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TECHNICAL REPORT
NATICK/TR-78/014

**EFFICIENCY AND COST FACTORS IN
RE-THERMALIZING FROZEN FOODS IN
TYPICAL DINING HALL EQUIPMENT**

by

John Swift
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January 1978

**UNITED STATES ARMY
NATICK RESEARCH and DEVELOPMENT COMMAND
NATICK, MASSACHUSETTS 01760**



**Food Engineering Laboratory
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Tests were made to determine cost and uniformity of heating when rethermalizing frozen entree items in a gas-heated standard oven, a gas-heated convection oven, a convection electric oven and 5- and 15-psig steam cookers. These are the only types of equipment that are generally available in military dining halls for rethermalizing bulk frozen food in a cook - freeze system. While all 5 types showed wide variation in temperature uniformity the overall results indicate the performance of the 5-psig cooker to be the best. The per-lb cost of utilities ranged from 0.17¢ for the 5-psig steam cooker to 0.54¢ for the electric convection oven.		

PREFACE

The use of convenience foods is increasing in the Armed Forces and this trend is expected to continue, probably even to accelerate. Increasingly burdensome labor, facility, and equipment costs as well as heavy pressures to increase "fighting" strength of units at the expense of the "logistical tail", dictate that military food service utilize convenience foods to the maximum extent possible. High on the list of suitable convenience foods are the frozen prepared entrees.

Frozen prepared foods, including frozen precooked entree items, can have high acceptability by military consumers if they are properly prepared, handled, and reconstituted for serving. While their use for field feeding is debatable, they fit very well into garrison situations which are very similar to institutional and industrial feeding.

While preparation and handling of frozen precooked entrees have been investigated to some extent, very little has been done on the costs and labor involved in the various methods of reconstitution. Therefore, this study was designed to obtain an overall concept of costs and efficiencies of the principal methods of reconstitution now used. Boil-in-bag rethermalizing was not included at this time due to problems in changing piping to collect the condensate.

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1. The first part of the paper is devoted to a discussion of the general principles of the theory of the structure of the atom. It is shown that the structure of the atom is determined by the laws of quantum mechanics, which are based on the principle of the uncertainty of the position and momentum of the particles.

2. In the second part of the paper, the author discusses the problem of the structure of the nucleus. It is shown that the structure of the nucleus is determined by the laws of quantum mechanics, which are based on the principle of the uncertainty of the position and momentum of the particles.

3. In the third part of the paper, the author discusses the problem of the structure of the molecule. It is shown that the structure of the molecule is determined by the laws of quantum mechanics, which are based on the principle of the uncertainty of the position and momentum of the particles.

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EFFICIENCY AND COST FACTORS IN RETHERMALIZING FROZEN FOODS IN TYPICAL DINING HALL EQUIPMENT

INTRODUCTION

Frozen precooked entree items are normally packed in full or half-size steam table pans or in individual serving sizes. The most common container is the half-size steam table aluminum pan (disposable) containing five pounds of products such as casseroles. In addition, boil-in-bag products are available, but they are not considered in this project.

Reconstitution is usually accomplished from the frozen state and is done as rapidly as possible without burning or otherwise damaging the product. Standard ovens are used in many cases, but convection ovens are coming more into use. Steam cookers are used also. For this study it was decided to use a gas-heated standard oven, gas-heated convection oven, convection electric oven, five-pound steam and fifteen-pound steam cookers, with the expectation that these would be enough to give a generalized picture of reconstitution costs being met with commonly used reconstitution methods. These are the only types that are generally available in dining halls.

The heating rate of a food product depends in part on its heat capacity and conductivity which in turn are related to the composition and physical shape. Generally, however, products may be grouped into classes displaying similar reconstitution characteristics, and the products selected for this study are representative of these groupings.

US customary units have been used throughout because the controls of rethermalizing equipment are marked in degrees Fahrenheit and because the anticipated readers — personnel who are concerned with the operation of military dining halls — are generally unfamiliar with the International System of Units.

