A PRELIMINARY STUDY OF THE HEATING AND TEMPERATURE DISTRIBUTION IN AN ELECTRIC RANGE OVEN

by

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INTRODUCTION

To the home economist the operational characteristics of the oven of the domestic range are of great interest and importance. Knowledge of these permit use of the oven with efficiency in fuel consumption and success in processing foods. Answers to the following questions should be available. What variations in temperature occur throughout the oven? How does the temperature distribution change upon addition of the "load"? How does the power consumption depend on the "load"? What is the oven's heating efficiency---that is, what part of the total power consumed is actually used for heating the "load"?

The oven of the domestic gas range has been quite thoroughly investigated. Monroe (11) found uneven temperature distribution in both the empty and the "loaded" gas oven. The heating efficiency of the air-insulated oven she used increased from about 1 per cent with only one pan in the oven to about 6 per cent with 8 pans, which nearly filled the oven. Finney and Barmore (2) showed the greater uniformity of baked products attained with the reduction of door size so far as possible and with the proper insulation of the oven. Others (3, 4, 12, 13, 14) have investigated the relative thermal efficiencies of utensils made of different materials and finishes in gas and electric ovens. In each case it was found that choice of utensil is of far greater importance with the gas oven than with the electric oven.

This study was designed to answer the above questions for an electric oven, using utensils made of a material acceptable for heating electrically. Although but one oven was used, it is believed that results obtained parallel those that would be obtained for other electric ovens, since the method of heating and insulating the ovens of electric ranges has been quite well standardized in the past few years.

APPARATUS

Stove

An Electromaster apartment-sized electric range, Model T41-1, manufactured by Electromaster, Inc., Mount Clemens, Michigan, was used. Figures 1 and 2 show two views of the range. The inside dimensions of the oven were as follows: height, 38.5 cm; width, 42 cm; depth, 50.5 cm. The oven was insulated with approximately 5.08 cm of glass wool, and lined with black porcelain enamel. Figure 3 shows the oven units. For preheat, the control knob was turned past "On" to "Broil", so that both units were turned on; then the knob was returned to the desired temperature. After preheating, both units turned off, and during reheat intervals only the lower unit turned on. The upper unit had a rated capacity of 2.5 KW, the lower unit, 2.0 KW.

Thermocouples

Since the use of an ordinary liquid-in-glass thermometer would have necessitated opening of the oven door, thereby permitting a loss of heat and a consequent error in results, thermocouples were selected for use in measuring the temperatures within the oven. There were several advantages in the use of Chromel P-Alumel thermocouples. The emf-temperature curve in the temperature range used is very nearly a straight line. They

Fig. 1. Apparatus for measuring temperatures.

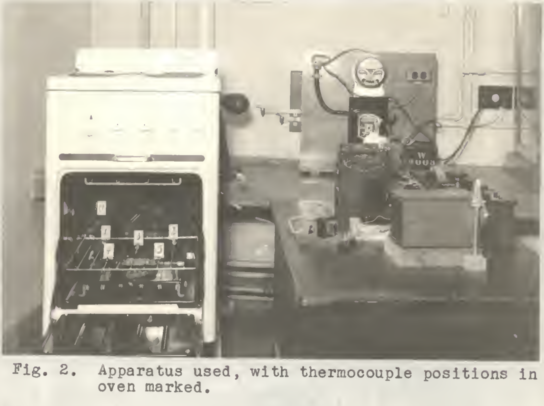

Fig. 2. Apparatus used, with thermocouple positions in oven marked.

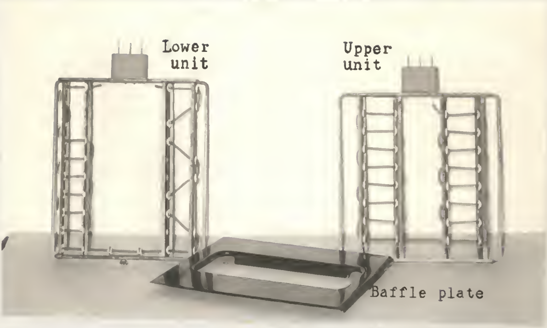

Fig. 3. Oven units with baffle plate for lower unit.

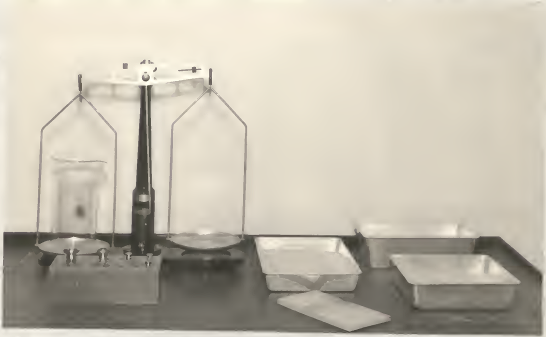

Fig. 4. Three pan sizes used, sand-weighing apparatus and sand-leveling board.

are easily welded, and they normally have so heavy an oxide coating (from exposure to air) that it is not necessary to insulate the two wires of each thermoelement from each other, or different elements from each other. The latter was one of the main advantages in this study, since the opening through which the wires were admitted to the interior of the stove, the oven vent, was too small to have permitted wires that required heavy insulation from each other. Also, since in normal operation of the range heated air passes freely from the vent pipe, an error would have resulted had the vent pipe been closed by the wires.

Eleven Chromel P-Alumel thermocouples were welded, then calibrated at three points: the boiling point of water, the freezing point of tin, and the freezing point of lead. The operational time cycle of the oven limited the number of thermocouples that could be used at any one time, so only seven of the eleven thermocouples were used. The calibration points for these are shown in Table 1.

Table 1. Calibration points for thermocouples used.

Thermocouple number	EMF in millivolts		
	Steam point 99.076 °C.	Tin point 231.89 °C.	Lead point 327.4 °C.
0	4.121	9.415	13.305
1	4.089	9.355	13.215
2	4.100	9.325	13.145
3	4.087	9.355	13.225
4	4.102	9.440	13.210
5	4.111	9.375	13.230
6	4.108	9.390	13.230

Table 2 shows a typical set of steam-point data, those readings taken for thermocouple 0. The temperature was found (from boiling-point tables), corresponding to the barometric pressure, 735.25 mm Hg, and the emf used as shown in Table 1 was the average of 10 readings taken at half-minute intervals.

Table 2. EMF of thermocouple 0 at boiling point of water.

Time (min.)	EMF (mv)	Time (min.)	EMF (mv)
0.5	4.1210	3.0	4.1208
1.0	4.1210	3.5	4.1214
1.5	4.1223	4.0	4.1205
2.0	4.1236	4.5	4.1202
2.5	4.1200	5.0	4.1206

Figure 5 shows the curve from which the emf corresponding to the temperature at which tin freezes (231.89 °C.) was found for thermocouple 0. Figure 6 shows the similar curve for the freezing point of lead (327.4 °C.) for thermocouple 0. Figure 7 is the calibration curve for thermocouple 0. Similar curves were obtained for the several thermocouples. A single curve was used for thermocouples 1 and 3, and a single one for thermocouples 5 and 6. In each case a straight-line approximation was made to the experimentally-found points.

