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SOLAR COOKING INTENSIVE EXPERIENCES IN SOUTH OF IBERIAN PENINSULA AND ITS IMPORTANCE IN RESEARCH PLANNING

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Abstract: *The Southern part of the Iberian Peninsula has a great solar energy potential available for domestic and industrial scale applications. Despite this potential, solar cooking has not been widely adopted. Both authors are employed by universities, one as a teacher in the University of Algarve (Portugal) and other as a laboratory technician in the University of Huelva (Spain). They are each passionate about incorporating solar cooking in their daily lives. They both solar cookers frequently, and have advocated their use in their respective countries for many years. They consider themselves "well contaminated with the solar cooking virus". They entered the solar cooking world by making and using several types of solar cookers, most of which were low cost devices made from recycled materials, later working on some commercialized units. This extensive experience of solar cookers and on solar cooking has enabled them to develop and optimise different types of solar cookers, and test different cooking vessels. By contrast, some published authors appear to have had little day to day experience of using solar cookers. Thus, the main goal of this study is to list some important aspects of the practical use and performance of solar cookers that the research community should investigate.*

Keywords: Solar cooking, intensive practical use, feedback, research community.

1. INTRODUCTION

The sun emits a large amount of electromagnetic radiation, but only a small fraction is intercepted by the planet Earth. Even so, only 1% of this small fraction could meet the current energy demands of the whole human race. In 2011, Intergovernmental Panel on Climate Change [1] described solar cooking as a decentralized mitigation option, but still in an early stage of technological maturity.

Research studies about solar energy applications such as water heating, air conditioning, water distillation, drying, cooking and industrial process have mostly been done by academics in the context of Masters theses, PhD theses, and specific projects. Their results have usually been presented at conferences, and published in scientific journals or books.

The solar irradiance at the surface of the Earth varies according to the locality, hour, month and the composition of the atmosphere. The maximum value observed for the solar irradiance, in clear sky days in most parts of the globe, is approximately 1000 Wm^{-2}. Conventional domestic cooking devices have rated heating capacities of about 1800 W. This amounts to the solar power reaching a surface normal to the sun's rays with a collecting area of 2 m2. A 1.2 m-diameter parabolic solar cooker, i.e., with a collecting area of 1.13 m^2 built with aluminium sheet of high reflectivity can provide the same useful cooking power as a photovoltaic system of 4 m^2.

In 1987, the international organization Solar Cookers International was created to promote the dissemination of solar cooking, focusing on the economic, social and environmental benefits of its use. The associated solar cooking wiki (www.solarcooking.org) is an excellent source of information about solar cooking. The technology related to solar cooking is well established, but unfortunately most of the existent solar cooking devices are being used only by a small number of individuals preoccupied with the use of a more ecological cooking solution. In a few cases, solar cookers are used on a community scale, or by small businesses, such as bakeries.

The south of the Iberian Peninsula has a great solar potential that is being explored for electricity generation and for hot water production, but not for domestic and industrial scale cooking applications. In this region, a significant number of families could cook, bake and prepare hot drinks for more than 300 days per year by using solar cookers, and some institutions could also use community solar cooking systems for large number numbers of people, as demonstrated by some Indian institutions.

2. ON COMMON SOLAR COOKERS

There are many solar cooking devices of different materials, design, performance and application. The most common solar cooking devices operate by direct use of solar energy without any additional energy storage process, i.e., the cooking process is possible only when the solar radiation is available, during the daytime.

As with any concentrating solar power system, almost every solar cooker is composed of two optical elements, a reflector and a receiver. The reflector collects the solar radiation and concentrates it, as much as possible, onto the surface of the receiver that functions first as an absorber of the solar radiation and then as a conductor of the thermal energy for cooking, baking or for hot drink preparation. Ordinary glass mirrors and black pots are readily available in the market that can be used respectively as efficient reflectors and receivers.

Community scale solar cooking systems are usually split. That is, the reflector is outside the building, and reflects concentrated sunlight onto the receiver in the cooking area inside the building. The simplest solar cookers are not split. The main types - panel, box, tube, and parabolic - all have the reflectors and receivers within the same unit.