PROCEDURE

Heating programs were set arbitrarily to conform with common practice developed through dining hall experience. Therefore, it was decided to base the study on set-point temperatures of 350°F for the conventional type oven and 300°F for the convection ovens. The steam cookers were operated at their rated pressures. This fixes the set-point temperatures at 227°F for the 5-psig steam cooker and 250°F for the 15-psig steam cooker.

In all cases, the equipment was preheated to the set-point temperature. The foil pans containing the entree items were quickly positioned in the cavity or chamber, and the thermocouple leads connected to a recorder. Initial temperatures of the product were generally about 5°F. Readings were taken as soon as the cavity was secured and subsequently whenever a thermocouple probe reached 160°F and 212°F. The test was

terminated as soon as the last probe reached the target temperature (160°F, which is the minimum internal temperature for reheating frozen foods in dining halls). The pans were weighed at the end of the test, and any losses were replenished by the addition of water. Most of the samples were reused a total of five times in order to minimize the consumption of food material.

No attempt was made to determine the sensory characteristics of the reconstituted food since this is the subject of a separate study.¹

Products

The entree items used in this study were Turkey a la King, Sweet and Sour Pork, Swiss Steak, and Fried Chicken pieces (oven-fried). They were made using production guides developed for use in Central Food Preparation Facilities using a cook-freeze system.² Aluminum foil half-size steam table pans with crimped-on aluminum covers were used to contain the product (Ekco Products Co., Cat. Nos. 6132-50 and 1012-30). The covers were crimped in place with a mechanical lidding machine. The fried chicken was loaded 10 pieces per container, and the net weight of each pan determined. The weight varied, but averaged about 2.8 pounds. The net weight of the other three products was 5 pounds per container.

Product temperatures were measured using thermocouples and a multipoint recorder. Location of the thermocouples and placement of pans are shown in Figures A1 through A5. All thermocouple lead wires were No. 22 (AWG) type T (copper-constantan) with nylon or silicone impregnated glass fibre insulation. They were dressed across the door gasketing of the electric and gas ovens with no overlapping so the door could be closed to within the thickness of a single lead (0.042 in.). Leads to the pressure cookers were introduced via pressure-tight feed-throughs. Ecklund needle type thermocouples (type CNS) were inserted through gasketed fittings in the bottom and one end of the aluminum foil pans. The bottom probe was close to the geometric center of the product while that in the end penetrated the product 1-1/4" about midway between the top and bottom surfaces. Locally made twisted-point thermocouples were positioned near the center of the oven cavities and at the midpoint of the sensing bulb of the temperature controllers.

¹Loveridge, V. A., G. C. Walker and J. M. Tuomy. *Effect of Freezing Rate and Method of Rethermalization on the Organoleptic Qualities of Eleven Meat Entrees* (in press).

²Helmer, R. L. and Hilton T. Schlup. *Meat entree item production guides developed for use in Fort Lee interim Central Food Preparation Facility*. Technical Report TR 74-27, U.S. Army Natick Development Center, March 1975 (AD A009 733).

Heating Equipment

Make and Model numbers of the equipment used follows:

Oven	Make	Type/Model
Conventional Gas	Vulcan-Hart	17845A
Convection Gas	Vulcan	TAG-5FD
Convection Electric	G.S. Blodgett	RE43
Steam (5 psig)	Market-Forge	A-1
Steam (15 psig)	Vischer	85A

The convection gas oven was equipped with a 1-HP circulating fan and the convection electric oven had a 3/4-HP fan in each of its two compartments.

All equipment was serviced prior to use. Steam traps were checked, gas flames were adjusted, and temperature controls were tested for performance.

In order to have a basepoint for evaluation of relative efficiency of the various pieces of equipment, runs were made using distilled water. These runs were identical to the ones with product, except that at the end of the heating period each pan was vigorously agitated and the average temperature determined as rapidly as possible with a fast acting digital thermometer. Using the thermal characteristics of distilled water and the energy consumption, the apparent efficiency of the particular piece of equipment was calculated. In addition, temperature variations within the unit with respect to the containers being used were determined.

