MECS-TRIID Project Report (public version)

Delivering eCook at ground level

SOWTech One World Technology

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Executive Summary

Wood based fuel has been the only affordable fuel for cooking for many people for generations and it is not sustainable. Felling of trees for firewood is causing environmental problems including deforestation leading to soil erosion and loss of soil fertility. There are also serious health issues from smoke inhalation. The aim of this project is to design a solar powered eCook stove that is affordable and acceptable to rural communities in Sub-Saharan Africa and especially in Malawi.

The project looked at the current situation in Malawi with regard to cooking practices and reviewed the eCook stoves available at present. The local people in Malawi are aware of the situation regarding the ever diminishing wood supply as reflected in the ever increasing cost of buying wood. They were keen to have solar powered cooking capability and had an input into the design of the eCook stove.

One of the overriding design requirements was that it should be suitable for local manufacture with the minimum of components bought out of country. We are indebted to our Malawian partners, Aquaid Lifeline, for helping us to achieve this.

The initial prototype was designed and built in the UK. At all stages Aquaid Lifeline were consulted as to the availability of materials and to ensure that the proposed designs could be built locally. As research showed that meals were often cooked early morning, before sunrise, or in the evening after sunset, decision was made to use a form of heat storage system. The use of phase change material (PCM) as the heat store was selected after collaboration with California Polytechnic State University (Cal Poly). A vessel suitable for holding the PCM was designed and also an insulated box to house the PCM vessel to prevent heat loss prior to using the eCook stove for cooking.

Two forms of heater were developed, one using ceramic tiles and the second a clay based plate. Resistive wires were used as the form of heating. This required the development of a Power Optimisation Device (POD) to optimise and control the power drawn from the PV panel as this would fluctuate with the intensity of the sun. The POD was also able to prevent the unit from overheating and allowed the provision of a USB socket for mobile phone charging which was a desirable feature as determined in the user-centred design process.

The prototype was tested in the UK and there were a number of design iterations due to situations encountered. One of these was the change to using the heater immersed in an oil bath rather than in the PCM as it was shown that removal of the heater from the solid PCM material was difficult should the heater fail.

In the UK PCM was successfully melted and the heat transferred to the hotplate. The hotplate temperature was at 97°C three hours after the heater had been turned off and was still above 70°C 19 hours later. The prototype was used to cook some potatoes as a trial.

A prototype was built in Malawi using local labour and materials with the exception of the POD and heater which were brought from the UK due to time constraints. The concept and use of the eCook stove was demonstrated to the local people. There was much interest shown in the eCook stove both from a technical point of view and a practical one. Despite it being the rainy season with limited sunshine some of the local ladies were able to use the eCook stove to cook the local staple food, maize flour, and make nsima porridge.

There is still work to be done to make a product that can be used by local people. However there has been much interest shown in it not only by local households but also local sellers of street food and organisations that cook meals on a larger scale to feed children in schools where sometimes that is the only hot meal that they get in a day.

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1. Introduction

1.1 Cooking food is part of what it is to be human. For most people in low income communities wood based fuel is the only current affordable option. Wood fuel has been a sustainable form of energy in these communities for generations. However social changes including population growth, urbanisation, soil degradation and climate change have destabilised the supply and demand balance and there is now widespread recognition that an alternative to wood fuel must be found. Wood fuel is also known to be a serious smoke-derived health hazard. There are numerous secondary impacts of the health issues as well as the impact on soils and ecosystem changes resulting from deforestation.

1.2 Solar power is one of the options for sustainable cooking power in the areas where wood fuel dependency is a problem. To effect the change from wood fuel to solar however is a transition that is challenging. The issues range from making the technical package work in the field and to making it affordable for adoption amongst those who can afford little. The technical package must also be compatible with the social and human context of cooking. The preparation and sharing of food is a very deep seated aspect of every society so any change to what has been a very long-standing arrangement will be difficult to introduce. The business model also needs to support independence, jobs and self sufficiency. The paradigm shift required to change the practise of wood-based cooking will be more acceptable if it can foster community development rather than social inequality and dependency. This means seeking community engagement in the transition including the building of as much of the new infrastructure as possible locally such as the eCook stoves.

1.3 The lead organisation of this project is Sustainable OneWorld Technology CIC. The organisation is a community interest company which generates sustainable technical solutions to development challenges that are ecologically sustainable and to implement these in a way that is equitable and in non-exploitative partnerships with low income communities.

Aims of the project

1.4 The aim of this project is to make cooking with solar energy derived from photovoltaic panels something which can replace cooking on 3-stone open fires.

Objectives of the project

1.5 The first objective was to undertake a study of the target user group's cooking habits, preferences and practices to input into a user-centred design process. This included an understanding of the current cooking and eating habits on 3-stone fires, knowledge of what food are cooked and eaten and when it is needed. The broader social and peer group behaviour issues are also relevant when seeking to change behaviour.

1.6 The aim of the project is only achievable with an affordable product which is also accepted by those who currently cook on 3-stone fires. We seek to design a product which is not imported as a finished product. The objective is to develop a product which is can be assembled locally and which uses the minimum amount of imported components.

2. Methodology

Outline of the concept

2.1 The concept behind the methods used in the project were to establish, by demonstration, the possibility that an eCook stove could be made which uses local materials for manufacture and that it is possible to build and then trial such a device.

2.2 The concept is that solar energy can be used to provide the heat required to cook food. However often the time when the cooking is required is not when the sun is shining. A method of storing the energy until it is required is needed.

2.3 The use of batteries to store electrical energy, such as lead acid, lithium ion or salt batteries was considered and rejected on the basis of cost, availability and environmental impacts. Innovations in this field may change this analysis in the future.

2.4 The concept of thermal storage is a long-standing approach in the western world in appliances such as the “AGA” range cooker and thermal storage is in use as part of home heating systems, eg night storage heaters.

2.5 Phase change materials (PCM) have been shown to be an option for thermal storage eg Sunamp heat batteries.

Research undertaken

2.6 There were a number of research methods during the project.

2.6.1 Desk and internet research was undertaken to establish the extent of the use of eCooking in Africa to date.

2.6.2 A review was undertaken into forms of thermal energy storage available. This was used to make an informed choice as to the most appropriate storage to pursue.

2.6.3 Desk and internet research was used to inform about PCM. This led to exchange of information and ideas with Pete Schwartz and his team at California Polytechnic State University (Cal Poly).

2.6.4 Laboratory research was used to test and trial various methods of producing a low cost heating element that could be easily manufactured in Malawi.

2.6.5 An email survey was undertaken with Angus Gaisford of Aquaid Lifeline in Malawi into the cooking habits of the low income families he is familiar with.

2.6.6 Field research was undertaken as part of the user-centred design process. This was preceded by a consultation with an experienced product anthropologist with professional background in product development. This consultation gave additional insights which were subsequently used. On the field trip to Malawi local people were observed cooking on wood fires and face to face interviews were conducted. The trip also included meeting people who could aid the manufacture process in Malawi.

2.7 This research was used to inform and influence our design of the eCook stove.

2.8 The designs were shared with our Malawi partners prior to the building of a prototype eCook stove to be used for cooking trials in the UK.

3. Implementation

The work conducted

3.1 Initial desk research was performed to see the current state of eCook stoves worldwide but focussing on Africa to ensure that the project was not duplicating work already done. The report can be found in Appendix 1.

