ON A LOW-COST TECHNIQUE FOR MANUFACTURING FOOD DEHYDRATORS

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Abstract. *Dehydration of foods is a good alternative of raising product value for small size rural producers. However, usual manufacturing techniques and shortage of manufacturers cause a dehydrator's market price to be an obstacle to this alternative. This work describes a technique for manufacturing food dehydrators based on adapting ordinary industrial ovens. It is shown to be possible to build a dehydrator up to 90% less expensive than a commercial dehydrator. Dehydrators and ovens have some aspects in common. Both have a thermally insulated chamber, a metallic structure and a heating system. Based on these similarities, it is possible to transform an oven into a dehydrator by three simple modifications: (a) to create a controlled flow of the heated air within the chamber and outwards it; (b) to create an adequate path to allow the heated air to flow through the dehydrating load and (c) to lessen radiation heat transfer. In this paper, a study of case was performed, in which an industrial oven was converted into a dehydrator. A four-burner industrial oven's insulated chamber was used. The heat flow was obtained with the installation of a set of PVC ducts at preexisting holes in the rear of the chamber. The ducts were connected to an exhauster and the flow rate of the ensemble was calculated so that the psychrometric conditions inside the chamber granted the dehydration of bananas. However, the exact tuning of the ideal conditions was made empirically. Two thermocouples were arranged inside the chamber and through their results the ideal gas flow and exhausting flow could be set. The prototype dryer was subjected to a test with a load of 3.5 kg of bananas, and it was obtained an average mass reduction of 0.2 kg/hour. The reduction of mass can be raised by raising the gas consumption, along with a respective raise in the exhaustion of air from the chamber. The present prototype was built with only 13% of the price of a commercial dryer of similar size.*

Keywords: *food dehydration apparatus, alternative manufacturing techniques*

1. INTRODUCTION

Dehydration of fruits is a good alternative of raising product value for small size rural producers. This segment of market is also not well explored by urban microentrepreneurs (IPARDES, 2005).

A major obstacle to this venture is the high cost of its main apparatus: the fruit dehydrator. A medium size dehydrator's price is around US$ 1.3 thousands (Tab. 1). This price discourages candidates to this vein of business. Others end up producing dehydrated fruits on ordinary ovens. This process is inadequate, for it adulterates the product and causes it to lose its flavor, nutrients, visual appeal and consumers' attractiveness.

Table 1. Typical prices of fruit dehydrators on Brazilian market.

Model	Capacity [kg of bananas]	Tray	Price
PD-150	150	Aluminum	US$ 3,130.00
PD-150	150	Stainless steel	US$ 3,880.00
PD-25	30	Aluminum	US$ 1,290.00

Source: Meloni (2006)

However, a detailed examination of both process – oven' and dehydrator's – reveals they are similar to the point that it is possible to convert an oven into a dehydrator through simple modifications. These modifications can be performed from junkyard parts with a total cost estimated to be around US$ 170.

This paper describes a technique of manufacture of fruit dehydrators based on the adaptation of ordinary ovens. The paper begins summarizing the fundamentals of dehydration of fruits. Next, the principles of operation of dehydrators and ovens are overviewed; special attention is drawn to the similarities between them. It is investigated how these similarities can be used to convert an oven into a dehydrator. A study of case is described, in which an industrial oven was converted; its performance on the dehydration of a load of bananas is reported.

2. DEHYDRATION OF FRUITS

As in other methods of dehydration (filtration, liofilization, evaporation, centrifugation), the purpose of drying is the partial separation of water from the solid matter (Strumillo and Kudra, 1986). In the case of agricultural products, this solid matter is the food substance which contains, in variable proportions, carbohydrates, proteins, lipids and mineral salt (Lasseran, 1982).

The particularity of drying with respect to the other techniques of separation is that the withdrawal of molecules of water is obtained by a movement of the water, due to a difference of the steam partial pressure between the surface of the product and the surrounding air.