The solar cooking process consists basically of placing the pot in the focal zone and controlling the cooking process according to the type of cooker and the food being prepared. The pot should be a good absorber of the concentrated solar radiation and a good thermal conductor of the heat to the food being cooked. The cooking process is more efficient when the ambient temperature is high and wind velocity is very low.

In most common solar cooking system, the solar radiation is collected by a reflector device using materials with high reflectivity, for example, mirrors, polished aluminium or special reflective foils. The rate of energy concentrated in the cooking zone depends on the reflectivity, surface shape and aperture area of the reflector device. In some community cooking systems there is a secondary reflector that redirects the concentrated solar radiation to the receiver.

Reflectors with a parabolic shape can provide a very high level of concentrated solar radiation on the focal cooking zone, but they must be moved at least every 15 minutes to track the sun. The heating capacity of a parabolic solar cooker with a 1.4 m-diameter reflector is similar to some domestic gas burners.

Most reflector devices used in box solar cookers are composed of one or more plane reflective surfaces providing a low level of solar concentrated radiation on the cooking zone. Solar radiation is collected by two or more panels before being absorbed by the black pot. In the case of panel solar cookers there are a large number of models with different reflector configurations made of multiple panels, where some of the collected sun rays are reflected multiple times before reaching the black pot. Panel and box solar cookers are able to slow cook food for up to two hours without any need to move them to track the sun. However, with a parabolic solar cooker, solar radiation is reflected directly on the black pot, so it is impossible to cook continuously for more than about 15 minutes without adjusting the reflector to track the sun.
A box solar cooker is basically a thermally insulated box having usually at least one adjustable reflector and a clear glass cover, in a horizontal or tilted position, on the top of the chamber that serves as a heat trap. For better cooking efficiency, the walls and the floor of the box must be thermally insulated. Several pots can be used easily, for cooking or for baking, at the same time. A panel solar cooker is usually composed of a few flat reflectors, but some panel cookers are designed with curved panels. Instructions for making some models are freely available, meaning that anyone can make one, easily and quickly, without need of any special tools. The cooking pot must be placed inside a transparent enclosure, which can be a heat resistant plastic bag, two pieces of glass or any other suitable transparent heat trap. The heat trap creates a green house effect, which is crucial for getting a good final result in cooking or baking.
The time period required for cooking or baking by using direct solar radiation depends on the size and configuration of both the reflector and receiver elements of a solar cooker, tracking of the solar cooker and also on the weather conditions. The clouds serve as a solar radiation filter, slowing down the cooking process, or even making it impossible. The heat losses from a cooking vessel, placed in the cooking zone and exposed directly to the surrounding air, are mainly by convection to the air and thermal radiation to the surrounding surfaces. The convection losses are important when the air velocity is high and the air temperature is low. Under severe conditions, good cooking results can be achieved only if the solar cooker is large or very efficient, which is the case with evacuated tube solar cookers.

3. COOKING EXPERIENCE AND RESEARCH TOPICS

Both authors are employed at universities and share the same passion for solar cooking. Celestino is a teacher in the University of Algarve (Portugal) in the areas of heat transfer, applied thermodynamics and air conditioning and Francisco Javier is a laboratory technician in the University of Huelva (Spain).
Both have been important advocates for solar cooking for many years. They both use solar cookers almost every day, i.e., they prioritise the use of solar energy whenever possible for cooking, baking, hot drink preparation and also for other purposes like canning vegetables or jam and chutney preparation in their homes by using fast and slow solar cooking devices.
They began solar cooking using several types of solar cooker, mostly low cost apparatus constructed by themselves using recycled materials and also some commercial models. They do not usually use cooking systems with thermal energy storage. This means that they are not used to cooking at night or during very cloudy days by using solar energy stored in a storage medium. However, when it is sunny, they cook meals for several days, just in case. The use of weather forecasts is very useful for planning, in advance, the amount and type of food to be cooked the following day or for cooking and baking more on a sunny day when the forecasts say that the next few days will be very cloudy.
Manufacturers usually provide very little information about the performance of their solar cookers. A large number of scientific studies about the performance of solar cookers have been published, based on heating water and glycerine. But these have not included the topics in the following sections.

