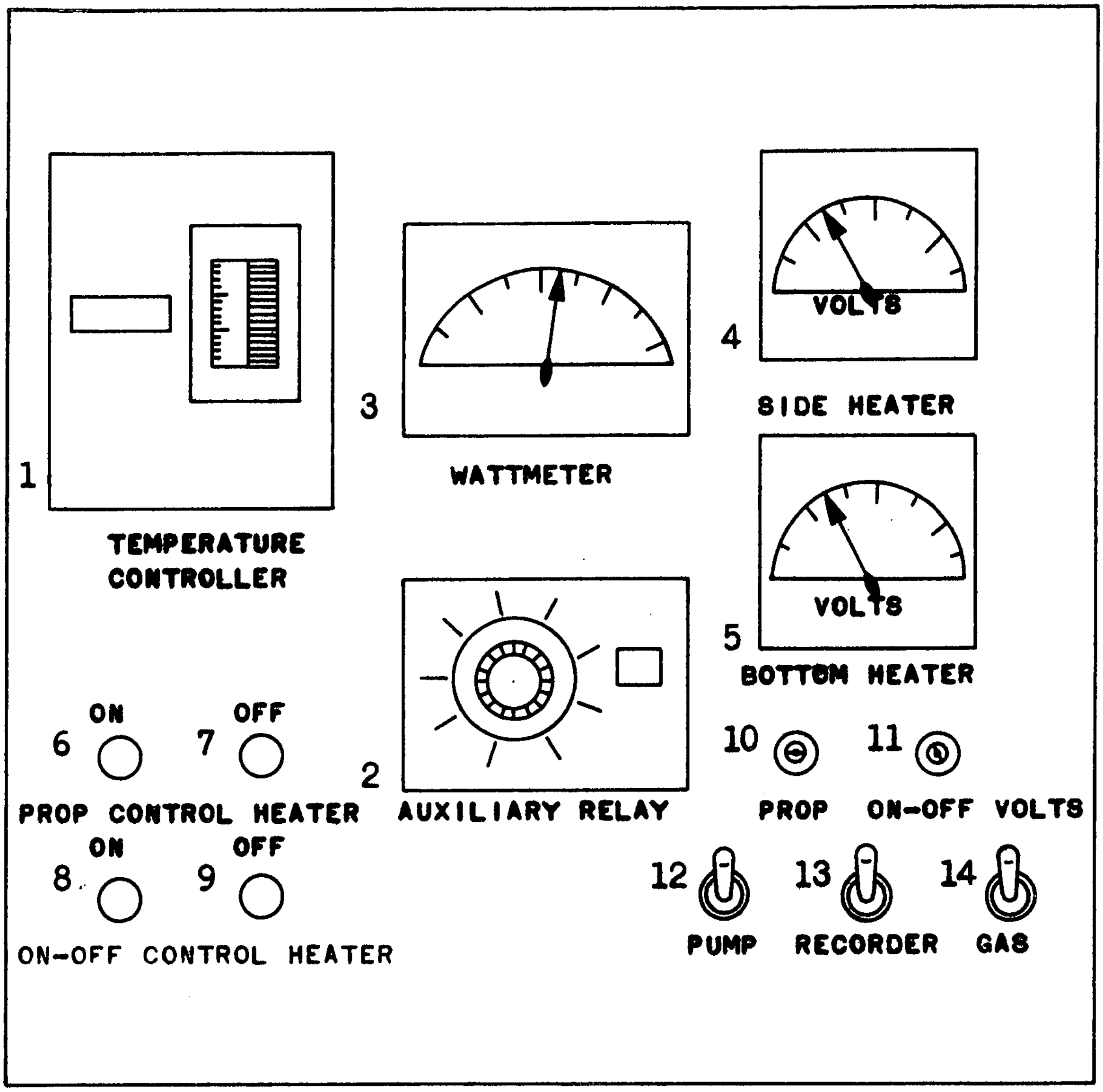


FIGURE A-6. CONTROL PANEL

vided with the test chamber, contains a description of the pilot amplifier.