To facilitate reading the thermocouples, a switch which accommodated all of them and permitted the use of but one reference junction was used.

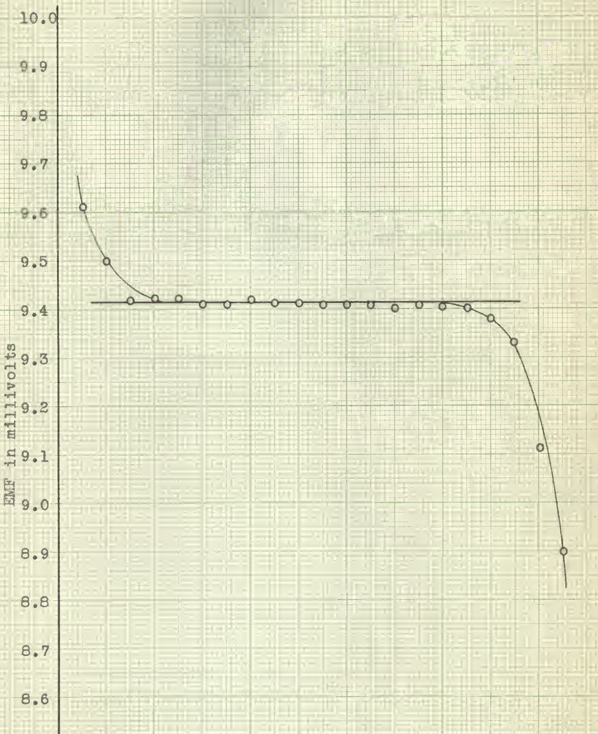

Fig. 5. Tin freezing point determination for thermocouple 0.

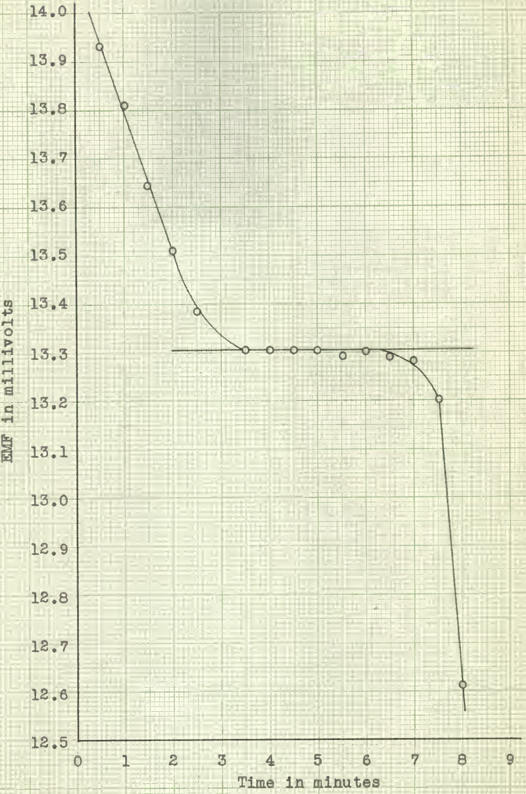

Fig. 6. Lead freezing point determination for thermocouple O.

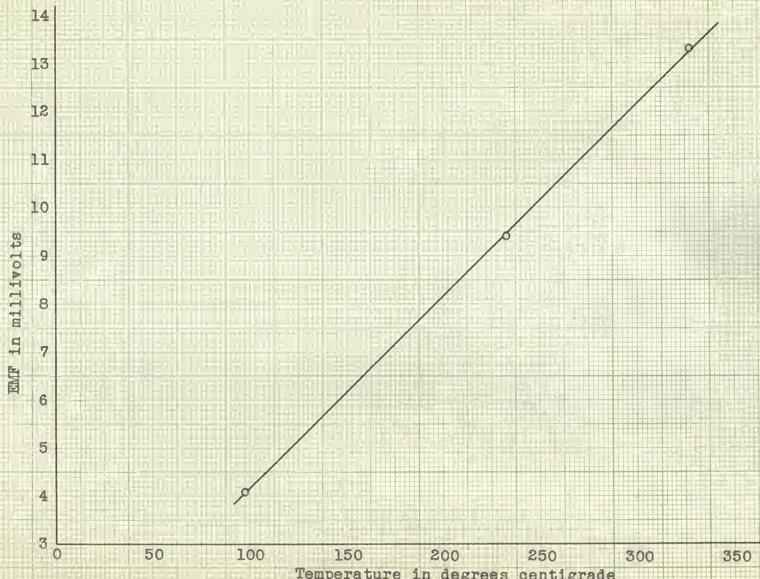

Fig. 7. Calibration curve for thermocouple O.

Pans and Cooking Medium

Aluminum pans were chosen because they are representative of those used by housewives, and because it has been shown (4, 13) that aluminum is a satisfactory material for use in an electric oven. Ottawa sand was used for the cooking medium for several reasons. The moisture content was low, not greater than one per cent by weight, so the specific heat does not vary as it does for food, due to loss of moisture during the cooking. It is not known whether or not chemical reactions which take place in foods affect the temperatures obtained, but such changes were eliminated by the selection of a substance of constant chemical composition. Ottawa sand contains no organic matter, and the size and shape of the grains were uniform, which made possible a more uniform incorporation of air. Also, the sand heated slowly enough so that it was possible to find variations in temperature.

Each pan contained 2 pounds (907.2 gm) of sand, which was leveled with a small board. The sizes of the pans used, and other apparatus used with them are shown in Figs. 4, 12, 13, and 14. The weights of the various pans used are given in the following table.

Table 3. Weights of pans, in gm.

Pan	Wt.	Pan	Wt.
Square No. 1	105.85	Loaf No.2	113.30
Square No. 2	111.20	Rectangular	115.30
Loaf No. 1	117.60		

Other Apparatus

In Figs. 1 and 2 are shown the instruments used in measuring the emfs of the thermocouples and the power consumption of the oven. The following are included:

1. Rubicon Type B Potentiometer

2. Leeds and Northrup Galvanometer with Thordarson 6v transformer for the galvanometer light

3. 3-volt driving voltage---2 Edison cells in series

4. Eppley Standard Cell

5. Weston Model 432 wattmeter, 0-1.5-3 KW

A small mirror was placed so the light on the front of the stove that automatically turned on and off simultaneously with the units could be seen, and the times at which these occurred were noted. For each test the oven and the stop-watch used for time measurements were started simultaneously.

The wattmeter could be read directly to 0.04 KW. Several readings were taken during each test. A constant power supply was provided for the stove, and the wattmeter readings did not vary more than 0.02 KW.

PROCEDURE

The experiment was performed in a relatively convection-current-free corner of a basement room, in which the room temperature was nearly constant, ranging from 28 °C. to 31.5 °C., a change of but 6.3 °F. The insulation of the oven was so efficient that the oven exterior became but warm to the touch, so it was believed unnecessary to insulate the apparatus from the oven. In use the table holding the potentiometer, etc., was farther from the oven than shown in Fig. 2, but was moved nearer for the photograph.

