Heat Sink Reference Oven[1]

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ABSTRACT

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A "heat sink" oven or chamber for standardizing test baking conditions in ovens of different design is described. The totally enclosed chamber of specified dimensions provides fixed conditions of moisture and air movement, and the moderating or damping effect of the heat sink on the rate of heat transfer from the oven in which it is placed allows close specification of baking conditions. Bread was baked in ovens of different design with and without the heat sink. Control point, environment, and internal loaf temperatures were monitored on a recorder, and bread properties were examined. The range in loaf volume for loaves baked in the heat sink was narrower than that obtained when loaves were baked under normal operating conditions in different ovens, and replication was improved. The heat sink oven may be useful in resolving one of the major sources of variability when a reference baking method is used in different laboratories with different ovens.

The complex chemical, biological, and physical interactions that occur in the production of bread create much difficulty in simplifying and standardizing test baking methodology so that a number of collaborators in different laboratories can obtain the same results for a given set of test flours (Tipples 1979). Some progress toward the development of a standard baking test or reference method has recently been made by the International Association for Cereal Chemistry. However, although processing conditions can be specified to a large extent, some baking equipment, notably the oven, is more difficult to standardize through specification. Ovens constructed differently (in size, materials, and heaters, and with or without forced air circulation, etc.) produce different levels of heat transfer through radiation, convection, and conduction, and therefore specifications of temperature require qualification that cannot always be satisfied. Furthermore, if a commercially produced laboratory oven is specified, it may not be available to many laboratories for economic or space reasons—particularly if the oven would be used only for reference purposes.

This article describes a heat sink oven or chamber that may be used within an existing bake oven. It embodies one of the oldest principles used in baking bread: utilization of the residual heat of the walls, floor, and roof retained following a preheating stage. As originally practiced, this method was crude and subject to considerable variation between bakes; it depended on many factors for consistency of performance. The device presented here allows for close specification of baking conditions largely because of the inherent moderating or damping of the rate of heat transfer from the oven in which it is placed. At the same time, the heat is sufficient to bake a loaf of bread, and the totally enclosed chamber of specified dimensions provides fixed conditions of moisture and air movement.

This article describes results of a study conducted with bread baked in ovens of different design with and without the heat sink. Control, environment, and internal loaf temperatures were monitored on a recorder, and bread properties were examined.

MATERIALS AND METHODS

Equipment

Heat Sink Oven. The heat sink oven was constructed from 12.7-mm (0.5-in.) aluminum plate. Overall dimensions are 290, 220, and 255 mm for width, depth, and height, respectively. All surfaces are coated with mat black paint. The front panel, used as a door, is hinged at the bottom and has a simple turn-button to tighten the door in the closed position (Fig. 1). The door gasket is of silicone rubber, 12.7 mm wide and 3 mm thick. The total weight is 12.3 kg.

Research Oven. The bake oven in current use in the Grain Research Laboratory (GRL) was manufactured by National Manufacturing Company, Lincoln, NE. It has a rotating hearth (810 mm in diameter) and is equipped with a Partlow temperature controller (Fig. 2). It was modified after purchase by replacing the open coil heating elements with low-lag fin-strip heaters to avoid possible exposure of laboratory personnel to formaldehyde fumes through reaction of alcohol with open elements. An open circulating fan (of low velocity) was installed at the top of the oven chamber to reduce the stratification of temperature from bottom to

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top. The fan motor is located on top of the oven and is wired in parallel with the motor driving the hearth. In normal baking procedures, the hearth is stopped before the oven door is opened, at which time the fan is also stopped to minimize loss of oven heat to the outside room.

