THE DURABILITY OF EVACUATED SOLAR COOKING TUBES – SOME PRELIMINARY FIELD TRIALS

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Abstract: *Solar cookers that utilize evacuated borosilicate glass cooking tubes have reached market maturity. At least seven different models are now available, and more are promised. One major obstacle to wider adoption of this type of cooker is the perception that the evacuated glass tubes are fragile, and of uncertain durability. This paper describes some preliminary field tests using a variety of evacuated tubes. A number of breakages are reported. The putative reasons for these breakages are listed and discussed. Some suggestions are made for future product development.*

Keywords: Evacuated Borosilicate Tubes, Solar Cooking, Durability

1. INTRODUCTION

James Dewar invented the double walled vacuum insulation vessel in 1892 [1]. Since then, his design has been widely adopted for keeping food or drink hotter or colder than its surroundings. Since the 1980s, designs based on the same principles have been applied to the manufacture of solar water heating tubes, constructed from borosilicate glass. The growth of the renewable energy industry has led to the refinement of this design and mass production has driven down the price of glass-in-glass tubes. In 2009, 8.5 million square metres of solar hot water tubes were manufactured in China alone [2]. At a meeting of *Solar Cookers International* in Granada, 2006, Alex Kee Koo Yak suggested using these ubiquitous tubes for pasteurising water [3]. Since then, interest in this application has grown, and extended to food cooking. At the time of writing, there are at least seven different evacuated tube cookers on the market. Some of these designs have convenient stands, and reflectors which increase the cooking power available within the tube [4]. Such stoves are very efficient at converting sunlight into sensible heat that can be used for cooking. In addition, because of excellent thermal insulation, they can maintain cooked food at serving temperature for several hours. One obstacle to wider adoption of this efficient technology is the perception that these evacuated glass tubes are fragile and of uncertain durability. This paper describes some preliminary field tests and observations about the durability of this sort of cooker, using a variety of evacuated tubes and cooker configurations. All tube breakages were documented and the circumstances recorded. A number of explanations for these breakages are considered below.

2. EQUIPMENT

Three types of evacuated cooking tubes were available for testing. All were manufactured in China. The names of the tube manufacturers are unknown. The tube dimensions are as follows:

Tube type	**SM70**	**SM125**	**Rand**
Capacity (net)	**1.3 litres**	**2.4 litres**	**3.65 litres**
Internal length	**57 cm**	**55 cm**	**54 cm**
Gross length	**63 cm**	**60.5 cm**	**62.7 cm**
External diameter	**7 cm**	**10 cm**	**12 cm**
Internal diameter	**5.5 cm**	**8 cm**	**10 cm**

Table 1. Evacuated tube specifications.

The SM70 tubes were mounted in a standard SM70 solar cooker, a mature, market-ready design. The SM125 tube was mounted in an early proto-type solar cooker. The ‘Rand’ tube was mounted in a home-made prototype designed by Stewart macLachlan. All temperature readings were obtained from *Lascar* [5] dataloggers fitted with a stainless steel K-type thermocouple probes.

3. HYPOTHESES

A number of preliminary hypotheses were developed to account for the observed tube breakages. They are presented below.

3.1. Shipping breakages

Anecdotal evidence from solar cooking community forums (e.g. the Solar Cookers International Facebook Group) and from personal communications suggests that evacuated tubes can get damaged in transit. Over the past two years, the authors have imported 131 evacuated tubes into the UK. Only two arrived broken. It remains unclear why these two tubes were broken when others, similarly packed, arrived intact. A consignment of 120 cookers/tubes survived the journey from China with no losses, whereas two smaller deliveries, containing four and two tubes respectively, each contained one broken tube. It is the authors' impression that smaller consignments, or individual cookers, may be more vulnerable because they are handled by people on many separate occasions. Large consignments can only be handled by machinery, because of their weight. This conclusion may not augur well for the survival of tubes distributed individually via couriers or domestic postal services.

