Second International Conference

>Advances in Solar
>Thermal Food Processing

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Conference Proceedings

Editors

Celestino Rodrigues Ruivo

Dave Oxford

UAlg ISE
UNIVERSIDADE DO ALGARVE
INSTITUTO SUPERIOR DE ENGENHARIA

The Second International Conference for Solar Thermal Cooking and Food Processing, held at the University of Algarve, Institute of Engineering, Faro, Portugal, on 22nd - 24th January, 2018.

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Programme 22nd January 2018, CONSOLFOOD2018

08:30 **Registration and reception**

09:00 Opening session

Session O1 (moderator: Eduardo A. Rincón Mejía)

09:25 **Membrane FixFocus mirror as multifunctional solar power station for diverse village applications,** Jürgen Kleinwächter, Portugal (L1)

09:50 **Hot stone cooking with an ultralight membrane solar concentrator,** Fernando Chacon, Douglas Baillie, Daniel Müller, Paul Gießler, Portugal (L2)

10:15 **Photovoltaic solar cooking with thermal energy storage (TES),** A.Lecuona, D. Victoria, J.A. Perteguer, E. García-Arés, Spain (L3)

10:30 **Solar cooker as a public furniture. Thermal modeling,** A.Lecuona, E. de la Rocha, J. I. Nogueira, Spain (L4)

10:45 **Modelling, testing and parametric analysis of a parabolic solar cooking system with heat storage for indoor cooking,** N. Mbodji, A. Hajji, Morocco (L5)

11:10 **Break for solar "caroffee", "carotea" and carob cake**

Session O2 (moderator: Dave Oxford)

12:10 **Development of a large capacity orange bagasse dehydrator,** Eduardo Rincón Mejía, Bernd Weber, Mexico (L6)

12:35 **Combined membrane and solar drying technologies for fruit preservation in Mozambique,** Ricardo Bernardo, Henrik Davidsson, Pia Otte, Randi Phinney, Lucas Tivana, Sewden, Norway, Mozambique (L7)

13:00 **Solar lunch**

14:30 Poster session P1 (see poster list PL1)

Session O3 (moderator: Bernhard Müller)

15:30 **From development aid towards an economic factor: sustainable production of clean cookstoves in Madagascar,** Christian Frost, Switzerland (L8)

15:55 **Challenges in promoting solar cookers in India: social acceptance, cooking habits and technologies,** Neha Mehta, Kinjal Pandya, India (L9)

16:10 **Networking to advance the use of solar cookers as educational tools in the classroom,** Mary Buchenic, Jennifer Gasser, USA (L10)

16:25 **The task of creating programs to promote solar cooking,** Jennifer Gasser, Mary Buchenic, USA (L11)

16:40 **The broken promise of solar cooking. The case of Goudoubo Refugee Camp in Burkina Faso,** Isabella Troconis, UK (L12)

17:05 **Short break for solar "caroffee", "carotea" and carob cake**

Session O4 (moderator: Celestino Ruivo)

17:20 **Solar restaurant Le Presage,** Aubert Pierre-André, France (L13)

17:45 **Evolution of solar cooking technology in India and way ahead,** Deepak Gadhia, India (L14)

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09:15-15:00 **Exhibition of different types of solar cookers, solar dryers and other equipment related to solar food processing outside in the courtyard, weather permitting.** Coordinator: Juan Bello LLorente, Spain

Poster List PL1

P1 - Concrete funnel solar cooker: experiences with making and cooking, Jignesh R. Mehta, Celestino R. Ruivo, India, Portugal

P2 - Development of a permanent solar cooker for the UK – Convenience, reliability and safety, Dave Oxford, Stewart MacLachlan, UK

P3 - Thermal performance evaluations, energy savings and payback periods of a box-type solar cooker in Ibadan, Nigeria, Ademola K. Aremu, Olaoluwa S. Awotunde, Nigeria

P4 - Solar cooking using the box type and funnel type cookers under Indian conditions, Anasuya Ganguly,Saurav Mehta,Srikanth Mutnuri, India

P5 - Design, realisation and experimentation of a solar cooker fitted with an ellipsoidal concentrator: preliminary results of cooking tests, Siaka Touré,Modibo Sidibé, Ivory Coast

P6 - Comparative performance of two parabolic solar cookers: influence of a glass cubic box, Modibo Sidibé, Touré Siaka, Diomande Idrissa, Ivory Coast

P7 - Testing the SUNTASTE, a new box type solar cooker built out of cork, Ailton Tavares, Afonso Cavaco, Manuel Collares-Pereira, Nuno Oliveira Martins, Portugal

P8 - Solar ovens built with very basic materials found in rural areas, Margarita Mediavilla, Spain

P9 - Analysis of solar cooking in relation to food sovereignty, Bailey Jannika, Quiroga V. Noelia, Raimondo Emilia, Esteves Alfredo, Argentina

P10 – LAZOLA solar box cookers a unique manufacturing concept, Jo Hasler, Christian Fenner,Michael Bonke, Germany

P11 - Efficiency of a compound parabolic concentrator kitchen in Iztapalapa, Mexico City, E. Barrera Calva, Verónica Frías, E. Antaño Díaz, E. Rincón Mejía, J. Hernández, Mexico

P12 - Construction and evaluation of a solar thermal-wind hybrid dryer for food processing in Chiapas, MX, J.M. Hernández-Jarquin, Kinarkumar R. Patel, G. Pavon Gomez, E.A Mojica Castillo, J.E Conde Diaz, R. Iglesias Diaz, J. Pantoja Enriquez, Mexico, India

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Session O5 (moderator: Jean-Jacques Serra)

09:10 **Heliac solar cooker,** Sedi L. Byskov,Karsten Dupont, Gideon P. Caringal, Maria Matschuk, Henrik Pranov, Denmark (L15)

09:35 **A comparison of Copenhagen solar cookers with other similar sized panel cookers,** Sharon Clausson, USA (L16)

10:00 **The solar cooker Tolokatsin V,** Eduardo A. Rincón-Mejía, Mexico (L17)

10:15 **Solar Cookers International: how the performance evaluation process contributes to global gains in solar cooking,** Alan W. Bigelow, Julie L. Greene, USA (L18)

10:25 **Solar cookers international reports recent gains in the global solar cooking movement,** Julie L. Greene, Alan W. Bigelow, Caitlyn S. Hughes, USA (L19)

10:40 **Break for "caroffee", "carotea" and carob cake**

Session O6 (moderator: Stewart MacLachlan)

11:20 **Simulation of a solar assisted counterflow tunnel dehydrator,** A. Carrillo-Andrés, J.M. Sojo-Gordillo, F. Dominguez-Muñoz, J.M. Cejudo-López, Spain (L20)

11:45 **Development of solar dryers, Cuban experience for food preservation,** Boris Albrech Zaldívar Núñez, Glensy Palay Alonso, Cuba (L21)

12:10 **Introduction of solar drying by NGO Narmada in Nimar region of Madhya Pradesh state of India under the guidance of BARC, GOI.,** Raghav S Deosthale, Shankar Kewat, India (L22)

12:35 **Solar lunch**

14:30 Poster session P2 (see poster list PL2)

Session O7 (moderator: Jignesh R. Mehta)

15:45 **DryEcoMate – An horticultural dehydrator, using solar thermal and photovoltaic energy, low cost production, modular and portable,** João Garcia, J.Pássaro, R.Rosado,L.Coelho, M. Ley, J.Rodrigues, P.Madureira, Portugal (L23)

16:10 **Concentrated solar thermal integration into spice roasting industry: an energy analysis of an Indian masala manufacturing facility,** Tavish W. Fenbert, Vishal Sardeshpande, USA, India (L24)

16:35 **Break for "caroffee", "carotea" and carob cake**

Session O8 (moderator: Tavish W. Fenbert)

17:10 **Beam steering lens array for solar cooking,** Håkon J. D. Johnsen, Ole Jørgen Nydal, Jan Torgersen, Norway (L25)

17:35 **Father Himalaya solar furnaces: optical principles, technologies and lineage,** Jean-Jacques Serra, Jacinto Rodrigues, France, Portugal (L26)

Session V1:

18:00 **Story and experiences of Father Himalaya**

18:40 **Break**

19:30 **Conference solar dinner**

Programme 23rd January 2018 January 2018, CONSOLFOOD2018

Exhibition of different types of solar cookers, solar dryers and other equipment related to solar food processing outside in the courtyard, weather permitting. Coordinator: Juan Bello LLorente, Spain

Poster list PL2

P13 - Solar drying - a gigantic opportunity to combat hunger and poverty, Bernhard S. Müller, Germany

P14 - Enhanced methods to accelerate the dissemination of solar cookers, Faustine Odaba, Kenia

P15 - 10th grade high school physics education via solar cooking, Hezi Yizhaq,Daniel Feuermann, Israel

P16 - Searching for the relevant scale for food transformation in dense urban areas in France, Cathelineau Vincent, Genin Chloé, De Maria Arnaud, Bertin Kévin, France

P17 - My story of solar ovens, Júlio Piscarreta, Portugal

P18 - Soil pasteurization in the UK – a new job for solar cookers, Dave Oxford,Stewart MacLachlan, UK

P19 – Purification of water using solar energy, Avinash Reddy, Srikanth Mutnuri, India

P20 – Design, realization and test of a portable solar box cooker with booster mirrors, Giovanni Di Nicola, Gianluca Coccia, Sebastiano Tomassetti, Mariano Pierantozzi, Italy

P21 – Ovens and solar cookers, powerful didactic tool for green building, Juan Bello Llorente, Spain

P22 – Simulation of a solar funnel cooker using MATLAB, Rafael Cubero-Leiva, Fernando Domínguez-Muñoz, Francisco R. Villatoro, Celestino Ruivo, Spain, Portugal

P23 - Sharing government perspective and participation in promoting Solar Cooking in India, Suresh Ruparel, India

Programme 24th January 2018

09:15-12:00 **Exhibition of different types of solar cookers, solar dryers and other equipment related to solar food processing outside in the courtyard, weather permitting.**
Coordinator: Juan Bello LLorente, Spain

9:00-10:00 Round table

The dissemination of solar cooking and solar drying practices: Where do we go from here?'

Moderator: Dave Oxford
Members: Bernhard S. Müller, Neha Mehta, Alan W. Bigelow, Isabella Troconis

Dissemination of solar cooking, solar drying and other solar food processing technologies. problems, obstacles and solutions (Faro declaration of intent)

10:00-12:00 **Networking between participants**

09:00-12:00 **Solar cookers in action preparing "caroffee", "carotea", carob cake and lunch.**

Solar Cooking Team

Coordinators: Juan Bello LLorente, Spain and Celestino Ruivo, Portugal

Collaborators: Francisco Javier Macías Fuentes, Spain; Pierre-André, France; Neha Mehta, India, Kinjal Pandya, India; Raghav S Deosthale, India and Shankar Kewat, India

12:30 **Solar lunch**

14:30 Closing session

Introduction

Authors were invited to present one or more of the following: a) an A1 poster for presentation, b) a verbal presentation, delivered as a lecture, usually supported by a Powerpoint presentation, and c) a full-length paper for publication in these **Proceedings.**

This document contains all of the abstracts and full-length papers submitted for inclusion in CONSOLFOOD2018. It may be updated from time to time if papers are revised, or further full-length papers arising from submitted abstracts are received.

Abstracts or full-length papers presented as Posters are listed first, then abstracts or full-length papers delivered as Lectures.

All of the submissions have been scrutinised by one or more members of the Scientific Committee, but they have not necessarily been revised to accommodate suggestions made by the reviewers. Therefore, they should not necessarily be regarded as having been subjected to strict peer-review.

Getting further information

Authors may be contacted via the email address that appears under the title of each abstract or full-length paper. Where several email addresses appear, it is the convention that the name of the corresponding author bears an asterisk (*). If this is the case, please only contact the corresponding author.

PDF versions of abstracts, and many of the Powerpoint presentations, can be freely accessed and downloaded from: http://www.consolfood.org/2018-downloads/

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Audio interviews with some of the CONSOLFOOD conference speakers are available on the sunpod website: http://www.sunpod.de/alle-episoden/ Interviews in English have the UK flag next to them. The others are in German.

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CONCRETE FUNNEL SOLAR COOKER: EXPERIENCES WITH MAKING AND COOKING

Jignesh R. Mehta[1] * and Celestino R. Ruivo[2]

1: Department of Mechanical Engineering, Faculty of Technology and Engineering, The Maharaja Sayjirao University of Baroda, Vadodara, India-390001
e-mail: j.r.mehta-med@msubaroda.ac.in, web: http://www.msubaroda.ac.in

2: Institute of Engineering, University of Algarve, Faro, Portugal

email: cruivo@ ualg.pt web: http://www.ualg.pt

Abstract: Hundreds of millions of people in the world depend on firewood and cow dung for their cooking energy needs. These methods are not human and environment-friendly, while on the other end the solar energy is available freely and can help to save time and health of the deprived population.

Various designs of solar cooker like box type solar cooker, funnel solar cooker and concentrating cookers like Scheffler dish are available. Prof. Celestino Ruivo from University of Algarve, Portugal has developed methodology to prepare "Concrete Funnel Solar Cooker", which is a very sturdy, economical and easy to fabricate design of solar cooker. It can be put in open place near the house or terrace and no special care is needed to maintain it with very long life. The students of The Maharaja Sayajirao University of Baroda at Vadodara, India got inspired by this idea and took up fabrication of mould, making of the cooker and testing as their final year Bachelor project under the guidance of Dr. Jignesh Mehta with continuous guidance from Prof. Celestino Ruivo. This work describes their experiences with the project and results of testing and demonstrations with cooking.

The mould has mainly three parts; funnel piece, middle piece and bottom piece. The funnel piece has two parts, inner and outer and are assembled with a gap of 30 mm between them. They are made from hot rolled mild steel plates with 3 mm thickness and spacing tubes are spot welded on them for filling up concrete. The middle piece has two steps, upper level works as platform for cooking and the lower level allows a metal tube to pass through it to rotate the funnel about the base. Around 100 liters of concrete is needed with ratio of cement, sand and grit being 1:1:2. Glass mirrors were used as reflectors and were fixed on inner surfaces of the funnel piece as well as platform of the cooker.

The tests like water heating test as per ASAE method, oil heating and cooking demonstrations were carried out. The standard cooking power of this cooker as per ASAE method came out to be 59 W as compared to 29 W for a box type cooker design. The temperature could reach up to 161^{o}C with oil on a sunny day. Rice making and tea making were successfully demonstrated. Thus, the concrete funnel solar cooker is a very convenient and useful design, which can help alleviate health and environment related problems related with cooking.

Keywords: Solar energy, cooking, environment, social upliftment, renewable energy

DEVELOPMENT OF A PERMANENT SOLAR COOKER FOR THE UK - CONVENIENCE, RELIABILITY AND SAFETY.

Dave Oxford[1]* and Stewart macLachlan[2]

1: SLiCK solar cookers, Little Oaks, Menagissey, Cornwall, TR4 8DH, UK.
e-mail: daveoxford@metronet.co.uk web: http://www.slicksolarstove.com

2: SliCK solar cookers, 43, Ellingfort Road, London, E8 3PA, UK
e-mail: ecozoom.uk@btinternet.com web: http://www.slicksolarstove.com

Abstract: *Attempts to introduce solar cookers to new populations or markets often result in disappointment (e.g. Kebede & Mitsufuji, 2014, Beltram & Levine 2014). The reasons for these failures have been widely studied (e.g. Ahmad, 2001) and attempts made to devise better strategies (e.g. Larsen & Seim, 2015). This paper describes an ongoing project to introduce solar cooking to the UK by a) increasing familiarity with the technology, and b) developing a solar cooker that performs adequately in the UK climate, and c) meets the requirements of potential users. The challenges are the same as those encountered in attempts to do the same in other cultures – the cookers need to be recognized and understood, perform well in the climate, and satisfy a number of consumer requirements regarding convenience, reliability, and safety. Most standard household kitchens in the UK contain built-in ovens, hobs and microwaves, enabling baking, boiling, steaming, frying and other cooking techniques. This cooking equipment is permanent, convenient, durable, and reliable, and situated indoors. Many households have several sources of fuel available for cooking, including solid fuels, gas, and electricity. The total cost of these fuels usually represents a very small proportion of the annual household budget. Domestic cooking in the UK is therefore usually cheap, convenient, and reliable. Solar cookers simply cannot compete in this domestic cooking sector. The only time that UK residents cook outdoors at home while the sun is shining is when they have a barbecue. If solar cookers are to gain recognition and a foothold in the UK, they must first compete with barbecues. But anecdotal evidence suggests that few UK residents would recognize a solar cooker, still less believe it could be used effectively in their climate. The authors introduce a rapid, simple visual recognition test for assessing familiarity with solar cooking devices. They then report on the development of a permanent, convenient, reliable and safe solar cooker that is suited to local climatic conditions, and can compete in the UK outdoor cooking market, currently dominated by charcoal and gas barbecues. In particular, factors are addressed that are known to impede the adoption of solar cookers in any community, including: awareness and unfamiliarity, convenience, habitual behaviour patterns, reliability, cost, and safety. Results of extensive performance testing and design modifications resulting from user feedback are presented as part of a full description of the product development program.*

Keywords: Solar cooker recognition survey, barbecues, UK market, product development.

THERMAL PERFORMANCE EVALUATIONS, ENERGY SAVINGS AND PAYBACK PERIODS OF A BOX-TYPE SOLAR COOKER IN IBADAN, NIGERIA

Ademola K. Aremu[1]* and Olaoluwa S. Awotunde[2]

1: Agricultural and Environmental Engineering Department, Faculty of Technology, University of Ibadan, Nigeria
email: ademolaomooroye@gmail.com

2: Agricultural and Environmental Engineering Department, Faculty of Technology, University of Ibadan, Nigeria
email: olaoluwaawotunde@gmail.com

Abstract: *This work presents the development, evaluation and some economic analysis of a box-type solar cooker in the tropical climate of Ibadan. The performance evaluation included the determination of the first and second figure of merits (F_1 and F_2), the cooking power and the standardised cooking power. Based on the number of solar meals that can be cooked in a year, economic analyses of the solar cooker were carried out. Some financial parameters were estimated for the solar cooker which includes Cumulative Cash Flow (CCF), Net Present Value (NPV), Simple Payback Period (SPP), and Discounted Payback Period (DPP) with respect to other cooking fuels viz; Liquefied Petroleum Gas (LPG), Kerosene, Charcoal, Firewood and Electricity. The annual energy savings and Carbon dioxide (CO_2) mitigation as a result of using the solar cooker were also estimated. A maximum stagnation temperature of 126^{o}C was achieved in the solar cooker and the water boiling test took 120 minutes. The F_1 and F_2 values ranged from 0.11 – 0.13 and 0.24 – 0.30 respectively. Maximum cooking power and standardised cooking power of 92.4 W and 85.6 W respectively were achieved. The CCF of the solar cooker ranged from $140.34 to $382.39 while NPV ranged from $89.09 to $348.33 with cooking using electricity yielding the least and cooking using LPG yielding the highest. The LPG has the shortest SPP and DPP of 7 months while electricity has the longest SPP and DPP of 18 months and 20 months respectively. Annual energy savings ranged from 1728 MJ to 18922.6 MJ. Annual CO_2 mitigation was estimated to be between 164.8 kg and 2119.3 kg.*

Keywords: Figure of merit, Cooking powers, Economic analysis, Energy savings

1. INTRODUCTION

In Nigeria, the energy sources used for cooking includes fossil fuels (Kerosene, Liquefied Petroleum Gas, Biomass fuels/Fuel wood and Coal) and Electricity. Each of these has one major challenge or the other. The non-functional or low capacity production of our refineries and the problem of vandalization of our oil pipelines have made the country a net importer of refined petroleum fuels which leads to a hike in their prices, hence making them unaffordable by the people, majority of whom are low income earners. Again when they are available, the supply favours the urban areas than the rural areas where 70% of the country's population live.

Electricity production in Nigeria is more from thermal generator that make use of gas. The problem of vandalization of gas pipelines has reduced production from these sources, causing very low supply. Apart from this, about 30 million people are not connected at all and the low supply available is also in favour of the urban areas. For example, only 40% of the population is connected to the national grid with 90% of rural areas having unreliable or no electricity at all. This leaves a majority of the people with the use of biomass fuel which apart from being available also attracts low cost. The reliance on Fuel wood for the supply of energy for cooking has deforestation as its attendant problem, which contributes also to desertification. The equivalent of 410,000 hectares of forested land is being lost annually [1], [2]. Another major concern with the use of burning biomass is indoor air pollution from open fire usually in houses without chimneys leading to respiratory diseases and premature deaths. Furthermore, constant search for Fuel wood represents burden for women and children particularly in rural areas.

In an attempt to address all these aforementioned problems, there is a dire need to search for an alternative energy source which if available, will be affordable; address the health issue and reduce the pressure on biomass resources. This makes solar energy through the use of solar cookers a viable option. Nigeria receives 16.7 x 10^{15} kJ of solar energy each clear day. Estimates have revealed that using one percent of the available land area (983.2 x 10^6 m^2) for 180 clear days in the year operating at 5% conversion efficiency, the equivalent of 15.0 x 10^{14} kJ of useful energy would be available annually to the country, this figure is equivalent to the national fossil fuel production with the dual advantage of renewability and environmental protection [3].

The use and availability of solar cookers in Nigeria has been restricted to research institutions [4] hence, the need for the effective dissemination of the technology to the teeming populace. For this to take place, apart from having to convince people on its functionality, there will be the need to also prove its economic viability. Hence, the objective of this work was to evaluate the thermal performance and economic viability of a box-type solar cooker in Ibadan metropolis, Oyo State, Nigeria.

2. METHODOLOGY

A family size solar box cooker capable of cooking meals for 4 to 5 persons was constructed. The constructed cooker has an aperture area of 0.25m^2. The boxes were made of plywood while coconut coir was used as insulating material. Aluminium foil was as the reflector.

2.1 Performance Evaluation

Stagnation temperature test was carried out for the solar box cooker and first figure of merit (F_1) was determined using equation 1. Water heating test was also carried out and the time taken to boil a known mass of water was recorded. The second figure of merit (F_2) was also determined using equation 2. Cooking power was determined using equation 3 at intervals and was corrected to a standard of 700W/m^2 using equation 4 [5]. The standardized cooking power was plotted against the temperature difference for each interval. A quantity of food sufficient to feed 5 persons was cooked on each of the cookers, recording the time spent and the energy consumed [6].

$$F_1 = \frac{F'\eta o}{F'U_L} = \frac{T_p - T_a}{H} \tag{1}$$

$$F_2 = \frac{F_1\ MC\ _w}{A\Delta t}\ln\frac{1-\frac{1}{F_1}\frac{T_{w1}-T_a}{H}}{1-\frac{1}{F_1}\frac{T_{w2}-T_a}{H}} \tag{2}$$

$$P_i = \frac{T_2-T_1\quad MC\ _w}{600} \tag{3}$$

$$P_s = P_i\ \frac{700}{H_i} \tag{4}$$

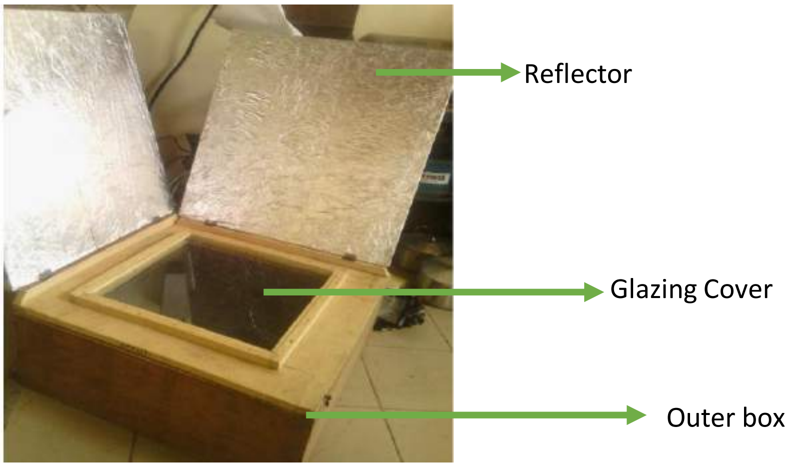


Figure 1: Solar box cooker

2.2 Economic Analysis

The costs of operating each of the cookers were estimated per annum for all the cookers and compared with the cost of combined usage of solar cooker with the existing cooker. Some of the financial parameters used by [7] were adopted in the financial evaluation of the solar box cooker. Other parameters such as Cumulative Cash flow (*CCF*) and Simple Payback Period (*SPP*) were also estimated.

The cost of operating each of the fuel cookers was estimated per meal for a representative meal cooked on each of the cookers. The operating C_{oi} was taken as the addition of the running cost and maintenance costs. Since solar box cooker has little operating cost i.e. its maintenance cost; the saving per meal compared with other cookers is given by equation 5. This was estimated per annum considering the average number of days with sufficient insolation in a year. The solar cooker usage was taken as a capital project investment with the cost of the solar cooker C_{cs} as the capital investment and the annual savings P_i with respect to cooker i utilization as the cash inflow; the cumulated cash flow *CCF* was calculated using equation 6.

$$S_i\ =\ C_{Oi} - C_{OS} \tag{5}$$

$$CCF = -C_{CS} + NP_i \tag{6}$$

Where N is the useful life of the solar cooker (years). The simple payback period *SPB* was calculated using equation 7.

$$SPB = \frac{C_{CS}}{P_i} \tag{7}$$

Considering the time value of money with interest rate r, Net Present Value, *NPV*, of the project is given by equation 8.

$$NPV = -C_{CS} + \sum_{y=1}^{N} \frac{P_i}{(1+r)^y} \tag{8}$$

The discounted payback period *DPB* was given by equation 9.

$$DPB = \frac{\ln\left(\frac{1}{1-rSPB}\right)}{\ln(1+r)} \tag{9}$$

2.3 Annual Energy Savings

The energy savings which accrued to solar cooker usage is the energy saved from the usage of the solar box cooker compared with the existing cookers. The mass of fuel consumed in cooking each meal using the existing cooker is given by equation 10.

$$m_{ri} = m_i t_{ri} \tag{10}$$

The annual energy savings is given by equation 11.

$$E_i = m_{si} h_i \tag{11}$$

With respect to electric cooker, annual energy savings E_e is given by 12.

$$E_e = cooker\ wattage\ \times\ t_r n_y \tag{12}$$

2.4 CO_2 Mitigation

The environmental pollution mitigated annually (via reduction in CO_2 release) as a result of using the solar box cooker depends on the amount of CO_2 prevented from being released from each of the cooking fuels. The annual carbon dioxide mitigation is given as follow in equation 13.

$$Annual\ CO_2\ mitigation = E_i \times fuel\ specific\ CO_2\ production \tag{13}$$

3. RESULTS AND DISCUSSION

3.1 Performance of Solar Box Cooker and Economic Analysis

The stagnation temperature of 126.0^{o}C was obtained as the maximum value using the solar cooker. The temperature profile recorded during the stagnation test is shown in figure 2. This same trend was also reported by [8]. The first figure of merit F_1 has range of 0.24 to 0.30 with maximum cooking power of 97.65W. Similar findings were reported by [9] and [10]. A maximum standardized cooking power of 85.56W was obtained.

The capital cost expended in constructing the solar box cooker was $56.25. The costs of these cookers are less than one third of some commercially available model. Similar findings were reported by [11]. The weather data analysis in Ibadan showed than an average of 300 meals can be cooked in a year. The financial parameters obtained for the solar box cooker used as supplementary with the existing cooking fuels are given in Table 1. The NPV of the savings generated as compared to each cooker usage is substantial. This is quite encouraging at a time of economic instability, especially to the low income families. The returns from solar box cooker can be ploughed into other uses to help improve the standard of living of such families. The solar box cooker can be encouraged to supplement the conventional cooking methods. If invested in, the solar box cooker has a short payback period. If a loan is taken to invest in the solar box cooker, the loan can be repaid in a short time. This is estimated based on the assumption that the cash inflow is uniform throughout the months of the year. However, this may not be so because the revenue is dependent on seasonal variation of the weather condition within the year. It is based on the assumption that the solar box cooker is used instead of any of the existing cookers at every available period of sufficient solar insolation. If utilized, solar box cooker will help strengthen the economy of families in Ibadan city and other locations where there is abundant sunshine.

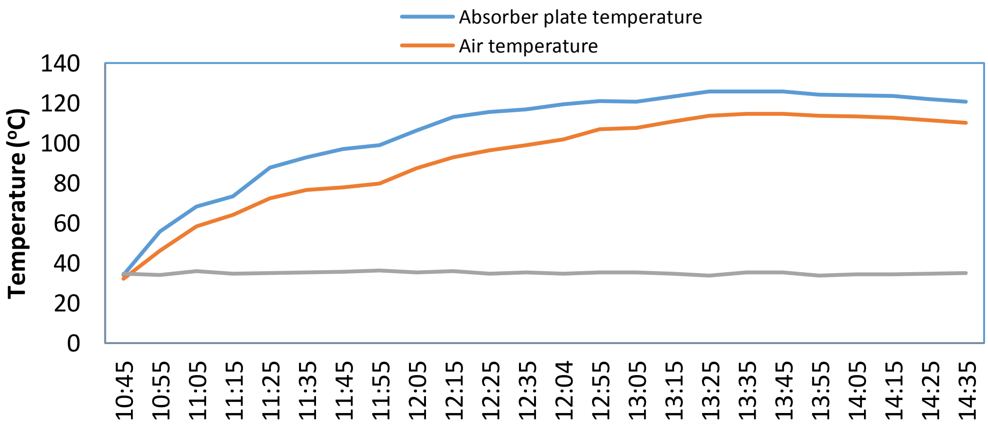


Figure 2: Temperature profile during stagnation test

2.2 Annual Energy Saved

The estimated annual energy saving of the solar box cooker with respect to each of the cooking fuels is shown in Table 2. A huge amount of energy could be saved by usage of solar box cooker in each family. When cooking is done with kerosene or fuel wood, about 80 – 90% of energy is wasted to the environment [12]. The solar box cooker prevents such wastage. This shows a great prospect for country like Nigeria and other developing countries who are yet to meet their energy demands; especially in electricity supply. The energy saved from electricity consumption could be diverted to other use.

Table 1: Estimated Financial Parameters Using Solar Box Cooker as a Supplementary to Kerosene, Charcoal and Fuel Wood Cookers.

COOKER SUPPLEMENTED	ANNUAL SAVINGS ($)	CCF ($)	NPV ($)	SPB (Months)	DPB (Months)
LPG	109.47	491.09	348.33	7	7
Kerosene	58.86	238.13	161.35	12	13
Charcoal	72.15	304.48	210.40	10	11
Fuelwoood	77.87	334.57	231.55	9	10
Electricity	39.33	140.38	89.10	18	20

2.3 Carbon Dioxide Mitigation

The CO_2 mitigation using solar box cooker annually is shown in Table 2. A huge amount of CO_2 will be prevented from being released to the atmosphere by using the solar box cooker. Firewood burning releases the highest amount of CO_2 to the atmosphere when used for cooking compared with kerosene and charcoal. The attendant deforestation occurring with usage of wood as fuel for cooking is a strong reason for replacement of wood with solar box cooker.

Table 2: Estimated Annual Energy Savings and CO_2 Mitigation Using Solar Box Cooker

COOKING FUEL	ANNUAL ENERGY SAVINGS (*MJ*)	ANNUAL CO_2 MITIGATION (Kg)
LPG	3963.72	250.11
Kerosene	2291.52	164.76
Charcoal	8530.41	955.41
Fuelwood	18922.60	2119.33
Electricity	1728.00	233.42

CONCLUSION

The results from this study show the performance and economic analysis of a box-type solar cooker. The first and second figure of merits (F_1 and F_2) had a range of 0.11 – 0.13 and 0.24 – 0.30 respectively. The cooking power was 92.4W. A maximum stagnation temperature of 126^oC was obtained in the solar cooker and the water boiling test took 120 minutes. Standardised cooking power of 85.6 W was recorded. The CCF of the solar cooker ranged from $140.34 to $382.39 while NPV ranged from $89.09 to $348.33. Cooking with electricity yields the least and cooking with kerosene yields the highest. The kerosene has the shortest SPP and DPP of 7 months while electricity has the longest SPP and DPP of 18 months and 20 months respectively. Annual energy savings ranged from 1728 MJ to 18922.6 MJ. Annual CO_2 mitigation was estimated to be between 164.8 kg and 2119.3 kg. Solar box cooker has tremendous benefits ranging from cost saving to energy saving. It is therefore recommended that solar cookers are good alternative for cooking in the quest to make human activities go greener.

REFERENCES

[1] Ekechukwu, O.V. 2001. Design and measured performances of a plane reflector augmented box type solar energy cooker. United Nations Educational Scientific and Cultural Organization and International Atomic Energy Agency. The Abdus Salam International Centre for Theoretical Physics.

[2] Gujba, H., Mulugetta, Y. and Azapagic, A. 2015. The Household Cooking Sector in Nigeria: Environmental and Economic Sustainability Assessment. *Open Resources*, Vol.*4*: 412-433. doi:10.3390/resources4020412.

[3] Adegbulugbe and Akinbami (1992). Nigeria Journal of Renewable Energy, Vol. 3, Nos 1 and 2; PP 73 -90.

[4] Sambo, A. S. (2005). Renewable Energy for Rural Development: The Nigeria perspective. IsescoScience and technology Visoin, Volume 1 (May 2005; 12 – 22), Retrieved on 4th February, 2012 from http://www.isesco.org

[5] ASAE, 2003. Testing and Reporting Solar cooker performance. Standard S580. American Society of Agricultural Engineers.

[6] Mullick S. C., Kandpal T. C. and Saxena A. K., 1987. Thermal test procedure for ox-type solar cookers. Solar Energy Vol. 39, No. 4, pp353-360

[7] Kumar S., Rubab S. Kandpal T. C., and Mullick S. C., 1995. Financial feasibility Analysis of Box type Solar cookers in India. Centre for Energy studies, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi 110 016, India.

[8] Mohod A. G. and Power A. G., 2011. Development and Evaluation of Multi-reflector foldable type solar cooker. Agricultural Engineering International: CIGR Journal. Manuscript No. 1990. Vol. 13, No. 1, 2011.

[9] Rikoto, I.I. and Garba, I. 2013. Comparative analysis on solar cooking using box type solar cooking with finned cooking pot. International Journal of Modern Engineering Research. Vol. 3(3): 1290 – 1294.

[10] Aremu, A.K. and Ogunlade, C.A. 2014. Comparative evaluation of a foil interior and black painted interior box-type solar cooker. Nigerian Journal of Solar Energy. Vol.25: 22 – 27.

[11] Gupta, M. and Bafna, M. 2017. Performance analysis of an economical portable housing solar cooker (EPHSC). International Journal of Civil, Mechanical and Energy Science. Vol.3 (2), 121 – 125.

[12] Nitin Saxena, Manish Saxena and Archana Saxena, 2014. Implementation Issues and Economic Viability of Box type solar cooker in Indian Scenario. MIT International Journal of Electrical and Instrumentation Engineering, Vol. 4, No. 1, January 2014, pp 26 – 31.

LIST OF NOTATIONS

i	notation to represent fuel types (g for LPG; k for Kerosene; c for Charcoal; w for Fuelwood and e for Electricity
m_{ri}	Mass of fuel consumed by cooker in cooking representative meal *i* (Kg)
m_{si}	Mass of fuel saved in the year by using fuel *i*
t_{ri}	Time spent in cooking representative meal using fuel *i*
p_i	Purchase price of fuel i ($)
C_{ci}	Capital cost of cooker using fuel *i*
C_i	Cost of cooking the representative meal using fuel *i*
C_{im}	Cost of ignition material per meal ($)
C_{ri}	Running cost of cooker using fuel i ($)
C_{oi}	Operating cost of cooker using fuel i ($)
C_{os}	Operating cost of the solar cooker ($)
C_{mi}	Maintenance cost of cooker using fuel f ($)
S_i	Savings per meal on cooker using fuel f ($)
n_y	Number of meals that can be cooked in the year with Solar Box Cooker
P_i	Annual savings of cooker using fuel ($)
CCF	Cumulative Cash flow ($)
C_{cs}	Capital cost of solar cooker ($)
N	Number of useful years of solar box cooker
SPB	Simple Payback period (months or years)
NPV	Net Present value ($)
DPB	Discounted Payback period (months or years)
E_i	Annual Energy savings by using Cooker *i*
h_i	the specific heating value of fuel *i*

Solar cooking using the box type and funnel type cookers under Indian conditions

Anasuya Ganguly[1], Saurav Mehta[2] and Srikanth Mutnuri[3]
[1]Assistant Professor, Department of Biological Sciences, BITS-Pilani, K K Birla Goa Campus
[2]MSc Biological Sciences and BTech Mechanical Engineering student, BITS-Pilani, K K Birla Goa Campus
[3]Associate Professor, Department of Biological Sciences, BITS-Pilani, K K Birla Goa Campus

Abstract:
India is a land of sunshine. It is only wise that we use this sunlight wisely. With the advent of solar energy utilization, we would like to make a comparative statement about different solar cookers. In this study we have used two different type of solar cookers to cook different types of food, and have compared their efficiencies. We have cooked the same dish (recipe) in both for easy comparison. Since solar cooking can sometimes be very slow, as in the case of the box cooker, we cannot rule out the growth of microbes in the food. To be sure about the quality of food prepared by solar cookers we have tested the food cooked on bacterial growth plates, and documented the results. All the experiments were carried out in Goa, India where is a seasonal variation of sunlight in summer and during the monsoons. Hence the season the food was cooked was also documented. In this conference we present the results of these studies.

Keywords: Solar Cookers, box type solar cooker, funnel type solar cooker, renewable energy, solar energy

DESIGN, REALISATION AND EXPERIMENTATION OF A SOLAR COOKER FITTED WITH AN ELLIPSOIDAL CONCENTRATOR: PRELIMINARY RESULTANTS OF COOKING TESTS

Siaka Touré[1] *, Modibo Sidibé[2]

1: Laboratoire d'Energie Solaire, UFR SSMT, Université FHB Abidjan Cocody
22 BP 582 Abidjan 22
E-mail: siakaahtoure@yahoo.fr
2: Laboratoire d'Energie Solaire, UFR SSMT, Université FHB Abidjan Cocody
22 BP 582 Abidjan 22
E-mail: sidibmo20@gmail.com

Abstract: This article is about the realization and experimentation of an elliptical solar cooker. This prototype has a single focus and a reflective surface made of galvanized sheet. Its opening diameter is 120 cm and focal length is 60 cm. In a first step, Cooking Tests of six eggs in 0.5 L of water were carried out by fixing the maximum cooking time to 2 hours. The first results showed that the cooking of the eggs was partial. Despite adequate illumination, the temperature 82 ^{o}C, at which starts the cooking of certain foods according to «International Solar Cooker", could not be reached. Thus, a glass cubic box was built that served as an envelope for the pan. In 60 minutes with this new configuration, a temperature of 88.23 ^{o}C was reached, which is widely more than the 82 °C required. After 80 minutes of cooking, a temperature of 92.12 ° C was reached. Finally, after 80 minutes of cooking, all six eggs were completely cooked. . In the second step, the reflective surface was coated with mirror. In such configuration, 10 eggs were perfectly cooked after 40 minutes of cooking in 0.5 litres of water. 500 grams of rice were also cooked after 80 minutes of cooking, in 0.625 litres of water.

Keywords: solar cooker, ellipsoidal concentrator, realization, experimentation, glass cubic box.

1. INTRODUCTION

Energy needs for cooking are enormous. In most developing countries, the energy supply for cooking relies so far on conventional sources of energy, such as firewood collected from forest and charcoal. Those energy sources linked to biomass lead to depletion of the forest and therefore to the degradation of the environment. The use of solar energy is one of the alternative solutions which is clean, renewable and sustainable. In Côte d'Ivoire, solar irradiation is important. The daily total radiation varies of course from 3 to 5 Kwh/m², depending on the regions [1]. Solar cookers are therefore promising. The use of solar energy for cooking requires high temperatures. Such temperatures are obtained by means of concentration systems. Some studies have been made about the parabolic concentrator solar cookers. [2-5]. The hot box solar cookers have also been studied [6-7]. Another type is the conical solar cooker, which have been studied by several researchers [8-9]

2. DESIGN AND DESCRIPTION OF THE ELLIPSOIDD CONCENTRATOR

2.1. Design of the concentrator

2.1.1. Co-ordinates x and y calculation for the designed ellipsoidal concentrator

An ellipse is defined as "the set of all points P such that the sum of the distances between P and to distinct fixed points, called the foci, is constant"? The ellipse is represented in Figure 1, with its two focal points F1 and F2 along the Y axis.

For the design of the concentrator, only the focal point F1 was considered. In the x and y co-ordinates system, the ellipse equation is expressed as

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{1}$$

a and b are respectively the semi-minor axis and the semi-major axis of the ellipse. On Figure 1, a and b are given by a = OP; b = OV1. The two points V1 and V2 are the vertexes. The ellipse is characterized by the distance c = OF1 = OF2; this distance is expressed as

$$c = \sqrt{b^2 - a^2} \tag{2}$$

As for the focal length f, it is given by

$$f = V_1 F_1 = V_1 O - F_1 O \tag{3}$$

Hence, f is expressed as

$$f = b - c = b - \sqrt{b^2 - a^2} \tag{4}$$

For the design of the concentrator, a truncated ellipsoid is considered. As shown on Figure 1, AB is the opening of the concentrator. Let X0 and Y0 be the coordinates of B. Hence, the opening diameter is d = 2X0. In the design process, we sleeted a so that a =d. Hence, for a given value of d, X was expressed as

$$x_0 = \frac{a}{2} = \frac{d}{2} \quad (5)$$

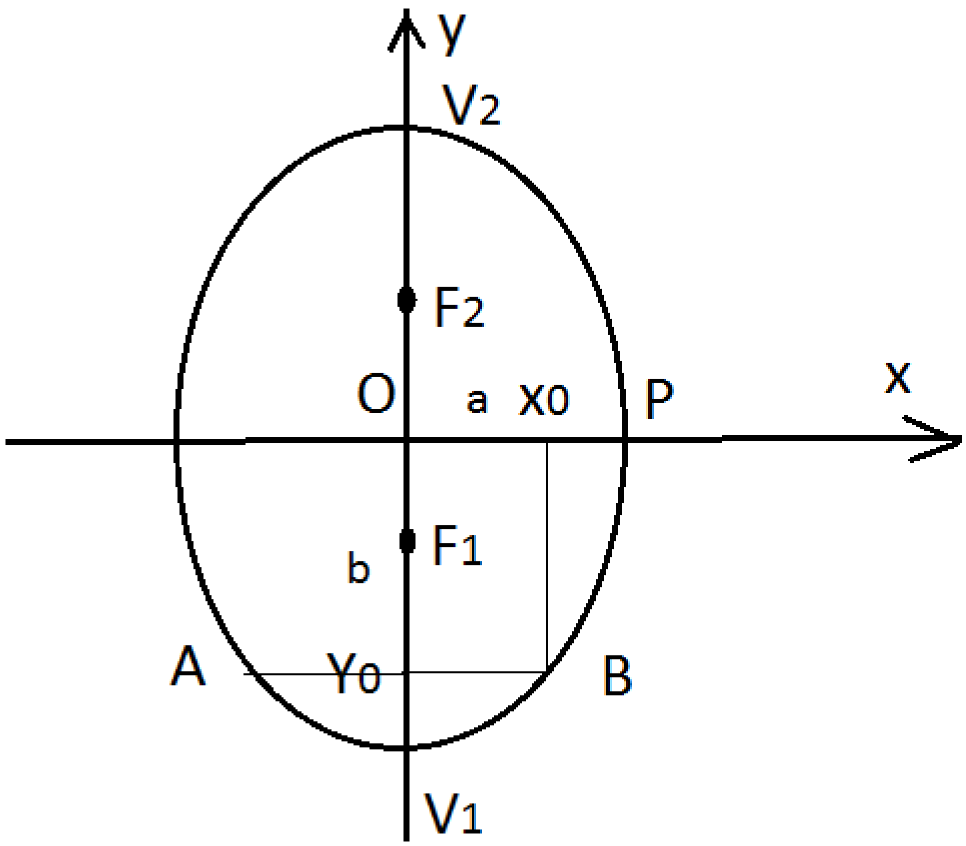


Figure 1. Representation of an ellipse showing its two focal points

As the semi-minor axis a was chosen so that a = d, for a chosen value of d, a is gotten. From equations (1) and (5), one gets

$$y_0 = 0.866b \quad (6)$$

As for the depth h of the ellipse, it is expressed as

$$h = b - y_0 \quad (7)$$

Combining equations (6) and (7), one gets

$$h = 0.13397b \quad (8)$$

From equations (2) and (5), one gets

$$c = \sqrt{b^2 - d^2} \tag{9}$$

Hence, the focal length is expressed as

$$f = b - \sqrt{b^2 - d^2} \tag{10}$$

2.1.2. Calculation of the length of the arc of the ellipse

An arc of ellipse is represented on Figure 2

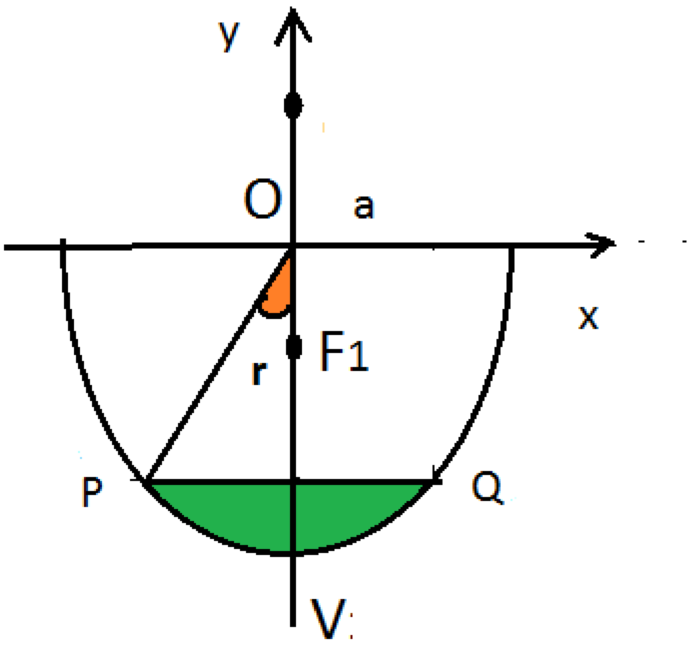


Figure 2. Representation of an arc PQ of h ellipse

Let P be a point of the ellipse and r be the angle between the semi-major axis OV and the line OP . The coordinates of P are expressed as

$$x = asinr$$

$$y = bcosr \tag{11}$$

The length of the arc PV is expressed as [10]

$$s = \int_{r_v}^{r_p} \sqrt{x'^2 + y'^2}\, dr \tag{12}$$

The eccentricity e of the ellipse is expressed as

$$e = \frac{\sqrt{b^2-d^2}}{b} \qquad (13)$$

Let L be the whole ellipse length. It is expressed as [10]

$$L = 2\pi b \times [1 - \left(\frac{1}{2}\right)^2 \times \frac{e^2}{1} - \left(\frac{1}{2}\times\frac{3}{4}\right)^2 \times \frac{e^4}{3} - \left(\frac{1}{2}\times\frac{3}{4}\times\frac{5}{6}\right)^2 \times \frac{e^6}{5} - \left(\frac{1}{2}\times\frac{3}{4}\times\frac{5}{6}\times\frac{7}{8}\right)^2 \times \frac{e^8}{7} - \cdots] \qquad (14)$$

There are some approximations for the calculation of L. One of them is the Fagnamo approximation which is expressed as [10]

$$L = \pi \times [\frac{3}{2}(a+b) - \sqrt{a \times b}] \qquad (15)$$

Another approximation is the following [11]

$$\pi \times (a+b) \leq L \leq \pi \times \sqrt{2 \times (a^2+b^2)} \qquad (16)$$

Let the arc- PQ be considered shown on Figure 2. Its length s is calculated from the knowledge of the angle θ between the semi-major axis OV and OP, when PQ is the opening diameter of the concentrator-. The value of s is expressed as

$$s = \frac{2\theta}{2\pi} L \qquad (17)$$

where θ is expressed in radian. This angle θ is calculated from the' following relationship.

$$x_0 = a \times sin\theta \qquad (18)$$

2.2. Description of the ellipsoidal concentrator experimented

The opening diameter d of the concentrator was chosen to be d = 1.2 m. Therefore, by using equation (5), one gets a = 1.2 m. As for the depth h of the ellipse, it was chosen to be h = 0.20 m. Then from equation (8), one gets b = 1.4928 m. Finally, from equation (10), one gets the focal length f. It is found f = 0.60 m. The concentrator was built using steel rods. It has six facets. Its reflective surface. is made of galvanized steel sheet divided into six facets The base of the black painted pan is held by a collar at a distance l from the focal point, called the back axial distance. This distance l is gotten from the following relationship

$$d_2 = \frac{l.d}{f-h} \qquad (19)$$

Where d_2 is the diameter of the pan, f the focal length, h the depth of the ellipsoid and d the opening diameter. The eccentricity calculated from equation (13) is e = 0.594835. The whole length L of the ellipse calculate from equation (14) is L = 8.48m m. As the calculation of L is limited in equation (14), to e^8 , L = 8.4 was considered. From equation (18), one gets θ = 30 °. Then the theoretical value of the length of the arc of the ellipse, calculated from equation (17),is s = 1.36 m. An experimental building of the ellipse's arc was made by plotting the x , y coordinates on a plywood sheet using equation (1). From this plotting, the length s was measured and fond to be s = 1.32 m, which is close to the theoretical value. A photography of the experimental device with the ellipsoidal concentrator is shown on Figure 3.