The thermocouples were placed in the oven as shown in Figs. 2, 8, and 9. The junctions of the thermocouples were inserted into small Pyrex tubes which were held in position by brass holders on the rack. Preliminary tests showed that results varied widely when the thermocouple wires were attached directly to the racks, but the Pyrex tubes prevented such variation.

For the empty oven the temperatures ware found with the rack holding the thermocouples placed in positions 2, 3, and 4 of Fig. 9. Positions 1 and 5 were not used, since the straight rack on which the thermocouples were mounted could not be used on them. Thermocouple 0 throughout the study was kept in the position shown in Figs. 2, 8, and 9, with its junction beside the center of the thermostat rod. The tube containing it was suspended in a brass holder so it did not touch the oven wall. Thermocouples 1, 2, 4, and 5 were each located 10 cm from the

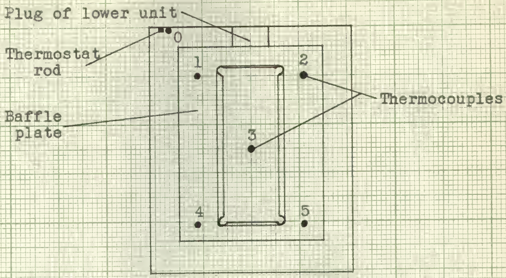

Fig. 8. Thermocouple positions, top view.

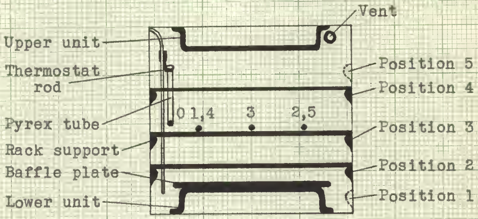

Fig. 9. Thermocouple positions, front view, and rack positions.

Scale: 1 in. = 20 cm.

outer wall; thermocouple 3 was in the center of the oven. Thermocouple 6 replaced thermocouple 1 after the weld of thermocouple 1 was accidentally broken. (Results obtained with thermocouple 6 are reported along with those from thermocouple 1 to prevent confusion.) Table 4 gives the heights of the thermocouples for the 3 positions used for the rack.

Table 4. Thermocouple heights.

Rack position	Height above oven floor cm	Height above baffle plate cm	Height of upper unit above thermocouples cm
2	11.0	5.0	22.5
3	17.6	11.6	15.9
4	26.8	20.8	6.7

For the entire study the thermostat was set for 425 °F. (218.3 °C.). Since the control knob was marked at 25-degree intervals, a small marker was used so the setting would be as constant as possible.

Because of the shortness of the operational time intervals of the oven, as controlled by the thermostat, and because of the time required to attain a balance with the potentiometer and to record the data, it was found that no more than three thermocouples could be read in a given experimental run. In each case thermocouple 0 and one or two others were read, with one reading taken each half-minute. Thus, using thermocouple 0 as the standard, it was necessary to make three runs of each test to obtain the time-temperature readings for all 6 thermocouples.

Empty oven tests were run for 75 minutes. These were made both at the beginning and the end of the study and agreement of results showed the thermocouples had not changed in their characteristics, nor the oven units in their heating rates and power consumption. The operation of the oven consisted of a succession of alternating periods of heating and cooling, so the resulting temperature graphs had a succession of points of maximum and minimum temperatures. A typical set of curves obtained from one run of data is shown in Fig. 10. The highest peak on each curve represents the temperature attained at the end of the preheating.

In the sand-heating or "load" experiments the pans were inserted at the end of the preheat period. This was done as rapidly as possible. For measuring the temperatures in the sand and on top of the sand one thermocouple was inserted in the center of the pan, to the center of the sand, and another was laid on the sand beside the first. Figure 11 shows part of a typical set of curves for a sand-heating set of data. Such data were taken for 2-hour periods, so but part could be represented here. Figures 12, 13, and 14 show the pan arrangements, as follows:

I: Square pan added, center upper rack

II: Square pan, center lower rack

III: Two loaf pans, lower rack

IV: Square pan, upper rack; two loaf pans, lower rack

V: Loaf pan, upper rack; square pan and loaf pan, lower rack

VI: Square pan, upper rack; rectangular pan, lower rack

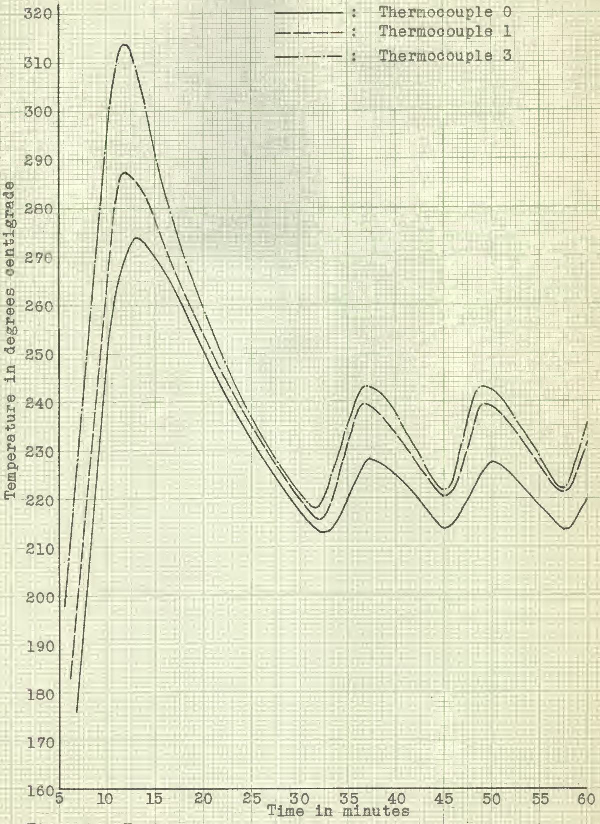

Fig. 10. Typical empty oven time-temperature curves.

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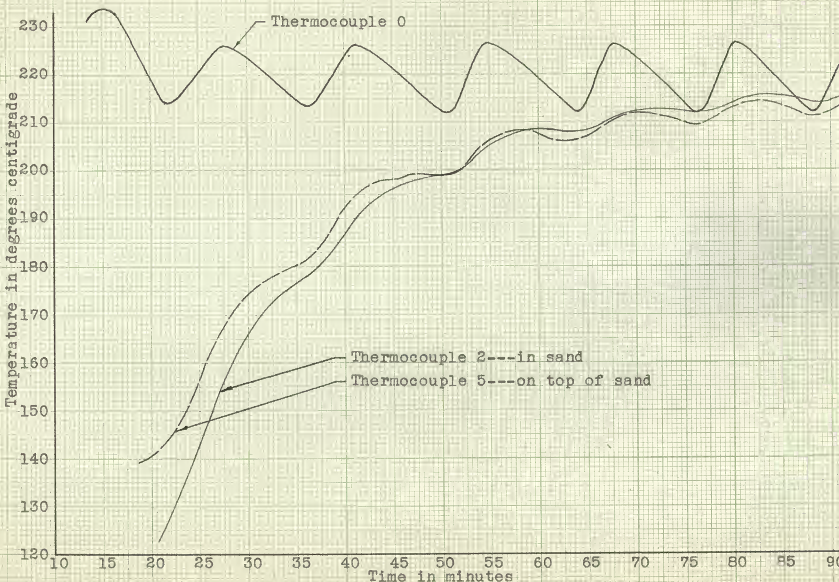

Fig. 11. Typical sand-heating time-temperature curves.