Most baking of test loaves is done within sheet metal forms referred to as "compartments." Five of these units are spaced equally around the periphery of the rotating hearth. They serve to buffer the different conditions within the oven and thereby to improve the replication of baking results over those obtained using the open hearth. The need for the compartments probably arises from the frequent opening of the oven door (between 6 and 12 times during the baking period of a given loaf) that occurs when loaves are introduced or removed from the oven in sequence, ie, following a 5 or 10-min schedule. Some radiation effects due to the close proximity of the compartment's sides and top to the loaf may also exist. The compartments also serve to moderate air movement

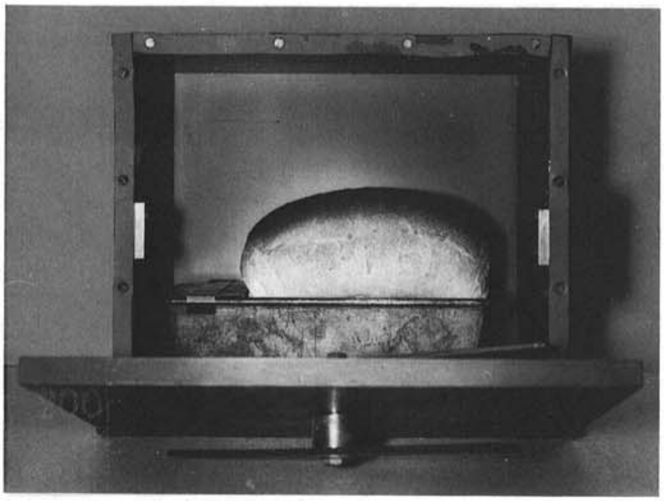

Fig. 1. Heat sink reference oven with hinged door open and baked 2/3-lb loaf in place.

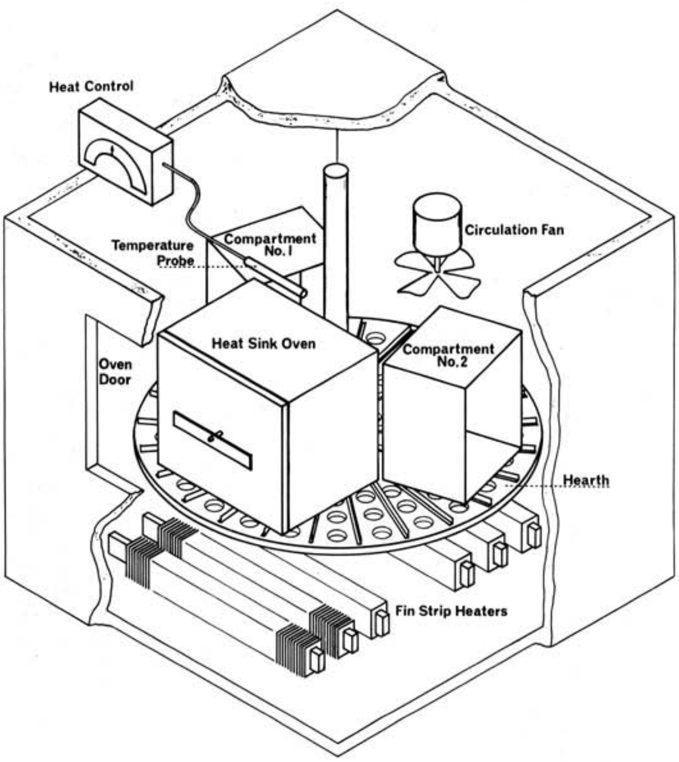

Fig. 2. Research oven, showing configuration of structure and placement of heat sink oven.

between the various loaf positions within the oven.

Reel Oven. A Nicholson 1 bag reel oven (Nicholson Equipment Ltd., Edmonton, Alberta) was located in the pilot bakery of the Canadian International Grains Institute.

Peel Oven. A Nicholson custom-built high-temperature stationary single-deck hearth oven (Fig. 3) was located in the pilot bakery of the Canadian International Grains Institute.

Muffle Oven. A laboratory box furnace (model 51828, Lindberg, Watertown, WI) was located in the GRL Technical Services Baking Laboratory and was used primarily for high-temperature baking of Arabic-type bread (Fig. 4).