Figure 3. Experimental device with the ellipsoidal concentrator

3. EXPERIMENAL STUDY OF THE ELLIPSOIDAL CONCENTRATOR SOLAR COOKER

Several cooking tests of eggs and rice were carried out. For the first experiment, the tests were made with 0.5 litres of water and six eggs in the pan. During the tests, temperature measurements were performed by using platinum resistance thermometers. Temperature data were recorded at a time interval of 10 minutes. The measured temperatures were the ambient temperature Ta, the temperature Tbas at the bottom of the pan and the cooking temperature Tcuisson. An Eppley –type pyranometers was used to record global solar radiation, at time interval of 10minutes. Every 20 minutes, the ellipsoidal concentrator was oriented in front of the sun by means of a manual tracking system. Two configurations were studied. In the first configuration, cooking tests performed without any glass cubic box around the pan. The maximum cooking duration was 2 hours, from 11:00 to 13:00; the maximum cooking temperature reached was 74.39 °C, which is lower than 82 °C. According to "Solar Cooker International", foods star to cook between 82 ° and 91 °C. Figure 4 shows the evolution of temperatures and solar radiation E with time, for the experiment without glass cubic box. The cooking of the six eggs was not perfect. This experiment showed that thermal losses of the pan, by radiation and convection, were very important. Consequently, in the second configuration, a glass cubic box as been installed, that served as a wrapper for the pan. The aim was to reduce the thermal losses. Figure 5 shows the evolution of temperatures with time in that second configuration. After 60 minutes the cooking temperature was 82.23 °C. After 80 minutes of cooking, the cooking temperature reached 92.12 °C and the six eggs were completely cooked. Farther experiments were made to improve this result. For that the reflective surface was coated with mirror, in order to increase its reflection coefficient. The mirror was cut in square pieces whose dimensions are 0.05 x 0.05 m². In that configuration, 10 eggs were perfectly cooked in 0.5 litres of water after 40 minutes of cooking. The cooing temperature reached was 91.47 °CC, while Tbas, the pan's bottom temperature reached was 117.75°C. Moreover, after coating the reflective surface with mirror, cooking tests of rice were carried out. 500 grams of rice in 0.625 litres of water were cooked after 80 minutes of cooking. The maximum cooking temperature reached for the rice was 102.75 °C, while the maximum Tbas (the pan's bottom temperature) reached was 131.99 °C

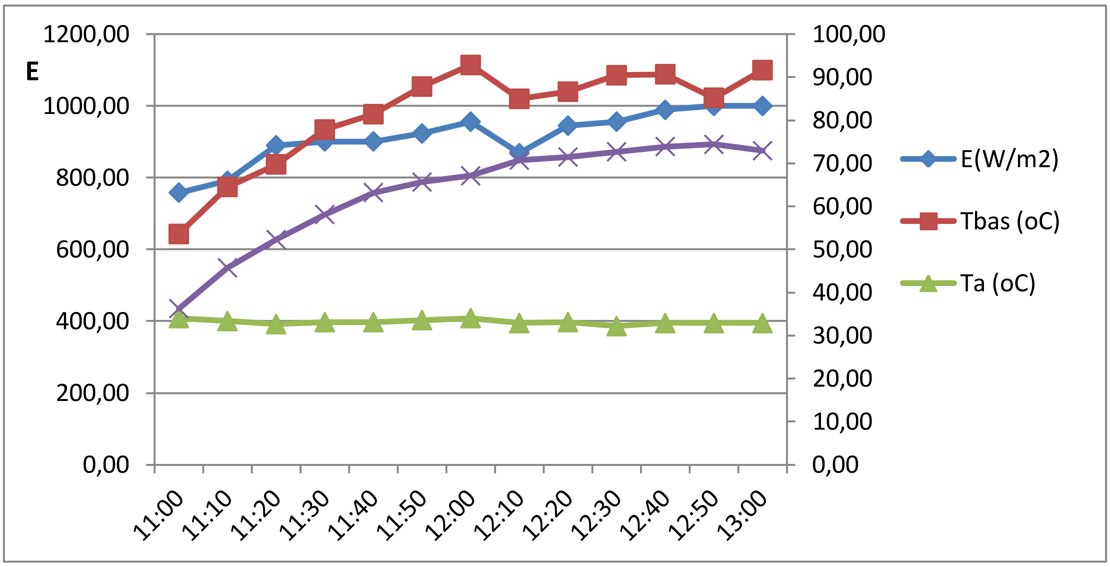


Figure 4. Temperatures and solar radiation evolutions for cooking without glass cubic box

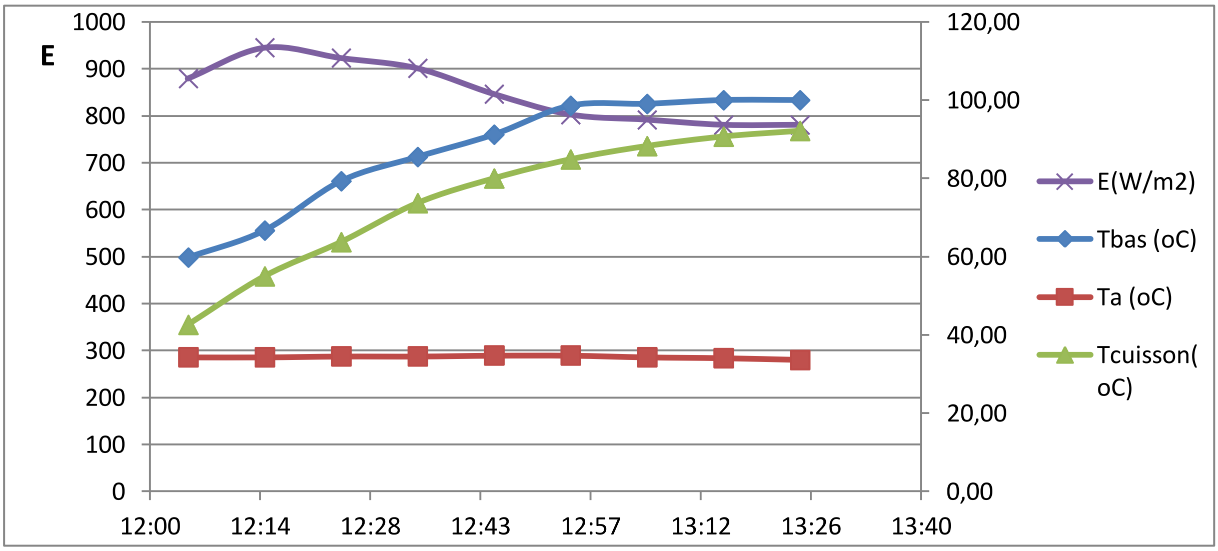


Figure 4. Temperatures and solar radiation evolutions for cooking with glass cubic box

3. CONCLUSION

A solar cooker has been designed with an ellipsoidal concentrator, by using one the two focal point of the ellipse. In a first step, the reflective surface was a galvanized steel sheet..In the experimental study, two configurations were tested: experimentation with and without glass cubic box. In the configuration with glass cubic box, six (6) eggs were completely cooked after 80 minutes of cooking. In the second step, the reflective surface was coated with mirror. In such configuration, 10 eggs were perfectly cooked after 40 minutes of cooking in 0.5 litre. 500 grams of rice were also cooked after 80 minutes of cooking, in 0.625 litre of water. The study showed that the ellipsoidal concentrator is efficient and well suitable for solar cooking.

REFERENCES

[1] Gnigbognima S,N'Cho P.. Forum Régioal sur l'initiative énnergie solaire de la CEDEAO. Présentation de la Côte d'Ivoire, 2010, 1-12

[2] Subbodh Kumar T, Kandpal C, Mullick S C. Heat Losses from A paraboloid Concentrator Solar Cooker. Experimental Investigations on Effect reflector Orientation. Renewable Energy, 1993 Vol 3 (8) , 871-876.

[3] Srinivasan M, Kulkarni LV, .Pasupathy CS A simple technique of fabrication of parabolic concentrators. Solar Energy 1978, Vol 22, 463-465.

[4] Gavisiddesha SP, Revenkar PP; Gorawar MB. Evaluation of Thermal Performance of Paraboloid Concentrator Solar Cooker. International Journal of Innovation Research in Technology & Science, 2013, Vol 1, Number 3, pp 58-65.

[5] El Ouederni AR., Dahmani AW, Askri F, Ben Salah M, Ben Nasrallah. Experimental study of a parabolic solar concentrator. Revue des énergies Renouvelables CICME 08 Sousse 193-199, 2008

[6] Khalifa AMA, Taha MA, Akyurt M. Solar Cookers for outdoor and indoors. Energy, 1985 Vol 10, Issue 7,819-829.

[7] Toure S, Sidibe M, Fasinou W, Gbane A, Salami H. A performance study of two solar cookers experimented in Abidjan (Ivory Coast).World Renewable Energy Congress VIII (WREC 2014), Denver, Colorado USA, August 29 – September 3, 2004.

[8] Sharaf E. A new design for an economical, highly efficient, conical solar cooker. Renewable Energy, . 2002, Vol 27, Issue 4,599-619.

[9] Toure S, Sidibe M. Design and evaluation of a conical solar cooker in glazed and non-glazed configurations: cooking tests. IOP Conference Series: Earth and Environmental Science 93 (2017) 012011 doi:10.1088/1755- 1315/93/1/012011

[10] Mehl S. Longueur de l'ellipse. www.chronomath.com, accessed on 2016. 09. 18

[11] Lassère P. Sur la longueur d'une courbe. Université Paul Sabatier. www.math-univ-toulouse.fr/lassere/pdf/longueurcourbe, accessed on 2016. 09. 18

[12] Solar Cookers International, www.solarcooking.org/francais/Plans-fr.pdf accessed on 2016. 12. 25

Siaka Touré, Modibo Sidibé

Comparative performance of two parabolic solar cookers: influence of a glass cubic box

Modibo Sidibe[1]*, Siaka Toure[1] and Idrissa Diomande[1]

[1]Solar Energy Laboratory, F.H.B. University of Abidjan, 22 BP 582 Abidjan 22 Côte d'Ivoire
E-mail: *Sidibmo20@gmail.com; siakaahtoure @yahoo.fr; idiomande13@yahoo.fr*

Abstract:

This work consists of experimentally comparing the performance of two parabolic solar cookers with the same opening diameter and the same galvanized sheet coating. The first cooker called CSP_1 and the second cooker CSP_2 have respectively the focus located below and above the plane of opening of the paraboloid. A first series of cooking tests was carried out with both prototypes. The overall loss coefficient obtained on each absorber was 13.64 W / m^2.°C for CSP_1 and 24.03 W / m^2.°C for CSP_2. This shows that energy losses by convection and radiation are high with CSP_2. The cooking was only perfect with CSP_1. In order to improve the performance of CSP_2, a glass cubic box around the pan was associated. Thus, a second series of cooking tests was carried out. The overall loss coefficient has been 14.98 W / m^2.°C with CSP_1 and 8.48 W / m^2.°C with CSP_2. This reflects the improved performance of CSP_2 by introducing the glass cubic box. Favorable temperatures for cooking food (rice and eggs) were obtained with the two parabolic solar cookers.

Keywords: Parabolic solar cooker, galvanized sheet, focus, glass cubic box, performance.

1-Introduction

In Côte d'Ivoire, like in most developing countries, wood energy is widely used for cooking. Its share in the overall satisfaction of energy needs is estimated at around 76% (in 2008) [1]. The domestic use of vegetation cover (firewood, charcoal, etc ...) and the extraction of wood fuel increases with population growth. This is one of the major causes of deforestation. The supply of wood and charcoal is also becoming more and more difficult and expensive. This is linked to a galloping desertification. To overcome these problems, one of the natural and easy alternative is obviously the use of solar energy. Côte d'Ivoire has an enormous solar potential characterized by a daily average radiation varying between 3 and 5 kWh / m² depending on the region and a sunshine duration of 6H [1]. This free, non-polluting energy can be converted into useful energy for cooking by collectors such as parabolic solar concentrators.

Many studies have been done on these solar cookers. Various configurations exist with respect to the paraboloid opening plane. We call CSP_1 and CSP_2 the respective configuration whose focal point is located below and above the paraboloid opening plan. Gavisiddesha et al [2] have designed and studied the performance of a CSP_1 type with a focal length of 0.30m and a depth of 0.40m. As for A. R. El Ouederni et al [3], they have constructed a type of CSP_2 with a focal length of 0.75 m and a depth of 0.4 m. Similarly I. Zeghib et al [4] built another CSP_2 type with focal length of 0.894 m and a depth of 0.080 m. The prototype built by I. Ladam Mohammed [5] has a focal length of 0.698 m and a depth of 0.29 m.

Our work consists firstly, to carry out an experimental comparative study of these two cookers CSP_1 and CSP_2 and then, to evaluate the effect of a glass cubic box on the performance of CSP_2.

2-Realization and description of the prototypes

Table 1 shows some characteristics of the two parabolic solar cookers designed in the Solar Energy Laboratory (L.E.S) of Felix Houphouët Boigny Cocody University, Abidjan. The reflective facets are galvanized steel sheet whose thickness is 0.8 mm.

Table 1: Characteristics of the two prototypes

Cooker	Opening diameter (m)	Focal length (m)	Depth of parabola (m)	Number of facets
CSP_1	1.2	0.18	0.5	18
CSP_2	1.2	1.0	0.09	6

Two experiments were carried out as shown in **Figure 1** where CSP_2 is without a glass cubic box and **Figure 2** where CSP_2 has a glass cubic box. Black painted receptors or pans are perched on a beam and held by a collar. In this position, the base of the pan is held at a distance from the focal point called the back axial distance L of the focal point as shown in **Figure 3**. Thus, the lateral face and the base of the pan are flooded by the reflected rays emanating from the paraboloid. The following relationship, allows the calculation of this back axial distance L:

$$d_2 = \frac{L \cdot d}{f - h} \quad (1)$$

Where d_2 is the diameter of the pan, f the focal length, h and d respectively the height and the opening diameter of the parabola. Each paraboloid is secured to a manual tracking system of the sun, which ensures its stability and the orientation of the opening according to the height of the sun. In order to limit the losses by convection and radiation on the absorber and create a greenhouse effect, a glass cubic box was introduced into CSP_2. It wraps up the focus and the pan of the cooker.

Figure 1: Experimental device where CSP_2 is without glass cubic box.

Figure 2: Experimental device where CSP_2 is provided with a glass cubic box.

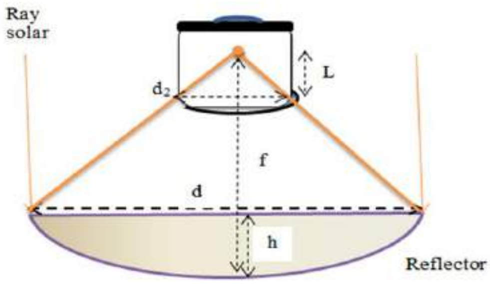


Figure 3: **Back axial distance L of the focal point**

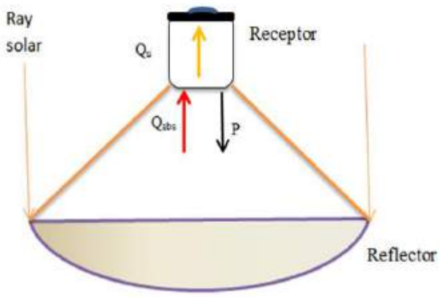


Figure 4 : Energy balance of the absorber.

The performance indicators that have been defined in this paper are the overall loss coefficient and the efficiency. For that, we have to evaluate the heat balance.

3- Thermal balance

3.1. Energy balance of the receiver without glass cubic box

If Q_u is the useful power received by the receiver, it is given by the difference between the absorbed power Q_{abs} and the losses P. The thermal balance on the absorber is shown in **Figure 4**.
Q_{abs} is expressed by [6]:

$$Q_{abs} = \eta_0 I_p C_g \rho \gamma A_{abs} \quad (2)$$

$\eta_0 = \alpha\tau$ is the optical efficiency,
α = Receiver absorption coefficient
τ = Transmission coefficient of the glazing (if any)
I_p = Direct irradiance of the radiation (W / m^2)
ρ = Reflection coefficient of the parabolic reflector
γ = Intercept coefficient expressed as [6]:

$$\gamma = 1 - \exp\left(-820\left(0.7 \cdot \frac{r}{f}\right)^2 (1 + \cos\phi)\right) \quad (3)$$

Where ϕ is the opening angle of the parabola in degrees.
r designating the exergy is governed by Eq.(4) [7]:

$$r = 1367 * \pi * \left(\frac{d}{2}\right)^2 * \left(1 - \frac{Ti}{T}\right) \quad (4)$$

With
Ti = Initial temperature of the pan (°C)
T = Final temperature of the pan (°C)
A_{abs} = Total surface receptor that is expressed by:

$$A_{abs} = \pi \cdot \frac{d_2^2}{4} + \pi \cdot d_2 \cdot h_{abs} \quad (5)$$

With:
d_2 = Receiver opening diameter
h_{abs} = Receiver height
Eq. (2) can be rewritten as follows:

$$Q_{abs} = A_{abs}.P_{abs} \quad (6)$$

With

$$P_{abs} = \eta_0 \cdot I_p \cdot C_g \cdot \rho \cdot \gamma \quad (7)$$

$$C_g = A_{op}/A_{bs} \quad (8)$$

C_g is the geometric concentration coefficient of the concentrator, with
A_{op} = Aperture area of the collector
Losses P are expressed by:

$$P = P_{cv} + P_r \quad (9)$$

P_{cv}, the loss by convection is written:

$$P_{cv} = h_{cv} \cdot A_{abs}.(T_{abs} - T_a) \quad (10)$$

Where h_{cv} is the coefficient of loss by convection.
P_r, the loss by radiation is written:

$$P_r = h_r \cdot A_{abs} \cdot (T_{abs} - T_c) \quad (11)$$

Where h_r is the coefficient of loss by radiation.
If we assume that the temperature of the sky T_c is (by approximation) equal to T_a the ambient temperature, we have:

$$P_r = h_r \cdot A_{abs} \cdot (T_{abs} - T_a) \quad (12)$$

Equation Eq. (9) becomes:

$$P = h_{cv} \cdot A_{abs} \cdot (T_{abs} - T_a) + h_r \cdot A_{abs} \cdot (T_{abs} - T_a) \quad (13)$$

The coefficient of loss by convection h_{cv} is given for the temperature ranges by the following expressions [8]:
$100\ °C < T_{abs} < 500\ °C$

$$h_{cv} = 7.5 + 4v \quad (0 < v < 4\ m/s) \quad (14)$$

or

$$h_{cv} = 7.3\ v^{0,80} \quad (4 < v < 40\ m/s) \tag{15}$$

With v the wind speed (m / s).
The speed at the site was estimated at 2.5 m / s, average value in the city of Abidjan [9].
The radiation loss coefficient is written:

$$h_r = \varepsilon \cdot \sigma \cdot (T_{abs}^2 + T_a^2)(T_{abs} + T_a) \tag{16}$$

Finally we can write:

$$P = A_{abs} \cdot (h_{cv} + h_r) \cdot (T_{abs} - T_a) \tag{17}$$

We deduce the useful power Q_u:

$$Q_u = Q_{abs} - P \tag{18}$$

$$Q_u = A_{abs} \cdot P_{abs} - A_{abs} \cdot (h_{cv} + h_r)(T_{abs} - T_a) \tag{19}$$

$$Q_u = A_{abs}(P_{abs} - (h_{cv} + h_r)(T_{abs} - T_a)) \tag{20}$$

3.2. **Energy balance of the receiver with glass cubic box**

The powers absorbed and useful are determined respectively from the eq. (2) and eq. (18).
The cubic glass enclosure envelops the absorber of the solar parabolic cooker. The greenhouse effect is then generated. In this case the coefficients by radiation and convection appear inside and outside of the glass cubic box.

• **Inside the glass**: - the coefficient of exchange by radiation between the absorber and the glass is written [8]:

$$h'_r = \varepsilon_{av}\sigma(T_{abs}^2 + T_v^2)(T_{abs} + T_v) \tag{21}$$

Where:
ε_{av} = Absorber - glass emissivity. It is governed by the relation [8]:

$$\varepsilon_{av} = \frac{1}{\frac{1}{\varepsilon_a} + \frac{1}{\varepsilon_v} - 1} \tag{22}$$

With ε_a and ε_v respectively emissivity of the absorber and the glass.
The coefficient of exchange by natural convection inside the glass cubic box (absorber- glass) is given by the correlation eq. (23) [8]:

$$h'_{cv} = 1.1 * (T_{abs} - T_v)^{1/4} \tag{23}$$

T_v= Temperature of the glass we assume uniform.

- **outside the glass:** - the coefficient of exchange by radiation between the glass and the sky is written:

$$h''_r = \varepsilon_v\sigma(T_v^2 + T_c^2)(T_v + T_c) \tag{24}$$

The coefficient of exchange by convection between the glass and the ambient is given by the correlation (14).
The resulting coefficient of exchange is given by the following expression [8]:

$$h_{rc} = \frac{1}{\frac{1}{h'_{cv} + h'_r} + \frac{1}{h''_{cv} + h''_r}} \tag{25}$$

Therefore, the global efficiency and internal efficiency of the collector are given by the following relations:

$$\eta_g = \frac{Q_u}{Q_d} \quad (26)$$

Where $Q_d = I_p C_g \rho A_{abs}$

$$\eta_i = \frac{Q_u}{Q_{abs}} \quad (27)$$

We indicate that the direct component of solar radiation was obtained from a mathematical model which was studied and compatible with our experimental site [10].

4- Discussion and analysis of experimental results

During the cooking tests, measured variables were the overall irradiance using a pyranometer and temperatures (of the cooking, the ambient air, the bottom of the pan and also the inside and outside of the glass cubic box) using platinum resistance thermometers. The maximum duration of cooking for the two foods (eggs and rice) was 2 hours, in accordance with "Solar cookers international" [11]. Simple solar cookers used in the normal conditions, reach temperatures ranging from 82 ° C to 121 ° C or even more. Then the food start to cook between 82 ° C and 91 ° C, which is adequate but not enough to burn or lose their nutrients. The tests were carried out on the roof of the solar energy laboratory building in Abidjan (Côte d'Ivoire).

• **Test carried out without glass cubic box**, on 14/03/2017: This test concerned the cooking of 04 eggs in 0.5 L of water. **Figure 5** shows the evolution curves of the irradiance and cooking and ambient air temperatures versus time for CSP_1 and CSP_2.

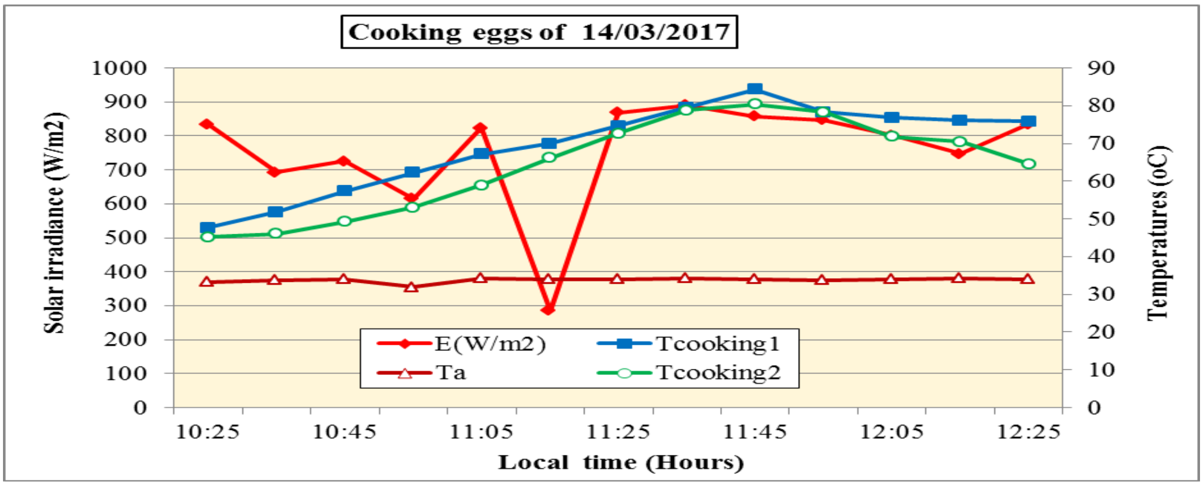


Figure 5: Evolution curves of irradiance and temperatures versus time.

In **Figure 5**, E is the solar irradiance, Tcooking is ths cooking temperature (^{o}C) and Ta is the ambient temperature (^{o}C).

In **Table 2**, are consigned the results of cooking test for 04 eggs in 0.5 L of water carried for CSP_1 and CSP_2 without glass cubic box.

Table 2: Results of the test performed on the 14/03/2017

	Direct Average irradiance (W/m^2)	Duration cooking	Max (Tcooking) (^oC)	Overall loss coefficient ($W/m^2.^oC$)	Overall efficiency %	Cooking state of eggs
CSP_1	755.71	10:25 - 12:25	**84.3** at 11:15	13.64	74.34	Total
CSP_2			**80.4** at 11:15	24.03	71.46	partiel

In that configuration, CSP_1 has a higher performance than CSP_2. Therefore we introduced a glass cubic box, with dimensions 0.35 m x 0.35 m x 0.35 m in CSP_2.

- **Tests carried out with glass cubic box on CSP_2 and no glass box on CSP_1**

These tests involved the cooking of 05 eggs in 0.5 L of water for the days of April 15th and 16th, 2017 and the day of April 17th, 2017 for cooking of fat rice with 03 eggs in each pan. The results are shown in **Table 3**.

Table 3: Results of tests carried out with glass cubic box on CSP_2

	Day	Direct Average irradiance (W/m^2)	Duration cooking	Max (Tcooking) (^oC)	Overall loss coefficient ($W/m^2.^oC$)	Overall efficiency %	Cooking state of eggs and rice
CSP_1	15/03/17	648.66	10:20-12:20	**87.0** at 12:20	**14.11**	72.23	Total
CSP_2				**100.0** at 11:10	**8.11**	75.31	
CSP_1	16/03/17	957.11	12:25-13:25	**87.0** at 13:25	**13.59**	75.58	
CSP_2				**100.0** at 13:15	**7.98**	77.27	
CSP_1	17/03/17	900.38	11:35-13:35	**98.4** at 13:05	**14.98**	72.53	
CSP_2				**100.6** at12:35	**8.48**	75.67	

In **Figures 6**, **7** and **8** are shown the evolution curves of temperature and irradiance versus time.

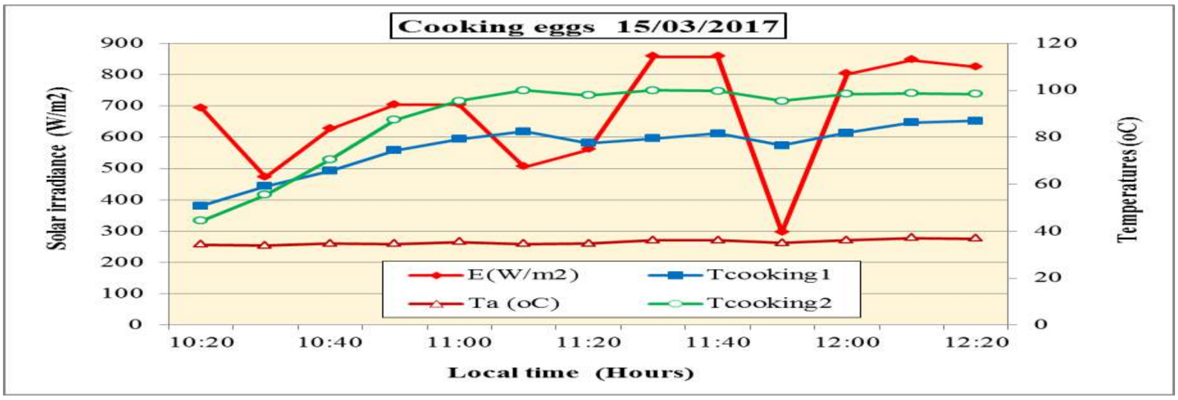


Figure 6: Evolution curves of irradiance and temperatures versus time.

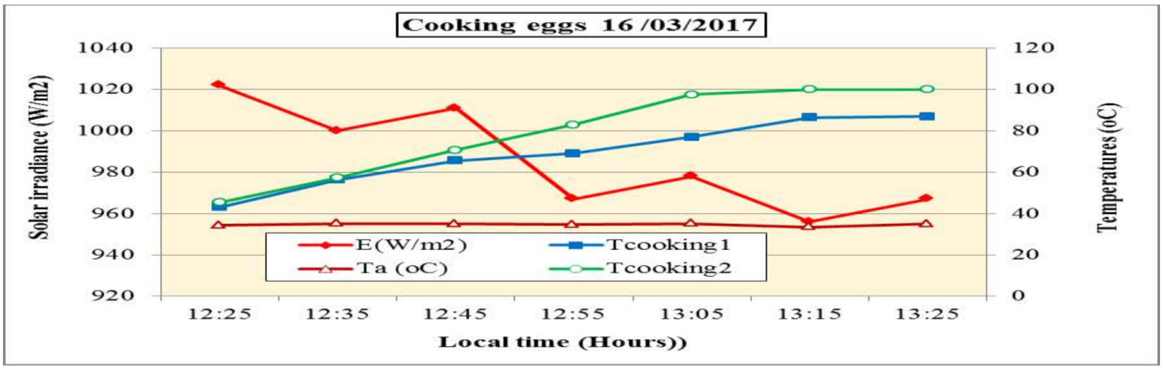


Figure 7: Evolution curves of irradiance and temperatures versus time.

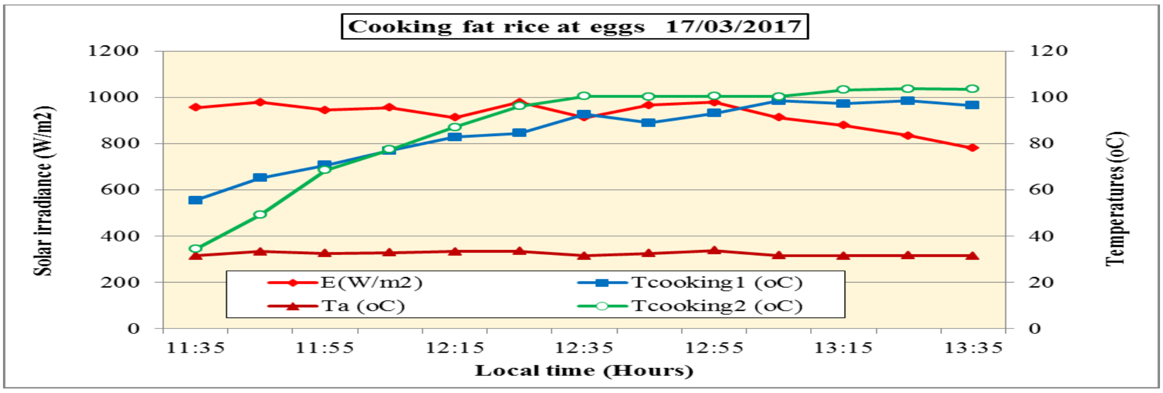


Figure 8: Evolution curves of irradiance and temperatures versus time.

The results of the tests carried out when CSP_2 has a glass cubic box show well the improvement to its performance. The eggs were completely cooked during the days of March 15th and 16th 2017. On the day of March 17th 2017, **Figures 9** and **10** demonstrate the perfect cooking state of fat rice at eggs and the formation of more cheese topping in the pan of CSP_2 than on that of CSP_1. The Cooking of fat rice at eggs was total.

Figure 9 : A) Cooking state in CSP1 (B) and Cooking state in CSP2

Figure 10: Cheese topping formed during cooking with (A) CSP1 and (B) CSP2.

5- Conclusion: In the climatic conditions of Abidjan, cooking with our parbolic solar cookers are attainable. Furthermore, the results obtained show that the introduction of the glass cubic box reduces the losses on the absorber and considerably improves the performance of the parabolic solar cooker.

Reference

[1] S. Gnigbognima, P. N'cho (2010). '*'Forum Régional sur l'initiative énergie solaire de la CDEAO, Présentation de la Côte d'Ivoire*''. 1-13.

[2] Gavisiddesha, P P Revankar, M B Gorawar,(2013) ''*Evaluation of Thermal Performance of Paraboloid Concentrator Solar Cooker''*, International Journal of Innovation Research in Technology & Science , Volume 1,Number 3, pp 58-65.

[3] A. R. El Ouederni, A.W. Dahmani, F. Askri, M. Ben Salah and S. Ben Nasrallah, 2008, '*'Experimental study of a parabolic solar concentrator*'', Revue des Energies renouvelables CICME08 Sousse, 193- 199.

[4] I. Zeghib, R. Chenni and T. Kerbache (2007), *Design and Construction of a Thermal Collector of High Temperature*, Journal of Engineering and Applied Sciences 2(12), 1827-1833.

[5] Ibrahim Ladan Mohammed, (2013), *Design and development of a parabolic Dish Solar Thermal Cooker*, International Journal of Engineering Research and Applications, vol. 3, pp1179 -1186.

[6] M. Ouannene, B. Chaouachi, S. Gabsi, (2009) Design and Realisation of a paranbolic solar cooker, Int. Symp. On convective heat and mass transfer in Suistainable Energy, April 26- May 1, 2009, Tunisia.

[7] Truls Gundersen, An Introduction to the concept of exergy and energy quality, Department of energy and Process Engineering Norwedian University of Science and Technology Trondheim, Norway, version 3, November 2009, PP1-25.

[8] Desautel J., Les capteurs Héliothermiques, EDISUD, La Calade- 12100 Aix- en- Provence, PYC-EDITION, 1979.

[9] Moyennes météo par mois en Côte d'Ivoire en 2017, http://www.historique-meteo.net /Afrique/cote-d-ivoire/2017/#65qmuYM5UbMdDT8t.99. *(consulté le 14 février 2017).*

[10] Sidibé M., Soro, D., Fassinou, W.F., and Touré , S., *Reconstitution of Solar Radiation on a Site of the Littoral in Côte D'ivoire*, International Journal of Engineering Research and Technology. ISSN 0974-3154, (2017), Volume 10, Number 1, pp. 19-34.

[11] Solar Cookers International, www.solarcooking.org/francais/Plans-fr.pdf (*consulté le 25 Décembre 2016*).

The SUNTASTE, a new cork based solar box cooker

Ailton Tavares[1*], Afonso Cavaco[1,2], Manuel Collares-Pereira[1] and Nuno Oliveira Martins[3]

1: Renewable Energies Chair, University of Évora, IIFA, Largo Marquês de Marialva, 7002-554, Évora, Portugal.

e-mail: {acmt, collarespereira} @uevora.pt, web: http://www.en.catedraer.uevora.pt/

2: Portuguese Solar Energy Institute, IPES, Largo Marquês de Marialva, 7002-554, Évora, Portugal.

e-mail: afonso.cavaco@ipes.pt, web: http://www.ipes.pt

3: *SunOk, LDA, Campo de Ourique, Lisboa, Portugal.*

e-mail: nom@sunok.eu, web: http://www.sunok.eu/

Abstract: *Following the experience with the SUNCOOK [1], a plastic based box type solar cooker incorporating non imaging optics as a way to produce a certain degree of solar energy concentration (a factor of 2.0 X concentration on average) while retaining it stationary for full operation for periods as large as 3 hours, the idea came for developing a new cooker, the SUNTASTE [2], with an improved geometrical configuration and ease of operation (stationarity), this time based on a natural material: cork. The choice of cork offers the possibility of having it both as the structural element for the whole box, and at the same time taking advantage of the fact that it is highly insulating.*

Two versions of the SUNTASTE with different sizes but essentially with the same optics, were produced and tested according to the method defined in [3,4]. The tests of both versions were carried out in several consecutive high DNI days and also included a SUNCOOK for the sake of a direct comparison. The paper provides a brief description of the new cooker and presents the testing results of the two prototypes of each size produced. It can be reported that preliminary measurements show that is fair to expect for the new product, a performance in many regards comparable to that of the SUNCOOK.

Keywords: Solar Cooking Performance, Solar Cookers.

1. INTRODUCTION

Solar box cookers have known a continuous development since they were proposed [5] as early as in the sixties of the previous century. Simple box designs, with cooking plates at the bottom, augmenting mirrors placed in cover lids, side mirrors to enhance stationarity under operation or to providing extra solar irradiance concentration, have been proposed and tested. Tilted covers have also been a fixture of some of the models proposed and many of these cookers have been used all over the World, either as products to be purchased on the market or produced by their users directly, built according to plans provided by solar cooking promoters, individuals and organizations [5,6].

One cooker has been particularly successful, incorporating inside the box, non-imaging optic concentrators [7], thus enhancing its thermal and optical performance [1]. This solar cooker was a truly industrial product, fabricated in plastic (different kinds of plastic, pending on temperature and their location within the cooker) with a substantial input from the Portuguese plastics and plastic molds industry [8,9].

The use of plastic is certainly interesting from the point of view of product manufacturing and quality assurance, but also from the point of view of potential low cost, quite beyond those already achieved (under development). However, and in the meantime, new directions are being explored and one of them is the basis of the efforts reported in this paper.

The idea is to use another abundant material, cork as the main material in the cooker. Cork is a natural material with excellent thermal properties, a natural insulator (k= 0,045 W/mK) and at the same time strong enough to be, by itself, the structural material of the cooker. It is easy to form/machine to the necessary shape, and, thus it is an excellent base for solar cooker production. There is also top manufacturing experience of cork products in Portugal, quite besides the fact that Portugal is the primary World producer of cork.

This paper describes briefly such a cooker, the SUNTASTE, presently produced in two models (Compact and Large). It then presents results of measurements made during the fall of 2017. Because, during the fall, the sun has already a low altitude in the sky at the latitude at which the cooker was tested, it was thought interesting to compare it with the SUNCOOK, referred above, to give a measure of its highest available performance at other times of the year. The paper ends with some brief conclusions.

2. SUNTASTE DESCRIPTION

A photograph of the cooker can be seen in Fig.1, showing the two versions (Compact and Large) side by side. As can be seen, cork is used for the side walls, front and back wall. The lid is manufactured in aluminum. The cooker has a double glass cover with the bottom glass slid into place and the top glass glued to the cork. The cover is tilted to an angle of 17º chosen to minimize condensation accumulation on the bottom glass surface (condensed water will slide down truly minimizing negative effects of the cover on transparency).

The cooking plate is a black anodized aluminum (2,5 mm thick) plate, laying at the bottom, which can be removed for cleaning. Dimensions of both cookers can be seen in Table 1.

Table 1- Dimensions of SUNTASTE COMPACT and SUNTASTE LARGE.

SUNTASTE	External dimensions (cm)	Plate area (cm)	Cover area (cm)
COMPACT	52×43×32	36×30	44×36
LARGE	66×43×32	50×30	58×36

The rectangular shape was chosen to reduce the effects of longitudinal (E-W) losses of incoming solar irradiance and its dimensions were chosen as a function of practical considerations [2] of the manufacturer, production and commercial ones, related, for instance to the number and size of pots and pans that are provided or recommended to be used with the SUNTASTE.

The choice made in terms of geometry and dimensions correspond to an average concentration value (A_n/A_p) of approximately 2X.

Figure 1 - The SUNTASTE, (COMPACT and LARGE) front and back view.

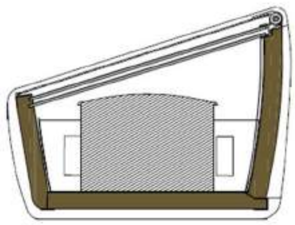


Figure 2 - cross section on transversal plane of the SUNTASTE.

Acceptance angles of the SUNTASTE (COMPACT and LARGE) and hours of stationarity provided, can be seen in table 2. Cork thickness for bottom and side walls can be seen in table 3.

Table 2 - Acceptance angles of the CPC walls and hours of stationarity provided.

Element	Acceptance angle θ_a (deg)	Stationarity time (h)
Front CPC	59.8	4.0
Side CPC	48.6	3.2

Table 3 - Wall thickness.

SUNTASTE	Thickness bottom walls (cm)	Thickness side walls (cm)
COMPACT	2.5	3.1
LARGE	2.5	3.1

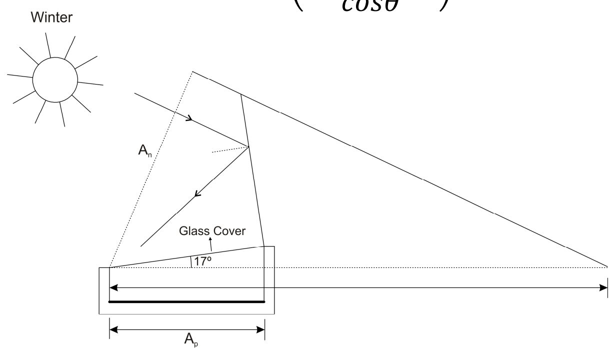
3. MEASUREMENTS AND RESULTS

The two SUNTASTES were tested side by side with the SUNCOOK [1]. The idea for doing so came from the fact that this cooker was well characterized then and the comparison made here, will allow for extrapolations of results to be expected at other times of the year. This procedure highlights once more the need for universally accepted standards, which will facilitate cookers comparison in the future. In any case two Figures of Merit F_1 and F_2 discussed in [4] are calculated and one result is derived from them, time from ambient to boiling, is presented. F_1 is given by

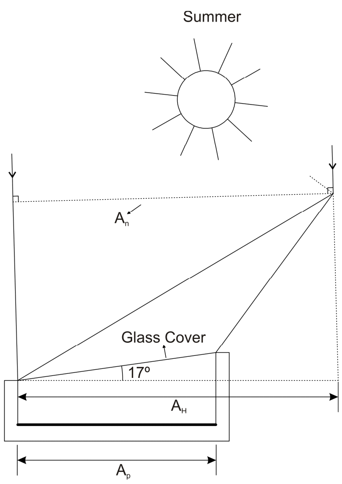
$$F_1 = \frac{\eta'_0}{U_L} = \frac{A_p}{A'} \frac{\left(T_{ps} - T_{as}\right)}{I_{hs}} \quad (1)$$

$$A' = \left[A_c \times \frac{\cos(\theta - \delta)}{cos\theta} + \left(\frac{A_n}{cos\theta} - A_c \times \frac{\cos(\theta - \delta)}{cos\theta}\right) \times \rho\right] \quad (2)$$

$$A_n = A_H \times \cos\theta \times \left(\frac{\cos(\theta - \delta)}{cos\theta}\right) \quad (3)$$



(a)



(b)

Figure 3 - Solar cooker: (a) – Tested in winter; (b) – Tested in summer.

And F_2 by

$$F_2 = \eta'_0 \times C_r = F_1 \times \frac{(MC)_w}{A' \times \tau} \times \ln\left[\frac{\left(1 - A_p \times \left(\frac{T_{w1} - T_a}{A' \times F_1 \times I_h}\right)\right)}{\left(1 - A_p \times \left(\frac{T_{w2} - T_a}{A' \times F_1 \times I_h}\right)\right)}\right] \quad (4)$$

Time to boiling is calculated according to

$$\tau_0 = -\frac{F_1}{F_2} \times \frac{(MC)_w}{A'} \times \ln\left[1 - \frac{A_p \times (99.2^1 - T_a)}{A' \times F_1 \times I_h}\right] \quad (5)$$

Where, η_0 is the optical efficiency, U_L the heat loss factor, T_{ps} the plate temperature at stagnation, T_{air} the ambient temperature at stagnation, A_p plate area, I_{hs} irradiance on horizontal plane at stagnation, A_c is the cover area, A_n normal area to incoming beam irradiation, Θ the zenith angle, δ the mirror tilt, ρ the mirror reflectivity, A_H projected area by the lid on the horizontal plane (see Figure 3), $(MC)_w$ is the product between mass of water and its specific heat capacity, τ time between T_{w1} and T_{w2}, T_{w1} initial water temperature value (40ºC), T_{w2} final water temperature value (80ºC), T_a average ambient temperature and I_h average insolation on a horizontal plane between T_{w1} and T_{w2}.

With A_n =0,244 m^2, A'= 0,458 m^2 for SUNTASTE COMPACT and A_n=0,318 m^2, A'= 0,597 m^2 for LARGE, the results are as follows. $(MC)_W$ was calculated according to $(MC)_{WCOMPACT}$ = 1.463[2]kg×4186 J/kg.K and to $(MC)_{WLARGE}$ = 1.911kg×4186 J/kg.K.

Table 4 - Figure of merit F_1.

SUNTASTE	F_1 (m^2K/W)
COMPACT	0,054
LARGE	0,052

Fig. 4 shows the rise in plate temperature and Fig. 5 shows the water temperature. Testing was carried out in the middle of November, during high DNI days.

Analyzing Fig. 4, it can be seen that, the plate stagnation temperature is 131ºC and 137 ºC for COMPACT and LARGE SUNTASTE, respectively. It is to be noted that during the tests in plate stagnation temperature the sun was very low in the sky (Θ = 57.48º).

[1] Boiling water temperature at the place where the tests carried out [10].
[2] According to [11], the water mass M obtained considering 6 kg/m^2 of A_n.

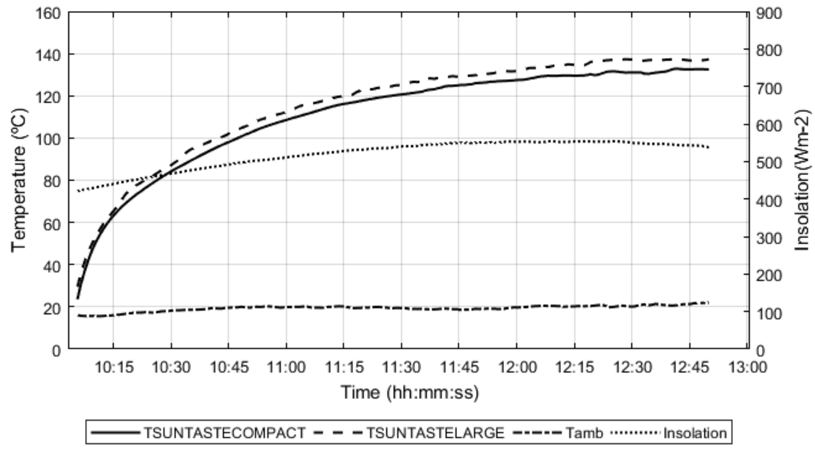


Figure 4 - Rise in plate temperature with tracking every 15min (November 15th).

Table 5 – Figure of merit F_2 and boiling time of water for the testing day.

SUNTASTE	F_2	τ_0 (min)
COMPACT	0,096	129
LARGE	0,092	157

According to the measurements (Fig. 5), the time for water to go from ambient temperature to boiling are 145 and 177 minutes for SUNTASTE COMPACT and LARGE, respectively. These values are not so distant from τ_0 presented in table 5, but they are not quite the same because during the test initial water temperatures in both SUNTASTE were higher than ambient temperature. As in the test quoted earlier, the sun was very low in the sky (Θ = 58.67º), thus the incoming irradiance was close to the minimum in a sunny in our latitude.

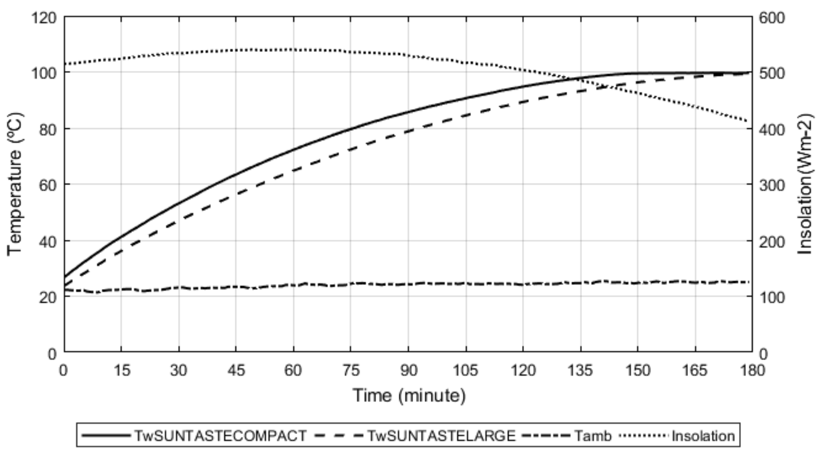


Figure 5 - Rise in water temperature with tracking every 15min (November 16th).

4. CONCLUSIONS

The test of solar box cookers is an extreme important issue, since it allows to evaluate their performance, as well as to relate cost/benefit between different alternative, according to the needs of the users.

The use of non-imaging optics enables higher temperatures and, in turn, higher performance. It does not require sophisticated solar tracking, so SUNTASTE can be used without user intervention.

Although the tests were carried out in November, it can be seen that the SUNTASTE solar cookers reached still high stagnation absorber/plate temperature and are close to SUNCOOK stagnation plate temperature. Regarding tests with water, the time the water takes to go from ambient temperature to the local boiling temperature (99.2 ºC) is over two hours, 146 minutes and 177 minutes, for SUNTASTE COMPACT and LARGER, respectively.

It was clearly confirmed that the tilted glass cover on the SUNTASTE greatly reduces the condensation formation on the interior side of the cover, providing better transparency of the cover and thus transmission of incoming sunlight.

5. REFERENCES

[1] Collares Pereira M, Almeida JP, Oliveira JC. Description and testing of a novel solar box type cooker incorporating CPC type optics. ISES Solar World Congress, Goteborg, Sweden, 2003.

[2] Suntaste Specifications, SunOK, LDA. http://www.sunok.eu/home/products/suntaste/details, accessed on 2017.12.07.

[3] BIS – Bureau of Indian Standards- second revision of IS, 13429 (part 1) – Solar Cooker-Box type- specification, Part 1-Requirements.

[4] Collares Pereira M, Cavaco A, Tavares A. Figures of merit and their relevance in the context of a standard testing and performance comparison methods for solar box- cookers, Submitted to Solar Energy, on December 08th, 2017.

[5] M. Telkes. Solar Cooking Ovens, Solar Energy, 1959, 3: 1-11.

[6] Solar Cooker International, http://www.solarcookers.org/index.php, accessed on 2017.12.07.

[7] Roland Winston. Nonimaging Optics, Academic Press, 2004.

[8] SUNCOOK, http://www.sunok.eu/home/products/sun-cook, accessed on 2017.12.07.

[9] IBEROMOLDES, http://www.iberomoldes.pt/, accessed on 2017.12.07.

[10] Boiling point of water and altitude, https://www.engineeringtoolbox.com/boiling-points-water-altitude-d_1344.html, accessed on 2017.12.07.

[11] De Castell ME, Pastrana AF, Collares Pereira M, Vázquez L, Esteves A. Propuesta de procedimiento para la evaluación del comportamiento térmico de cocinas y hornos solares, Averma vol. 3,133-5, 1999.

SOLAR OWENS BUILT WITH VERY BASIC MATERIALS FOUND IN RURAL AREAS

Margarita Mediavilla

Grupo de Energía Economía y Dinámica de Sistemas,
Escuela de Ingenierías Industriales,
Universidad de Valladolid
Francisco Mendizábal 1, 47014 Valladolid, Spain
e-mail: marga@eii.uva.es
http://www.eii.uva.es/energiasostenible

Abstract:

One of the important factors of solar cookers design is finding prototypes that can be built by the same people who will use them, this way the users can understand and repair them. This is important because solar cookers are especially useful for people with very low incomes. In the case of Sahel's rural areas relatively common materials such as wooden planks, screws, brackets or aluminum sheets can be too expensive. Even cutting wood by following straight lines, getting carton boxes, finding insulators like rock wool or reflectors like aluminum foil can be difficult.

That is why three prototypes of solar ovens have been developed trying to use as few industrial materials and tools as possible. We decided to construct ovens without reflection since the construction of reflectors requires flat surfaces and this can be problematic if adequate materials are not available.

The result has been three ovens that use a structure of wood (in two of them just sticks without metallic elements of union) and paper glued with white glue or flour glue. A mud and paper adobe is used in the interior areas to withstand indoor temperatures. The insulator used is paper. The only industrial materials that could not be replaced are the glass and the wood panels that get the door closed (the latter has been tried with mediocre results).

The resultant ovens get temperatures that exceed 100 degrees in temperate latitudes (central Spain) without the use of reflectors, which is comparable to other prototypes constructed with more sophisticated materials. The construction with this type of materials is simple and does not require special skills or tools, although it is laborious and requires patience.

Keywords: solar owen, low cost, low complexity, self-construction, rural areas.

ANALYSIS OF SOLAR COOKING IN RELATION TO FOOD SOVEREIGNTY

Bailey Jannika[1*]; Quiroga V. Noelia[1] ; Raimondo Emilia[2]; Esteves Alfredo[1]

[1]Instituto de Ambiente, Hábitat y Energía (INAHE), CCT CONICET Mendoza
e-mail: jbailey@conicet-mendoza.gob.ar, web: http://www.mendoza-conicet.gob.ar/portal/inahe/

[2]Facultad de Ciencias de la Nutrición, Universidad Juan Agustín Maza, Mendoza
email: emiliaraimondo@gmail.com

Abstract: *The use of fire by Homo Erectus was a transformative step in the history of man's relationship with food; cooking food not only meant easier digestion but the incorporation of previously indigestible foods into the diet; and as well as improving the appearance, taste and storage life of food, the parasites it contained were eliminated. Consequently, and thanks mainly to the discovery of cooking, human beings today are capable of metabolizing a great variety of nutrients in a vast array of foods. A great number of rural and urban communities in developing countries have limited access to fuel. When access is available it mainly consists of firewood gathered by members of a family; in itself a time consuming activity. Bottled gas is an alternative energy source although its high cost makes it impractical and inaccessible to the majority. In principle, food sovereignty encompasses all means of access to food, both physical and economical, however it doesn't take into account the source of energy for cooking and it is the latter that governs the person's dietary intake and level of nutrition and determines whether or not the person is vulnerable to food insecurity. This analysis will examine food security in relation to the accessibility of energy sources; how at present this constitutes a conditioning factor in good nutritional practises and what role energy sources play in modifying food and ultimately in the development of human beings. It is only through anthropological analysis that the importance of the general population's access to food and the influence of solar cooking becomes apparent. Given the original transcendence of fire and subsequent sources of cooking fuel, the concept of caloric energy could be considered the next step in the evolution of food preparation for human beings.*

Keywords: solar oven, solar cooker, solar energy.