Energy Metering

Electric energy was measured with ordinary kilowatt-hour meters having scales to register kW·h in units. Fractions of a kW·h were estimated by interpolation. Gas was measured with a diaphragm-type meter having an expanded scale graduated in hundredths of a cubic foot. Steam was measured by collecting and weighing the condensate. The condensate was directed through a cooler to avoid flashing of vapor during the let-down in pressure.

Preliminary Studies

The response characteristics of the thermostatic control for each oven both empty and loaded were determined at the planned setpoint temperatures. The results are shown in Tables 1 and 2.

Table 1**Response Characteristics of Ovens (Unloaded)**

Oven	Set-Point (°F)	Temp. @ Sensor		Cycle Time (Min)
		Cut-in (°F)	Cut-out (°F)	
Conventional Gas	350	345	373	30
Convection Gas	300	289	302	10
Convection Elec.				
(Top Sec.)	300	284	324	20
(Bottom Sec.)	300	280	293	20

Table 2**Response Characteristics of Ovens (Loaded)**

Oven	Set-Point (°F)	Temp. @ Sensor		Cycle Time (Min)
		Cut-in (°F)	Cut-out (°F)	
Conventional Gas	350	338	338	0
Convection Gas	300	305	324	—
Convection Elec.				
(Top Sec.)	300	270	313	—
(Bottom Sec.)	300	270	313	—

Cavity temperatures were within one or two degrees of those at the sensing bulb of the thermostatic control. Although the average of the cut-in and cut-out readings differed from the setpoint, no corrections or adjustments were made because the variations were considered to be representative of dining hall equipment.

It is interesting to note, however, that the situation changes when the cavities are filled with frozen material. The temperature at the sensing element generally drops below the setpoint of the conventional gas oven, rises above the setpoint of the convection gas unit, and just about straddles the setpoint of the convection electric oven.

The summary in Table 2 shows the temperature at the sensor when reconstituting a typical entree item (Turkey a la King). Cycle times for the convection ovens could not be deciphered because of overlapping of the plot on the recorder chart.

The cavity temperature (TC) of the conventional gas oven, however, never reaches that of the sensing element when reconstituting frozen food. In the case summarized above, the cavity temperature was 171°F lower than the sensing element at the start of the test and still 65°F lower after 3-1/4 hours. The cavity temperature of both the convection ovens, on the other hand, was again just about the same as that at the sensing element. These results are also considered normal for each specific item of equipment. It is suspected, however, that temperature shifts are influenced at least in part by the number, positioning, and loading of pans.

RESULTS

Distilled Water

Table 3 shows the end-point temperature from pan to pan when heating distilled water in the 5 types of test equipment.*

A summary of temperature extremes is shown in Table 4. It is evident that there are very significant differences in the heating rate of individual pans in all cases. Since water was used, it can be assumed that the observed differences are due to equipment rather than product characteristics. Even the steam cookers showed unexpectedly wide variations in pan-to-pan temperatures.

The tests with distilled water also show that there are wide variations between the apparent efficiency of energy utilization varying from 33% for the conventional gas oven to 95% for the 5-psig steam cooker (Table 5). It should be noted that efficiency of energy use for the entree items cannot be deduced directly from the water figures.

*Pressure in the 15-psig cooker reached only 5 psig.

Table 3

**Summary of Temperatures from Pan to Pan
(Heating Distilled Water)**

Pan No.*	Conventional Gas Oven °F	Convection Gas Oven °F	Convection Elec. Oven °F	5 Psig Steam °F	15 Psig Steam °F
1	169	174	149	147	176
2	145	174	162	154	174
3	153	181	145	149	131
4	147	169	142	165	169
5	185	158	158	151	—
6	160	165	158	163	—
7	144	172	138	151	—
8	196	187	133	153	—
9	—	207	185	178	—
10	—	207	174	172	—
11	—	160	144	172	—
12	—	187	149	178	—
Set Point	350°F	300°F	350°F	5 psig	15 psig**
Time All TC's Reached 160°F	140 min.	55 min.	38 min.	10 min.	7 min.
Initial Temp.	7°F	1°F	9°F	-11°F	-22°F
Weight Loss	1%	0.5%	0.2%	0	0

*Figures A-1 through A-5 show pan placement.