Thermocouple Thermometer. A model BAT 7 (Bailey Instruments Co., Inc., Saddle Brook, NJ) thermocouple thermometer with a recorder output was used. It had type T thermocouple probes with a time constant of 0.5 sec and a sensing bead diameter of approximately 0.5 mm. Leads insulated with Kapton were 1.5 m long and had an o.d. of 0.72 mm. Calibration of recorder response was achieved using water at 30° C, boiling water, and a 220-g body of metal heated to 240° C (indicated on the Bailey instrument) as references.

Recorder. The recorder was a Ricken Denshi model SP-G5V. A chart speed of 300 mm/hr was used for all tests.

Temperature Measurements

The control point temperature was monitored by attaching a thermocouple to the oven-sensing probe.

Heat sink temperature was monitored from a thermocouple probe located in one wall of the heat sink. A hole 1.5 mm in diameter was drilled vertically from the top edge of the aluminum wall of the heat sink to a depth of 26 mm, running parallel with the wall. The thermocouple probe was inserted the full depth of the hole.

Loaf environment temperature was monitored by a thermocouple probe located 170 mm from the bottom of the loaf pan and above the loaf being measured.

Internal loaf temperature was monitored by a thermocouple inserted into the center of the dough from one end immediately after panning. Thermocouples were connected to the recording system and temperature monitoring began when the loaf was placed in the oven following a proof period. Figure 5 shows measurements obtained when the research oven controller was set for 225° C.

Flour

Straight-grade flour was milled on the GRL pilot mill (Black 1980) from a sample of No. 1 Canada Western red spring wheat, 13.5% protein. Protein (N × 5.7) was 13.0%; ash, 0.44%; starch damage, 27 Farrand Units; and baking absorption (short process), 65%.

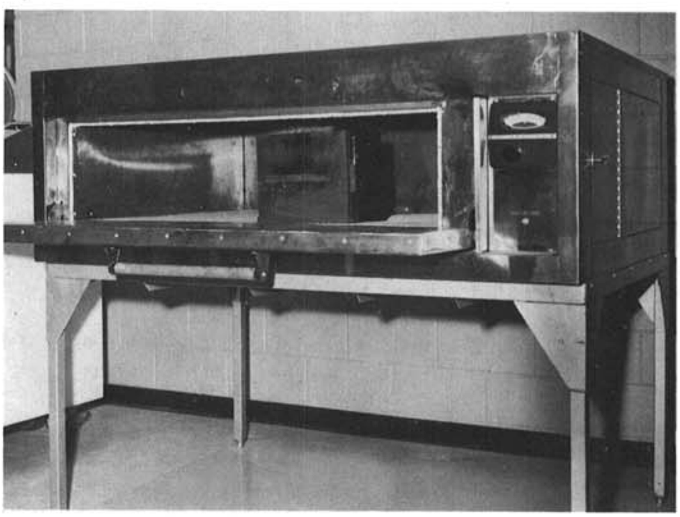

Fig. 3. Nicholson custom-built, high-temperature, stationary, single-deck hearth oven with heat sink oven in place.

Baking Method

The GRL Canadian short process method was used for all results presented here.

The formula, on percent flour basis, was: flour, 100, (800.0 g); yeast, 3.0; sucrose, 4.0; salt, 2.4; shortening, 3.0; ammonium phosphate, 0.1; whey powder, 4.0; malt syrup (60° L), 0.15; dough water, 65 (the maximum consistent with machinability of the dough); potassium bromate, 30 ppm; and ascorbic acid, 37.5 ppm. Doughs were scaled at 362 g, equivalent to 200 g of flour.