LAZOLA SOLAR BOX COOKERS
A UNIQUE MANUFACTURING CONCEPT

Lazola-Initiative zur Verbreitung solaren Kochens e.V.
(Lazola Initiative for spreading solar Cooking)

Glesekerstraße 13, D-33098 Paderborn - **www.lazola.de**
Jo Hasler, info@lazola.de, **Christian Fenner**, c-fenner@gmx.de
Michael Bonke, optimist@optimist.com

Abstract: Over the years the Lazola initiative has developed, tested and continually improved various models of metal solar box cookers suitable for serial production in developing countries.

- The cookers are very robust, durable, easy to use and powerful. They come in two sizes.
- They consist of materials that are mostly available locally.
- All production steps can be learned also by non-experts by means of a **video tutorial**: Each step is explained in a short video clip and further explained in writing. Video clips and explanations can be used together on a tablet at the workplace.
- Cookers are produced by hand in the region where they are to be used. This includes after sales services.
- Only few machines are required for production (sheet metal shears, bending bench, circular saw and drilling machine)

Further aspects of the Lazola production concept:

- A great number of simple jigs are used to perform most production steps, making tasks a lot easier and ensuring accurate results. Measuring and marking is largely unnecessary.
- The jigs were developed by the Lazola initiative specifically for the LAZOLA production; They can be obtained from the Lazola Initiative.
- By using the jigs, all working steps are standardized and ensure exact working results.
- The entire production concept is designed for a small-batch production. This saves time and makes the results more accurate.
- The production does not require qualified workers. All construction processes can be learned by skilled, technically interested persons without preceding technical training
- Many skills conveyed in the video can be usefully applied in other fields of work. Therefore, many a knack shown is of particular use in technical training.

The Lazola Initiative presumes that, due to the dramatically increasing scarcity and the prohibitive price of fossil fuels, efficient box cookers will be required in large quantities in the near future.

The Lazola Initiative supports NGOs and private initiatives with know-how in the implementation of LAZOLA production projects in developing countries; but it does not carry out any projects itself. However, it arranges experts for the performance of on-site training Workshops and offers training workshops in Germany.
The Lazola Initiative offers all information free of charge - like the sun - accessible to everyone. We hope that our very solid and practical support may give many an impulse to make good solar cookers.

Keywords: Box Cooker , Construction Video , Local production , Adapted technology

EFFICIENCY OF A COMPOUND PARABOLIC CONCENTRATOR KITCHEN IN IZTAPALAPA, MEXICO CITY.

E. Barrera Calva[1] , Verónica Frías [1], E. Antaño Díaz[1], E. Rincón Mejía [2], J. Hernández [3]

1: Process engineering and hydraulics. Basic Sciences and Engineering.
Autonomous Metropolitan University, San Rafael Atlixco Avenue 186 Leyes de Reforma first section zip code 09340 Mexico City.
veronicafriasenergia@gmail.com, http://ixil.izt.uam.mx/pema/index.php/dr-enrique-barrera-calva/

2: Autonomous University of Mexico City, San Lorenzo 290, corner Roberto Gayol, Del Valle Sur,Mexico City, Zip Code 03100.
rinconsolar@hotmail.com, https://www.researchgate.net/profile/Eduardo_Rincon-Mejia2
3: Solar Module, Sea of the Nectar Apple 116 Lot 5 Z.C. 13460 juanamariajarquin@hotmail.com

Abstract: A concentrated solar-powered parabolic concentrator stove is built, a thermal analysis is carried out, the temperature profiles are obtained at daytime and its thermal performance to demonstrate its mitigating capacity and the benefits that are obtained from being implemented at the city level, such as at the national level. Taking into account the high concentrations of pollutants that exist in the air in a city as populated as Mexico City (8.918 million inhabitants) and the health problems that are there, it is necessary to attack the problem. A very good strategy to breathe a cleaner air in cooking food that uses solar energy. An effective surface kitchen of 0.791 m^2 is built, with Stainless Steel Absorber, surface of Polished Steel, covered with clear glass and as insulating polyurethane foam. (see image 1).

Image 1. CPC kitchen.

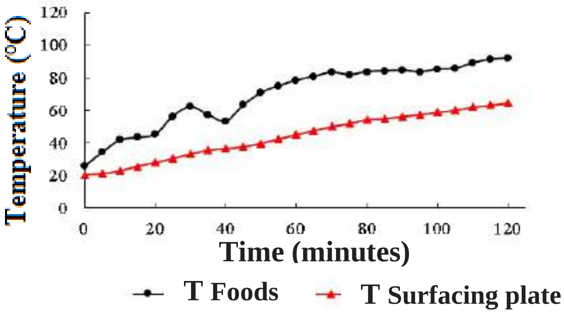


Image 2. Thermal profile

By placing it in the sun with food on August 18 in Mexico City, with a level of insolation of the order of 18 MJ / m^2, a thermal profile can be seen, see figure 2, which leads to a thermal efficiency of the order of 17.88%. Assuming that the solar cooker is used in a day at least 3 hours in the home, the heat used is 1.96 MJ, which represents the energy displaced by fossil fuels, which represents savings in one day. Taking into account its useful life of 15 years, the energy saving could reach 10.71 GJ unitarily. The scope and impact that this solar technology could have is the reduction of 1.43 MtCO2 nationwide.

Keywords: Thermal, Solar, Thermal profile, mitigating capacity, thermal efficiency.

CONSTRUCTION AND EVALUATION OF A SOLAR THERMAL-WIND HYBRID DRYER FOR FOOD PROCESSING IN CHIAPAS, MX

J.M. Hernández-Jarquin[1], J.E Conde Diaz[2], G. Pavón Gomez[2], E.A Mojica Castillo[2], R. Iglesias Diaz[2], J. Pantoja Enriquez[2], Kinarkumar Rajesh. Patel[3]

1: KIN Energías Renovables, Calle Sagitario Mz. 6 Lt.5, Tuxtla Gtz, C.P 29018, Chiapas, México, juanamariajarquin@hotmail.com, +521 961 195 8866 – Red Mujeres en Energías Renovables y Eficiencia Energética (REDMEREE)

2: Centro de Investigación y Desarrollo Tecnológico en Energías Renovables (CIDTER), Universidad de Ciencias y Artes de Chiapas. Col. Lajas Maciel 1150, Tuxtla Gutiérrez, C.P. 29039, Chiapas, México. www.unicach.mx

3: Institute of Technology, Nirma University, Ahmedabad, Gujarat 382481, India, 15mmen03@nirmauni.ac.in, web: http://www.nirmauni.ac.in

Abstract: Solar dryers are a solution for solar food processing and some of these devices are designed to dry just with the heat of the sun during the day reducing the period of drying. To increase the quality of solar food, it is required to maintain the most important operation parameter - the temperature. As a solution of the sun intermittency and to maintain a constant temperature, an auxiliary system is required to backup the main system. We propose a solar thermal system as the main resource in the drying process and electrical heat back up powered by a wind system. The first subsystem is solar thermal heating; it is composed of 2 solar vacuum tube collectors consisting of 30 heat pipes, a thermal storage tank, a heat exchanger, 2 fans and a water circulation pump. The second consisting of a wind turbine, a voltage regulator, a battery bank and an inverter and 2 heat resistances, thus keeping 24-hour stable working conditions; which work as follows:

Collector capture solar radiation for heating a fluid which is stored in a thermal storage tank. This heat in the fluid is transferred to the drying chamber through the heat exchanger, while the energy generated by the wind turbine is used for the operation of the fans and pump for the circulation system of air and water. A control system also provides a portion of the thermal energy to the drying chamber with the dissipation of heat with electric resistances. The evaluation of solar dryer was conducted in no load condition without backup and with backup while controlling the temperature at (40, 50, 60 and 70) °C. The results show that without backup the chamber temperature depends of the solar radiation and they go from 50 to 70 °C during the day and in the night the temperature keep constant. When backup system is used low temperatures can be maintained during 24 hours and electrical resistance are used early in the morning and in evening time, and for low temperatures backup is not needed in high radiation days. For high temperatures, electrical resistances always are used early in the morning and in evening time and the backup system is fundamental to maintain the temperature constant and the use of it is longer compared whit low temperature. For charged chamber with apple samples, the temperature was controlled at 50,60 and 70°C during 24 hours.

Keywords: Solar thermal-wind hybrid system, Construction and evaluation of solar dryer.

SOLAR DRYING - A GIGANTIC OPPORTUNITY TO COMBAT HUNGER AND POVERTY

Bernhard S. Müller

Lernen-Helfen-Leben e.V.,
Achtern Diek 12, 49377 Vechta, Germany
www.l-h-l.de, e-mail: bs_mueller@gmx.net

Abstract: Nearly half of world food production fails to reach consumers. Current food production could easily feed the entire world. Indeed, it could feed up to 14bn humans. So why is there still hunger?

Drying is undoubtedly the most important solar food processing procedure. Numerous methods are already available, to meet all small and large scale requirements. Whenever there is over-production, or the food does not meet existing "standards", it can be dried and sold later, when there is a demand for it. Solar food dryers can also carry out other non-food related tasks, such as drying briquettes, pellets, wood, etc. to obtain a cleaner burn in gasifiers or cookstoves in parts of the world where the inhabitants rely on burning solid fuels.

The author has distributed a large number of solar food dryers in Africa. It became obvious that families, farmers, food syndicates etc. previously knew nothing about the opportunities offered by food drying technology, or had been misinformed. Once the advantages were demonstrated, dryers were adopted enthusiastically, and without any hesitation. This can only mean that the agencies responsible for economic development – various branches of government, and their representatives – have failed to disseminate information about food drying technology, or provide the necessary financial and technical support to enable the spread of these cheap, simple, beneficial practices.

In line with the *Faro Declaration of Intent**, the author strongly recommends an alternative model for promoting food drying technology – empowerment of a network of ‘grass roots’ educators, supported by NGOs, in developing and developed countries. All of the principles are easy to understand, and easy to apply. Large capital investments are not required, and the author’s experience demonstrates that food drying practices spread very rapidly and automatically once adequate advice and support is in place.

Keywords: Solar Drying, Solar Food Processing

*The *Faro Declaration of Intent* was agreed following the CONSOLFOOD conference of January, 2016, which took place in Faro, Portugal.

ENHANCED METHODS TO ACCELERATE THE DISSEMINATION OF SOLAR COOKERS

Faustine L. Odaba

Natural Resources and Waste Management Alliance (NAREWAMA)
P. O. Box 60358-00200, Nairobi, Kenya
e-mail: narewama@gmail.com or narewama@gmx.eu

Abstract: About $800bn have been dissipated for development aid purposes since the liberalisation of the former colonies occured. Although it is well known throughout the world that the methods of World Bank, Unesco, UNEP, UNFCCC and other involved organisations do not lead to an improvement, NGOs in the western world and Japan who could do it better, are jammed if they don't respect their guidelines. Hence, this miserable and unsatisfactory process lingers on. An end is not in sight.

African countries, but also poor ones in Latin America and Asia, complain that development aid programmes are designed wrongly; the help does not reach those who are in need. The countries do not really develop. The rich ones get richer, the poor ones poorer. Authors of high reputation, such as Axelle Kabou "Et si l'Afrique refusait le développement?" and Chika Onyeani "Capitalist Nigger" are just bright shining diamonds in a long row of analysts who explain why the common development aid procedures are not helping at all. Also, Ali A. Mazrui and James Shikvati from the renowned Kenyan institute IREN blame the situation in equal measure.

The use of solar cookers can reach a rate of 38% of all cooking tasks which has been ascertained independently by the German semi-governmental organisation GTZ (now GIZ) and Theresa Beltramol of the University of California Berkeley, separately. In other words, the degree of deforestation could be decreased by 38% rapidly in such areas where wood and charcoal are the main cooking fuel.

To accomplish this task, NGOs in developing and developed countries must be empowered. To shovel large amounts of financial help from government to government is definitely not the right way to continue. It is the duty of small organisations to develop appropriate technologies and applications to distribute the knowledge via grass roots workers to the population throughout the particular countries in cooperation with countries who know and countries who need. Africans must have African solar cookers, not German, American, Swiss, Chinese, Indian or Japanese ones. The world needs to understand and follow the "Faro Declaration of Intent", issued on the occasion of the international conference CONSOLFOOD, January 2016 in Faro, Portugal.

Keywords: Solar Cooker Dissemination Development Aid

10TH GRADE HIGH SCHOOL PHYSICS EDUCATION VIA SOLAR COOKING

Hezi Yizhaq[1,2] and Daniel Feuermann[1]

[1]Swiss Institute for Dryland Environmental and Energy Research,
Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus, Israel.
[2]Sde Boqer Environmental High School Midreshet Ben-Gurion 8499000, Israel.
email: H. Yizhaq yiyeh@bgu.ac.il,
web: http://in.bgu.ac.il/en/bidr/nic/Pages/staff/Hezi%20Yizhaq.aspx

email: D. Feuermann daniel@bgu.ac.il
web: http://in.bgu.ac.il/en/bidr/SIDEER/DSEEP/pages/staff/Daniel_Feuermann.aspx

Abstract: Though every high school and local or country-wide governmental education office has its own guidelines and emphases for any field of learning, with suitable adjustments, solar cooking can serve as an excellent tool by which to teach students of any level natural phenomena, or, more specifically, physics. We report from a three year experience at an environmental high school where 10th graders, enrolled in the natural sciences, where taught physics.

The guiding principle was to teach the students both in theory and by ‘doing’, namely, by building and testing solar cookers of different designs (parabolic mirror, box and panel). We present the curriculum, the subjects covered in the course, as well as the experimental work performed with the students; the success and failures of over- or underestimating the efforts and time required to design and build cookers from low-cost materials.

The courses ran for two-semesters. The first semester was used to introduce the physical concepts, such as temperature, heat transfer, solar radiation, efficiency, and material properties. Towards the end of the first semester, groups of students started to develop ideas for designing and constructing solar cookers, based on available material with the teacher guiding the students to a ‘doable’ design, given the amount of time and resources available, with the actual construction starting in the second semester, culminating towards the semester end with outdoor testing and actual cooking food.

Keywords: High School, Solar Cooking, Education, Physics Curriculum

Searching for the relevant scale for food transformation in dense urban areas in France

An empirical research to link Concentrated Solar Power and biogas generation for the joint conception of local heat networks and small food transformation units

CATHELINEAU Vincent, GENIN Chloé, DE MARIA Arnaud and BERTIN Kévin

CATHELINEAU Vincent, CEO of Transistore, M.D. entrepreneurship, MoS engineering, vincent.cathelineau@transistore.fr

GENIN Chloé, intern at Transistore, B.D. agronomy, chloe.genin@transistore.fr

DE MARIA Arnaud, President of Transistore, M.D. engineer, arnaud.demaria@transistore.fr

BERTIN Kévin, Associate at Transistore, M.D. engineer, kevin.bertin@transistore.fr

Abstract:

As social and environmental entrepreneurs, we try to contribute to the war on climate change. The game is set already: get carbon neutral before 2050 and start right now with a massive yearly decrease in GHG emissions. Since we need answers immediately, we will focus on the one we chose to work on, for it seems to us as one of the most relevant for this matter.

We develop two business models. Both are neighbourhood cooperative organizations. The first is dedicated to energy production and distribution, the second is dedicated to energy use for local food transformation. The concept that binds them is simple: if we want to reach energy market prices for solar thermal we need to find how to use summer heat. If we add up local biogas production, we can complement the lack of sunshine in winter and decrease the size of thermal storage, but we need the waste of food transformation to increase biogas production. With both axis, thermal autonomy becomes more accessible to old properties.

In this article we will describe a technical system containing a mix of CSP techniques along with a methanizer. We will describe the main devices required for using the energy and piloting the system. Then we will introduce a shift between a money oriented industry to multitask sun-oriented lines of food transformation at the scale of a neighboorhood. Beyond that, we will see how this project may contribute to spreading a mindset in which people start to rethink the city in terms of urban integrated agro-energetic partly autonomous systems.

Keywords: Transition, entrepreneurship, local food processing, concentrated solar power, methanization, cooperative organizations

MY STORY OF SOLAR OVENS

Piscarreta, Júlio

e-mail: jsp4925@gmail.com

Abstract: The personal interest historial in solar oven development is described in this short text. From the first contact with the technology to the latest solar oven prototype developed, the author describes its personal experience in this type of technology.

Keywords: Solar oven, cork, cooking

1. INTRODUCTION

One day I read, in the 60's at the Atom, the science and technology magazine, the news of the Missis Telkes experiment, which had cooked a chicken in a solar oven in November in New York.He also stated that the solar oven was a thermal insulated box and had a glass. I was very excited, and I wrote in my pocketbook: make a solar oven. Years went by and I never remembered building a solar oven again.In 1976, an admiral, who only came to know 30 years later that he had been the entrepreneur, with the support of the French embassy, managed to bring an exhibition he had seen in Paris about “alternative energies”, which was the name that was given at the time.In the exhibition, which took place at the Rectory of the Classical University, there was an image of the solar oven and much information about the principles and uses of the alternative energies unknown to me, such as the Orgone, the Willelm Reich mantle and organ box. From then on I decided to build a solar oven in wood.

2. THE FIRST PROTOTYPES

My colleague António Gama brought a book from Canada, with the construction of several devices for the use of renewable energies. In the same year, in the carpentry workshops of my school, with that colleague, we built the first wood oven, isolated with black cork agglomerate, with double glass and only with one reflector.

Later, when I went to do the pedagogic stage in Setúbal, I built a solar oven with zinc plate and 4-panel rock insulation, which was replicated by other schools in 1978/79. At the Teatro da Comuna in Lisbon, the CLAC (Clube dos Amigos da Comuna), I developed various activities on Saturdays and among them, me and my colleague António Gama, we taught the construction of solar ovens for children and adults. It was in this context that the first solar fair was held in the Eduardo VII Park in 1997 in Lisbon, during the Book Fair. For the construction of the wood and cork insulated ovens, the participants paid for the materials 350$00.

3. SOLAR OVEN TEACHING ACTIVITIES

I traveled to various schools, associations, Ponta Delgada Prison, fairs, across the continent and islands teaching the construction of ovens in carton, paper pulp, Styrofoam, and wood. In the meantime I made several prototypes of demountable ovens for the campers and also parabolic ovens. I participated for some years in the Ecovillage Solar Encounters in Granada, Spain and also in meetings of inventors, demonstrating the solar ovens.

4. SOLAR OVEN PATENT

In 1981 I registered in Portugal, the patent no. 71511 F, for a collapsible solar oven and refrigerator in glass fiber, which once cooked for 22 people. Three copies were offered to Cape Verde by a Non-Governmental Organization, the Soroptimist International, 1ºClube de Lisboa, and 33 were sent to Africa. It was due to the order of these furnaces that I became entrepreneur.

5. SOME CURIOSITIES

- One night, that I was awake, I noticed that the wood oven, used as a refrigerator for night irradiation, reached 7º C inside, while outside were 17ºC.

- I remember that more than once in fairs I was asked: “Where do you put the wood, to burn?”

- Another event that happened, was when I taught to build a oven in recycled paper with a cane structure , the owner of the oven, put it to dry inside a Renault 4L. Later when it was opened, inside the canes were all busted, because they were still green.
- On one occasion the host of this meeting, Dr. Celestino Ruivo, left a furnace in recycled paper to cook in the sun, but as it was raining, when his daughter pick it up , the oven bottom and the pan stood stuck to the ground.

-In 2012/13/14 I had on the island of S. Tomé the first surprise with the solar oven in cardboard.
The sun shone in the sea and rarely on the island. In a single time it reached only 80ºC but after a short time, the Sun disappeared and we were not able to cook.

The TÀ SOL ovens, built in cork agglomerated with the resin, are the best in the world in ecological terms, because it has a small ecological footprint, a small water footprint and the insulation material comes from a tree, the cork oak, which for 150 years, produces cork that is withdrawn every 9 years.

SOIL PASTEURISATION IN THE UK – A NEW JOB FOR SOLAR COOKERS.

Stewart macLachlan[1]* and Dave Oxford[2]

1: SliCK solar cookers, 43, Ellingfort Road, London, E8 3PA, UK
e-mail: ecozoom.uk@btinternet.com web: http://www.slicksolarstove.com

2: SLiCK solar cookers, Little Oaks, Menagissey, Cornwall, TR4 8DH, UK.
e-mail: daveoxford@metronet.co.uk web: http://www.slicksolarstove.com

Abstract: *Growing plants can suffer from soil-borne pests and diseases, and competition from weeds. Conventional solutions involve the use of selective herbicides, fungicides, insecticides, mechanical weeding, and mulching. Since the 1970s, growers have experimented with heat-treatment of soil using solarisation, pasteurisation, and sterilisation. When soil is heated, many pests (e.g. nematodes), fungi (e.g. phytophthora), bacteria (e.g. agrobacterium) and weed seeds (e.g. rumex obstusifolius) are destroyed, and this is advantageous to food growers. There are disadvantages associated with each of the conventional soil heating methods: On a large scale, solarisation, which involves overlaying soil with clear polyethylene sheeting and allowing sunshine to heat the soil, requires the right climatic conditions, and these usually coincide with the growing season. On a medium scale, purpose built ovens, used to sterilise soil, are expensive to buy and operate. On a small scale, domestic gas/electric ovens or microwave ovens are quick and convenient, but the smells produced by the process are unacceptable. For the past two years, the senior author has been experimenting with various equipment combinations to see if it is possible to use a simple solar cooker to pasteurise small quantities of compost in the UK climate. The results show that a simple panel cooker loaded with 2 kg of compost will easily reach the temperatures required to destroy most of the pests, disease vectors, and weed seeds present in untreated compost. Moreover, this can be achieved before the planting season begins, in February. Further tests showed that no weeds germinate in the heat-treated compost, leaving the desired plants to grow, free of competition. This series of experiments demonstrates that these results can easily be achieved on a domestic scale at negligible cost, and without using any energy other than sunlight.*

Keywords: Crops, Growing, Soil treatment, Solar cooker.

PURIFICATION OF WATER USING SOLAR ENERGY

Avinash Reddy and Srikanth Mutnuri*

*corresponding author
Applied Environmental Biotechnology Laboratory, Department of Biological Sciences, Birla Institute of Technology and Science – Pilani (BITS Pilani) K K Birla Goa campus, Goa 403726, India
e-mail: srikanth@goa.bits-pilani.ac.in

Abstract: Solar cookers have existed since the 1800s, but in the past decade or so, there has been a sudden explosion of interest in this area resulting in hundreds of new solar cooker designs. However, that one kind of solar cooker that would make it an every household's commodity is missing .Through our design of a solar cooker, we aim to attain regular, desired cooking temperatures, at minimized costs. Apart from this our design also helps to purify water and get DISTILLED WATER. We modified the existing solar cooker so as to collect distilled water apart from cooking food. The idea was to capture, condense and collect the water vapour which is produced from the water in the containers of the solar cooker by using sunlight. The initial setup passed the captured water vapour through a plastic tube and into a container surrounded with ice. As it had very low efficiency some modifications were made to certain sections of the equipment.

The position of the solar cooker (with respect to sun)and the condensing point was also changed. After several modifications made to the equipment and experiments where performed The final modification was to change the point of condensation by adding a jacket around the pipe which acted like a heat exchanger thereby reducing the temperature of the water vapour. This helped provide a larger area for heat exchange and condense the water vapour there by improving effiency.

The apparatus is assembled as in the diagram. (The diagram represents a batch apparatus, as opposed to a continuous apparatus.) The tap water is put into the round bottomed vessels and the fractionating column is fitted at the top. As the mixture boils, vapor rises up the column. The vapor condenses on the glass platform and some vapor condenses inside the column, and runs down into the bottle below which is known as distillate. The results are encouraging wherein solar cooker and a solar still could be integrated.

Property/sample	Tap water	Sample collected	Pure water
Ph	7.69	7.38	7.0
T.D.S	0.201	0.195	0
Conductivity	0.268	0.306	0.55

Keywords: solar cooker, solar still, distilled water

DESIGN, REALIZATION AND TEST OF A PORTABLE SOLAR BOX COOKER WITH BOOSTER MIRRORS

Giovanni Di Nicola[1] *, Gianluca Coccia[1], Sebastiano Tomassetti[1] and Mariano Pierantozzi[2]

1: Dipartimento di Ingegneria Industriale e Scienze Matematiche, Università Politecnica delle Marche, Via Brecce Bianche 12, 60131, Ancona (Italy)
e-mail: g.dinicola@univpm.it, g.coccia@pm.univpm.it, s.tomassetti@pm.univpm.it

2: Scuola di Ateneo Architettura e Design, Università degli Studi di Camerino, Lungo Castellano Sisto V 36, 63100, Ascoli Piceno (Italy)
e-mail: mariano.pierantozzi@unicam.it

Abstract: *Solar cooking is considered one of the most attractive ways to utilize solar energy. Thus, in this work a concentrating solar box cooker prototype was manufactured and tested. The cooker has a cooking chamber with a glass cover on the top and comprises a row of booster mirrors. The prototype can be manually oriented both along the azimuthal and the zenithal planes. In the cooking chamber, there is a rotating support able to rotate of 360°, in order to maintain vessels in balance when the zenith orientation changes. A test bench adopted to determine the thermal performance of the prototype is described. Two different experimental test were carried out: with and without load. Experimental tests without load were carried out to evaluate the maximum cooker temperature. Tests with load, instead, were conducted using an aluminum vessel filled with water, up to the fluid boiling. Results show that the cooker is able to cook food at high temperature, fast and with good efficiency.*

Keywords: Solar, thermal, experimental, concentrating

1. INTRODUCTION

Solar cooking is considered as one of the simplest and attractive ways of the utilization of solar thermal energy [1]. Energy for cooking is one of the fundamental uses in developing countries, where wood is still the primary energy source. In addition to the environmental issues, the firewood use also causes some serious health problems such as burns, eye disorders, and lung diseases [2].
Solar cookers represent a possibility to meet the energy demand in the domestic sector of developing countries where, generally, there is abundance of solar radiation; e.g., a mean daily solar radiation of 5-7 kWh/m^2 and more than 275 sunny days in a year have been estimated [3]. However, the large-scale dissemination of solar cookers still remains limited as most of these devices are only used for research purposes [4]. The main obstacles to the dissemination of the technology are the resistance to acceptance as it is a new technology, variable nature of solar radiation, limited space availability in urban areas, and higher initial costs [5].
A solar box cooker prototype with a high concentration ratio (10.78) was designed, realized, and tested by the authors in a previous work [6], based on their experience on parabolic trough collectors [7,8,9,10]. Experimental tests with and without load were carried out, and showed that the prototype is able to cook food fast and at high temperature. Load tests were conducted with both water and peanut oil; 1 kg of the former fluid could be boiled in about 11 minutes, while the latter fluid was able to reach temperatures higher than 200 °C in around 41 minutes.
The solar box cooker described in this work is the second prototype realized in DIISM (Department of Industrial Engineering and Mathematical Sciences). To test the cooker performance, we tried to follow and perform the most widespread and reliable quantitative procedures available in literature.

2. DESIGN, MATERIALS AND OPTICS

The proposed cooker, shown in Figure 1, is composed by a wooden box containing a zinc-coated steel frame with the function of cooking chamber (or absorber). The chamber was painted with a special selective coating (SOLKOTE HI/SORB-II) having a higher solar absorptance (0.90) than that of a common black paint. In the chamber, there is a vessel support able to rotate of 360°, in order to maintain the pots/food in balance. The cooking chamber walls were thermally insulated with glass wool to reduce heat losses and obtain higher cooking temperatures.

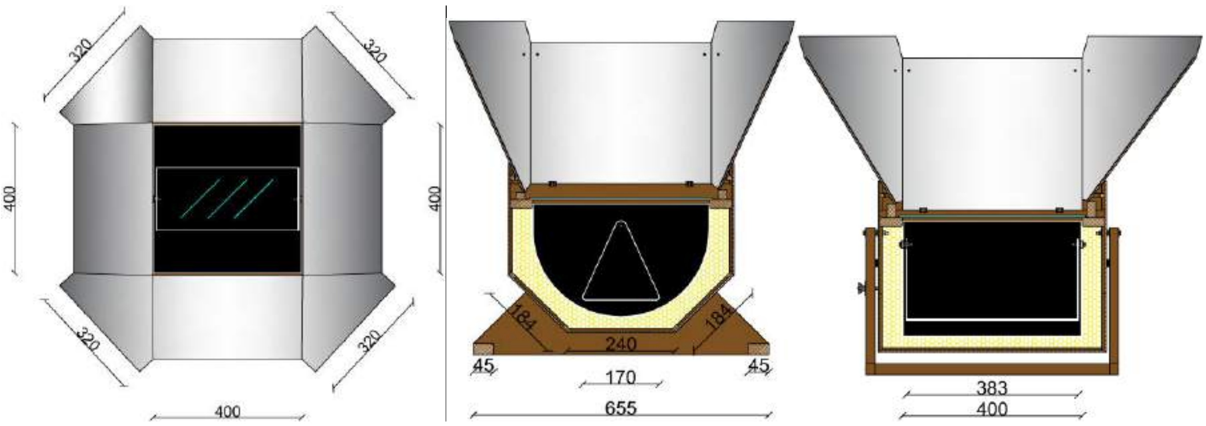


Figure 1. Views and cross-sections of the solar cooker prototype.

The box has a glass cover on the top, which allows solar radiation to be transmitted to the absorber.

The cover is made of tempered glass, which is high resistant and suitable for solar thermal applications (transmittance of about 0.90) and can be easily removed to insert food/pots in the cooking chamber.
The higher part of the box is surrounded by 8 booster mirrors. The mirrors were manufactured with special aluminum reflective foils (MIRO-SUN Weatherproof Reflective 90) glued on phenolic compound elements. Respect to traditional aluminum foils, these mirrors guarantee an overall reflection of about 0.94. The mirrors allow an additional amount of solar radiation to be reflected and concentrated towards the cover and the cooking chamber.
The cooker aperture area, A_a, is equal to 0.681 m^2, while the glass cover area, A_g, is 0.167 m^2. Thus, the cooker concentration ratio is:

$$C = \frac{A_a}{A_g} = 4.08 \tag{1}$$

Additionally, the prototype has two border wooden hands that allow both its movement and its azimuthal orientation. A zenithal orientation is also possible as the cooker is able to rotate around the horizontal axis via a bolt moving into a runner. This rotation can be blocked with an external butterfly screw.
The cooker has a maximum height of 0.753 m and a mass of about 20 kg. Its overall cost is around 300 EUR; the aluminum foils are the most expensive items. The overall time required by one specialized and two non-specialized workers to realize the whole prototype is about 50 hours.

3. TEST BENCH

The solar box cooker prototype was characterized adopting the test bench reported in Figure 2.

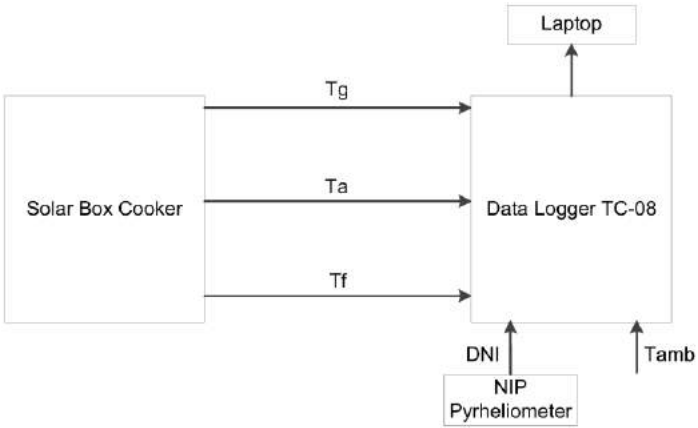


Figure 2. Solar box cooker test bench.

K-type thermocouples were used to measure temperature of ambient air (T_{amb}) and in two points of the cooker: the glass cover (T_g) and the absorber (T_a). The testing fluid temperature (T_f) was measured with a T-type thermocouple.
The direct normal irradiance, *DNI*, was measured through a first-class normal-incidence pyrheliometer (NIP) mounted on a solar tracker. Since the solar box prototype considered in this work has a quite high concentration ratio and, hence, it is not able to exploit diffuse solar energy [10], only direct solar radiation was measured.

The signals provided by the thermocouples and the pyrheliometer were acquired by a Pico Technology TC-08 data logger.

4. EXPERIMENTAL TESTS AND RESULTS

Experimental tests were carried out on the DIISM roof (latitude 43.5867 N, longitude 13.5150 E). The cooker orientation was adjusted about every 5-10 minutes, to guarantee a correct alignment with the sun. Two kinds of experimental tests were conducted: with and without load. Tests without load allowed to evaluate the maximum temperature reachable by the solar box cooker.

Tests with load, instead, were accomplished inserting in the cooker 2 kg of water contained in a cylindrical aluminum vessel having 18 cm diameter and 12 cm height. The vessel included a lid with a small hole, used to let the insertion of a T-type thermocouple.

4.1. Tests without load

Three tests without load were carried out under different environmental conditions. A summary is provided in Table 1. The first figure of merit, F_1, is defined as [11]:

$$F_1 = \frac{T_{a,\max} - T_{amb}}{DNI} \tag{2}$$

where $T_{a,max}$ is the maximum temperature reached by the absorber, while T_{amb} and DNI are, respectively, the corresponding ambient temperature and direct normal irradiance measured when the stagnation temperature is reached. For the solar cooker under study, the average F_1 was found to be equal to 0.19 °C/(W/m^2).

Table 1. Tests without load.

Day	T_{amb} (°C)	T_a (°C)	DNI (W/m^2)	F_1 (°C/(W/m^2))
23/05/2017	29.39	197.30	839.71	0.20
09/06/2017	23.39	187.42	971.75	0.17
13/06/2017	31.27	189.10	841.24	0.19
Mean				0.19

As an example, Figure 3 shows the temperatures and the solar radiation detected during the last test.

4.2. Load tests

Table 2 reports the results obtained through three load tests, while Figure 4 depicts the temperatures and the solar radiation detected on September 14, 2017.
In order to characterize the cooker performance under load, several parameters (provided in Table 2) were calculated based on the obtained experimental data. The first parameter was the time required to take the water temperature from T_1 to T_2, Δt. This parameter was used to derive the specific boiling time, t_s, defined as the time required for a cooker of aperture area A_a to take 1 kg of water from T_1 to T_2 [12]:

$$\Delta t_s = \frac{\Delta t * A_a}{m_f} \tag{3}$$

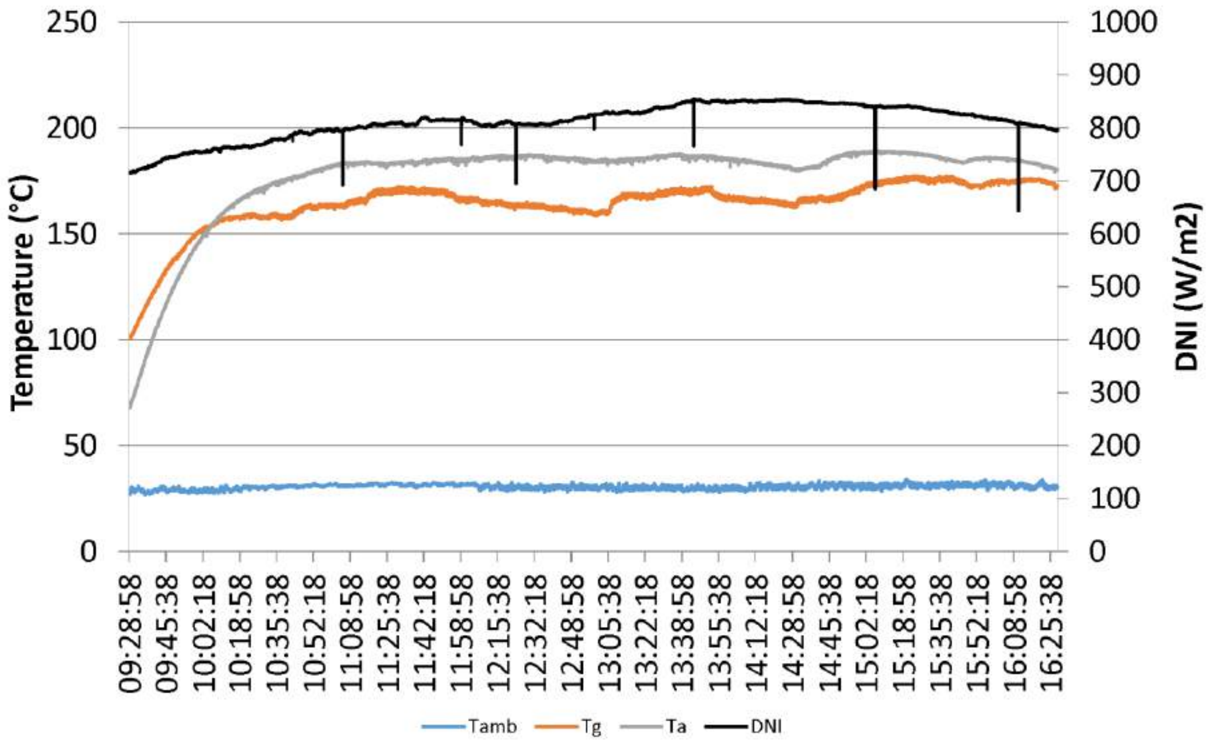


Figure 3. Test without load (13/06/2017).

Table 2. Tests with load.

Quantity	Test 01	Test 02	Test 03
Day	02/08/2017	14/09/2017	22/09/2017
$T_{amb,av}$ (°C)	36.59	25.00	22.42
DNI_{av} (W/m^2)	736.84	865.07	890.50
m_f (kg)	2	2	2
T_1 (°C)	40	40	53
T_2 (°C)	90	90	90
Δt (s)	5223	6063	5153
t_s (min m^2/kg)	29.64	34.41	29.24
t_c (min m^2/kg)	24.27	33.07	28.93
η_{av}	0.16	0.12	0.10
F_2	0.20	0.16	0.14

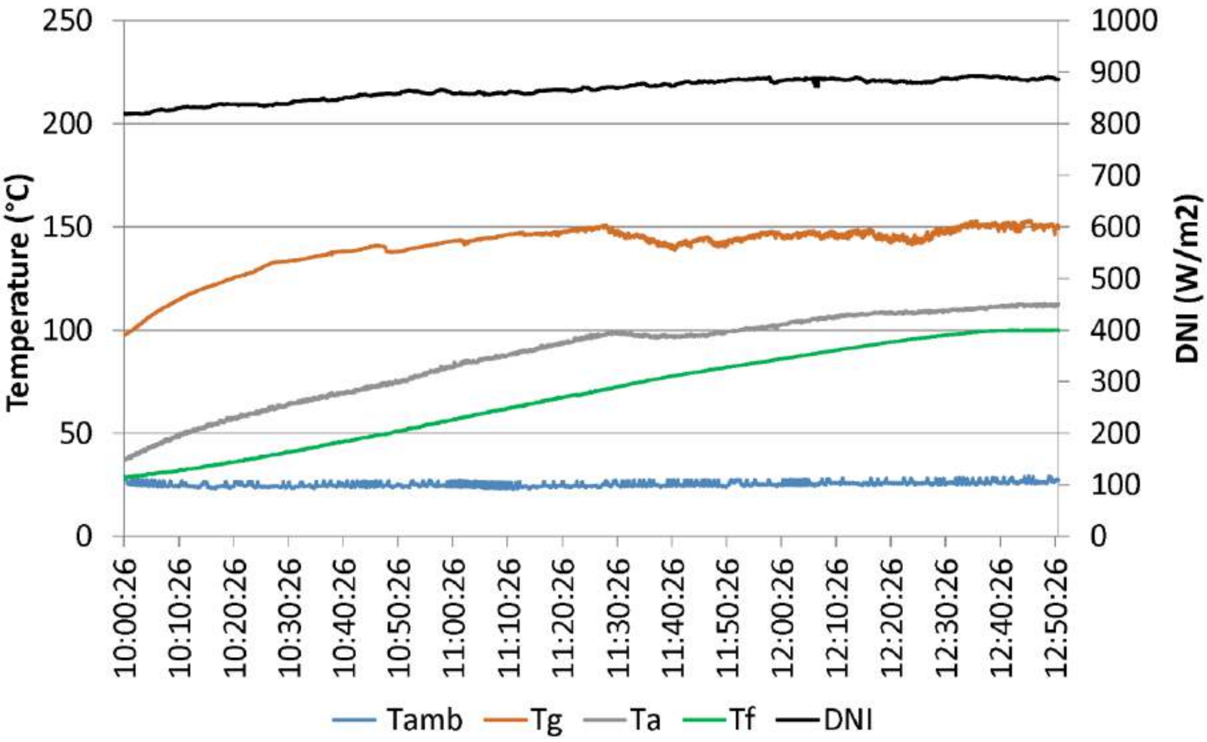


Figure 4. Test with load (14/09/2017).

where m_f is the mass of testing fluid. Another parameter is the characteristic boiling time, t_c, generally used for making comparisons between various solar cooker designs under different solar radiation levels [12]:

$$\Delta t_c = \frac{\Delta t_s * DNI_{av}}{DNI_{ref}} \tag{4}$$

where DNI_{av} is the average direct normal irradiance during the time interval Δt, while DNI_{ref} is a reference direct normal irradiance equal to 900 W/m^2.
The average overall solar cooker thermal efficiency is [12]:

$$\eta_{av} = \frac{m_f * c_f * (T_2 - T_1)}{DNI_{av} * A_a * \Delta t} \tag{5}$$

where c_f is the specific heat of water.

Finally, the second figure of merit, F_2, was introduced to involve the temperature increase measurement with time of a known amount of fluid placed in the cooker. It is defined as [11]:

$$F_2 = \frac{F_1 * m_f * c_f}{A_a * \Delta t} \ln \left[\frac{1 - \frac{1}{F_1}(T_1 - T_{amb,\,av}) / DNI_{av}}{1 - \frac{1}{F_1}(T_2 - T_{amb,\,av}) / DNI_{av}} \right] \tag{6}$$

As can be noted from Table 2, the cooker shows a good thermal performance, which is particularly influenced by the ambient temperature.

5. CONCLUSIONS

This work describes the design, manufacture and test of a prototype of solar box cooker with a concentration ratio of 4.08. The main findings of the work are as follows.

- The cooker is portable and can be manually oriented both in the azimuthal and zenithal planes.
- Experimental tests without load show that the cooker is able to reach a maximum temperature of about 200 °C.
- Tests with load (water) indicate that the prototype has a good thermal performance, being potentially able to cook food fast and at high temperature.

ACKNOWLEDGMENTS

The authors would like to thank Eng. Gianni Crovatto for his appreciated support and advices about solar cookers, the technicians of DIISM (Eng. Giuliano Giuliani, Gabriele Gabrielli, Gaetano Borrelli, Francesco Tartaglini) and all the students who contributed to the prototype manufacture and testing.

REFERENCES

[1] Cuce E, Cuce PM. A comprehensive review on solar cookers, Applied Energy, 2013, 102:1399-1421.

[2] Pohekar SD, Kumar D, Ramachandran M. Dissemination of cooking energy alternatives in India—a review, Renewable and Sustainable Energy Reviews, 2005, 9.4:379-393.

[3] Nahar NM. Performance and testing of a hot box storage solar cooker, Energy Conversion and Management, 2003, 44(8):1323-1331.

[4] Yettou F, Azoui B, Malek A, Gama A, Panwar NL. Solar cooker realizations in actual use: An overview, Renewable and Sustainable Energy Reviews, 2014, 37:288-306.

[5] Muthusivagami RM, Velraj R, Sethumadhavan R. Solar cookers with and without thermal storage—A review, Renewable and Sustainable Energy Reviews, 2010, 14(2):691-701.

[6] Coccia G, Di Nicola G, Pierantozzi M, Tomassetti S, Aquilanti A. Design, manufacturing, and test of a high concentration ratio solar box cooker with multiple reflectors, Solar Energy, 2017, 155:781-792.

[7] Coccia G, Latini G, Sotte M. Mathematical modeling of a prototype of parabolic trough solar collector, Journal of Renewable and Sustainable Energy, 2012, 4(2):023110.

[8] Coccia G, Di Nicola G, Sotte M. Design, manufacture, and test of a prototype for a parabolic trough collector for industrial process heat, Renewable Energy, 2015, 74:727-736.

[9] Coccia G, Di Nicola G, Colla L, Fedele L, Scattolini M. Adoption of nanofluids in low-enthalpy parabolic trough solar collectors: Numerical simulation of the yearly yield, Energy Conversion and Management, 2016, 118:306-319.

[10] Coccia G, Di Nicola G, Hidalgo A. Parabolic trough collector prototypes for low-temperature process heat, Springer, 2016.

[11] Mullick SC, Kandpal TC, Saxena AK. Thermal test procedure for box-type solar cookers, Solar Energy, 1987, 39(4):353-360.

[12] Khalifa AM, Taha MMA, Akyurt M. Design, simulation, and testing of a new concentrating type solar cooker, Solar Energy, 1987, 38(2):79-88.

SOLAR OVENS AND COOKERS, POWER DIDACTIC TOOL FOR GREEN BUILDING

Bello J.[1] *

1: Department of Building and Civil Engineering, CIFP Someso
Rúa Someso 6. 15008 A Coruña. Spain
e-mail: juanbello@edu.xunta.es, web: http://www.edu.xunta.gal/centros/cifpsomeso/es

Abstract:

Renewable energies and energy efficiency are two important sections of ecological building. Bioclimatic design of buildings can be considered the best use of solar energy. Green building is a very important factor in combating climate change.
Make and use ovens and solar cookers allow teaching many technical concepts: Design, Orientation, Collection of sunlight, Conservation of heat, Isolation, Thermal inertia, Movement of the sun, Solar azimuth and altitude, Seasons of the year, Greenhouse effect, Transformation of light into heat, Energy economy…
Students learn from the teacher's explanations, observing how the food boils, touching the hot pot and feeling the high temperature, smelling the aroma of cooked food and finally tasting the food. We can sum it up as "learning from the five senses". In this way, the most exciting and successful didactic experiences are achieved.
This teaching tool is very flexible, it can be applied to many areas and it is possible to work at all levels of education. It also enables people without previous studies to help their communities reduce their energy dependence on fuel wood or conventional fuels for cooking or heating their homes, to move towards sustainable development, use renewable energy, reduce deforestation and increase energy independence.
This work is based on more than 20 years of teaching experience using solar ovens and cookers.

Keywords:

Solar didactics, Green building, Climate change, Energy economy, Sustainable development

SIMULATION OF A SOLAR FUNNEL COOKER USING MATLAB

Rafael Cubero-Leiva[1,3], Fernando Domínguez-Muñoz[1],

Celestino R. Ruivo[2] and Francisco R. Villatoro[3 *]

1: Departamento de Ingeniería Mecánica, Térmica y de Fluidos, Escuela de Ingenierías Industriales,
Universidad de Málaga, Ampliación del Campus de Teatinos, s/n, 29071, Málaga, Spain
e-mail: fdominguezm@uma.es, web: http://webdeptos.uma.es/mmt/

2: Departamento de Engenharia Mecânica, Universidade do Algarve, Faro, Portugal
e-mail: cruivo@ualg.pt web: http://solarcooking.wikia.com/wiki/Celestino_Ruivo

3: Departamento de Lenguajes y Ciencias de la Computación, Escuela de Ingenierías Industriales,
Universidad de Málaga, Ampliación del Campus de Teatinos, s/n, 29071, Málaga, Spain
e-mail: frvillatoro@uma.es web: http://www.lcc.uma.es/

Abstract: *A software for the calculation of the radiation heat transfer in solar funnel cookers by means of the radiosity method has been developed in Matlab. The software has been used to study a folding solar cooker. The cooker geometry is discretized using a triangular mesh where a piecewise constant approximation is assumed for the radiosity function. Form factors, including self-occlusions, are calculated by properly refining the triangular mesh. The concentration factor of the solar cooker is estimated as a function of its position and orientation with respect to that of the Sun.*

Keywords: Solar Cooker, Concentration factor, Numerical model, Radiation heat transfer, Radiosity method.

1. **INTRODUCTION**

A solar panel cooker uses a multifaceted mirror to concentrate sunlight from above in a cooking vessel placed at its focus inside a clear, transparent enclosure, to create a greenhouse effect [1,2,3]. Funnel cookers are simple to construct, store and transport, so they result in low-cost, effective cooking kits. The simulation of the thermal heat transfer in a flat plate collector will help the development of optimal designs and recommendation practices for the best performance. Most mathematical models for the numerical simulation of solar cookers use heat balance equations for the each component of the cooker [4]. They are not able to determine the distribution of the concentrating irradiance on the surface of the cooking vessel.

The radiative heat transfer in a funnel cooker can be calculated by means of using ray-tracing and radiosity methods [5,6]. Both methods determine the direct irradiation from the Sun and the indirect irradiation from the sky, including the effect of self-shadowing and the exchange of radiative energy between the surfaces of the cooker. The selection between ray-tracing and radiosity for the simulation of solar cookers is a matter of personal preference. The main disadvantage of the ray-tracing method is that Monte Carlo techniques are required for indirect irradiation, resulting in an increase of the computational cost. On the other side, the main disadvantage of radiosity is that the sky and the Sun are projected into a finite volume enclosure. In practice, both methods are expected to yield similar irradiance maps on the panels of the solar cooker and the surface of the cooking vessel, which can be compared with those obtained by reciprocal optical tests [7] and by other simulation methods, as those used for box solar cookers [8].

On the best of the authors' knowledge, the radiosity method has not been used in the simulation of the solar cookers, in fact, the ray-tracing has been used only for box solar cookers [9]. In this paper, preliminary results for the simulation of panel solar cookers using the radiosity method are presented; the concentration factor for the cooking vessel is calculated comparing the results with and without the solar cooker as a function of the position of the Sun in the sky. Section 2 recalls the radiosity method and the form factor calculation. Section 3 describes the geometry of the solar funnel cooker used to obtain in the results presented in Section 4. Finally, Section 5 summarizes our main conclusions.

2. RADIOSITY METHOD

The radiosity equation describes the amount of energy emitted by a surface as the sum of the inherent emission of the surface (for heat sources) and the reflected energy on the surface (dependent of its reflectivity coefficient) from all the energy that it receives from all other surfaces [5,6]. A map of the thermal radiation over all the surfaces can be determined by solving the radiosity equation by means of the finite element method.

