On the construction and users acceptance of funnel concrete solar cooker

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Abstract – Solar applications are useful in sunny parts of the world. Despite this fact, the potential for solar cooking is not yet well understood. This beautiful technology is not exploited by many countries where it can serve rich and poor.
Author* became "seriously infected with the solar cooking virus" after attending the Solar Cookers International Conference in Granada-Spain on 2006. He started cookingwiththe well-known and simple cardboard solar Cookit. Several solar cookers of different types have been tested and used by the author*.
A funnel solar cooker in concrete was developed by the author*. It has been used since 2009. High technology is not needed for its construction. It should be produced locally by using appropriate moulds. Moulds can be easily fabricated using simple welding and drilling machines which are available in plenty in all parts of the world. Despite reasonable dissemination of solar cooking technologies, the potential of funnel cookers is not exploited as it happened in few other designs.

1. Introduction

Both south of Portugal and south of Spain have great solar potential. It has already been exploited in some thermal applications. These include domestic water heating systems but do not yet include domestic or large-scale institutional solar cooking applications as demonstrated by many projects in India. A significant number of families could cook their meals for more than 270days per year by using solar cookers. For the rational and economic use of energy, the solar cooking process could be used for Mid-Day-Meals in schools and canteen of companies as well as in restaurant kitchens. A large variety of meals could be solar cooked slowly or quickly as in conventional cooking devices. It is a known fact that 1% of the solar energy hitting our planet would be enough to power all human activity. Despite advances in solar thermal energy research for applications such as water distillation, food drying and cooking, the available solar cooking devices are used by few.
The quantity of solar energy hitting the surface of the earth varies according to the latitude, hour, month and composition of the atmosphere. The maximum flux value is about 1000 Wm^{-2}, meaning that a solar thermal device well designed with an aperture area of about 2 m^2 can cook food for an average family as effectively as conventional cooking devices using electricity or cooking gas.
There are several models of solar cookers with different designs, materials, performance and areas of application. Most simple solar cooking devices adopted for domestic use are direct cooking in real time. There are also cooking devices, which are capable of storing solar heat for use in non-sunny hours. Solid, liquid or phase change materials can be used as the thermal energy storage medium.
When operating directly with solar energy, the radiation is directed in the cooking zone of the cooker. Glass mirrors, polished aluminium or reflective foils can be used to make the needful concentration of the Sun's rays. The energy flux concentrated in the cooking zone depends upon the reflectivity and shape of the surface and also on the aperture area of the device. For good

performance, the outside surface of the cooking vessel should be dark. Even if this surface is not optimal, successful cooking can be achieved by increasing the aperture area of the solar cooker and ensuring maximum radiation is concentrated in cooking zone. Knowledge of fundaments of optics is crucial to design an efficient and effective solar cooking device.

Flat reflective surfaces like those used in common slow cookers, panel and box cookers, focus the radiation into a cooking area being necessary to track reflectors the sun after one to two hours. The solar cooking process consists basically of putting a pot in the cooking zone and monitoring the cooking time according weather conditions, the type of cooker, the quantity and type of food, i.e., based on experience of the user. The cooking vessel needs to be covered with some greenhouse which is enclosure of transparent glass or plastic. The cooking vessel should be a good conductor of heat to transfer heat to the food being cooked, but it is important that risk of burning does not exist which can happen when using a parabolic cooker with a very small focus zone. The cooking process is less efficient on cold or windy days due to thermal losses.

A parabolic solar cooker with a diameter of 1.4 m has a thermal power similar to the power used in many conventional gas burners in family kitchens. It requires solar tracking around every 15 to 30 minutes. This is not a big issue because a large variety of foods such as rice can be cooked successfully in a very short period of time. Parabolic solar cookers must be used with care and "turned off" when not in use if risk of fire exists in the surroundings.The concentrated beam of sunlight, when not focused on the bottom of the cooking pot, can cause accidental fire.