3.2. High temperatures

It is not unusual to come across comments suggesting that evacuated tubes are more likely to break if raised to temperatures above 200^{o}C. For example, this advertisement mentions this risk explicitly [6]. To test this assertion, a tube was exposed to high temperatures. An SM70 was left in a south-facing orientation for three weeks. It was not moved at all except to remove and reload 120g, 500g, and 1000g of cutlery in successive weeks. The purpose of the cutlery was to provide thermal mass to buffer any rapid changes in tube temperature. The air temperature inside the cooking tube was recorded using a data-logger and a K-type thermocouple in a stainless steel probe. The oven and ambient temperatures appear in blue and pink respectively in the graph at figure 1 below. An estimate of the duration of daily insolation was obtained from Heathrow Airport Weather Station [7]. These estimates are superimposed in on the graph in red (below).

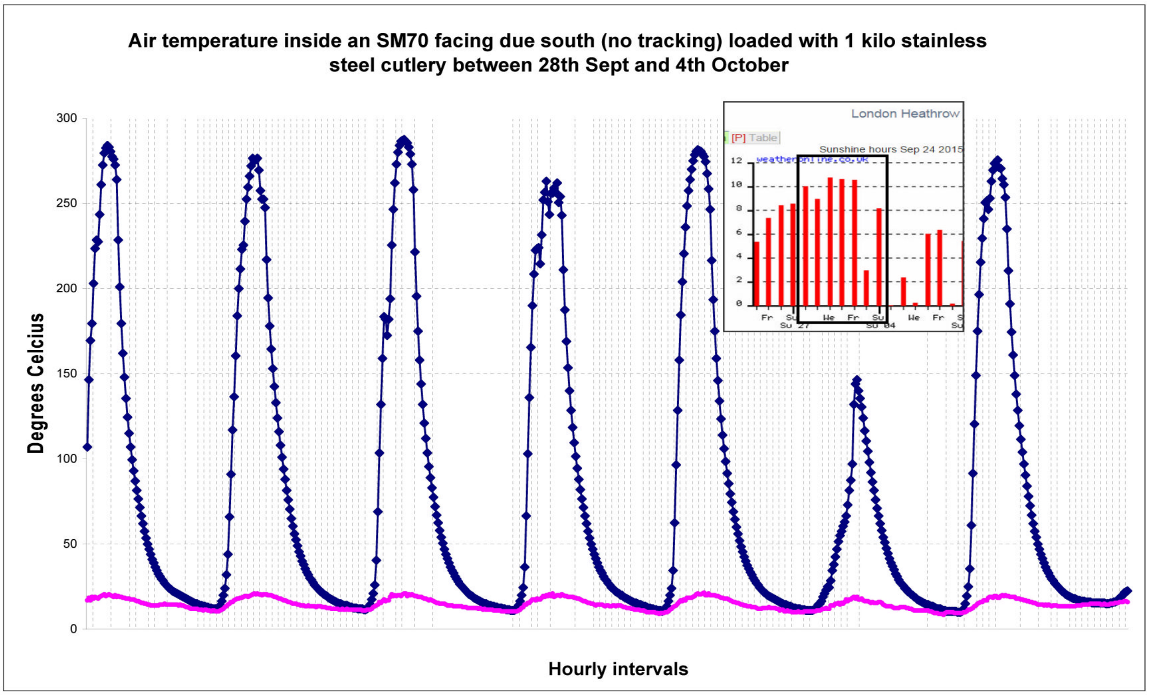

Figure 1. Air temperature inside an SM70 solar cooker facing due south for a week.

The air temperature in the tube rose to maxima of 287°C, 313°C and 330°C when loaded with 1000g, 500g, and 120g of stainless steel respectively. The authors conclude that exposing a tube to temperatures above 200°C, or even above 300°C, is unlikely, in the absence of other adverse factors, to destroy it.

3.3. Thermal shock

Manufacturers instructions that accompany the SM70 warn against cooking frozen food without first thawing it. To test whether frozen food would harm the tube, the food tray of an SM70 was loaded with some peppers (capsicum) straight from a domestic freezer. In the UK, domestic freezers maintain temperatures of between -10°C and -18°C. A quantity of small tomatoes and basil were also added so that there was more unfrozen than frozen food. The cooker was positioned for maximum solar gain. After approximately 30 minutes, the tube shattered. The authors conclude that there is a risk of tube destruction by thermal shock. Every effort should be made by solar cooks to minimise thermal gradients in this sort of tube.