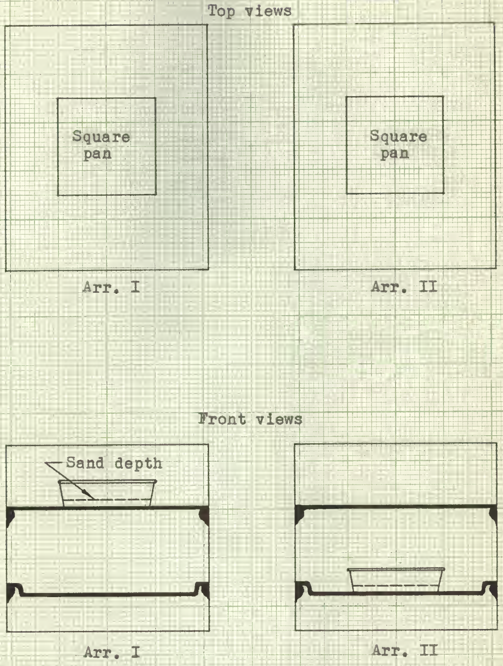

Fig. 12. Pan or "load" arrangements I and II.

Scale: 1 in. = 20 cm.

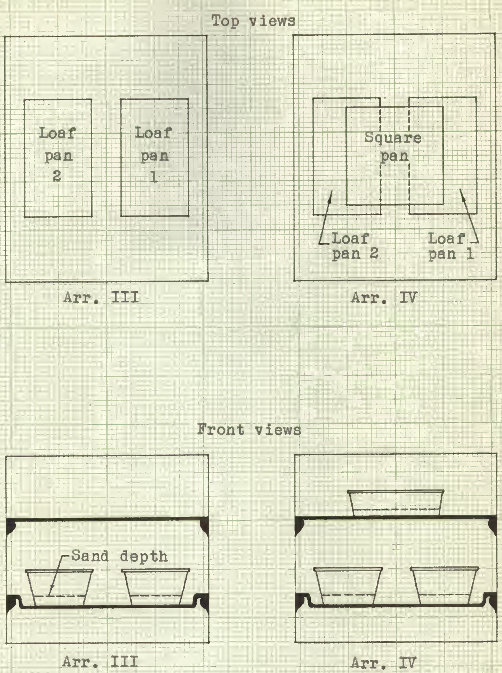

Fig. 13. Pan or "load" arrangements III and IV.

Scale: 1 in.= 20 cm.

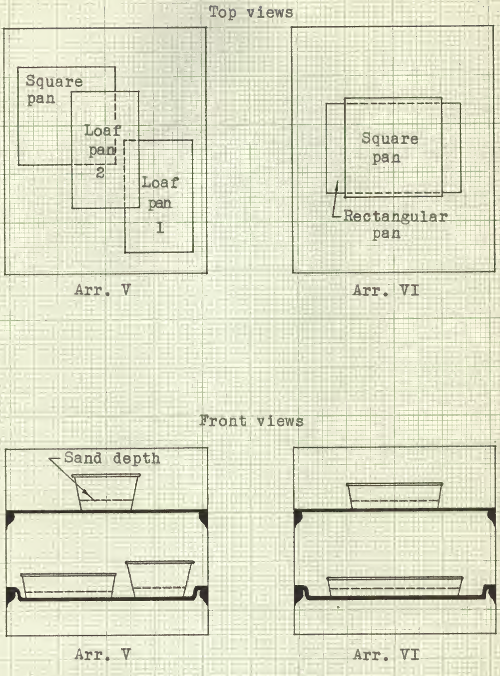

Fig. 14. Pan or "load" arrangements V and VI.

Scale: 1 in.=20 cm.

The experimental graphs were plotted in centigrade degrees, as in Figs. 10 and 11. Since home economists use the English system of units, and since the thermostat control was marked in degrees Fahrenheit, results were converted to degrees Fahrenheit.

RESULTS

Temperature Distribution

Since but three thermocouples could be read each time, the temperatures for each thermocouple for the runs of each test were averaged to the nearest 0.5 °C., then compared with the averages of the values for thermocouple 0 for the same runs. Despite the attempt to have a constant setting of the thermostat, a variation of 6.5 °F. (3.6 °C.) occurred in the average temperatures of thermocouple 0, and a variation of 18 °F. (10 °C.) in the preheat maxima of thermocouple 0. Thus, for better interpretation, final conclusions were drawn from difference graphs, in which the line of zero difference represented the average temperature of thermocouple 0 for the runs of the particular test, or from graphs of temperatures linearly adjusted to the average value of the temperatures for thermocouple 0.

Table 5 gives the preheat maximum temperatures for the thermocouples. Column a is the averages of the preheat maximum temperatures read from the experimental graphs for the several runs made with the rack in each of the 3 positions, and Column b the Fahrenheit equivalent. The average preheat maximum temperature for thermocouple 0 for all the empty oven tests was 533.4 °F. The "Adjusted preheat maximum" in Column c is the value in Column b plus the difference of the value of thermocouple 0 for the test and the average for thermocouple 0 for all the tests (533.4 °F.). Column d gives the respective differences of the temperatures of the thermocouples and the average temperature of thermocouple 0. Figure 15 is the graph which represents Columns c and d.

Figure 16 represents the average time-temperature curve for each thermocouple with the thermocouple rack in position 2 in the empty oven. Similarly, Figs. 17 and 18 show the average curves for the thermocouples with the rack in positions 3 and 4. It will be noted that in each case the first minimum is lower than the average minimum. The horizontal lines represent the average temperature maintained at the thermocouples. Table 6 gives these average maintained temperatures. Column a is the temperatures in °C., Column b the equivalent in °F., and Column c the respective differences of the temperatures of the thermocouples and the temperature of thermocouple 0. Figure 19 represents Column c.

In the same manner used for finding the average temperatures maintained in the empty oven, the average temperatures maintained at the several thermocouples with their rack in positions 3 and 4 with one square pan in the center of the lower rack, arrangement II of Fig. 12, were found. Table 7 gives the average temperatures and the differences with respect to the temperature of thermocouple 0. Figure 20 permits comparison of these differences for the empty oven and for the "load" used, and represents part of Column c of Table 6 and all of Column c of Table 7. The line of zero temperature difference represents the temperature of thermocouple 0, which remained at approximately 430 °F. with or without a "load" in the oven.

Table 5. Preheat maxima and preheat maxima differences, empty oven.