3.1. On the use of different solar cookers and different cooking vessels

Most commonly available models of solar cooker on the market, mainly online, are sold with just one cooking vessel or sometimes without one. Frequent solar cooks like the authors have different cooking vessels that they select according to the meal and the amount of food to be cooked, just as in conventional cooking with gas or electricity. The performance of a solar cooker depends on the type of cooking vessel used. Thus, strictly, if a cooker reflector is operating sometimes with a cooking vessel CVA, and at other times with a cooking vessel CVB, it may mean that the two systems perform differently. When using a small cooking vessel, the thermal losses are expected to be smaller than those occurring with a big cooking vessel because the external surface area is smaller and the optical efficiency can be smaller, depending on the solar cooker design.

Moreover, any cooking vessel can be used at with a full load (CS100) or partially loaded (e.g. CS50 for 50% of maximum load) for making, for example, a vegetable soup or herbal tea. This loading also impacts on the performance of the system, by altering cooking time. The cooking process with system CS50 is expected to be faster than the cooking process when using CS100, but the efficiency of the system at partial load is expected to be lower because the temperature of the surface of the cooking vessel that is not in direct contact with the load will be higher, i.e., the thermal losses will be higher. In addition, the convective heat transfer to a cake or a bread being baked is not as effective as when making a soup or a herbal tea.

Different sizes of cooking vessel, made of differing materials, can be used to cook, bake, or prepare hot drinks using panel, box, or parabolic solar cookers. But most tube cookers, both evacuated and non-evacuated types, require a particular tray designed for each specific cooker.

For example, Celestino is used to preparing "caroffee" and coffee in a small Italian coffee pot designed for making nine small cups of coffee, in 3 to 10 minutes, and 2 liters of soup in a pot designed for a maximum load of 3 liters, in 30 to 60 minutes, depending on the weather conditions, by using the PRINCE15 parabolic cooker. When solar irradiance is weak, due to clouds, or air temperature is too low in winter and wind speed is too high, Celestino uses a massive glass enclosure made of two front-loading washing machine windows to ensure success while using parabolic solar cookers like the PRINCE15 or the SK14 (which can both intercept around 1.5 m2 of sunlight) to cook, bake and prepare hot drinks. These three examples of using a PRINCE15 solar cooker are shown in Figure 1.

a) b) c)

Figure 1. Parabolic solar cooker PRINCE15 with different cooking vessel: a) Italian coffee maker, b) black pot and c) set of glass enclosure and black pot.

Most common commercialized parabolic solar cookers can fry food as well as a conventional domestic gas burner if the sky is clear, the ambient air temperature is medium to high, and the wind speed is low. Under these favourable conditions, a glass enclosure is not needed. Indeed, it is not recommended because there is a high risk of breakage due to thermal shock. When baking under these favourable weather conditions, the pot-in-pot method should be used. The oven effect is created inside the external pot, which receives the solar radiation. In this technique, the baking vessel is placed inside the external pot, i.e., it is not directly exposed to the concentrated solar radiation. If it were exposed directly to solar radiation, the surface of any bread or cake being baked would be burned in just a few minutes and the inner part would be not baked.

Francisco Javier is used to cooking with a parabolic solar cooker which has a trivet with adjustable height, i.e., this trivet can be adjusted to focus the solar radiation on a larger or smaller area of the receiver, which changes the density of heat flux on the receiver surface. When the heat flux density is high, the food can be burned, and when the heat flux density is extremely high, even the receiver can be burned. Francisco Javier uses the high density heat flux strategy mainly when cooking ingredients with liquid in large thick pots. If there is a strong wind blowing when this solar cooker is in use, extra precautions must be taken to