3.2 The types of thermal storage solutions were discussed internally and with our specialist consultants. A key operational ambition of our proposal was to find a way to store thermal energy over the course of a day and to make it available to use as needed without the use of batteries for the storing of electricity. Energy storage as electricity is currently too expensive to meet for our ambition of eCook for low income communities. Initial ideas centred around using a solid thermal storage unit such as metal or concrete but calculations showed that the size of the thermal storage needed was too large to be practical and there were also logistical and monetary problems. The MECS team introduced us to the work of Prof. Pete Schwartz of California Polytechnic State University (Cal Poly) who were investigating the use of phase change material (PCM) as a thermal heat store for cooking purposes. Contact was established with the team and there has been a significant exchange of information and ideas. This led to switching our design approach from simply energy storage via thermal mass, such as that found in an AGA cooker, to energy storage in PCM. The existence of PCM was previously known to our team but the range of chemical options and the price points of the materials were not. A review was undertaken and Erythritol was chosen as the PCM to take forward in the prototype. More information is given in Appendix 2.

3.3 A field trip was included as part of the user-centred design process. The trip involved face to face interviews with ladies in rural villages to find out how and when they cooked their meals and what they cooked. The basic concept of the eCook stoves were discussed with them and they were asked for their views on what they would like and what they would be prepared to use. The report of the field trip is given in Appendix 3.

3.4 The main findings from the field trip were:

- wood was becoming more scarce and more expensive and they were therefore receptive to using solar power to cook with even if they had to buy the eCook stove initially.
- meals were cooked up to 3 times a day, early morning, lunchtime and evening, with the main meal in the evening.
- stirring the pot is an important part of the cooking.
- having a phone charger incorporated would be an incentive for buying the eCook stove.
- security of the solar panel was raised as a concern.
- A two-ring cooking capability would be desirable to enable two elements of the meal to be cooked concurrently.

Design of the e cook stove

3.5 The next stage in the project was that of designing the cooker. Details are given in Appendix 4.

3.6 The decision had been made to use PCM. Basic design criteria had then to be chosen. Energy calculations were undertaken to match the engineering of the solar panel to the cooking requirements and the design of the cooker itself (see Appendix 5). One outcome from these calculations was the decision to base the procurement on the output of the solar panel. This panel may generate more power than is needed for a single cooker, but it was established from the user-centred design work, that two cooking stations in one home, two rings in a western context, would be a desirable outcome. Such an arrangement would bring the advantage of being able to cook and prepare two elements of the meal concurrently. For example, the beans/relish can be cooked at the same time as the Nsima. At present only one item is cooked at a time on the fires.

3.7 Samples of Erythritol were procured and some limited heating and cooling/cooking assessments were undertaken.

3.8 There are two methods for converting electrical energy to heat which have been used in prior work for the heating of PV or electrically powered cookers; diodes and resistive wire. After a review of these two options the resistive wire approach was determined to be our preference. There were a number of factors which led to this decision, but the primary reason was cost when units are being built at scale. See Appendix 6.

3.9 The resistive wire approach needs an electrical controller to undertake a number of functions; to deliver the correct voltage of electrical power, to be able to control the heat input and cut it off when it reaches a preset temperature. This is to ensure that the heating element does not overheat and burn out and that the PCM is not overheated. An electrical controller also gives us the option to build in a 5v supply for the charging of phones; a feature which is considered highly desirable by the target market. We have coined the term Power Optimisation Device (POD) for this controller. See Appendix 5 for details of the POD.

3.10 Electrical power calculations have been done based on the performance of a degraded PV panel. Power output will drop with time due to the age of a PV unit. In dusty conditions the output is also compromised. These factors have been taken in consideration before determining the power required. The power required to melt the PCM has been estimated but this is subject to the insulation performance of the whole structure.

3.11 The shape and size of eCook stove was reviewed. One particular balance considered at length has been the compromise between the bulk and weight of the insulated lid against the user requirements for ease of handling. Whilst a two plate cooker is ultimately considered the most desirable design it was felt to be better to concentrate on a single unit until the engineering system has been proven to work.

3.12 The functional requirements of the eCook stove were continually reviewed. These requirements included:

- The location of eCook stove either inside or outside the house.
- The security issues of having a solar panel outside.
- The types and sizes of pans regularly available and used by households.
- The type of food and the volume of food cooked by a typical sized household.
- The desire for phone charging.

3.13 There were also theoretical calculations and decisions that had to be made to answer such questions as:

- Which PCM was the most desirable to use?
- How much heat is needed and therefore how much PCM is required to produce that heat?
- What is the temperature of the heat released during the phase change cycle?
- How big does the structure need to be?
- How much power can be obtained from a standard PV panel of which size?
- What output is need for the heater to convert PV to heat?
- How long can the PCM hold the heat for?

When finding the solutions to these questions the situation of the final end user had to be taken into account at all times. The solution had to be practical for use by people living in rural Africa. Details of these decisions and the reasons for making them are given in Appendix 4.

3.14 Once the basic design had been agreed by the UK team construction level drawings for the components of the system were sent to our partners in Malawi. We wished to ensure that supported local manufacture was a realistic option. For example, we reviewed the solar panels which are available in Malawi to ensure we incorporate a panel which is comparable into our prototype design.

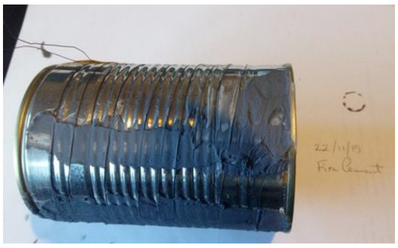
Prototype building

3.15 Once the basic plans had been approved by our Malawian partners the components of a prototype eCook stove were built and tested.

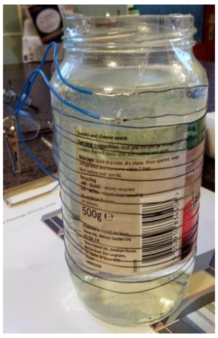
3.16 As we had elected to use resistive wires as the form of heating we needed to build a device which could optimise and control the power drawn from the PV panel. This is needed to match the power taken with the fluctuating power generated by the differing light conditions. This device also needs to be able to prevent the unit from overheating. A prototype electrical controller was designed and built. The unit was tested with a solar panel. This controller was constructed on prototype board for testing. The initial testing was successful. See

Appendix 5. Companies were then approached to see the viability of producing the board in volume on printed circuit boards. The quotes were at a favourable price. A small number of boards were procured for testing purposes. A solar panel simulator was built to continue with testing due to the lack of solar energy available in the UK at this time of year. The testing of the electrical controller has been successful and it was able to switch the heat input off and on. It has also been possible to include the transformers and a USB socket needed to provide phone charging capability.

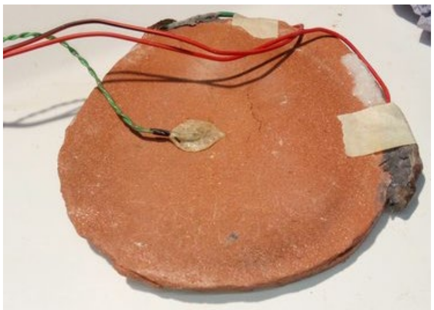
3.17 The heater was the next component to be built. The energy from the solar panel needs to be transferred into the eCook stove where it can heat the PCM to melt it. The heater had to fulfil a number of criteria. It had to be robust to survive immersion in the PCM but it also had to be simple enough to be manufactured by non specialists in locally available materials in Malawi. A number of options were trialled. Deatils are given in Appendix 6.



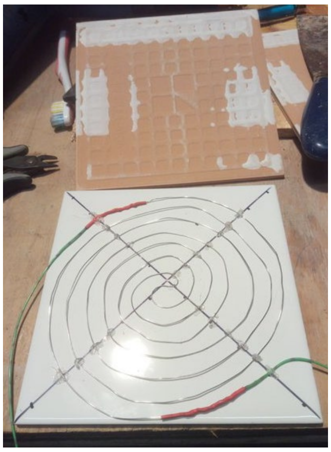
3.18 The first prototype was based on a metal can (to act as thermal transfer) but it was found to be unreliable and encouraged the short circuiting of the resistive wire. See Appendix 6.2.