Thermocouple	a Preheat maximum °C.	b Preheat maximum °F.	c Adjusted pre.max. °F.	d Difference °F.	Rack position
0	283.5	542.3	533.4		2
1	295.5	563.9	555.0	+21.6	
0	282.0	539.6	533.4		
2	287.0	548.6	542.4	+ 9.0	
3	315.5	599.9	593.7	+60.3	
0	281.0	537.8	533.4		
4	312.5	594.5	590.1	+56.7	
5	298.5	569.3	564.9	+31.5	
0	273.5	524.3	533.4		3
1	287.0	548.6	557.7	+24.3	
0	277.0	530.6	533.4		
2	289.0	552.2	555.0	+21.6	
3	317.0	602.6	605.4	+72.0	
0	274.0	525.2	533.4		
4	309.0	588.2	596.4	+63.0	
5	300.5	572.9	581.1	+47.7	
0	279.0	534.2	533.4		4
1	311.5	592.7	591.9	+58.5	
0	277.5	531.5	533.4		
2	299.0	570.2	572.1	+38.7	
3	351.0	662.0	663.9	+130.5	
0	279.5	535.1	533.4		
4	319.5	607.1	605.4	+72.0	
5	315.5	599.9	598.2	+64.8	

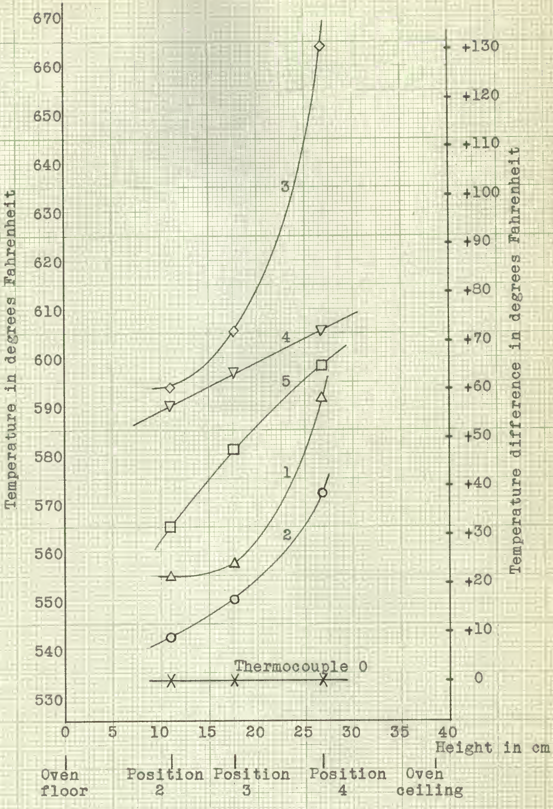

Fig. 15. Preheat maxima and preheat maxima differences (empty oven).

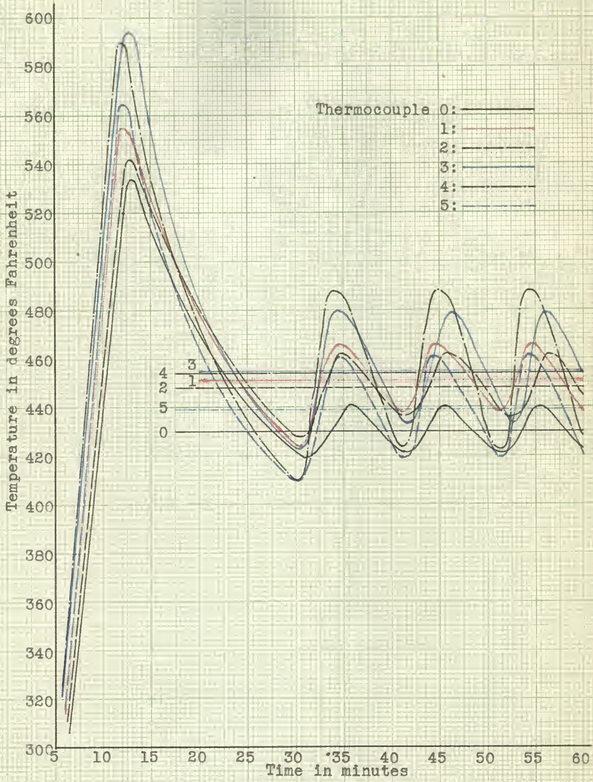

Fig. 16. Time-temperature curves, thermocouple rack in position 2 in empty oven.

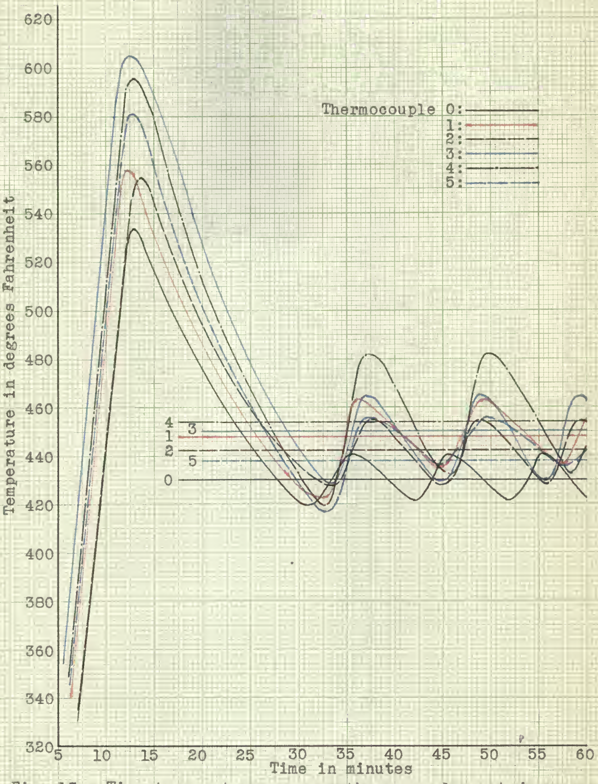

Fig. 17. Time-temperature curves, thermocouple rack in position 3 in empty oven.

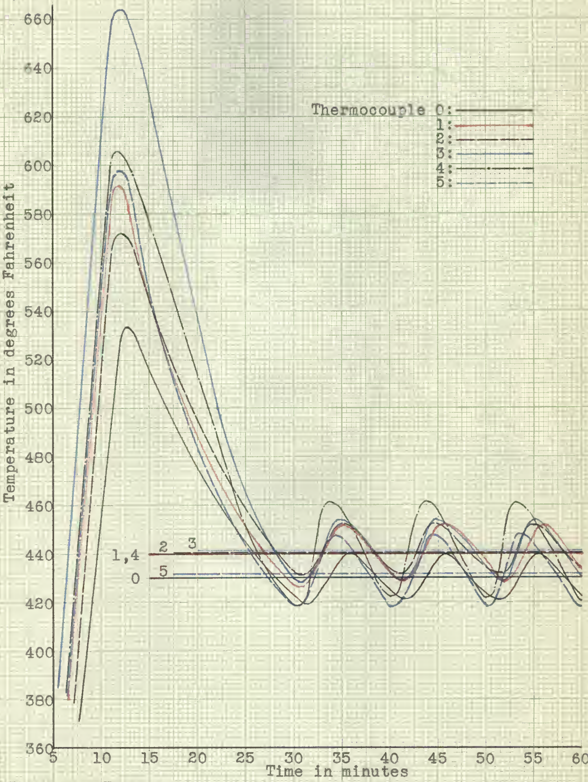

Fig. 18. Time-temperature curves, thermocouple rack in position 4 in empty oven.