The standard implementation of the radiosity method starts with a discretization of the surface of all the objects into triangular elements over which a piecewise constant approximation is used for the radiosity function. Therefore, the integral equation is rewritten into a linear system of equations for the unknown constant values of the radiosity in every element. The radiosity equation can be written as

$$B_i = E_i + \rho_i \sum_{j=1}^{n} F_{ij}\, B_j, \qquad (1)$$

where B_i is the radiosity at the i-th surface, E_i is its emissivity, ρ_i is its reflectivity, and F_{ij} is the form factor between the i-th and j-th surfaces, i.e., the ratio of energy received by the i-th surface from the total energy emitted by the j-th surface. The matrix representation of Eq. (1) is given by

$$\begin{array}{cccc} 1-\rho_1 F_{11} & -\rho_1 F_{12} & \cdots & -\rho_1 F_{1n} \\ -\rho_2 F_{21} & 1-\rho_2 F_{22} & \cdots & -\rho_2 F_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ -\rho_n F_{n1} & -\rho_n F_{n2} & \cdots & 1-\rho_n F_{nn} \end{array} \quad \begin{array}{c} B_1 \\ B_2 \\ \vdots \\ B_n \end{array} = \begin{array}{c} E_1 \\ E_2 \\ \vdots \\ E_n \end{array},$$

which can be easily solved by using Matlab's set of iterative methods. The irradiance radiosity (the energy incoming into every geometrical element) is given by

$$G_i = \;_{j=1}^{n} F_{ij}\, B_j \,. \tag{2}$$

The exact calculation of the form factors F_{ij} requires the numerical calculation of the following equation

$$F_{ij} = \frac{1}{A_i} \;_{A_i}\;_{A_j} \frac{\cos\theta_i \cos\theta_j}{\pi r^2}\, V_{ij}\, dA_i\, dA_j \,, \tag{3}$$

where A_i is the area of the i-th surface, θ_i is the angle with respect to the normal vector of the i-th surface of the vector connecting the centers of surfaces A_i and A_j, and V_{ij} is the visibility function (the amount of area A_i visible from the center of the area A_j). Equation (4) is numerically evaluated by means of a simple quadrature method; concretely, every area is divided in small elements where the visibility function is either 1 or 0, and the differential form factor is approximated by

$$dF_{A_i \to A_j} = \frac{\cos\theta_i \cos\theta_j}{\pi r^2}\, V_{ij}\, A_j \,,$$

where the sum of these differential form factors yields the form factor F_{ij}.

For solar cookers the most important design factor is the concentration ratio, given by

$$CR = \frac{G_{total}\,(with\ cooker)}{G_{total}\,(without\ cooker)}, \tag{4}$$

i.e., the quotient of the total irradiance of the cooking vessel calculated with and without the concentrator cooker; the total irradiance is obtained by using

$$G_{total} = \frac{\;_i A_i G_i}{\;_i A_i},$$

where Eq. (3) applied to the solution of Eq. (1).

3. SOLAR FUNNEL COOKER

This paper presents preliminary results obtained by using a prototype software for the simulation of arbitrary solar cookers by means of using the radiosity method. This prototype has been developed by the first author as part of his M.E. thesis. This software is currently under further development, so here we only present an initial exploration of its potential for the thermal analysis of solar cookers.

Figure 1. Pictures of a solar funnel cooker by Teong Tan [10] (top), of a transparent enclosure (bottom left) and a black cooking vessel (bottom right).

Figure 1 shows pictures of a panel solar cooker (top), a cooking vessel (bottom right) and a transparent enclosure to use the greenhouse effect (bottom left). Our software input is a text file with the description of the polygonal geometry of these three objets. Instead of simulating an existent solar funnel, like the one shown in Fig. 1 (top), from Teong Tan [10], or that used by Celestino Ruivo [11], we have preferred a simplified design. Future work will use their designs in order to compare the predictions of our software with experimental measurements using thermographic cameras.

Figure 2 (left) shows the polygonal geometry of the solar funnel cooker used in the simulations reported in next section of this paper. We also have simplified the cooking vessel up to the extreme; Fig. 2 (center) shows the polygonal shapes of the transparent enclosure and Fig. 2 (right) that of the cooking vessel. Obviously, our results are expected to be highly dependent on this simplification; current work in progress will use rounded versions of these vessels by taking into account a large number of polygons (in our current prototype it is very easy to specify a detailed geometry using the input text files, however we have not developed yet a graphical interface for the automatic introduction of the geometry).

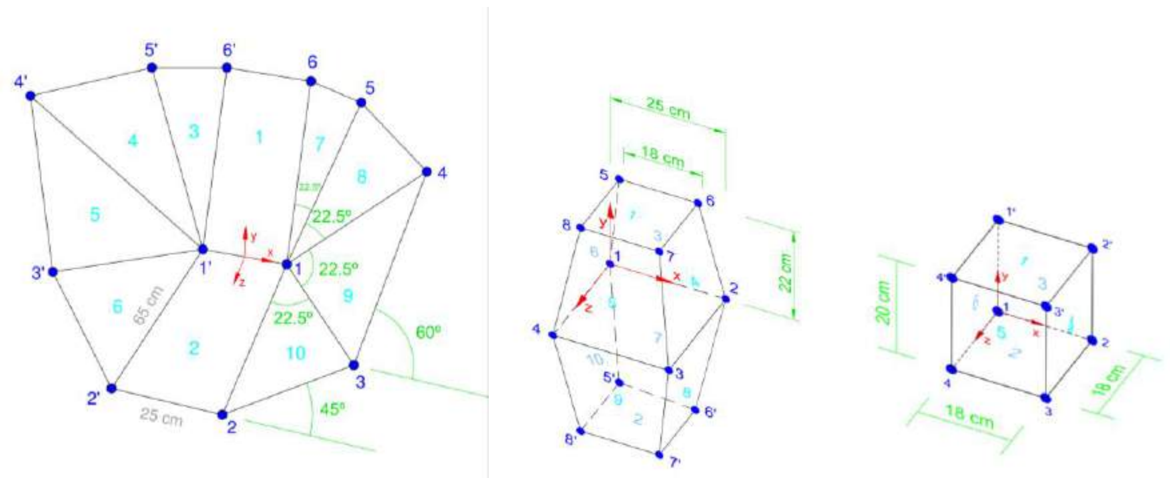


Figure 2. Geometry of the solar funnel cooker simulated in this paper (left), the transparent enclosure (centre) and the cooking vessel (right).

The radiosity method requires that the solar cooking is inside a global enclosure. In our software the hemispherical sky and the circular solar spot are approximated by using a prism and a square solar spot, respectively, as shown in Fig. 3. The area of the projection of the Sun is adjusted as a function of the size of the global enclosure. In our simulation the sky and the Sun are reflectionless emitters. The total solar irradiance in a sunny day of about E_T = 1000 W/m^2 can be distributed between the Sun (E_S) and the sky (E_K) such that $E_S + E_K = E_T$. Obviously in sunny days it is expected that $E_S = E_T$., but in a cloudy day there is a non-null contribution of the sky ($E_K \neq 0$).

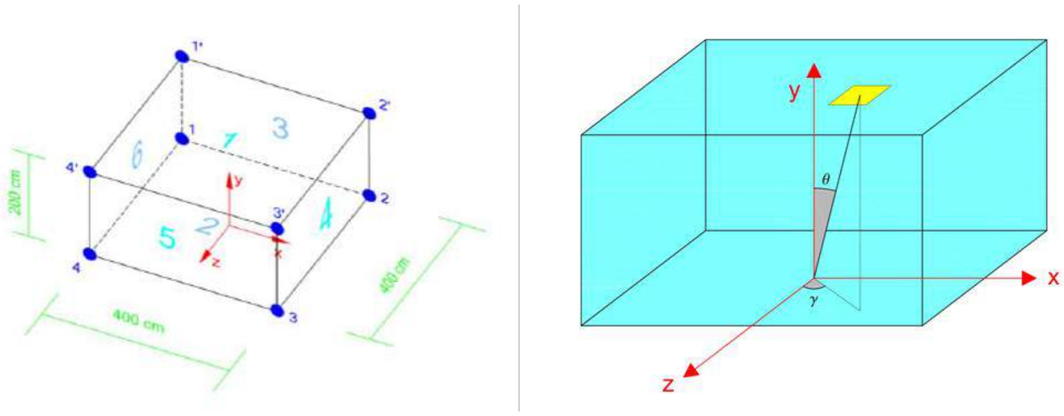


Figure 3. Geometry of the global enclosure of the scene (left) and Sun angular location (right).

4. PRESENTATION OF RESULTS

In the current state of development of our software, only a prototype yet to be validated by comparison with experimental data, our results must be considered as preliminary. Here on we only summarize the extensive set of simulations done by first author in his M.E. Thesis. Our software allows the variation of a large number of parameters of the solar cooking scenery. The panel solar cooker can be rotated with respect to its own axis (centered on the base polygon) and the inclination of the angle of the cooker back panel can be changed in order to focus more or less radiation on the cooking vessel. The position of the cooking vessel inside the transparent enclosure vessel and its height with respect to the base of the cooker can also be changed. The position of the Sun in the sky and the percentage of radiation associated to the faces of the sky enclosure can be controlled in a one by one basis. Finally, the number of triangle elements in which every polygon is divided for the radiosity calculation and that for the form factor estimation can also be specified independently for every object in the scene.

Figure 4 (left) shows a representative result for the concentration ratio calculated using Eq. (4) on the transparent enclosure vessel, cf. Fig. 2 (center), as a function of the position of the Sun in the sky, determined by the angles θ and γ as shown in Fig. 3 (right), when the Sun is the only source of irradiation (there is no emission from the sky). The back panel of the cooker has an inclination of 100º and every polygon is divided in 16 triangular elements for the calculation of the radiosity. The black (asterisk marked) curve in Fig. 4 (left) corresponds to the summer season, when the Sun is high in the sky; the largest concentration factor is obtained when the solar cooker faces the Sun, with θ = 15º; this angle changes as the inclination of the back angle of the cooker does. The red (circle marked) curve in Fig. 4 (left) corresponds to autumn and spring seasons, when the Sun is a little lower in the sky; the concentration factor depends on the hour of the day, decreasing as the Sun approaches either sunrise or sunset. Finally, the blue (plus sign marked) curve in Fig. 6 (left) illustrates a winter season situation; the self-shadowing of the cooker, and the shadows of the cooker into the cooking vessel result in poor performance; moreover, when the Sun is low in the cooker is not useful.

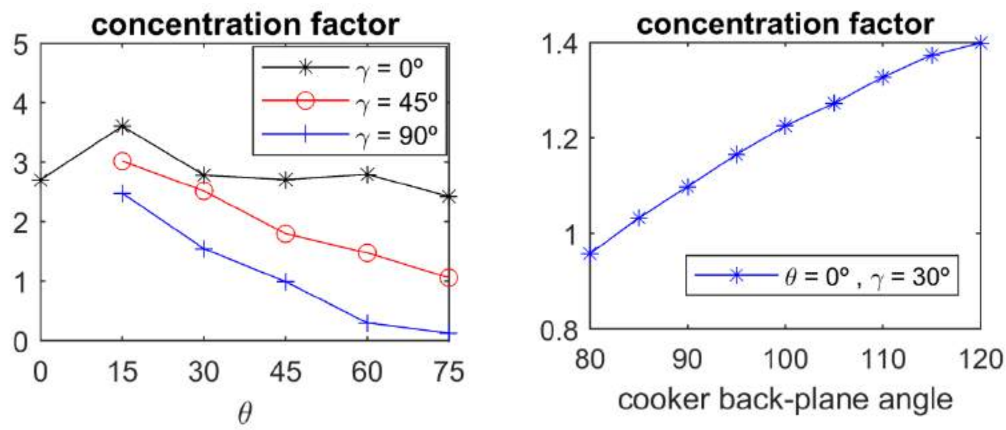


Figure 4. Left: Concentration factor for the total irradiation in the cooking vessel as a function of the position of the Sun in the sky (given by angles θ and γ). Right: Concentration factor as a function of the inclination of the back panel of the solar cooker.

Figure 4 (right) illustrates the effect in the concentration ratio of the inclination of the back panel of the funnel cooker; in our input file the shape of the cooker is always continuous at the edges of the polygons, so this angle controls the amount of parabolicity. For a fixed position of the Sun of θ = 0º (summer) and γ = 30º (before midday, cooking for the lunch), cf. Fig. 3 (right), the concentration factor is larger as more open are the panels of the cooker.

10. CONCLUSIONS

This paper has presented a prototype software for the simulation of solar panel cookers by means of the radiosity method. The geometry of the solar cooker, cooking vessel and transparent cooking enclosure is approximated by plane polygons in three dimensions, by using an input text file. The Sun position in the sky relative to the cooker can also be selected, so the transitory evolution of the heat transfer during the cooker operation can be estimated. The sky can also emit a part of the total radiation. For validation, a simplified solar panel cooker has been simulated under several situations. The results presented in this work are preliminary, but apparently are consistent with the expectations.

Future work is in progress, with emphasis in the validation of the software by means of real experiments with panel solar cookers. Additionally, the prototype software will be improved with a graphical interface for the generation of the input files. Finally, a future comparison with the ray-tracing method will be accomplished.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Muthusivagami RM, Velraj R, Sethumadhavan R. Solar cookers with and without thermal storage—A review. Renewable and Sustainable Energy Reviews, 2010, 14: 691-701.
[2] Cuce E, Cuce PM. A comprehensive review on solar cookers. Applied Energy, 2013, 102:1399-1421.
[3] Ruivo CR. Solar cooking is feasible, it is not a myth. International Journal of Engineering and Management Research (IJEMR), 2018, 8: 1-6.
[4] Chejne F, Macía A, Estrada D, Velásquez HI, Londoño C. Radiation model for predicting temperature evolution in solar cooker. Dyna, 2011, 166: 68-74.
[5] Siegel R, Howell JR. Thermal radiation heat transfer, Taylor & Francis, 4th ed., 2002.
[6] Cohen MF, Wallace JR. Radiosity and realistic image synthesis, Academic Press, 1993.
[7] Bradley W. Reciprocal optical test for measuring solar cooker performance. http://www.solarcookers.org/files/5414/2747/1563/Reciprocal_Optical_Test.pdf
[8] Yettou F, Azoui B, Malek A, Gama A. Study and simulation of concentrating irradiance in box solar cooker with tracking reflectors. Revue des Energies Renouvelables, 2012, 15: 661-670.
[9] McCluney R. Solar cooker reflector optical evaluation and design evolution. FSEC Solar Cooker Report, 2001. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-GP-214-01.pdf
[10] Tan T. Fun-Panel. The Solar Cooking Wiki, 2013. http://solarcooking.wikia.com/wiki/Fun-Panel
[11] Ruivo CR. Celestino Solar Funnel Cooker. The Solar Cooking Wiki, 2012. http://solarcooking.wikia.com/wiki/Celestino_Solar_Funnel_Cooker

Sharing government perspective and participation in promoting Solar Cooking in India

Suresh Ruparel

Senior Project Executive(MIS/CST/Biomass)
e-mail: sjruparel@geda.org.in, web: https://geda.gujarat.gov.in

Gujarat Energy Development Agency, 4th Floor,Block No.11 & 12,Udyogbhavan,Sector 11,

Gandhinagar-382017, Gujarat, India

Abstract: Gujarat Energy Development Agency (GEDA) is State Nodal Agency (SNA) of state of Gujarat and was one of the first in India to start large project to promote Solar Cooking in India. During the Conference I will represent GEDA and share the program of GEDA to Promote Solar Cooking and also share the experiences and details of the progress and projects rolled out by GEDA starting from Solar Box Cooking, Solar Parabolic Cooking system for domestic cooking, For Scheffler Community Solar Cooking Systems for indoor cooking to Solar Steam Cooking Systems supported by GEDA with Central and State Subsidy.

We will also share our perspective and experience of supporting the movement starting from advertisements, to participating in exhibitions to having mobile van which goes in rural parts of Indias and schools and events to promote Solar and Sustainability.

To Support Solar Cooking GEDA was one of the co-sponsor of SCI World Conference 2017 at Muni Seva Ashram and is also supporting research projects so that solar cooking becomes for acceptable and popular not just for demo but for cooking.

Indian Government has very ambitious Plan to promote Solar and 100 GW is planned and in addition another 60 GW and during my visiting to share and learn at Consolfood2018 in FARO I will interact and connect with pioneers and promoters from other parts of worlds and learn from experts and take their inputs how to introduce innovative technologies and support system to popularize solar cooking.

Keywords: solar cooking, promotion, supporting

A NEW DESIGN FOR A BOX-TYPE SOLAR COOKER

Kota Anjaneyasarma

Visakhapatnam Steel Plant, 122/C, Sector-1, Ukkunagaram, Visakhapatnam, Andhra Pradesh-530032, India

email: sarma_ka@vizagsteel.com

Abstract: By concentrating sun rays with panel type reflectors into a compound parabolic trough kept in an insulated box for cooking food with less and minimal intervention of people for tracking the sun and to cater the common man day to day cooking needs .Cooking needs are of boiling, baking and frying for temperatures up to 120 ºC with assured performance justifiable quantity of food and boiling time period.

Keywords: sun-ray analysis, tracking reflector, parabolic trough, overlapping reflections, solar thermal cooking,

Membrane FixFocus mirror as multifunctional solar power station for diverse village applications

Jürgen Kleinwächter

'Free-Lab' for Solar Village Technologies, Healing Biotope Tamera,Monte de Cerro, 7630-303 Colos, Portugal

e-mail: j.kleinwaechter@hotmail.de

Abstract: Solar radiation is by far the strongest and cleanest energy source on earth. Due to the high surface temperature of 5500°C of the Sun and its room-angle of half a degree seen from earth, the solar rays reach practically in parallel our planet. This means, that by using a paraboloid reflector tracking in two axes the sun, very high energy densities of over one MW/m^2 are reached in the focus. Consequently usable temperatures up to 1500°C can be reached (and by using a CPC as secondary optic the concentration can be further enhanced, making even higher temperatures possible). This reachable temperature spectrum corresponds to the full process temperature range used today by centralised industries. The corresponding products (Ceramics, metal alloys, chemical products, medical products, food processing and many more) are normally considered to be only economically producible by great industries using fossil fuels or electricity. This means not only that the classical production of process heat contributes to a large extent to the global greenhouse gas emissions, but that a large population in the villages of the south are not enough wealthy to buy this products-consequently the scissor of disparity between the rich and the poor nations is growing. To prevent this negative fact, the author and his late father developed in the eighties of last century to the demonstration stage a novel type of light weight membrane concentrator, the 'FixFocus' (FF), with following characteristics: stationary focus at ground level, formation of the required excentric paraboloid reflectors by pneumatic deformation of thin reflective and transparent membranes, low overall material requirement (and therefore low 'Grey Energy' to produce the system), locally producible and job creation.

Recently the 'Free Lab' in Tamera simplified the Prototype in such a way, that local production can be executed with relative simple meanings, all by maintaining high efficiency ('Eco-Hightech').

Colleagues of the author (Fernando Chacon, Douglas Baillie, Daniel Müller, Paul Gießler) will report in conference CONSOLFOOD2018 about the praxis experiences to cook , bake and fry all type of meals very efficiently around the clock with the FF. It is evident, that temperatures above 300°C are not useful for food processing; however, the high optical accuracy of the FF mirror makes possible cavity receivers, which due to their minimal radiative , transmission and convective losses allow to store process heat day and night. This represents the key element for local autonomy and to tape into the 'Solar Abundance' represented by the photonic solar energy stream reaching the most distant places. A FF mirror of only 3,5 m^2 aperture area is capable to replace in average in sunny countries per year about 8 tons of cooking wood.

Free Lab Tamera and the SunOrbit R+D Company (www.sun-orbit.de) are working to combine the FF Concentrator, beside its food processing capacity, on following realizations: i) Coupling with the sunpulse Stirling Engine for 24 hr, ii) creation of power (electrical and mechanical) and heat (co-generation), iii) processing of ceramics, metals, building materials, iv) lighting rooms and caves using special light pipes, v) photocatalytic water cleaning and vi) photocatalytic water splitting.

Keywords: Air deformed membranes; FixFocus; Cavity receiver; Eco Hightech; Around the clock storage of process heat; Extreme light weight-low 'Grey Energy'; Abundance; Local autonomy.

Hot Stone Cooking with an Ultralight Membrane Solar Concentrator

Fernando Chacon , Douglas Baillie, Daniel Müller, Paul Gießler

Solar Village-Technology, Healing Biotope-Tamera
Monte do Cerro, 7630-303 Colos, Portugal
e-mail: fernando.chacon@me.com, web: http://www.tamera. https://www.tamera.org/project-groups/autonomy-technology/

Abstract: Over the last 3 years the Technology Team in Tamera's SolarVillage testfield has developed a 3,5m^2 high-precision solar concentrator. Its inflatable membrane technology using 100μm ETFE (Ethylene-tetraflouroethylene) film creates an excellent lightweight paraboloid form. The off-axis design allows the focus to remain stationary and close to the ground while the concentrator tracks the sun. The concentrated solar radiation falls into a well-insulated cavity receiver where it is absorbed. The precision optics create a small focus (< 6cm) making it possible to reach high temperatures and to minimize radiation and convection losses in the receiver due to the small area of the aperture. Black granite stones in the receiver serve as absorbing surface and as thermal storage. These 10 kg stones can be taken out of the receiver onto a cooking surface as needed, and each deliver about 30 minutes cooking time. After heating during the day, the aperture is closed and the thermal energy in the receiver can be stored over several hours. Depending on the stone temperature, cooking at night or in the early morning is then possible.

Keywords: Hot Stone Cooking, Off-Axis Solar Concentrator, Energy Storage, Membrane Technology

PHOTOVOLTAIC SOLAR COOKING WITH THERMAL ENERGY STORAGE (TES)

Antonio Lecuona-Neumann[1] *, Daniel Victoria[1], Javier A. Perteguer[1], Ernesto García-Arés[2]

1: Grupo ITEA, Departamento de Ingeniería Térmica y de Fluidos, Universidad Carlos III de Madrid
Avda. de la Universidad 30, 28911 Leganés, Madrid, Spain
lecuona@ing.uc3m.es, http://www.uc3m.es
2: Oficina Técnica, Universidad Carlos III de Madrid
Avda. de la Universidad 30, 28911 Leganés, Madrid, Spain

Abstract: *Photovoltaic cooking seems viable under some circumstances.*

Solar cooking during the night seems an interesting capability as well as during cloudy intervals during the day.

Electric energy storage in batteries can cost more than the rest of the Photovoltaic (PV) cooking system, namely: panel, wiring, controller and end converter into heat. The supply of the heavy batteries to remote locations can increase their price even more. When they are abandoned after their operative life as residues it involves the risk of pollution.

Thermal energy storage can be an alternative to batteries for a lower price and complexity. Phase Change Materials (PCM) offer high energy density, viable for cooking if their melting temperature is above 100 ºC.

Erythritol is a PCM that offers advantages over some other candidates. Its thermal conductivity seems too low for a fast enough heating and cooking so that its enhancement seems a requirement.

The paper offers the result of some experiences to develop an electric utensil capable of both direct use of the PV electricity through a simple electronic controller and independent use the AC grid power when desired. Moreover, it implements a TES.

The aim is to propose some designs of utensil that can be purchased at a reasonable price and implemented after modification using local manufacturing and maintenance.

The reported results indicate that the design is viable, but still, some problems need to be solved.

Keywords: Solar, Thermal, Food processing, Photovoltaic, TES.

1. INTRODUCTION

The usual way of solar cooking is through the optical/thermal way [1]. Solar radiation, either directly or optically concentrated, dissipates as heat on a surface highly absorbent of the sun rays. This heat is directly or indirectly used to cook. Temperatures high enough for cooking are reached thanks to the optical concentration or/and by producing a greenhouse effect by a glass or plastic sheet covering the pot. Efficiencies based on the incident solar power $P = A_a G_T$ [2] on the aperture area A_a rarely exceed 25% [1]. Typically this heating is externally applied to the pot containing the food, thus carrying high heat losses to the ambient. Only some very large solar thermal cookers apply the heat internally. This is the case of producing steam with the solar heat and bubbling this steam inside the cooking food; but in this case, the maximum temperature cannot be higher than the steam $<$ 150 ºC.

If solar electricity would be produced, a Joule effect resistance $R = V \cdot I^{-1}$ could be located in contact with the food and both could be thermally insulated to gain the higher temperatures appropriate for fast cooking or for the desired recipe. The power produced is $P = VI = V^2 R^{-1}$, being V the voltage applied to R and I the intensity passing through the circuit.

At low scales, electricity is produced by the photovoltaic (PV) effect that with commercial technology nominally surpasses 18% of peak efficiency, and on average higher than 15% seems not real-world. This would require about 50% more aperture area exposed to the sun rays. PV panel are massively produced today so that their prices has fallen to below 0.5 € W_p, making a family size solar cooker of $A_a = 2\ \mathrm{m}^2$ yield at the peak irradiance $G_{T,p} = 1\ \mathrm{kW\ m^{-2}}$ up to a peak power $P_p = 360\ \mathrm{W}$ with a procurement cost of 180 €. Actually 310 W_p are commercially declared for 2 m^2 single panel. This seems satisfactory, but the price, for a solar cooker. With the high thermal insulation possible, heat losses to ambient can be low.

But one has to bear in mind that the electricity produced can be used for other purposes along the day. Especially interesting are charging portable LED based lights, flash lamps and also mobile phones, among others, as their charge capacity is minute compared with the theoretical production of the referred PV panel of 1.5 kWh day^{-1} as annual average in sunny regions. In contrast, heating 2 kg of water from 15 ºC up to 100 ºC consumes 0.2 kWh. Moreover, the expected life span of a PV panel is 20 to 30 years, making the electricity cost ($LCOE \sim 6\ \mathrm{c€\ kWh^{-1}}$) competitive with the grid supply, at least for remote locations. In addition to that, safety of the inhabitants is increased.

Thus a big step can be produced to families located in remote and even isolated locations, switching from burning wood for cooking and oil for lighting to a fully electrified sustainable home. This is only ideal, as the solar electricity would not be available every day, but the big step would be certainly real. Establishment of a family or community small electricity (smart) grid now is open, even an ulterior larger one could be easily implemented. Hydro, wind or biomass based electricity becomes possible as a renewable energy backup. Actually some initiatives reckons the high value of PV for lighting and telecommunication, but as is frequent, ignores solar cooking because of the higher power required. Such are M COPA [3] and Pay-As-You-Go [4].

An additional advantage of PV cooking can be claimed. This is cooking indoors, avoiding sun exposure, bad weather pains, food contamination by dust or animal intrusion and even health risks in high altitude locations. Intimacy is also gained. The daily effort of collecting the thermal solar cooker after its use outdoors disappears and indoor space for its stowage is not necessary.

The capability of cooking when solar is not available is greatly appreciated, typically dinner and following day breakfast. The use of batteries for storing electricity is common in PV, but their price is high, probably doubling the other parts total cost. The most common lead/sulphur type is

contaminating, very heavy and their life is short. Moreover its discharge capacity is much less than the nominal capacity. The avoidance of batteries seems of high interest.
Maximum solar collection is produced by a two-axis motorized solar tracking. This seems impractical for the intended application. Only some manual seasonal elevation adjustment seems reasonable to compensate solar declination. The panel should be oriented toward the equator with local latitude tilting.
This paper proposes an innovative PV cooker. It is based on a DC circuit, not requiring batteries for operating. Instead a Phase Change Material (PCM) Thermal Energy Storage (TES) is proposed. This requires a specific control circuit for the PV panel, whose development results are described. The reason for that is that commercial PV controller are based on a battery charger, thus requiring to be connected to a battery bank.

2. PV SOLAR COOKING PROPOSAL

A single panel fixed to the roof feeds a proprietary circuit controller to adapt the operating curves of the PV panel under varying sun radiance to a fixed resistance added to an electronic commercial cooking pot modified to suit this new application, but not renouncing to its original purpose. The maximum PV power is applied. Part load capability should be an ulterior development, as well as external electric charging, as Figure 1 depicts. As an option the inner container can incorporate a PCM-TES. If the thermal insulation of the electrical pot is not enough, after cooking process A, the food can be moved to a highly insulating device, process B, similar to a “hay basket” heat retention device [1], Figure 1, either with the PCM-TES or without it.

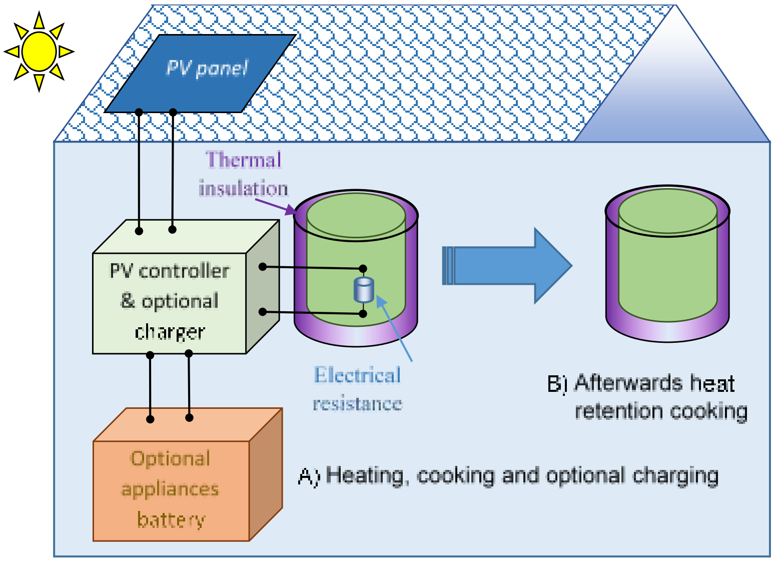


Figure 1. General layout of the proposed PV cooker. PCM-TES not explicated.

3.1. PV operating curves and controller

Figure 2 depicts the typical voltage-intensity $V-I$ and the corresponding voltage-power $V-P$ curves of a silicon PV panel under different solar irradiations. Intersections with a fixed load resistance R [Ohms] directly attached are indicated with round points, as well as the Maximum

Power Point (MPP) combination, $\max(I \cdot V)$, with stars. This corresponds to the tangent hyperbola $I \cdot V = \text{const.}$ The selected value of R in this particular case makes that the star and circle coincides at an irradiance of 1.0 kW m^{-2}. As one can notice, even in the present case, where R matches the MPP at maximum expected irradiance at noon, during lower irradiations the power obtained diminishes drastically (round points). A higher resistance would increase the extraction of electrical power, but this would require a high power switch, expensive and probably dangerous. The $V-P$ curves show the Maximum Power Point Tracking (MPPT) line, joining the stars that define the maximum power deliverable at all irradiances. As one can notice, the appropriate $V = \text{const.}$ line approaches the MPPT line fairly well. This raises the idea of conceiving an electronic circuit that instead of incorporating an MPPT algorithm using a microprocessor (as it is commercially available), simply controls a PV panel adjustable input V by modulating the duty cycle of a pulsed solid state circuit, named pulse width modulation PWM circuit. This way the PV panel is periodically connected and disconnected from the load R, using a MOSFET solid-state relay, so that the RMS value of the input V is constant. This can be performed with a simple circuit. With an ideal circuit the vertical of constant voltage V would be described when the radiance varies.

A circuit has been developed keeping in mind to minimize the cost and the possibility of being manufactured, repaired and maintained in low technology locations, actually on-site. For that, a single side printed circuit board (PCB) is necessary. The price to pay is some power loss in the circuit. Figure 3 depicts the circuit. Test already performed indicate that for irradiances above around 600-700 W m^{-2} the present control circuit is not necessary, indicating a way of improvement.

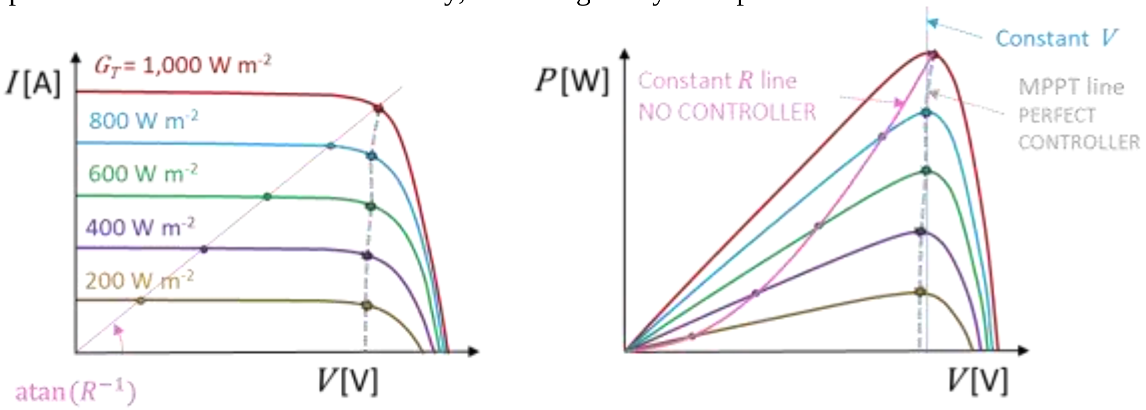


Figure 2. Curves of a PV and a MPP matched resistance R. (left): panel $V-I$ vurves at several irradiances. (right): corresponding panel $V-P$ curves showing the MPPT line (grey dashed line) and the approximating $V = \text{const.}$ line (vertical thin continuous line).

3.2. Cooking utensil and PCM-TES

A locally manufactured utensil formed by a pot with the embedded single resistance R could serve as an embodiment of the concept. In the present research an alternative option has been chosen, based on a commercial electronic pressure pot similar to a rice cooker, manufactured in China. It consumes up to 900 W @ 230 V AC, with an on-the-shelf cost of around 30 €. As Figure 4 depicts its baseplate has been mechanized for incorporating a plane DC resistance for 24 V nominal PV power. This way future operation using AC grid is maintained. Figure 4 shows its construction and modifications implemented. Moreover, the removable inner pot has been separated in two parts by an aluminum sheet:

I. The lower part forms a vessel or tank containing 3.0 kg of a PCM that is a sugar polyol, erythritol, industrially used as a low-cost calorie-free sweetener [5]. This substance show a phase change at 118 ºC involving 340 kJ/kg heat, an amount similar to ice melting/solidification. It is edible and of low cost. Aluminum tubes are incorporated to the PCM to enhance heat conductivity. All the test performed have not shown appreciable supercooling effect. This way the heat coming from the bottom located resistance directly heats the PCM storage, Figure 4.

II. The upper part of the inner pot is reserved for indirect cooking, either using solar heat simultaneously to PCM charging or using just the TES-PCM off line after it was charged during the day. In any case, an empty inner pot can be used for direct cooking.

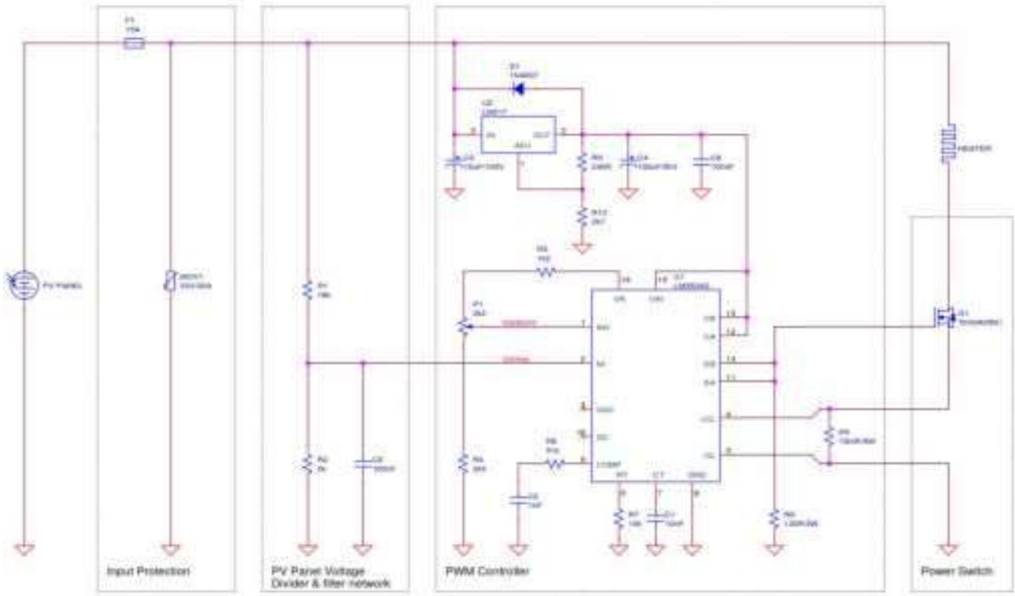


Figure 3. Circuit for operating without batteries. An internal voltage regulator serves as a reference.

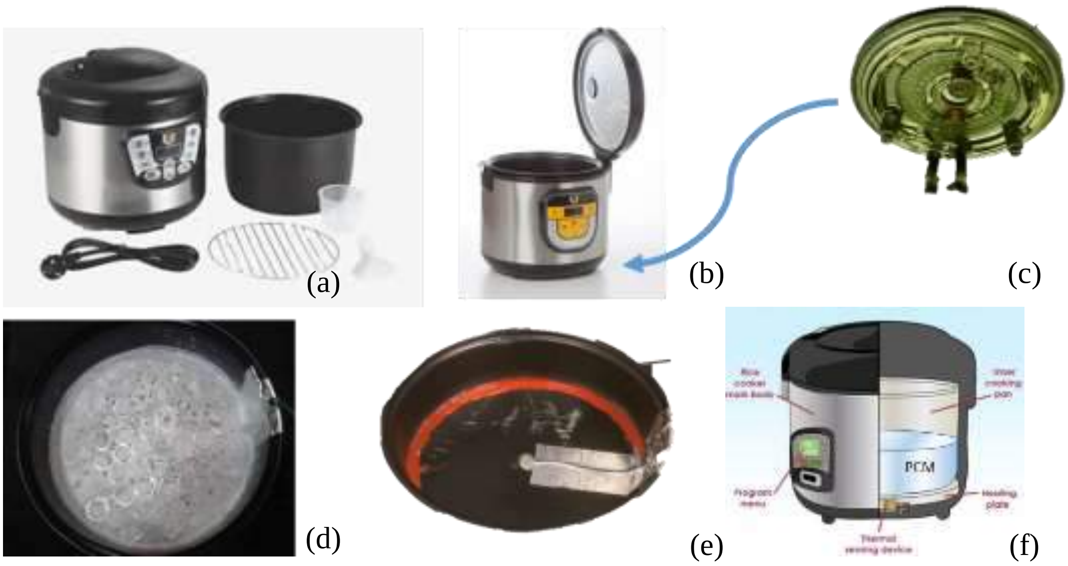
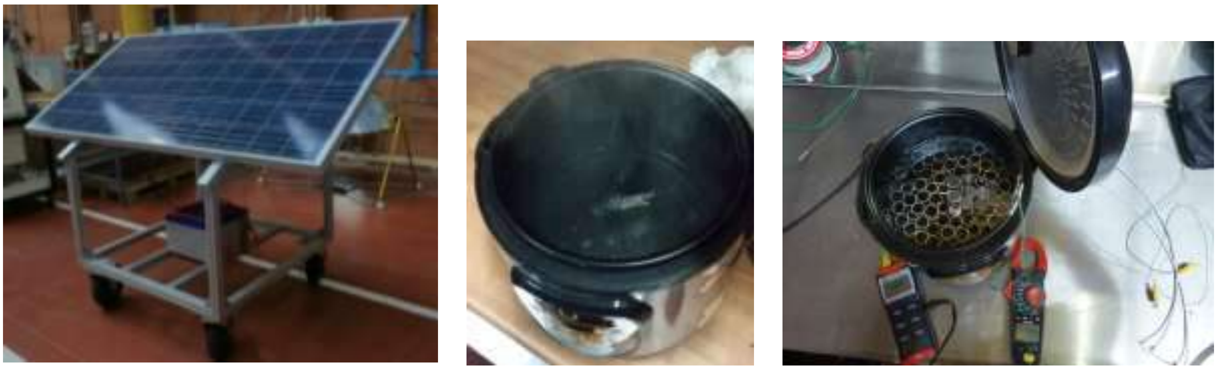


Figure 4. (a) Original electronic pot set showing the removable inner pot of the utensil. (b) Open utensil showing the pressure cooking valve and the thick insulating walls. (c) Modified baseplate showing the inner flat DC resistance for PV. (d) Erythritol powder filling the lower part of the inner pot and showing the aluminum tubes. (e) Top of the inner pot PCM-TES tank leaving space for cooking; it shows the top monitoring thermocouple. (f) diagram of the design layout.



(a) (b) (c)

Figure 5. (a) Test rig. (b) boiling test without PCM. (c) PCM melting test with the TES vessel open.

4. RESULTS

The test have been performed following well documented practices to determine basic performances of the cooker, such as described in [1]. Here only some of them are described.

For the experimental determination of the capacity of retaining heat by the electronic pot thermal insulation, a no load (water empty to avoid evaporation losses) cooling test has been performed. Figure 6 shows an initial cooling down to the phase change temperature, when temperature stabilizes, during 5.8 h. This period reduces to 4.0 h when the inner pot is loaded with water. After that, cooling continues thanks to sensible cooling, reaching the 70 ºC line indicated after 9.3 h, Figure 6. It indicates that dinner cooking is possible using the bare PCM-TES device, but not overnight breakfast cooking, although food heating and sanitary hot water preparation is possible the following morning. If the charged pot is moved to a "hay" basket the constant temperature period increases up to 14 h, enabling the following day breakfast cooking.

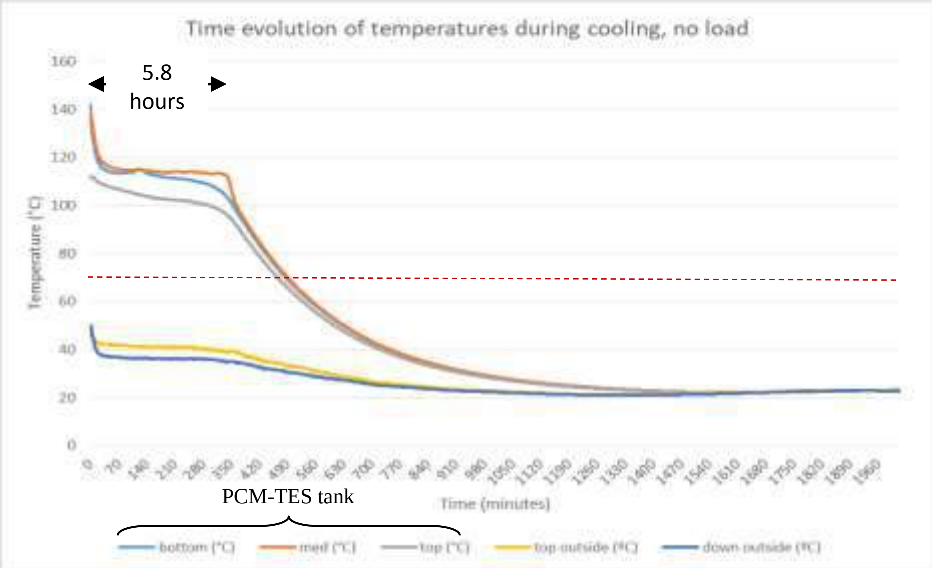


Figure 6. No load cooling test of the electronic pot with the PCM-TES incorporated.

Figure 7 shows the dynamic capability of the electronic pot, not loaded and with the PCM-TES fully charged, to heat successive loads of cold water, with intermediate un-loadings. It shows that 74 ºC are reached in the three first loads after 25 minutes each. The fourth load does not reach this temperature, barely surpassing 60 ºC.

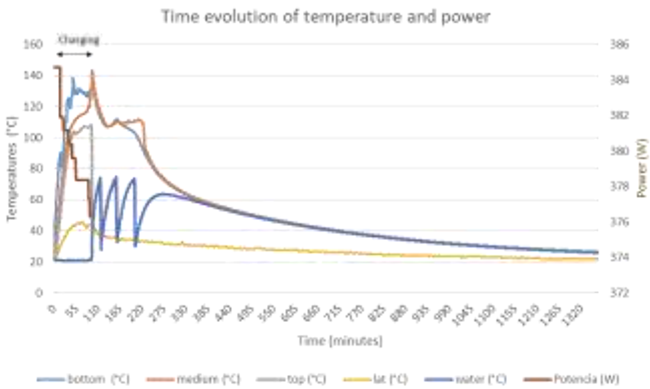


Figure 7. Charging the electronic pot incorporating the PCM-TES and afterwards loading four consecutive times with 2 kg of ambient temperature water to be heated.

5. CONCLUSIONS

- A new type of solar cooker has been developed. It uses a family owned single PV panel and no batteries for storage. Instead a PCM-TES storage serves for cooking when the sun is not shading. An edible, low cost PCM, erythritol has been tested successfully filling a moveable kitchen utensil.
- A composite material has been developed for enhancing the heat transfer inside the PCM. For that, short pieces of aluminum tubes have been tested. For a lower cost steel can be used.
- A proprietary PV control basic circuit has been developed showing also that simple electronics can be appropriate for supporting the PV cooker and at the same time propel a local technological development. This circuit can be refined to implement a better control and incorporating auxiliary services, such as incorporating a USB charging port.
- Results indicate a promising concept. Still practical testing is needed before a pilot deployment.

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REFERENCES

[1] Lecuona-Neumann A, Cocinas solares. Fundamentos y aplicaciones. Herramientas de lucha contra la pobreza energética. Barcelona: Marcombo, 2017.
[2] Duffie JA, y Beckman WA. Solar Engineering of Thermal Processes. Hoboken, New Jersey: John Wiley & Sons, 1991.
[3] http://www.m-kopa.com/products/ accessed 2018/01/07.
[4] http://www.wri.org/blog/2017/02/pay-you-go-solar-could-electrify-rural-africa accessed 2018/01/07.
[5] Lecuona, A., J. I. Nogueira, R. Ventas, M. C. Rodríguez-Hidalgo, and M. Legrand. Solar cooker of the portable parabolic type incorporating heat storage based on PCM. Applied Energy 111 (2003): 1136–1146.
[6] CYTED Project “ALMACENAMIENTO DE ENERGÍA SOLAR PARA COMUNIDADES AISLADAS” Coordinator: Juan José Milón, UTP, Arequipa, Perú. http://www.cyted.org/?q=es/detalle_proyecto&un=933 and https://www.facebook.com/cytedAESCA/ accessed 2018/01/06.

SOLAR COOKER AS A PUBLIC FURNITURE. THERMAL MODELING

Antonio Lecuona-Neuman[1] *, Eduardo de la Rocha[1], José I. Nogueira[1]

1: Grupo ITEA, Departamento de Ingeniería Térmica y de Fluidos, Universidad Carlos III de Madrid
Avda. de la Universidad 30, 28911 Leganés, Madrid, Spain
lecuona@ing.uc3m.es, http://www.uc3m.es

Abstract: *Solar cookers and solar oven are typically operated by trained people and after operation they are collected for cleaning and protecting them of outdoors weather and spoilage. Exceptions are large solar concentrating solar cookers, such as the ones based on the Scheffler type. But they are always protected outdoors.*

The possibility of having a solar cooker that can be left outside permanently with no maintenance, but just a minimum, and that can be accessed whenever the user desires would be very interesting.

This calls for a heavy and robust design. The risk for eyes precludes the sun concentrating types. Still some risk for children ask for an elevated construction. Sometimes a heavy cooking is not necessary, e. g. schools, workplace, beaches, rest areas of parks, etc. where already prepared food just need heating. Preventing the contamination by dust calls for an enclosed construction, like an oven.

Within our team, taking in mind those considerations, and after a conceptual stage the result is a solar cooker/oven of a new kind: it should be like any other urban furniture.

This solar cooker works like a flat solar collector. The absorber plate is thick in order to transfer by conduction the heat to an attached cavity under it, forming the oven. At the same time this thick plate acts as a heat storage, so that when the user opens the oven, it is already hot. In order to maximize solar collection, azimuthal manual orientation is allowed with a latch for wind resistance.

The non-conventional layout and operation asks for a full modeling for ascertaining its potential and minimizing cost.

The paper offers the numerical detailed modeling and the results, supporting the concept.

Results show that a 1D lumped parameters modeling gives orders of magnitude of the relevant parameters, but because of the extension of the absorber plate (2m×2m) a low order 2D model better predicts the behavior, although the computer effort is higher.

Keywords: Solar cooker, oven, public furniture, community, renewable

1. INTRODUCTION

Solar cooking is typically performed with devices of:

- Small format. Individual or family size of aperture area $A_a \sim 1\ \mathrm{m}^2$. They are collected from the outdoor location after their use in order to avoid spoilage.
- Intermediate format. They serve small communities. $A_a \sim 10\ \mathrm{m}^2$. They stand outdoors. Typically they are of the concentrating type, such as the Scheffler type.
- Large format. Such are those preparing hundreds or thousands of meals at the same time. There is a field of solar concentrators and a heat carrying fluid to cook remotely, typically indoors, in a communal kitchen. $A_a \sim 100 - 1{,}000\ \mathrm{m}^2$.

Typically all these types of solar cookers are of use in regions where there is a necessity of using the solar energy instead of a conventional heat source [1]. The main reason is to avoid the many inconveniences of burning wood or another type of biomass. Such are the formation of toxic fumes, the heavy work or high cost of procuring firewood, the risk of fire, deforestation, among others.

There is a lack of knowledge of the capabilities of solar cooking. Actually, much people initially reject the idea of cooking with the sun or just feel surprised. Moreover, solar cooking is almost non-existent in developed countries as the energy consumption for cooking is a small fraction of the energy bill, especially if the use of pre-cooked food still advances more than it has nowadays. Only reduced groups master their use and possibilities. This is in contrast with the well-known renewables energies, like photovoltaics, wind and solar thermal for water preparation or for the production of electricity. They are much publicized in the media.

All this is a barrier for getting attention and help for developing actions to fight energy poverty in the undeveloped and developing countries, where the use of biomass is causing much trouble and where solar cookers can be of much help.

Having a solar cooker that can be used by anyone as you go, that does not need a permanent care and that can stand outside under the view of the general public can be of much help in developed countries for:

- Creating conscience of the energy poverty.
- Familiarizing with solar energy.
- Making solar cooking visible.
- Avoid wild fires caused by outdoors barbequing.
- Avoid fumes and smells in a condominium caused by barbequing.
- Heat a meal and even cook it with the sun in open public spaces, such as parks, beaches, etc. Also in shared private patios.
- Educate children in renewables and being clean in the energy use, both in open public spaces and in schools.
- Show an image of corporate responsibility by offering the employees a way of having a warm lunch at work.

Such solar cooker seems not existent. In energy poor countries this cooker can perform similar duties, but also can be useful as a first entrance for disseminating solar cooking.

2. DESIGN

A concept study has been endeavoured to develop a solar cooker design that can offer no-compromise performance in a permanent outside location, being robust and resistant to weather action, as safe as possible, even for children, and ready to operate. Moreover, it should be resistant to vandalism. A grounded installation was conceived as necessary and with simple operation, including sun tracking. For that a non-concentrating design was decided, more like an oven that an open air cooker. Some kind of simple and durable heat storage is necessary. The result of this study was a design, sketched on Fig. 1. It actually is an urban furniture with a look as a tree, giving some shadow to the users. This version is tall, trying to avoid dog and children damage, but a less elevated version is possible. The vertical post allows a manual sun tracking with a lock function to avoid motions caused by wind. Only a manual rotation every 30 min approximately. The azimuthal orientation is mainly toward the equator. The tilt angle is fixed to near the local latitude when manufacturing.