This difference can be achieved by exposing the product to the sun. In this method, the lack of circulation of air causes the process to be slow. Another technique is to confine the product in a recipient, with forced heated air flow, which characterizes a faster process. In large scale production, the sun drying process is worth (Valley Sun, 2006). In small scale production, to which this work is dedicated, dehydrators – also called *dryers* – should be used.

Foods in general need water for the chemical and biochemical reaction responsible for their degradation to occur (Alves et al, 1996). When part of their water is withdrawn, their degradation starts to occur more slowly. For this reason, dried food can be maintained at room temperature for a long period of time. This method of conservation is an alternative to fresh food maintained under refrigeration (Cabral and Alvim, 1981).

2.1. Dehydration of bananas

In order to illustrate the main parameters of dehydration of fruits, the dehydration of bananas is described, which are one of the most consumed dried foods.

At the place of production, the bananas undergo a reception, where they are weighed, selected and unskinned. From weighing the load of fruits at the beginning and at the end of the process, it is possible to measure the right point of dehydration through Eq. (1).

$$Pf = Pi\frac{(100-Ui)}{(100-Uf)} \quad (1)$$

In Eq. (1), Pf and Pi stand for the final and the initial weigh of the product. Uf and Ui stand for the final and initial humidity, respectively. The ideal reduction of mass for dried bananas is around 77% (Phoungchandang and Woods, 2000). Thus, the end of the drying process is defined to be when only 23% of the weigh of the initial load of bananas remain on the dryer.

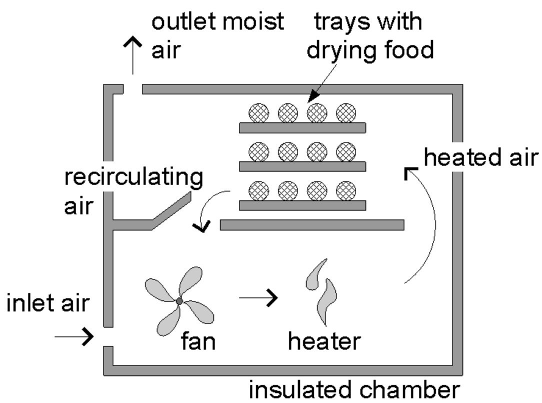

Figure 1. Main thermal processes that are observed in a small size dehydrator.

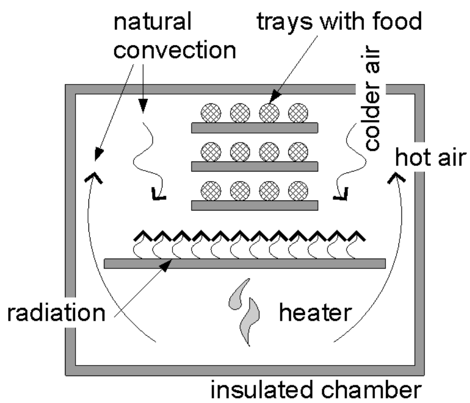

Figure 2. Main thermal processes that are observed in an ordinary oven.

Other fruits will present roughly the same process of dehydration. Only the washing process and final and initial values of ideal humidity can vary a little.

3. DRYERS, OVENS AND CONVERSION

Dehydrators are thermomechanical devices that consist basically of a thermally insulated chamber, with a heat system for the circulating air, which can be an electrical resistance or a gas burner, and with a system of ventilation/exhaustion (Fig. 1).

Small size dehydrators have trays with surface area between 0.3 and 1 m^2. Depending on the fruit to be dried, these trays can be loaded from 6 to 10 kg/m^2 of area of the tray (Meloni, 2006).

The heated air is forced to flow through the chamber by a fan or a centrifugal or axial exhauster. The velocity of the flow varies from 1 to 10 m/s, depending on the fruit being processed.

Some models of dryer works with recirculation of the air, in order to save thermal energy. There is a limit for the amount of air to be recirculated, due to the load of humidity the air carries with it. Therefore, the recirculation of air is usually around 60 and 80%.