The 610A-10 pilot amplifier is designed to work with load impedances between 30 and 150 ohms inductive load. When operating with a purely resistive load, the current should not exceed 2 amperes and the resistance should not be less than 30 ohms. With heaters having less resistance, an additional resistor can be placed in series with the heater.

2. Control panel.

The control panel is pictured in Figure A-6. The gages and controls are described as follows:

a. Temperature controller.

Item 1 is the temperature controller. The red indicator light is on when the controller is energized. The needle indicates the sensor temperature. Adjustment of the temperature set point is accomplished by turning the thumbwheel. To adjust the proportional band and the offset, the two screws must be loosened and the front of the controller must be pulled out from the panel (see Barber Colman Instruction Manual $\frac{1252}{1N7-6}$).

b. Auxiliary control relay.

Item 2 is the Auxiliary Control Relay. The green light is on when the heater is on in the on-off control mode. The control knob adjusts the on-off action set point within the proportional band of the temperature controller.

c. Wattmeter.

The wattmeter is item 3. The volt terminals of the meter must be connected to measure the voltage drop across the heater and the ampere terminals must be connected in series with the heater.

d. Voltmeters.

Items 4 and 5 are DC voltmeters which measure the voltage drops across the side and bottom heaters, respectively.

e. Proportion control heater switches.

Item 6 is a Switchcraft momentary contact pushbutton switch which turns on the heater for the proportional mode of control. The button is lit by a 6-volt lamp when the heater is on in this mode. A momentary contact pushbutton switch, item 7, turns off the heater.

f. On-off control heater switches.

For on-off heater control, the heater is energized by depressing another pushbutton switch, item.8. This button is lit whenever the on-off heater control mode is on. Item 9 is the turn-off switch for this mode.

g. Proportional control voltage adjustment.

The proportional control heater voltage is adjusted with a 5,000 ohm potentiometer, item 10. To make this adjustment, the heater must be turned on in proportional control mode, and drawing full power. A clockwise adjustment of the potentiometer screw increases the voltage.

h. On-off control voltage adjustment.

The on-off control heater voltage is adjusted with a 10,000 ohm potentiometer, item 11. To increase the voltage turn the potentiometer screw clockwise while the heater is on, in the on-off control mode.

i. Toggle switches.

Items 12, 13 and 14 are 10 amp-120 volt, SPST toggle switches. The first switch may be used to control the vacuum pump by plugging the vacuum pump power cord to the 110 volt power outlet in the rear of the control box. The second switch may be used to control the power to the temperature recorder in the same manner. The third switch operates the solenoid gas inlet valve. This value is closed when there is no power to the solenoid.

3. Control circuits.

The primary control circuits are the heater mode control circuits and the switching circuits. These are illustrated in Figures A-7 and A-8.

a. Heater switch circuits.

The heater switch circuits are for energizing the main power relay and the mode control relays. The main power relay provides power to the temperature controller and the pilot amplifier for both control modes. The mode control

