SOLAR FOOD PROCESSING- AUTHORS EXPERIENCE WITH COOKING AND DRYING IN COSTA RICA.

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1. Abstract

Since 1977, author is doing research on different models of solar water heaters, stills, dryers and mainly cookers – hot box, hybrid sol- electric cookers, cooker cum water heater/pasteurizer, cooker cum dryer etc. In addition to publish results in technical journals, disseminating the experience through lectures, TV, Radio, newspapers, workshops, seminars in Costa Rica and in another 35 countries, author and his family is also using at home most of these devices when ever the climate permits.

In this short presentation, part of the experience related to food processing – some cookers and dryers and their uses for cooking, drying and water pasteurization in Costa Rica will be informed. In some rural communities the cookers and driers have been used for income generation purposes.

2. Introduction

Food processing is the integration of various processes with the basic materials to get the required product of given quality at the right time, using the minimum fuels and minimizing the adverse impact on the environment. Conventional fuels like oil, coal and biomass are used to achieve this, spending expensive budget and creating deforestation, air pollution and global warming.

There is no simple solution to revert this global warming- however, as mentioned by Al Gore- 2007, shared Nobel Prize Winner for peace, some possible steps are: the saving of energy, use of renewable sources of energy, conservation and recycling of materials etc.

The necessity of the use of solar energy, clean, abundant and free fuel, to reduce the consumption of firewood or fossil fuels is well recognized by various national and international organizations.

On the other hand, in spite of various efforts made, the widespread use of conventional solar devices have not become possible due to different reasons, including the impossibility of using during the period lacking sufficient sunshine and limited uses of a solar device.

During last thirty years, author has studied many solar thermal devices for different processes like heating water, drying and cooking the required product at domestic level. Although the simple solar devices are cheaper, it has main limitation that it could not be used during cloudy days and thus utility is limited for 180- 270 days per year in our climate. On the other hand this device with some modification can be used for other applications requiring low temperature (drying and pasteurization etc.) and thus can be used for more number of days and this period can be extended further if the system has a back up fuel, like electricity Although the details of these devices are published in technical journals, we will like to share some of the experience. Depending on the process, one or more of these devices can be used. We will be mentioning only cookers and dryers.

3. Solar Devices

3.1. Solar Cookers

The first hot box oven was made by the author in Feb. 1979, for the personal house to warm lunch cooked previous night. Since that time we have designed, constructed, got one patent, studied, published, promoted in many countries different solar cookers, mainly for cooking meals- hot box types (1), hybrid solar- 110 VAC electric (2) , cooker cum dryer (3), solar electric microwave oven (4), hybrid solar- 12 VDC electric cooker (5) etc. Details of these can be seen in authors book (6) and the recent paper (7), however we will mention some of these.

3.1.1. Simple Hot Box Oven

One of the improved made in 1982 is shown the Photo 1 (1). The outer box and the reflector is made of stainless steel to have the large duration. Inside it has a galvanised iron metal sheet painted black on top to absorb solar radiation, glass wool as heat insulation and double window glass to allow solar radiation and at the same time, impede the exit of heat radiation emitted by the hot plate. The box has one reflector to increase the solar radiation The hot air in the box is used for cooking meals, kept inside the box.

Photo 1. Solar Oven Constructed in 1982 and still in use by authors family.

On sunny day the air temperature inside the box can reach up to 130- 150 °C. This can be used for cooking, baking, roasting food, and also for purification of tap/ river water from microbiological point of view (pasteurization). Three- four meals can be cooked in 2-3 hours.

This model (patented in 1984) is promoted by an author in Costa Rica, Dominican Republic, Guatemala, Honduras, Peru, Cuba, Portugal, Paraguay, Argentina and Venezuela. Since 1990 a model similar to this is being promoted by an NGO (Sol de Vida, Guanacaste) for cooking and selling solar food for tourists for promotion and some income generation.

3.1.2. Hybrid Cooker

In Hybrid cooker (2), solar energy is integrated with conventional energy sources, such as electricity (as backup fuel), is shown in the Photo 2. It is basically a hot box, but the black metallic plate has an electric resistance underneath and a thermostat to regulate the temperature.

The hybrid cooker is connected to electricity, and the thermostat is fixed at some desired temperature (depending on the urgency required). If solar radiation alone is able to reach this temperature, electricity will not be consumed. If the solar intensity falls to achieve the prescribed temperature, electricity is passed automatically to raise the temperature etc. In this way the food is cooked reliably but with the minimum consumption of electricity.