Table 6. Average maintained temperatures and average maintained temperature differences, empty oven.

Thermocouple	a Average temp. °C.	b Average temp. °F.	c Ave. temp. difference °F.	Rack position
0	221.9	431.4		2
1	233.6	452.5	+21.1	
0	222.4	432.3		
2	232.5	450.5	+18.2	
3	236.3	457.3	+25.0	
0	221.7	431.1		
4	235.1	455.2	+24.1	
5	226.0	440.2	+ 9.1	
0	220.1	428.2		3
1	230.2	446.4	+18.2	
0	220.1	428.2		
2	227.0	440.6	+12.4	
3	231.4	448.5	+20.3	
0	220.4	428.7		
4	233.4	452.1	+23.4	
5	224.8	436.6	+ 7.9	
0	221.0	429.8		4
1	226.5	439.7	+9.9	
0	219.4	426.9		
2	225.3	437.5	+10.6	
3	225.5	437.9	+11.0	
0	223.0	433.4		
4	228.6	443.5	+10.1	
5	224.0	435.2	+ 1.8	

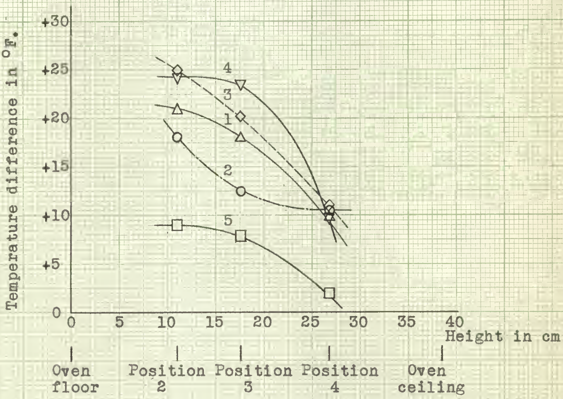

Fig. 19. Differences of average maintained temperatures for empty oven.

Table 7. Average maintained temperatures and average maintained temperature differences, "load" arrangement II.

Thermo-couple	a Average temp. °C.	b Average temp. °F.	c Ave. temp. difference °F.	Rack position
0	221.2	430.1		3
1	222.1	431.8	+1.7	
0	220.6	429.1		
2	221.1	429.9	+0.8	
3	221.8	431.2	+2.1	
0	221.5	430.8		
4	223.6	434.5	+3.7	
5	221.8	431.2	+0.4	
0	221.4	430.6		4
1	222.9	433.2	+2.6	
0	220.9	429.6		
2	223.3	433.9	+4.3	
3	223.1	433.6	+4.0	
0	221.1	429.9		
4	223.2	433.7	+3.8	
5	220.7	429.2	-0.7	

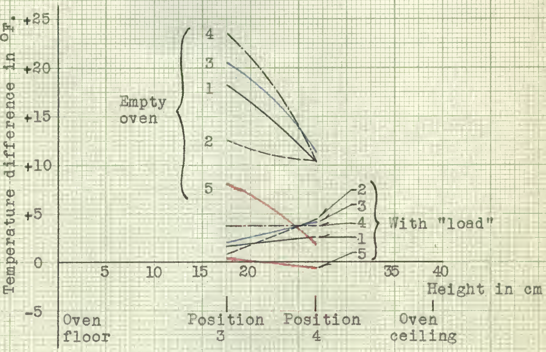

Fig. 20. Differences of average maintained temperatures for empty oven and for oven with "load" arrangement II.

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The rate of heating of the pans of sand further illustrated the temperature distribution of the oven. Figure 21 shows the rate at which the three pans of arrangement IV heated. The heating time in minutes was measured from the time at which the pans were in the oven and the door again shut. Temperatures of the "loads" were read from the experimental graphs, converted to °F., then compared with the average oven temperature of each pan and the temperature of the oven for a 2-hour period. From Figs. 3 and 13 it may be noted that loaf pan 2, which attained the average oven temperature most rapidly, was set over the part of the lower unit in which the coil of the heating element was quite concentrated.

Similar results were found for arrangement III, two loaf pans on the lower rack: loaf pan 2, in the same position as for arrangement IV, heated more rapidly than did loaf pan 1. With arrangement I it was found that the square pan alone on the upper rack did not heat as rapidly as it did in arrangement IV.

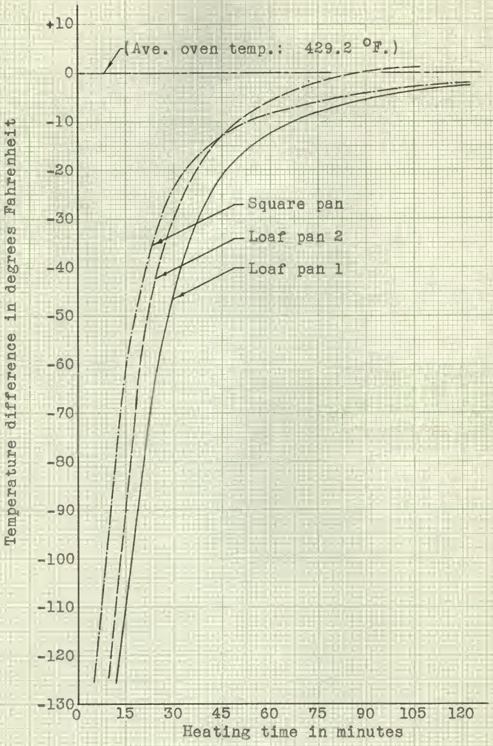

Fig. 21. Rate of heating of pans of arrangement IV.

Operational Times

The time intervals of the successive heating and cooling periods were averaged for each set of tests, and from these the average operational cycle for each "load" arrangement was determined. The average preheat time interval for the entire study was 11.54 minutes. Although the "load" tests were run for 2 hours, it was found that after one hour the operational times remained nearly constant, so, for comparison, only approximately one hour is used. Table 8 gives the lengths of the heating and cooling intervals during approximately one hour of operation. Table 9 gives the totals for Table 8, and is represented by Fig. 22. In Tables 8 and 9 the columns are as follows:

Column a: Empty oven
" b: Arrangement I
" c: " II
" d: " III
Column e: Arrangement IV
" f: " V
" g: " VI

Table 8. Heating and cooling intervals with various loads, in minutes, for approximately one hour of operation.

