Thermosyphon Kit for Conversion of Electrical Bakery Ovens to Gas

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Abstract

Electrical driven bakery ovens are cost ineffective due to two main reasons: the electricity fare is high and the quality of the product is poor, causing the waste of a high amount of bread, inadequate for selling. A Kit, designed to convert bakery ovens from electrical into gas is presented in this paper. The Kit consists of twenty thermosyphons displayed in two rows of ten, vertically aligned, closed to the lateral walls of the oven. A combustion chamber is installed under the rear face of the baking chamber. Twenty burners are specially designed for this application and installed under each thermosyphon evaporator. The heat is generated by gas burning (GLP or Natural) in the combustion chamber. These ovens present several advantages when compared to the electrical conventional ones: uniform temperature distribution inside the baking chamber; no contact between the combustion gases and the bread; short temperature recovering time after operational door openings, easy control of the cooking temperature, reduced operation cost and short time of investment recovering. The higher heating ramp time is a disadvantage, but new developments are proposed to solve this problem in the near future.

Key Words: thermosyphon, heat pipes, bakery ovens, baking chamber, combustion chamber.

1. INTRODUCTION

The Brazilian Government has to deal with the serious energy crisis that the country faces. Several energy conservation programs have been created, including the stamping of bakery ovens, which are ranked according to its energy use efficiency. In this frame, bakery oven factories are looking for simple technological solutions to improve the thermal performance of the equipment that they manufacture.

Thermosyphons are efficient devices designed to transfer high heat rates from large distances when subjected to small temperature differences (see Peterson [1]). They are basically composed by a sealed metal tube, which is evacuated and where a certain amount of working fluid is inserted. There are three main regions in a thermosyphon: evaporator, adiabatic section and condenser. Saturated liquid and vapor operates in a closed cycle inside the tube.

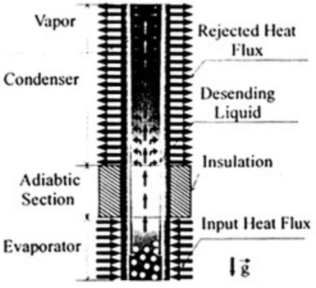

Figure 1. Schematic of the thermal performance of a thermosyphon.

Figure 1 shows a schematic of the thermosyphon thermal performance. The heat imposed to the evaporator, always located at a lower position, evaporates the liquid accumulated in a small pool. The formed vapor migrates to the condenser by pressure unbalance. Heat is removed from the condenser and the condensed liquid returns to the evaporator by the action of gravity.

1-1 The Ordinary Baking Oven

According to Mantelli et al. [2], the ordinary bakery ovens are usually driven by GLP or electricity. Wood is still used in a minor scale. The gas represents a lower operational cost but the electrical ovens are considered safe and easy to operate. Both models, specially the electrical ones, present thermal inefficiencies. In this case, the generated heat is concentrated in about 10% of the volume of the baking chamber, being inefficiently distributed by means of a 1 HP ventilator, causing super and under-heated areas, which affect the quality of the baked bread.

On the other hand, the GLP ovens reject combustion gases at high temperatures, resulting in energy losses. In addition to this, the combustion takes place in a lower region of the baking chamber and the hot gases, resulted from the gas burn, heat the baking chamber. Besides, to guaranty a reasonable temperature distribution, a ventilator, similar to the one employed to the electrical oven, is used.

1-2 The Bread Baking Process

According to Kupka and Mantelli [3], despite of the equipment to be employed (gas or electrical) the baking process involves two basic steps. First, the already grown bread dough at room temperature is inserted in the pre heated oven. The dough temperature increases to up to 100 °C, when the dough water starts to be vaporized. Then, in a second phase, the temperature of the dough is kept in an almost constant level, while the water is eliminated through the external surface of the bread. Hasatani et al. [4], [5] made an experimental analysis of the behavior of two bread doughs with the same compositions but with different weights and submitted to three different temperature levels: 150 °C, 200 °C and 250 °C. The initial dough weights were 1560 g and 50 g. The bread baking was monitored by a weighing scale so that it was possible to relate the temperature level to the dough weight. These authors concluded that the vapor flux, from the bread to the environment, reaches its maximum at the point when the dough presents a uniform temperature. The bread hard cover starts to be formed when the heating phase is finished. Independently of the dough weight, the bread baking temperature is kept at around 100 °C.