This model was designed mainly for the areas where electricity from the grid is available.

Photo 2. Hybrid Solar Oven with 110 VAC Electricity and Sun (1986).

Models similar to this one are being sold at least in India, Colombia and Ghana.

3.2. Solar Driers

3.2.1. Direct Solar Dryer

Photo 3 shows one of the model designed and studied in 1994, in collaboration with Swedish students Magdalena and Asa to dry bananas (8).

Photo 3. Natural and forced circulation Solar Dryer (1994)

It is made of metal sheet. The dimensions of the dryer are 120 cm X 102 cm with height of 40 cm at the front and 61 cm at the rear part. The glass was tilted 10 degrees. A wire mesh to put drying tray was constructed of iron bars. Holes for air entrance and exit were made on the front and back of dryer respectively.

To keep the products to be dried, the upper half of the glass cover was fixed and lower half could be lifted (Photo 3). To be able to measure the relative humidity and air velocity in the solar dryer three small holes were made on the right side of the dryer. These holes could be closed with a cover when required.

An arrangement was made for the entrance of ambient air (pipe in the front) and exit of humid air (duct at the back). Both the duct and the pipe had holes for measuring the relative humidity and the velocity of the air. The duct and the pipe were closed with metal lids at night or during the bad weather. Part of the study was done also using the fan (12VDC) for increasing air flow rate.

The experiments were done in August 1994 to dry Banana (Photo 4). The moisture content of the bananas varies between 70-80% depending on the state of ripening and the type of bananas. The average value of the moisture content is 77%.

Bananas at different state of ripening were bought at the market, on the day of the experiment. A load of about 1 kg peeled bananas was used in the dryer. The bananas were sliced into thin and thick parts, cut longwise and crosswise and placed on separate four trays.

The weight of the bananas on each tray was measured before the experiments were started. During the experiments the weight of the partial dried banana was measured every 4 hours, whereas other parameters, like temperatures in different locations, solar radiation, ambient wind speed and relative humidity were measured every hour (8).

The first experiment was performed with airflow of about 0.0035 m^3/s through the dryer while the other two experiments were done with a lower airflow of 0.002 m^3/s. The airflow was provided by an electric fan which was used to simulate a chimney but easier to regulate. A power supply was used to adjust the speed of the fan. Some results are:

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The average temperature in the banana was 27-33 º C,
Air flow was 0.002- 0.003 m^3/s,
Average Ambient Temperature 21.2- 23.6 ºC.
Average Solar Intensity 306- 480 W/ m^2.
Average Relative humidity 67- 80%.

Using the solar radiation, the energy needed for the evaporation of water from the bananas, and Latent heat of evaporation of water from banana (2657 kJ/kg), the efficiency of solar dryer (explained later on) was fond to be about 21%.

Photo 4. Bananas before and after solar drying.

Experiments were performed also to find out how the bananas were affected by sunlight. One tray was covered with black sheet of paper whereas the others were exposed to sunlight. No great differences could be seen. The color, taste and consistency were all about the same.

One of the conclusions from these experiments was that the best type of bananas for drying was very ripe bananas sliced into thin and small pieces. For the drying the shape of bananas was not as important as the thickness. The taste and sweetness were depending on the state of ripening.

In 1998 a model similar to this was designed and constructed by this author for a rural community (Costa Pajaros, Puntarenas). Since then It is being used for drying and selling herbs (medicinal plants) for tourists and thus serves as income generation.

3.2.2. Direct and Indirect Solar Dryer

In this study we have designed a Solar dryer (Photo 5) that include both types of known dryers- direct and indirect and in the modular form. The circulation of air through the products is via natural circulation using chimney, whose height could be varied (0.8m- 1.4 m). This dryer can be used for both normal as well light sensitive products. In this preliminary study (9) we have studied the dryer only with air (no load), measuring solar intensity, ambient temperature, humidity of air at different points and air velocity. Increase in air temperature of 40- 60 °C was observed in the solar dryer. Also the humidity of ambient air (80 to 20%) was reduced to 11- 14% at the exit of air collector and to 10% inside the solar dryer.

Photo 5. Direct and Indirect Solar Dryer (2007).