On the other hand, ovens (Fig. 2), which also have thermally insulated chambers, do not have forced circulation of air. The chamber where the food is placed is separated from the burners' chamber by a metallic plate, and the process that goes on is cooking, instead of dehydration. The process occurs mainly as consequence of the radiation that comes from the heated plate, and in a smaller degree due to the natural convection of air inside the chamber. There is no defined path through which the air should circulate within the oven, and there are no intentional escapes of air to the exterior. For this reason, the air inside the chamber ends up saturated with water.

However, both equipments share common characteristics. Among them, the thermally insulated chamber, the metallic structure and the heating system – by gas or electrical resistance. Besides, junkyards use to have ovens which show different injuries, but keeping intact their thermal insulation and sometimes their heating system. It can be taken advantage of these similarities and of the availability of inexpensive ovens to define a general technique of manufacture of small size dryers based on the conversion of ovens.

The conversion involves two simple modifications:

(a) To create a controlled flow of the heated air within the chamber and outwards it and

(b) To create an adequate path to allow the heated air to flow through the dehydrating load.

This technique was applied to an industrial oven. The manufacture of the dryer and its selection of materials are reported in the next section.

4. CASE STUDY

In this case study, an industrial oven was converted into a dehydrator, so that the aforedescribed technique could be tested and its main bottlenecks could be indentified (Silva, 2006).

The project of adaptation started from an oven which metallic structure, heating system and insulation were well preserved. These are the most expensive components of an oven and, having them, it can be almost guaranteed that the final dryer would not be too expensive.

A four-burner industrial stove, very similar to the one depicted in Fig. 3, was available. The top burners presented small irregularities, but the thermal insulation of the oven, as well as the metallic structure based on L-shaped steel bars and the gas system were in good state of conservation.

Figure 3. Oven similar to the one used in this project.

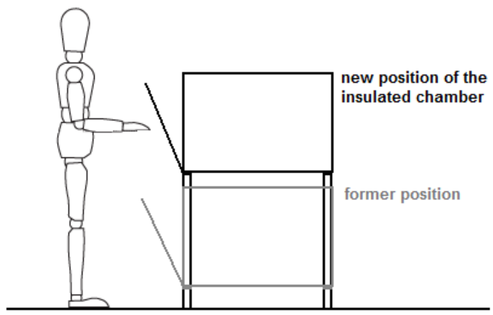

Figure 4. Elevation of the insulated chamber, in order to improve ergonomics.

The stove was disassembled. The top cover, the burners, the valves and the chamber were removed from the metallic structure. The chamber was again screwed in the structure, in a higher position. It was necessary to drill new holes in the metallic structure to place it properly.

With the new position, the chamber where the trays with food would be placed was brought to a height closer to the human work position; the project became more ergonomic (Fig. 4).

The distribution of the insulation throughout the chamber was studied. It was necessary to define a path through which the air could flow, with a minimal removal of the insulation material. It was verified that the chamber was insulated only on its side walls, on the front door and on its ceiling. Its back and its floor were built with metallic sheets without any insulation. Besides, the back sheet had two rows of 25 mm circular holes, one of them in the top of the chamber, and the other in the bottom, next to the gas pipes.

The chamber where the food used to be placed (the cooking chamber) was separated from the inferior chamber (the burner's chamber) by a steel sheet that did not reach the whole extension of the chamber. There was a space at the sides of the oven, internally, in which the heated air flowed by natural convection to the top of the cooking chamber. In order to create a controlled flow of the heated air through the right paths, and not freely, this space has to be closed. Two new steel sheets, which now separate completely the cooking chamber from the burner's chamber, were placed (Fig. 5).

Figure 5. View of the separation of the chambers inside the oven.