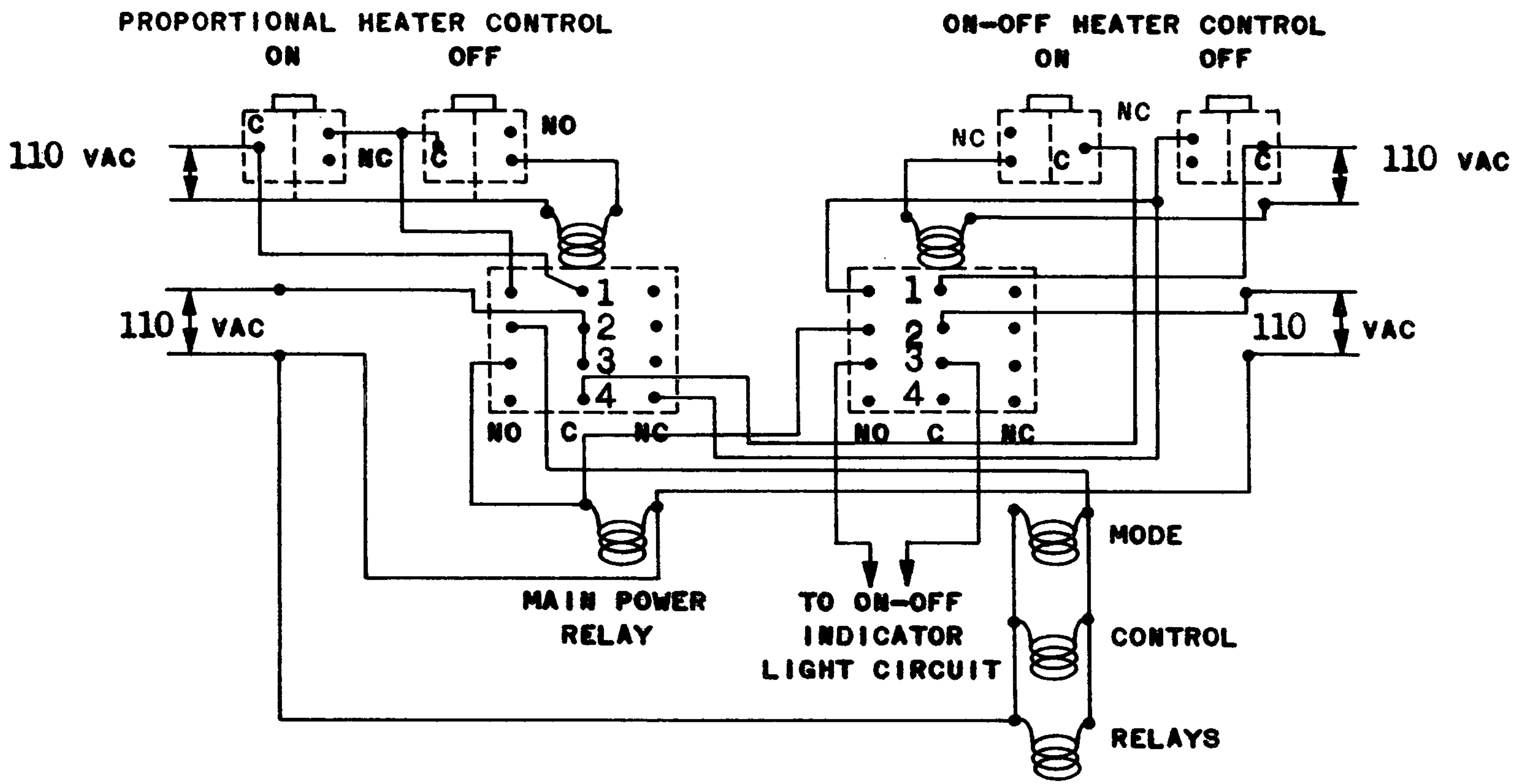


FIGURE A-7. HEATER SWITCH CIRCUIT.