2. THE THERMOSYPHON KIT

A common electrical bakery oven bought from the market was adapted with thermosyphons, in order to be able to work both with gas and electricity.

The thermosyphons used in the Kit were specially developed for this application (Mantelli et al. [6]). To allow the action of the gravity in the return of the condensed fluid to the evaporator, the thermosyphon should be positioned in a vertical (or close to) position. On the other side, to facilitate the heat transfer from the burners, the thermosyphon evaporator should not be vertical; in fact, the more tilted the evaporator in relation to the condenser, the better.

As described by Mantelli et al. [7], the following configuration was selected. The selected tube is made of stainless steel (a good material for food manipulation) and presents an external diameter of 1,905 cm. The condenser is 1 m long, while the evaporator is 30 cm long with an inclination of 45°. The water was selected as the working fluid, due to its good thermal properties and for the reason of being harmless in the case of accidental fluid release to the baking chamber. The filling ratio (ratio of the liquid volume to the evaporator volume) was chosen to be 80%. Figure 2 shows a drawing of the thermosyphon developed.

As concluded by Mantelli et al. [6], each thermosyphon should transfer at least 400 W of heat power to work properly. Around 20 thermosyphons were aligned, in two lines of ten, along each of the lateral walls of the oven.

Geometrically, the oven can be described as composed by two main compartments: the upper, representing the baking chamber and the lower, representing the combustion chamber, where the burners are installed. Figure 3 shows those compartments before the thermosyphon installation. The thermosyphons are positioned to lead through both compartments. The combustion heat generated by the burners is transferred to the baking chamber by means of the thermosyphons, in order that only the heat is transferred, not the combustion gases, which can be harmful to the health. In Figure 3 one can also see the ventilator in the central region of the baking chamber, which is a part of the original oven. The tubes located close to the ventilator are actually the electrical resistors.

Figure 4 shows a schematic of the Kit installed in the bakery oven, without the trays. In this figure one can observe the vertical long condenser located close to the baking chamber lateral walls and the inclined evaporator, in the combustion chamber. It is important to note that the Kit can be installed in the oven with no major modifications, within the space available between the trays and the chamber walls.

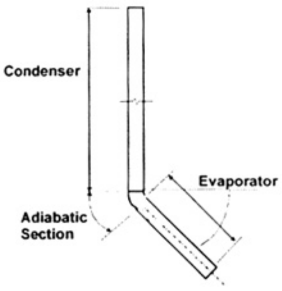

Figure 2. Schematic of the thermosyphon developed for the Kit.

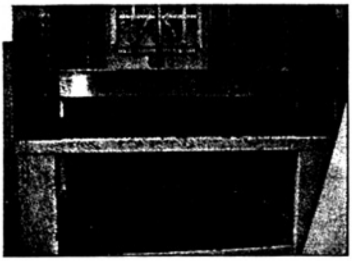

Figure 3. Photo showing the combustion and the baking compartments.

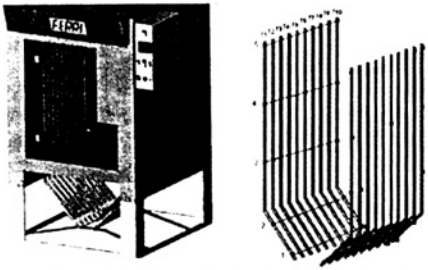

Figure 4. Kit installed in the baking chamber.