3.19 The second prototype was based on a glass jar and this has proved effective. These prototypes were able to bring water in the jar to 90°C from 13°C in around 16 mins. We established that used glass jam jars are available in Malawi waste streams. See Appendix 6.3.



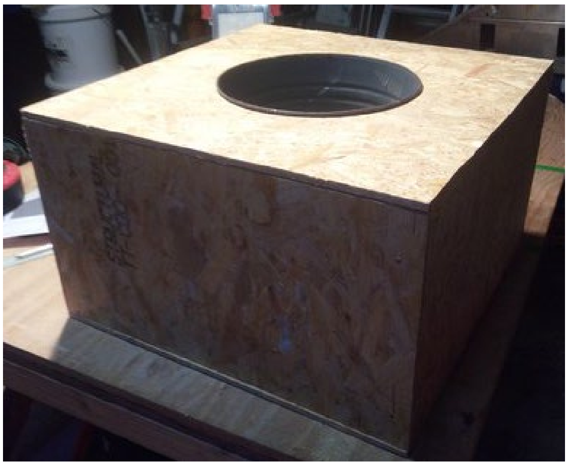
3.20 A third prototype was built by embedding the resistive wires in a clay disc with thermistor for connection to the electrical controller. This was then fired at a local pottery to simulate the available materials and conditions in Malawi. Unfortunately when the disc was fired the clay shrank exposing the bare wires which were burnt in the firing process. An alternative approach was to make a thicker clay disc with preformed grooves which is fired before the wires are laid in the grooves. This is then covered with a second disc before refiring. See Appendix 6.4B.



3.21 A fourth prototype was made using shop bought ceramic tiles in place of the clay discs. Before trying this approach our Malawian partner confirmed that these tiles were available in Malawi at a realistic cost. The heating wires were cemented between two tiles using fire resistant mortar. This prototype has proved to be the most promising design. See Appendix 6.4A.

3.22 One important aspect of the design was the requirement to insulate the vessel containing the PCM. During the day energy will be put into the PCM from the solar panel causing the PCM to melt. This needs to be kept in the liquid phase until it is required for cooking when the change from liquid to solid will release the heat to be used for cooking. The PCM vessel therefore needs to be insulated to retain all the heat. The thermal insulation properties of various materials were researched. The best insulation materials are polyurethane based but these are not practical for an eCook stove designed for building and use in Africa. The thermal insulation properties of a material is also proportional to the amount used. The thicker the insulating layer the more it will insulate However there are practical implications to this as the cook stove cannot be so bulky that it is difficult to reach the cooking surface and any pans on it.

3.23 The prototype eCook stove was fabricated as a hollow wooden box of dimensions 60 x 60 x 35 cm. Having checked that aluminium cooking foil is available in Malawi, the inside of the box was foil lined to reflect the heat back into the box. The inside of the box can then be packed with locally available materials. Options that have been discussed with our Malawian partners include rice husks and maize wastes. These materials are not readily available in the UK so the prototype has been packed with loft insulating material. See Appendix 4 for details.



3.24 The container for the PCM needs to be robust to withstand the constant heating and cooling down and also water tight. In Malawi it is expected that these will be made by local metal workers who are experienced in making cooking pans. For the UK prototype we are using a manufactured metal waste paper bin as the container for the PCM vessel as it is our cheapest and most readily available option.

3.25 Another important part of the eCook stove is the design of the hotplate that will be used for cooking on. There were a number of issues that needed to be overcome. The first one was the material that the hotplate would be made of. It needed to be able to transfer the heat efficiently to the cooking pot and therefore a metal plate has been chosen as the best conductor. In the prototype an old frying pan is being used for this purpose. However, we have also experimented with metal and sand as a metal pan to metal hotplate only works well if both are flat. In trials if they were not both flat then a layer of sand on the hotplate improved heat transfer significantly.

3.26 Another key technical challenge to be overcome was how to transfer the heat from the PCM to the hotplate. When the PCM melts and solidifies it expands and contracts in volume and therefore having the hotplate “floating” in the PCM is not viable. However leaving an air space creates an insulating layer between the PCM and the hotplate. The PCM can also be self insulating when the temperature drops and the PCM solidifies. This will always be the surface nearest to the hotplate when the cooking pan is drawing heat out. The cooling will be from the top layer of PCM leading to this top layer solidify first in much the same way as ice forms on the top of a pond. There is therefore a need to build a structure which can transfer heat from all layers of the PCM to the hotplate. See Appendix 4 for more details.

3.27 Metal bolts were added to PCM and whilst they did transfer heat from one area of the PCM to another, they appeared to have little impact on the overall heat distribution.

3.28 A second trial was the addition of stones into the PCM to conduct the heat through the material. In the first trial the addition did seem to improve the heat distribution but in the second trial the results were more ambiguous.

3.29 In a third trial sand was added as a heat conductor. Whilst the mixture did work, the overall amount of sand which was incorporated was too high in proportion to the amount of PCM to be a realistic option for both heat transfer and hotplate. The mix was approximately 5 parts sand to 1 part PCM.

3.30 A “tower” of ceramic tiles was built above the ceramic tile heater. The tiles were spot cemented together using fire resistant mortar. This allowed the PCM to flow between the tiles improving the heat flow but the top of the tower was above the PCM and the air space between the tiles acted as an insulator. This idea has not been pursued further at the current time but it has not been discarded completely.

3.31 The best material for the heat transfer is a metal. The metal used has to be readily available in Malawi. Empty food tins were used to build towers between the heating plate and the cooking hotplate. The tins had holes punched into them to allow the PCM to flow into and out of them. However the structure was unstable as the tins did not sit flat and were slightly different in height to each other.

3.32 The next prototype for the support of the hotplate and the transfer of heat was a combination of ideas. Three pillars were made using empty food tins at the base. These had three copper pipes placed in each tin and the tubes held in place by gravel. The hotplate was then placed onto the copper tubes. The tins were perforated to allow the PCM to flow into them. This method has shown heat being conducted to the hotplate over many hours. However we consider that this aspect of the design can be significantly improved.

3.33 Another limitation of the hotplate approach is that most cooking pans do not have flat bottoms. They warp with use especially when used on wood fires. For the most efficient heat transfer from the cooking hotplate to the cooking pan the greatest area of metal must be touching metal. The use of sand as a heat transfer medium may be an option going forward.

Prototype heating trials

3.34 The first trials undertaken were to establish that the prototype cook stove could heat the hotplate to a temperature suitable for cooking on. The prototype was built but only partially filled with PCM. The solar panel simulator was used to provide the initial energy. This was fed into the POD. Indicator lights showed that the current was flowing and a second indicator light showed that there was power to the USB port. The USB port was used to charge a mobile phone.