**Pressure reached only 5 psig.

Table 4
Summary of Temperatures from Pan to Pan
(Heating Distilled Water)

Equipment	Minimum °F	Temperature Maximum °F	Difference °F
Conventional Gas Oven	144	196	52
Convection Gas Oven	158	207	49
Convection Electric Oven	133	185	52
Steam Cooker (5 psig)	147	178	31
Steam Cooker (15 psig)*	131	176	45

*Pressure reached only 5 psig.

Table 5
Apparent Efficiency of Energy Utilization
(Based on Heating Distilled Water)

Equipment	Energy Utilized/ Energy Supplied	Relative Efficiency (%)*
Conventional Gas Oven	0.33	35
Convection Gas Oven	0.46	49
Convection Electric Oven	0.74	79
Steam Cooker (5 psig)	0.94	100
Steam Cooker (15 psig)	0.86	91

*Considering 5 psig Steam Cooker as 100 percent.

Products

Temperature plots for all products show that there are wide variations in product temperatures during the heating process. The maximums range from 126°F in the convection electric oven to 72°F in the 5-psig steam cooker. Some of the variation was undoubtedly due to the placement of the TC probes. In some cases, the probes could have been immersed in sauce or gravy where heat transfer is enhanced by convection, and in other cases the probe could have been lodged between chunks of solids where heat transfer is confined to conduction. Another factor which is believed to be more significant is the existence of hot and cold spots within the oven cavities. Their presence and location are discussed in Procedures under Preliminary Studies.

The variation in heating rates with their implication of hot and cold spots is also evident from test data in Table 6, which shows the lag between the time the first and last thermocouples reached 160°F.

Table 6

Time Lag Between Thermocouples Reaching 160°F

Equipment	Turkey A la King (hours)	Swiss Steak (hours)	Fried Chicken (hours)	Sweet & Sour Pork (hours)
Conventional Gas Oven	0.91	0.93	0.27	1.00
Convection Gas Oven	0.45	0.36	0.20	0.68
Convection Elec. Oven	0.77	0.43	0.56	0.72
5-psig Steamer	0.32	0.55	0.06	0.47
15-psig Steamer	0.70	0.29	0.14	0.52

Actually, the time lag was probably greater than the figures indicate since pans without thermocouple probes could have been heated at faster or slower rates. The figures suggest, however, that the heating rate in the 5-psig steam cooker is most uniform as evidenced by the relatively low time lag.

The elapsed time from the start of a test until all thermocouple probes reach 160°F or more is shown in Table 7.

Table 7

Elapsed Time for All Thermocouples to Reach 160°F

Equipment	Turkey A la King (hours)	Swiss Steak (hours)	Fried Chicken (hours)	Sweet & Sour Pork (hours)
Conventional Gas Oven	3.23	2.95	1.85	3.05
Convection Gas Oven	1.57	1.28	0.71	1.43
Convection Elec. Oven	1.85	1.55	1.18	1.73
5-psig Steamer	1.95	1.65	0.82	1.82
15-psig Steamer	1.71	1.12	0.43	1.26

The averages of the values in Table 7 indicate that the reconstitution rate of pans with thermocouple probes was fastest in the 15-psig steam cooker and slowest in the convention gas oven. The 5-psig steam cooker was slightly faster than the electric convection oven and both were slower than the gas convection unit.

Another indication of uneven heating was the observation that by the time all TC probes reached 160°F, a number had already reached 212°F.

Table 8 shows the total period of time that a temperature of 212°F was being recorded before the last thermocouple probe reached 160°F.