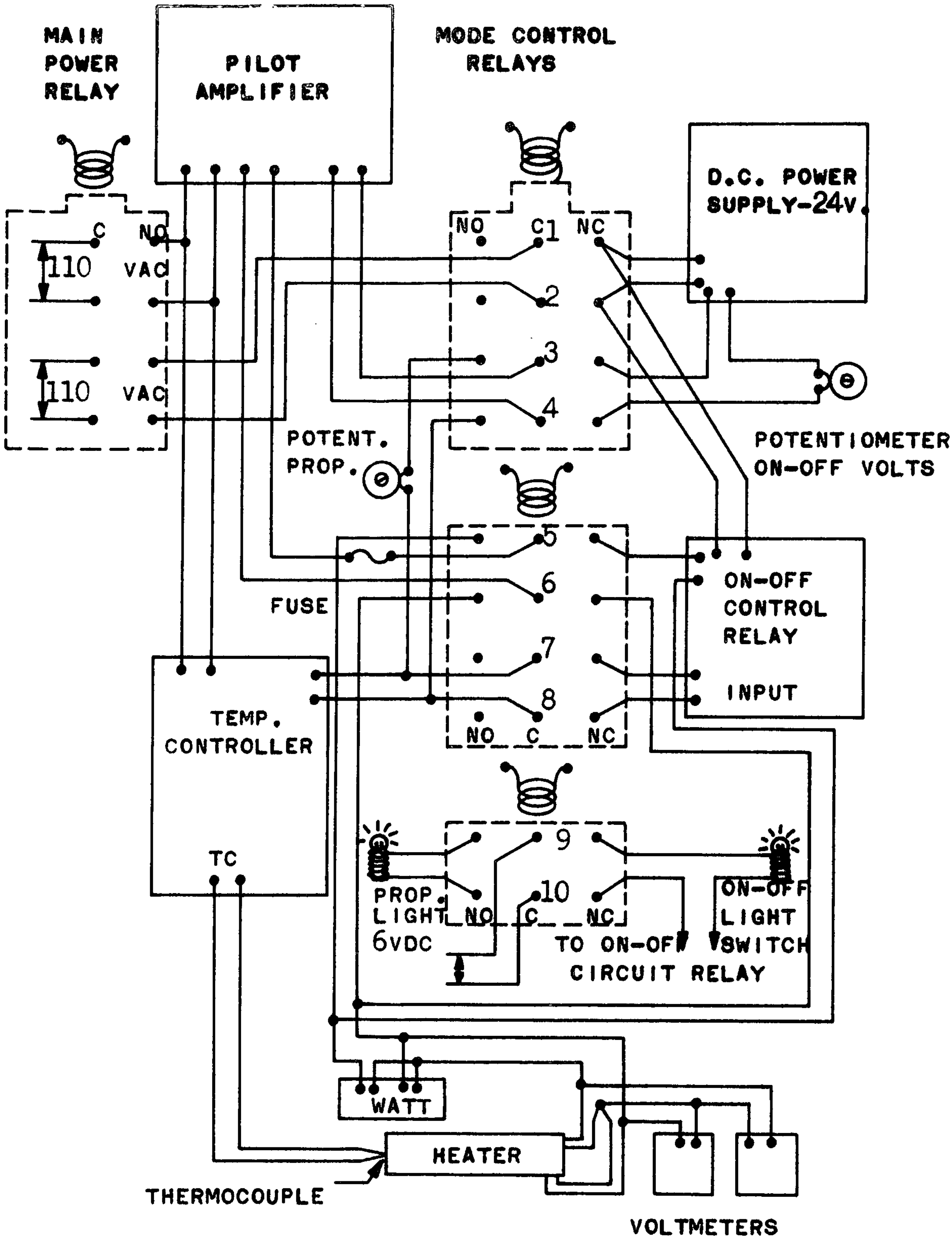


FIGURE A-8. HEATER MODE CONTROL CIRCUITS relays are tied together to act as one 10-pole, double throw relay.

b. Heater mode control circuits.

The heater mode control circuits are all linked to the mode control relays. When energized the mode control relays connect the necessary circuits to provide proportional heater control. When not energized, on-off control is provided by the "normally closed" contacts. Both modes cannot be energized at the same time. If both heater control turn-on switches are pushed simultaneously, the proportional control mode will be activated.

c. Relays.

The main power relay (Figure A-8) is a 4PDT, 120 volt continuous, 15 amp. relay. Only the normally open contacts are used.

The mode control relays (Figure A-8) are two 4PDT, 120 volt continuous, 8 amp. relays and one 2PDT, 120 volt continuous, 1 amp, relay. The lower current rated relay is used to switch the heater mode indicator lamps which illuminate the heater turn-on pushbuttons.

The heater switch circuit relays (Figure A-7) are 4PDT 120 volt continuous, 8 amp relays. Due to the low power drawn by these circuits, relays with a 2 amp rating would suffice.

d. DC power supply.

The 24 volt DC power supply (Figure A-8) is a Wanless Model DPS-3 20 watt power supply rated at 1 amp.

e. Illumination of switches.

The heater turn-on switches are illuminated by 6-volt lamps which are powered by 6-volt DC power (Figure A-8).

f. Fuse.

A 2.5-ampere fuse is installed in one of the heater power lines to protect the heater.

D. Thermocouple Probes.

A thermocouple probe is pictured in Figure A-9. The lower part of the probe is a 21 ga. stainless steel hypodermic needle having an outside diameter of 0.032 inch with the tip crimped and filed to a blunt point. The handle is a length of stainless steel tubing which is joined to the needle by a force fit.