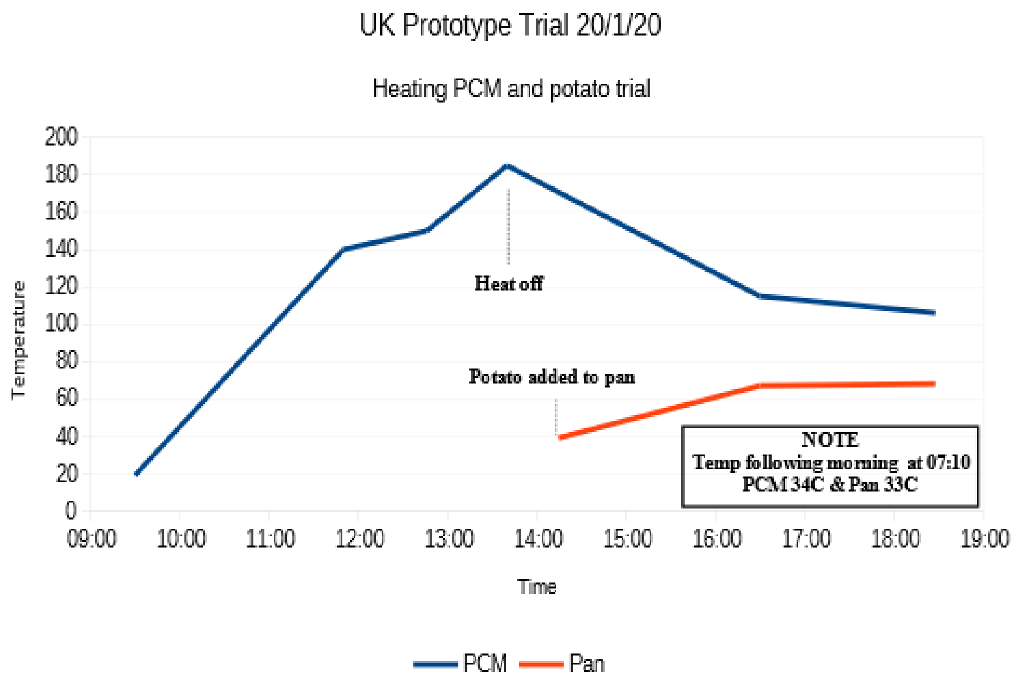
3.35 The clay disc was used as the heater as it had an embedded thermistor connected to the POD. This meant that the heating could be controlled. The POD is built so that at a set temperature the energy flow is reduced and eventually turns off the heater to prevent the PCM overheating and "boiling off".

3.36 The power supplied to the heater was sufficient to fully melt the PCM. The heat successfully transferred to the hotplate. The heater was turned off and 3 hours later the hotplate was at 97°C and the temperature of the PCM was 117°C. The cook stove was left in an unheated workshop overnight and after 19 hours the temperature of the hotplate was still higher that 70°C.

3.37 There is a temperature difference between the melted PCM and the hotplate. We expect this to be overcome by the addition of more PCM and a better heat transfer device between the PCM and the hotplate.

3.38 There had to be a rethink in the design as a failure of the heater showed up a flaw in the design. With the heater unable to operate it could not melt the PCM and we had difficulty in retrieving it from the solid PCM. We therefore looked at ways of putting the heater outside of the PCM vessel and have been using the heater in an oil bath which surrounds the PCM vessel.

3.39 The eCook stove was trialled using potatoes in a pan. There was a failure of the heater plate during the trial but the temperature achieved before the failure was sufficient to cook the potatoes overnight.



3.40 A trial was also done using maize flour. Although the temperature obtained in the pan was insufficient to boil the water flour mix it was hot enough to denature the flour and

produce a solid food stuff similar to Malawian nsima.

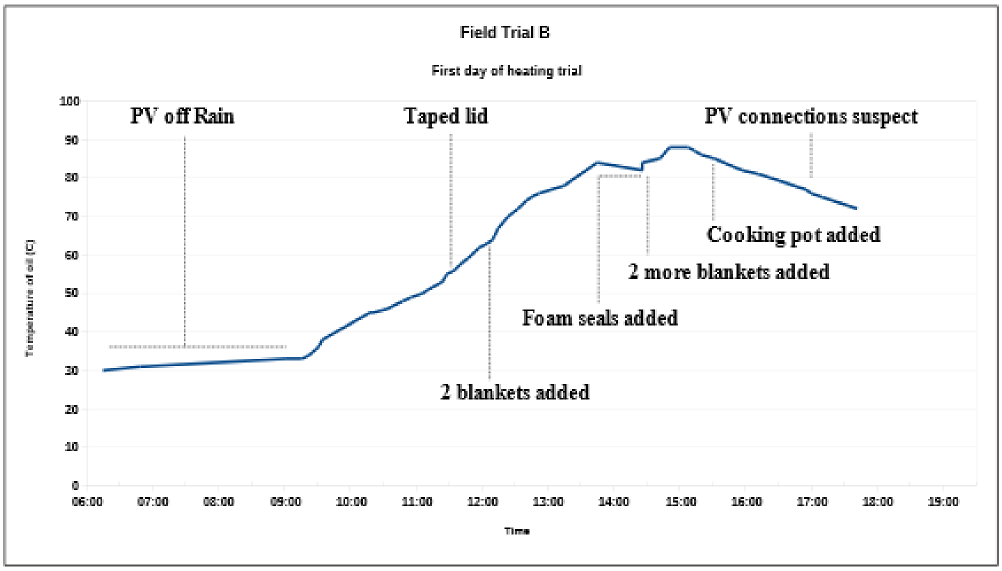
3.41 We were able to do a heating trial using a clay heater plate connected directly to a solar panel. The trial took place outside on a cold but sunny February afternoon. We were able to heat up water from 4°C to 60°C in 50 mins. At that point the sun went in and we were unable to continue the trial.

Malawi prototype trials

3.42 Production drawings of the eCook stove components had been previously sent to our partners in Malawi and they had arranged for them to be made locally. John Mullett went out to Malawi in February 2020 to train on the assembly of the eCook stove and to trial it. The details of his visit are given in Appendix 7.

3.43 At the time of the visit it was the rainy season in Malawi and most days were overcast with little or no sun. The prototype was assembled and the functionality of the components tested. The temperature of the oil bath reached 73°C but the weather conditions prevented any further temperature rise.

3.44 Full trials were commenced on the second day. It was shown that the insulation was inadequate as there was considerable heat loss from the stove. Further insulation in the form of blankets and foam tape was procured and this improved the heating potential. A mix of water and maize flour was placed in the pan on the eCook stove. There was some thickening of the maize flour achieved.



3.45 It was found that there was a large temperature differential between the oil temperature and the cooking pot temperature and it was concluded that the PCM was acting as an insulating layer. The decision was taken to transpose the oil and the PCM so that the oil was in direct contact with the heat transfer rods. This did achieve a thickened nsima paste but over too long a time to be acceptable. It also showed that the insulation was still insufficient.

3.46 Trials were performed using the heater as a hotplate outside of the insulated cook stove. Water was heated and when at a suitable temperature a local lady used the solar powered hot plate to cook nsima porridge.

3.47 Time was also spent, when in Malawi, explaining to local people about the concept of the eCook stove and how it could be built and how it worked. See Appendix 8 – Dissemination for more details.

The project findings

3.48 The findings of the project have been divided into three sections: local buildability, local cooking interest and technical developments.

Local buildability

3.49 A key objective of the project was to devise an eCook Stove that could be built by a local business with minimal imports. This has been successful. The main components of a prototype eCook stove were built by local people in Malawi. It was then assembled by the local people under the guidance of John Mullett who supplied the POD and heater plates.

3.50 The POD and heater plates were supplied by SOWTech because of the time restraints of the field trip visit. As explained below and in Appendix 5 the POD has been developed so that it can be assembled locally. The heater plates have also been developed, in collaboration with our Malawian partners, with components that can be readily sourced in Malawi enabling the heaters to to built locally.

Local cooking interest

3.51 There has been a lot of local interest in the eCook stove. We were able to use the hotplate connected to the PV panel to cook maize flour to produce Nsima porridge. We were also able to cook Nsima using the slow cook approach but the length of time this took was too long for practical use at present due to the lack of sunshine.

