Acta Scientific Applied Physics

Volume 4 Issue 1 January 2024

Review Article

Forty-Four Years of Experience with Research, Promotion and Uses of Solar Cookers - Review

Shyam S Nandwani*

Retired Professor, Heredia, Researcher, Promotor, and User of Solar Energy, Costa Rica

***Corresponding Author:** Shyam S Nandwani, Retired Professor, Heredia, Researcher, Promotor, and User of Solar Energy, Costa Rica.

Received: May 10, 2024

Published: May 22, 2024

Abstract

Not because of Global warming, wood deforestation, but only due to necessity, in February 1979 author made at his house a simple solar food warmer just to heat the meal cooked previous night. Looking into the success, many other solar and hybrid cooking ovens have been designed and studied, for research and also for personal use at home, whenever the climate permits. In the present work although all the models are mentioned in brief, only the models which are being used in the house will be mentioned in some detail.

The different models have been disseminated at different communities, educational centers, through Lectures, Workshops, Radio, Newspapers and TV program, in Costa Rica and other 42 countries. In addition to publish research papers in journals, national and international conference, got a national patent in 1985, and published a book on Solar Cooking in Spanish in 1993 and revised edition in 2004. In summary this article is review of some of my published papers on Solar cooking during last 44 years and some recent results.

Keywords: Food Warmer; Solar Oven; Multipurpose and Hybrid Solar Electric Oven and Dryer; Global Warming

Introduction

I started working at Universidad Nacional, Costa Rica in August 1978, to do research on Solar Energy. The main source of electricity in this country was hydropower, about 70 percent, the rest is generated by imported oil. Like most people, 1 was also using an electric range for cooking at my house. During dry season (December- April), due to high solar radiation there is more evaporation of water, thus there is a shortage of water in rivers/dams. With the result extra electricity is generated by more imported oil. At the start of 1979 (summer), the national electricity utility, decided to ration electricity, to reduce importation of oil, for two days a week, from 7am to 5pm. Many people started buying Gas range. I am being an applied physicist and working on Solar energy thought of making simple food warmer to heat the food cooked previous night, but with solar energy.

Solar food warmer

As shown in Photo 1 basically it is a wooden box, galvanized iron sheet painted black as solar radiation absorber, glass wool as heat insulation on four sides and below metal plate and one window transparent glass on top of the box to reduce the heat losses. The low wavelength solar radiation coming from the Sun passes through transparent glass and is absorbed by black paint. With this the metallic plate is heated. To reduce the heat losses at four

Photo 1: Simple Solar Food Warmer.

sides and at bottom of the box, heat insulating material like glass wool is used. The window glass on the top of the box impedes the transmission of higher wavelength heat radiation coming from metal plate, with the result; the air in the box is heated and can be used for warming food kept in the box. The maximum air temperature in solar oven reached up to 80-90 °C and 3-4 meals could be heated during mid-day in 40- 60 minutes. This solar food warmer was constructed and published in local English newspaper [1] as shown in Photo 2.

Photo 2: From local Newspaper. Sunny lunch. Dr. Nandwani and his daughter wait for their meal, being heated on the Solar Oven.

For last 44 years I have designed, studied conventional solar oven, hybrid solar electric AC/ DC oven, short term sensible and latent heat storage oven, multipurpose solar oven with dryer, dual compartment solar oven for research, solar electric microwave oven, etc. (Photo 3), and concentrating cooker etc.

Photo 3: Some Solar Ovens designed, studied and in use by author and family.

Although the details of all these ovens can be seen in various published articles [5,13]. However, we will mention in brief some of the models used in our house.

Hot box oven for cooking

After observing the success with food warmer, I decided to improve the box and convert it into a solar food cooker/oven. The temperature required for water/food pasteurization is about 70^0C and food cooks at 80-100^0C. Temperatures higher than this only reduce the cooking time.

Two changes have been made in the solar food warmer mentioned already. Firstly, we added another window glass on the top of the box to reduce more heat losses due to wind and secondly, we used one reflector to increase the solar radiation. falling on absorbing plate. Reflector can be adjusted (recommended) every hour or two depending on the user. Photos 4a and 4b show the design and working Solar Oven [2] constructed in 1982 and still in use at author's house. The air in the box is heated through the greenhouse effect and is used for cooking meals and other uses.