Interval	a	b	c	d	e	f	g
Preheat	11.54	11.54	11.54	11.54	11.54	11.54	11.54
1st Cooling	17.93	16.38	11.15	10.08	9.06	9.29	12.10
1st Reheat	3.54	4.08	4.86	5.42	6.20	5.83	5.45
2nd Cooling	7.49	7.53	8.14	7.25	8.98	9.83	8.67
2nd Reheat	3.05	3.16	3.64	3.66	4.70	5.21	3.22
3rd Cooling	7.24	7.72	8.17	8.46	10.24	9.71	8.70
3rd Reheat	2.95	3.22	3.25	3.71	4.14	4.53	3.12
4th Cooling	7.08	7.75	8.83	7.88	10.01	8.12	7.75
4th Reheat	2.45	3.75	2.92	3.29	3.73	4.17	2.75

Table 9. Operational time totals, in minutes, with various loads, for one hour of operation.

	a	b	c	d	e	f	g
Preheat	11.54	11.54	11.54	11.54	11.54	11.54	11.54
Reheat	9.54	10.46	12.17	14.79	15.04	15.57	11.79
Cooling	38.92	38.00	36.29	33.67	33.42	32.89	36.67

Figure 23 shows the average time-temperature curve for thermocouple 0, and the operational times for the empty oven. The time intervals a and b indicate the time lag of the temperature at the thermostat behind the operation of the units, a the time of continued heating after the units have turned off, b the time of continued cooling after the lower unit has turned on. This lag decreased with length of time of use of the oven, until a minimum of about 1 minute for a and about 1/2 minute for b were reached.

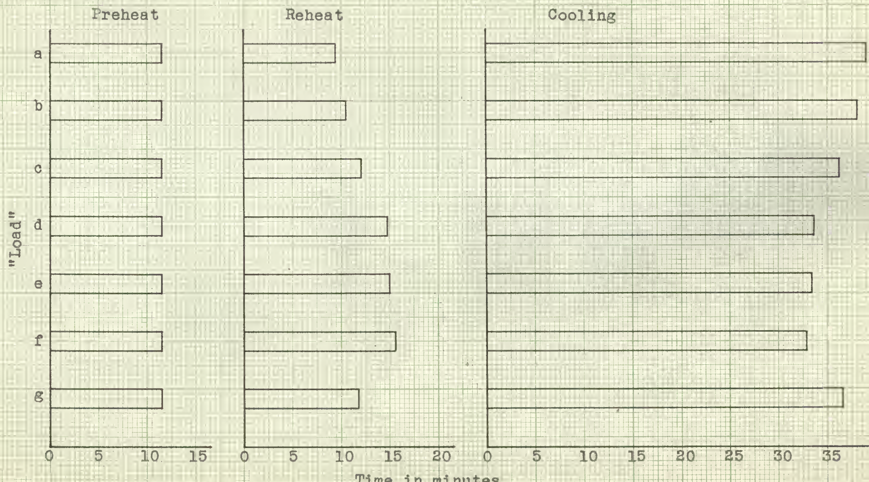

Fig. 22. Operational time totals for various "loads" for one hour of operation of oven.

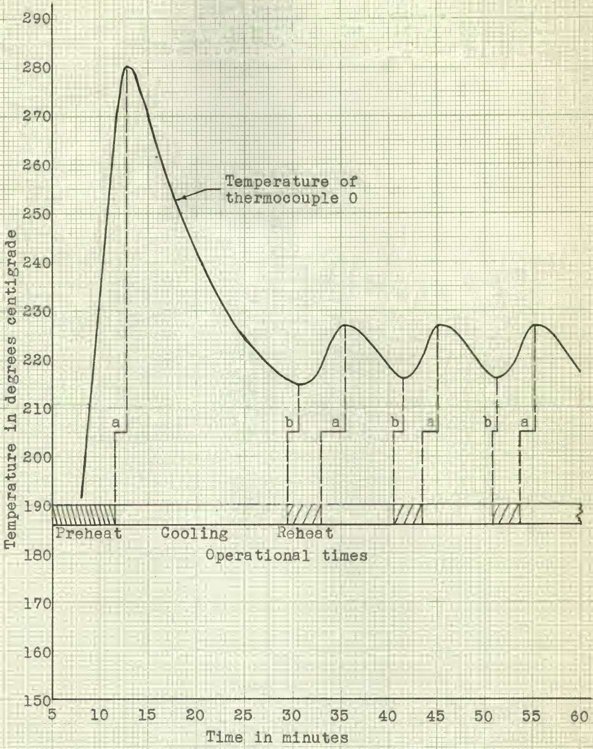

Fig. 23. Average time-temperature curve for thermocouple 0 with empty oven operational times.

Power Consumption

Power consumption was computed in KWH for one hour of operation of the oven. Total power consumed is the product of the time in hours and the power in kilowatts, 4.24 KW for preheat, 2.00 KW for reheat. Table 10 gives the power consumptions of the several "load" arrangements. The "difference" in each case is the difference of the total power consumption with the "load" and the total for the empty oven. Table 10 is graphically represented by Fig. 24, with the "differences" shaded.

Table 10. Power consumptions for one hour of operation of oven with various pan arrangements, in KWH.

	a	b	c	d	e	f	g
Preheat	0.816	0.816	0.816	0.816	0.816	0.816	0.816
Reheat	0.318	0.348	0.405	0.492	0.501	0.518	0.393
Total	1.133	1.164	1.221	1.308	1.317	1.334	1.209
Difference		0.031	0.088	0.175	0.184	0.201	0.076

To analyze the use of the total power consumed, the temperature of the "load", the pans and the sand, at the end of one hour of heating was determined for three arrangements: I, square pan alone on the upper rack; III, loaf pans on the lower rack; and IV, square pan on the upper rack and loaf pans on the lower rack. From the known masses of the pans and the sand, their specific heats, and their change in temperature the amount of heat in calories used in heating the "load" was calculated,

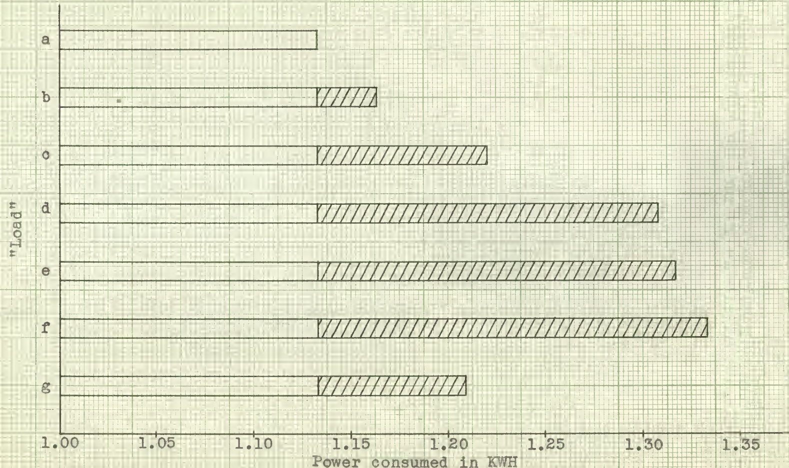

Fig. 24. Total power consumptions for one hour of operation of oven for various "loads".