Doughs were mixed at high speed, using the GRL-1000 mixer (Kilborn and Tipples 1974) at 160 rpm, with mixing bowl temperature controlled to produce a finished dough temperature of 30° C. Doughs were mixed to a stage corresponding to 110% of the energy required for peak consistency as judged from a mixing curve. Doughs were scaled, rounded lightly, and placed in crocks for 15 min in a cabinet controlled at 30° C and 90% rh. They were removed and punched lightly seven times, then returned to the cabinet for an intermediate proof period of 15 min. Doughs were then sheeted, molded using the GRL molder, placed in baking pans, proofed for 70 ± 1 min at 38° C, and baked.

Bread Evaluation

Test loaves were weighed 1 min after removal from the oven. Loaf volume was measured 30 min after baking, and loaves were sealed in plastic bags. Loaves were appraised visually after 20 ± 2 hr for crust color, external appearance, crumb structure, and crumb color.

Preliminary Studies with the Research Oven

Air velocity measurements, in meters per minute, were made at room temperature with a Hastings air meter probe. Measurements were made at approximately mid-loaf height (100 mm from the hearth) at the five positions in the oven: 0, 72, 144, 216, and 288°, moving counterclockwise from the position by the door and viewed from above. Readings were made with the fan on and with the oven door either open or closed. Similar measurements were also made with the compartments removed.

Loaves were baked from identical doughs in the research oven at 205° C for 30 min. Baking variables were: position in the oven, use of the fan, use of a compartment, use of the heat sink oven.

In working with the heat sink in the research oven, the hearth drive was disconnected and the arrangement shown in Fig. 2 was used. The hearth was not rotated during baking. It was, however, swung back and forth to insert loaves into or remove them from compartments 1 and 2. When the compartments were removed, loaves were baked on the hearth in positions 1 and 2 corresponding to the positions of the compartments. Moisture was provided from two containers (2 L each) of boiling water located in the center of the oven. Loaf volumes were reported on the basis of 100 g of flour and were averages of duplicate bakes.

Studies with Various Ovens

Loaves were baked from identical doughs in four ovens using the heat sink and in three ovens under normal conditions. For each oven a day was required to determine the individual control setting required to produce an average heat sink temperature of 215° C (measured in the heat sink wall). This was the minimum temperature required to produce satisfactory crust color in the heat sink after a 30-min baking period. These control settings were then used to bake bread on subsequent days within the heat sink, within the sheet metal compartments, and, in some instances, on the open

Table I
Air Velocity (m/min) Within the Research Oven.

Condition		Position[a]				
Oven Door	**Metal Compartment Used**	**0°**	**72°**	**144°**	**216°**	**288°**
Closed	No	13.5	46.0	23.0	10.5	6.0
	Yes	15.0	21.0	13.5	12.0	13.5
Open	No	12.0	53.0	24.0	7.5	7.5
	Yes	10.5	24.0	18.0	12.0	10.5

[a] Moving counterclockwise from opposite oven door (0°) when viewed from above.