3. THE EXPERIMENTAL WORK

After the installation of the Kit, the oven assisted by thermosyphons was monitored by means of several Type K fiber glass recovered thermocouples, installed in different points along the walls, the tubes, the baking chamber environment, the combustion chamber, etc. The temperature reading errors of the thermocouples were ± 1 °C. Figure 5 presents the temperature reading points used to monitor the temperature distribution inside the baking chamber, while in the right side of Figure 4, the thermocouple positions over the thermosyphons are shown.

The gas and energy consumption need to be measured for the reason that the energy conservation is one of the objectives of the present work. The gas consumption was measured through its volume and weight, using a mass flow rate gage of ± 0,1 dm^3 of uncertainty and the weight was measured by means of a analogical scale of ± 10 g of uncertainty. The measurements were repeated each 15 minutes during the experiments. The electrical energy consumption was obtained through a electrical power meter, with an uncertainty of ±5 W.

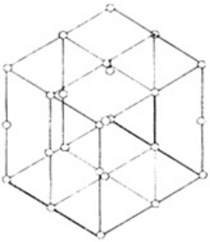

Figure 5. Lay out of the baking chamber temperature reading positions.

4. EXPERIMENTAL RESULTS

In all the tests performed, the measurements were done in transient conditions, which are the actual conditions in which real ovens work.

The temperature distribution of the baking chamber was measured for the electrical and the thermosyphon assisted ovens. Figure 6 shows a comparison between the temperature distribution for the thermosyphon assisted oven (left) and the electrical one (right).

The temperature distribution of the central regions of the baking chamber can be observed in Figure 7. The two left pictures refer to the mean planes between the front and the rear walls (upper) and between the two vertical lateral walls (lower) for the electrical oven, while the two right pictures refer to the thermosyphon assisted gas oven. In fact, these pictures represent the region where the bread is actually cooked.

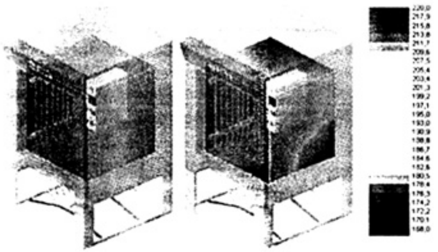

Figure 6. Baking chamber temperature distribution for themosyphon assisted oven (left) and electrical oven (right).

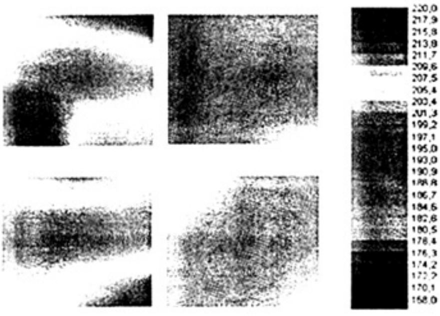

Figure 7. Temperature distribution for mean vertical planes of the baking chamber.

From Figures 6 and 7 one can see clearly that the thermossifon assisted oven presents a very uniform temperature distribution and no waste of the product is observed.

Figure 8 shows the bread obtained using the thermosyphon assisted oven (upper picture) and electrical oven (lower picture). One can note that the quality of the bread produced using the electrical oven vary very much along a single tray. This can not be observed form the thermosyphon assisted oven.

Figure 9 presents the time evolution of the temperatures for some locations along the thermosyphon assisted oven. The temperature of the combustion chamber reaches much higher levels than the temperature of the baking chamber, showing that a considerable amount of the energy being produced by the gas burn has not been used for baking. This happens due to problems in the design of the combustion chamber. As expected, the rear wall, which is in fact the division wall between the combustion and the baking chamber, and that therefore is in contact with the combustion hot gases, also presents high temperature levels. On the other hand, the released gases temperature is not very high, indicating that recoverable energy is not being wasted to the atmosphere.