3.4. Piston effect

SM70 and SM125 cooking tubes have small internal diameters which are easily filled to capacity. After the SM125 tube shattered on its first outing, the authors attributed this breakage to rapid explosive expansion of juice from a segment of capsicum that had fallen over the edge of the food tray and onto the hot inner glass tube. This was possible because the SM125 features a sloping tube design that allows food to slide down the tray under gravity. After further reflection, and after an SM70 cooker with a horizontal tube failed, the authors thought it more likely that on each occasion, the tube had been blocked. On both occasions, a small amount of resistance was felt as the food tray was inserted, and this may have been due to food forming a seal within the tube. The authors suggest that in those circumstances, air and steam produced by the cooking process are unable to escape and pressure builds within in the tube until it fails. A further breakage in this category occurred when a Rand tube was left, empty, on a table with its silicon bung in place, wrapped tightly in bubble-wrap. Initially in shadow, it shattered when the solar azimuth angle changed and the tube was exposed to sunlight for an unknown period of time. Using data from the SM70 high temperature trial, it is evident that a small tube loaded with 120g of steel can reach temperatures of 300°C. A naked tube (without reflectors) with no added thermal mass could be expected to reach that temperature eventually when exposed continuously to sunlight. With such a temperature increase, and assuming an initial temperature of 10°C, if the air contained in the tube were unable to escape, its pressure would increase from an initial value of 1 atmosphere to a final value of 2 atmospheres. The authors could not find any pressure testing data for Rand tubes, but offer the hypothesis that this breakage was due to increased internal air pressure.

3.5. Mechanical stress

Two further breakages occurred when tubes were held in the vertical position, and being used to heat water. These events were the most puzzling. It seemed to the authors that the only available explanation is that these were straightforward mechanical failures in which the force imposed by the weight of water overcame the tensile strength of the internal tube. The reader’s attention is drawn to the structure of these tubes. The tube-in-tube formation is a continuous structure made of borosilicate glass. When the outer tube is supported by munsen rings in a solar cooker, the inner tube is supported only by the fused area at the mouth of the cooking tube and three or four stainless steel spacers at the opposite end of the tube. These supports must of necessity be flexible to allow for the different coefficients of thermal expansion of glass and metal. If loaded to capacity with water, a considerable tensile stress must be induced at the upper end of the inner tube as the whole device is tilted. The authors question whether the flexible spacers at the other end of the tube exert sufficient force to accommodate that load.

4. POSSIBLE FUTURE DESIGN TRENDS

It must be remembered that the solar cooking tubes currently in use were designed for a different purpose. It is easy to think of two modifications that would better suit them for cooking. Firstly, tubes with larger diameters would enable larger food items to be cooked and make their use more convenient. Secondly, they could be made less vulnerable to damage. One way of achieving this would be to make the inner tube from stainless steel while preserving the other elements of the design – the glass outer tube, the evacuated space between the tubes, and the selective coating on the outside of the inner tube. Such a design already exists, though not for cooking. Utility scale concentrated solar power plants deploy linear parabolic reflector troughs with evacuated collector tubes at their focus [8]. These tubes usually contain heat transfer fluid at temperatures of up to 400^{o}C [9]. They are said to be very durable (Gordy Bishop, personal communication). They are similar in construction to evacuated tubes made entirely of borosilicate glass, except that the inner tube is constructed of stainless steel. Thermal expansion and contraction are accommodated by flexible bellows (see figure 2 below).