3.52 The use of the hotplate, without the heat storage PCM element, can be a way to use the eCook stove in the presence of sunshine. There was also interest in using this approach to heat oil to cook street food such as mandasi. Mandasi are produced by local sole traders to sell in markets. They cook on 3 stone fires using wood as the fuel at present..

3.53 There is also a lot of interest in the eCook stove development by those organisations that prepare meals on a larger scale to feed school children. Being able to use solar power rather than wood would save both in cost and deforestation and potentially allow more meals to be provided.

Technical developments

3.54 We have been able to demonstrate that the PCM, Erythritol, can be melted using the power from a solar panel. This PCM can retain the heat over a number of hours and be used to cook food. The temperature differential between the temperature of the PCM and the temperature of the hot plate has shown that the eCook stove can be used to “slow cook” food. This will allow food to be cooked over a longer period of time and disconnect the cooking time from the presence of sunshine.

3.55 One major technical development was the design and production of the Power Optimisation Device (POD). We have developed a device that will regulate the power from the solar panel that is low cost and which is fabricated so that it could be made, and repaired, locally using readily available tools with minimal training.

3.56 Overall our findings are that there is much interest in the eCook stove and that, although there are still some technical problems to overcome, we have made good progress and have developed a product with potential to become an eCook stove that can be used in rural Africa to alleviate some of the issues caused by the use of wood as a cooking fuel.

Limitations of the innovation/approach/design/system

3.57 The limitations of our work on this project can be summarised as follows:

3.58 The use of solar power to capture heat energy only works well during periods of strong sunshine. An alternative of secondary cooking capability will still be required. Undertaking our field testing during the wet season highlighted this challenge.

3.59 The food eaten by the those with the lowest income is cooked using high intensity heat (fire). The cooking procedures and recipes are based on this type of heat. Whilst our PCM stored heat was released at 118°C we were not able to transfer this temperature to the cooking pan in the work undertaken to date. The cooking pan in the eCook stove did not achieve boiling temperatures and as this is part of the "usual" way of cooking this is a limitation. Further work on the choice of PCM and the hotplate design should overcome these limitations.

3.60 We were able to demonstrate heat sufficient to slow cook most foods but this form of cooking will require new recipes/approaches to cooking.

3.61 Achieving a paradigm shift in wood fuel use may be easier to achieve by provision of an alternative or supplementary fuel for cooking enterprises that feed many. These enterprises know they have a problem with wood fuel and are prepared to work towards alternatives. However achieving this may not be considered the best approach to effecting alternative cooking for the vast majority. Having said that, home cooking is not how around a third of all Malawi children get their hot meal.

3.62 The stored heat battery using PCM materials will be easier to demonstrate for cooking porridge in bulk cooking.

3.63 One of the limitations of the trials work undertaken is that direct heating and hotplates were only considered towards the end of the project. These approaches show promise and the limited work on these ideas was a limitation.

3.64 The use of a PCM has been shown to work. A limitation is the local availability of the material. The materials are however mass produced and there is no technical reason why local production of PCM could not be supported if demand was demonstrated. However it is a challenge for early trials.

3.65 Whilst local production of the electrical heaters and POD's is possible, there is a need to invest in training and capacity building.

4. Practical applications of the concept to the national cooking energy system (including costs)

4.1 A number of practical applications have come to light as a consequence of our work on this project. They are not outcomes that we would have been expected before we undertook the study and especially the fieldwork in Malawi. The applications fall into two categories, those which do involve heat storage and those which do not.

Direct heating

4.2 One of the outcomes is the concept of the PV powered hotplate. This would be a flat, probably metal hotplate with a resistive heater attached and a PV panel which powers the hotplate via our POD. This product could be made now given the expertise developed to date.

4.3 The application for the hotplate would be as a unit which could boil water in direct sunlight. This is a challenging task for stored heat at this time, but simple enough if undertaken with direct sunlight. African beans are a key protein source for our target beneficiaries but they require boiling to denature the toxins. The boiling time required is limited, so passing beans onto a “slow cooker” for the balance of cooking would be realistic.

4.4 A second direct heating option which would be quick to develop would be a direct PV powered deep fat fryer. Frying food such as mandasi (donuts) is a way in which some entrepreneurs make a living. Many street food vendors also use frying as a means to cook their offerings.

4.5 To produce such a unit would require a few small changes to the apparatus already developed so that the oil could be taken to 190°C. The system would comprise a PV panel, POD and a heater. The cooker itself could be manufactured from steel or concrete.

4.6 The use of a deep fat fryer would never be mainstream cooking for the poor, but it could be a useful demonstration unit to introduce and familiarise the community to the concept of PV cooking. There is however a real market for this style of cooking of value added products. Given that such cooking is undertaken by those who generate cash it could mean that they would have the resources to buy such a cooker. Obviously if the weather did not support PV cooking then the traditional stove could be used as an alternative at these times.

Cooking with stored heat

4.7 The challenge of cooking the food consumed by the poorest using stored heat is difficult when boiling the food is the norm. Slow cooking and stews are not available to the low income on a regular basis. However the research did indicate a possible approach that could have merit for large scale cooking for the poor. As discussed elsewhere in this report, there are charities who give thousands of children the only hot meal they get. Mary’s Meals is one such organisation. This organisation has a daily challenge to find the wood necessary to cook these meals. Their ladies start the cooking process at around 3am so that the porridge is ready for the children before they start school. The charity used to supply the wood fuel for cooking in most locations but due to the challenge of supplying the wood, the local population now has to supply their own wood. Only in urban areas does the charity provide some fuel in the form of bamboo briquettes but the supply is erratic and not available at scale. The scale of the cooking undertaken by this organisation is very significant. They feed over 860,000 children in Malawi every school day. This equates to over 2,000 pots of food which is more than 250,000 litres of porridge and this is for only 30% of primary school aged children.

4.8 The way in which we could see the eCook stove work being applied is to use the technology we have developed to provide hot water to cook with. It would involve a solar powered heat store or battery, filled with PCM, which is charged during the day. The heat battery is insulated and retains its heat overnight. Hot water is provided from the heat battery at the commencement of cooking. The firewood consumption would be dramatically reduced as the water heating would be from approx 90°C to 100°C rather than 20°C to 100°C. This would save raising the temperature of the liquids by 70°C. Although this would not replace the wood based cooking it would reduce it considerably and provide other benefits such as reduced cooking time. The organisation would be capable of rolling out any new technology across multiple locations as they have a centralised and standardised system.

4.9 The same provision of hot water to prime the cooking process could be relevant also to other cooking applications too.

4.10 The other heat storage application is the slow cook oven. Much has been learnt from this project regarding the design and layout of the unit. Further reviews of higher temperature phase change materials could make it easier to get higher hotplate temperatures. Improvement to the insulating materials available is needed and further work on hotplate heat transfer is also required. It is going to take a significant evolution in cooking behaviour to move away from the intense hot cooking processes used when heating with wood/charcoal. This process of change from using hot temperature fuels to longer cooking at lower temperatures will not occur until a suitable cooker is available to the poor. Without it the transition will not even begin.

Costs

4.11 An eCook stove will only be acceptable to people if it is affordable and they can see a cost benefit to having one. Feedback from the user-centred designed process indicated that people were willing to pay for the stove. They could see that the cost could be offset against the price of buying wood and that the price of wood was increasing and availability was decreasing.

4.12 The main cost of the eCook stove is the solar panel. The panel in Malawi cost about 80,000MK (£85). The Malawian government has recently removed taxes from all renewable energy products. The trend is for the cost of such solar panels to reduce.

4.13 The POD was designed so that it did not use modern manufacturing methods requiring complex factory based equipment. It is a double sided printed circuit board which would probably be manufactured in China but the device could be assembled locally.