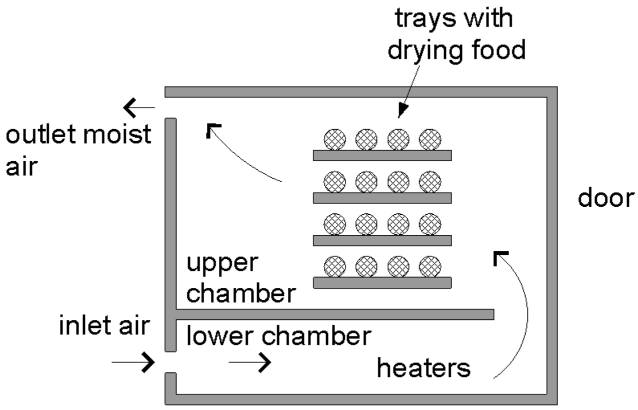

Figure 6. Side view of the dryer, showing the new path the air will follow inside the chamber.

After this modification, the holes at the bottom of the former chamber became part of the inferior section of the chamber, and the others became part of the superior chamber. It was taken advantage of this disposition of holes to create the path for the air to flow through the dryer, which is depicted in Fig. 6. The lower holes will furnish the inlet air, which will be heated by the gas burners inside the lower chamber. The heated air will flow through the drying fruits and then leave the chamber by the upper holes.

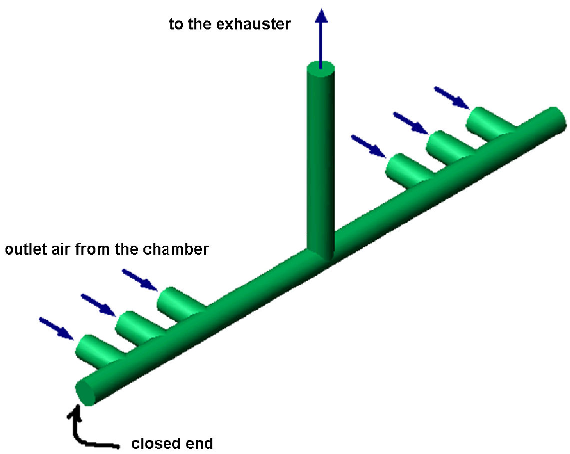

Figure 7. System of exhaustion pipes.

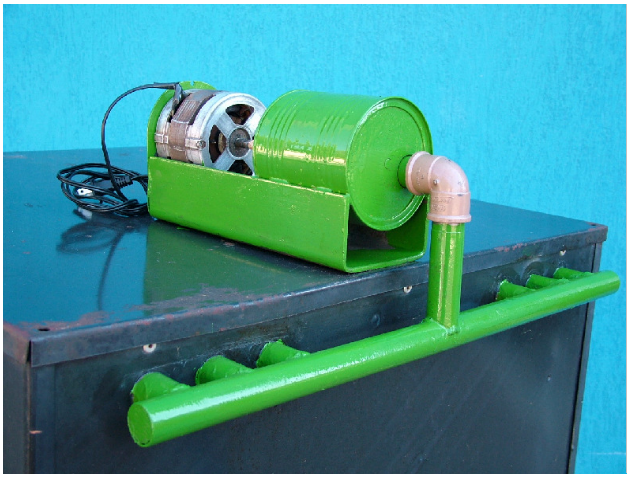

Figure 8. Exhaustion system.

There are two possible ways to force the air to flow inside the chamber: by ventilating ambient air inwards the dryer, or by exhausting the humid, heated air outwards it. The option was made by the exhaustion system because it offers more guarantees that the humid air will be removed from the process.

The remaining space inside the chamber, available to drying, became then 32 x 52 x 71 cm, which could fit up to five trays of 52 x 71 cm. If the new dryer is used to dry bananas, for example, with the recommended load of 15 kg/m^2 of tray, the capacity of this dryer will be 27.7 kg of fresh bananas. From Eq. (1), the production of the dryer will be then 6.37 kg of dried bananas.

The six holes at the upper rear of the chamber had 25 mm of diameter. A few PVC tubes with this diameter were available in a junkyard, which were then used to assemble a system of pipes to collect the exhaustion air from these holes (Fig. 7).

To build the exhauster, it was used a low power electric motor (Fig. 8). The motor was formerly part of a broken air purifier. The helix of the exhauster was taken from a computer cooler.