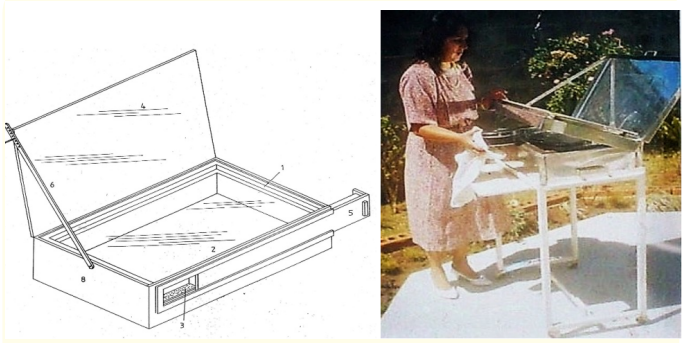

Photo 4: Design (left) Hot box type Oven. 1. Two transparent window glasses, 2. metallic plate, 3. heat insulating material, 4. reflecting sheet, 5. door to keep and take out cooking pots, 6. rod with some holes to adjust reflector angle, 8. outer wooden box. And working model used by author's wife (right).

With these two changes, the maximum air temperature inside the oven was increased to 150 °C with no food inside, and 110-130°C while cooking.

This oven has been used for cooking, baking, roasting food (rice, beans, vegetables, lentils, and meat etc.) and for purification of tap/

river water from micro-biological point of view (pasteurization). This model can not be used for frying meals which requires the temperature of oil as 180- 200 ºC. On an average sunny day, three to four meals can be cooked in 3-4 hours. Once convinced with its working, oven was made with stainless steel as an outer box for family use. In 1984, we got the national patent on this solar oven. (November 1984, No.2367).

Limitations of solar oven

There are lot of advantages, solar energy is a clean, free, and abundant fuel. Of course it has some limitations too. We will not say disadvantages of solar cookers, but we can say limitations of solar cooking or solar energy. As is obvious, we cannot use solar ovens during all 365 days., due to clouds and rain etc. On the other hand, we also need both rain for agriculture, drinking water, hydroelectric plants, and clouds for relaxation and enjoyment etc.

Solar ovens with heat storage

To use solar energy at least on cloudy (not rainy) days for cooking and other applications, like pasteurizing water and drying agricultural products, we can mention two ways.

- Storing solar energy either in the form of heat or electricity and use later.
- Hybrid Systems. Here solar energy during cloudy periods can be combined with conventional fuels, electricity (gas or firewood etc.) to finish our objective, with minimum quantity of conventional fuels.

We will mention both in brief, and the details can be read in my published articles.

Solar oven with sensible heat Storage

Believing that if during sunny period, solar oven could store heat for 2-3 hours, it would help in cooking during cloudy period. Thus in 1990 I did an attempt to use low-cost firebricks to store heat for cooking.

It is like conventional solar oven except in place of metallic iron sheet various number of bricks (22X11X1,25 cm). In our case 18 firebricks arranged in two layers were put to absorb solar radiation (Photo 5). Because of thermal mass it can store some solar energy in form of heat. Later, the meal is introduced, with the release of heat from bricks, one can expect to cook the meal. Unfortunately, stored heat was not sufficient to cook meal, although could heat some water [4].

Photo 5: Sensible heat storage solar oven, using bricks.

Oven with latent heat storage

In this case instead of bricks, some phase change material is used. The study was done during my 6 months stay at Fraunhoffer Solar Energy Institute, Freiburg, Germany in 1996. Here instead of metallic plate, metallic slab filled with Vestolen A6016 (a phase change material, PCM) was used for short term heat storage (Photo 6). Again, the material, although better than bricks, was not sufficient to cook meal with stored energy [9].

Photo 6: Latent heat storage solar oven, using Phase Change Material.

However, there are models developed in Germany, Australia and recently in India. which can cook with the stored heat, but costing about US$1500-2000, expensive for poor people, but also does not make sense for common family having varieties of cooking ranges at very low prices.

Hybrid oven

Even during sunny day in the morning, the food may not be cooked properly due to sudden change in climate, this could be sufficient reason for cook to get frustrated. This happened with my wife too and it compelled me to look for an alternative solution. Thus, hybrid oven was made in 1986 [3]. To the best of my knowledge this was the first of this kind in the world.

In Hybrid oven, solar energy is integrated with conventional energy sources, such as electricity (as backup fuel). Hybrid could be with alternating or direct electricity. I have made both types.