3.2.3. Solar Cooker Cum Dryer

Photo 6 shows the solar oven cum dryer. As can be seen it is a conventional hot box solar oven with galvanized iron plate painted black as an absorbing surface and two normal window glasses as covers, separated by a distance of 2 cm. It has one reflector and 11 holes in front of the box for the entrance of the ambient air as well as another 11 holes at the back of the box for the exit of hot humid air (3).

Photo 6. Passive Cooker cum Dryer (1993).

To use the device as a solar oven, all the holes are closed tightly and rest of the process is same, whereas to use it as a solar drier, during day some or all the holes are opened and after sunset (or during rainy period) the holes are closed so that the ambient humid air should not enter in the drier. The rest of the process is similar to conventional solar drier.

Various types of experiments have been performed. Based on our experience with the climate at our specific place and the temperature requirements for drying of domestic products like vegetables and spices and cooking, it is observed that this combined device can be used for 10- 11 months in a year as compared to 7-8 months if used only for cooking purpose.

4. Multipurpose and Hybrid Food Processor

Recently author has combined all the previous devices to design, construct and study a single device- Hybrid Food processor to cook, pasteurize water, dry different products and demineralize water (10) etc. As can be seen the Photo 7, food processor is made of inclined stainless steel box. It has an electric black plate as an absorbing surface and two normal window glasses on the top. At the front and at the back there are some holes which can be covered or opened depending on the requirement. It also has one reflector made of bright stainless steel sheet, to increase the solar radiation on metallic plate. The whole box has glass wool insulation on the four sides and below the metallic plate and has a thermostat to regulate the plate temperature.

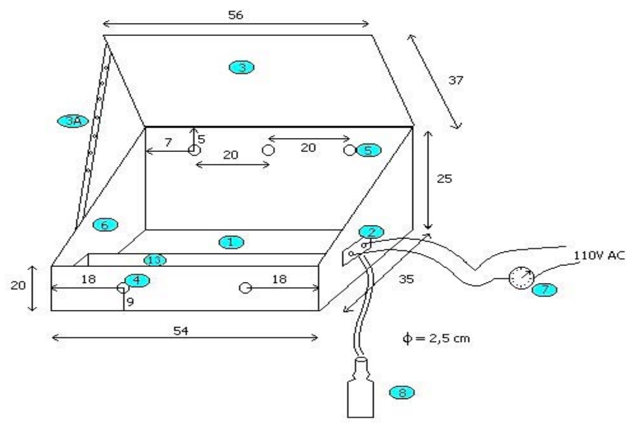

Photo 7. Hybrid Fuel Food processor (2005): 1. Electric plate, 2.Electric inlet and thermostat, 3. Reflector, 3A. Rod to adjust reflector , 4. Two inlet holes for air, 5. three outlet holes for humid air, 6. Outer box, 7. Electric Timer, 8. bottle for distilled water, 13. Trough/ gutter for distilled water.

This device is being used at author´s home for practical purposes- cooking, pasteurizing water and drying domestic products for last four years. On a sunny day and without any load, the plate temperature, only with solar radiation reaches about 130-150 °C. It works fine. During the partial cloudy days, absorbing plate is connected with electrical energy, in addition to solar, to realize the process required.

To know the amount of electrical energy used (if any) by the device for any process firstly we used conventional wall/table electrical watch, and later on portable watt-hour meter (Photo 8). It runs only if the electricity is passed.

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Photo 8. Measurement of integrated electric (left) and solar (right) energy used.

Various types of experiments have been performed to measure quantitatively its performance (10).

4.1. Cooking and Water Pasteurizer. All the five holes are closed and the rest of the operation is same as conventional oven (Photo 9). The maximum plate/air temperature was reached about 150° C, without any food inside and between 100- 120ºC while cooking.

Photo 9. Food Processor in the mode of cooking (right pot) and water pasteurisation (left jar) mode.

Food is cooked with only solar and / or combined with electric energy, consuming the minimum quantity of electric energy if required. Cooking time is between 2-4 hours depending on the climate and the quantity of food. Real cooking is done many times. The results are similar to conventional solar and hybrid cookers.

On one particular day to cook 2156 g of meal (additional weight of pots, 835 g), 410 Wh of solar and 400 Wh (16 minutes of electricity) of electric energy (worth US$0.025), was used. Total input energy is 810 Wh or 696.6 kCal. (10).

Useful energy gained by food (vegetables and cake)

$$\text{Effective Efficiency}, \eta = \frac{}{\text{Total input (solar + electrical) energy}}$$

$$= \frac{M_F * C_F * \Delta T}{A_P \int Hi\, dt_S + P_E * \int dt_E}$$

= 158.8 kCal / 696.6 kCal = 22.8 %.