The component cost of a single POD for the prototype was around £5. When ordered in quantity the cost will reduce to pennies rather than pounds.

4.14 The ceramic tile heater components cost around 50p and the clay heater plates were considerably less than this.

4.15 All other components of the eCook stove including the outer casing and the inner metals vessels were built in country and this experience has shown us that it can be further value engineered with more cost effective raw materials sought.

4.16 We would expect, with economies of scale, that the eCook stove could be manufactured at a cost acceptable to local people whilst giving employment to those fabricating it in country.

5. Next steps

5.1 The project has brought insights into options for moving forward with PV powered cooking. A brief comment will be made on some of these. These are not placed in any particular order of significance.

5.2 **A PV powered hotplate for boiling during the day** - The technology we have developed in the project means that we can build a hotplate for boiling liquids which can be used during sunshine. This would make it possible now to make Nsima or to render African beans safe. These are necessary "boiling" tasks and ones that are currently difficult using the PCM stored heat.

5.3 Develop a micro-enterprise deep fat fryer - Using the technology we already have to produce a deep fat fryer which would work in full sunshine and enable "value added" products such as Mandasi to be made and sold. This unit would require a small change in the temperature regulation sensors to enable the oil to reach deep fat cooking temperatures (c 190°C). However, as the food goes straight into the hot oil temperature transfer to the food is not a problem.

5.4 Both of the above projects are low hanging fruit but have limited scale and reach potential,. However they would represent a good demonstration or "show what can be done" potential.

5.5 **Develop a heat store for the provision of hot water for cooking using PCM** - Mary's Meals, a charity based in Scotland, provides a cooked meal every day for over 30% of all the children in Malawi. The meal comprises of maize and soya porridge locally referred to as likuni phala, fortified with essential vitamins and minerals. The porridge mix and the methods of cooking are standardised throughout the programme. To make the porridge water is heated from ambient (18°C) to around boiling by burning unsustainable wood fuel. If the cooking was started with the water already at approx. 85°C, this would mean a major reduction in the wood fuel requirement. We consider that the PCM heat storage approach could be designed and scaled to provide hot water for cooking without requiring a major change in tools or methods of cooking.

5.6 The project would be to use the PCM heat store to capture sunshine through PV during the day, hold the heat in insulated structures and then, when hot water is required, pass cold water through the heat store to generate hot water for cooking. Hot water would not be stored but simply piped to the cooking pot as and when needed. Using hot water would mean far less wood burned to bring water up to the required temperature and thus effecting an immediate and dramatic wood fuel saving. The production of the meals is standardised and the same approach is also used in 18 other countries so there is the potential to repeat in multiple locations once the technology is proven.

5.7 Evolution of "slow cook" options for low income communities - The existing eCook stove we have built needs further refinement to improve heat transfer into the cooking vessels. We would like to pursue such improvements, perhaps in partnership with other organisations such as Cal Poly. We would like to explore other food groups that might be suited to slow cooking without boiling. The transition away from intense wood heat cooking will probably requires the introduction of slow cook options to these communities. We would like to continue to work towards this objective.

Dissemination Plan

5.8 We have begun to disseminate information about our project to interested parties. See Appendix 8 for further details. SOWTech has a newsletter that is sent to our supporters on an irregular basis. These supporters include personnel from some of the major international charities and NGO's eg Senior Officer for Water, Sanitation, and Hygiene promotion in emergency response in the International Federation of Red Cross and Red Crescent Societies, people we have worked with in the past and other similar minded people. We have sent out two newsletters about the project (they are also on our website sowtech.com/lynns_letters.html). A number of people have responded directly to the newsletter with positive comments.

5.9 We have also shared the plans with our Malawian partners to ensure that the work we are doing in the UK can be easily replicated in Malawi. They have given us feedback as to what materials are available at an affordable cost and what isn't.

5.10 On the field trip to Malawi we discussed the concept and preliminary plans for the eCook stove with the potential customers and users of the stove. The results of the discussions were positive and are reported on elsewhere in this report.

5.11 During the field trip we also had the opportunity to take part in a debate with secondary school children on the impact of new technology. The main focus was on mobile phones and internet as that was the technology they knew about. However the debate was opened up as we introduced the idea of a solar powered eCook stove to them. The concept was well received as they were very aware of the problems of using wood as a fuel both to the environment and to health as well as the supply and cost issues.

5.12 We have been sharing our knowledge and experimental results with the team at Cal Poly under Prof. Pete Schwartz as they are working on a similar project and hope to continue with the collaboration.

5.13 We have also been discussing the concepts of the project with an entrepreneurial company working in Zimbabwe looking towards future expansion of the project.

5.14 We have produced a series of appendices for this report that will be converted into standalone reports on aspects of the project which will be published on our website.

5.15 We are looking to produce of videos suitable for uploading onto YouTube to show the work relating to the eCook stove project.

5.16 Further articles will be written in "Lynn's Letter" to share the information about the project with our distribution list.

5.17 We intend to continue with our talks with organisations such as Aquaid Lifeline and Mary's Meals to pursue the development of suitable eCook stoves with them and disseminate the information about it to them.

6. Conclusion

6.1 The aim of our project was to make cooking with solar energy derived from photovoltaic panels something which can replace cooking on 3-stone open fires.

6.2 Our first objective was to undertake a study of the target user group's cooking habits, preferences and practices to input into a user-centred design process. The results of this study was that there was an appetite for something that could replace wood based fuel as this was becoming more scarce and as a consequence more expensive. The staple food stuff cooked by the poor in rural locations in Malawi has remained unchanged for generations and as such is ideally suited for cooking on an intense heat source. Meals are usually nsima porridge for the children in the morning and then nsima with red beans and relish in the evening.

6.3 Local ladies had input into the user-centred design for the project. They were keen to try an eCook stove. They would like it to have more than one cooking area, not use wood fuel and have the ability to charge a mobile phone. Stirring the pot was an important part of the cooking process but this was not continuous. They wanted the time taken to cook a meal, from first building the fire to serving, to be no longer that it takes now.

6.4 The second objective of the project was to design a product which is not imported as a finished product but which is could be assembled locally and which uses the minimum amount of imported components. This has been a key design criterion throughout the project.

6.5 At all stages of the project we have been in communication with our Malawian partners to ensure that the materials we were planning to use were available in country at an affordable price.

6.6 We have developed an eCook stove that has been shown to be able to be fabricated in Malawi. On the second field trip to Malawi the structural components of an eCook stove were made by the locals and the solar panels bought locally. The Power Optimisation Device, which is required to optimise and control the power drawn from the PV panels, was produced as part of the UK prototype but was designed so that it could be assembled (and be repaired) locally by trained technicians. The heater plate was brought from the UK due to time constraints but it was agreed that they could easily be made locally in country.

6.7 On the field trip to Malawi the eCook stove was assembled and trialled. The local people were enthusiastic about it and keen to learn about it. Some of the local ladies were able to try cooking using it and they made their local staple food, nsima porridge.

6.8 In conclusion we have achieved our objectives of the user centred design process and of working with our Malawian partners to produce an eCook stove that can be built locally with minimum imports. There is still development work to be done to produce a viable product for rural households but there are a number of avenues that we are exploring where the eCook stove so far developed can be used to reduce the amount of fire wood used.

7. Appendix

7.1 We have produced a number of appendices as separate documents that give a more in depth explanation of the work done for this project including photographs and diagrams.

Appendix 1 – Review of ecooking in Sub-Saharan Africa

A review looking at the current methods of cooking in Sub-Saharan Africa with emphasis on the situation in Malawi. The types of eCook stoves that are available at present including those in development as well as those that have been trailed in the field and are in production.