Solar oven with alternating electricity

As shown in Photo 7, it is like a conventional hot box oven, but the black metallic plate has an electrical resistance beneath (about 1250 W) and a thermostat to regulate the temperature. The hybrid oven is connected to house AC electricity and the thermostat is fixed at 90-100 °C. If solar radiation alone enables the system to reach this temperature, electricity will not be consumed. If the solar intensity falls below this, and plate temperature does not attain the required temperature, electricity is connected automatically to the electric plate to raise the temperature and is disconnected if the solar intensity is increased [3].

Photo 7: Hybrid Electric cum Solar Oven, used at home and demonstration at Exhibition in Costa Rica.

Recently I have started to add smart switch and Camera to make Hybrid Solar oven more friendly [14]. At present hybrid models are sold commercially at least in India, USA, Colombia, and Africa.

Solar oven with direct electricity

For the non-electrified region, one can make use of Photovoltaic panels. Photo 8 shows the solar oven with this concept. Here instead of 110 VAC I have used 12VDC electricity coming from PV panels.

Eight electric resistances in the form of rods are rivetted firmly underneath a metallic aluminum plate. This plate is kept in the conventional oven with insulation on 4 sides and underneath and two glasses on the top and one.

reflector as in conventional oven. To operate them with 12V we connected these resistances in parallel to get maximum power 190 Watts. For the study in addition to PV panel (12V, 50Wp) we also used a battery (12.5V / 90Ah) and did the experiment for heating water and cooking some food [11]. Food was cooked. Of the course the price was higher (US$800-1000) but justify for some educational centers in Non electrified areas.

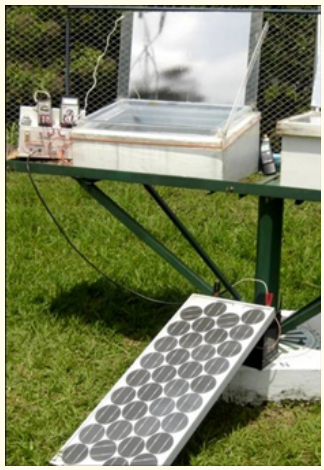

Photo 8: Solar Electric Oven with 12V PV panel.

Multipurpose hybrid solar food processor

Cooking needs higher temperature thus requires high solar radiation. Depending on the climate/ solar radiation at a given place, solar oven can be used for cooking during 7-9 months in a year. On the other hand, water heating and drying needs less temperature (around 50-70 °C) and thus low solar radiation. It means if the

same oven, with some modification is used for both purposes, it can be used for 9-11 months in a year.

Many devices mentioned already were combined to construct a single device- Hybrid Food processor to cook, pasteurize, distill water, and dry different products [10,12].

As shown in photo 9, this multipurpose oven is conceptually like a conventional solar oven but is made of inclined box, with an outer dimension of 0.54 m X 0.35 m and 0.20 m high in front and 0.25 m high at the back side. It has an electric black plate as an absorbing surface with an area of 0.13 m^2 (0.45m X 0.28m) and two normal window glasses on the top, separated by 2 cm., as well as thermostat to regulate the plate temperature. It also has one reflector made of bright stainless sheet. To use as a dryer, the box also has 2 holes in front of the oven for the entrance of ambient air as well as another 3 holes at the back of the oven, for the exit of hot humid air. The holes could be closed for cooking and pasteurizing or opened for drying agricultural products, herbs, and roast spices etc. The food to be cooked or products to be dried, are kept over metal electric plate (Photo 9).

Photo 9: Hybrid Food processor in the author house.

As explained in the hybrid oven, here also during the cloudy days absorbing plate is connected automatically with electrical energy (in addition to solar), to realize the process required [10].

It has been known that heat can deactivate pathogenic (disease causing) microbes. Also, water can be pasteurized (drinkable) at temperatures well below boiling, at 67-70 ºC, depending on the time.

To use the device as a dryer (Photo 10), holes in front and at the back are opened, during the sunny (drying) period and are closed after sunset or during rainy period. The real solar drying has been done with various domestic products, like tomatoes, coriander, onions, and pineapple etc.

Photo 10: Food Processor in the mode of cooking(left) and drying (right) mode.

On one day to cook (photo 10), 2156g of meal (additional weight of pots, 835 g), 0. 410 kWh of solar and 0.400 kWh of electric energy was used. Total input energy used was only 0.810 kWh.