M_F mass of Food (kg)
C_F specific heat of food (kcal/kg °C)
ΔT rise in temperature (ºC)
A_P area of the absorbing plate (m^2)
P_E power of the electric plate (W)
H_I solar intensity on horizontal surface (W/m^2)
dt_S and dt_E time of solar and electric consumption.

Here we have taken specific heat of food as that of water, 1 kCal / kg ºC.

It has been known that heat can deactivate pathogenic (disease causing) microbes. Although it is recommended that contaminated water can be made safe by boiling, but it is also true that same water can be pasteurize (drinkable) at temperatures well below boiling, at 67-70 ºC, depending on the time.

4.2. Dryer: To use as a dryer, holes in front and at the back are opened, during the sunny (drying) period and are closed after sunset. The metallic tray(s) with the products to be dried are kept at the top of the absorbing plate.

The real solar drying has been done with various domestic products (like tomatoes, coriander, onions and pineapple etc.). In particular case of tomato and coriander (herb for cooking), no electric energy was required, and some of the results are:

-the integrated solar intensity during the drying period was 0.930 kWh on an absorbing plate of 0.13 m^2,
-the air temperature inside the dryer was varying between 35-45 °C,
- weight of the final dried tomato was only 34 g (reduction of 350 g, from an initial weight of 384 g),
- weight of the final dried coriander was only 6.5 g (reduction of 103 g, from initial weight of 109 g),

- total loss of weight or water evaporated is 0.454 kg. Using sensible heat and latent heat, the energy required for this drying process will be 258.7 kCal or 0.30 kWh

Thus thermal efficiency of the box as a dryer, η is: 0.30/0.930= 32.3%.

To minimize the color loss of green coriander, it was covered with a perforated metallic tray to reduce the direct solar radiation.

Coriander was dried to the extent that it could be crushed by hand to convert into powder and was kept in a plastic container for later use. Dried tomatoes in small pieces were also stored in the plastic container.

In another experiment of drying onions (June 18 and 19, 2005), both electrical and solar energy were used. Onions were peeled and cut in small pieces. Total weight of only onions was 570 g. We put in two trays, one covered with metal perforated plate to reduce the direct solar radiation (Photo 10). Started experiment at 08:45 am. The air temperature in the uncovered tray was between 45- 75 ºC whereas in covered plate, it was between 40- 60 ºC. The day was not very sunny. The experiment was performed during 9 am to 2 pm and then 8 to 12 md on the next day, Because of the bad climate, total 4 hours of electricity was connected however only 45 minutes (roughly 1.1 kWh) of electricity was used. The weight of the dried onion was 53 g means that 10% of the initial weight. The onions in uncovered plate were browner than in covered tray. This was then kept in a vacuumed bottle for later use.

Photo 10. Food processor in the mode of drying, fresh (left) and dried (right) onions.

5. Conclusions

Various solar devices for processing food- cookers, dryers (for fruits, vegetables and condiments / herbs)., pasteurisers (to inactivate microbes), including hybrid (solar electric) and multiple purposes devices, designed and studied for last thirty years are mentioned. Some of these are also used at home for personal use.

On an average sunny day, conventional cooker can cook one meal for 3- 4 persons in two-three hours (9 am- 12 md) and two meals in three- five hours (9 am- 2 pm). Using solar cookers only seven months a year, one can save on the average, 1160 kWh of electricity, 650 kg of firewood or 205 litres of kerosene (or LPG) per year (6). However multipurpose device can be used for another 3-4 months a year for warming food, heating water and drying, which require less temperature for these operations.

Based on personal experience author has found hybrid system and multipurpose as a useful device, mainly from convenience, fuel saving, economic and also from ecological point of view (11). It can work using only solar energy for different purposes (in non electrified region) and at any time for more number of days using solar and electricity (in electrified region) but with the reduced consumption of conventional fuel.

Effective thermal efficiency of food processor was found in the range of 23- 32 percent depending on the mode of use.

Some of these models are being used in rural communities for selling solar cooked food and solar dried herbs and thus serving as income generating project.

Solar energy is free, abundant and pollution-free fuel. If the earth instead of receiving the solar radiation which only heat the environment, some simple boxes (solar cookers and solar dryers) are placed, the food will be cooked and or dried and the environment will be more comfortable.

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