To compare the performance of the electrical and thermosyphon assisted ovens in normal operation and to simulate the normal operation of a bakery, ten full runs of bread were baked in a row (five with the electrical and five with the thermosyphon assisted oven). The temperature readings for a thermocouple located in the center of the baking chamber is plotted against time for both tests in Figure 10. A complete baking cycle is composed by a heating ramp, where the baking chamber temperature is elevated from the room to the baking temperature, around 200 °C. At this time, the oven is opened to insert the dough full trays and a sharp temperature drop can be observed. Then the bread heats up and the baking chamber temperature also increase but in a lower rate than when it is empty. When the bread is ready, the oven is opened again to remove the baked bread and the temperature drops again. The door is then closed and the cycle starts again, but from the second cycle on, the initial temperature level is higher.

In Figure 10, one can observe that the electrical oven took around half the time to proceed with the five baking cycles, showing that heating ramps (rate of heating from the room to the baking temperature) for the first and subsequent runs are much steeper then for the thermosyphon assisted oven. For these ovens, the electrical resistances dissipates heat inside the baking chamber, so that 100% of the energy produced is delivered to the air to be heated and the heat losses happen just through the baking chamber external walls. Actually, it is desirable to warm up quickly the oven from the room temperature or after the bread is removed from the chamber. Therefore, the heating ramp can be considered one disadvantage of the thermosyphon assisted oven. However, the dough should have been kept at baking temperatures (around 200 °C) for some time to allow the dough to undergo all the chemical reactions that they need to grow and to form the hard cover. Actually, high heat fluxes cause poor temperature distribution, and poor quality of the bread. Furthermore, the electrical oven temperatures are difficult to control, as it can be observed by the different values of the temperature peaks observed in Figure 10 for the oven warm up, before the insertion of the dough to be baked.

5. ECONOMIC ANALYSIS

An economic analysis was performed for the operation of both the electrical and thermosyphon assisted ovens. The cost of the bread depends on the number of consecutive baking runs. Table 1 shows the costs, in the Brazilian currency (1 Real ≅ 3 US$), involved for one baking run, for the electrical and thermosyphon assisted oven. The price of the KWh of electricity was considered R$ 0,288. The price of the GLP was R$ 30,00 for 13 Kg of gas. Each baking run was considered to produce 240 breads. The gas power was estimated by the multiplication of the inferior heat power (45217.44 kJ/Kg) and the gas weight.

The waste of the product by over or under-baking represents an important increase in the cost of the bread production. The baking runs using electrical oven, performed in the Laboratory, following the procedures recommended by the oven manufacturer, showed that more then 10% of the breads were inadequate for selling.

In contrast, the cost of the Kit, including stainless steel tubes, burners, gas feeding tabulation, charging and cleaning materials, etc, is around R$ 1600,00. Considering all these costs, an analysis was performed for the kit investment recovering time. In other words, a study was done to find out how many months were necessary to return the capital invested in the Kit, considering the cost savings in energy and in the lack of bread waste.

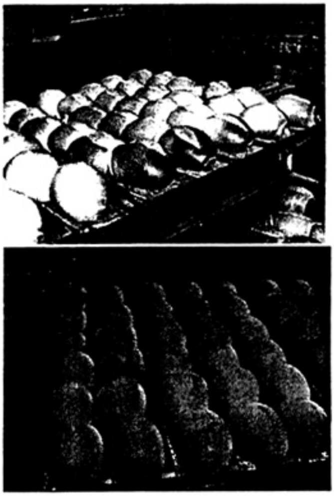

Figure 8. Photos showing the quality of bread for electrical ovens (upper) and thermosyphon assisted ovens (lower).

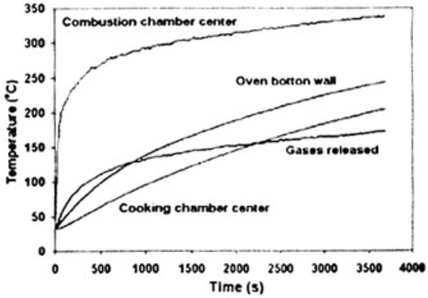

Figure 9. Temperature as a function of time for several points in the thermosyphon assited oven.