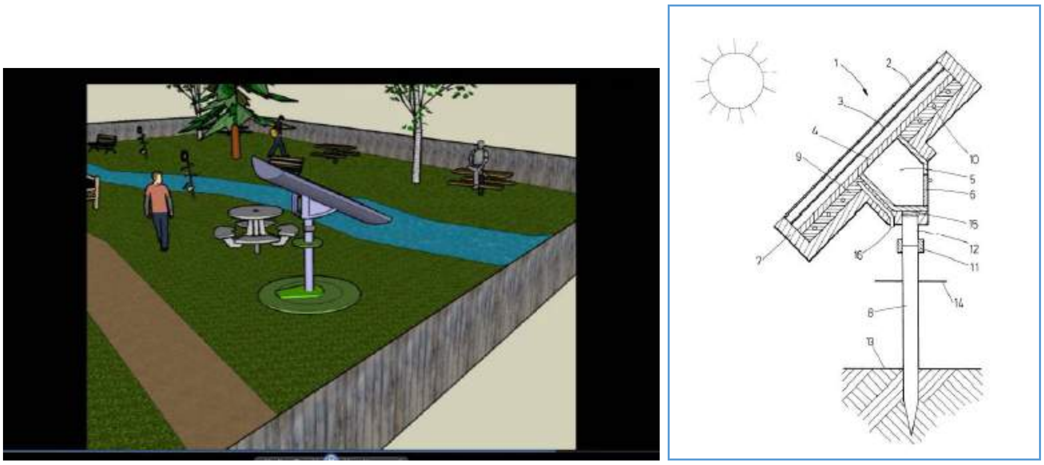


Figure 1. (left) Solar cooker rendering, shown in a park. A step allows reaching the oven door. A shelf facilitates cooking manoeuvres and ingredients storage. The height avoids children damage. (right) cross cut of the design, including extra heat storage below the absorber plate and the capability of heating water for cleaning.

The solar is composed by two main parts. The upper one is a 1.5×1.5 m to 2.0×2.0 m flat panel solar collector with heat storage capabilities. One or two parallel flat glass upper covers give the greenhouse effect. The lower one can be made of plastic. Below them there is a flat absorber plate made of thick metal, either aluminum of iron. Its purpose is to store and conduct the absorbed heat to the center part where the oven is hanging. Its upper side can be black painted or covered with solar selective paint either with adhesive optically selective film. On the lower side, a small box is soldered, around 30 to 40 cm side length, forming the oven. Its thick walls are heated by conduction from the absorber plate. An oven transparent double walled door allows managing the food under cooking. The oven box supports the device as it is connected to the central column, which in this embodiment is founded on the ground. The side and lower sides are thermally insulated with a thick layer of fiberglass mat that is externally protected to be impervious. This design has been patented [2].
The unconventional proposal calls for:

- A thermal modeling that estimates its performances and allow to optimize the design.
- A public security study and a civil regulations study.
- An evaluation of a prototype including a user’s and by passers survey to gather their opinion evaluation in terms of social value.

This paper addresses the first duty. The main questions are: Does this layout reach high enough temperatures? Is it fast enough for heating and cooking? Does the heat last enough to work on the go?.

3. THERMAL MODELING

The first approach is to resource to the simplest modelling. This is a lumped parameter 1D thermal model of capacitances and resistances, as indicated in Fig.2. A better modelling is obtained discretizing (Δx and Δy) the absorber plate surface, yielding a 2D model with more time dependant unknown temperatures to be solved. This modelling introduces the thermal conduction resistance in the x and y direction. This means the plane of the absorber plate. Side heat losses are neglected in front of upper and lower convection and radiation heat losses. Water is allowed to boil. Fig. 3 indicates the thermal circuit and the modes of heat transfer considered.

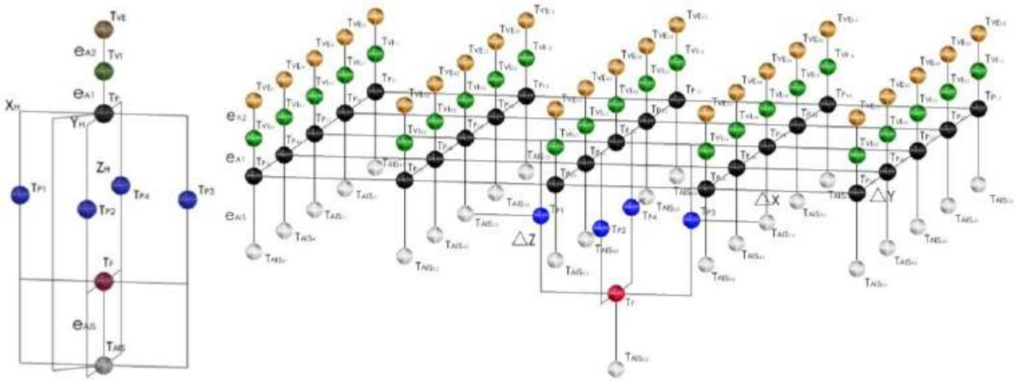


Figure 2. 1D (left) and 2D (right) temperature nodes of the solar oven, ambient temperatures omitted. Bullet are for temperature nodes, colors: brown and green are for the two glass plates with $_A$ for intermediate air. $_E$ for external and $_I$ for internal glasses, black are for the absorber plate $_P$, blue are for the oven lateral cavity walls $_P$, red are for oven bottom wall $_F$, and grey are for the lower insulation $_{AIS}$. Δz is the oven average height. e is for uniform thicknesses.

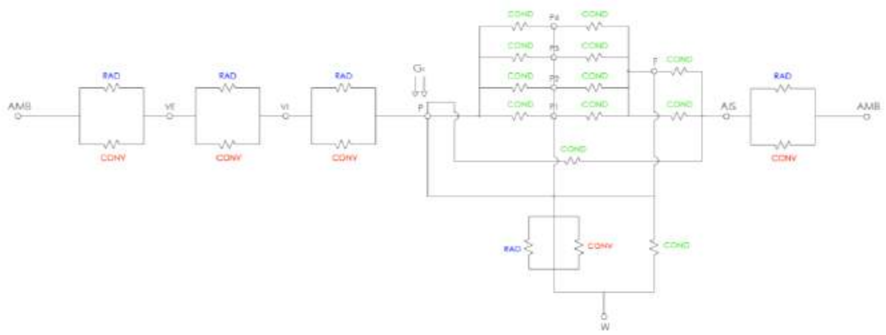


Figure 3. 1D thermal circuit of the model. G_T indicates the tilted solar irradiance. W is water and pot.

3.1. Equations

The general equation is heat conduction with temperature T. The thermal diffusivity is $\alpha = k\rho^{-1}c^{-1}$:

$$\nabla^2 T + \frac{\dot{q}'''}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

$\dot{q}'''$ is the volumetric net heat power, solar input when applicable and convection and radiation losses when applicable. This equation is discretized and the material properties, boundary and initial conditions applied. Explicit time-marching algorithms have been implemented in Mathcad® to solve the system of simultaneous equations for each time step $p \rightarrow p+1$. This way $T^{p+1} = A \cdot T^p + B$.

Lateral losses are avoided as: $T_P{}^p{}_{\begin{cases}0,n\\6,n\\m,0\\m,6\end{cases}} = T_P{}^p{}_{\begin{cases}1,n\\5,n\\m,1\\m,5\end{cases}}$.

4. RESULTS AND DISCUSSION

Table 1 presents the main parameters of the solar cooker modeled. The heat transfer modes considered are between:

- Glass plates, VI and VE: convection and radiation.
- Absorber plate, convection and radiation with VI and conduction with AIS and P1 to P4. AH convection and radiation with average temperatures of the rest of oven walls.
- Bottom oven wall (F) and rest of oven walls by convection and radiation using average temperatures of P1 to P4.
- Water temperature is limited to $T_w \leq 373\,\mathrm{K}$ further heat addition results in boiling.
- All runs start with a homogeneous ambient temperature T_{AMB} with $\Delta t = 10\,\mathrm{s}$.

The internal heat resistances in the pot are so low that numerical instabilities arise for the time step chosen, so that $T_W = T_F$ has been imposed.

The first kind of runs, Section 4.1 have been performed with constant solar irradiance in order to ascertain the cooker basic performances, like characteristic heating and cooling times, water boiling rate and stagnation temperature, and normalized tests, with the aim to compare 1D with 2D models. The second kind of runs, Section 4.2, aims at representing consecutive working days. Here only clear days in Madrid have been considered.

Table 1. Main parameters of the modelled solar oven.

Thermal parameters	Geometrical parameters
Absorber emittance $\varepsilon_{RS} = 0.35$	Optical efficiency: $\eta_o = 0.75$
Absorber absorbance $\alpha_{RS} = 0.91$	Pot size $h_O = 25\,cm$; $r_O = 15\,\mathrm{cm}$
Insulation conductivity $k_{AIS} = 0.038\,\mathrm{W\,K^{-1}\,m^{-1}}$	Mass of water: $m_w = 2\,\mathrm{kg}$
Glass emittance $\varepsilon_V = 0.95$	Tilt angle $\beta = 40\,\mathrm{deg}$
Aluminum emittance $\varepsilon_V = 0.07$	Insulation thickness $e_{AIS} = 0{,}1\,\mathrm{m}$
Pot heat thermal capacity: $C_{po} = 2{,}637.0\,\mathrm{J\,K^{-1}}$	Aperture area $A_a = 2.0\,\mathrm{m} \times 2.0\,\mathrm{m}$
Between absorber and inner glass h_{A1} Hollands et al. 1976	Plates thickness $e = 0.01\,\mathrm{m}$
In between glasses: $h_{A2} = 1{,}25 \cdot (T_{VI} - T_{VE})^{0{,}25}\,\mathrm{W\,K^{-1}\,m^{-2}}$	Oven size $0.4\,\mathrm{m} \times 0.4\,\mathrm{m} \times 0.4\,\mathrm{m}$ av.
Collector top-air: $h_{SUP} = 11.8\,\mathrm{W\,K^{-1}\,m^{-2}}$	Glass plates thicknesses $e_{VI} = 0.03\,\mathrm{m}$; $e_{VE} = 0.05\,\mathrm{m}$
Collector bottom-air: $h_{INF} = 7.0\,\mathrm{W\,K^{-1}\,m^{-2}}$	
Oven-inner air convection with pot: $h_{aH} = 10.0\,\mathrm{W\,K^{-1}\,m^{-2}}$	

4.1. Constant irradiance heating and cooling tests

Heating is first analyzed, with $G_T = 1.0\ \mathrm{kW\ m^{-2}}$ and $T_{AMB} = 30\ ºC$ starts until temperatures stabilize at the stagnation temperature. Figure 3 shows main temperatures with an empty pot to avoid water evaporation. The 1D model gives constant temperature to the whole absorber plate T_P, while the 2D model gives higher temperatures to the outer elements, implying higher heat losses, because heat diffusion toward the center element that is the oven ceiling.

Figure 4 shows the comparison between the 1D and the 2D model. There are evident differences in the heating curve, being faster in the 1D model as a result of thermal diffusion in the absorber plate and lower heat losses. The total power initially reached the correct value of $1.0\ \mathrm{kW} \times 4.0\ \mathrm{m^2} \times 0.75 = 3\ \mathrm{kW}$ and tends to null at a similar stagnation temperature between the two models for long times, around 200 ºC. This seems satisfactory, both as a check of the model and supporting the viability of the concept. This also indicates that the 1D model is insufficient to describe the losses.

Figure 5 indicates the cooling process ($G_T = 0$) of a previously heated cooker, relevant for keeping the cooker hot during cloudy intervals and during the night. Initial temperature was 200 ºC. The characteristic cooling times, time for 1/*e* reduction of the over-temperatures, [1] of the oven floor have been calculated, $t^*_{en0D_H} = 2{,}73\ \mathrm{h}$ and $t^*_{en2D_H} = 10{,}94\ \mathrm{h}$.

Now the boiling capacity is tested. Figure 5 also depict the time evolution when a load of 2 kg of water into the pot is heated. The times for boiling [1] are $t_{eb0D} = 1{,}06\ \mathrm{h}$ and $t_{eb2D} = 2{,}38\ \mathrm{h}$. In this case $t^*_{en0D_W} = 4{,}18\ \mathrm{h}$ and $t^*_{en2D_W} = 6{,}82\ \mathrm{h}$. During boiling the power to water have been computed: $Q_{W0D} \cong 175\ \mathrm{W}$ and $Q_{W2D} \cong 81\ \mathrm{W}$. The steam productions obtained are: $\dot{m}_{eb0D} = 1.250\ \mathrm{g\ h^{-1}}$ and $\dot{m}_{eb2D} \sim 448\ \mathrm{g\ h^{-1}}$ what sees satisfactory even for traditional recipes where much water is supposed to evaporate.

2D model further results:

- With the aim to reduce cost and weight, some test runs were performed with all the metal plate thicknesses reduced to 5.0 mm, obtained only moderate reduction in performance, thus being an attractive option.
- Increasing the load up to 10 kg of water, still boiling is reached, but taking longer times. Not surprisingly higher solar efficiencies are reached.

4.2. Clear day tests

The solar irradiance follows the Hottel model [3]. Ambient temperature follows a sinusoidal variation between a minimum T_{MIN} at 4:00 am to a maximum T_{MAX} at 4:00 pm, solar time. Several test have been performed, as follows: three day time evolution to reach the cyclic steady-state followed by the water boiling test. These runs were performed both in summer and in winter clear days. Some of the results are shown in what follows.

Favorable and extreme circumstances somehow show a range of capacities. June and January have been selected as extreme average temperatures and sunshine in Madrid, as it would be the place for testing a prototype. The aim of this test is to show the capacity of cooking the lunch and dinner after three previous days of equalization:

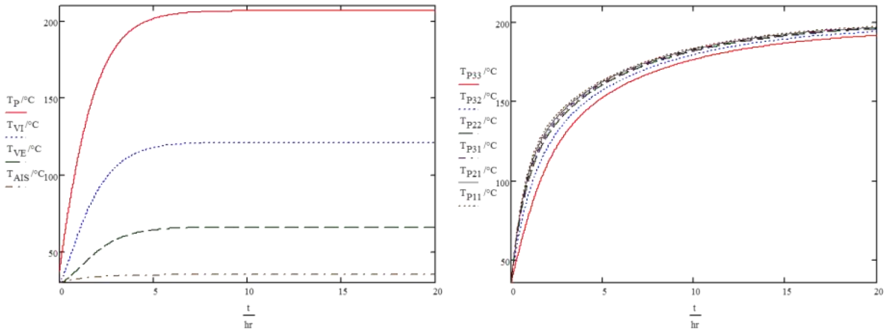


Figure 3. Time evolution of temperatures during no load test under constant irradiance (G_T = 1.0 kW m^{-2}). (left): Main temperatures of the 1D model. (right) temperature of some of the absorber plate elements of the 2D model.

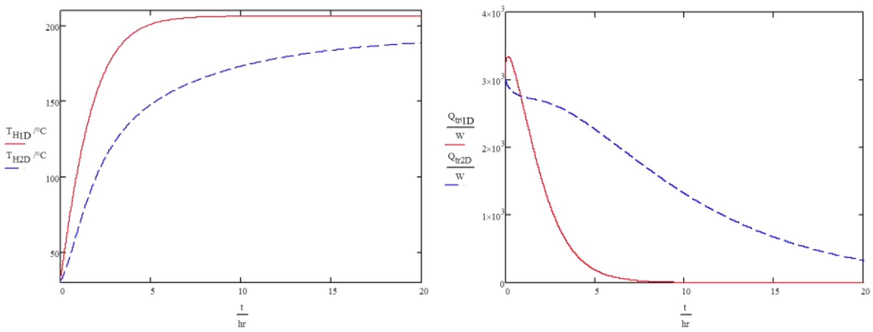


Figure 4. Comparison of time evolution during no load heating (G_T = 1.0 kW m^{-2}). (left): Temperature of the bottom wall of the oven T_H. (right): Total power time evolution. (red continuous line): 1D model and (blue dash line): 2D model.

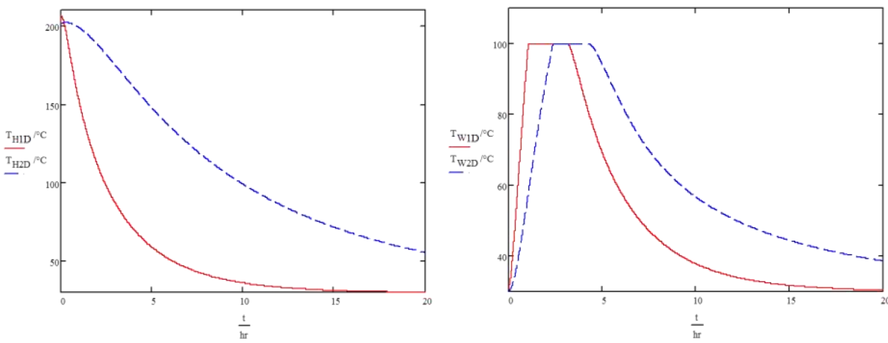


Figure 5. Results of different model and test cases. (left): Temperature time evolution during no load cooling (G_T = 0) of the bottom wall of the oven T_H. (right): 2 kg water load heating (G_T = 1.0 kW m^{-2}) with boiling and cooling. (red continuous line): 1D model and (blue dash line): 2D model.

- June: ambient $T_{MAX} = 40°C$, $T_{MIN} = 23°C$. With no load, maximum oven temperature is 160 ºC at 14:00 h solar time when $t_{ebMIN} = 12$ min, and during the night temperature minimum is 50 ºC at sunshine, $G_{T,\max} = 925\ \mathrm{W\ m^{-2}}$, the water temperature time evolution is shown in Fig. 6. Lunch cooking can be performed in short time. Starting heating at 17:30 h. $t_{eb} = 31\ \mathrm{min}$, and it seems that dinner food could be ready around 20:30 h.

- January: ambient $T_{MAX} = 11\ °C$. $T_{MIN} = 1\ °C$. With no load, maximum oven temperature is 128 ºC at 14:00 h solar time, and during the night temperature minimum is 28 ºC, with $G_{T,\max} = 802\ \mathrm{W\ m^{-2}}$. Lunch cooking is possible but with a larger time for boiling than in summer. Starting at 14:00 h water boiling takes $t_{eb} = 46\ \mathrm{min}$, and boiling lasts for 90 min. Starting later does not allow boiling.

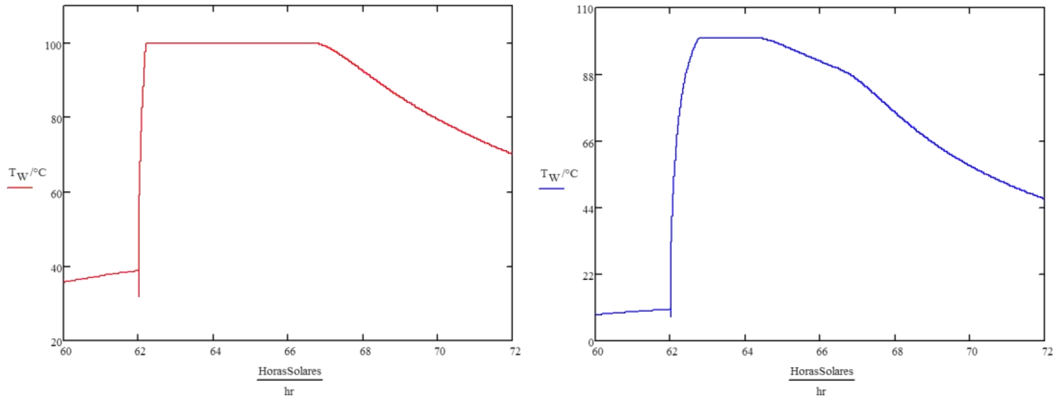


Figure 6. Water temperature time evolution, 2D model, starting with 2 kg water load in the afternoon. (left) June. (right) January. Start at 14:00 h after three previous days of equalization.

12. CONCLUSIONS

- An innovative solar cooker-oven has been proposed of a different kind than current. It will serve as an urban or free-space public furniture to work as you go, being permanently outdoors with minimum maintenance. It incorporates sensible heat storage into its materials.

- The thermal modeling performed promises good performances, supporting the concept. It can cook lunch and dinner during the whole year during a clear day at mid latitudes. Meal heating and sanitary hot water preparation is easier than cooking.

- The heat diffusivity of the absorber plate plane plays an important role in the oven temperature time evolution, so that 2D modeling can represent this phenomenon but not 1D modelling as here presented. The 1D model needs some improvements if better predictions are expected. The introduction of some diffusive element is suggested.

REFERENCES

[1] Lecuona-Neumann A, Cocinas solares. Fundamentos y aplicaciones. Herramientas de lucha contra la pobreza energética. Barcelona: Marcombo, 2017.
[2] Lecuona-Neumann A, Rodríguez-Aumente PA, Nogueira-Goriba JI, Santos Rodríguez M. "Horno solar". Spain Patent ES-2540160 B1, 13th April, 2016.
[3] Duffie JA, y Beckman WA. Solar Engineering of Thermal Processes. Hoboken, New Jersey: John Wiley & Sons, 1991.

MODELING AND TESTING OF A PARABOLIC SOLAR COOKING SYSTEM WITH HEAT STORAGE FOR INDOOR COOKING

N. Mbodji and A. Hajji *

Process Engineering and Environment Research Unit,
Institut Agronomique et Vétérinaire Hassan II
BP 6202-Rabat-Instituts, 10101 Rabat, Morocco
e-mail: ahajji61@hotmail.com, web: http://www.iav.ac.ma

Abstract: *This paper presents a dynamic thermodynamic model of a Parabolic Solar Cooking System (PSCS) with heat storage, along with a comparison of the model solution with experimental measurements. The model uses various thermal resistances to take into account heat transfer between the different parts of the system. The first experimental setup consists of a parabolic concentrator (0.80 m diameter and 0.08 m depth) and a 1.57 L cylindrical receiver. The second experimental setup is composed of a parabolic concentrator (1.40 m diameter and 0.16 m depth), the same receiver and a 6.64 L heat storage. Tests were carried out in Rabat, Morocco between April 24th and July 10th, 2014, and between May 15th and June 18th, 2015. Synthetic oil is used as a transfer fluid and a sensible heat storage. Comparison between predicted and measured temperatures shows a good agreement with a relative error of ±4.4%.*

Keywords: Modeling, Parabolic Solar Cooking System, Heat Storage, Indoor Cooking

1. INTRODUCTION

With increasing population, economic growth, and environmental concerns, the use of solar energy in domestic cooking is becoming a good alternative for sustainable development which will greatly decrease mortality, deforestation, and soil erosion. The World Health Organization (WHO) reports that each year, 1.6 million people die from respiratory diseases caused by indoor air pollution due to solid fuel use for cooking [1]. A domestic solar cooker saves 100 trees in 15 years of life, prevents annually the release of 1.5 ton of CO_2, increases the household purchasing power (by reducing the budget allocated to cooking), and gives more time to women and children who spend 15 h per week to the chore of wood [1]. While most solar cookers in use today do not have heat storage, this feature will alleviate the mismatch between solar heat energy supply and energy demand for cooking. Heat storage is important for indoor solar cooking requirements and will ensure continuity of service, reduce the use of conventional energy, and give a reasonable cooking time compared with conventional cooking [2]. Modeling solar concentrating systems including parabolic solar cooking systems (PSCS) is a key tool in order to increase their effectiveness and optimize their operating conditions. Several models of solar cookers have been proposed in the last years, but most of them dealt with box and oven types of solar cookers. Very little modeling work considered detailed dynamic temperature distribution and heat transfer in PSCS with storage. Existing models of parabolic solar systems—other than cooking applications—emphasize optimization of power production and not maximizing fluid temperature. In cooking systems, the fluid temperature determines not only the types of food that can be cooked but also the cooking time. There is therefore a need to develop a detailed dynamic model of PSCS with heat storage, which will determine the temperature variations in all system components. The present work is focused on developing such a model and on its experimental validation. The “Methods” section describes the experimental system components and the heat transfer processes involved in its operation. Particular attention was given to the receiver, the key element which absorbs incoming solar radiation, converts it to heat, and transmits it to the heat transfer fluid. The “Results and Discussion” section gives the governing equations derived from heat balance relationships and heat transfer coefficient formulas, describes their numerical solution and presents the model validation by comparison with other known models and with the experimental results obtained from prototype testing.

2. METHODS

2.1. System description and operation

Figure 1 shows the schematics of the experimental system used in this study and described in more details in a previous paper [3]. The system is composed of the following elements: a solar concentrator, a receiver, a heat storage tank, and a circulation pump placed in the primary fluid circuit. Synthetic oil SAE-40 is used as the heat transfer fluid, and the system has a two-axis tracking mechanism.

Figure 2 shows pictures of the second experimental setup. The key part of the PSCS is the receiver also called the absorber which is composed of two black iron cylinders as shown in Figure 3. The inner cylinder, with a volume of 1.57 L, has a thickness of 1.5 mm, a diameter of 0.1 m, and a length of 0.2 m and is black acrylic painted to maximize absorption of solar radiation. The outer cylinder is larger with a thickness of 1 mm, a diameter of 0.2 m, and a length of 0.25 m. The absorber is maintained at the focal point by four square sliding iron tube arms expandable from 0.4 to 0.6 m in length. Glass wool is placed between the two cylinders, as insulation to reduce heat losses. The front of the receiver can optionally be equipped with a glass cover. Table 1 gives the system size parameters and optical properties of each material in the two devices.

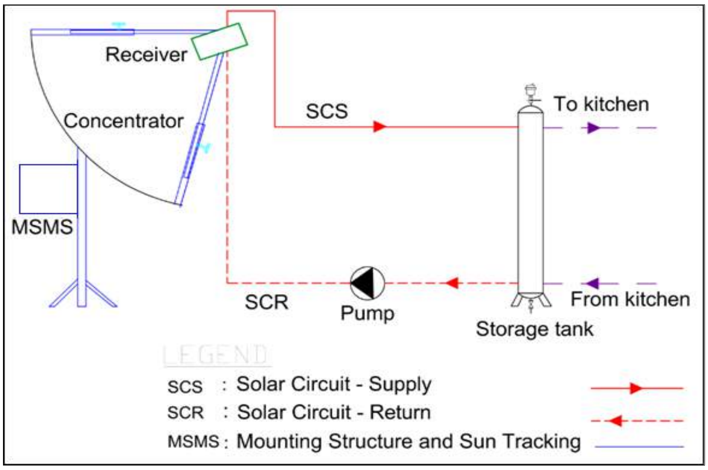


Figure 1. Schematics of a solar cooking system with heat storage

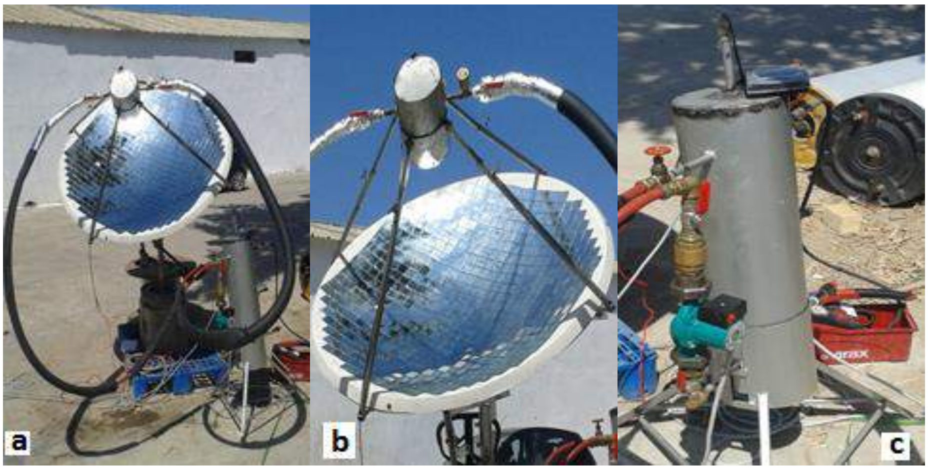


Figure 2. Detailed pictures of the second experimental setup: (a) complete system, (b) concentrator and receiver, (c) heat storage tank and circulation pump

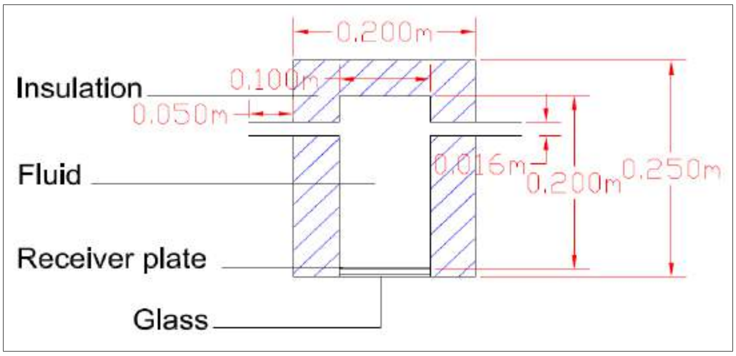


Figure3. Longitudinal section of the receiver

Tableau 1. System size parameters and optical properties

Designation	First experimental device	Second experimental device	Unit
Concentrator			
Diameter	0.8	1.4	m
Depth	0.08	0.16	m
Focal length	0.5	0.77	m
Total mass	5.1	24.7	kg
Surface area	0.353	1.41	m²
Mirror Reflectance	0.85	*	
Receiver			
Diameter	0.1	*	m
Length perpendicular to the aperture	0.20	*	m
Square sliding tube	0.4-0.6	0.7-0.9	m
Insulation thickness	0.05	*	m
Thickness	1.5	*	mm
Mass	2.34	*	kg
Surface area	0.079	*	m²
Intercept factor	0.9	*	
Absorptance	0.8	*	
Glass cover			
Diameter	0.12	*	m
Thickness	6	*	mm
Mass	0.23	*	kg
Surface area	0.014	*	m²
Absorptance	0.01	*	
Transmittance	0.8	*	
Storage			
Diameter		0.12	m
Length		0.65	m
Insulation thickness		0.06	m
Thickness		3.0	mm
Mass		8.97	kg
Surface area		0.26	m²
*: same value in both systems			

2.2. Heat transfer modes

Incident sunlight reaching the parabolic dish is concentrated on the glass cover at the front face of the receiver. A first part of the concentrated solar radiation is reflected to the ambient, the glass absorbs a second part, and a third part is transmitted through the glass cover. The latter part is absorbed by the receiver plate. A small part is reflected back to the glass cover. Heat is transmitted to the fluid via the black-painted metal absorber. The selective coating layer has a high absorptance and a low emittance in order to reduce thermal radiation losses. Figure 4 shows a cross section of the receiver and all heat transfer processes involved. The absorber is considered to be very rigid, and its properties are not affected by temperature. The thermal resistances and the different modes of heat transfer between the external environment (ambient and sky), the receiver, and the fluid are depicted in Figure 5. We take into account the energy stored in each node and consider a one-dimensional space temperature variation in the receiver and heat storage tank. The different heat losses, which are conduction through the receiver insulation, convection from the receiver to the ambient air, and radiation from the receiver to the sky, are also considered in a similar manner as Guendouz [4] and Rongrong et al. [5]. For evaluating the different heat loss coefficients, we used the equations presented by Duffie and Beckman [6] and Incropera et al. [7].

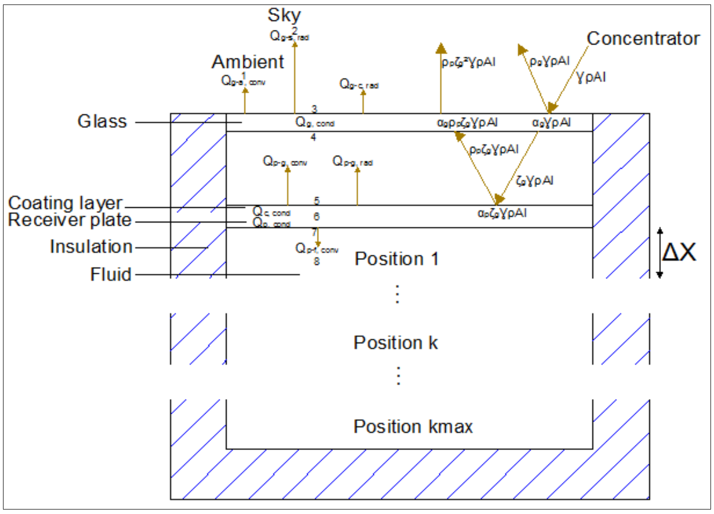


Figure 4. Cross section of the receiver with heat transfer processes

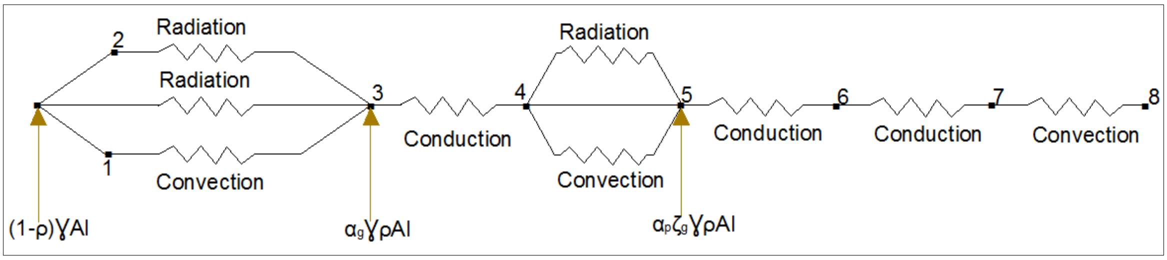


Figure 5. Equivalent thermal resistance model

3. RESULTS AND DISCUSSION

3.1. Governing equations and numerical solution

The present model of the PSCS considers all the above mentioned heat transfer processes, takes into account the presence of the glazing on the receiver, and assumes one-dimensional variations of the temperature along the receiver and the storage tank. The first law of thermodynamics is applied between times t and t + Δt to various system components to obtain the governing energy balance equations in a convenient explicit finite difference form ready for numerical solution. For reasons of space, we present only some equations.

For receiver plate, the energy balance is given (from receiver to glass):

$$m_p C_p \Delta T_p = [\alpha_p \tau_g \gamma \rho A_c I_c - h_3(T_p - T_{f,r}^1)A_p - (h_1 + h_2)(T_p - T_g)A_g]\Delta t \quad (1)$$

At the receiver, the fluid is divided into several zones (from receiver to fluid):
Fluid portion in the position 1 of the receiver:

$$m_{r,k} C_f \Delta T_{f,r}^1 = \left[\dot{m}\, C_f(T_{f,r}^2 - T_{f,r}^1) + h_3(T_p - T_{f,r}^1)A_p - \frac{\lambda_f}{\Delta X_r}(T_{f,r}^1 - T_{f,r}^2)A_p - h_g(T_{f,r}^1 - T_a)S_{ur} \right]\Delta t \quad (2)$$

Fluid portion in the intermediate position k $(1 < k < kmax)$ of the receiver:

$$m_{r,k} C_f \Delta T_{f,r}^k = \left[\dot{m}\, C_f(T_{f,r}^{k+1} - T_{f,r}^k) + \frac{\lambda_f}{\Delta X_r}(T_{f,r}^{k-1} - T_{f,r}^k)A_p - \frac{\lambda_f}{\Delta X_r}(T_{f,r}^k - T_{f,r}^{k+1})A_p - h_g(T_{f,r}^k - T_a)S_{ur} \right]\Delta t \quad (3)$$

Fluid portion in the position $kmax$ of the receiver:

$$m_{r,k} C_f \Delta T_{f,r}^{kmax} = \left[\dot{m}\, C_f(T_{f,s}^1 - T_{f,r}^{kmax}) + \frac{\lambda_f}{\Delta X_r}(T_{f,r}^{kmax-1} - T_{f,r}^{kmax})A_p - h_g(T_{f,r}^{kmax} - T_a)(S_{ur} + A_p) \right]\Delta t \quad (4)$$

Similarly, the storage tank is divided into $imax$ fluid zones.
Fluid in the position 1 of the storage tank:

$$m_{s,i} C_f \Delta T_{f,s}^1 = \left[\dot{m}\, C_f(T_{f,s}^2 - T_{f,s}^1) - \frac{\lambda_f}{\Delta X_s}(T_{f,s}^2 - T_{f,s}^1)A_s - h'_g(T_{f,s}^1 - T_a)(S_{us} + A_s) \right]\Delta t \quad (5)$$

Fluid in the position i $(1 < i < imax)$ of the storage tank:

$$m_{s,i} C_f \Delta T_{f,s}^i = \left[\dot{m}\, C_f(T_{f,s}^{i+1} - T_{f,s}^i) + \frac{\lambda_f}{\Delta X_s}(T_{f,s}^{i+1} - T_{f,s}^i)A_s - \frac{\lambda_f}{\Delta X_s}(T_{f,s}^i - T_{f,s}^{i-1})A_s - h'_g(T_{f,s}^i - T_a)S_{us} \right]\Delta t \quad (6)$$

Fluid in the position $imax$ of the storage tank:

$$m_{s,i} C_f \Delta T_{f,s}^{imax} = \left[\dot{m}\, C_f(T_{f,r}^1 - T_{f,s}^{imax}) - \frac{\lambda_f}{\Delta X_s}(T_{f,s}^{imax} - T_{f,s}^{imax-1})A_s - h'_g(T_{f,s}^{imax} - T_a)(S_{us} + A_s) \right]\Delta t \quad (7)$$

For the resolution, we use the finite difference method. The resolution of the model allows determining the temperature of the concentrator, of the glass, of the plate on the front face of the receiver and the fluid into different zones at the receiver and storage.
The above governing equations are solved numerically to determine the time variations of the temperatures of the concentrator, the glass cover, the plate on the front face of the receiver, and the fluid at different positions both in the receiver and the storage tank.

3.2. Convergence and validation of the numerical solution

The time step is lowered until stability and convergence of the numerical solution is obtained. Figure 6 shows the time variation of the receiver plate temperature at time steps (Δt) 100 s and 10 s, the latter coincide with the curves obtained using smaller values time steps (1s and 0.1s). When the other temperatures are considered, similar behavior is observed, and total stability was obtained with 0.1 s which is the adopted value throughout the present work.

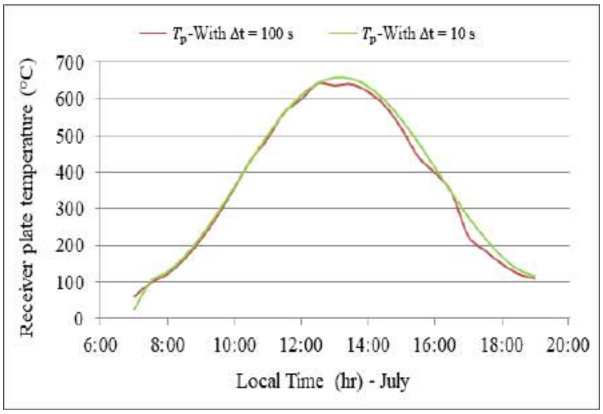


Figure 6. Time variation of the receiver plate temperature at different time steps

Our solution was compared with the results of the simpler model described by Newton [8] which consider that the receiver metal plate and the fluid have the same temperature. Zeghib [9] used the same model but he considers that there is a temperature gradient along the receiver. Figure 7 shows that the temperature difference between the receiver plate and the fluid in position 1 tends to vanish when the heat transfer coefficient is infinite (actually larger than 3,000 W m^{-2} °C^{-1}). Similarly, the temperature difference between the plate and the fluid in position kmax decreases to 0 when the fluid thermal conductivity is infinite (actually larger than 2,000 W m^{-1} °C^{-1}).

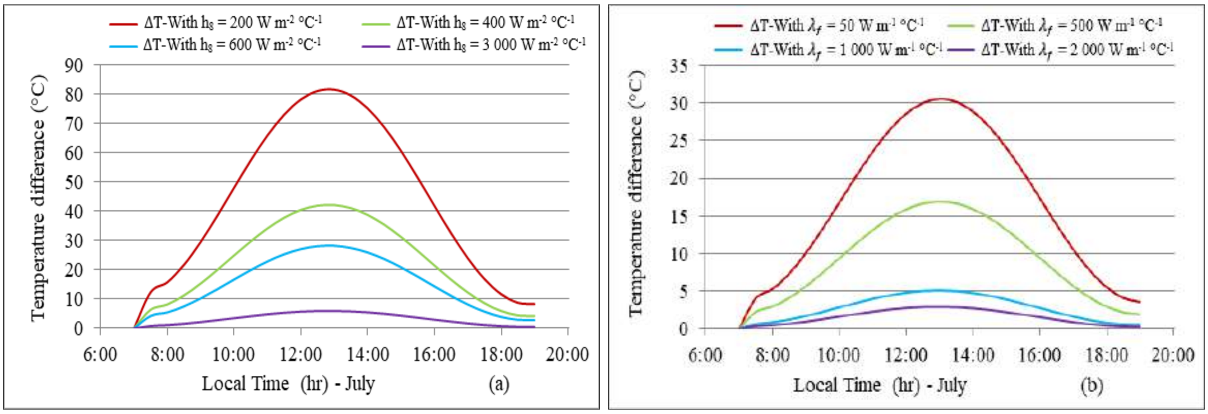


Figure 7. Time variation of the temperature difference between the plate and the fluid when increasing (a) the heat transfer coefficient, and (b) the fluid thermal conductivity

Figure 8 presents the fluid temperature at position kmax in the receiver obtained by solving our model using a high heat transfer coefficient (a heat coefficient of 10,500 W m^{-2} °C^{-1} is taken, to guarantee that the plate temperature and the fluid temperature at position k = 1 are equal) and varying the fluid thermal conductivity. At higher values (λ_f) larger than 6,000 W m^{-1} °C^{-1}), the numerical solution matches the one results obtained using the simple model of [8-9], under the same operating conditions and with the same time step (0.1 s).

The first experimental system was tested in the region of Rabat (Morocco) during the period from April 24th to July 10th, 2014. Tests were conducted from 9:00 am to 5:30 pm local time, under clear sky conditions.

Figure 9 compares the measured and the theoretical fluid temperatures in the upper part of the receiver in closed circuit of the first experimental device using SAE-40 synthetic oil at 15-minute intervals which reached a maximum temperature of 153 °C after 5 hours.

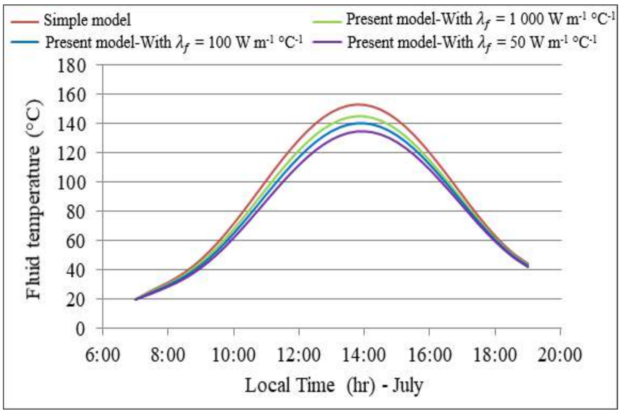


Figure 8. Comparison of the present model with the simple model of [8-9]

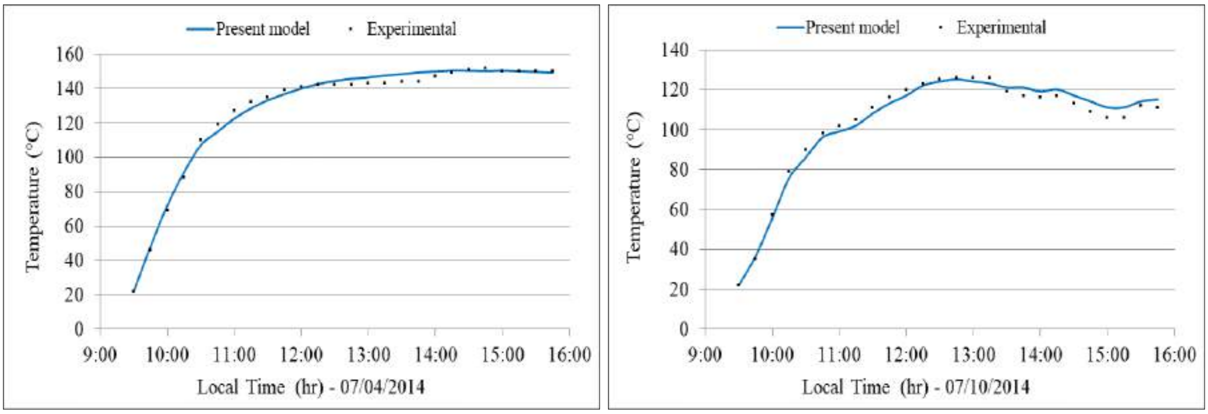


Figure 9. Measured and predicted fluid temperature in the receiver in closed circuit of the first experimental device

The second experimental system was tested at the same location during the period from May 15th to June 18th, 2015 under clear sky conditions.

The measured and the theoretical fluid temperatures in the upper part of the receiver in closed circuit of the second experimental device using SAE-40 synthetic oil at 5-minute intervals are given in Figure 10. The maximum fluid temperature was 150 °C reached after 1 hour of heating.

A good agreement is noticed between the theoretical values and the experimental results. The relative error (RE) is between ± 2.4 and ± 4.3%, and the root mean square error (RMSE), which represents the arithmetic mean of the squares of the differences between the forecasts and the observations, is between 1.2 and 3.0 °C. These values are summarized in Table 2.

Figure 11 shows the oil temperature measurements in the upper part of the receiver and in the lower part of the storage tank using SAE-40 synthetic oil at 15-minute intervals. The maximum fluid temperature in the storage was 75 °C.

Table 3 summarizes the relative error and the root mean square error which were, respectively, between ±4.0 and 5.9%, and between 1.3 and 1.5 °C in the receiver, and between ±4.4 and ±7.5%, and between 1.3 and 1.9 °C in the storage tank. The increase in RE noted on the day of May 27th, 2015 is due to the temperature difference that was greater than 5 °C between the receiver and the storage tank due to the blocking of the pump shaft at the end of the afternoon.

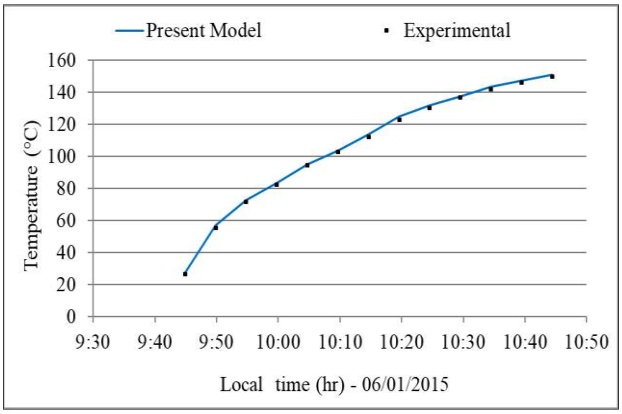


Figure 10. Measured and predicted fluid temperature in the receiver in closed circuit of the second experimental device

Table 2. Relative and root mean square errors in closed circuit

Date	**07/04/2014**	**07/10/2014**	**06/01/2015**
RE (%) - Receiver	±4.3	±4.3	±2.4
RMSE (°C) - Receiver	2.8	3.0	1.2

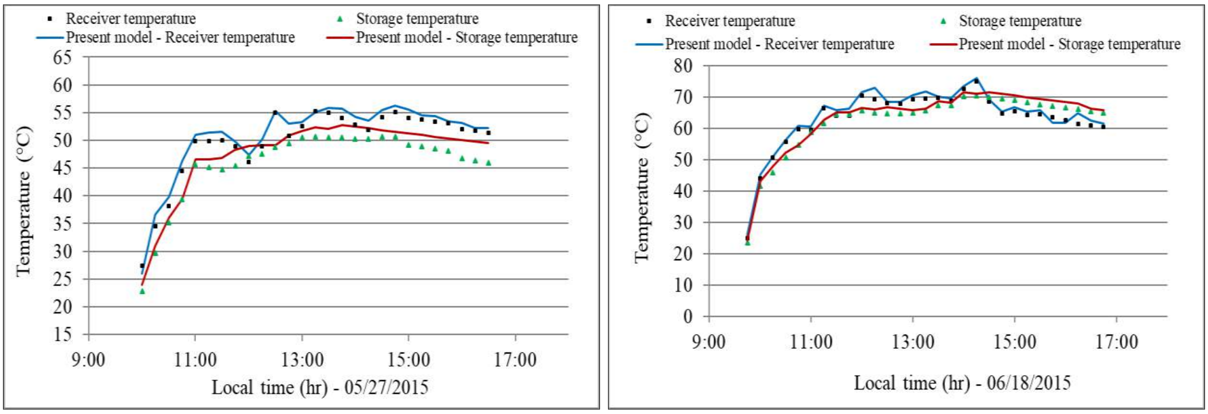


Figure 11. Measured and predicted fluid temperature in the receiver and in the storage tank in open circuit of the second experimental device

Table 3: Relative and root mean square errors in open circuit

Date	**05/27/2015**	**06/18/2015**
RE (%) - Receiver	±5.9	±4.0
RMSE (°C) - Receiver	1.3	1.5
RE (%) - Storage	±7.5	±4.4
RMSE (°C) - Storage	1.9	1.3

4. CONCLUSION

The present model of parabolic solar cooking systems introduced with heat storage for continuous use allowed a valuable analysis of the performance of such systems. Improvement over previous simpler models included a non-uniform receiver temperature and temperature difference between the glass, receiver cover, and thermal fluid. The model-governing equations were solved using an explicit finite difference method, and the method was mathematically validated.

The results of the simulation were compared with experimental results, which proved that the model predicts adequately the thermal behavior of the described system with a relative error ± 4.4% and a root mean square error of 3 °C. Therefore, the model is valuable, and can be used to study the operation, to design any of its components, and also to forecast the performance.

The performance of a PSCS can be significantly affected by numerous parameters such as weather conditions (solar radiation, wind) that vary according to the site, material optical properties (reflectance, absorptance, emissivity), system design parameters (aspect ratio, rim angle, intercept factor, exposure ratio), and operating parameters (mass flow rate, glazing, air between the glass and the plate on the front face of the receiver, tracking mechanism, fluid nature, heat losses).

REFERENCES

[1] ASDER. Solar cookers—Technical presentation. Savoyard Association for the Development of Renewable Energies, Chambery, France, 2012. http://www.asder.asso.fr/phocadownload/cuiseur%20solaire.

[2] Prasanna UR. Modeling, optimization and design of a solar thermal energy transport system for hybrid cooking application. PhD thesis, Indian Institute of Science, 2010. http://www.utdallas.edu/~prasanna.ur/thesis.pdf
Mbodji N, Hajji A. Performance testing of a parabolic solar concentrator for solar cooking. ASME Journal of Solar Energy Engineering, 2016, 138(4). DOI: 10.1115/1.4033501

[3] Guendouz B. Use of solar energy for air conditioning needs. Chapter 3: State of the art of solar collectors and modeling. Magister's thesis, Abou Bakr Belkaid University, Tlemcen, Algeria, 2012. http://dspace.univ-tlemcen.dz/bitstream/112/1200/1/GUENDOUZ-BOUHELAL.pdf

[4] Rongrong Z, Yongping Y, Qin Y, Yong Z. Modeling and characteristic analysis of a solar parabolic trough system: thermal oil as the heat transfer fluid. Journal of Renewable Energy, 2013. DOI: 10.1155/2013/389514

[5] Duffie JA, Beckman WA. Solar engineering of thermal processes, 2nd edition, New York: John Wiley & Sons, Inc, 1980.

[6] Incropera F, Dewitt DP, Bergman TL, Lavine AS. Fundamentals of heat and mass transfer. 6th edition, New York: John Wiley & Sons, Inc, 2007. http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=4585&context=etd

[7] Newton CC. A concentrated solar thermal energy system. Master's thesis, Florida State University, Tallahassee, FL, 2006. http://diginole.lib.fsu.edu/islandora/object/fsu:180899/datastream/PDF/view

[8] Zeghib I. Design and construction of a parabolic solar concentrator. Master's thesis, Mentouri – Constantine University, Algeria, 2005.