Appendix 2 - Simplified Guide and Review of Phase Change Material

A guide to what Phase Change Materials (PCM) are, how they work, applications of PCM and the reasons for our choice of PCM.

Appendix 3 - Report of initial user-centred design visit to Blantyre area of Malawi, 9-16 October 2019

Report of the visit was made to the Blantyre area of Malawi from 9-16 October 2019 by Lynn McGoff of SOWTech C.I.C. as the initial consultation in the user-centred design process for the developing of an eCook stove using solar pv as the stoves energy source.

Appendix 4 - Design and Construction of the SOWTech UK Prototype eCook Stove

The Appendix gives an account of the design and fabrication of the UK prototype of the eCook stove excluding the heater and the Power Optimisation Device. It includes pictures and diagrams explaining what has been undertaken but the technical text has been kept to a minimum. The account seeks to convey the areas where things have not gone according to plan as well as those that we are pleased to report.

Appendix 5 - Power control, thermodynamics and PV panels SOWTech eCook stove

This appendix covers three topics regarding the cooking power topics relating to the project. There are three discreet topics covering the development and use of a Power Optimisation Device to control and optimise the PV power derived from the PV panel, the thermodynamic calculations which formed the basis of the power requirement, and a brief account of the PV panel specification issues options identified during the procurement of PV in Malawi.

Appendix 6 - Development of PV powered heaters for the eCook stove

The development of the eCook stove required heaters to be developed which would be powered by photovoltaic cells. One of the requirements was that they should be suitable for local manufacture. This appendix summarises the steps taken which led to the development of two types of heater. Both types of heater can be made locally to the end user as they are simple to make and require the minimum of bought in components.

Appendix 7 - Technical Report of the Field Trials of the Malawi Prototype

This appendix gives an account of work undertaken to build a prototype eCook stove in conjunction with partners Aquaid Lifeline, at the children’s village at Namisu, near Blantyre, Malawi. The work was undertaken on 10-14 February 2020.

Appendix 1

Review of eCooking

in Sub-Saharan Africa

Contents

Version control		
Version Number	**Date issued**	**Update information**
V1.0	29/09/2019	First published version
V2.0	8/11/19	Version control table added. SunFire Solution stoves added

Introduction

This review will look at the current methods of cooking in Sub-Saharan Africa with emphasis on the situation in Malawi. The types of eCook stoves that are available at present including those in development as well as those that have been trailing in the field and are in production.

It is envisaged that this document will be an ongoing work as details of new eCook stoves are found.

Current cooking situation

Types of food cooked

Cooking practises in rural and peri-urban Sub-Saharan Africa have changed little in generations. The type of food cooked and the ways of preparation and cooking the food has been passed down from mother to daughter orally with few recipes written down.[1] Over much of Sub-Saharan Africa the staple starch component in the diet is a maize-based porridge called various names including nsima, ugali, pap, obusuma, kimnyet, nshima, Mieliepap, phutu, sadza, kwon etc.[2] It can also be made from sorgham and millett. The cereal grains are boiled in water or milk and stirred to form a thick paste or porridge which is eaten with a meat or vegetable stew. This is an oversimplification as each culture has its own variation.

Cooking the maize porridge requires long slow cooking to break open the cereal grains. According to our research in Malawi the main meal is eaten in the early afternoon. This consists of nsima served with a tomato and onion relish, a meat/fish dish and/or vegetables such as pumpkin leaves, amaranthus or rape/spinach, dry beans that have been slow cooked. The women of the family start to cook this meal in the mid to late morning. The meal is cooked in an aluminium pot (with a capacity of about 5 litres for a family of 8) with a smaller pot for the relish, vegetables and stews.

Current stoves used

The most common and the traditional means of cooking in the poorer areas of Sub-Saharan Africa is on a three stone cook stove. This comprises three level bricks or stones onto which the cooking pot is placed. A fire is lit in the central area of the stones and firewood is continually fed into the fire between the stones. Charcoal is also often used instead of or as well as wood. The wood has to be collected or bought as does the charcoal. This method of cooking is highly inefficient with 85 to 90% of the energy content in the wood lost as heat to the environment outside the cooking pot.[3]

There have been advances in wood stove design. These stoves are designed to be more fuel efficient. One design is a brick/stone built stove covered in local clay. The wood is put in an opening at the front and the pans are put on the top of the stove. The heat from the fire is directed upwards to the pot reducing the heat

1 Stirring the Pot: A History of African Cuisine (Africa in World History), James C. McCann, 2009
2 https://en.wikipedia.org/wiki/Ugali
3 https://www.permaculture.co.uk/articles/cooking-efficiently-3-stone-fires-biomass-hobs

dissipating around the outside of the pot and being lost. The fire is also protected from the weather, especially wind which can blow the heat away from the cooking pot.

Rocket stoves are also proving popular. These stoves are available in a variety of shapes and sizes but they all have an L-shaped combustion chamber that is insulated. This chamber improves the combustion of the wood and channels the hot gases up to the cooking pot.[4] These means that they are more efficient in cooking the food and use significantly less fuel. Tests have shown that it uses 60% less wood fuel to boil 1L of water and simmer it for 30min.[5]

Current status of cooking fuels in Sub-Saharan Africa

According to the FAO in their study "The role of wood energy in Africa"[6] wood fuel accounts for 90-98% of the residential energy consumption in most of Sub-Saharan Africa. This includes both fire wood and charcoal. Overall in the years 1980-1994 the growth rate for firewood fell to 1% per annum but this was off set by a growth rate of 2.8% for charcoal. The population growth rate for the same period was 2.8%. However twice as much wood would be needed in terms of charcoal to meet the same useful energy need as firewood (considering 18% combustion efficiency for charcoal and 13% for firewood).

In Malawi between 1998 and 2014, the percentage of the population that relied on biomass energy actually increased from 94% to greater than 97%. Over this same period, reliance on charcoal nationally increased from 2% in 1998 to 11.3% in 2014, and charcoal surpassed firewood as the largest source of urban household cooking fuel (54.4% in 2014). Charcoal in Malawi is largely an urban fuel used by 11.3% of all households nationally and 54% of urban households in 2015.[7]

Progress of e-cookers in Sub-Saharan Africa

Over the last few years there have been a number of initiatives to reduce the use of wood and charcoal as the primary cooking fuel. The drivers for this change are primarily climate change, deforestation and health concerns. These will not be discussed in detail in this review as they are well documented in both the

4 https://www.cleancookingalliance.org/technology-and-fuels/stoves/
5 https://www.permaculture.co.uk/articles/cooking-efficiently-3-stone-fires-biomass-hobs
6 http://www.fao.org/3/x2740E/x2740e01.htm#TopOfPage
7 Malawi National Charcoal Strategy 2017-2027, Republic of Malawi, The Ministry of Natural Resources, Energy And Mining

scientific and general literature. The use of kerosene and LPG is one area of alternative fuels that is used, with biogas and briquettes also being advocated.[8]

Drivers for change

The three main drivers for change are climate change, deforestation and health issues.

1 Climate change

The primary source of heat for the earth's climate is the sun. This heat is absorbed by the atmosphere which then re-radiates it. Some of this is lost to space whilst the rest is absorbed and re-emitted by the greenhouse gases in the atmosphere. As the level of greenhouse gases increases more heat is trapped causing a rise in the earths temperatures.[9] The burning of wood and charcoal releases carbon dioxide which contributes to the increase in greenhouse gases.