A box solar cooker is usually a thermally insulated box. The clear glass at the top creates a greenhouse effect inside the box and the reflective surfaces around the box focushuge and needful amount of additional solar radiation into the box. To minimize thermal losses, the walls and floor must be well insulated. Insulating glass should be used in cold regions. The stagnation temperature of common box cookers is usually lower than the stagnation temperature of common parabolic cookers. Cooking at low temperature can be seen as an advantage when a relatively large amount of food needs to be cooked slowly and uniformly without the need of tracking frequently. Acceptable cooking results can be achieved on days with intermittent clouds if cooker is well designed and pebbles or a thick metallic plate is used as a heat storage medium. It is imperative that cooking temperature of the food does not drop below the minimum temperature needed to avoid bacterial contamination due to food safety reasons.

Common panel solar cookers are simple and easily constructed apparatus. Few specialized tools are required in construction process. Most devices have more than one reflective surface. It enables the concentration of solar radiation onto the cooking zone over a period of 2 to 3 hours without tracking the cooker to the sun. The cooking vessel must be put inside a clear, transparent enclosure, to create a greenhouse effect with captured heat. This effect is crucial for trapping heat for successful cooking. It can be achieved by using a heat resistant plastic bag or a glass enclosure.

Common parabolic solar cookers are very powerful and can cook very fast, but the risk of burning the food exists. When weather conditions are good for cooking it is not strictly necessary to use a black pot. Solar cooking is still possible at reduced speed with semi cloudy atmosphere with and high air velocity if the black pot with suitable greenhouse like glass enclosure is used.

The slow cooking process in an enclosed space leads to the conservation of moisture and of the nutritional properties of foods. Thermodynamic cycle resulting from the continuous vaporization and condensation of water greatly reduces water losses. Moreover, usually there is no risk of burning the food, no flame, no danger of explosion and no danger of igniting a fire.

2. Foldable funnel solar cooker

Despite the knowledge of author* about thermodynamics and heat transfer and despite his domicile in a sunny region, he was ignorant on solar cooking until July 2006. Only after the visit of Pedro Serrano, a Chilean friend teaching at the Faculty of Architecture in Val Paraíso, Chile and invited speaker for the Solar Cookers International Conference in Granada, Spain, author* was so surprised with the world of solar cooking. Author attended same conference without prior planning. He came back home with a simple cardboard solar Cookit. This cooker was tested over the next few days at his home in Portugal. From then until now, the author has been "well contaminated with the virus of solar cooking", and has become an important advocate for solar cooking in Portugal, Spain and other parts of the world including India. Other solar panel cookers were tested and developed using corrugated polypropylene sheet as a reflector and glass windows from discarded washing machines as glass enclosure to create the greenhouse effect. Fig. 1 shows a portable and foldable funnel cooker and also some successful results of roasting of figs with almonds and cooking rice with carrots. This cooker is delivering good performance for a full pot of 3 litres capacity when used during hot and sunny days. During cold sunny days acceptable results are achieved if same pot is half-loaded.

a) b) c)

Fig. 1 Funnel solar cooker: a) cooking process, b) roasted "starts" of figs with almonds and c) cooked rice with carrots