NOMENCLATURE

A_c	concentrator surface area, m²
A_p	receiver plate surface area, m²
A_g	glass surface, m²
A_s	storage cross section area, m²
C_p	receiver plate specific heat, J kg^{-1} °C^{-1}
C_f	fluid specific heat, J kg^{-1} °C^{-1}
h_1	CHTC plate to glass, W m^{-2} °C^{-1}
h_2	RHTC plate to glass, W m^{-2} °C^{-1}
h_3	CHTC plaque to fluid, W m^{-2} °C^{-1}
h_g	GHTC receiver to ambient, W m^{-2} °C^{-1}
h_g	GHTC storage to ambient, W m^{-2} °C^{-1}
I_c	direct normal irradiance, W m^{-2}
m_p	receiver plate mass, kg
$m_{r,k}$	receiver fluid partial mass in position k
$m_{s,i}$	heat storage fluid partial mass in position i
m	thermal fluid mass flow rate, kg s^{-1}
S_{ur}	receiver lateral surface area, m^2
S_{us}	storage lateral surface area, m^2
T_a	ambient temperature, °C
T_f	fluid temperature, °C
T_g	glass temperature, °C
T_p	receiver plate temperature, °C

Greek symbols

α_p	receiver plate absorptance
γ	intercept factor
Δt	time step, s
ΔX_r	receiver length step, m
ΔX_s	storage length step, m
λ_f	fluid thermal conductivity, W m^{-1} °C^{-1}
ρ	mirror reflectance
τ_g	glass transmittance

Sub index

c	concentrator
f	fluid
g	Glass
p	plaque
r	Receiver
s	Storage

DEVELOPMENT OF A LARGE CAPACITY ORANGE BAGASSE DEHYDRATATOR

Eduardo A. Rincón[1] *, Bernd Weber[2]

1: Programa de Energía, Universidad Autónoma de la Ciudad de México
San Lorenzo 290, Col Del Valle, 03100 Ciudad de México
Postal address
eduardo.rincon@uacm.edu.mx https://www.uacm.edu.mx

2: Facultad de Ingeniería, Universidad Autónoma del Estado de MéxicoCompany
weber@uaemex.mx

Abstract

The dehydration of agricultural products with solar energy has proven to be very effective, reliable and profitable. For very large scales - of the order of 100 tons per day to dehydrate - technical problems represent a great challenge. In particular, it is intended to dispense with fossil support for air heating, with the option of using biogas from the anaerobic formation of part of the bagasse. This report presents the details of the project and the results obtained in the development of a solar dehydrator for 150 metric tons of bagasse of orange, byproduct of an orange juice packaging company. Dehydrated bagasse is used as a feed component for cattle.

Keywords: Solar Dehydration, Solar Thermal Food Processing

COMBINED MEMBRANE AND SOLAR DRYING TECHNOLOGIES FOR FRUIT PRESERVATION IN MOZAMBIQUE

Ricardo Bernardo[1] *, Henrik Davidsson[1], Pia Otte[2], Randi Phinney[3] and Lucas Tivana[4]

1: Division of Energy and Building Design, Lund Technical Faculty, Lund University
P.O. Box 118, 221 00 Lund, Sweden
{ricardo.bernardo, henrik.davidsson}@ebd.lth.se , http://www.ebd.lth.se

2: Centre for Rural Research, Trondheim, Norway
pia.otte@bygdeforskning.no , http://www.bygdeforskning.no/en

3: Department of Food Technology, Lund Technical Faculty, Lund University
randi.phinney@food.lth.se , http://www.food.lth.se/food-technology-engineering-and-nutrition/

4: Department of Rural Engineering, University Eduardo Mondlane, Mozambique
lucastivana@yahoo.co.uk , http://www.agronomia.uem.mz/

Abstract: In many developing countries, such as Mozambique in southern Africa, large amount of food is spoiled due to lack of food conservation methods. A possible solution to the storage problem is to dry the fruits so that they can be safely stored at ambient temperature and later consumed. Our research project consists of adapting and combining solar dryers with newly developed membrane pouches for drying juicy fruits. The use of a pouch makes it possible to dry juice from juicy fruits such as oranges which are not possible to be dried at open-air since the juice is lost when the fruit is sliced open. The pouch is made of a food-grade breathable membrane (i.e. permeable to water vapour but not liquid water) to concentrate fruit juices/purées using solar irradiation and ambient air. By using solar dryers food safety is improved as a result of higher temperatures, drying time is reduced, productivity is increased and there is additional protection from outdoor environment. The final product is a fruit jam/purée with shelf life of over one year.

The project follows a multi-disciplinary approach gathering, among others, food engineers, physicists, social scientists and agriculture engineers to increase chances of acceptance by small-hold farmers in Mozambique. Preliminary concepts of solar dryers and membrane pouches were tested with farmers in Mozambique.

The full paper shows highlights on three main aspects of the project: the solar dryers, the membrane pouches and social acceptance by the farmers. So far it was verified that the drying time of the membrane pouches could be reduced from four/five days to approximately half of that time when using solar dryers. Measurements of drying rates from an indoor solar simulator laboratory in Sweden and from a field trip in Mozambique will also be shown. Some of the main challenges so far are: degradability of the membrane bags in direct sunlight, mould growth on the outside of the pouch, limited available materials for the solar dryers and gender equality regarding work load by the farmers.

Keywords: Solar dryers, Fruit drying, Solar thermal, Food processing, Membrane pouches

From Development Aid towards an Economic Factor: Sustainable Production of Clean Cookstoves in Madagascar

Christian Frost[1] *

1: ADES - Association pour le Développement de l'Energie Solaire Suisse – Madagascar,
Im Grindel 6, CH-8932 Mettmenstetten
e-mail: christian.frost@adesolaire.org, web: http://www.adesolaire.org

Abstract: ADES operates eight manufacturing centre in different regions of the country, where Madagascan employees manufacture and sell clean cookers, advise existing and potential users and raise awareness among the public. Thus, ADES directly creates jobs in Madagascar and facilitates the transfer of knowledge and technology. With direct investments we create sustainable local value chains and livelihoods in a country that belongs to the least developed countries in the world. About 500,000 acres of forest are lost every year. Eighty percent of the wood cut is used for cooking. Changing respective knowledge, attitudes and practices is a multi-generation task. ADES is responding by an indefinite, sustained and integrated programme consisting of production, sales and distribution, environmental education and awareness raising, user trainings, marketing and fundraising. Our target groups are actively involved in environmental and climate protection by purchasing our cookstoves – even at discounted price. Thus, they are not merely recipients of aid, but they themselves take care of their livelihoods. A broad network of local, female resellers and established contractual relationships with large customers are of central importance for the sustainable, country-wide distribution of our cookers. Mobile sales promotion in Madagascar`s North forms a new, innovative component of our sales and distribution concept. Innovation and constant optimization of production processes and products are guiding principles of our programme. Examples: With enhanced production our firewood consumption has increased. Yet our goal is to reduce the consumption of wood in Madagascar. Therefore, in collaboration with a company we developed Artemisia briquettes. In the production of active ingredients for malaria drugs based on Artemisia vegetable residues incurred. It has been proved that a high-quality fuel can be obtained from this biomass. So we had to build new kilns to be fired with Artesimia briquettes with good results: With almost half the amount of fuel, we are able to fire almost twice as many clay combustion chambers for our cookers. Because of higher heat, the clay combustion chambers fired with Artemisia briquettes are lighter, harder and therefore much more durable. This makes it possible to design future cookers in such a way that they require less metal and thus become more cost-effective. Having introduced a semi-industrial production our output will be doubled. The production of uniform cores having a homogeneous mixture is possible, which in turn increases the strength of the clay and reduces rejects during production. Branding of ADES e.g. product marketing via various communication tools is crucial to generate trust and awareness on our products in the country. The financing of our work is based on accessing diversified funding sources ensuring the financial sustainability of our programme.

Keywords: Madagascar, local value chains, local production, innovation, sustainability

Challenges in promoting solar cookers in India: Social acceptance, cooking habits & technologies.

By: Neha Mehta[1], Kinjal Pandya[2]

1: **Neha Mehta**, Innovior Solutions,
Address: 101, Pushkar Residency, Beside Nilkanth Duplex, Gotri-Vasna, Vadodara - 390021

E-mail: innovior.solutionsnk@gmail.com, web: http://www.innoviorsolutions.com (under construction)

2: **Kinjal Pandya**, Innovior Solutions,
Address: 101, Pushkar Residency, Beside Nilkanth Duplex, Gotri-Vasna, Vadodara - 390021

E-mail: innovior.solutionsnk@gmail.com, web: http://www.innoviorsolutions.com (under construction)

Abstract:

Cooking is basic need for all human-beings and it will be surprising to note that more than 3.2 million women and children die every year due to pollution in kitchen caused due to fire-wood and bio-mass cooking. Even in 21st century more than 50 % of the World’s population cooks on open fire.

Little Big World a NGO of Germany came to India to undertake and offer solar drinking water project in Gujarat India and we got to know them and work for them through Muni Seva Ashram the NGO we have been associated with since a decade and from where our journey with solar field have been stared.

While doing project we also undertook Medical camps and realized that Solar Cooking is not just about saving fuel cost (money) but also about Environmental protection and health. We have thus started a pilot of offering solar cooker in different mode based on similar concept of Income Generation and Micro-finance and will share the experience in the Solar Cooking Conference in Faro.

We have been promoting Solar Cooking in Schools and ladies group for many years and feel time has come to take bottoms up approach and have been going to Global Alliance for Clean Cookstove meet in Delhi for last two years and feel solar cooking is neglected and we were also been part of 1st International Solar Food Processing Network Conference 2013, MNRE Conference 2013, Green Carbon Mumbai (Deutsche bank solar cooking workshop 2012) and while in Faro want to learn from experiences of others and share our Indian experience and create Network to be more effective.

NETWORKING TO ADVANCE THE USE OF SOLAR COOKERS AS EDUCATIONAL TOOLS IN THE CLASSROOM

Mary M. Buchenic[1] *, Jennifer Gasser[2]

1: The Solar Sisters - Global Development Solutions
318 North Main Street Hubbard, OH 44425 USA
email: WeAreTheSolarSisters@gmail.com web: http://www.gdsnonprofit.org

2: The Solar Sisters - Global Development Solutions
318 North Main Street Hubbard, OH 44425 USA
email: WeAreTheSolarSisters@gmail.com web: http://www.gdsnonprofit.org

Abstract: *There is great potential for Solar Cookers to be utilized as educational tools in the classroom, particularly as the basis for cross curricular and/or project based learning. The theme of solar cooking has application for physics, environmental science, reading, math, geography, history, economics and more. A solar cooker can be an invaluable educational tool.*

A paradigm shift of the most nuanced kind must occur in our thinking for the potential to be realized. In a basic lesson involving solar cookers, students use a pattern to create a solar cooker and then use that cooker to prepare food. While this is a valuable way to introduce solar cooking technology to youth, we advocate taking the solar cooker to another level by identifying it as a teaching tool, a means to an end, the use of which can result in rich, in-depth, multi-disciplinary education.

How do we facilitate this paradigm shift and shape the solar cooker as an indispensable and ubiquitous educational tool?

- *Understand the goals of education in your country. Learn 'Educationese' and utilize the lingo to your advantage.*
- *Identify decision makers within educational institutions.*
- *Begin the process of networking with decision makers both directly and indirectly.*
- *Share proven educational strategies for implementation of your ideas.*
- *Be a presence and be a voice - always. Support is often found in unexpected places.*

We discuss our efforts to advance the use of solar cookers as educational tools and share our successes and failures as we network with school systems, teachers, and universities.

***Keywords**: Solar Cooking, Education, STEM, Curriculum, Solar Energy*

1. INTRODUCTION

There is great potential for the Solar Cooker to be utilized as an educational tool to advance understanding of science concepts, human interaction with technology engineering design process, and math application. In addition, the Solar Cooker used thematically for cross curricular units can succesfully bridge a multitude of disciplines including langauge arts and the social studies. Adoption of revised internationally benchmarked science standards; an emphasis on STEM (Science, Technology, Engineering, and Math); and trends toward Inquiry Based Learning and Cross Curricular Teaching Strategies; all present a framework within which Solar Cookers can be effectively utilized.
How can solar cooking enthusiasts, experts, educators, and promoters facilitate the acceptance of the solar cooker as an indispensable educational classroom tool? One must have an understanding of the current status of education reform, particularly in science and STEM, and in the methodologies that produce high levels of student engagement, enthusiasm and understanding. It is essential to network with educators at all levels and with the organizations and institutions that support education, and to be willing to share expertise, provide resources, and link solar cooking activities with the educational goals and standards for which educators are responsible.

2. SCIENCE EDUCATION STANDARDS

In the 1990s, more than 300 scholarly reports were calling for an overhaul of science education in the United States with an emphasis on updated scientific and technologic knowledge along with adoption of more effective teaching strategies. Support for science education reform was considerable. [1]

2.1. National science education standards

In 1996, in response to the calls for reform, the National Academy of Science published the National Science Education Standards (NSES). The NSES were designed to guide educators in achieving the nation’s goal of scientific literacy for its citizens. Individual standards were created that served as learning goals or objectives to be met at particular grade levels. The authors advocated creative problem solving, critical thinking, use of the scientific method, collaboration, cooperative team work, use of technology, and deeper understanding of the natural world. The document included a vision for science education that relied less on lecture and more on investigation and inquiry, less on fragmented lessons and more on long-term plans, less on theory in isolation and more on theory in practice in school settings. [2]

2.2. Next generation science standards

In 2010, Achieve, an independent, bipartisan, non-profit education reform organization in Washington, D.C., released its report titled, *International Science Benchmarking Report - Taking the Lead in Science Education: Forging Next-Generation Science Standards.* The study sought to collect data that would guide a new conceptual framework for science education - one that reflected the expectations and best practices of ten high academically performing nations. The information collected was critical to the formation of the Next Generation Science Standards released in 2013. The new standards, or learning objectives, are internationally benchmarked for Kindergarten through grade 12. Their adoption is voluntary. At this writing, 19 states in the United States have adopted the NGSS, while a total of 40 states have demonstrated an interest in somewhat aligning their individual state standards to NGSS. [3]

3. EMPHASIS ON STEM (SCIENCE, TECHNOLOGY, ENGINEERING, AND MATH)

The United States Congressional STEM Education Caucus was created in 2005 by Representatives Vernon Ehlers of Michigan and Mark Udall of Colorado. The bipartisan caucus seeks to strengthen STEM education both in schools and the workforce by providing a forum for Congress and the science, education, and business communities to discuss problems and solutions related to STEM education. Engineering is included in the current standards with an emphasis on the Engineering Design Process which differs from the Scientific Method. (The Caucus was renamed STEAM in 2013 to include the Arts.) [4]

4. TEACHING METHODS – CROSS CURRICULAR AND INQUIRY BASED LEARNING

Methods of teaching that are conducive to the use of a Solar Cooker include Cross Curricular Instruction and Inquiry Based Learning.
Cross Curricular Instruction is a method of teaching that explicitly helps students understand connections from one discipline to another. It can range from simple to complex.

- Support – Instructor references other disciplines in the context of his/her own instruction.
- Coordinate – Two or more teachers support coordinating lessons.
- Collaborate – Two or more teachers collaborate on a theme based unit that addresses multiple content standards across disciplines.

Inquiry Based Learning can be divided into three categories.

- Structured Inquiry – Students follow precise teacher instructions to complete a hands-on activity.
- Guided Inquiry – Students develop the procedure to investigate a teacher-selected question.
- Student-Initiated Inquiry – Students generate questions about a teacher-selected topic and design their own investigation. [5]

5. SOLAR COOKER AS AN EDUCATIONAL TOOL

From 1996 through 2011 the author conducted solar cooking lessons in her classroom. The cookers became tools for education, a means to an end that included deepened understanding of science concepts, and later expanded to include educational goals in language arts, math and the social studies.

5.1. Science tool

The early Science Education Standards that guided initial lessons included:

- The sun is a major source of energy for the earth, and its energy interacts with matter.
- Electromagnetic radiation is emitted by the sun and travels to earth in waves.
- Light interacts with matter by transmission, including refraction, absorption, and reflection,
- Heat is produced when light is absorbed by matter.

The solar cooker provided an ideal instructional opportunity to fulfill the early goals set forth by the National Academy of Sciences. The lessons included problem solving, critical thinking, experimentation, team work, use of technology, and a deeper understanding of the concepts.
As Science Education Standards in the United States evolved to more closely align with international standards, the solar cooker continued to be a relevant and useful instructional tool. It became evident that one could include many Next Generation Science Standards while teaching a solar cooking themed unit. The following tables include examples of standards taken from the NGSS Middle School

document. Please note that many additional standards at various grade levels and across the science disciplines also correspond to a solar cooking unit. Lessons can be adapted in complexity to be suitable from primary grades to high school level. The following is a small sampling only. [6]

Table 1. Portion of Next Generation Science Standards for Middle School
Engineering, Technology, and Applications of Science [6]

NEXT GENERATION SCIENCE STANDARDS FOR MIDDLE SCHOOL ENGINEERING, TECHNOLOGY, AND APPLICATIONS OF SCIENCE
Students who demonstrate understanding can: MS-ETS1-1. • Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. MS-ETS1-2. • Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. MS-ETS1-3 • Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Table 2. Portion of Next Generation Science Standards for Middle School
Earth and Space Science / Human Impacts [6]

NEXT GENERATION SCIENCE STANDARDS FOR MIDDLE SCHOOL EARTH AND SPACE SCIENCE
Students who demonstrate understanding can: MS-ESS3-3. • Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment. MS-ESS3-4. • Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

Table 3. Portion of Next Generation Science Standards for Middle School
Physical Science / Waves & Electromagnetic Radiation [6]

NEXT GENERATION SCIENCE STANDARDS FOR MIDDLE SCHOOL PHYSICAL SCIENCE
Students who demonstrate an understanding can: MS-PS4-2 • Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

In Table 4, a solar oven (highlighted by author) is included as an example of a device that can support the following Middle School Physical Science Standard: ***Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.***

Table 4. Portion of Next Generation Science Standards for Middle School Physical Science [6]

MS-PS3.1. Students who demonstrate understanding can: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a styrofoam cup] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]		
Performance expectation developed using following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system.	**PS3.A: Definitions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. **PS3.B: Conservation of Energy & Energy Transfer** Energy is spontaneously transferred out of hotter regions or objects and into colder ones. **ETS1.A: Defining Delimiting Engineering Problem** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. *(secondary)* **ETS1.B: Developing Possible Solutions** A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. *(secondary)*	**Energy and Matter** • The transfer of energy can be tracked as energy flows through a designed or natural system.

5.2. Cross curricular tool

Initially, the author's solar cooker lessons were limited to the science classroom; however, it soon became apparent that the topic of solar cooking could easily form the basis for a cross-curricular collaborative unit of instruction. Colleagues teaching the social studies, math, and the language arts demonstrated interest in the solar cooking lessons but understood they had their own required education standards to meet. Examination of the corresponding standards in these three subjects revealed many learning objectives that could be met within a solar oven themed unit of study. Thus, solar cooking expanded beyond the science classroom. The following tables include a small sampling.

Table 5. Ohio Academic Content Standards – Social Studies [2]

ACADEMIC CONTENT STANDARDS FOR MIDDLE SCHOOL SOCIAL STUDIES – ECONOMICS
ECON.68.1a • Identify the short and long term consequences of a personal economic decision. ECON.68.3a • Describe how the wants of people determine what goods and services are produced. ECON.68.5a • Explain why some goods are easier to find than others and how this affects price.

Table 6. Common Core Math Grade 5 [7]

COMMON CORE MATH GRADE 5 - EXPRESSIONS AND EQUATIONS
CCSS.MATH.CONTENT 5.G.A.1
• Use a pair of perpendicular number lines, called axes, to define a coordinate system, with the intersection of the lines (the origin) arranged to coincide with the 0 on each line and a given point in the plane located by using an ordered pair of numbers, called its coordinates.

Table 7. English Language Arts Standards Grades 6 – 8 [7]

ENGLISH LANGUAGE ARTS STANDARDS GRADES 6 – 8 SCIENCE & TECHNICAL SUBJECTS
CCSS.ELA-LITERACY.RST.6-8.7
• Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).
CCSS.ELA-LITERACY.RST.6-8.9
• Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

6. NETWORKING TO PROMOTE SOLAR COOKERS

The Solar Sisters, GDS (Jennifer Gasser and Mary Buchenic) network to bring solar cooking to the general population as well as to the education community. What strategies have worked for us?

6.1. Characteristice of networking approach

An assessment of the Solar Sisters Networking approach reveals five important characteristics.

1. Without visibility, there is no networking. Be a presence and a voice. Cook and share food.
2. Approach is positive and enthusiastic, but without presumption or sermonizing.
3. Contacts can be incidental or planned but are always person to person.
4. Communications are rooted in understanding of both educational and social goals.
5. No request for a solar demonstration is turned down - ever.

6.1. Networking results in positive outcomes

The Solar Sisters have facilitated a wide variety of solar cooking programs. Each one, large or small, has extended outreach and the ability to share the value of solar cookers with an ever growing audience. Here is a sampling of four programs which were all the result of a simple person to person conversation held with the individual listed as Contact.

Fellows Riverside Gardens, Youngstown, Ohio, U.S.A.
Contact: Educator at Fellows Riverside Gardens
Program Connection: Garden District Kids
Outcome: One day solar cooking demonstration and tasting event for enrolled children and parents

Youngstown State University, Youngstown, Ohio, U.S.A.
Contact: Dean of Beeghly College of Education
Program Connection: Center for Human Services Development
Outcome: Inclusion of The Solar Sisters' Programming in Center's after school educational classes
Outcome: Family Night – Learn about and make solar cookers for family members in Puerto Rico

Hiram College, Hiram, Ohio, U.S.A.
Contact: Professor of Biology and Director of Learning Streams International
Program Connection: Learning Streams International – U.S. / Pakistan / Dominican Republic
Outcome: Near peer mentor workshop and additional general workshop with makerspace
Outcome: Travel to Pakistan for ecology program at Forman Christian College in Lahore
Outcome: Mentor and two Pakistani teachers using solar cookers as classroom tools for education
Carnegie Science Center, Pittsburgh, Pennsylvania, U.S.A
Contact: Program Manager for Carnegie STEM Girls
Program Connection: Chevron STEM Center at Carnegie Science Center
Outcome: STEM Girls – one day workshop
Outcome: Energy Summit – two day workshop
Outcome: National Engineers Week – three day demonstrations and engagement
Outcome: Sci Tech Days – one day presentation

7. CONCLUSIONS

- The establishment of the solar cooker as an educational classroom tool can be enhanced through networking efforts.
- There is great interest in solar cooking which creates many opportunities for personal contact.
- The novelty of seeing food cooking in the sun works to ones benefit in scheduling events.
- Educators welcome outside opportunities for students to experience hands-on enriching activities.
- Educators understand the potential for solar cookers in the classroom when the rationale is explicitly and clearly conveyed.
- Discussion of educational applications, including alignment to standards, is essential.
- Flexible programming and willingness to adapt are essential.

REFERENCES

[1] Bybee RW, McInerney JD. Redesigning the Science Curriculum, Biological Sciences Curriculum Study, Colorado Springs, Colorado, USA, 1995
[2] National Science Education Standards, National Academy of Sciences, National Academy Press, Washington DC, USA, 1996.
[3] International Science Benchmarking Report Taking the Lead in Science Education: Forging Next-Generation Science Standards Executive Summary, https://www.achieve.org, accessed on 2017.12.17.
[4] Mansfield, W. The Congressional Science, Technology, Engineering, and Mathematics (STEM) Education Causus and the Congressional Academic Competition: History and Current Practice, Congressional Research Service, Washington, DC, USA, 2014.
[5] Integrating the Inquiry Approach in Science, http://www.glencoe.com/sec/teachingtoday, accessed in 2016.
[6] DCI Arrangements of the Next Generation Science Standards, Achieve, Washington, DC, USA, 2013.
[7] Common Core State Standards Initiative, http://www.corestandards.org, accessed on 2016.12.19.

THE TASK OF CREATING PROGRAMS TO PROMOTE SOLAR COOKING

Jennifer L. Gasser[1] * and Mary M. Buchenic[2]

1: Global Development Solutions (Jennifer L. Gasser), We are the Solar Sisters,
318 North Main Street, Hubbard, Oh 44425 USA
e-mail: wearethesolarsisters@gmail.com, web: http://www.GDSnonprofit.org

2: Global Development Solutions (Mary M. Buchenic), We are the Solar Sisters,
318 North Main Street, Hubbard OH 44425 USA
e-mail: {wearethesolarsisters@gmail.com}, web: http://www.GDSnonprofit.org

Abstract: *The task of organizing a full-scale, adjustable program to actively promote solar cooking education in our community has proved challenging. We created four programs - Solar Express Suitcase, Solar Snacks, Build and Cook, Enablers for Good - that are flexible and adaptable to individual learning styles, age, experience and interest levels. The Explore, Demonstrate, Guide and Enable (EDGE) model of Boy Scouts of America provided an excellent framework for our efforts.*
***EXPLORE**: The **Solar Express Suitcase** program includes lesson plans, activities, experiments, Copenhagens, recipes and materials. The suitcase offers teachers, summer camps, after school programs and clubs opportunities for group interaction and self-paced exploration of principles related to the science of solar cooking.*
***DEMONSTRATE**: The **Solar Snacks** program. Participants discover joys of solar cooking using all senses: hearing, seeing, smelling, tasting and touching. Instructors discuss basic concepts using DARE, and demonstrate safe use and cooking. Participants taste solar cooked snacks.*
***GUIDE**: The **Build and Cook** program emphasizes hands-on building of cookers by pattern or through innovation. Guidance is given as needed and appropriate food is safely cooked or water is safely pasteurized.*
***ENABLE**: The **Enablers for Good** program encourages participants to become the teachers and to share knowledge with others through a variety of Extension Activities that encompass entrepreneurship, community volunteering, the arts, and more.*
Sharing knowledge is a critical component of solar cooking advocacy and education. By enabling and validating all efforts to promote solar cooking, we show that there is no "wrong way" to participate.

Keywords: Solar cooking, education, programming, community

1.INTRODUCTION

One year after embarking on a mission to provide educational STEM programming for schools and social organizations, The Solar Sisters discovered they had a diverse audience with varying expectations. The interest in solar cooking produced a multitude of leads. The initial projects were diverse and intuitive, with hands-on, creative activities. Developing each individualized program was time consuming, and the expectations were managed through a checklist. Cooking demonstrations and solar oven displays were the most popular programs. Outdoor cooking was run on a “rain or shine” basis due to Ohio’s perpetual cloud cover. Finding the right program balance in complexity and participant challenge was the primary program goal. Each project was successfully run, in part, due to meticulous planning and preparation.

During a mission trip to Haiti, the 6 person solar team was charged with expanding the convent kitchen through the use of solar ovens. The existing kitchen was condemned after the 2010 earthquake and the building offered little water or fuel source. The school served over 500 lunches daily from the old kitchen. The solar team was funded, in part, by a Rotary grant which included two Eagle Scouts, demonstrating the use of the Haines solar panel cooker for individual and family distribution. The BSA training method was a teaching model[1]. The E.D.G.E. model is a step by step training technique to impart informaion to another person.

The BSA programs for out-of-school experiences with community partnerships were lauded for impacting student success and a likely extension for solar cooking [2]. From 4H, Big Brother and Sister, the YWCA, Girlstart [3], Inspiring Minds, Youth Mentorship, Junior Achievement and Scouting, organizations serving youth in-and-out of school environments offer the greatest structure for long standing enrichment programs. The programs are not academically centered and provide activities related to interests, leadership, team bonding and group relationships, rather than academic testing links. However, the youth development programming is proven to increase academic success [4]. The Boy Scout Model offered promising training data. The new program design must assess needs and evalualate outcomes to be successful [5]. Solar cooking demonstrations was the tool used to create an interactive, hands on project that has purposful activities with application[5] to everyday life and career pathways.

2. CREATE A NEEDS ASSESSMENT USING EXISTING DATA

The Solar Sister’s solar cooking education program is designed to increase the participant’s knowledge and skill through active learning and critical thinking. By assessing the content, visibility and location of each program, data developed. Upon examination of the data, the program strengths and needs list was created Available program data indicated the need for customizable program features. Specifying a target audience is helpful in addressing needs.

The data showed that 46% of the total programs were in-school, compared to 54% out-of-school or (social) porgrams. Solar cooking visability was an overreaching goal for all programs. A total of 51 projects completed in fifteen months (21 International and 30 Domestic), provided solar cooking visability to approximately 23,270 people in 26 school related programs and 24 social programs.

The existing program strenths included the variety, creativity, overall visability and total number of projects completed. While the areas of need were in evaluation (finding a tool for pre planning and post assessment) and program expansion and compartmentilizing (one size program does not fit all needs). The question arose: If new programs allow for creative adjustments and adaptation for age and size of group; then, could each new program be a self contained unit or compartment of a larger program? The base of each program would connect to STEM learning goals and maintain a high level of content customization.

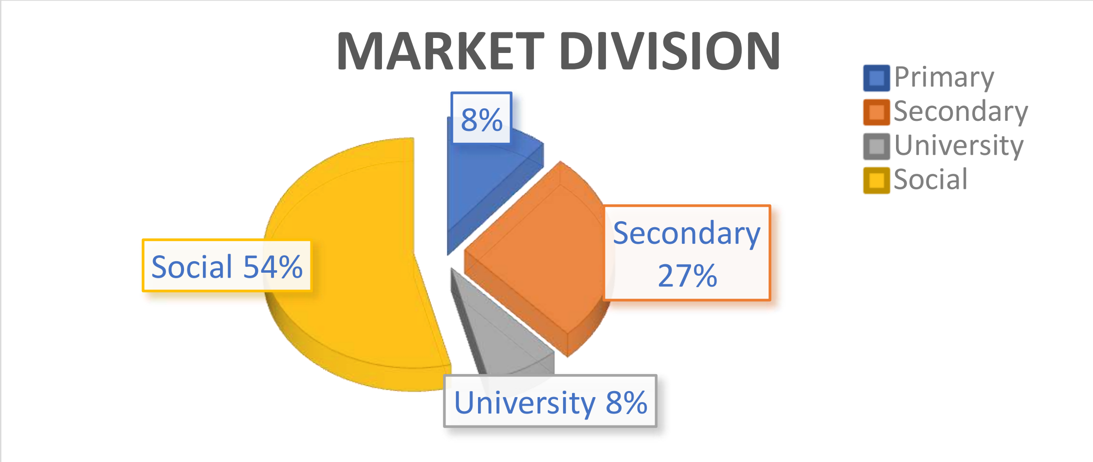


Figure 1. Program Totals - Social vs School

2.1. Domestic and International

Cultural needs and food selections offer locally sourced foods (farm to table when possible) for all programs. Regional variations in cooking style and content are encouraged though active participant involvement. With agressive pre assessment planning and clear input on expected outcomes, both domestic and international programs can run smoothly. By using the data to develop criteria for future programs, the needs assessment starts the strategic planning process.

Domestic programs presented 30 days of projects, allowing 23,676 people visability to solar cooking information through demonstration, workshop, and oven display. Similarly, international projects presented 21 days of programs allowing 1,594 people solar cooking visability [TABLE 1.] If each one shares with one other person, the exponential growth is enormous. No specific target audience was detected.

2.2. Visability

Visability is a difficult number to accurately assess. The visability of the project is determined by group size, number of presentations and each attendee reaching one more person. The data does not include visibility from social media, marketing or advertising for the events. The overall project visability is based on 51 days of projects reaching 23,270 persons both in the United States and abroad. The categories recorded were Shool (primary, secondary and University) and Social (groups, organizations, libraries, centers and businesses). The data showed projects divided into the following categories: primary (1%), secondary (8%), university (1%) and social groups (90%). The mean was 6,317 person visability. The median was 75 people visability and the mode is 200 people visability. The range is 19,996 people [Table 1.]. Further research is necessary to find a way to quantify the visibility. The numbers are conservatively estimated and only included from the Solar Sister projects and those under the Global Development Solutions, 501c3.

Table 1. Solar Sister's Program Table.

	Primary	Secondary	University	Social
Type	11%	27%	8%	54%
Visibility	1%	8%	1%	90%
Domestic	16%	1%	1%	28%
International	0%	12%	0.50%	24%

2.3. Managing Expectations

Moving from an arena where lessons are measured, timed, and outcome driven by testing, to the hybrid programming model for the 21st century [6] makes managing expectations difficult. The important question to answer is: What does a successful program look like? To best manage expectations, information must be communicated both verbally and in writing. The importance of gathering and recording precise information in a pre-program meeting is the first step to a successful project[6]. Use of a pre-program assessment guides the process. Adjusting to changing expectations with each project requires advanced planning, refocusing attention and constantly looking for creative ways to promote solar cooking. Acroynms such as DARE, DARCIE, EDGE, CAREer have value in programs to lend consistency and continuity. Presentations convey material through visual, auditory and written means to address a variety of learning styles.

3. CREATION AND DESIGN

The first step to new program creation is the development of goals and objectives. The Solar Sister's goals promote solar cooking through STEM educational programs, demonstrations and consultation and in social enterprise and mission work (both in the United Stated and abroad). The objectives are to obtain high visibility through each project, network all contacts for future collaboration, add a scalable element to adjust for time and group size constraints and a usable evaluation tool.

The long range goal is to encourge the use of solar ovens as a fun, environmentlally positive way to cook food. Through promotion and education, the Solar Sisters are dedicated to the helping solar cooking achieve global acceptance. The hub is Hub-bard Ohio and primary, first level ring of concentration is within a 60 mile radius, to ensure that the effort begins at the local level.

The objectives must be measurable and relevant [7]. Evaluation is a critical component of growth. If no target audience is defined, thus creating a wide possibility for program content, and rendering the evaluation process nearly impossible. Many programs are developed by intuition and experience, should have an element of logic. The EDGE method is model training, the primary purpose of model training is to successfully transfer knowledge from one person to another.[1] By identifying the audience and the target goal the steps of explain, demonstrate, guide and enable are a thorough process to ensure the materials are received by the audience and remembered [1]. Variables exist in motivation, education, interest, aptitude, constraints and cultural differences, but the EDGE method is able to level the varialbles and establish a program format that allows for the most material retention throughout the demonstration. Using the EDGE method in demonstrations about solar cooking makes the review of oven information methodical. When cooking, the EDGE method works well to reinforce solar cooking principles and safety procedures. After basic understanding is achieved, the EDGE method extends the learning to design, engineering and career pathways using the same steps.[6,7]

4. IMPLEMENTATION

Simple solutions are the best solutions. The EDGE method creates internal consistency with a system of checks and balances. The EDGE method was expanded to create four innovative programs to address the needs of all project education by developing strong goals. All programs are scalable for group size and time allotment.

4.1. Explain

The lending program, **Solar Express Suitcase** includes lesson plans, activities, experiments, Copenhagens, recipes and learning materials for a group of 30. The suitcase offers teachers, summer camps, after school programs and clubs opportunities for group interaction and self-paced exploration of principles related to the science of solar cooking. The Solar Suitcase promotes relationships, engagement with STEM activities, inquiry and participation through purposful activities.

4.2. Demonstrate

The **Solar Snacks** program. Participants discover joys of solar cooking using all five senses:seeing, hearing, smelling, tasting and touch. Facilitators discuss basic concepts of solar cooking using the DARE method, and demonstrate safe use of the cooking ovens. Through creative and informal space utilization, the ovens create an opportunity for participants to make decisions about their learning through relationships and inquirey. Participants taste solar cooked snacks and make connection of solar cooking principles through food.

4.3. Guide

The **Build and Cook** program emphasizes hands-on (minds-on) building of cookers by pattern or through innovation. Guidance is given as needed and appropriate food is safely cooked. An informational resource booklet is included with the take home kit for extensions in learning. This program encourages participation with partners or small groups through reflection and relevance. Students build relationships and have a useable mini Copenhagen panel cooker with clips, black reusable food tin and oven bag. The materials offer individual exploration or continued group activities. Facilitators look for opportunities to reinforce learned information through DARE and practical application and use of the oven. Questions and extended response answers offer peer to peer learning.[7]

4.4. Enable

The **Enablers for Good** program encourages participants to become the teachers and to share knowledge with others through a variety of Extension Activities that encompass entrepreneurship, community volunteering, business, interests, hobbies, career pathways, the arts, and more. Actively engaging participants in real life activities extends the key concepts into every day life, connecting the principles to activities outside of the program. Participation in purposful activities offers a high level of engagement with STEM due to physical and cognitive engagement. The extensions can be a great exercise to create design, build and improve solar cookers or work on solving global issues.

Sharing knowledge is a critical component of solar cooking advocacy and education.[6]. By enabling and validating all efforts to promote solar cooking, we show that there is no “wrong way” to participate and allow for small or large groups. From self paced discovery to a makers workshop and engineering extensions, this program is now multi-faceted and scalable.

5. EVALUATION, ORGANIZATION AND ASSESSMENT

By integrating an evaluation model into the programming process, important feedback is received from participants, attendees, facilitators and staff. The information provides evidence of the outcomes and determines program merit and project accomplishments. Information and critiques are reviewed to ensure the program objectives have been met. Regularly defining program strengths and needs leads to growth and refined programming. Student and facilitator reflection is assessed by asking open ended questions.

The Twelve Dimensions of Success [8] is the evaluation tool that is commonly used for rating out-of-school STEM programs. The tool is specifically designed for observation by using twelve indicators of program quality. The target assessment areas include features of the learning environment, activity engagement, STEM knowledge and practices and youth development in STEM. Three specific categories within each heading are rated using a 4-point rubric of evidence based observation. The program requires training and evaluation certification [8].

6. CONCLUSIONS

By creating four scalable programs, customization of the solar cooking experience is possible for any age group or interest level. Developing an effective project with learning outcomes keeps programs focused on the goal. The format of the programs gives an opportunity to readjust, if necessary, mid program to ensure consistency and full attendee engagement and active participation.

The key findings are:

- The EDGE Method is simple, versatile and scalable
- The Four solar cooking programs offer easy customization for small or large-scale groups
- The pre-and post-evaluation assessment of each program offers opportunity for growth
- Managing expectations is possible with precise planning and oral and written communication
- Serving groups within a 60-mile radius of a hub, creates a regional distribution business model for increased penetration and visibility for solar cooking.

REFERENCES

[1] Teaching the EDGE Method., https://www.scouting.org/filestore/pdf/26-242.pdf accessed on 2017.10.03.

[2] Vandell D. L., Afterschool Program Quality and Student Outcomes: Reflections on Positive Key Findings on Learning and Development from Recent Research.

[3] Bussiere, L., & Hudgins, T. (2014). Girlstart After School: Analysis of program impact on participants'' academic achievement. Retrieved from http:// issuu.com/girlstart/ docs/after_ school_impact _analysis accessed on 2017.11.29.

[4] Examining the impact of an after school STEM program | 20 After school Alliance. (2013a). Defining youth outcomes for STEM learning in afterschool. Washington, D.C. Retrieved from www.aerschoolalliance.org/STEM_Outcomes_2013.pdf accessed on 2017.12.03.

[5] The Impact of Youth Development Programs on Student Academic Achievement. March 2011http://www.nationalassembly.org/Uploads2/Resources/SchoolSuccessBrief.pdf accessed on 2017.10.4

[6] Designing Education Projects Manual. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Second Edition, http://www.oesd.noaa.gov/leadership/DEP_ 2ndEdt_Final.pdf accessed on 2017.12.15.

[7] Bagby, J.H., et al. A Resource Guide to Planning and Operating Afterschool Programs. Copyright © 2008. http://www.sedl.org/pubs/fam95/introduction.html accessed 2017.12.15.

[8] A Guide to PEAR's STEM Tools: Dimensions of Success & The Common Instrument Suitehttps://www.thepearinstitute.org/dimensions-of-success accessed on 2017. 12.16.

The Broken Promise of Solar Cooking. The Case of Goudoubo Refugee Camp in Burkina Faso

Troconis, Isabella; London School of Economics and Political Science

54 Lincolns Inn Fields, WC2A 3LJ, London, United Kingdome

e-mail: i.troconis@lse.ac.uk, http://www.lse.ac.uk/Geography-and-Environment

e-mail: i.troconis@lse.ac.uk

Abstract: There has been a recent boom in renewable energy programs in African refugee settlements. Solar cookers are being disseminated with many-promised health, environmental and socio-economic benefits for women, including a decrease in smoke intake and drudgery. While solar energy initiatives for water pumping and lighting are widely used by refugees, the case for solar cookers has not been evident. This dissertation presents a case study of the introduction of the Blazing Tube solar cooker (BT) in Goudoubo Camp, Burkina Faso between 2013 and 2016. By using the energy ladder hypothesis as a theoretical framework, this paper identified and assessed the energy needs, preferences, behaviors, and adoption patterns among refugee women. Results from 37 interviews and 2 focus groups indicated that the BT failed to meet many of the participating women's needs and expectations. These findings go beyond those put forward by the energy ladder hypothesis and provide practitioners with a more holistic understanding of refugee women's energy behavior.

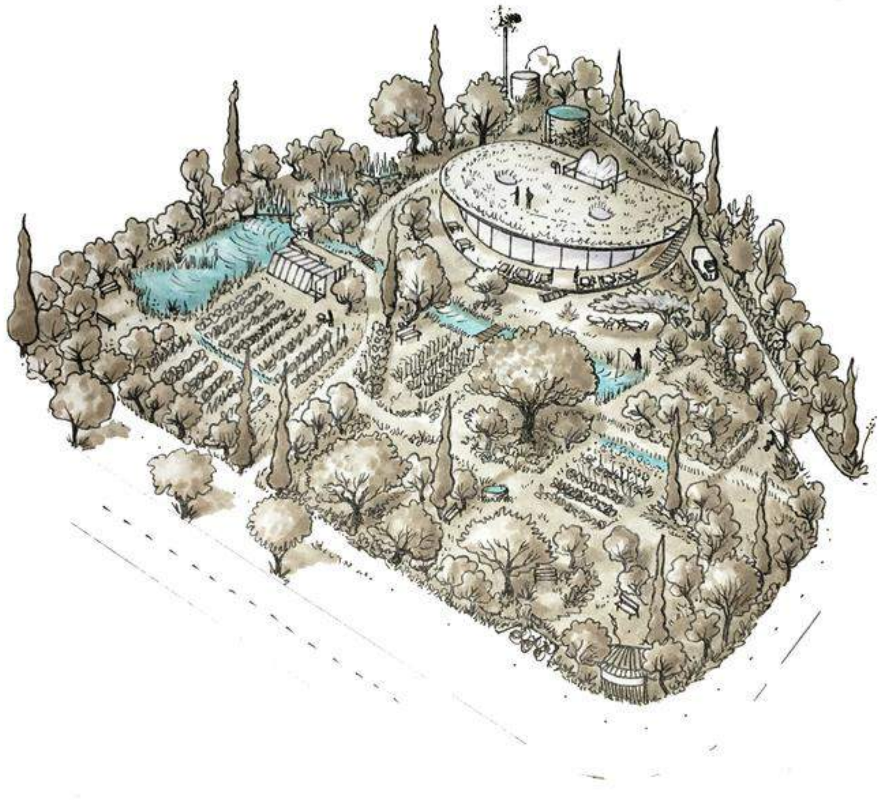
Keywords: Solar cookers, protracted refugee situation, energy ladder hypothesis, women

SOLAR RESTAURANT LE PRESAGE

Aubert Pierre-André

Association Rêves Germés
2 Place des Marseilles, 13001 Marseille, FRANCE
revesgermes@gmail.com / contact@restaurantlepresage.fr
http://restauranlepresage.fr

Abstract: After 4 years of development and two testing phase, the solar restaurant project *Le Présage* is about to become a real restaurant. This abstract will present the results of the second testing phase (the first testing phase has been presented during the SCI World Conference held in India in January 2017) focusing on the economical model of the restaurant as well on the cooking methods used during this second testing phase. The project has now demonstrated to potential of such a restaurant and the author will present the plans of the future restaurant that will open on March 2019, the economics behind and how to secure a total investment of 800 k€. The authors will also engage the discussion on how to set the solar cooking movement on the forefront of the medias.



Keywords: solar restaurant, Scheffler mirrors, community building, social investment.

Evolution of Solar Cooking technology in India and way ahead

By: Deepak Gadhia[1]

MSA Renewtech Foundation/ Muni Seva Ashram,
Address:
e-mail: Deepak.gadhia@greenashram.org
web: http://www.greenashram.org

Abstract:

Indian government has been promoting solar cooking since its Independence in year 1947 and by 1985 there were already more than 550,000 Solar Cookers (Box type).

Solar Box Cookers were supported with subsidy and promoted among rural population to reduce deforestation.

550,000 solar cookers sound impressive and a big number but for a country like India it does constitute a fraction of its population.

There is substantial number of people who use and love the Solar Box Cooker as cooking happens at low-temperature and retains its nutritious values and it has been seen that major users are school teachers and semi-urban house holds but the Target group of rural women did not accept the same as it was found to be too slow and that it could not cook all items.

Sk 10/ Sk 14 Parabolic Solar Cookers were introduced in 1990's by Gadhia Solar and Eco Center ICNEER based on technical support from Dr Dieter Seifert of Germany and they were more acceptable as it could cook fast, fry but affordability remained a major hurdle as people who could afford it did not need (as they has access to subsidized Liquidified Petroleum Gas-LPG) and people who needed it could not afford it. Middle Class women refused to use same as it required to go out and cook and they demanded that why cannot they have same luxury like man who sit and work in Comfort of their air-conditioned offices.

Thus Scheffler Parabolic Concentrators were introduced that enabled cooking in comfort's of the kitchen but to over come the price hurdle it was introduced as Community Solar Cookers and introduced in Mid-day Meal programs and for schools and hostels and Ashram.

On request of a Spiritual Institution Brahma Kumari's a NGO an Institutional Solar Steam Cooking System was developed for first time in World that cooked with solar steam.

In the presentation different types of Solar Steam Configurations and with different types of Solar Concentrators that have now evolved in India will be presented and discussed.

The way forward to make them more users friendly by over coming the limitations of timing (to be able to cook at night and to be able to fry) with different storage systems will be shared and discussed.

Key words: Experience with different models, integrations, acceptance, challenges, Networking, Interacting, sharing and learning, co-operation

Heliac Solar Cooker

Sedi L. Byskov *, Karsten Dupont, Gideon P. Caringal, Maria Matschuk and Henrik Pranov

Heliac, Savsvinget 4D, 2970 Denmark

e-mail: sb@heliac.dk*, kd@heliac.dk, gc@heliac.dk, mm@heliac.dk, hjp@heliac.dk
web: http://www.heliac.dk

The majority of solar cooker designs fall into the categories of panel, parabolic, evacuated tube and box cookers.[1] These cookers increase the solar concentration on a surface by use of reflection. Few cookers use refraction to concentrate light. Until recently the cost of fresnel lenses and the immediate associated risks with burns and eye damage (retinal burns) have not been encouraging for inventors wanting to develop a fresnel lens based solar cooker. Heliac is the first company to offer large fresnel lenses at low cost. The focal point of these lenses has been purposely broadened to diminish the risk of getting skin, retinal as well as unwanted burns of materials in or at the proximity of the cooker.
Heliacs most recent design of a fresnel lens based solar cooker is illustrated in Figure 1. It boils 1 liter of water in less than 15 minutes. Sunlight entering at normal incidence to the lens plane is reflected by a mirror and focused at the bottom of a cooking pot. The sides are covered with fabric to avoid glare from concentrated sunlight. The cooker has a dual rotation axis with manual tracking. The construction is made such that the mirror normal is always halfway between the angle tended by the lens normal and direction along mirror axis normal and pot bottom, thus avoiding the need to adjust the mirror, allowing the sun to be tracked quickly and easily every 10 min.

Figure 1: Heliac Solar Cooker vs 4.3

The specifications for construction can be freely accessed from Heliac by anyone who wishes to produce the cooker, thus allowing cookers to be produced by local craftsmen. 6 people in Zambia, Tanzania, Uganda, Sweden, Switzerland and India have begun constructing the cooker according to the Heliac construction manual. The feedback from the builders and users will be used to customize the Heliac Solar Cooker to specific regions.

Keywords
Fresnel lens: An object able to focus or defocus light by use of several refractive elements
Refraction: The deflection of light occurring when light enters an interface at an angle other than 0

[1] A Comprehensive Review on Solar Cookers, Erdem Cuce and Pinar Mert Cuce, 2013

A COMPARISON OF COPENHAGEN SOLAR COOKERS WITH OTHER SIMILAR SIZED SOLAR COOKERS

Sharon L. Clausson

Oursuncooks.com, San Diego, California, 92109

Abstract: *The Copenhagen Solar Cooker is very efficient for its size. Claims were made that it is more efficient per square centimeter of reflected area when compared with other panel cookers. This paper describes field testing of two popular panel solar cookers using the same square centimeters of reflective material to make the Copenhagen Solar Cooker and a Fun-Panel Solar Cooker (made with Teong Tan's 2008 free pattern on freewebs.com) Two testing methods are used. The first is the WBT Water Boiling Test designed by Bernhard Muller. The second test is done with the new SCI PEP testing station designed by Alan Bigelow and built by Glenn Clausson. The same size pan and contents are used in each cooker. Testing is side by side at the same time of day. Results listed in comparison chart. A thermal image of each cooker will be shown for reference.*

Keywords: Copenhagen, Panel Solar Cookers, Cook-It, Fun-Panel

1. **INTRODUCTION**

The Copenhagen Solar Cooker was invented in 2009 by the author, Sharon Clausson [1]. The Fun-Panel Solar Cooker directions were published in 2008 by Teong Tan [2]. The Copenhagen Solar Cooker was made with self-stick reflective Vinyl on a polypropylene substrate. The Fun Panel was built out of cardboard and foil. The Fun-Panel and the Copenhagen were built with approximately .75 square meters of material. The tests are to determine how much cooking power each design produces. Two different cooking evaluations were used. The first test was the WBT designed by Bernhard Muller [3]. The second was the PEP testing protocol designed by Dr. Alan Bigelow Ph.D. Science Director for SCI and built by Glenn Clausson [4]. The pans used were both 4.25l and each held 2000ml.of water. The pictures from a thermal camera Pure Thermal 1 Camera by GroupGets.com [5] were used to show heat distribution pattern of each cooker.

2. PEP TEST EQUIPMENT

Two types of panel solar cookers were used in the evaluation:

a. Copenhagen Solar Cooker by the author Sharon Clausson (adjusted to .75 square meters) [1]
b. Fun Panel by Teong Tan (adjusted to .75 square meters) [2]

For the quantitative portion of my evaluation I used:

a. The Water Boiling Test by Bernhard Muller [3]
b. PEP testing station designed by Alan Bigelow for SCI and built by Glenn Clausson [4]
c. Pure Thermal 1 Camera by GroupGets.com [5]

PEP station test equipment:

Electronics platform	Arduino Mega open source electronics, liquid crystal display and removable SD card
Temperature	Type K thermocouples to measure water and ambient temperatures
Wind speed	Anemometer (Adafruit)
Solar irradiance	SP-215 amplified pyranometer (Apogee) mounted to a horizontal bubble-leveled plane
Additional	Global positioning system

3. PEP TESTING STEPS

* Align testing station with the pyranometer wire connector at a North /South compass direction.
* Use bubble level on mount fixture to level the pyranometer.
* Put thermocouple plugs into sockets with ambient probe out of direct sunlight.
* Push thermocouple probes through pot lids and secure with threaded nuts.
* Align solar cookers for maximum sun and put empty pots on racks in the solar cookers.
* Connect 12 VDC battery to testing station.
* Premeasure equal amounts of water and add to pots then cover with lids.
* Compare ambient temperature to water in pots, if they are within 2C then press reset button to start new test. If water temperature is below ambient then wait for equalization and restart by pressing reset. If water temperatures are more than 2C above ambient then change water and add new ambient

temperature water.
*Adjust cooker every 20 minutes to track the sun. format.

