THE "SOLAR NEST"- A VERY LOW COST SOLAR COOKER

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ABSTRACT

This project shows that an effective solar cooker can be made for less than $US5 using materials that are available almost anywhere. This has been achieved by recognising that as the oven does not need to exceed 100°C, multiple glazings and highly insulated boxes are not necessary. This project demonstrates that most foodstuffs can be cooked using a 0.25m^2 frame with double glazing of transparent polyethylene plastic film and a "nest" of locally available fibre instead of a box. A series of standardised tests on the "nest" were also conducted using single and double glass and double Tedlar.®

1. INTRODUCTION

It is estimated that nearly half of the world's population use wood as energy source[1] with an average wood consumption of about 2-3kg/person/day, or about 1 tonne/person/year. This gives rise to about 1-2 tonnes of CO_2/person/year. (In perspective, this is about 10% of the average developed-country CO_2 production). In some countries this is sustainable, but many now report deforestation for firewood at a rate of 1million hectares/year[2]. Some of the adverse consequences of this include:

- In 2000, nearly 470 million tons of wood was consumed in homes in sub-Saharan Africa in the form of firewood and charcoal. This is more wood per capita than is used in any other region in the world.
- Further, deforestation is exacerbating desertification in low rainfall and arid countries and soil instability/landslides in higher rainfall areas.
- More than 1.6 million people, primarily women and children, die prematurely each year worldwide (400,000 in sub-Saharan Africa) from respiratory diseases caused by the pollution from wood fires[3].
- The collection of firewood has become an arduous and often dangerous task. There are many reports of women and children spending up to 5 hours daily walking up to 10km each way to collect wood, often exposing themselves to assault. As a result, these women and children are denied opportunities to undertake other activities or attend schools[4].

Therefore, any effort to reduce fuelwood consumption while increasing the standard of living should be welcomed.

2. PREVIOUS WORK

There is abundant literature on the development and introduction of box-, panel- or reflector-type solar cookers in Africa, Asia and the Americas. Sizes have ranged from single-pot to several square metres in reflector area and production volume from one-off to several hundred units. Most of these cookers can readily attain temperatures of 125-150°C and cook most meats and grains in 2-3 hours[5].

While *technical* success has been almost universal, *social* and *economic* success is less common. Socially, there are many reports of the mismatch between solar cooking times (daylight) and eating times (at night). However, there are also many reports that do not indicate any temporal mismatch problems and some instances where long-held cooking customs and preferences have been abandoned in the face of the superior qualities of the solar cooker. Economically, most reports indicate solar cooker prices from $US20-$200. While these prices may be considered low by Western economic standards, such cookers cannot be afforded by many people, where this cost would be about the same as their annual cash income. Further, the appearance of expensiveness of these cookers has led to their theft and/or use as a tradeable item. In summary, although these cookers have been successful at the demonstration stage, widespread adoption has been inhibited by prices that would remain unaffordable even at large scale production, coupled with real or apparent social disruption caused by limited distribution of these prized devices.

The present work demonstrates that this cost problem can be overcome.

3. PERFORMANCE REQUIREMENTS OF A SOLAR COOKER

Cooking is essentially the application of heat and moisture to raw foodstuffs to make it digestible. The main processes are the breaking down of complex proteins in meat and legumes, the conversion of complex carbohydrates to starches and sugars in grains and the breaking down of cellulose cell walls in vegetables to make the contents (carbohydrates and vitamins) accessible. In most cases these processes occur above about 80°C. A further outcome of cooking is that most harmful bacteria may be killed or their numbers diminished by the processes of pasteurisation and sterilisation. Temperatures from 80°C-200°C can accelerate the cooking process, cause further reactions (such as caramelisation) that enhance flavour, melt and remove excess fat and ensure total sterility. Temperatures above 200°C, found in naked flames, grills and toasters can achieve cooking objectives, but at the risk of reducing the foodstuffs to carbon.

In practice, most bacteria will not multiply above 50°C, and most are killed by pasteurisation above 65°C (See Fig. 1). Flavour enhancement aside, most cooking objectives can be met if the cooking environment can be sustained above about 80°C for several hours.

4. THE BASIC PHYSICS OF THE SOLAR COOKER

A cooking device therefore needs to attain cooking temperatures above 80°C and then maintain that temperature within a practical period of time. Attaining cooking temperatures requires an energy input proportional to the mass of the food and the total energy available is directly proportional to the effective aperture area of the collector and the radiation transmissivity of the glazing material. Maintaining cooking temperatures will depend on the balance between energy gains and losses at that temperature. Losses arise from glazing opacity, conduction, convection and radiation from the cooking vessel to the oven and from the oven's top and sides to its environment. (see fig xxx).