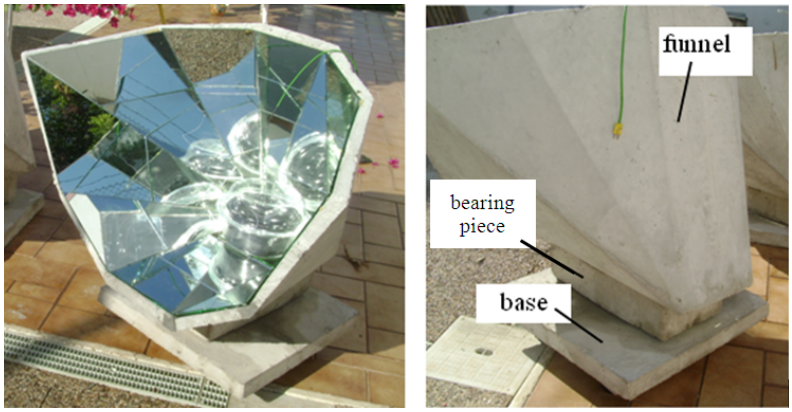
Low cost portable funnel cooker and solar Cookit cooker are not the most suitable devices to be used every day at a fixed place because reflective foil degrades over time. Also there is change of getting blown by wind. For longer lives, it is necessary to keep them inside when they are not being used. This requirement does not encourage the user for daily solar cooking. To overcome this limitation, the author developed a funnel cooker made of concrete with common mirrors as reflectors. It has the same shape and similar performance as the portable and foldable model, at times better.

3. Concrete solar funnel cooker

The concrete funnel cooker is composed of a black pot, glass enclosure, and the concrete structure in 3 pieces. Funnel has glass mirrors glued to inside face. The funnel is mounted on the rotating concrete bearing piece which is in turn mounted on the base. Base has the rotating axis. The main piece is located above the middle piece. The funnel and bearing piece can rotate about the axis of the base. The main funnel can be tilted according the altitude of the sun. A set of four wheels can be added under the base when the cooker must be moved for a sunny position daily, monthly or seasonal. The device shown in Fig. 2 is located just two meters from the conventional kitchen of author's home, which is located in Faro-Portugal at latitude of 37 ºN. Some advantages of this

solar cooker are: relative low cost production in most parts of the world using local available materials (sand, cement and mirrors), intuitive and practical use, its water, rain and wind resistance and no risk of fire.

Fig. 3 depicts the three concrete pieces after they have been taken out of the moulds. The moulds are made in steel sheet. Some details of the main piece mould are shown in Fig. 4. Initial and final steps of filling this mould are illustrated in Fig. 5. The first set of moulds and the first solar concrete cooker was built in Portugal on year 2009.



a) b)

Fig. 2 Concrete funnel solar cooker: a) front view and b) back view.

a) b) c)

Fig. 3 Concrete pieces: a) funnel, b) bearing piece and c) base.

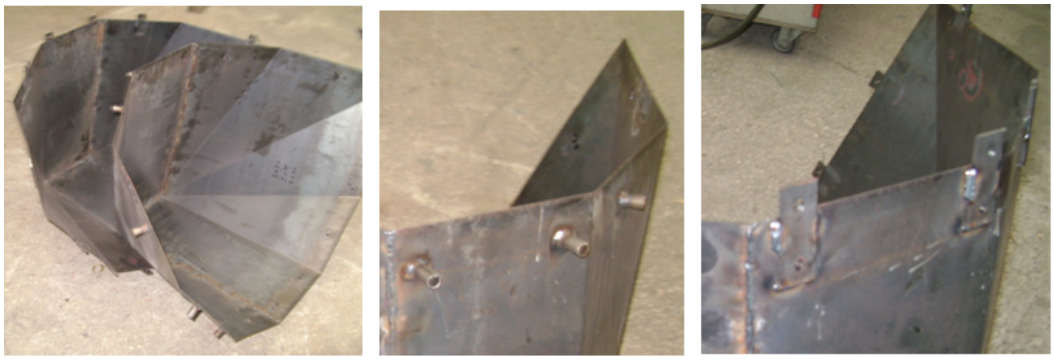


Fig. 4 Mould for making the funnel concrete piece.