Table 8

Recorded Time at 212°F

Equipment	Turkey A la King (min)	Swiss Steak (min)	Fried Chicken (min)	Sweet & Sour Pork (min)
Conventional Gas Oven	0	2	0	8
Convection Gas Oven	7	0	0	55
Convection Elec. Oven	22	0	25	45
5-psig Steamer	0	0	0	0
15-psig Steamer	0	0	0	0

The above figures are probably on the low side since areas of some of the pans without TC probes must have reached 212°F, as evidenced by a loss in weight. It is to be noted that in no instance did the product temperature ever reach 212°F in either of the steam cookers, nor was there any weight loss. Temperatures as high as 212°F are objectionable because of the risk of degrading the quality of the product and because of a potential loss of product moisture.

A two-test average of the actual energy consumed in rethermalizing the various products is shown in Table 9.

Table 9
Energy Consumed as BTU per lb of Product

Equipment	Turkey A la King	Swiss Steak	Fried Chicken	Sweet and Sour Pork
Conventional Gas Oven	1120	1060	1100	990
Convection Gas Oven	838	696	628	808
Convection Elec. Oven	444	376	444	477
Steam Cooker (5 psig)	495	440	376	449
Steam Cooker (15 psig)	773	557	472	595

The cost of reconstituting typical entree items is shown in Table 10. In all cases the 5-psig steam cooker was the most cost effective with an average energy cost of less than a third of that for the convection electric oven. The 15-psig steam cooker, the convection gas oven and the conventional gas oven were intermediate with respective average energy costs of 0.21, 0.27, and 0.31 cents per pound of product.

Table 10
Cost of Energy per lb to Rethermalize Entree Items
(Cents per lb)

Equipment	Set- Point	Turkey A la King	Swiss Steak	Sweet and Sour Pork	Fried Chicken
Conventional Gas Oven	350°F	0.32	0.30	0.29	0.31
Convection Gas Oven	300°F	0.30	0.26	0.28	0.24
Convection Elec. Oven	300°F	0.56	0.45	0.56	0.57
Steam Cooker	5 psig	0.19	0.16	0.18	0.14
Steam Cooker	15 psig	0.27	0.19	0.21	0.16

The costs in Table 10, represent the cost of energy consumed in heating a cavity filled with product from an initial temperature of about 5°F to a minimum end point temperature of 160°F. The end point was established when all the thermocouple probes reached 160°F or higher. Not all the pans contained thermocouple probes, but there was at least one pan with two probes on every shelf. The pans with probes were randomized from shelf to shelf and were always positioned in the same location. Figures A-1 through A-5 show the arrangement of the pans and the locations of those with probes. It is recognized that some of the pans without probes may have been over- or underheated, but this is not considered significant as far as energy consumption is concerned.

Evaporation losses were calculated by dividing the weight loss (after heating) by the initial weight. Averaged results of two test runs with each entree are shown in Table 11.

Table 11

Evaporation Losses during Rethermalization

Equipment	Turkey A la King (%)	Swiss Steak (%)	Fried Chicken (%)	Sweet and Sour Pork (%)	Average (%)
Conventional Gas Oven	1.6	1.6	0.4	2.5	1.5
Convection Gas Oven	4.8	4.5	1.4	6.0	4.2
Convection Elec. Oven	3.8	1.5	2.3	5.7	3.3
5-psig Steam Cooker	0	0	0	0	0
15-psig Steam Cooker	+1.1	+3.0	+4.5	+7.5	+4.0

These losses with gas and electrically heated equipment can be anticipated by increasing the water content of the formulation. A similar approach can be used to compensate for the weight gain in the 15-psig steam cooker but in this case the water content of the formulation would be adjusted downward. A possible explanation for the high yields in the 15-psig steam cooker is that the crimping of the covers could be loosened by the initial differential in pressure between the headspace in the pan and the cavity. Any openings due to a break in the crimping would provide additional access for steam to condense on the cold surface of the product.