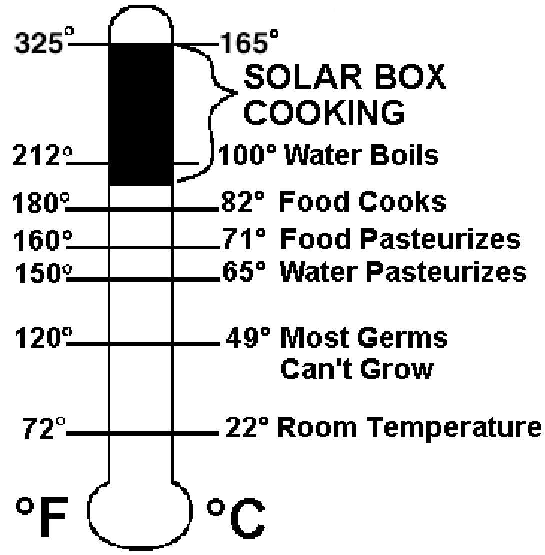

Fig. 1: Key design temperatures for cooking [6]

Ideally, a solar oven would have:

- A large effective aperture to maximise radiation collection
- High transmissivity of glazing in solar radiation spectrum range
- High absorbtivity of internal surfaces in solar radiation spectrum range
- Small box area to minimise conductive losses
- Thick insulation of box to minimise side and bottom conductive losses
- Multiple glazing to minimise top conductive losses
- Low transmissivity of glazing in far infrared range (50°C-200°C)
- High conductivity of interior material to cooking vessel
- High conductivity of cooking vessel
- Sealed cooking vessel to minimise convective losses
- Well-sealed box to minimise convective losses

While the conventional reflector-enhanced solar box cooker maximises most of these design ideals and attains temperatures of up to 150-200°C, it generally does so at an increasing cost and/or the use of materials that are often not available in many less affluent countries.

The objective of the present project was to achieve effective cooking conditions at a minimum cost, knowing that these conditions can be incrementally enhanced with increased resources. A cost objective of US50 cents-$US5 was used.

As rice, sorghum, lentils and vegetables are the most common foods used, the cooker does not need to achieve temperatures above 100°C and indeed, for most purposes 80-85°C is sufficient, but does need to be effective in available daylight hours.

5. THE "SOLAR NEST" COOKER

To make an affordable cooker, it has been assumed that transparent sheet plastic (polyethylene), some fibrous material and 4 reasonably straight sticks are available. The oven comprises a "nest" of fibrous material- in this case shredded coconut husk- about 200mm high with a cooking cavity approximately 450mm diameter and 150mm deep. (see Fig. 2) In the basic model commonly available transparent sheet polyethylene was stapled to a 500mm x 500mm frame made from 40mmx20mm battens- like a double-glazed window with an effective aperture of about 0.25sqM, which was placed over the cavity. The cooking vessel was a 200mm-square pressed steel pan 50mm deep. A small sheet of the same plastic formed a lid to the pan to maximise direct solar gain to the pan and to minimise heat loss by evaporation/convection.

A series of cooking tests were conducted on clear sunny days during March 2007 in Perth, Western Australia (Latitude 32°S) with maximum air temperatures of 25-32°C. A mass of water plus grain of 1kg was placed in the pan, and placed in the cavity at 11am local solar time. In all cases satisfactory cooking was achieved before 3pm local solar time. A dish of chicken and vegetables and a 1kg leg of lamb were also fully cooked.

The tests demonstrated that by using an aperture of 0.25sqM, practical cooking temperatures and times can be achieved with transparent sheet plastic without the need for complex reflectors to increase the effective aperture or glass to increase the heat trapping. The "nest" eliminates the need for a box, and could be made from any locally available fibrous material, such as bark, grass, straw, cloth or sterilized animal manure. While the performance of the oven can be enhanced by being deeper, blackened and by using one or two sheets of glass, these tests demonstrated that satisfactory cooking can be achieved with as little as 50cents of sheet plastic in a wide range of circumstances.

6. TESTING OF DESIGN ENHANCEMENTS

Although practical trials of cooking common foodstuffs were successful in the simplest of designs, further tests were conducted on a range of "enhancements" to the design, recognising that improved performance (ie higher

Fig.2: The "Solar Nest" cooker.

temperatures and/or shorter cooking times) would always be desirable within cost constraints.

The test was standardised using an electronic probe thermometer immersed in 1 litre of water in the pressed steel pan used above. Temperature measurements were taken every 15 minutes. Temperatures of 105°C-120°C were obtained in the cooker without the pan of water.

The first enhancement was to place a black steel plate under the pan. As this showed a marked increase in performance, it was used for all further tests, which were:

- Single glass sheet
- Double glass sheet
- Double Tedlar® plastic sheet

The results for these tests are shown in Fig. 3. All glazings achieved the 80°C cooking threshold within 3 hours, with the black metal plate making about 7°C difference, which is an important increase at these temperatures. The single glazing, double glazing and double Tedlar® achieved the 80°C threshold at least an hour earlier than the double plastic and achieved maximum temperatures of about 15°C higher than double plastic. Tedlar® was chosen as it is durable at high temperatures and has low infrared transmissivity than polyethylene[7].