**The results on the first 2 tests are the beta testing of the equipment. A wiring error occured which reversed the polarity. After that was corrected the readings were in the normal range.

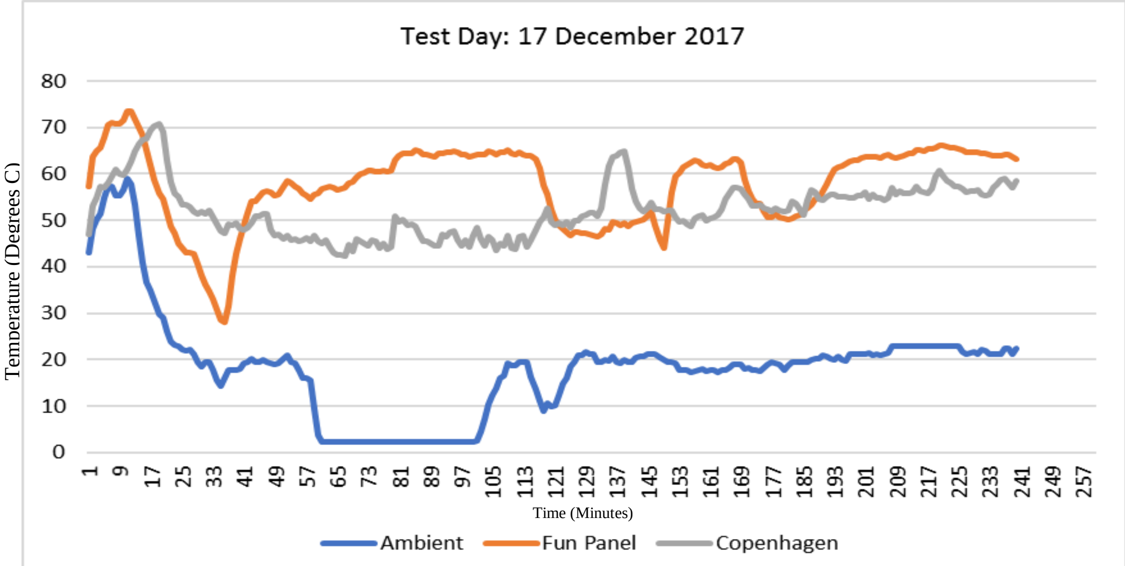


Figure 1 . Graph of Test Day 17 Results

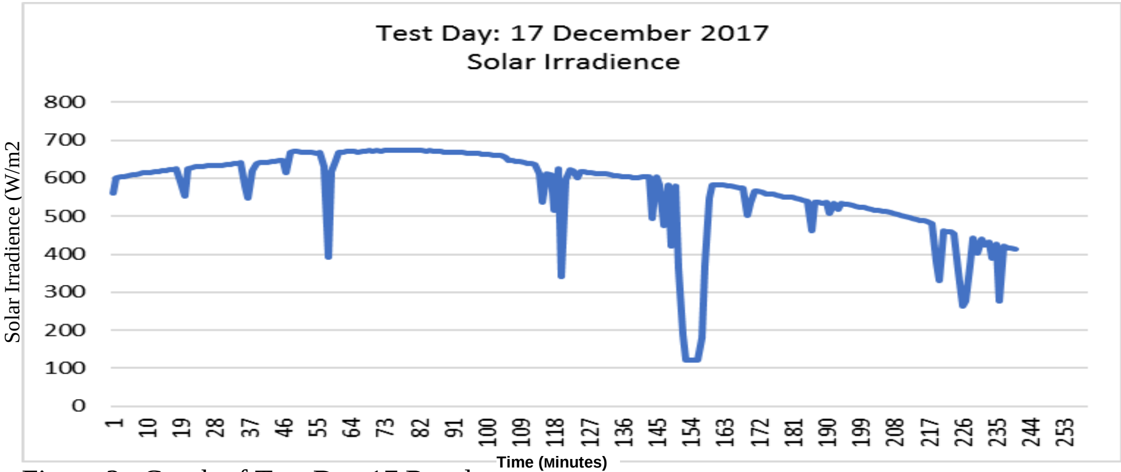


Figure 2 . Graph of Test Day 17 Results

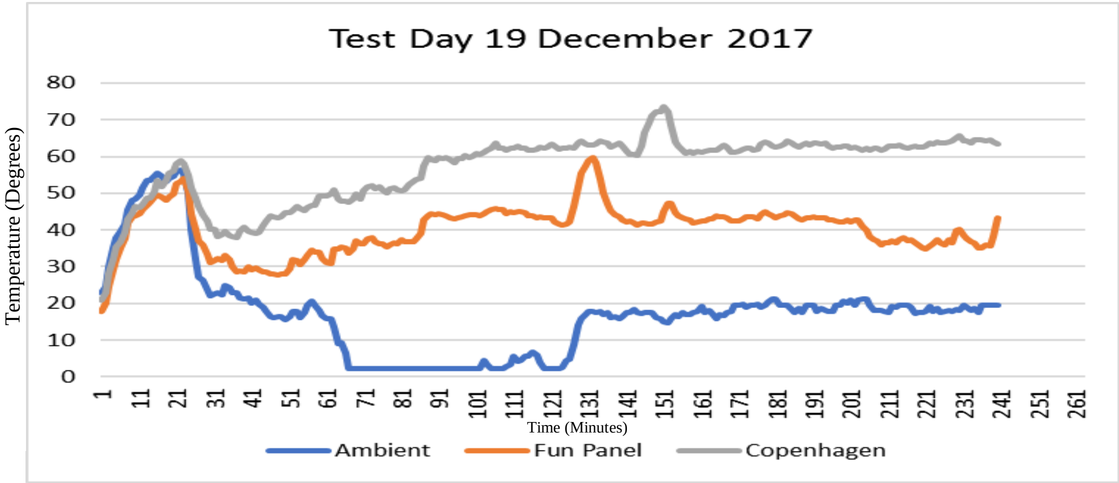


Figure 3 . Graph of Test Day 19 Results

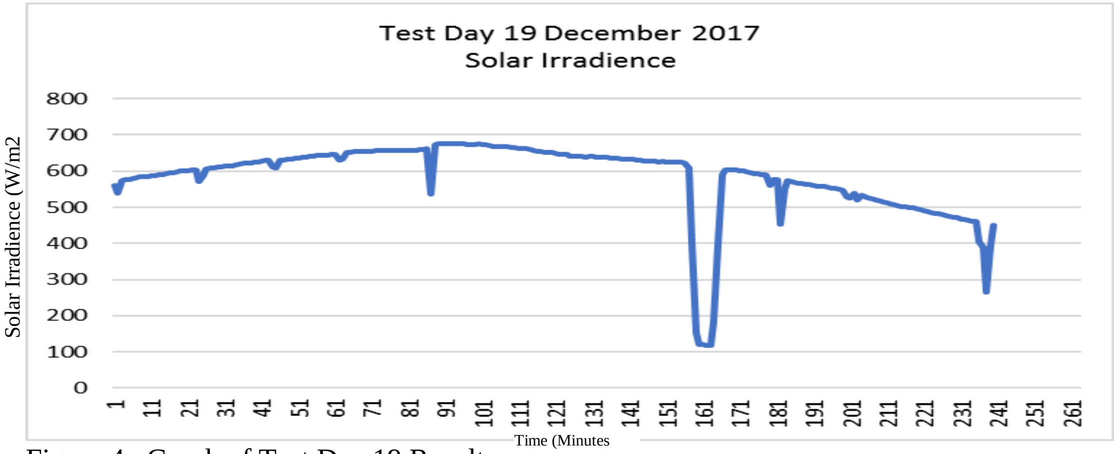


Figure 4 . Graph of Test Day 19 Results

4. WBT WATER BOILING TEST

The Water Boiling test for Solar Cookers WBT SC allows comparison with other cook stoves and open fires. The test is for cooking ability only. It is easy to understand and record test results. It can be set up in the field with a minimum of equipment.

Equipment

Accessories needed to run the test:

a. A solar cooker on a horizontal surface.
b. A blackened pot with a lid.
c. A thermocouple or thermometer.

d. An appropriate amount of water.
e. A precision scale to weigh water.
f. A measuring devise to calculate aperture area.

Fixed and variable parameters.

The WBT SC has a fixed parameter: the amount of water. In smaller or weaker solar cookers use 1 liter, and for larger ones use 2.5 liters.

The variable parameters are
a. location, mainly latitude
b. position of the sun
c. type of cooker
d. aperature area
e. reflector material
f. insulation, if any
g. heat trapping material
h. date and time
i. initial water temperature
j. local boiling point

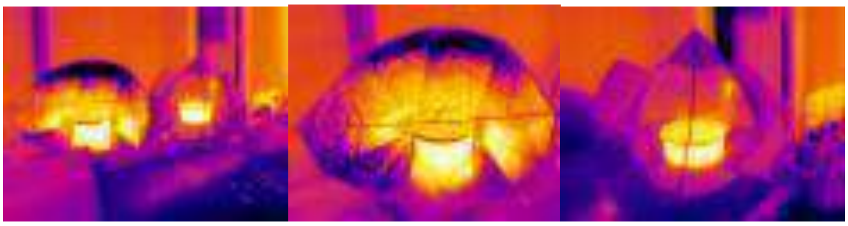
To avoid confusion, the test should not be conducted if sun is less than 30 degrees above horizon (zenith angle more than 60 degrees), and if the ambient and/or water temperature is less than 0C (32F)

5. THERMAL IMAGING COMPARISONS

Thermal imaging equipment:
a. Pure Thermal 1 camera by GroupGets.com - data sheet
https://groupgets.com/manufacturers/flir/products/lepton-2-0 on a
https://hackaday.io/project/8796-pure-thermal-1-development-board
b. USB cable
c. Laptop computer with Windows XP using Windows Pictures and Fax Viewer

6. THERMAL IMAGING TEST STEPS

a. Set up solar cookers in the sun
b. Put correct measure of water in pans and put in solar cookers.
c. When pots are hot attach camera to USB cord and cord to laptop
d. use keyboard to take pictures



Both Solar Cookers Fun Panel Copenhagen

Figure 1. Thermal image of Fun Panel on left and Copenhagen Solar Cooker on right.

The Yellow is the hottest and the deep purple the coolest. Note the very different distributions of solar Energy in each cooker. Future tests will be done on each solar cooker the author has made.

7. ACKNOWLEDGMENTS

I want to acknowledge the inputs of the following:

Alan Bigelow, Bernhard Muller, Glenn Clausson, Mariano Munoz, Bryan Monroe and SCT.

8. CONCLUSIONS

The comparison of these two solar cookers combined with three evaluation methods highlighted their differences and similarities. It showed the weaknesses and strengths of the different testing methods.

- To do the PEP test the author's husband built the PEP Station from directions offered on the Solar Cookers International website and designed by Dr Alan Bigelow Ph.D. The build went well. Testing some components took more time than expected. Not having familiarity with graphing software author had difficulty interpreting the raw data. A suggestion on this beta project would be to include a more comprehensive explanation for parsing the raw data.
- Bernhard Mullers' WBT SC test was much simpler and less expensive. The readings from the PEP were used to populate most of the WBT SC form. This method is much easier for field testing and just as accurate. The equipment is also minimal.
- The purpose of using the Pure Thermal1 Camera was to show yet another way to look at solar cooker performance. More tests with this camera are needed to learn how to utilize the information it provides. A clear difference can be seen by looking at the thermal images of the Fun Panel and the Copenhagen side by side.
- The shape of both cookers is very similar when in use. Observations in the early day and later day, not included in the tests, showed the water in the Copenhagen solar cooker getting hotter than the water in the Fun Panel. However during test hours they were quite similar. After the test ended the water in both cookers had almost the same temperature.
- The Copenhagen was enlarged to match the .75 square meter size of the Fun Panel. Further research needs be done with a Fun Panel made of the same material as the Copenhagen.
- The Copenhagen could benefit from the addition of booster panels between the points. Both

cookers reached higher Temperatures with a supporting dowel to hold “wings” open.

- Teong Tan invented the Fun Panel from an aeronautical engineering point of view. The author invented the Copenhagen from an intuitive artistic maker point of view. The similarities in the performance of both is notable.
- An hour after sunset the water in the Fun panel was 30.1 C and the water in the Copenhagen was 42.4 C and the ambient was 19.01. It must be noted that because of its adjustable design the Copenhagen panels can be clipped into a cone shape which holds the heat a little longer.
- More research is needed to see if adding an insulated wrap to the pans left in the cookers would hold the heat longer.
- This paper reflects the evaluations of a previous paper by Dane Dormino and Steven Jone [6].
- Both the Fun Panel and the Copenhagen Solar Cooker perform well enough to cook and food chosen and in very similar amounts of time.

REFERENCES

[1] Clausson, SL Copenhagen solar cooker inventor, 2009 Author of this paper.
[2] Tan, T, Fun Panel solar cooker construction plan July 2008 www.freewebs.com/sunnycooker.
[3] Muller B The water boiling test for solar cookers. WBT SC v. 1.0.3 April 2014.
[4] Bigelow, A PEP ASAE S580.1 protocol solar cooker performance testing unit.
[5] https://hackaday.io/project/8796-pure-thermal-1-development-board
[6] http://solarcooking.org/research/Dormio-report.htm

THE SOLAR COOKER TOLOKATSIN V

Eduardo A. Rincón-Mejía

Programa de Energía, Universidad Autónoma de la Ciudad de México
San Lorenzo 290, Col. Del Valle, 03100 México, México
Eduardo.rincon@uacm.edu.mx, https://www.uacm.edu.mx

Abstract: In 1995 the first Tolokatsin solar cookers were designed and constructed, based on non-imaging optics, with a multi compound solar concentrator, a hollow cylindrical absorber inside which a stainless steel recipient for containing the food to be cooked used to be placed. They could be sized for practically any volumetric capacity (from 1 to more than 100 L) with only slight variations in their designing parameters. These solar ovens were designed for a quickly heating up, but trying that after reaching around 100°C the temperature doesn't go much above 120 °C in order to avoid the formation of hazardous substances, like acrylamides, or the burning of the meals. However, for semi cloudy skies, this limited concentration delayed the cooking time, and jeopardizing the success of the process in cloudy days. The new solar cooker Tolokatsin V has a much greater geometric concentration, and optimized according to Rincon criteria, and it also has a higher optical efficiency. Even though its stagnation temperature is 160 °C, this value cannot be reached out with full meal charge, when it works in a stationary position. This allows a safe and quick cooking even in semi cloudy days, more efficiently than with the Tolokatsin original design. This paper presents the design criteria and parameters values for this brand new design, and the merit figures according some recognized standards for solar cookers.

Keywords: Tolokatsin solar cookers. Solar cooking.

SOLAR COOKERS INTERNATIONAL TEST STATIONS FOR A PERFORMANCE EVALUATION PROCESS MOTIVATE A NETWORK OF TESTING CENTERS

Alan W. Bigelow*, Justin Tabatchnick and Julie L. Greene

Solar Cookers International
2400 22nd St Ste 210, Sacramento, California 95818, USA
e-mail: alan.bigelow@solarcookers.org, web: http://www.solarcookers.org

Abstract: Solar Cookers International (SCI) has designed and built portable test stations for a performance evaluation process (PEP) for solar thermal cookers. These PEP test stations, along with reproductions built by other groups using SCI's open-source, test station design plans, make for a single, uniform platform used for evaluating the thermal performance of solar cookers in a network of testing centers convened by SCI. Having a common test platform across the solar cooker industry creates a level playing field by which cooker performance can be compared. This initiative by SCI is a response to the solar cooking sector's expressed need for an independent, neutral agency to develop the capacity for testing solar thermal cooking devices. The PEP test station is based on commercially-available, low-cost components, including: thermocouples, an anemometer, a pyranometer and Arduino hardware. The test station control software was designed by SCI to conduct the American Society of Agricultural and Biological Engineers ASAE S580.1 protocol for Testing and Reporting Solar Cooker Performance; it measures temperature changes in an amount of water proportional to the intercept area of a solar cooker, while monitoring wind speed and solar insolation, for normalizing results.

Keywords: Solar cookers, Solar cooking, Tier 4 cookstoves, Testing standards, Thermal evaluation

SOLAR COOKERS INTERNATIONAL REPORTS RECENT GAINS IN THE GLOBAL SOLAR COOKING MOVEMENT

Julie L. Greene, Alan W. Bigelow and Caitlyn S. Hughes

Solar Cookers International
2400 22nd Street, Suite 210, Sacramento, California 95818 USA
Email: julie@solarcookers.org {alan.bigelow@solarcookers.org, caitlyn.hughes@solarcookers.org} Web:www.solarcookers.org

Abstract: Solar Cookers International provides up-to-date information on progress of the global solar cooking movement. This presentation will share the latest advocacy efforts by Solar Cookers International as it speaks with one voice for the global solar cooking movement by exercising its special consultative status at the United Nations. Advocacy talking points for solar cooking as a solution to the Sustainable Development Goals and inclusion in country voluntary plans to achieve the Paris Agreement 2015, SCI's development phases for solar cooker performance evaluation protocol (PEP) that harmonizes with international standards, social entrepreneurship development, successful project outcomes, and results of data collection and evaluation will be shared. The speaker will also share three specific ways that conference participants can engage in global advocacy and increase partnerships to amplify their work.

Keywords: advocacy, evaluation, SDGs, solar cooking, sustainable development

SIMULATION OF A SOLAR ASSISTED COUNTERFLOW TUNNEL DEHYDRATOR

Carrillo-Andrés, A., Sojo-Gordillo, J.M., Domínguez-Muñoz, F.,Cejudo-López, J.M.

University of Málaga, Industrial Engineering School, Energy Research Group. C/ Arquitecto Peñalosa s/n. 29071. Spain, Phone: 34-951-952-401, e-mail: acarrillo@uma.es

Abstract: A widely used class of vegetable dehydration systems are the "tunnel-and-truck" dehydrators, where the prepared material lies over horizontal trays stored in trucks which move discontinuously in opposite direction of the air flow. This way the driest product is facing the inlet hot and dry air blowed to the system. When product of one truck is ready, is removed from the tunnel leaving space for advance the remaining truck one place forward. This way, a new truck full of wet product can be inserted at the end of the tunnel. The thermal energy required for the process can be supplied by several sources including gas, biomass, solar energy or a combination of them. Solar energy is for free but reaches the Earth with quite a low flux and a strongly fluctuating rate. This imposes the need of special designs and control strategies. This paper presents a study based on simulation models of the dehydrator and the solar thermal system. The dehydrator simulation model is tuned to match experimental data from a particular prototype based on fossil fuel. A solar system simulation model is then applied to the analysis of different design options.

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Keywords: Dehydrator, Dryer, Thermal, Solar, Food processing

1. **INTRODUCTION**

A widely used class of vegetable dehydration systems are the "tunnel-and-truck" dehydrators [1]. A schematic can be seen in Figure 1. An electric fan moves air (2-3) through a hot water heating coil (3-4), and then across several trucks loaded with the product to be dehydrated (4-5). The humidity content of the air increses while its temperature decreases, as the air and the product exchange mass and heat. Then some air must be exhausted and replaced with fresh outside air in order to reject some moisture to the environment (6) and keep the drying process going on. A recovery sensible heat exchanger is used to reduce the amount of energy needed to condition the incoming fresh air.

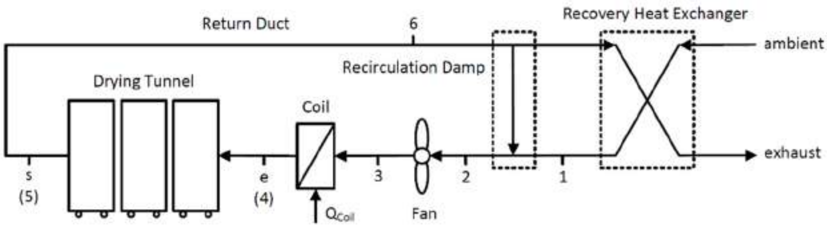

Figure 1. Schematic of the system components.

A prototype of a five-truck dehydrator has been tested experimentally. The prototype has a gas boiler and a hot water heating coil. This paper presents a preliminary evaluation of the potential use of solar energy to reduce the dehydrator fuel consumption. A simulation model of the dehydrator was developed and tuned to match experimental data. Then a simulation model of a solar water heating system is used to analyze different design options.

2. EXPERIMENTAL TESTS

Several tests were conducted on the dehydrator prototype but, at the time of writing, only partial load tests (only the first truck loaded) could be completed successfully. A particular test, dehydrating sliced bananas, with a process air temperature set point of 60 °C is taken as the reference test, see Table 1.

Table 1. Parameters and measurements of the reference test. Only the truck #1 is loaded with sliced bananas.

Parameter	Value	Comment
Outside air temperature (°C) and relative humidity (%)	Around 20°C 50 %	Measured
Process air setpoint temperature (°C)	60	Measured
Process air mass flow rate (kg/h)	18906	Measured with digital vane probe
Exhaust air mass flow rate (kg/h)	945	Measured, it is 5% of the process flow rate
Global heat loss coefficient UA (W/C)	110	Determined from stationary heating tests
Heat recovery efficiency	0.8	Calculated from measurements
Fan motor electrical consumption (kW)	2.35	Measured
Wet product initial weight per truck (kg)	81.3	Measured
Dry product weight per truck (kg)	21.1	Estimated
Total water loss (kg)	58	Measured with a weight scale under truck #1
Heating coil energy (kWh)	104	Measured with an energy meter
Fan motor heat energy (kWh)	38	Measured with an energy meter
Heat loss to ambient (kWh)	70	Calculated from UA and temp. differences
Heat loss due to exhaust (kWh)	32	Calculated from energy and mass balances
Dehydration latent energy (kWh)	38	Calculated from product weight loss

The prototype has a weight scale under truck #1 so the weight can be continously measured and recorded, from the beginning to the end of the test, see Figure 2.

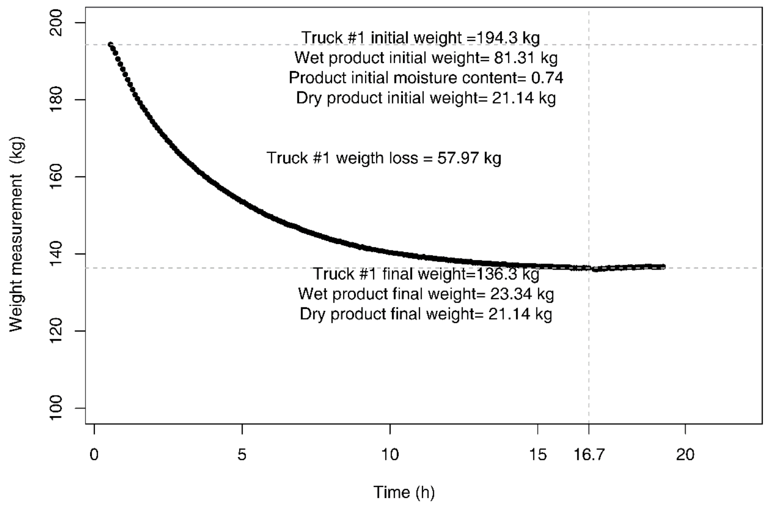

Figure 2. Truck #1 weight versus time for the reference test.

Is interesting to analyze the different thermal energy rate magnitudes in order to check the energy balance, see Figure 3. In spite of some noisy data, there is a good balance between thermal power input (Qcoil + Qfan) and thermal power output (Qlat.sc +Qloss +Qex).

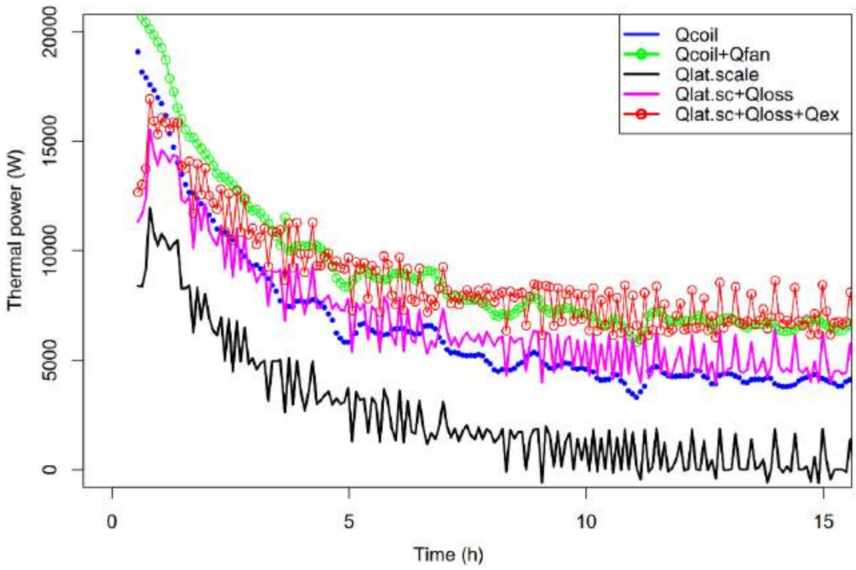

Figure 3. Energy balance. **Qcoil:** Hot water heating coil power, calculated as the first derivative of the hot water energy meter readings. **Qfan:** Electric power absorbed by the fan electric motor. The heat is intendend to go into the air stream. **Qlat.scale**: Thermal power associated to the evaporation of water from the product. Calculated from the latent heat of water and the evaporation rate, calculated as the first derivative of the weight scale readings. **Qloss**: Thermal losses to the environment, calculated with the global UA and the temperature difference dehydrator - ambient. **Qex:** Thermal power to condition incoming fresh air.

2. DEHYDRATOR MODEL

A model of the dehydrator is programmed using EES[2]. Besides the usual psychrometrics and energy and mass balances involved, there is a key point to be modelled: the drying rate of the product. This rate is clearly variable along the process. From the Figure 2 data, the normalized drying rate of the product in dry basis can be computed and plotted versus the product moisture content excess, see Figure 4. There is a clear dependence between both magnitudes. A third degree polynomial fits well the experimental data. The same procedure is then applied to another reference test with a process air setpoint of 50 °C. A linear interpolation is then applied to find the drying rate for any other temperature in the range 50-60 °C. Obviously this quite simple approach is only valid for this particular dehydrator, product, and operating conditions.

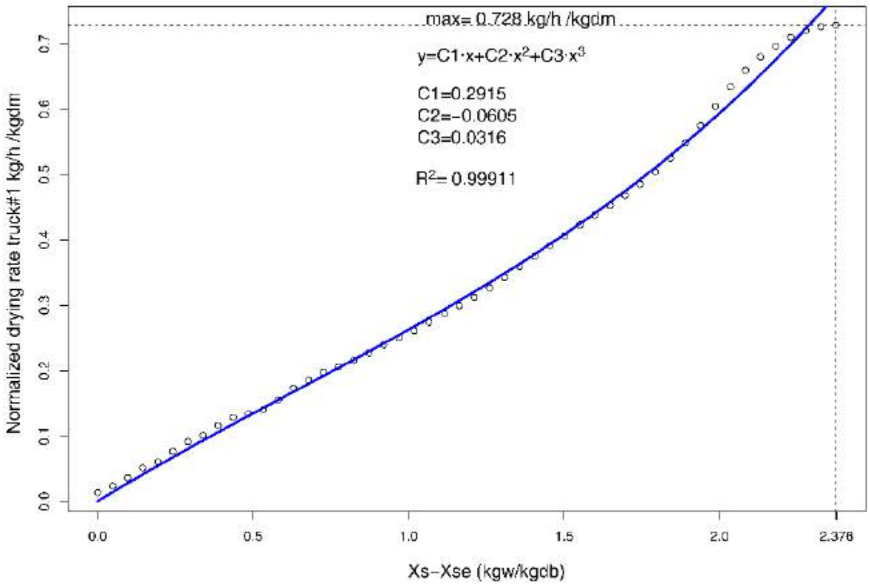

Figure 4. Normalized drying rate vs product dry basis moisture content excess for the reference test with the process air setpoint set at 60 °C

In order to check the model, the reference tests are reproduced with a good agreement between experimental and simulation data, see Figure 5. Then the model is used to simulate a full load operation scenario, that is, the five trucks loaded with product. The other operating conditions remains the same as in the reference test, except the exhaust flow rate, that is increased from 5% to a 25% of the process flow rate. The simulation results (Figure 6) show how the process air temperature drops across the trucks, and how the difference between trucks decreases along time, as was expected. The thermal power required in the heating coil is a very important result, see Figure 7. It starts around 70kW and decreases along time, as the drying rate does. This curve will be the energy demand for the thermal solar system,

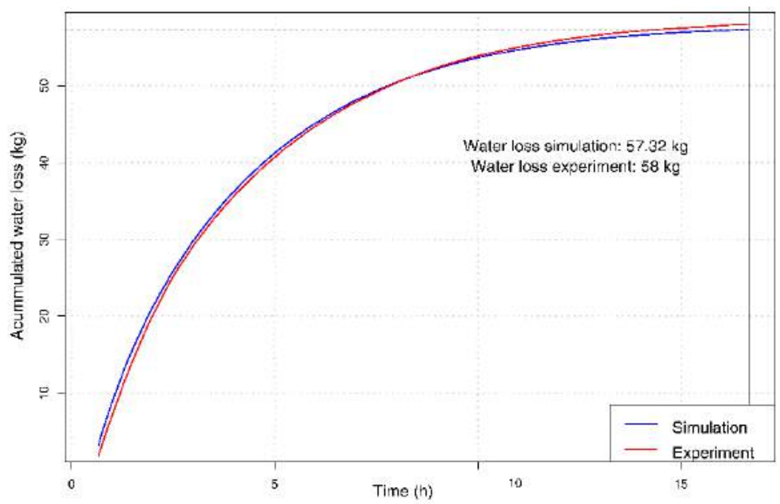

Figure 5. Acummulated water loss. Simulation vs experiment.

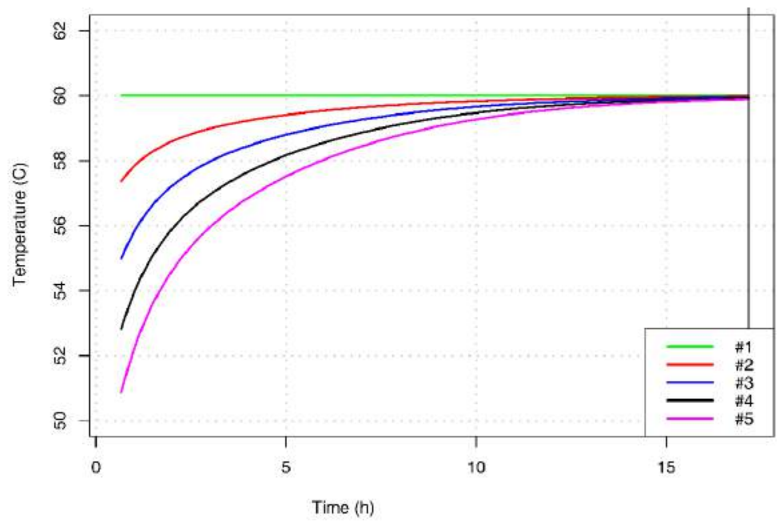

Figure 6. Process air temperature at the inlet of each truck in the full load simulation scenario.

3. SOLAR THERMAL SYSTEM MODEL

TRNSYS [3] is used to model a solar thermal system located in Tenerife (Spain), see Table 2. This location is selected because it is an important banana production area. Several simulations are conducted for a range of collector areas and tank volume to collector area ratios. In addition to that, two different strategies for controlling the heating coil are tested. In the first strategy the back-up heater setpoint temperature is set at a constant value of 80 °C. To manage partial load there is a tempering valve to reduce the effective inlet water temperature to the coil by recirculating some flow rate from the coil outlet. In this way the flow rate discharged from the solar tank is reduced. In the second strategy, the back-up heater setpoint temperature is reduced at partial load and the flow rate discharged from the solar tank is always maximum. The process air setpoint temperature is set at a constant value of 60 °C.

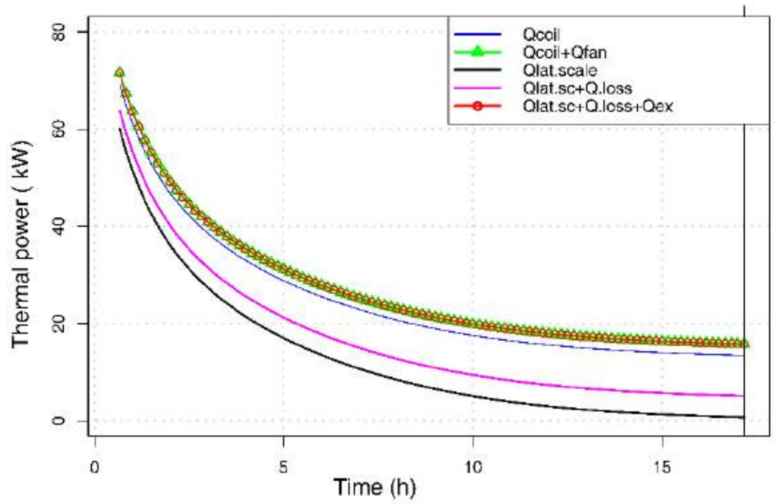

Figure 7. Energy magnitudes in the full load simulation scenario. There is a balance between thermal power input (Qcoil + Qfan) and thermal power output (Qlat.sc +Qloss +Qex)

Table 2. Parameters of the solar thermal system.

Parameter	Value	Comment
Weather file	Tenerife.EPW	EnergyPlus weather data [4]. Lat: 28.47 °N
Energy demand from drehydrator (kW)	Qcoil from Fig 7	A batch operation is assumed starting at 16h every day of the year and finishing at 9h next day.
Collector type	select. flat plate	Co=0.809 C1=4.030 W/m2K C2=0.007 W/m^2K^2
Slope and azimuth	30 ° facing south	Typical parameters
Collector area (m^2)	50 to 300	Aperture area
Solar tank volume to col. area ratio VA (l/m^2)	50-75-100	Typical range
Collectors arrangement	2 units in series	Typical arrangement
Solar field flow rate ratio (l/hm^2)	40	Nominal value for the selected collector.
Thermal losses in piping	Neglected	This is a preliminary analysis
Solar tank insulation	100 mm	k=0.04 W/mK
Maximum temperature allowed in tank (°C)	90	Typical value
Back-up heater position	Series with tank	An “ideal” back-up heater is assumed
Back-up heater setpoint temperature (°C)	80 or variable	Two different control strategies, see text
Heating coil nominal thermal power (kW)	70	Data from the simulation of the full load test Fig7
Heating coil air flow rate (kg/h)	18906	Actual air flow rate in the prototype
Heating coil water flow rate (kg/h)	4225	A balanced heat exchanger is assumed
Heating coil nominal air temperatures (°C)	47 inlet 60 outlet	60 °C is the process air setpoint, 47 °C from simulation of the full load scenario Fig.7.
Heating coil nominal water temp. (°C)	80 inlet 67 outlet	80 °C is the water temperature setpoint of the boiler of the prototype.
Heating coil exchange effectiveness	0.4	Calculated from assumptions above

4. RESULTS AND CONCLUSIONS

Two figures of merit are used to measure the performance of the solar system: a) the solar fraction (SF), defined as the fraction of the total load which is covered by solar energy, and b) the net collector efficiency (NCE), defined as the fraction of useful solar heat with respect to the solar radiation incident on the collector. The Figure 8 shows a huge improvement in performance when the VA ratio increases from 50 to 75 l/m^2 (but not so much from 75 to 100). The variable setpoint temperature control strategy also improves the performance of the solar system, and it is very dependent on the VA ratio and the collector area. The improvement is negligible for cases with low SF, and maximum when SF is around 75-80 %. For example, for the case with VA=75 l/m^2 and A=175 m^2, the SF increases from 76.8% to 82.3% (5.5 points). The NCE is around 35% for cases with VA 75-100 l/m^2, collector area up to 150 m^2 and variable back-up setpoint control, and then shows a marked decline for larger areas. This paper presents a preliminary analysis: there still remains several aspects to be researched in how the dehydrator and solar system perform together under different operating conditions.

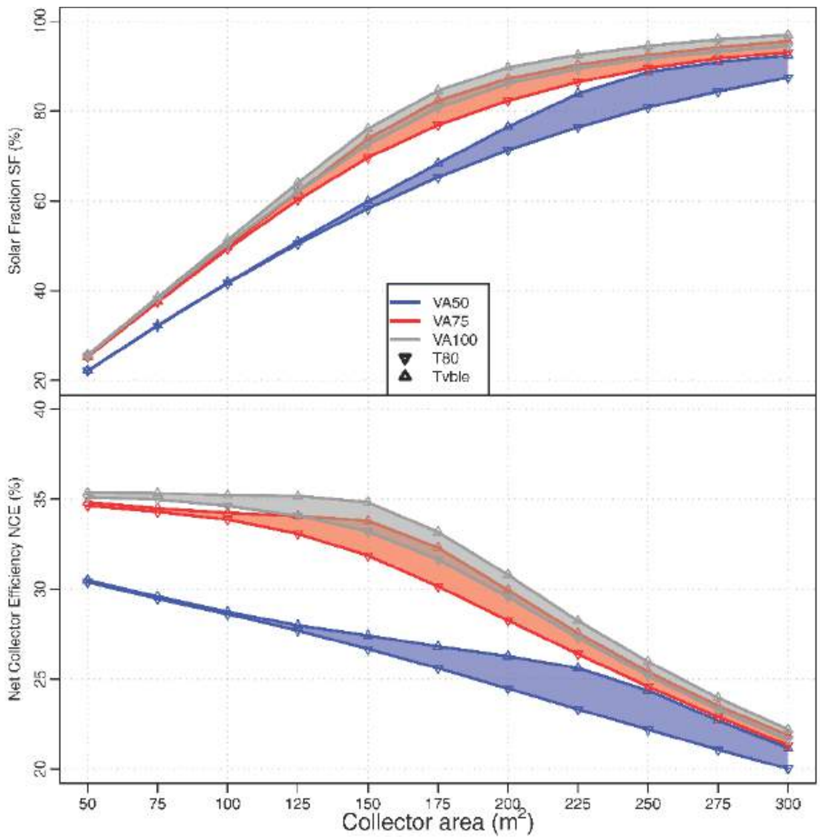

Figure 8. Solar Fraction and Net Collector Efficiency for the solar system.

REFERENCES

[1] W.. Van Arsdel, Tunnel-and-truck dehydrators, as used for dehydrating vegetables, en: Veg. fruit dehydration, a Man. plant Oper., 1944. doi:10.1007/s13398-014-0173-7.2.

[2] S.A. Klein, EES (Engineering Equation Solver), (s. f.). www.fchart.com.

[3] S.A. Klein, J.A. Duffie, W.A. Beckman, TRNSYS 16: A transient system simulation program., (2007). https://sel.me.wisc.edu/.

[4] D.O.E., EnergyPlus, (2015). www.energyplus.net.

Development of solar dryers, Cuban experience for food preservation.

Boris Albrech Zaldívar Núñez, Glensy Palay Alonso

1: Grupo de energía solar (genSolar), Sociedad Cubana Para la Promoción de las Fuentes Renovables de Energia y el Respeto Ambiental (CUBASOLAR)
Calle 20 # 4111 e/ 18ª y 47, Playa, La Habana, Cuba
boris@cubasolar.cu, web: http://www.cubasolar.cu

2: División de Comunicación, Centro de Gestión de la información y Desarrollo de la energía (Cubaenergia),
Calle 20 # 4111 e/ 18ª y 47, Playa, La Habana, Cuba
gpalay@cubaenergia.cu, web: http://www.cubaenergia.cu

Abstract: Well-founded studies predict the depletion of energy resources, especially petroleum resources, in just a hundred or two hundred years if the current and prospective consumption rate continues. This energy policy, based on conventional fuels, has catastrophic consequences for humanity and the environment.

A rational energy policy, supported by scientific advances, would lead to a considerable reduction in the current consumption of fuels. Energy efficiency appears as a necessary, but not sufficient, factor for the survival of man on the Earth.

Solar energy converted to heat can be used in food cooking, sea water purification, heating of fluids and drying. Its large-scale use, with a considerable economic effect, is currently obtained only in thermal processes of low temperatures (below 100 ° C).

With the aim of promoting the development of the food program, energy saving, energy efficiency and the use of renewable energy sources, different types of solar dryers have been developed in Cuba, which offer more advantages than conventional dehydrators.

Drying is the operation of reducing the humidity to a certain product, by the evaporation and elimination of the water contained therein, without altering its chemical composition. It is widely used in industrial processes, as well as in the conservation of agricultural, livestock and marine products. In Cuba, the drying of minerals, wood, tobacco, coffee, cocoa, rice, fodder, seeds, aromatic and medicinal plants, fruits, fish, meat products among others are particularly important.

The presentation will illustrate the results of the development of three types of SECSOL Dryers. The benefits of the design of a grain dryer using a rotary drum, a wood dryer and a multipurpose dryer for the drying of vegetables, fruits, medicinal plants and spices will be analyzed. It will also offer the data of its technical characteristics as well as the essential keys for its construction and correct operation.

As a complement to the presentation, the behavior of this type of dryer will be explained under real operating conditions, using as reference the production process carried out in a non-agricultural cooperative that produces condiments and nuts without using extenders or chemical additives for the conservation (100% natural). This experience is very new in Cuba. It is important to point out that the raw material used in this factory is extracted from organic farms, transforming the whole drying process into a polygon of integral development.

Keywords: Solar, Thermal, Food processing

INTRODUCTION OF SOLAR DRYING BY NGO NARMADA IN NIMAR REGION OF MADHYA PRADESH STATE OF INDIA UNDER THE GUIDANCE OF BARC,GOI.

RAGHAV S DEOSTHALE [1*] SHANKAR KEWAT [2*]

1,2 : RURAL TECHNOLOGY CENTER, NIMAR ABHYUDAYA RURAL MANAGEMENT & DEVELOPMENT ASSOCIATION (NARMADA), 149, LEPA PUNARVAS, KASRAWAD, KHARGONE, MP, INDIA- 451228

Email- narmada.akruti@gmail.com, www.narmadalaya.org

ABSTRACT- *Solar driers of various designs and sizes to be used for providing low cost food preservation/processing method for agricultural produce and thus provide employment. Area of operation i.e. Nimar Region of Madhya Pradesh, India receives at least 270 days of sunlight and temperatures soar up to 49 c during summers. This geographical advantage is conducive for spread of this technology whereas challenges of socio-economic condition need to be addressed. Awareness is being generated for 2 designs currently available and work on a 3rd design is in progress.*

KEYWORDS- *SOLAR DRIERS, INDIA, BARC, RURAL EMPLOYMENT, WOMEN EMPOWERMENT*

1. **Introduction**

Nimar Abhyudaya Rural Management & Development Association (to be referred as NARMADA), is a NGO operational in the Nimar Region of Madhya Pradesh, India, for the past 8 years. (1) Primarily, the institutions focus was on providing education to deprived children in rural areas near the city of Mandleshwar. But gradually it was observed that the amount school drop outs was very high and many students left education only because the schools were far. NARMADA, then focused on such students. (2) After lot of efforts, 5 boys from the LEPA village successfully completed a diploma in Basic Rural Technology from Vigyan Ashram, Pabal. They are now skilled workmen and experts in electrification, carpentry, plumbing, welding and other fabrication. Their skill needs to given a direction. (3) NARMADA, has been using solar technology, be it cooking, electricity or very recently drying for quite some time. The interest shown by these young minds in solar technology was encouraging, and hence NARMADA started making solar dryers. (4) This paper contains details of how it started, Nimar region, what is the aim, who are the partners, what problems we face and what can be done?

2. **How it started ?**

It was during a training program at Dr. Mrs. Janak Palta Mcgilligan (Janak Didi) place 'GIRIDARSHAN' at Sanawadiya,Indore, that the karyakarta's (volunteers) of NARMADA were introduced to solar drying. We saw the tunnel dryer on her roof and also the dehydrated products. During our 3 day stay at Giridarshan, we observed the dryer for almost 3-4 times everyday.

The idea of preserving agricultural produces at low cost had clicked in our minds. (2) One student from NARMADA, Shankar Kewat, came back to the ashram and after some research on internet, fabricated 2 solar dryers in a single night. One was of the tunnel type and the other of the cabinet type. The test results were encouraging. Shankar then went ahead and fabricated a model of the tunnel dryer and presented it at a State Level Science Competition and it won him the first price. This is where the journey begun.

3. **The Nimar Region.**

Nimar region lies in the southwest of Madhya Pradesh state of India and comprises of the Khandwa and Khargone district. The holy river Narmada flows through the region and Narmada along with its tributaries and distributaries is the lifeline of the region. In the past few years, Nimar has shown tremendous development in the field of agriculture. Primary reason for it being the advancements made in the irrigation sectors. Dams, large & small and the widespread network of canals have ensured that water is available to farmers throughout the year. (2) Farmers are now able to harvest 2-3 and sometimes 4 crops in a year. Primary crops are chilly, wheat, maize, tomato and soybean. Chilly of Nimar is famous throughout the world and is exported to various parts. (3) However, sometimes the farmers have to throw away a large part of their produce, specially tomatoes and chilies. There are two reasons behind it. One, being the lack of proper transport facilities and two, fluctuating rates of the market.

4. **What is the aim?**

   (1)This is where solar driers come into the picture. A part of the produce of tomato and chilly, which the farmer throws away, can be dehydrated and stored. The technology is cheap and user friendly. (2) Domestic solar dryers can be a great tool for creating women entrepreneurs. Also it can be used to give employment to rural youth. Our primary aim is to promote the usage of solar dryers in the villages of Nimar region. The fabrication process itself will give employment to youth. (2) Secondly, we aim to develop our own brand of solar dried products. This will help provide a direct market to the users of solar dryers.

5. **Who are the partners?**

   (1)After research on the internet, we found out about a solar dryer developed by Bhabha Atomic Research Center,Mumbai. BARC is a premier research institute which works under the government of India.They, under a program called ‘AKRUTI’, transfer this technology to the NGO’s on subsidiary basis. NARMADA tied up with BARC in April 2017 and to date has manufactured 6 solar dryers of BARC design. (2) Unconditional support of Shrikrishna Gupta Sir, Head,Technology Transfer & Collaboration Department,BARC, has been there right from the word go. He hails from the Nimar Region and his love towards his homeland has been visible in his support. (2)The pilot project was funded by Bharat Yuvotkarsh Nyas,Pune,India.

6. **What are the problems we face?**
   (1) 80% of farmers in India have small land holdings. They live hand to mouth. The income they generate from one crop, they use it to sow the next crop. (2) The bigger farmers are happy with whatever they earn and seldom look to explore new avenues. (3) Age old practices of preservation are prevalent and the current generation of farmers is cynical about any new technology. Roof top drying in the open is a common practice, but it does not ensure hygiene and is time consuming. (4) A farmer gets busy in preparation of his next crop as soon as he harvests. So it is not possible for him to get involved in the process of drying and preserving his produce. (5) Solar dryers have limited capacity and thus it is not possible to process and preserve bulk produce.
7. **What has to be done?**
   (1) Promotion and training of Solar Driers among landless labors. When they do not have occupancy as labors, they can generate income. Solar Dried products will provide secondary/additional income to them. (2) Create SHG's (Self Help Groups) in nearby villages who will use solar driers. (3) Provide training in drying and packaging of dried products.(4)Create and establish a brand and provide a market to end users. Proper acquisition of products will ensure spread of technology via word of mouth. (5) The brand equity of BARC will

generate interest and genuineness of process and hence BARC design and approvals are linked.

5

8. Conclusion.

(1)India is taking giant steps to promote use of solar energy. This is the right time to become a part of the revolution and take solar technology to every doorstep.(2)Solar Technologies can be best utilized in the rural areas as it can very easily fulfill the demand and supply chain. Also space is easily and cheaply available in rural areas.(3)To promote it in rural areas, solar technologies need to be subsidized. Panels are subsidized but solar dryers need to be subsidized as well. Larger, global organizations must start this process. Their initiative will generate trust and lead governments to help the sake.

6

DryEcoMate – An horticultural dehydrator, using solar thermal and photovoltaic energy, low cost production, modular and portable

J. Garcia[1, 2], J.Pássaro[1], R.Rosado[1], L.Coelho[1,2] ,M. Ley[3], J.Rodrigues[4], P.Madureira[4]

[1] Instituto Politécnico de Setúbal, Escola Superior de Tecnologia, Departamento de Engenharia Mecânica, Estefanilha, 2910-761 Setúbal, Portugal
[2] CINEA-IPS, Centro de Investigação em Energia e Ambiente, Campus do IPS, Estefanilha, 2910-761 Setúbal, Portugal
[3] Regipomo, EN8, Edif. Salamanca, Nr. 21. Bloco A – 3º Esq. 2665-258 Malveira
[4] Synforege Lda, EN 10, Km138, Fracção N, Fonte da Talha, 2695-715 São João da Talha

Abstract: *DryEcoMate is a horticultural dehydrator developed through a partnership between the Polytechnic Institute of Setúbal, Synege and Regipomo. It is an energy-efficient, low-cost, modular, and portable dehydrator that works exclusively with renewable energy, namely solar thermal and photovoltaic and can operate independently of the instant weather conditions. To optimize a dehydration process, it is essential to optimize the following factors: Time, Product Quality, Energy Efficiency, Cost and Flavor / Odour. DryEcoMate allows the optimization of these factors by effectively controlling dehydration air temperature and air circulation speed, depending on the type of product to be dehydrated, the solar radiation and outdoor temperature at each time. DryEcoMate allows the use of outdoor air conditions at each moment, optimizing the process by reading the temperature and relative humidity conditions of the outside air, the air at the entrance of the dehydration chamber and the air at the exit of the dehydration chamber as to allow, at each instant and through the recirculated air / air flow mix, the control system to optimize the operating conditions of the equipment. DryEcoMate is a lightweight mobile device that allows to be moved and placed in the position that best suits it and allows greater efficiency in operation at all times. This equipment allows its placement in the best orientation at all times depending on the solar time, but also on the location of the production of dehydration at each moment of production. For this, in addition to its lightweight construction, the implementation of 100% swivel wheels allows ease of orientation and placement location. DryEcoMate is equipped with a solar thermal panel, a photovoltaic solar panel, a dehydration chamber, an electric resistance, fans to force air circulation inside the chamber, motorized air dampers actuators / valves, temperature and RH probes and a control system, which allows the equipment to operate under optimized conditions in each instant.*

Keywords: Vegetables dehydration, Solar thermal energy, Photovoltaic solar energy, low cost dehydration.

1. INTRODUCTION

Dehydration is a simple and affordable food preservation method, which consists of removing enough water so that the food can be preserved for a long period of time. There are three key factors for food dehydration to be successful: temperature, relative humidity and air velocity. The temperature should be the most suitable so that the moisture of the food can be removed without running the risk of cooking it. The relative air humidity must be low in order to allow the absorption of the water released by the food. Air velocity shall allow saturated air to be released from the dehydration chamber. Food can be dehydrated using solar radiation, a furnace and also an electric dehydrator, always taking into account that the temperature, humidity and air velocity should be the most appropriate for the type of food. Table 1 shows the different dehydration temperature ranges according to the type of horticultural products

Table 1. Dehydration Temperatures [1]

	Temperature (°C)
Herbs	35
Vegetables	52
Fruits	57

Air velocity is not in itself a determining factor for the dehydration process. Different studies indicate that speeds up to 1.5 m/s are acceptable during the process [2]. However, the relative humidity of the air and the temperature inside the dehydration chamber are directly dependent on the air velocity and so it is a great advantage when there is the possibility of regulating the air velocity.