To summarize, in this case study, the two necessary modifications to the conversion oven-dryer were made:

(a) By separating the burner's chamber from the cooking chamber with the metallic sheets, it was created a path through which the air is obligated to flow, instead of flowing freely as it used to do inside the former oven;

(b) With the exhauster, a forced flow inwards the chamber and outwards it is achieved, which guarantees the removal of part of the saturated air.

Moreover, all the equipments and materials involved in the manufacture of the dryer came from reuse. The rest of the structure was based in plates, tubes, cans, frames and fixation elements which could be easily obtained from junkyards.

The construction of the dryer took around four hours of machinery time, mainly of lathing and milling machines, as well as roughly twenty hours of assembling and selection of materials. Table 2 summarizes the costs to manufacture a dehydrator like the present prototype.

Table 2. Estimated cost to build a dryer like the present prototype.

Item	Cost
Discarded industrial oven, with well preserved insulation, structure and gas system.	US$ 25.00
Steel sheets, pipes, connections, metallic frames from junkyard.	US$ 20.00
Rent of 4 hours of machinery.	US$ 90.00
Discarded low power electric motor.	US$ 20.00
Five trays of thermal-resistant plastic screen.	US$ 20.00
TOTAL COST	US$ 175.00

The present prototype was subjected to an experiment with a load of bananas, which is reported in the next section.

5. EXPERIMENT

This section describes an experiment to which the present prototype was subjected (Tamagawa, 2006).

The dehydrator obtained was not designed to perform a specific rate of heat transfer to the inlet air nor to have a specific outward flow velocity. As it is a non-conventional equipment, these dehydration parameters had to be tuned empirically to each type of drying load.

For this purpose, two thermocouples were arranged inside the chamber and through their results the ideal gas flow and exhausting flow could be set.

The experiment was carried out with a load of 3.5 kg of bananas. Figure 9 shows the dryer loaded with this load.

Figure 9. Dryer with the load of bananas.

Figure 10. Detail of the load of bananas, with one of the thermocouples.

Figure 10 shows a detail of the load of bananas, in which one of the thermocouples can be seen.

Four bananas, placed in different spots inside the drying chamber, were weighed before and after the experiment, and the results are shown in Tab. 3. A high rate of reduction of mass is observed, but these values do not correspond to what is observed in commercial dehydrated bananas. The ideal values are shown in the last column of Tab. 3 (Chauca, 2004).

Table 3. Results of dehydration of four bananas.

Sample	Initial weigh	Final weigh	Reduction	Ideal final weigh
1	50g	15g	70%	12g
2	80g	20g	75%	18,8g
3	70g	20g	71%	16,5g
4	60g	15g	75%	14g

In the whole load of bananas, the initial mass of 3.5 kg was reduced to 1.8 kg. The ideal final mass expected, observed in commercial dehydrated bananas is 1.0 kg for this initial load. However, one of the reasons for this difference is that the experiment was maintained by 8.5 hours only, instead of the 24 to 28 hours needed by a commercial dehydrator to produce commercial bananas (Chauca, 2004).

During the experiment, it was not possible to keep inside the chamber the ideal temperature for dehydration of bananas. This temperature is 65 ºC, and the temperatures observed were above this value. As the reason for the high temperatures observed, it is pointed out the radiation heat transfer coming from the burners through the metallic sheet that separated the two chambers.

6. CONCLUSION

This paper described a technique of manufacture of fruit dehydrators based on the adaptation of ordinary ovens. The technique was presented, the requirements an oven must fulfill to be converted were listed. A case study was described, in which an industrial oven was converted into a small size dryer. The prototype dryer was experienced with a load of bananas, which have shown a great reduction of mass, though yet distant from the ideal.

The main conclusion of this work, therefore, is that the radiation heat transfer to the drying chamber must be minimized in order to allow the fruits to dehydrate properly, instead of being partially cooked. For this reason, a third conversion step should be included:

(c) To lessen radiation heat transfer.

Different materials might be considered to separate the cooking chamber from the burner’s chamber. These materials must be thermoresistant, non-toxic and non-expensive. A possible candidate is the temperate matte glass.

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