7. FURTHER IMPROVEMENTS

Within the cost-constraints of this design, significant further improvements are possible. The fibre nest used was quite shallow and experience with conventional box cookers indicates that increasing the depth to achieve a pan-top to

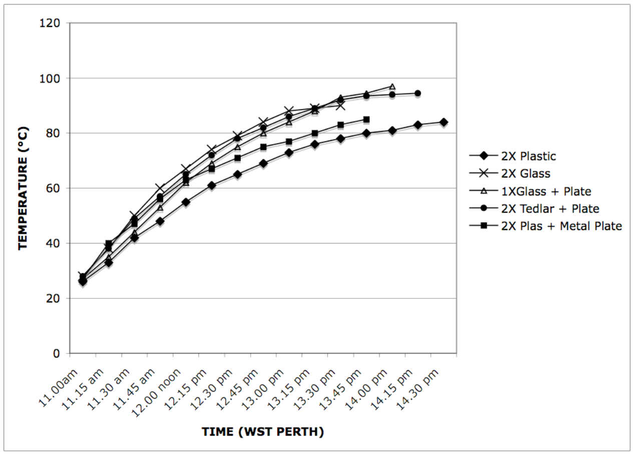

Fig. 3: Time/temperature tests on various types of glazing.

glazing distance of about 200mm would reduce radiative losses. Blackening the interior- possibly with a layer of charcoal would increase the solar radiation absorbtion. The nest could be sloped to face the afternoon sun at an angle close to 90°. (The present project was conducted during March at a latitude of 32°S, giving a maximum glazing angle of about 60° at noon). Placing the solar nest next to a white, vertical equator-facing surface such as a whitewashed north/south-facing wall would provide a crude reflector increasing the temperature by up to 10°C as well as creating a higher-than-ambient surrounding air temperature. Alternatively, a dark wall would increase the ambient temperature by 5-10°C near the wall. Ensuring that the cooker is protected from breezes would also reduce convective losses. Finally, if transparent sheet plastic is used, it should be stretched as tightly as possible over the frame to maximise the insulating air gap and minimise flapping, which pumps hot air away from the cooker. Undoubtedly, further innovations would be found by users to suit local circumstances. (See Fig.4)

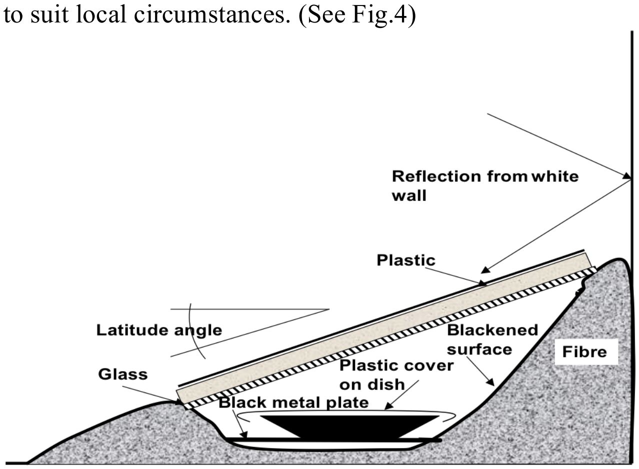

Fig. 4: Possible improvements to the solar nest

8. CONCLUSIONS

The project demonstrated that cooking temperatures for a range of common foodstuffs can easily be attained with simple readily available materials on clear sunny days over 25°C. While the cheapest oven- double-plastic on a wooden frame- can serve most cooking purpose, significantly better performance is possible with just a single sheet of glass. The durability of the glass could be improved by setting the glass into a wooden frame with a sheet of plastic used as the outer glazing. Such a cooker would cost less than $US5 and could be made with scrap materials in many places. This cost difference from the $20-$200 of most compact, well-built cookers is very important to many people in impoverished countries. Further, at $5 or less, very wide-scale distribution of core materials (plastic, glass and battens) can be contemplated by governments or aid agencies. Although this simple solar cooker cannot totally replace firewood, it can make a significant reduction in demand, thereby improving both the environment and personal amenity.

9. REFERENCES

(1) http://www.who.int/mediacentre/news/statements/2004/statement5/en/index.html

(2) See for example http://www.atmosphere.mpg.de/enid/ACCENT___en/Nr_ss__Sept__2__6_Africa_s_emissions_5ts.html

(3) "World Health Organization; Indoor Air Pollution- The Killer in the Kitchen." WHO Media Statement 2004 at www.who.int/mediacentre/news/statements/2004/statement5/en/index.html

(4) See for example Practicalaction.org

(5) See for example http://www.solarcooking.org/

(6) http://solarcooking.wikia.com/wiki/Image:Thermo2.gif

(7) Information from DuPont Tedlar® Fact sheet.