Two thermocouples are normally provided in a probe, one located approximately 0.05 inch from the tip and one located 0.18 inch from the tip. Chromel and constantan wires 0.002 inch in diameter are used. They are each insulated with plastic tubing. Lead wires are attached to the thermocouple wires in the probe handle. The probe handle is filled with an epoxy cement.

An additional thermocouple may be placed in a probe by using a 19 ga. needle.

Omega miniature thermocouple connectors are connected to the ends of the thermocouple lead wires.

Figure A-10 shows the thermocouple probe in place.

Appendix B Operating Instructions

The test chamber and accessory equipment were designed to be operated with a minimum of operating instructions. The following instructions should provide the operator with all of the basic procedures used in operating the equipment.

A. Obtaining a Vacuum in the Test Chamber.

To create a vacuum in the test chamber close the front door tightly, close the vacuum - break valve, open the valve between the vacuum pump and the test chamber and start the vacuum pump.

The vacuum gage indicates the pressure difference in inches of mercury between the pressure in the test chamber and atmospheric pressure. To obtain a pressure of 5 psia (10.18 inches Hg) subtract 10.18 from the atmospheric pressure (in inches Hg) to obtain the desired vacuum gage reading.

B. Change of Chamber Atmosphere.

To introduce an atmosphere other than air into the chamber, obtain a hard vacuum in the test chamber. Then connect a supply of the desired gas to the gas inlet valve. Open the gas inlet valve using the toggle switch on the control panel. Close the gas inlet valve when the desired chamber pressure has been reached.

C. Operating the Heater.

Insure that the heater leads from the heater assembly are connected to the proper power lead connections in the thermocouple and

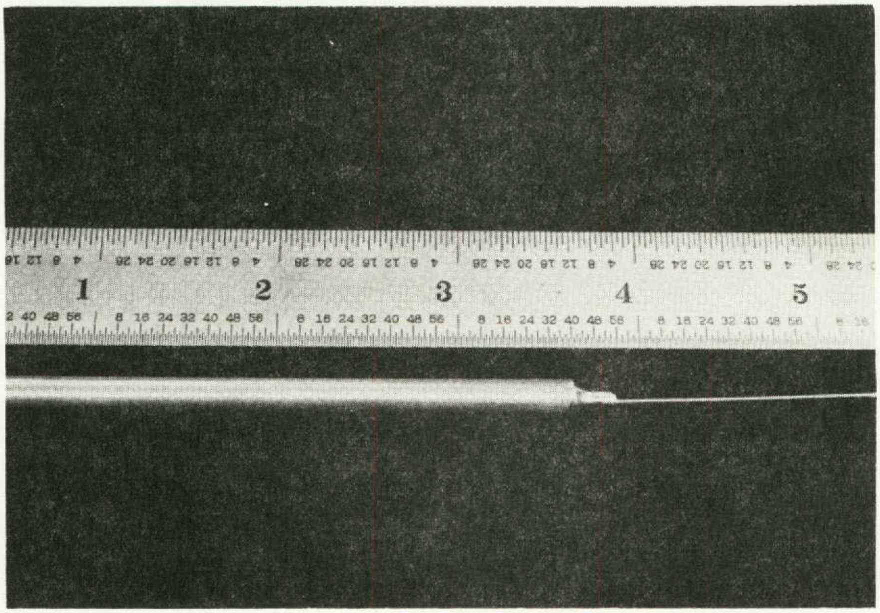


Figure A-9. Thermocouple Probe.