Table 12 summarizes the results of reconstituting frozen Turkey a la King, Swiss Steaks, Fried Chicken, and Sweet and Sour Pork in typical types of dining hall heating

Table 12

Summary of Averaged Test Results and Costs

Equipment	(Col. 1) Set Point (° F)	(Col. 2) Time for all TC's to reach 160° F (hours)	(Col. 3) Time Lag- 1st TC to Last TC (hours)	(Col. 4) Time at 212° F (min)	(Col. 5) Btu's used per lb. of product	(Col. 6) Evapor- ation Loss (percent)	(Col. 7) Cost (¢/lb)
Conventional Gas Oven	350	2.77	0.78	2.5	1068	1.5	0.31
Convection Gas Oven	300	1.25	0.42	23.0	743	3.3	0.27
Convection Elec. Oven	300	1.58	0.65	15.5	435	4.2	0.54
5-psig Steam Cooker	227	1.56	0.35	0.0	440	0.0	0.17
15-psig Steam Cooker	250	1.13	0.41	0.0	599	0.0	0.21

equipment. The figures in columns 2, 3 and 4 provide an indication of the magnitude of localized overheating. The evaporation loss (column 6) reflects the losses and offers additional evidence of overheating. Column 7 is based on the prevailing cost of utilities at NARADCOM -- 4.54 cents per kW·h for electricity, \$3.27 per 1000 lb for steam, and 29.99 cents per 100 cu ft for gas. These figures are averages, separate figures for each product are shown in Table 10.

The time lag, the time at 212°F, and the yield figures for the gas and electrically heated equipment indicate the prevalence of non-uniformity in heating and localized overheating.

The best combinations of results were obtained with the 5-psig steam cooker. The only objectionable characteristic is the relatively low heating rate. The uniformity of heating, however, was the best; evidence of overheating was the least; and the cost of energy per lb of product was the lowest.

DISCUSSION

It is evident from the results of this study that cooking and baking equipment which is typical of that in dining halls, display major deficiencies and wide differences in performance when used for rethermalizing bulk frozen foods in a cook-freeze system.

Table 12 shows that, as far as energy consumption is concerned, the convection electric oven and the 5-psig steam cooker are almost identical and consumed only 41 percent of the energy used by the conventional gas oven. However, due to difference in utility costs at NARADCOM, the cost per pound of product (0.54¢) for the convection electric oven is more than three times the cost of reconstituting the frozen entree items in the 5-psig steam cooker (0.17¢).

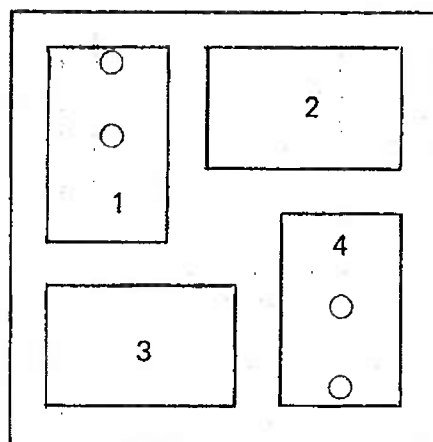
The apparent equipment efficiency, as determined by heating distilled water (Table 5), of the 5-psig steam cooker is highest at 94% while the conventional gas oven is lowest at only 33%. Heating rates were also the most uniform in the 5-psig steam cooker as evidenced by the relatively short lag between the time the first and last thermocouple probes reached 160°F (Table 12, 0.35 hours).

While all five types of equipment showed wide variations in temperature uniformity, the overall results indicate that the performance of the 5-psig steam cooker to be the best.

There are other rethermalization methods such as boil-in-bag and microwave heating which might be used. Judging from the irregularities found in this study, using typical types of dining hall equipment for rethermalizing frozen food, it is evident the subject should be investigated in greater depth, with attention being focused on the design and development of equipment for the specific purpose.