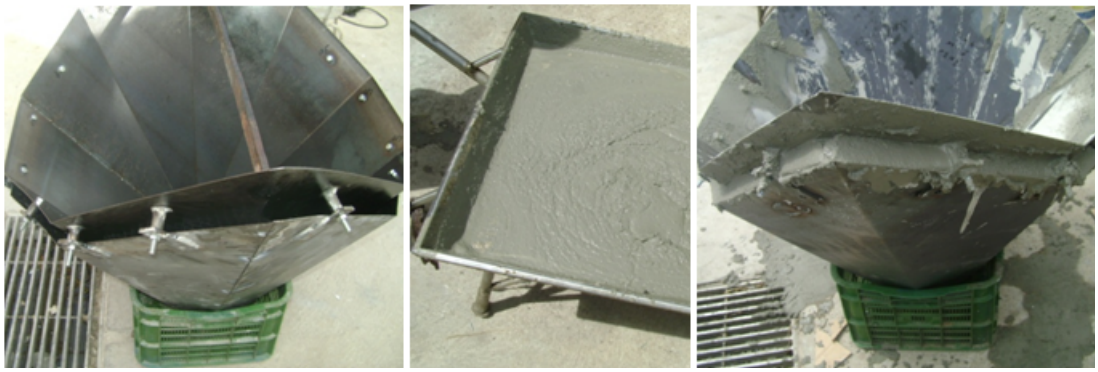


Fig. 5Filling mould process.

Fig. 6 Moulds for the: a) bearing piece and b) base.

A second set of moulds was manufactured in Dhule – India in February 2015 at PRINCE center; a workshop equipped with suitable tools and specialized workers. Mould manufacturing steps are shown in Fig. 7. Some concrete cookers have been constructed using aluminium reflecting sheet with good quality instead of using common mirrors. Filling process of the moulds is shown in Fig. 8. It took place just in a neighbour company specialized in manufacturing artefacts in concrete.

Fig. 7 Construction of moulds at the workshop (Dhule-India).

Fig. 8 Filling mould process at the manufacturing artefact company (Dhule-India).

The pieces of concrete were ready to be assembled after two days curing. Fig. 9 illustrates some of the simple and easy steps in assembling the three pieces and sticking the reflectors to funnel piece. Anodised, polished, hardened aluminium reflectors were used as reflectors. These are high quality reflectors normally used by SK-14 and PRINCE concentrating cookers.

Fig. 9 Assembling process and sticking reflector aluminium sheets.

Recently, a third set of moulds were manufactured in Figueira da Foz – Portugal, birth place of the author. A solar cooking friend of the author, also passionately using and promoting solar cooking. He is using the moulds for constructing concrete funnel cookers. Few cookers are constructed using white cement with an excellent decoration by just painting the back side of the funnel and the other two pieces. Some views of two such decorative devices are shown in Fig. 10. In author's opinion embellishment with incorporation of art is also important aspect for promotion of solar cooking and aids in user acceptance.

Fig. 10Embellished concrete funnel cookers.

4. On the acceptance of concrete solar funnel cooker by the user

The number of concrete cookers have been constructed is estimated to be around twelve, mostly in Portugal and some in India. Two of constructed cookers made in Portugal are being used by two families in Seville-Spain. The location of the cookers with regards to kitchen in both cases is convenient. Despite the number of sunny cooking days per year is very high in the place only one of the families is using the concrete cooker and portable funnel cooker on regular basis. The old members of this family are retired teachers and they became well infected with the solar cooking

virus after participating in a solar cooking workshop integrated in a meeting of eco-villages. The old members of the other family are teaching in a school about 150 km distance. This family is using both funnel concrete cooker and parabolic cooker only during some weekends.

Author* of this work is an intensive user of solar cooking. He is using three concrete cookers and also two parabolic cookers at home in Faro-Portugal since year 2009. He is appreciating a lot slow cooking because slow cooking process is fitting well within his daily activity at university and at home. In contrary his wife is not so motivated with solar cooking. She uses gas, but mainly during cloudy days. The risk of divorce increases when his wife tries to cook on sunny days using gas burner or electrical oven !!!. Author is also used to start cooking some dishes in parabolic cooker and then move them to funnel cookers for ending the cooking process slowly. This strategy is used when he is cooking for more people than the four member of family at home. All solar cookers being used are permanent cookers located outside his home. Some of the cookers are placed just two meters distance of the door of kitchen but other set of cookers are located in terrace of his house, which is not so feasible for people using cooker in a daily sunny basis. One of the concrete funnel cookers is performing better than the other two devices because reflectivity of mirrors is reduced since two years. Repairing the cooker by replacing old mirrors by new ones can be done easily even by the user. The main difficulty for a common user concerns the cutting process of the mirrors with the right dimensions. It can be done by specialized worker in a small company working with common mirrors. Recycled pieces of new mirrors can also be adopted.