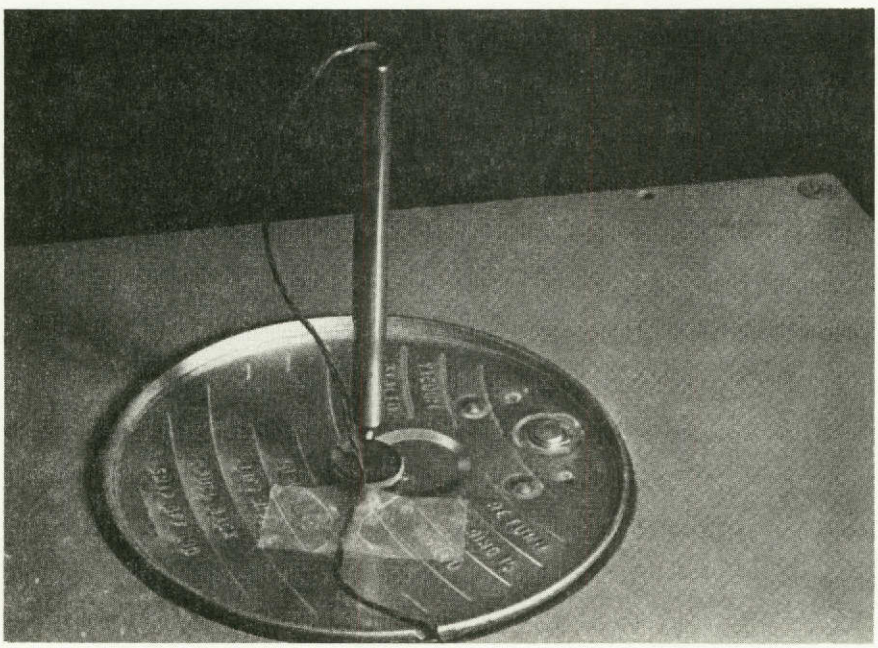


Figure A-10. Thermocouple Probe in Can in Heater.

power lead connector panel inside the test chamber. The power leads exiting the test chamber must be connected to the rear of the control box.

Turn on the heater in the desired control mode by pushing the appropriate switch on the control panel. Before the heater has reached the set temperature, the voltmeters should indicate the voltage at which the heaters have been set.

Turn the heater off by pushing the appropriate switch on the control panel. If both control mode "on" switches are depressed, the heater will be in proportional control mode.

D. Setting the Heater Temperature.

First set the setpoint adjust dial to the desired temperature. After the heater has reached the set point, maintain the red needle at the desired temperature by adjusting the setpoint adjust dial. The red needle indicates the actual temperature at the thermocouple locations in the heater.

To obtain a smooth proportional control action adjust the proportional band potentiometer and the offset potentiometer in the temperature controller according to the directions in Barber-Colman Instruction Manual $\frac{1252}{1N7-6}$.

E. Heater Voltage Adjustment.

To adjust the heater voltage in the proportional control mode, the heater must be operating in the proportional mode, and drawing full power (heater temperature below the temperature set point). Rotate the proportional voltage potentiometer on the control panel clockwise to increase the voltage.

Similarly to adjust the heater voltage in the on-off control mode, operate the heater in the on-off mode at full power. Rotate the on-off voltage potentiometer clockwise to increase the voltage.

Appendix C Food Heating Test Procedures

The procedures outlined are for a typical test to determine the heating time from a given initial food temperature to a mass average temperature of 149 F in a closed 401 x 105 food can.

A. Can Preparation.

1. Remove the pull ring from the can lid by scribing a line with a knife. Pry off the pull ring. (Note: this step is

optional. It is done primarily to simplify gluing of the rubber disk on the lid and to allow the lid insulation to fit closer to the lid.)

2. Scratch the center of the lid lightly with medium sandpaper to provide a better gluing surface for the rubber disk.

3. Mark the center of the can lid.

4. Glue a 1/2-inch diameter by 1/16-inch thick rubber disk to the center of the can lid using Eastmans 910 adhesive or any similar adhesive. Place a weight on the disk until the glue sets.

5. Punch a hole through the center of the rubber disk and the can lid with a pointed 20 ga. needle.

6. Mark the location of the hole with a ballpoint pen.

7. File a 1/16-inch x 1/16-inch notch in the rim of the can.

8. Equilibrate the can at the desired initial temperature. (Note: equilibration is much faster with the can in a liquid rather than in air.)

B. Conducting a Test.

Before inserting the can in the heater, it is desirable to accomplish some preliminary steps to minimize the time that the can is in the heater prior to heater turn-on. If the can is at a different initial temperature than the heater, there will be some heat transferred before the heater is turned on.