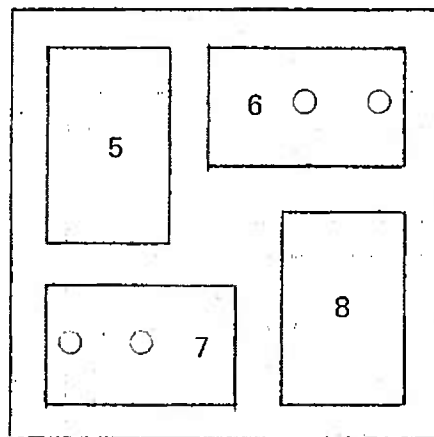
APPENDIX

Top Shelf



Front

Bottom Shelf

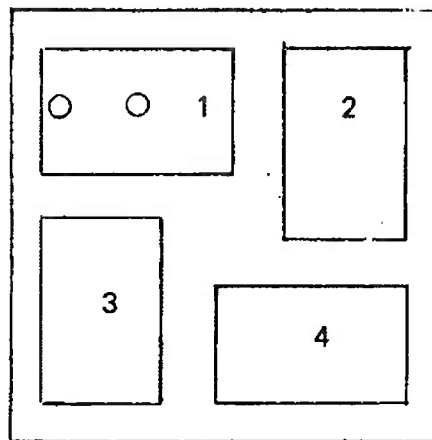


Front

- Notes:
1. "0" indicates TC probes
 2. Numbers identify individual pans

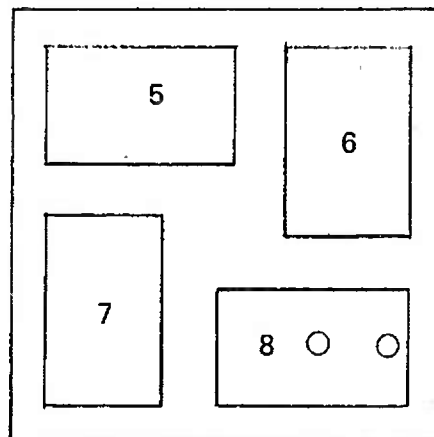
Figure A--1
Conventional Gas Oven
Pan and Thermocouple Placement

Top Shelf



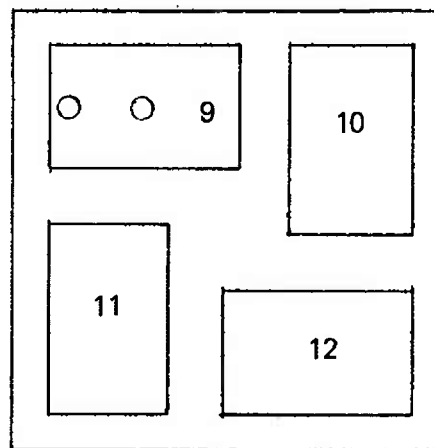
Front

Center Shelf



Front

Bottom Shelf

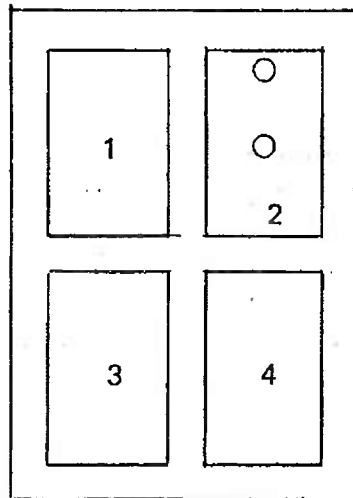


Front

- Notes:
1. "0" indicates TC probes
 2. Numbers identify individual pans

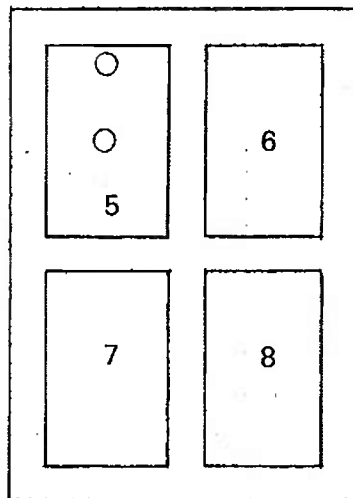
Figure A-2
Convection Electric Oven
Pan and Thermocouple Placement