In one of the experiments realized for drying pineapple during March 10 to 13, 2023, 337 g of pineapple cut into pieces were put in tray. During all four days the climate was sunny from 8 to 12 middays, and then it was raining – not common during this period. The oven/dryer air, pineapple, ambient temperature, and solar intensity were measured every 30 minutes. In addition, the weight of pineapple was measured each day. During the rain and at night all the holes were closed. At the end of 4 days (about 16 hours) the pineapple weight reduced from 337 to 76 g. In other words, the weight reduced to 77.4%. pineapples were dried and kept in tight plastic container to enjoy later.

Multicompartment solar oven

In this case to study and compare some properties of materials, a solar hot box with two similar compartments was designed (Pho-

to 11) and studied during my six months stay in 1996, at Fraunhoffer Solar Energy Institute, Freiburg, Germany.

Photo 11: Two compartment Solar Oven, constructed and studied at Freiburg, Germany.

This hot box has been used for,

- Comparing the behaviour of a metallic slab filled with a phase change material (Vestolen A6016) for short term heat storage with conventional absorbing plate.
- Studied Selective surface vs. black paint. Detailed results can be seen in the paper [9].

Solar electric microwave oven

During my research work at the University, I designed also Solar house with various PV panels, regulators, batteries, and inverters for research, including many devices like lights, fan, refrigerator, TV and Microwave oven. This microwave oven [7] was mainly for heating lunch for 5-6 colleagues (Photo 12).

Concentrating cooker

Photo 13 shows parabolic cooker assembled based on materials bought by a Nonprofit Organization, EG Solar in Germany [6]. On sunny days, this model produces temperature in the range of about 350- 400°C, and thus can be used for frying too. However, for its proper working, it needs direct solar radiation, perfect shape and some frequent (15-45 minutes) tracking.

Although I understand the advantages as well limitations of Concentrating Cookers and of Solar Ovens, and during my promotional lectures I explain both, however myself still prefer Solar

Photo 12: PV Solar Electric Microwave Oven fr heating lunch.

Oven for personal use at home, mainly because it can cook/work even unattended. You may be in the market; solar oven will be working for you.

Lunch warming at educational centers

In the university almost, for about 30 years I was heating my lunch with solar oven. I kept two solar ovens near to my department and some students started also putting their lunch boxes (Photo 14) for heating, while they were in their classes. Practically all the educational centres (including offices) students/workers use Microwave ovens to heat their lunch boxes. Although these educational centres have around 5 to 8 Microwave ovens, still students must make long queue to get their turn. Each lunch box takes about 2 to 3 minutes in the microwave oven (1000-1200W). This is an additional cost of electric bill for the institute. During last about fifteen-twenty years, directors of some schools and colleges are asking solar ovens for warming lunch of the students during midday. The objective is to reduce the buying of more microwave ovens and consumption of electricity. Photo 14 (right) shows three solar ovens installed in Belen, Heredia, Costa Rica. About 80-90 solar ovens are installed in about 30-35 institutes.

Additional advantages

In addition to normal advantages of Solar energy/oven, like free, clean and abundant energy, it's also good for economy, for the human and planet health [8]. We will mention these in brief.

Photo 13: Solar Concentrating Cooker in use.

Photo 14: Use of Solar Ovens for warming lunch at my university (Left) and St. Paul School, Heredia, Costa Rica.

Energy and cash saving

With an average solar intensity of 3.5 kWh/m^2 per day in Costa Rica, the maximum air temperature in hot box oven can reach to about 150 °C, without any meal inside and around 100-120 ºC with food, water and or products to be dried.

Normally 3-4 meals can be cooked in 3-5 hours. Based on the experience and climatic conditions in Costa Rica, a single family can use solar oven for 7-9 months in a year for cooking and/or 9-11 months for heating meal, This can save about 800-1000 kWh of electricity per year.

With the electricity cost of about $0.15-0.20/kWh, one can save about $120-$150/- per year. Payback period for domestic solar oven could be between 12- 24 months.

Human health

Food being cooked with no or less water and at low temperature (less than 100 ˚C) retains most of the nutrients as proteins and vitamins [5].

Studies have also shown that women who cook over indoor wood fires are more likely to have active tuberculosis. Children exposed to indoor smoke are two or three times likely have higher respiratory infection. Solar (Smokeless) ovens will help in keeping the health better. Thus, Solar ovens are economically and ecologically viable [8].

Educational projects

Photo 15 shows decorative solar oven made by primary class kids for doing some science projects and for curiosity.

Photo 15: Solar oven made by students at school for simple uses and for curiosity.