1. Place the heater assembly in the test chamber. Make sure that all necessary electrical connections are made and that the heater is functional.

2. Connect the thermocouple probe connections to the thermocouple connector panel in the test chamber. (Note: An exception to this procedure is when heating foods from an initial temperature below freezing. Then it is necessary to freeze the probe in the can and make these connections after placing the can in the heater.)

3. Insure that the heater cavity is clean and free of dust or foreign particles which would cause poor heater-can contact.

4. Set the temperature controller at the desired set point temperature.

5. Place the can of food firmly into the heater cavity with the filed notch facing the rear of the test chamber. Place the

probe in the can using one of the two following alternative methods:

a. Alternative 1.

Hold the heater lid in the left hand about one inch above the heater. With the right hand place the probe through the hole in the heater lid and then start the probe into the lid of the food can.

Attach the heater lid to the bottom of the heater assembly by clamping the two fasteners on the lid.

Push the probe down to the bottom of the food can and move the toggle lever on the heater lid to hold the probe down securely.

Using this alternative the thermocouple leads exit through the top of the heater lid.

This alternative cannot be used at initial temperatures below freezing when the probe is frozen in the food can.

b. Alternative 2.

This alternative must be used when the probe is frozen in the can.

Freeze the probe in the can so that it rests on the bottom of the can. Place the can in the heater cavity.

Connect the thermocouple probe connections to the thermocouple connector panel.

Run the thermocouple lead wire down along the probe handle. Tape the lead wires down so that they are secured in the notch in the can rim. Allow enough slack in the probe lead wires to that the heater lid will fit securely against the food can without interfering with the lead wires.

Tape down the thermocouple lead wires over the black dot at the edge of the bottom of the heater assembly so that the notch in the heater lid fits over the wires.

Place the heater lid on the bottom of the heater assembly so that the thermocouple probe handle goes up through the hole in the heater lid. Clamp the lid to the bottom with the fasteners.

Move the toggle lever on the heater lid to hold the probe down securely.

If the thermocouple leads are not placed in the notches, it is very likely that the leads will be pinched together and shorted out.

6. Shut the door of the test chamber.

7. Omit this step if atmospheric pressure is used. Open the manually controlled valve between the test chamber and the vacuum pump. Turn on the vacuum pump. Turn it off when the appropriate pressure has been reached (To obtain 5 psia, subtract 10.18 in Hg from atmospheric pressure in In. Hg). Close the valve between the test chamber and the vacuum pump. (See paragraph 14 below if a gas other than air is to be used.)

8. Turn on the temperature recorder.

9. Turn on the heater in the desired control mode. Record the time of heater turn-on.

10. Monitor the test.

   a. The heater voltmeter should initially indicate the set voltage if the heater is operating properly.

   b. The temperatures should rise.

   c. The red needle on the temperature controller should approach the set temperature when operating in either control mode.

11. Turn the heater off when the cooler probe thermocouple has reached 149 F. Record the time of heater turn-off.

12. Let the temperatures equilibrate for a period of 5 to 10 minutes after the two probe thermocouples reach the same temperature.

13. Shut off the temperature recorder.

   If a vacuum was used, open the manual vacuum break valve.

   Remove the heater lid and the thermocouple probe.

   Remove the can from the heater.

   If a subsequent test is to be conducted, place a cool food can in the heater until the heater has returned to room temperature.

14. For testing in atmospheres other than air, use the following procedures.

   Connect the gas source to the inlet of the solenoid operated gas inlet valve.

At step B7 above, operate the vacuum pump until a hard vacuum has been reached in the test chamber. Then close the valve between the test chamber and the vacuum pump and turn off the vacuum pump.

Open the gas inlet valve with the gas inlet switch on the control panel. Close the gas inlet valve when the desired pressure has been reached. If atmospheric pressure is desired, close the gas inlet valve at the moment atmospheric pressure is reached.

Do not allow pressure to build up in the chamber. Since the gas source will be at a higher pressure than atmospheric pressure, it would be easy to exceed the maximum pressure of 4 psig which is allowed in the chamber. Should this occur, the pressure relief valve would open and prevent damage to the chamber.