2. SOLAR DEHYDRATORS

2.1. Operation principle

Solar dehydrators use the energy of the sun to heat the air that will dehydrate the food. As the air is heated, its relative humidity decreases thereby, acquiring a greater capacity to absorb the moisture released by the food. The air circulation in the dehydrator allows the moisture released by the food to be transported out of it. Food dehydration can be divided into two phases: the first stage happens when the moisture that is in the outermost layers of food is evaporated. On a second stage the water in the inner layers of the food has to be transported to the outer layers so that it can be evaporated. Figure 1 relates the rate of the dehydration process to the amount of water present in the food.

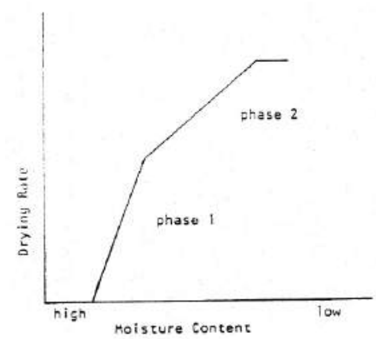

Figure 1. Relation between the rate of dehydration and the amount of water present in the food [3].

2.2. Types of solar dehydrators

Solar dehydrators can be divided into two families, depending on whether there is mechanical circulation or not. Dehydrators without mechanical circulation are referred to as passive dehydrators and those using circulating fans or pumps are called active dehydrators. In the family of passive dehydrators there are still two different types of dehydrators. Dehydrators where food is exposed directly to solar radiation are called direct passive dehydrators, and dehydrators where food is not directly exposed to solar radiation are indirect passive dehydrators. Figure 2 shows the different types of solar dehydrators [3].

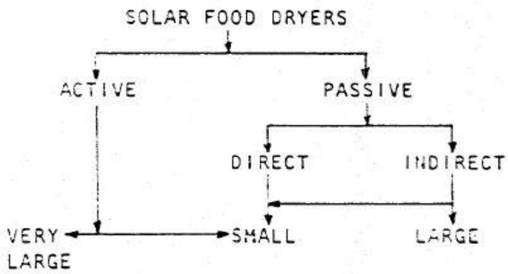

Figure 2. Relation between the dehydration rate and the amount of water present in the food. [3]

In direct solar dehydrators, foods are exposed to direct solar radiation. Typically these devices consist of a dehydration chamber covered by transparent glass or plastic and with openings allowing the entry and exit of air. In indirect passive solar dehydrators the dehydrated food is placed in a well-insulated dehydration chamber. Food dehydration of is ensured by a solar collector, which will allow the outside air to warm up and consequently its relative humidity will drop. In this case, the necessary air movement to the process is ensured by natural convection, and it is imperative that the intake of the outside air is performed at a lower height than the extraction of the indoor air. In active solar dehydrators the circulation of hot air is performed by a small fan, or in larger devices by an air circulation pump. These dehydrators are thermodynamically more efficient and the dehydration process is relatively faster [4]. Its main advantage is that it can be used to dehydrate large quantities of product.

2.3. Possible problems using Solar dehydrators

Dehydrating foods using exclusively and directly energy from the sun can be a time-consuming and unpredictable process as atmospheric conditions are an uncontrollable factor. There is also the "night" factor, since at night there is no solar radiation, the dehydration process can become very time consuming, thus putting at risk the quality of the food in the process of dehydration. So a dehydrator that combines the use of solar energy with another source of energy is the solution that is most interesting for people who want to dehydrate food and do not want to be exclusively dependent on the weather.

3. DRYECOMATE SOLAR DRYER

3.1. General description

DryEcoMate is a horticultural solar dehydrator, using solar thermal and photovoltaic energy, low cost production, modular and portable developed by IPS, Regipomo and Synege. The DryEcoMate Fruit and Vegetable Dehydrator is an energy-efficient, low-cost, modular, mobile dehydrator that works exclusively with renewable energies, namely solar thermal and photovoltaic and operating independently of the weather. However in special conditions it is possible, if the conditions do not allow it, to operate with conventional electric power. As mentioned previously, for an efficient dehydration the key factors to be controlled are Temperature T (ºC), Relative Humidity RH (%) and Air Velocity V (m/s). In this way DryEcoMate has the possibility to control these three factors, two in an active way (temperature and air speed) and another in a passive way (relative humidity).

3.2. Optimization of the dehydration process

To optimize the dehydration process, it is essential to optimize the following factors: Time, Product Quality, Energy Efficiency, Cost and Flavor/Odor. DryEcoMate allows the optimization of these factors by effectively controlling dehydration air Temperature and air circulation velocity depending on the type of product to be dehydrated, solar radiation and outdoor temperature. DryEco Mate allows the use of outdoor air conditions at any moment, optimizing the process by reading the temperature and relative humidity conditions of the outside air, the air at the entrance of the dehydration chamber and the air at the exit of the dehydration chamber so as to allow at each instant and through the recirculated air/air flow mix control system to optimize the operating conditions of the equipment.

3.3. Ecological design and construction

The design and construction of DryEcoMate is 100% ecological and only ecologically clean materials are used. In this way no type of glues, varnishes or toxic surface treatments are used. All types of tightening and fixing are completely mechanical.

3.4. Mobile equipment

DryEcoMate is a lightweight, mobile device that allows you to move and position it in the way that best suits you and allows you to be more efficient at all times. This equipment allows its placement in the best orientation at all times depending on the solar time, but also the location of the production of dehydration at each moment of production. For this in addition to its lightweight construction the implementation of wheels 100% orientable allows the ease its orientation and placement location.

3.5. Equipment Components

The DryEcoMate is modular with a solar thermal panel, a photovoltaic solar panel, a dehydration chamber, an electric resistance, fans to force air circulation inside the chamber, motorized air dampers actuators / valves, temperature and humidity probes and its control system that allows the system to operate under certain imposed conditions. The following is a brief description of the function of these accessories:

- The solar thermal panel - of its own design and built entirely from scratch guarantees, as long as the climatic conditions allow it, the heating of the air that circulates in the dehydration chamber for drying the products;
- The photovoltaic panel - has the function of charging the batteries that power the dehydrator support devices, namely, the system controller, air circulation fans, electric resistance and motorized actuators/valves;
- The dehydration chamber - consists of several shelves where the products are placed to be dehydrated. On these shelves, the dry and hot air passing through the fruit and vegetable products will dehydrate them;
- The PV fed electrical resistance - this equipment arises with the objective of giving support to the solar panel for heating the air inside the dehydrator. Thus, when the air is not at the set-point temperature, the electric resistance starts, heating the air in its passage;
- Air fans - these devices, which are connected to the control system, allow their speed to be variable. They have the function of forcing, with greater or less speed, the circulation of the air flow inside the dehydrator;
- Actuators/motorized valves - these devices have a coupled register and have as a function to regulate the admission and exit of circulating air in the dehydrator;
- Temperature and humidity probes - have the function of monitoring the temperature and humidity conditions inside the dehydrator, making the equipment devices work in order to guarantee an efficient product dehydration process;
- Control module - this device performs a wide variety of functions that are necessary to control the dehydration process, being the "brain" of the dehydrator. It monitors and controls the inlet, outlet, temperature, relative humidity and velocity of the circulating air.

3.6. Working principle

In order for the drying process to be as efficient as possible, it is necessary to control some variables associated with it, namely air temperature, relative humidity, air circulation velocity inside the equipment and air registers. For this there is the system controller. DryEcoMate's drying method is done by channelling heated air into the dehydration chamber. The renewable energy source used for air heating is the sun, which translates into significant energy savings. The climatic conditions necessary for the good performance of the equipment are relatively high temperatures, moderate wind and low relative humidity. The drying of the food consists of exposing the food in a closed chamber, which has several shelves, where the products are placed to be dehydrated and where there are suitable conditions for a good circulation of heated air with low relative humidity.

This dehydrator is a hybrid because it can operate using renewable energy, without recourse to any conventional energy source or, if the weather conditions are less favourable, to operate using conventional electricity, thus guaranteeing the adequate and necessary conditions for the process of dehydration. The innovation in this equipment consists in using new air circulation or recirculated air depending on the current weather conditions allowing the use of 100% new air circulation or the use of recirculated air depending on the position of the actuators/motorized valves which are positioned in the ideal conditions for the dehydrator to function (see figure 3). In addition to this position of the actuators/motorized valves to achieve the best operating conditions, the fans are also of a variable speed, allowing the dehydration air velocity to be ideal to achieve the best dehydration conditions according to the user defined objectives: fast dehydration (dehydration time optimization) or slow dehydration (taste/odour optimization of the dehydrated product).

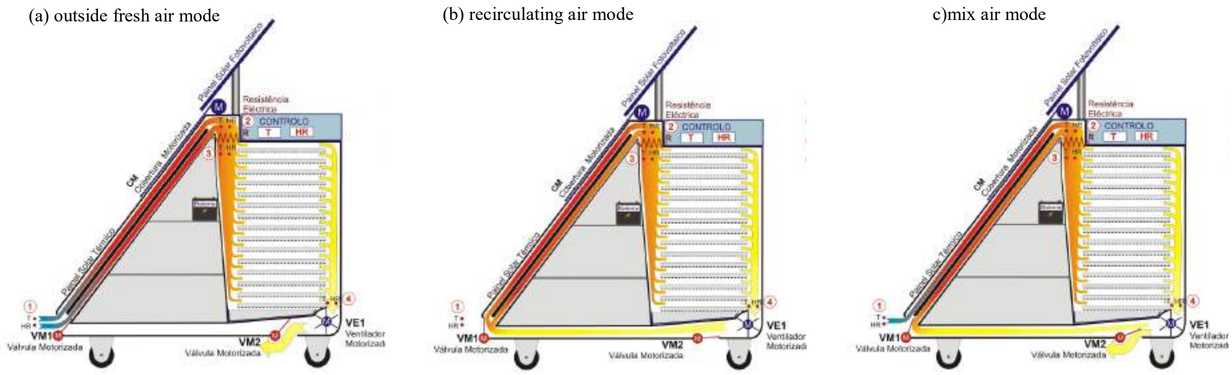

Figure 3 – Operation modes

Conditions for using fresh outside air

Under these conditions, where apparently the climatic conditions are most desirable for the operation of the machine, using only solar energy. Its operation consists of the outside air enters the opening on the lower zone of the solar panel and rises inside the solar panel, by the effect of natural convection, receiving heat from solar irradiation on the panel, and arrives at the entrance of the dehydration chamber. Here the air is forced to descend by the above mentioned effect and by the aid of air fans located in the lower zone of the dehydration chamber, where it is directed outwards. For this condition the air registers are positioned so as to allow air intake at the base of the solar panel and air exhaust (downstream of the air circulation fans). The dampers are driven by two motorized actuators/valves controlled by the system controller. With these conditions the inside air in the dehydration chamber is constantly renewed.

Conditions for using recirculation air

In these conditions there is no new air intake, due to the fact that the outside air temperature is not adequate, so the air recirculates inside the equipment and undergoes reheating when passing through the solar panel. Thus, the air recirculates inside the equipment, rising inside the solar panel, by the effect of the natural convection, receives heat originating from the solar irradiation on the panel, and arrives at the entrance of the dehydration chamber. Here the air is forced down by the aforesaid effect and by the aid of air fans located in the lower zone of the dehydration chamber until it returns again to the entrance zone of the solar panel. In this situation the air registers do not allow air inlet or outlet.

Conditions for using a mix of outside and recirculated air

Under these conditions part of the circulation air is reused, only part of the intake of new outside air being made. The new/circulated air mixture rises through the interior of the solar panel, by the effect of natural convection, receives heat from solar irradiation on the panel, and arrives at the entrance of the dehydration chamber. Here the air is forced down by the above mentioned effect and by the aid of air fans located in the lower zone of the dehydration chamber. In the lower zone the air register is in a position that allows part of the circulating air to be removed from the system, the rest being directed to the entrance zone of the solar panel where it will mix with the new outside air.

3.7. Control system

The dehydrator control system consists of several sensors that monitor the temperature and humidity inside and outside the dehydration chamber, as well as a set of motorized actuators/valves and fans that try to keep the parameters inside the dehydration chamber in optimal values for an efficient dehydration of food. These components are controlled by an Arduino control board, with microcontroller. The temperature and humidity sensors chosen are the DHT22 model. The fan module is composed of 4 associated 12V fans in a parallel serial connection so that they can be controlled by a 24V PWM signal. The heating resistor has a power of 50W with 24V supply. Motorized actuators/valves are powered at 24V with position control determined by a 0-10V analogue input, this control voltage is generated by PWM outputs used as DAC. The hardware control functions were developed using the open source software Arduino IDE 1.6.11. Figure 4 shows the principle scheme of the dehydrator with its main components.

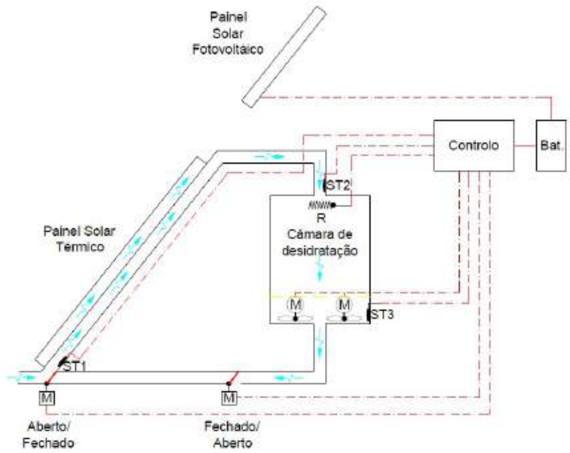

Figure 4 – DryEcoMate Drying Principle Scheme

4. CFD SIMULATIONS

4.1. Overall objective

In order to study and optimize the dehydration process as well as air flow inside the dehydration chamber, a CFD numerical simulation of the drying inside the DryEcoMate dehydration chamber was performed. For the numerical simulations, AnSys Fluent Software [10] was used in order to analyse and optimize the best airflow with in the dehydrating chamber.

4.2. Description of the numerical model

Two-equation turbulence models allow the determination of both, a turbulent length and time scale by solving two separate transport equations. The standard k-ε model in ANSYS Fluent falls within this class of models and has become the workhorse of practical engineering flow calculations in the time since it was proposed by Launder and Spalding [11]. Robustness, economy, and reasonable accuracy for a wide range of turbulent flows explain its popularity in industrial flow and heat transfer simulations. It is a semi-empirical model, and the derivation of the model equations relies on phenomenological considerations and empiricism. The standard - model [12] is a model based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε). The model transport equation for is derived from the exact equation, while the model transport equation for was obtained using physical reasoning and bears little resemblance to its mathematically exact counterpart. In the derivation of the - model, the assumption is that the flow is fully turbulent, and the effects of molecular viscosity are negligible. The standard - model is therefore valid only for fully turbulent flows. As the strengths and weaknesses of the standard - model have become known, modifications have been introduced to improve its performance namely the RNG model [13] -

4.3. Boundary conditions

Given the prototypical nature of the work being developed, the main focus of the numerical simulation was dedicated to the airflow inside the dehydration chamber, this is because, while the temperature is the driving force for the dehydration process to take place, the proper placement and airflow throughout the chamber is what will guarantee an uniform product treatment. This will provide a homogenous final consumable with all its parcels having the same properties and quality. With this in consideration the boundary conditions taken into account in the first set of simulation were Inlet velocity: 0,1 and 2.9m/s, for different cases and Outlet conditions: Outflow.

4.4. Simulation results

The CFD simulation results show the importance of the air flow in the dehydrating chamber and in the dehydrating process. Figure 5 shows some CFD simulation results on the velocity vectors, contours and streamlines in the dehydrating chamber. The results from the CFD simulation lead to some modifications and improvements in the dehydrating chamber, the shelves placement, geometry, in the airflow and in the dehydrating process.

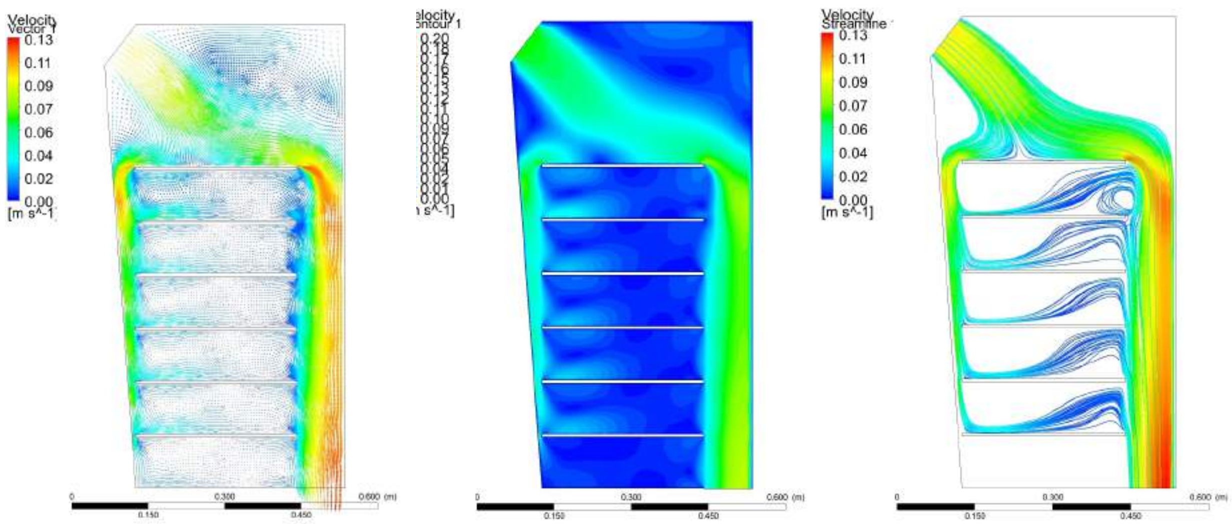

Figure 5. CFD simulation on velocity vectors, contours and streamlines in the dehydrating chamber.

5. RESULTS

Based on the CFD simulations and on the test made on the pre-prototype some improvements on the dehydration chamber were made. The final configuration of the DryEcoMate hybrid solar horticultural dehydrator is shown in figure 6. This figure show a photo of the actual pre-prototype and the correspondent design.

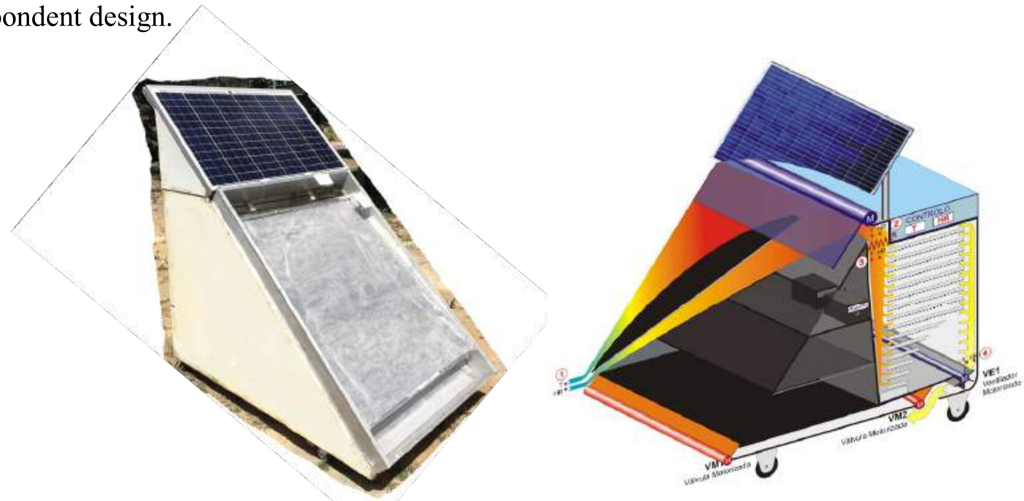

Figure 6. DryEcoMate hybrid solar horticultural dehydrator (photo and design).

After the construction of the DryEcoMate pre-prototype, some tests were carried out on this equipment and horticultural products were dehydrated on it. The dehydrated horticultural products in DryEcoMate have generally presented excellent taste and consistency, and the dehydration time being considerably lower compared to equivalent dehydration made in conventional electric equipment. Figure 7 show some eggplants dehydrated in DryEcoMate

Figure 7 – Eggplants dehydrated in DryEcoMate

6. CONCLUSIONS

The horticultural dehydrator DryEcoMate developed through a partnership between the Polytechnic Institute of Setúbal, Synege and Regipomo was presented. The objective was to develop an energy-efficient, low-cost, modular, and portable dehydrator that works exclusively with renewable energy, namely solar thermal and photovoltaic and can operate independently of the instant weather conditions.

It was verified that to optimize a dehydration process, it is essential to optimize the following factors: Time, Product Quality, Energy Efficiency, Cost and Flavor / Odour. DryEcoMate allows the optimization of these factors by effectively controlling dehydration air temperature and air circulation speed, depending on the type of product to be dehydrated, the solar radiation and outdoor temperature at each time.
The develop of DryEcoMate allows to use of outdoor air conditions at each moment, optimizing the process by reading the temperature and relative humidity conditions of the outside air, the air at the entrance of the dehydration chamber and the air at the exit of the dehydration chamber of so as to allow at each instant and through the recirculated air / air flow mix control system to optimize the operating conditions of the equipment.
DryEcoMate is a lightweight mobile device that allows to be moved and placed in the position that best suits it and allows greater efficiency in operation at all times. This equipment allows its placement in the best orientation at all times depending on the solar time, but also on the location of the production of dehydration at each moment of production. For this, in addition to its lightweight construction, the implementation of 100% swivel wheels allows ease of orientation and placement location.
The performance of CFD numerical simulation using Fluent Ansys permitted to optimize the design configuration, especially the dehydration chamber, based on the best air flow and heat transfer.

REFERENCES

[1] Patel, A; Shah, S.A; Bhargav, Hitesh. Review on Solar Dryer for Grains, Vegetables and Fruits. Birla Vishvakarma Mahavidyalaya Engineering College. International Journal of Engineering Research & Technology (IJERT), Vol. 2 Issue 1, January- 2013
[2] Boyer, R. Huff, Karleigh. Using Dehydration to Preserve Fruits, Vegetables, and Meats. Virginia Tech, Virginia state University, pp 348-597.,April 2008
[3] Gregoire, R.G. Understanding Solar Food Dryers. Volunteers in Technical Assistance (VITA), Virginia, 2009
[4] Kendall, P; Dipersio, P; Sogos, J. Drying Vegetables. Preserving Food: Drying Fruit and Vegetables. University of Georgia Cooperative Extension Service. College of Family and Consumer Science in cooperation with the College of Agricultural and Environmental Science. September 2012.
[5] Title of documentation, http://www.plenosol.com, accessed on 2016.06.10
[6] Title of documentation, http://www.us.idcook.com, accessed on 2017.02.12
[7] University of Hohenheim, Bauanleitung für kleine Solartrockner nach dem Konzept Tunneltrockner. Institute for Agricultural Engineering in the tropics and subtropics, University of Hohenheim, Stuttgart. Date unknown
[8] Title of documentation, http://www.blackblock.eu, accessed on 2016.09.15
[9] Title of documentation, http://www.sonnenobst.de, accessed on 2017.03.02
[10] Ansys, Fluent 12.0, Theory Guide. Ansys Fluent Guides, 2009
[11] B. E. Launder and D. B. Spalding. Lectures in Mathematical Models of Turbulence. Academic Press,London, England. 1972.
[12] V. Yakhot and S. A. Orszag. "Renormalization Group Analysis of Turbulence I Basic Theory". Journal of Scientific Computing. 1(1). 1–51. 1986.
[13] T.-H. Shih,W.W. Liou, A. Shabbir, Z. Yang, and J. Zhu. "A New - Eddy-Viscosity Model for High Reynolds Number Turbulent Flows - Model Development and Validation". Computers Fluids. 24(3).227–238. 1995.

CONCENTRATED SOLAR THERMAL INTEGRATION INTO SPICE ROASTING INDUSTRY: AN ENERGY ANALYSIS OF AN INDIAN MASALA MANUFACTURING FACILITY

Tavish W. Fenbert[1], Vishal Sardeshpande[2]

1: Department of Mechanical and Industrial Engineering, Northeastern University, Boston, USA
e-mail: fenbert.t@husky.neu.edu

2: Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Mumbai, India
e-mail: vishalsir@gmail.com

Abstract: Roasted spices are an important ingredient in masala spice blends, a staple in many Indian dishes. Due to the high volume of masala consumed in India, the energy used for spice roasting—in the forms of liquefied petroleum gas (LPG) and electricity—is a notable contributor to greenhouse gas emissions from the Indian spice processing sector. The masala manufacturing industry has the potential to integrate various forms of concentrated solar thermal technologies into roasting and boiling processes in order to reduce its carbon footprint. This study analyzes the energy used at a masala manufacturing facility in the state of Maharashtra, India, for three heating processes: (1) open flame LPG roasting (2) roasting in an electric thermal oil vessel, and (3) boiling in an electric thermal oil vessel. The LPG roasting processes operate at approximately 300°C with thermal efficiencies between 21% and 39%. The thermal oil vessels operate at approximately 140°C and require 4.81kW (roasting) and 34.1 kW (boiling) of electrical power. Approximate sizing and integration strategies are discussed for concentrated solar thermal technologies including the parabolic trough concentrator and Scheffler dish.

Keywords: Spice roasting, masala, solar, thermal

2. INTRODUCTION

Masala spice blends are a staple of Indian cooking. India consumes 6.22 million metric tons of spices annually [1], often in the form of masalas. The key component in each variety of masala is a mixture of roasted spices. Common roasted spices include coriander, cumin, bay leaf, and coconut; additional components of masalas include turmeric, chili powder, salt, garlic, and boiled onion. Due to the volume of masala consumed in India, the energy used to roast and process spices is a significant contributor to the greenhouse gas emissions of the Indian spice processing sector. The primary energy sources for roasting are liquefied petroleum gas (LPG) and electricity.

Power subsidies and the import of petroleum-based fuels create a burden on the Indian economy. In many parts of India, the government subsidizes electricity and LPG for domestic customers [2]. Over half of the 21.55 million tons of LPG consumed in India during the 2016-17 fiscal year was imported [3]. Introducing renewable energy into the masala production industry can both reduce the greenhouse gas emissions and reduce the energy spending of the Indian Government.

The masala production process includes five major steps (Figure 1). After cleaning, ingredients are roasted or boiled as necessary. Roasting can be done in small batches over an LPG flame or in larger batches in a thermal oil vessel, where oil is heated in a closed loop using electric heaters. Boiling is conducted in a similar electric thermal oil vessel (see Section 2). The cleaning, grinding, mixing, and packaging steps all require electric power, mainly for electric drives.

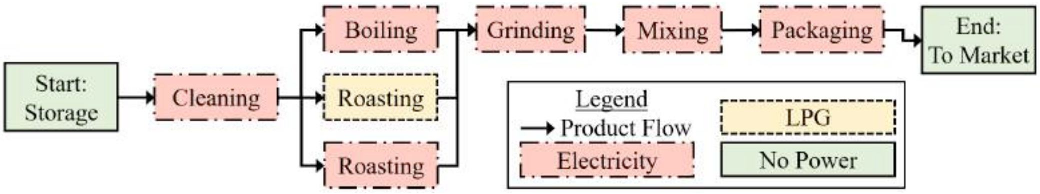

Figure 1. Masala production process flow diagram

Solar collectors are increasingly being used around the world to capture the sun's energy for purposes of power generation, industrial process heat, and cooking [4]. India is a particularly promising country for solar collectors, as most areas of India receive over 4 kWh/(m^2-day) of solar radiation [5] and have at least 300 days of sunshine per year [6]. Solar thermal collectors vary widely in size and scope, from non-concentrating flat plate collectors that can heat water up to 80°C [7] to concentrating collectors such as the parabolic trough concentrator (PTC) and Scheffler dish that can heat a working fluid to above 300°C (Figure 2) [4]. Unlike other high-temperature solar collectors designed for power generation, the Scheffler dish is designed specifically for cooking [8].

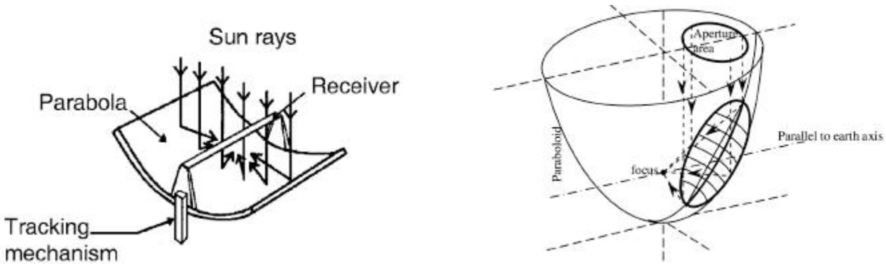

Figure 2. Diagram of PTC (left) [4] and Scheffler dish (right) [9]

The authors are interested in integrating solar thermal technology into the Indian spice roasting industry. This requires careful study of the effects of roasting a spice, current spice roasting processes, and the energy these roasting processes consume. Much information is available about how roasting a spice releases volatile oils [10] and can change the spice's appearance, aroma, texture, and nutritional value [11], but there are few studies concerning spice roasting practices and the energy consumed in the spice roasting process. To gather such information, the authors undertook a field study of a spice roasting factory located in central India. This paper discusses the results of the field study and potential options for integration of solar thermal technology into a spice roasting plant. There is potential for solar photovoltaic integration into the masala production process to offset electricity consumption, but this is outside the scope of this study.

2. METHOD

The measurements of the roasting and boiling processes were conducted during multiple visits to the spice roasting plant. The processes and measurement protocols are described in this section. Temperature measurements of the spices were taken with an infrared thermometer. Temperature measurements of the thermal oil were taken via a probe installed in the vessel's oil chamber.

2.1. Thermal oil vessel roasting and boiling

Boiled onion is one of the major ingredients for a spice mixture called 'Chatpat Masala;' roasted coriander is a main ingredient in both 'Garam Masala' and 'Chatpat Masala' spice mixtures. The boiling of onion and roasting of coriander in large batches take place in separate thermal oil based heated vessels (Figure 3). The two vessels are of a similar construction, with the onion boiling vessel being larger. Each vessel has an inner chamber with a helical stirring mechanism (not pictured) where ingredients are heated. Surrounding this inner chamber is a closed thermal oil bath with electric heating elements. The electric heating elements are programmable (of/off) based on the temperature requirements of the process. A thermocouple with continuous digital output monitors the temperature of the thermal oil bath and controls the on/off operation of the electric elements. A door on the underside of the vessel can be opened to discharge material after the boiling or roasting process ends.

The experimental protocol for these vessels involved measurements of ingredient masses, operating temperatures of ingredients and thermal oil, and total batch times.

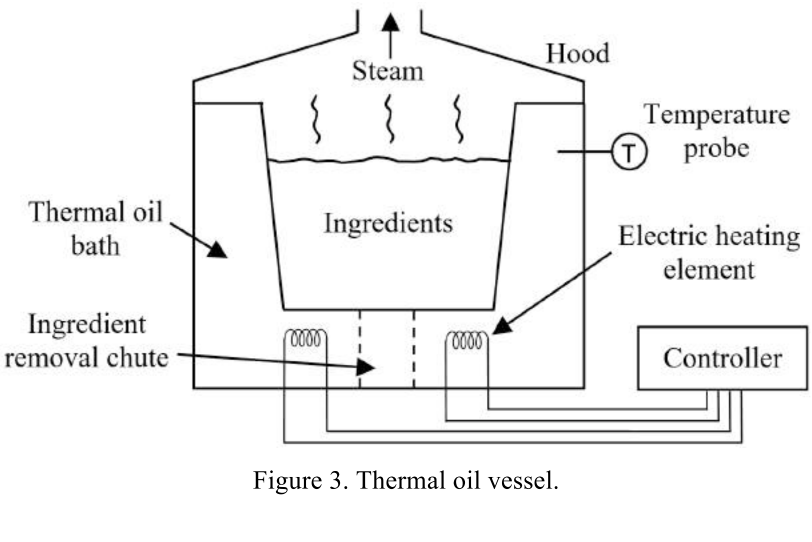

Figure 3. Thermal oil vessel.

2.2 Open flame LPG roasting

Most spices for masala spice mixtures are roasted over an open LPG flame. These spices are roasted in two distinct formats: shredded coconut is roasted in a rotating vessel positioned above an LPG flame, and other spices are roasted in a rounded pan stirred continuously by an operator (Figure 4). The set of spices required for one type of masala, such as 'Chatpat Masala,' are roasted in the pan individually, one after another. They are then mixed with other ingredients and ground together.

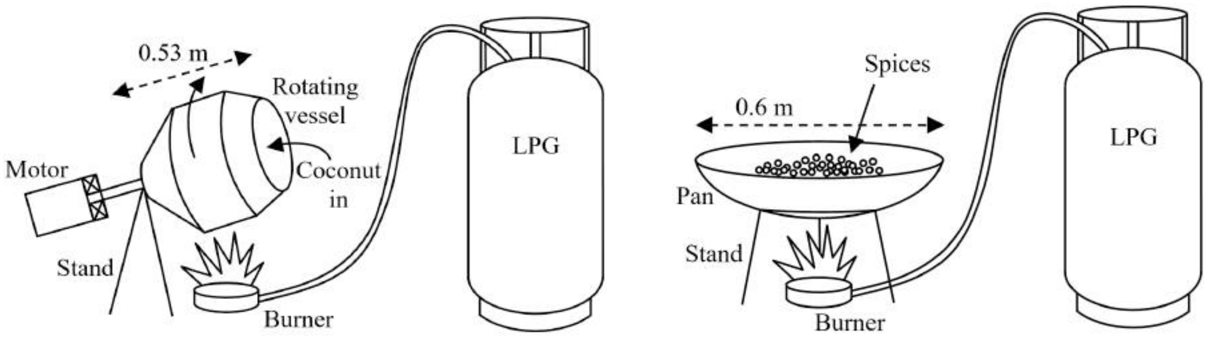

Figure 4. Open flame LPG roasting in rotating vessel (left) and pan (right).

Measurements were taken of the mass of cooking oil and spices roasted, the mass of LPG consumed, the time taken to roast each spice, and each spice's final temperature after roasting. Spice temperature measurements were taken using the infrared thermometer at a distance of about one meter from the pan.

3. THERMAL ENERGY USE DURING SPICE ROASTING

This analysis focuses on the mass and energy balances of each thermal process described in the previous section. These calculations reveal the thermal energy transferred to the ingredients and the power requirement of each process. Operating temperatures of the ingredients and the vessels are also presented here.

3.1. Thermal oil vessel boiling and roasting

Figure 5 shows the temperature of the thermal oil and the ingredients during the boiling of 700kg of onion in the thermal oil vessel. The thermal oil was heated for one hour before ingredients were added to the inner chamber. The onion mixture reached its steady-state temperature of 88°C approximately two hours after the ingredients had been added. The mixture continued to boil at steady state for 3.5 hours, then the onion mixture was removed from the vessel.

Figure 6 shows the temperature of thermal oil and coriander during the roasting of a 100kg batch of coriander in the thermal oil vessel. Unlike the onion boiling process, during which the ingredients reach a steady state condition, the temperature of the coriander slowly rose from room temperature to 89°C. There are large gaps in the temperature data because the author was taking measurements of another process in the factory while the coriander was roasting.

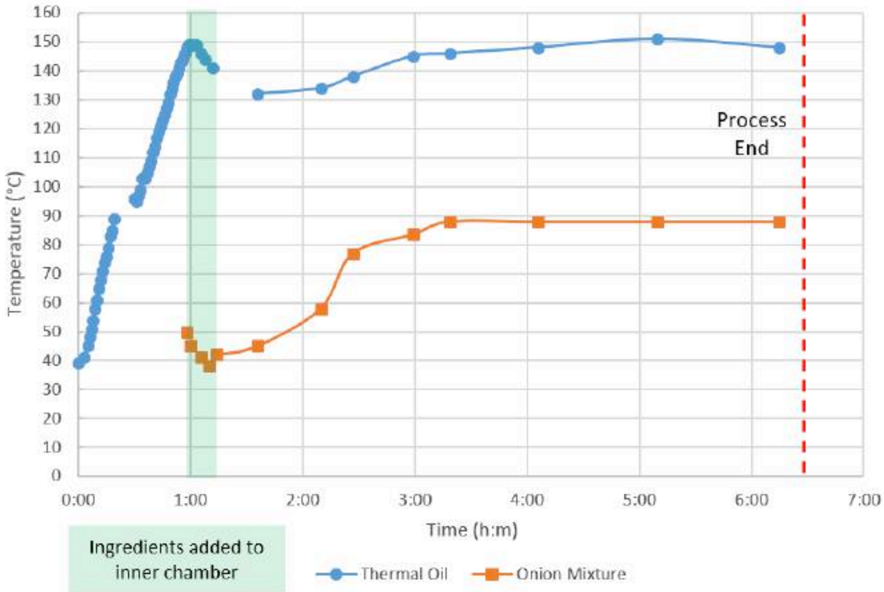

Figure 5. Plot of temperature versus time for onion boiling process.

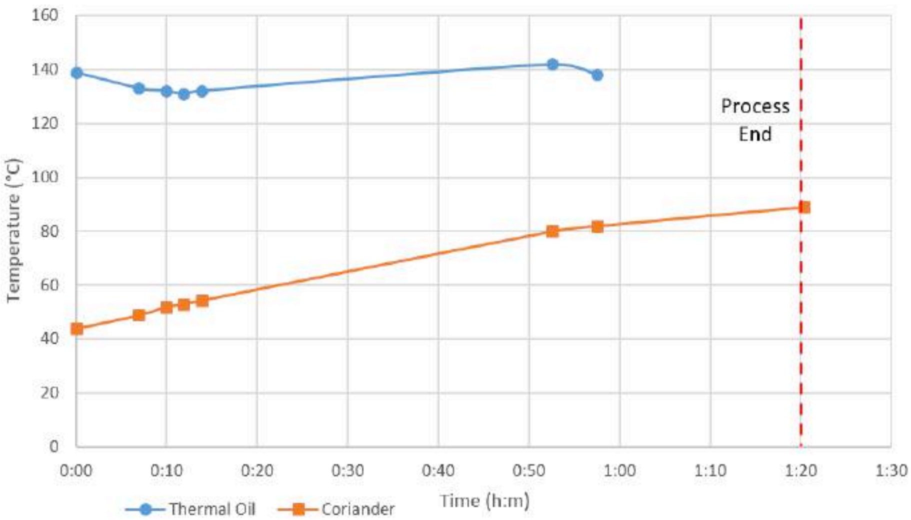

Figure 6. Plot of temperature versus time for coriander roasting process.

Figure 7 and Equation 1 show the mass balances for the thermal oil boiling and roasting processes.

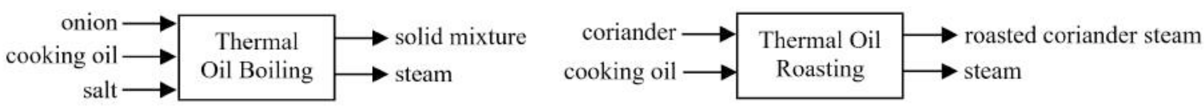

Figure 7. Mass balances for thermal oil boiling (left) and roasting (right) processes.

$$m_{in} = m_{out} \tag{1}$$

An energy balance for the onion boiling process (Figure 8, Equations 2 and 3), was used to calculate the total thermal energy delivered to the ingredients during the onion boiling process (Q_{elec}). The sensible heating of the ingredients was added to the energy required for evaporation of moisture. In these equations, c represents specific heat, ΔT represents change in temperature, ΔH represents the latent heat of evaporation for water at atmospheric pressure, and Q represents energy in the form of heat. For this analysis, the efficiency of conversion of electrical energy to heat was considered to be 100%, the energy lost to the environment (Q_{loss}) was considered negligible, and the sensible heating of salt was ignored. These estimates were appropriate for this analysis because overall trends in the data were being analyzed. Similar energy balance calculations were performed for the coriander thermal oil roasting process.

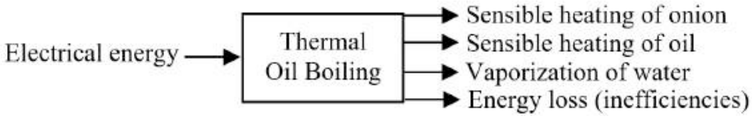

Figure 8. Energy balance for thermal oil boiling process.

$$E_{in} = E_{out} \tag{2}$$

$$Q_{elec} = m_{onion} * c_{onion} * \Delta T_{onion} + m_{oil} * c_{oil} * \Delta T_{oil} + m_{steam} * \Delta H_{vap} + Q_{loss} \tag{3}$$

During the onion boiling process, the total thermal energy delivered to the ingredients was 670MJ over a period of 6.5 hours. During the initial heating of the thermal oil, 7.3kW of power was required. After the ingredients were added, 34.9kW of power was required.

During the coriander roasting process, the total energy delivered to the ingredients was 23.1MJ over a period of 80 minutes, or an average power of 4.8kW. The moisture evaporated was conservatively assumed to be 5% because the final mass of the coriander was not able to be measured.

3.3. Open flame LPG roasting

Mass (Figure 9) and energy balances were performed for the open flame LPG pan and rotating vessel roasting processes using Equations 1 and 2.

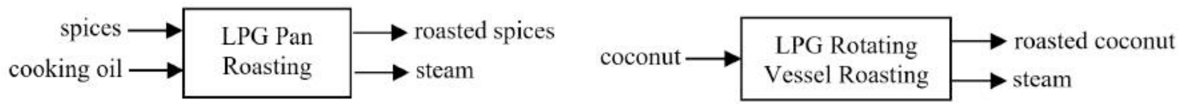

Figure 9. Mass balance for open flame LPG roasting processes.

The heat energy delivered to the spices, $E_{required}$, was then compared to the energy value of the LPG consumed, $E_{consumed}$, to determine the thermal efficiency, η_{LPG}, of the heating process, (Equation 4). The power required and power consumed were then calculated from these energy calculations.

$$\eta_{LPG} = \frac{E_{required}}{E_{consumed}} \tag{4}$$

Table 1 shows the average energy data for batches of various spices roasted in a pan and coconut roasted in a rotating vessel over an LPG flame. The pan temperature during this roasting process was approximately 320°C and the rotating vessel temperature was approximately 280°C.

Table 1. Open flame LPG roasting data

Particular	Unit	Pan	Rotating Vessel
Batch mass	kg	35	5
Batch time	min	28	7.4
LPG consumption rate	kg_{LPG}/hr	1.07	2.71
Power consumed	kW	13.7	34.7
Power required	**kW**	**5.31**	**7.24**
LPG heating efficiency, η_{LPG}	%	38.8	20.9

4. SOLAR THERMAL COMPATIBILITY WITH MASALA PRODUCTION INDUSTRY

This section outlines potential options for integration of solar thermal technology into the masala production process. Factors discussed include the temperature and power requirements of the roasting or boiling process, backup power, and the duration of the energy demand.

4.1. Temperature and power requirements

The heating method (direct or indirect), and the temperature requirement of a heating process are two requirements which guide the choice of solar thermal technology. Once these characteristics are appropriately matched, the chosen concentrator can often be scaled to deliver the necessary power.

The electric thermal oil boiling and roasting processes use an indirect heating method, so a solar concentrator that heats a working fluid would be the most practical to integrate with these processes. PTCs would be a good choice because they can heat thermal oil to the required operating temperature (approximately 140°C). To provide the 35kW of power necessary for steady state operation of the onion boiling vessel, PTCs with 117m^2 of collection area would be needed, assuming a normal beam radiation of 5kWh/m^2-day [5] and a 50% efficiency [12]. PTCs with a total collector area of 16m^2 could provide the required power input for the smaller coriander thermal oil roasting vessel.

The open flame LPG roasting processes use LPG as a direct heat source, so it would be most practical to integrate these processes with a solar concentrator that heats a cooking vessel, such as the Scheffler dish. The Scheffler dish also fits the operating temperature requirement (approximately 300°C). The collection area of the Scheffler dish needed to meet the power needs of the LPG roasting processes is approximately 50m^2, assuming a 20% efficiency [9]. Further analysis of the available solar space at the plant is needed to determine if these shadow-free areas are available.

4.2. Solar integration strategy

Integration of solar thermal collectors with existing processes requires consideration of duration and size of the energy demand, plant layout, backup power, and energy storage. The most crucial of these elements is ensuring that backup power or stored energy is available at all times in case of passing clouds or a non-sunny day. It is likely not practical to install a storage system for solar thermal energy at the roasting plant due to the high temperature requirements and the daytime energy demand of the plant. Therefore, present power systems must be kept in place

Integrating a system of PTCs with the electric thermal oil processes would be simple in this regard. The controller that determines when the electric heaters are turned on and off could continue to function as normal; the addition of heat to the system via the PTCs would allow the electric heaters to turn on less frequently. Retaining backup power for the LPG roasting processes with an integrated

Scheffler dish would be somewhat more difficult, as the Scheffler dish would concentrate solar radiation on the cooking vessel, the area where an LPG burner would generally be placed. Given the potential difficulty of switching quickly from Scheffler heating to LPG heating if clouds are present, it may be more practical to only use the Scheffler dish to roast spices on clear sunny days.

5. CONCLUSION

A field study of a masala production plant in central India was conducted to determine the temperature and energy requirements of their thermal processes in order to facilitate the integration of concentrated solar thermal technology. The roasting and boiling processes at the plant, using LPG or electricity as an energy source, operate at temperatures ranging from 140°C to 300°C and require between 4.8kW and 34.9kW of power. PTCs can be integrated into the roasting and boiling processes that use an electrically heated thermal oil vessel. A Scheffler dish can be integrated with roasting processes that use an open LPG flame. Further economic analysis of the masala production plant and available solar thermal systems are needed before integrating these technologies.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Statistics. Spices Board of India. Ministry of Commerce and Industry, 2017.
[2] A Citizens' Guide to Energy Subsidies in India. International Institute for Sustainable Development, 2012.
[3] Press Trust of India. India to import LPG from Iran to meet rising demand. Times of India, 2017.
[4] Kalogirou AS. Solar thermal collectors and applications. Progress in Energy and Combustion Science, 30, 231-295, 2004.
[5] India Solar Resource: Direct Normal Solar Resource. India Solar Resource Maps. India: Ministry of New and Renewable Energy, 2010.
[6] Sharma A. A comprehensive study of solar power in India and World. Renewable and Sustainable Energy Reviews, 15, 1767-1776, 2011.
[7] Rabl A. Survey of Solar Equipment and Applications. Active Solar Collectors and Their Applications, Oxford, USA, 1985.
[8] Scheffler W and Solare Bruecke. Introduction to the revolutionary design of Scheffler reflectors. SCIs International Solar Cooker Conference, Spain, 2006.
[9] Pillai I, Chandak A, Sardeshpande V, Somani S. Methodology for performance evaluation of fixed focus moving solar concentrators. World Renewable Energy Congress XI, UAE, 2010.
[10] Behera S, Nagarajan S, Rao LJM. Microwave heating and conventional roasting of cumin seeds (Cuminum cyminum L.) and effect on chemical composition of volatiles. Food Chemistry, 87, 25-29, 2004.
[11] Durmaz G and Gokmen V. Changes in oxidative stability, antioxidant capacity and phytochemical composition of Pistacia terebinthus oil with roasting. Food Chemistry, 128, 410-414, 2011.
[12] SopoNova MicroCSP Industrial and Utility Solar Collector. Sopogy, 2008.

BEAM STEERING LENS ARRAY FOR SOLAR COOKING

Håkon J. D. Johnsen[1] *, Ole Jørgen Nydal[2], Jan Torgersen[1]

1: Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology,
NTNU, NO-7491 Trondheim, Norway
e-mail: hakon.j.d.johnsen@ntnu.no, jan.torgersen@ntnu.no, web: http://www.ntnu.edu
2: Department of Energy and Process Engineering, Norwegian University of Science and Technology
e-mail: ole.j.nydal@ntnu.no

Abstract: Operation of concentrator based solar cookers is complicated by the need to accurately rotate the large parabolic mirror for solar tracking. Here we demonstrate a workaround. Via beam steering lens arrays, we can track sunlight with a simulated >70% efficiency across ±35° tracking range, using millimeter-scale lateral translation. This eliminates the need to rotate the mirror, facilitating the design of a simpler cooker. Full-day cooking can be achieved by manually reorienting the cooker 1-2 times a day in the general direction of the sun, while accurate automated tracking is performed by small low-cost actuators. Additional features such as adjustable power level can also be implemented.

The optical system was simulated and optimized using Zemax OpticStudio, and a functional 1:15 scale prototype has been constructed. The prototype demonstrates a promising total optical efficiency of ≈25% (beam steering lens array efficiency ≈60%, reflector efficiency ≈50%, focusing error efficiency: ≈80%). Total optical efficiency is expected to increase to 50%-60% using improved manufacturing methods. The lens array is expected to be compatible with injection molding, enabling low-cost high-volume production. By enabling low-cost automatic tracking, this technology may facilitate inexpensive, maintainable and user-friendly solar cooking, fostering its increased adoption across the world.

Figure 3: Functional small prototype with automatic tracking.

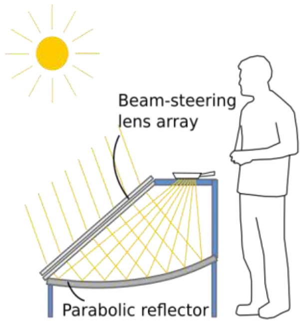

Figure 2: Sketch of solar cooking concept using beam steering.

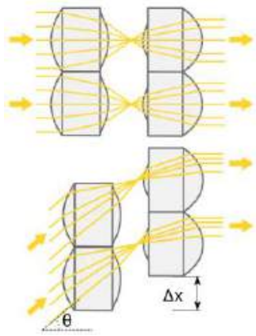

Figure 1: Illustration of how lateral translation of a lens array Δx can redirect sunlight arriving at an angle θ.

Keywords: Solar cooking, Beam steering, Automated tracking, Lateral translation

FATHER HIMALAYA SOLAR FURNACES: OPTICAL PRINCIPLES, TECHNOLOGIES, AND LINEAGE

Jean-Jacques Serra[1] *, Jacinto Rodrigues[2]

1: Association des Amis de Padre Himalaya,
6 Rue du veinat, 66690 Sorede, France
e-mail: jj.serra@wanadoo.fr, web: http://www.foursolaire.org

2: Professor emeritus, University of Porto,
Rua da Fontela, 90A, Gandra, 4740-476 Esposende, Portugal
e-mail: jacintorodrigues@sapo.pt, web: http://jacintorodrigues.blogspot.fr

Abstract: Manuel Antonio Gomes, a portuguese priest nicknamed Father Himalaya, is a major solar energy pioneer of the beginnings of XXth century. During five years (1900-1904), he designed, developped and tested various concepts of solar concentrators. The most advanced and largest one was the famous "Pyrheliophor" that won the first prize of World's Fair in Saint Louis (USA).
This paper provides the most complete description currently available of Father Himalaya works in the field of solar furnaces, from their inception in 1899 until the final experiments in 1904. It will present detailed technical descriptions of each version of the solar concentrator and an outline of the research conducted in each phase of the program.
Later concepts, developped by other researchers and based on the optical principles first used by Father Himalaya will also be raised and discussed.

Keywords: Padre Himalaya, Solar furnace, Concentrator, History