prevent the cooking pot being blown off the trivet.
Evacuated tube solar cookers have a very high efficiency. This means that when equipped with a large reflector, they are able to provide successful results in cooking, baking and preparing hot drinks even in adverse conditions, i.e., under very weak solar irradiance, very low air temperature and very high wind speed. In spite of this important advantage, neither author favours this type of solar cooker for daily cooking tasks because they both live in regions where adverse conditions for solar cooking are rarely seen. Evacuated tube cookers are quite expensive and have small cooking chambers, so the cost per kilogram of food they are able to cook is quite high. Also, the glass tubes are vulnerable to breakage, either when cleaning them, or due to thermal shock while they are being used. Celestino had some experience of cooking the classic delicious Portuguese custard tarts known as "pastéis de nata" at a solar festival in Lisbon, using the portable SLiCK SM70 [2] evacuated tube solar cooker. The results, seen in Figure 2, show that all of the tarts were baked, but some were overbaked. This illustrates the heat gradient that exists in this type of cooking tube. These tubes are always hotter towards the closed end of the tube. Only the tray provided by the manufacturer can be used, which is a limitation for cooks who would like to use commonly available cooking vessels in other types of solar cooker. Most of the meals that can be cooked in an evacuated tube solar cooker can be cooked with other simple and low cost models like solar panel cookers during sunny periods of the day.
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a) b)
Figure 2. Evacuated tube solar cooker baking Portuguese custard tarts (pastéis de nata): a) starting and b) final baking result.

3.2. On the use of a thermal energy storage in solar cookers

The authors have no important results to report about the use of materials for storing thermal energy generated by solar cookers in domestic settings. In this context, some studies have been published based on testing experimentally several cooking vessel prototypes for use in panel, box or parabolic cookers and some additional elements incorporating a phase change material in a box solar cooker, enabling cooking at night or during cloudy periods. In some studies, the phase change material adopted melts at a temperature higher than the boiling point of water, but in other published studies it is difficult to understand why the authors selected a phase change material with a melting temperature between 60 and 80 ºC.
It is well known that a phase change material has a high latent heat associated with phase change, i.e., when charged, a relatively small amount of the material can release a large amount of heat, but it is also well known that increasing the thickness of the solid layer increases its thermal conductive resistance when releasing heat. This prevents it from releasing sufficient heat for cooking when it's needed. Besides, a large amount of phase change material at a relatively high operating temperature makes its use dangerous in a domestic context. Any new commercial product must meet very strict safety standards.

In the authors' opinion, storage of sensible thermal energy in a suitable fluid or in a solid medium makes more sense if it is adopted in semi-industrial facilities or community scale systems. In this context, it is important to mentioned two systems tested by the community at Tamera [3]. The first one incorporated a tank for storing hot oil to be used in the evening, mainly for cooking vegetables. In this system, the hot oil was produced by a set of tubes with a Fresnel lens collecting solar radiation inside a green house. In a second system, thick plates of stone were used for storing sensible energy at very high temperatures. The plates were placed inside a chamber that receives concentrated solar radiation collected by a parabolic concentrator. This second system was able to cook delicious large pizzas in the evening, as illustrated in Figure 3.

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a) b) c)

Figure 2. Solar concentrating system in Tamera community: a) view of overall system, b) chamber with sensible storage medium and c) pizza.

4. CONCLUSIONS

Solar cooker manufacturers usually provide very little information about the performance of their cookers. A large number of scientific studies have been performed, testing solar cookers with water and glycerine, but there are very few studies that address all of the aspects mentioned in this paper. Moreover, the authors of some published studies apparently have little practical experience of solar cooking. Their results show only a weak relationship with the real performance of solar cookers. Thus, further research should be planned by the research community on the real process of cooking and baking and report the performance of the system: i) for different cooking vessels are used, ii) for different loading levels (low, medium and high), iii) under different weather conditions, i.e., low, medium and high solar irradiance, air temperature, and wind speed and iv) using a suitable thermal energy storage medium for cooking at night

The research team should include members with expertise in analysing thermal systems and evaluating the properties of the baked items and cooked food, and also a member with expertise in baking and cooking.

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