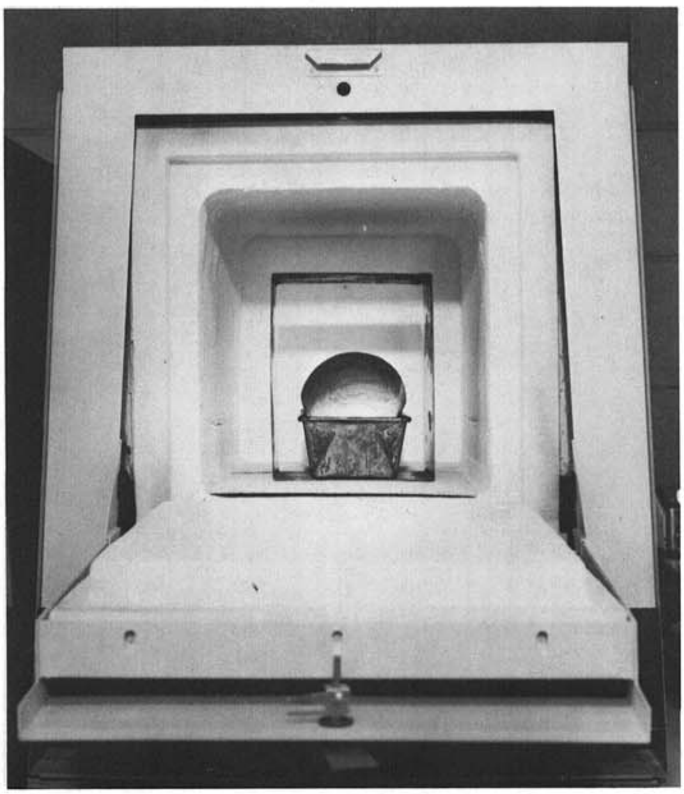

Fig. 4. Lindberg laboratory box furnace with 2/3-lb loaf within sheet metal compartment.

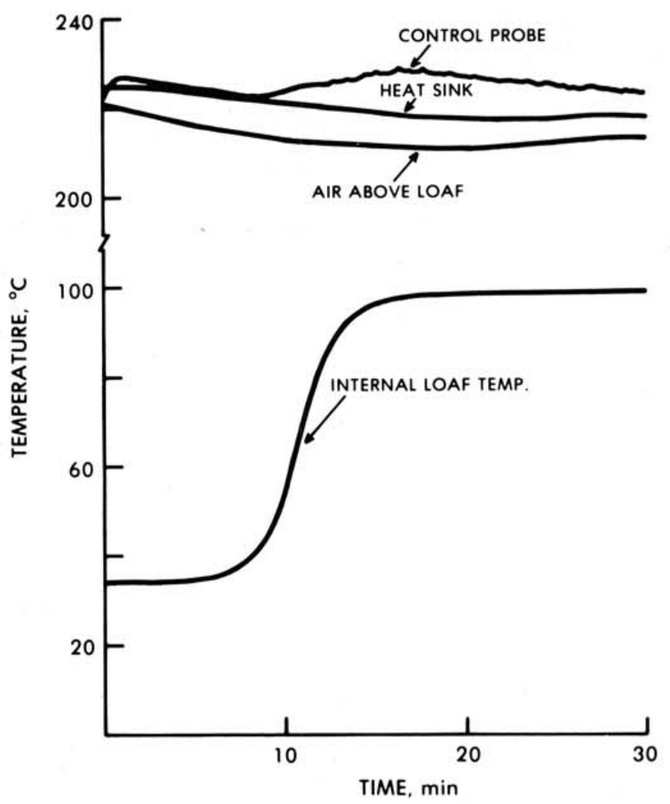

Fig. 5. Temperature measurements in the research oven (set at 225° C) taken at the level of the control probe, within the wall of the heat sink oven, 170 mm above bottom of loaf pan, and inside the loaf.

hearth.

For comparison purposes, loaves were baked under normal conditions. For each oven, baking times and temperatures were determined that would produce satisfactory crust color and a bake-out (as indicated by loaf weight) similar to that obtained with normal operation of the Research oven.

Increased Thermal Capacity

The effective wall thickness of one heat sink oven was increased by inserting additional 12.7-mm plates of aluminum and fastening them with machine screws to each surface (except the door).

RESULTS

Research Oven

Table I shows the stabilization effect of the compartments in terms of air velocity. The highest velocity, 46 m/min, occurred at the 72° position, which is close to the fan. With the oven door closed, air velocity ranged from this value down to 6m/min at the 288° position for the open hearth. Within the compartments, the air velocity variability was reduced to a range of 12–21 m/min. This illustrates one aspect of the moderating effect of the compartments. With the oven door open, variation in air movement was greater for both systems, indicating the desirability of switching the fan off before opening the oven door.