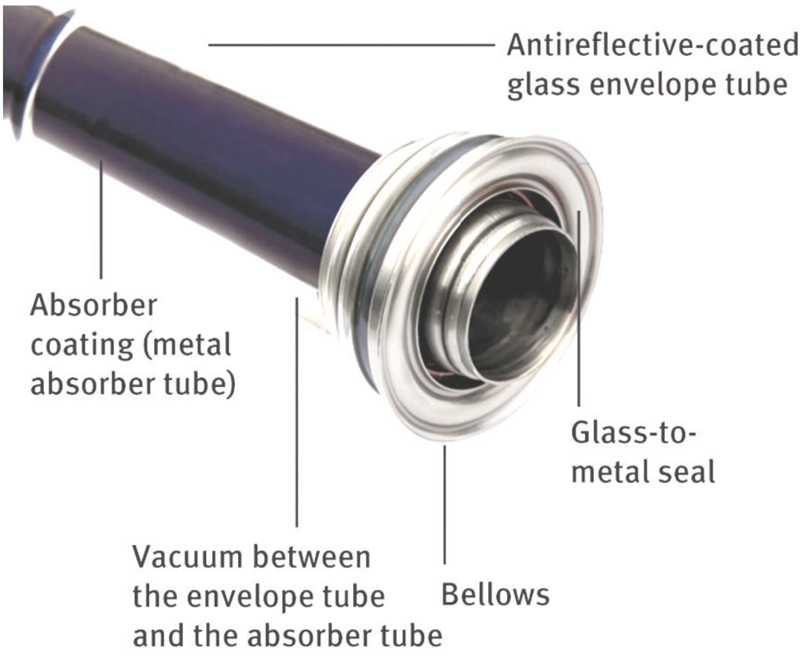

Figure 2. A metal in glass absorber tube manufactured by *Schott AG* [13]

It is not difficult to imagine a dedicated cooking tube of similar design but with a larger diameter. Further improvements in the durability of the outer glass tube may also prove possible. For example, *Schott AG* now produce a glass – ROBAX - with a negligible coefficient of thermal expansion [10] and *Corning* now produce a glass which is flexible instead of brittle [11]. Glass tubing, with a diameter of, say, 180 mm, a coefficient of thermal expansion close to zero, high resistance to surface damage, non-brittle, and with excellent transmissivity across the entire electromagnetic spectrum cannot be far off if sufficient funds were allocated to its development. Meanwhile, a tube cooker with a stainless steel inner tube is already available [12] and further developments in this direction now seem inevitable.

5. CONCLUSIONS

- There is a risk of tube damage while cookers/tubes are in transit. Large consignments of cookers or tubes may be at lower risk because they are handled by cranes, tail-lifts, and fork-lifts. Manually handled parcels are likely to encounter greater risks of being dropped or crushed.

- Merely raising the temperature of an evacuated tube is unlikely to result in failure, as long as thermal gradients are kept to a minimum. New owners need to be advised to reduce thermal gradients to a minimum.

- Steep thermal gradients are likely to result in breakage, and every effort should be made by solar cooks to reduce them. This type of tube should not be pre-heated or left unloaded in the sun. Once the cooking process has begun, no extra food or liquids should be introduced. All foods should be thoroughly thawed before cooking. After cooking, the tube should be allowed to cool slowly in the shade, and washing should not be attempted until it has cooled completely.

- If too much food is introduced to the tube, or if insufficient space is allowed for expansion (e.g. when baked goods rise) the tube may become blocked. Steam and/or expanding air produced during the cooking process may then be unable to escape, and the resulting overpressure may shatter the tube. Users should not be overambitious with the quantities they attempt to cook. Care should also be taken to avoid leaving tubes in the sun while the ends are tightly capped or blocked.

- Tubes with larger capacities (e.g. the ‘Rand’ tube – 3.6 litres) may be unwieldy when full of water while in the vertical position. It is possible that the forces imposed by 3.6 kg of water on the cantilevered inner tube at some angles of inclination are sufficient to induce a tensile fracture. Exact details of this process are still unknown to the authors.

- Field trials like the present study can generate working hypotheses about the vulnerabilities of evacuated tubes, but testing under controlled laboratory conditions will be necessary to provide definitive answers.

- Techniques already exist to construct more durable cooking tubes while maintaining the merits of the present generation of evacuated tubes. The next generation of dedicated cooking tubes could have larger diameters, a cooking compartment of stainless steel, and virtually unbreakable outer glass tubes. Market ready evacuated tube solar cooker designs are only two years old, so further progress in this direction seems inevitable.

6. REFERENCES

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7. AUTHOR AFFILIATIONS

Both authors collaborate in the SLiCKsolarstove initiative, and both are Associate Members of the SCI.

8. DISCLOSURE

The authors have collaborated in the import and sale of SM70 evacuated tube solar cookers in the UK.