Prof. Ajay Chandak's family in Dhule-India is using the concrete funnel solar cooker since 2015 together with parabolic cooker depicted in Fig. 10. This Indian family mentioned the following advantages about the concrete funnel cooker:

i) It is heavy and unaffected by wind.
ii) The solar cooker does not get toppled by the wind as it is pretty heavy.
iii) The Pin joint (bearing) is good for turning and focusing without much of effort.
iv) It is practically a non-tracking solar cooker. You keep the food and adjust the solar cooker once. Normally to intermittent trips required till the food is cooked. With some experience people can advance the solar cooker direction a bit to the west to use more of a solar window without tracking.
v) Quality of food, especially all boiled food and puffy stuff like breads and cakes is great
vi) As reflector shape is permanent and no skill is required in adjusting the shape of the reflector. Even novice people can use this solar cooker.
vii) Polished, anodized hardened aluminium reflectors have very good life.

Some limitations of the concrete funnel solar cooker mentioned by this Indian family are: i) Manufacturing solar cookers at site is required as transportation is difficult. ii) Procurement of suitable glass enclosure is another issue that needs to be resolved. As the market size for this design of solar cooker will grow, manufacturers dedicated design of glass enclosures can be developed.

a) b)

Fig. 10 Indian family using: a) concrete funnel cooker and b) parabolic PRINCE cooker.

5. Conclusions

The main motivation of the author for constructing the funnel concrete resulted from his experience in testing and using several types of portable panel solar cookers on a daily basis. Fixed solution of solar cooking device like a permanent barbecue close to house/conventional kitchen is very important to keep user motivated in cooking by the Sun. Moreover, solution resistant to weather conditions is also another important issue to guarantee.

Probably the use of concrete is not recognized as an ecological solution. It is an option easily implemented in different parts of world. Concrete cooker should be imperatively produced locally due to costs of transports. It is important to give some minor instruction how to make the cooker but not high skills from the workers are needed. A construction worker like a bricklayer or a mason has the suitable professional profile to make concrete cookers when moulds are available. A small industry of making concrete artefacts has also the facilities for large scale production of the main pieces in concrete.

Three set of moulds have been built and several funnel concrete cookers have been constructed since 2009 in both centre and south parts of Portugal and in Maharashtra, state of India. Several families have used these cookers but unfortunately few of them are using the funnel concrete cookers intensively in daily life during sunny cooking days. In author's opinion it is also happening with other types of solar cookers. One of the main difficulties in disseminating solar cooking is strongly related with the acceptance by the users. The potential of solar cooking is enormous but unfortunately true success of solar cooking is not many. Starting a project in a rural area or even in a city should be based on both social and technical approaches. Advocates on solar cooking should act as a missionary with a multiplying effect converting users as missionaries. It is important that an advocate of solar cooking lives for some time within the community to be considered one of them and to understand what are the common meals people are used to cook and what are the meals that can be easily replicated in solar funnel cooker, or for that matter any solar cooker. Advocate should execute and document recipe for local meals. It is important to highlight that solar cooking is not an alternative solution to the conventional process based on gas, electricity

or wood, but in sunny regions it is a solution for saving fuel and helping environment. The advocate of solar cooking will face several barriers. To overcome the barriers a great effort should put on it, sometimes without successful results, to promote the acceptance of solar cooking by people.