and the equivalent in KWH determined. (The specific heat of aluminum is 0.22 cal/gm/°C., of Ottawa sand, 0.20 cal/gm/°C.) This amount of power consumed was compared with the observed power consumption above the requirement for the empty oven, the "difference" value of Table 10, to find how much power was lost through the open oven door while the "load" was added. Table 11 gives the data and results of these computations. In Table 11 the elements of the left-hand column are as follows:

- t_1 : Room temperature or initial "load" temperature
- t_2 : Final "load" temperature after one hour of operation of oven
- ms : Heat capacity of the pan with the sand, the sum of the products of the mass and the specific heat of each
- Cal. : Calories used in heating the "load", $[ms(t_2-t_1)]$ for each part of the "load"
- Total cal.: Total calories used for the entire "load"
- Load KWH : KWH equivalent of total calories used, or KWH used for heating of "load"; 1 cal is equivalent to 0.0000011628 KWH
- Actual KWH: "Difference" value of Table 10
- Lost KWH : Actual KWH minus Load KWH, or power lost through open oven door

Table 12 gives the final analysis of the total power consumption in percentages. The power consumed in each case for "maintenance of oven temperature" was 0.318 KWH, which is the amount consumed by the empty oven during reheat intervals in one hour. This compensates for the loss of heat through the oven insulation and the vent pipe, and was assumed to remain constant throughout the study since the room temperature remained quite constant, and the oven temperature was kept the same, hence the rate of loss should have varied but little during the study.

Table 11. Determination of power used for heating of "load" and power lost through open oven door.

		b (Arr.I)	d (Arr.III)	e (Arr.IV)
t_1 (°C.)		28.5	30.0	29.0
t_2 (°C.)	Sq.pan	123.0		211.0
	Loaf 1		208.0	208.0
	Loaf 2		212.0	210.0
ms (cal/°C.)	Sq.pan	202.61		202.61
	Loaf 1		204.96	204.96
	Loaf 2		204.10	204.10
Cal.	Sq.pan	24921		36875
	Loaf 1		36483	36688
	Loaf 2		37146	36942
Total cal.		24921	73629	110505
Load KWH		0.029	0.083	0.128
Actual KWH		0.031	0.175	0.184
Lost KWH		0.002	0.089	0.056

Table 12. Total power consumption in percentages for "load" arrangements I, III, and IV.

	b	d	e
Preheat	70.1	62.3	61.9
Maintenance of oven temp.	27.3	24.3	24.1
Heating of "load"	2.5	6.6	9.7
Lost through open door	0.1	6.8	4.3
Total	100.0	100.0	100.0

The percentage analysis of the total power consumption for all the "loads" is given in Table 13, in which the "reheat" amount is not subdivided as it is in Table 12.

Table 13. Percentage analysis of power consumption, all "loads".

	a	b	c	d	e	f	g
Preheat	72.0	70.1	66.9	62.3	61.9	61.2	67.5
Reheat	28.0	29.9	33.1	37.7	38.1	38.8	32.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The heating efficiency of the oven is the percentage of the total power consumption that is actually used in heating the "load". From Table 12 it may be seen that the heating efficiency for arrangement I, square pan alone on the upper rack, was 2.5 per cent. For arrangement III, two loaf pans on the lower rack, the heating efficiency was 6.6 per cent; and for arrangement IV, square pan on the upper rack and two loaf pans on the lower rack, the heating efficiency was 9.7 per cent.

CONCLUSIONS

The heating efficiency of the oven was found to increase with an increase in the "load", rising from 2.5 per cent with one pan in the oven to 9.7 per cent with three pans in the oven. This most favorably compares with the heating efficiencies for the gas oven found by Monroe (11), 1.1 per cent with one pan in the oven to 5.9 per cent with 8 pans in the oven. It is believed this should be attributed, for the most part, to the increase in insulation afforded by the glass wool in the electric oven.

By far the greatest expense involved in use of the oven for a single hour is for the preheating, since it requires 61 to 72 per cent of the total power (Table 13). Thus, at the rate of 1-1/2 cents per KWH, the costs for arrangements I, III, and IV for one hour would be as shown in Table 14.

Table 14. Costs of operation for one hour, arrangements I, III, and IV.

	b (1 pan)	d (2 pans)	e (3 pans)
Preheat	1.23 ¢	1.23 ¢	1.23 ¢
Lost through oven sides, vent pipe and oven door	0.48	0.61	0.56
Heating of "load"	0.05	0.13	0.19
Total	1.76¢	1.97¢	1.98¢

From this it may be seen that once the oven is preheated it should be used, so far as is possible, for several baking operations,---either for a large "load" or for successive bakings. It is to be noted, also, that addition of a pan on the upper rack (for arrangement IV from arrangement III) added but 0.01 cent to the cost for one hour and increased the heating efficiency of the oven by 3.1 per cent.

A change in temperature with change in elevation in the oven was found, with the average maintained temperatures the lowest in the top of the oven. For prolonged baking processes it is to be recommended, therefore, that the center or lower part of the oven be used.

Uneven temperature distribution horizontally through the oven was also found, with a particular "hot spot" over the part of the lower unit in which the coil of the heating element was concentrated. Inquiry was made of the manufacturer of the reason for this coil distribution. The reply stated that during original tests of the oven, in the case of four-layer cakes, the layer placed in the left front corner did not brown as well as the other three; the concentration of the coil at this point tended to eliminate this (Appendix, Heinrich). From Fig. 21 it may be seen that the cool spot was over-compensated-for by the coil concentration. In private conversation with two owners of these ranges it was learned that they have observed the "hot spot", and excessive browning in the left front corner, also. It would be interesting to repeat this study using an oven with a symmetrically-distributed lower unit; since the stove used in this case was on loan only, changes in its construction for experimental purposes were prohibited.

Since the units are off over one-half the time in one hour of operation (Fig. 22), the user must be warned not to become alarmed, and not to open the door excessively, for thereby heat is lost to the room unnecessarily.

The results of the temperature distribution part of this study are not necessarily applicable to all electric ovens, since the lower unit of this oven is unsymmetrically distributed. However, the operational cycle and power consumption are probably representative, so that the heating efficiency and cost of operation should approximate those to be found for the modern domestic electric range oven.

ACKNOWLEDGMENTS

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Appreciation also is expressed to Dr. and Mrs. Roy C. Langford and others for their willing help and criticisms in the preparation of the manuscript.

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APPENDIX

(COPY)

ELECTROMASTER, INC.
Mount Clemens, Mich.

August 10, 1948

Mrs. Kathryn Leeper
Department of Physics
Kansas State College
Manhattan, Kansas

Dear Mrs. Leeper:

We have your letter of August 5, and will be interested in reading the results of your research problem on the T41-1 Electromaster range.

During the original tests of this range, we found that in the baking operation, especially in the case of four-layer cakes, the one placed in the left front corner did not brown as well as the other three. The concentration of the coil at this point tended to eliminate this difference.

With regard to the top unit, this is only on during the preheating process when baking, so it did not affect results. Also, for broiling, it was necessary to have it designed regularly.

Very truly yours,

(signed)

Emil J. Heinrich
Service Manager

js