Conclusions

Based on personal practical experience of solar cooking at home for last 44 years, author has observed that Solar Cooker has many advantages, but also have some limitations too- depending on the model, place of use and cultural habits of the family. Some means are mentioned to alleviate part of these problems. Solar ovens can be used for saving conventional fuels, money saving, convenience, environment, and recreation etc. At the end it will also help in the reduction of pollutants and thus global warming.

Benefits like deforestation, soil erosion, global warming, national foreign debt are not the primary worries for most of the users. For them the convenience, assurance, and necessity of fuels even at slightly higher price is more important.

If on the earth, instead of receiving the solar radiation which just heat the environment, some simple solar ovens (or other solar devices) are placed, the useful heat and/or electricity will be produced and at the same time the environment will be cooler/ comfortable.

With the combined efforts of designers, manufacturers, promoters, government, and Non-Government Organization, like Solar Cookers International (USA) [15], International Solar Energy Society (Germany), and World Renewable Energy Network (England) etc., its use could be increased.

Acknowledgements

The author is thankful to all ex-collaborators/Colleagues, Eliecer Madrigal, Marvin Alpizar, Carlos Delgado and Guillermo Torres etc. for the help in construction of solar devices and measurements. Also thankful to Solar Cookers International, Sacramento, USA. for sharing some information in relation to Solar Cooking and to the Abdus Salam International Center for Theoretical Physics, Trieste, Italy for providing me some visits to the Centre for looking the latest literature in relation to Energy and environment.

Bibliography

1. Nandwani Shyam S. "Sunny Visions- Getting a Charge from Old SUN". Report on this Solar Food warmer. The TICO TIMES Central American News Paper, Costa Rica, May 4 (1979): 21.

2. Nandwani Shyam S. "Experimental and Theoretical analysis of simple solar oven in the climate of Costa Rica I". *Solar and Wind Technology.* Pergamon Press 5.2 (1988): 159-170.

3. Nandwani Shyam S. "Design, Construction and Experimental Study of Electric Cum Solar Oven". *Solar and Wind Technology.* Pergamon Press, 6.2 (1989): 149-158.

4. Nandwani Shyam S. "Cheap solar oven with heat storage, preliminary Study for Costa Rica, Climate". The Heliograph, Royal Institute of Technology. Sweden 2 (1994): 4-13.

5. Nandwani Shyam S. "Book, La Cocina/Horno Solar, Hagala Usted mismo". Editorial Fundación Universidad Nacional, Costa Rica (1993 and 2003): 126.

6. Gerhard Jobst. "SK 12 Production and Solar Cooking Promotion in South America". Proceedings of the Second World Conference on Solar Cookers- Use and Technology, July 12-15, Heredia, Costa Rica (1994): 197-201.

7. Currin Ced., *et al*. "Preliminary study of Solar Microwave Oven". Proceedings of the Second World Conference on Solar Cookers- Use and Technology, July 12-15, Heredia, Costa Rica (1994): 149-158.

8. Nandwani Shyam S. "Solar Cookers Cheap technology with high ecological benefits". *Jr. Ecological Economics* 17 (1996): 73-81.

9. Nandwani Shyam S., *et al*. "Experimental study of multipurpose solar hot box at Freiburg, Germany". *Renewable Energy-An International Journal* 12 (1997): 1-20.

10. Nandwani Shyam S. "Design, construction and study of a hybrid solar food processor in the climate of Costa Rica". *Renewable Energy - An International Journal* 32.3 (2007): 427-441.

11. Nandwani Shyam S. "Design, Construction and Study of a Hybrid and Dual Voltage Solar Cooker in the Climate of Costa Rica". *Renewable Energy (Sovereign Publications), Annual Edition* (2008): 103-108.

12. Nandwani Shyam S. "Solar Food Processing- authors experience with cooking and drying in Costa Rica". Presented at International Solar Food Conference, held at Indore, India, Jan. 14-16, Published in CD Rom. (2009).

13. Nandwani Shyam S. "Solar Cookers and Dryers to conserve human and planet health". *Sustainability Science and Technology.* New Springer Encyclopaedia (2022): 9486-9509.

14. Nandwani Shyam S. "Hybrid Solar/Electric Oven with Smart Switch and Smart Phone". O*pen Access Journal, Acta Scientific Computer Sciences* 4.8 (2022): 10-14.

15. Solar Cookers International, Non Government Organisation, Sacramento, CA, USA. www.solarcooking.org. & www.solar-cookers.org (2022).