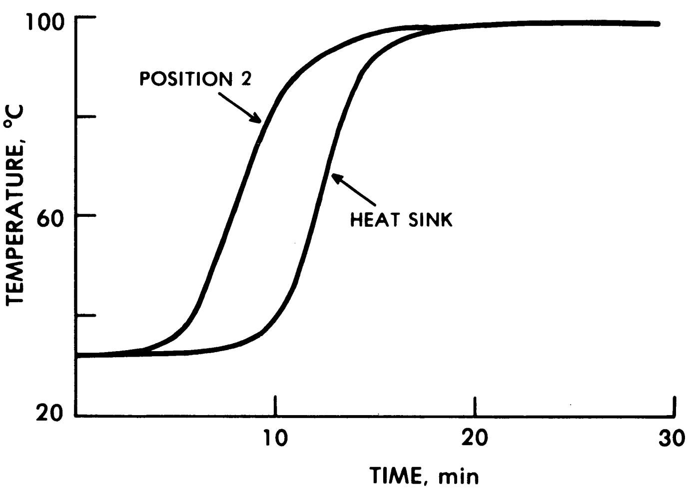

Fig. 6. Rate of change of internal loaf temperature in the research oven (set at 205°C) for loaves baked with the heat sink and at position 2 without the heat sink.

Results in Table II are arranged in inverse order of degree of bake-out, as determined from loaf weight measured 1 min after removal from the oven. Crust color ranged from dark to medium pale. The three loaves marked "satisfactory" were not visually distinguishable one from another. The control-set temperature of 205° was too low to produce proper crust color in loaves baked in the heat sink. These results illustrate that even in the same oven under the same temperature and time conditions, fairly large variations can occur depending on position and air circulation. Loaf volumes varied from 920 to 1,000 cc, loaf weight from 297 to 315.5 g, and loaf appearance score from 6.5 to 8.0. Considerably higher loaf volume and loaf appearance scores were obtained in position 2 where air velocity was highest.

Figure 6 shows the temperature curves recorded from the center of the baking doughs for the two extremes, position 2 and the heat sink. Curves representing the other baking conditions were intermediate to these but biased towards the heat sink result. This degree of variability was obtained despite the fact that the oven had low-lag evenly distributed heaters, air circulation, a precision temperature controller, and was set for one temperature.

Various Ovens

The control point to achieve the required heat sink temperature varied widely for the various ovens and was quite different from temperatures measured in the areas where bread was baked (Fig. 7). Results obtained in locations other than the heat sink were not considered comparable because normal conditions of humidity and bread load did not exist.

The range in loaf volume for the loaves baked in the heat sink (Table III) was narrower (925–942 cc) than that obtained under

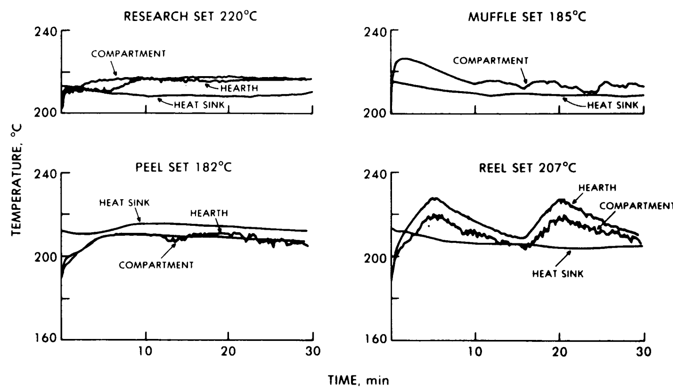

Fig. 7. Changes in temperature of heat sink, compartment, and oven hearth for four different ovens.