Top Shelf



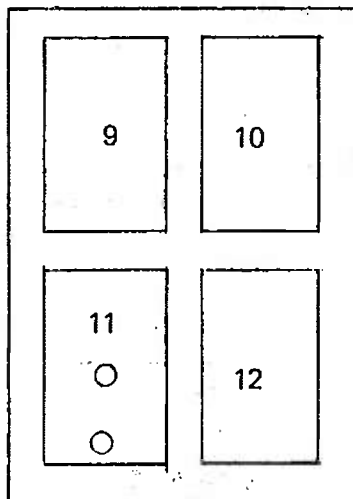
Front

Center Shelf



Front

Bottom Shelf



Front

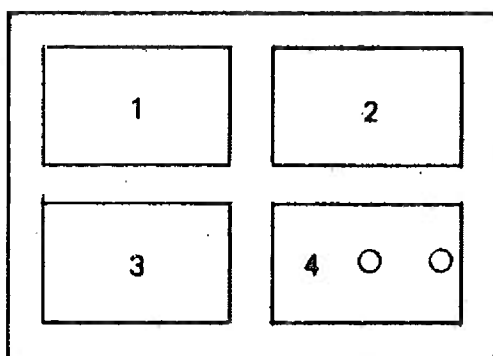
Notes: 1. "0" indicates TC probes

2. Numbers identify individual pans

Figure A-3

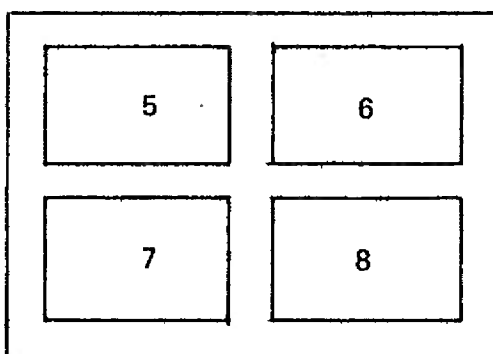
Convection Gas Oven
Pan and Thermocouple Placement

Top Shelf



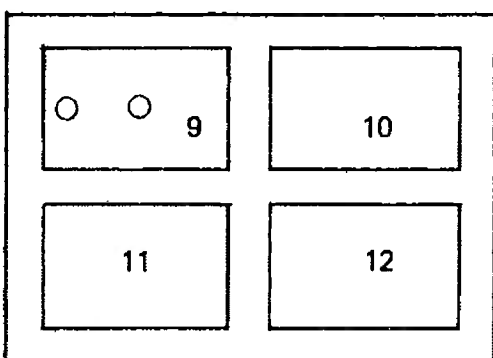
Front

Center Shelf



Front

Bottom Shelf



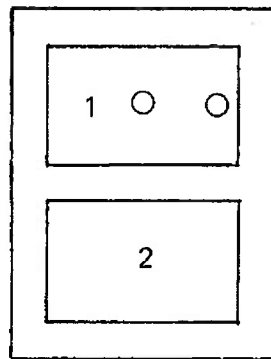
Front

Notes

1. "0" indicates TC probes
2. Numbers identify individual pans

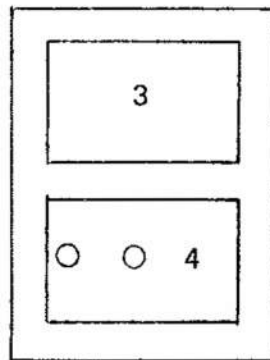
Figure A-4
5-psig Steam Cooker
Pan and Thermocouple Placement

Top Shelf



Front

Bottom Shelf



Front

- Note: 1. "0" indicates TC probes
2. Numbers identify individual pans

Figure A-5
15-psig Steam Cooker
Pan and Thermocouple Placement

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