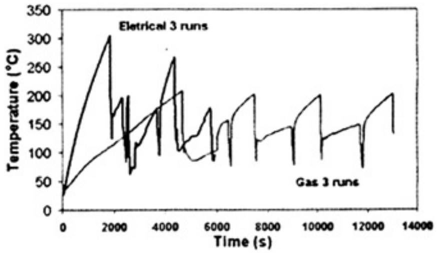

Figure 10. Baking chamber center temperature cycles for five baking in a row for the electrical and thermosyphon assisted ovens.

Figure 11 shows two curves of the investment returning time as a function of the number of baking runs per day. One curve considers no product losses while the other considers 10 % of losses. As already noted, the returning time decreases sharply as the number of baking run by day increases. Also, the losses parameter is very important. Considering ten runs a day, which is a typical number for a medium size bakery, if no losses are considered, the money invested can be recovered in about 18 months. If 10% of losses are considered, the recovering time is about 10 months.

6. CONCLUSIONS

A kit to convert electricity driven ovens to Natural or GLP gas was developed at LABSOLAR/NCTS. The project was proposed in the frame of the energy crisis that Brazil faces and has three main objectives: to substitute electricity by gas, to improve the efficiency in the energy use and to improve the quality of the bread.

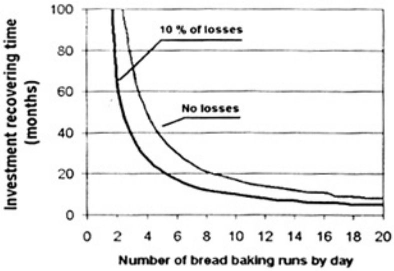

Figure 11. Investment recovering time as a function of the number of baking runs per day.

Table 1. Energy costs.

Electric Oven	
Ventilator power (mean value)	0.892 kWh
Thermal resistances	13.285 kWh
Overall consumption	14.18 kWh
Cost per hour	R$ 4.083
Cost per baking run	R$ 3.062
Cost per baking bread	R$ 0.0128
Thermosyphon gas assisted oven	
Volumetric mean consumption of gas	0.401 m^3/h
Mass mean consumption of gas	0.85 kg/h
Mean burner power	10.68 kW
Efective burner power (60 % of burner power)	6.41 kW
Ventilator cost per hour	R$ 0.257
Gas cost per hour	R$ 1.962
Overall cost per baking run	R$ 3.032
Overall cost per baked bread	R$ 0.0126

The kit is composed by thermosyphons installed close to the lateral vertical walls and was mounted inside a usual commercial oven. The modified oven can work both with electricity and gas. The temperature distribution inside the baking chamber is much more uniform for the gas then for the electrical oven. As a result, 100% of the bread produced presented the same quality all over the trays.

However, the heating time of the electrical oven is larger than that for the gas driven oven. In reality, the product waste causes larger economical losses then the energy waste.

The fact that the combustion chamber temperature is very high means that this chamber is not well designed. Actually, its volume is larger than the volume of the baking chamber. The heating ramp is of the same order of magnitude of the conventional gas ovens. Certainly the combustion chamber should be redesigned in the future to enable the energy conservation using the thermosyphon technology. It is important to note that even with this temporary adverse condition, the investment returning time is short. This time certainly will decrease much more after the combustion chamber improvement and after th implementation of an industrial series productio of the Kit.

The thermosyphon assisted ovens still presen other advantages when compared to the electrica conventional ones. In opposite to the conventiona gas ovens, there is no contact between th combustion gases and the bread. Also, th temperature recovering time during operational doors openings is shorter, given that the thermosyphon temperature increases and the device works as a thermal capacitor, which deliver more heat when the doors are shut again. Furthermore, the thermosyphon technology allows easy control of the baking temperature.

Acknowledgement

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