Table II
Characteristics of Loaves Baked from Identical Doughs in the Research Oven[a]

	Position					
	2	1	2	1	2	Heat Sink
	Compartment					
	No	No	Yes	Yes	Yes	No
	Fan					
Characteristic	**On**	**On**	**On**	**On**	**Off**	**On**
Loaf volume,[b] cc/100 g of flour	1,000	925	940	920	960	935
Crust color[c]	Dark	S	S	S	S−	MP
Appearance	8.0	6.5	7.0	6.8	7.5	6.8
Crumb structure[d]	6.8−o	6.8−o	6.8−o	6.5−o	6.8−o	6.8−o
Crumb color[e]	9.5	9.0	9.2	9.0	9.0	9.0
Loaf weight, g	297	301	305	307	311	316

[a] All results are means of duplicate bakes at 205°C for 30 min.
[b] A difference of 35 cc is significant at the 5% level.
[c] S = satisfactory, S− = satisfactory but slightly paler than S, MP = medium pale.
[d] o = Open.
[e] Rated on a scale of 0.5 to 10.0; higher numbers indicate greater visual brightness.

Table III
Characteristics of Loaves Baked from Identical Doughs in Different Ovens

	Normal Operation			With Heat Sink at 215°C			
	Research	**Reel**	**Peel**	**Research**	**Reel**	**Peel**	**Muffle**
Set temperature, °C	205	210	190	220	207	182	185
Load, number of loaves	3	35	15	3	4	4	1
Baking time, min	30	29	32	30	30	30	30
Test loaves baked, total	8	8[a]	8[a]	6[b]	12[c]	12[c]	4
Loaf volume, mean ± SD	988 ± 13	1,007 ± 53	953 ± 28	940 ± 13	942 ± 13	925 ± 15	938 ± 15
Crust color[e]	S	S	S+–v. d.[d]	S	S	S	S
Loaf weight, mean ± SD	311.6 ± 1.3	311.7 ± 1.6	311.2 ± 3.4	310.9 ± 0.9	310 ± 1.4	311.8 ± 0.9	310 ± 1.0

[a] From 12 loaves baked over two days. First three loaves used to estimate time and temperature to satisfy crust color and bake-out. Fourth loaf taken from oven slightly early to verify new temperature-time effect on bake out. These first four loaves discarded.
[b] From 10-loaf series baked over 2 days, as above.
[c] Two heat sinks in each oven baked over 2 days for each oven.
[d] Unable to obtain proper and uniform crust color in the range of 30 ± 3 min. Darker than satisfactory to very dark.
[e] S = Satisfactory.

normal operating conditions (953–1,007 cc), and replication was improved using the heat sink. The lower volumes obtained with the heat sink were probably related to the lack of air movement within the chamber.

Effect of Increasing Thermal Capacity of Heat Sink

When an additional aluminum plate was added to each surface of the heat sink, weight increased to 19.6 kg. Whereas the temperature of the single-walled heat sink varied during the baking period from 214 to 208°C, that of the double-walled heat sink varied from 214 to 210°C. Internal loaf temperature curves were only marginally different.

DISCUSSION

Different ovens and different conditions within the same oven can have very marked effects on bread characteristics, even where control temperatures appear similar. Oven control-indicator set-points do not always agree with the average temperature of the oven. A device constructed using the concept of the heat sink oven may be a practical solution to these problems for a reference baking method. In these investigations highly stable baking conditions and similar end product were obtained when the heat sink was used with ovens of different design. Specification of heat sink temperature (measured in the wall), dough weight, and baking time will, in large measure, govern other baking factors such as oven moisture and ratio of the different types of heat transfer, which are normally very difficult, if not impossible, to affect in ovens of different design.

The thickness of the heat sink walls appears to govern the degree of stability of temperature during the baking period. About 50 min is required for the recovery and equilibrium of temperature of the heat sink after baking a loaf of bread before the next loaf can be inserted. To shorten this period significantly through adjustment of the "mother" oven temperature control point would probably reduce the stability of the heat sink during baking. As has been demonstrated, placing dough in the heat sink when the specified wall temperature is reached results in a closely controlled bake that does not reflect the cyclic changes in temperature or air movement of the mother oven.

Heat sink ovens could be cast from aluminum to save some machining costs. A central manufacturing point would be ideal so that all units could be made in the same way.

ACKNOWLEDGMENTS

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