2 Deforestation

There is much talk recently about the burning of woo being carbon neutral.[10] However this is for managed forests where felled trees are replaced with the planting of new trees. These trees will absorb the carbon dioxide released by the burning of the felled wood. However in much of the world, including Sub-Saharan Africa, this is no the case. Trees are being removed and they are not being replaced causing wide-scale deforestation. The Malawi government in their National Charcoal Strategy predict that by 2030 the demand for charcoal and wood will have exceeded the supply of trees.[11] Not only is the source of carbon dioxide absorption being removed but the lack of tree cover is exposing soils to the elements which resulting in soil erosion.

3 Health issues

There are a number of health issues associated with the traditional wood & charcoal stoves. The burning of the wood and charcoal in enclosed spaces put particulates into the air causing respiratory problems. In Malawi, household air pollution is the number one risk factor for burden of disease, and the World Health Organisation reports that more than 50% of premature deaths among children aged under five worldwide are due to pneumonia. The open fires also give rise to increased risk of burns and scalds. The vast majority of hospitalised burn victims in Malawi are under the age of six years old with hot liquid scalds and open flame burns are the most common type of injury.[12]

Energy sources for eCook stoves

There are a number of energy sources suitable for eCook stoves. These include mains electricity, batteries, solar panels and a combination of energy sources. These will be discussed in this section.

8 Guide to cookstove technologies and fuels, Global Alliance for Clean Cookstoves
9 https://royalsociety.org/topics-policy/projects/climate-change-evidence-causes/basics-of-climate-change/
10 https://www.epa.gov/newsreleases/administrator-pruitt-promotes-environmental-stewardship-forestry-leaders-and-students
11 National Charcoal Strategy of Malawi 2017-2027, Republic of Malawi, The Ministry of Natural resources, Energy and Mining
12 https://www.goldstandard.org/projects/cleaner-and-safer-stoves-malawi

1 Mains electricity

In the western world electricity is taken as an essential commodity whereas in Sub-Saharan Africa it is at best a luxury and at worst non-existent. The IEA reported in 2014 that electrification rates vary enormously in Sub-Saharan Africa but in the majority of countries less than 50% of the population have access to electricity. In 20 countries less than 75% of the populations have access to electricity.[13] These percentages increase greatly when the difference between rural and urban electrification is analysed.[14] Overall in Sub-Saharan Africa the urban electrification rate is 59% compared to 16% rural electrification. There is less than 10% rural electrification in 25 countries with Chad, Liberia and South Sudan having 0% rural electrification.

Even in those communities that have mains electricity the stability of the supply is a problem. The IEA reports that for those in Sub-Saharan Africa that do have access to mains electricity the supply is often unreliable, necessitating widespread and costly private use of back-up generators running on diesel or gasoline. Electricity tariffs are, in many cases, among the highest in the world and, outside South Africa, losses in poorly maintained transmission and distribution networks are double the world average.[15]

2 Batteries

Although there have been many advancements in battery technology[16] the use of stand alone batteries to power cook stoves is limited[17]. Batteries are mainly used as a backup for electric stoves when there is disruption in power.[18]

The UK organisation Power-Aid have produced an “all-in-one portable power station” based on a lithium battery with a built in inverter with their Malawian partners although the cost of the unit makes it unaffordable for low income household use[19].

3 Solar power

One thing that Africa has plenty of is sun making solar power a realistic proposition as an alternative power source. Although solar panels exist the trend tends to be for large scale or for mini-grids[20]. Until recently the cost of solar panel has been prohibitively expensive and there has been no easy means to pay for the electricity used. This is all changing. The cost of solar panel is decreasing making them more affordable.. Also countries such as Kenya and more recently Malawi have removed VAT from solar panel. Another barrier to buying solar panels was the need to pay for them up front. In places where payment in instalment has been introduced the uptake has been higher. There has also been an upsurge in mobile phone ownership and usage in Sub-Saharan Africa. This has enabled the introduction of pay-as-you-go for electricity used via the phone[21].

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13 Africa Energy Outlook, International Energy Agency, 2014

14 A review of the behavioural change challenges facing a proposed solar and battery electric cooking concept, Ed Brown and Jon Sumanik-Leary, 2015

15 Africa Energy Outlook, International Energy Agency, 2014

16 Batchelor *et al*., *Energy Research & Social Science* 40 (2018) 257–272,

17 https://globalpressjournal.com/africa/democratic-republic-of-congo/fueled-passion-eliminating-deforestation-congolese-entrepreneur-debuts-battery-powered-cook-stoves/

18 eCook Global Market Assessment Where will the transition take place first? Technical Report · July 2018 DOI: 10.13140/RG.2.2.22612.30082

19 https://www.power-aid.org/power-box

20 https://www.pv-magazine.com/region/sub-saharan-africa/

21 https://www.newyorker.com/magazine/2017/06/26/the-race-to-solar-power-africa

eCook stoves available

There is little information on eCook stoves that are available in Sub-Saharan Africa. In affluent areas of cities and towns western style cookers are used but this report is not looking into such areas but is concentrating on rural and peri-urban areas. Most of the cookers that are available are imported from Asia.

1 Rice cookers/slow cookers

These are bought off the shelf and are normally imported from India or China[22]. The cookers work by the rice and water being added to the pot. The electrical heating element then heats the water to boiling point. The rice absorbs the water and cooks, Once the water is all absorbed the temperature rises and a thermostat trips the switch turning the cooker off. The types available range from the simple ones where the cookers switch of when the rice has absorbed the water to those that can be programmed for automatic cooking and warming of rice, porridge, soup etc. The cooker requires a constant electricity supply and can be used with a backup battery.

2 Pressure cookers

Most work on eCooking appears to have been done with pressure cookers. The advantage of pressure cookers is that the food can cook quicker than when using conventional methods which therefore reduces the energy needed. It is estimated that when cooking for one hour a pressure cooker uses around 25% of the electricity compared to an electric hot plate and over a 4 hour period of cooking it is twice as efficient as a slow cooker, 6 times more efficient than an induction stove and 7 times more efficient than a hot plate[23]. However there is much fear of using pressure cookers; a legacy of tales of them blowing up[24]. They also have to be imported into the country.

3 Electric hobs/hot plate

Electric hob/hotplates normally have space for one or two pans. They use a lot of energy and are not suitable for the long slow cooking that foods such as the maize porridge require. They are more suitable for the cooking of the sauce and relish accompaniments to the maize. These items need to be imported in usually from India or China but are available in retail shops[25].

22 https://www.alibaba.com/catalog/rice-cookers_cid606

23 Beyond fire: How to achieve electric cooking. Couture, T D and Jacobs, D, May 2019

24 K. Chepkurui, Leary, J., Minja, A., Sago, S., Batchelor S., Sawe, E., Brown, E., Leach M., Scott, N., Shuma, J. 2019. "eCook and Gender in Tanzania – March 2019 Final Report." TaTEDO, Loughborough University, University of Surrey & Gamos Ltd. supported by Innovate UK, UK Aid & Gamos Ltd. Available from: https://elstove.com/innovate-reports

25 Preliminary design and analysis of a proposed solar and battery electric cooking concept: costs and pricing, Leach and Oduro, 2015

4 Solar cookers

Solar cookers can be divided into two main categories. Those that use the solar power directly via parabolic solar collectors and those that use photovoltaic (PV) panels.

Parabolic solar cookers

Parabolic solar heaters work by concentrating the heat from the sun onto a small area. They produce very high temperatures and are therefore most suitable for quick cooking methods such as grilling or frying rather than long slow cooking[26]. Another limitation of solar cooking is that the sun is not available 24/7 and therefore the cooking time is restricted especially after sunset and on cloudy days[27]. There have been research done into thermal storage of the heat for use when the sunlight is not available. A means of tracking the sun is also advisable to maximise the energy harvested.

Examples

1. Cambridge Development Initiative at Cambridge University developed a solar oven surrounded by a solar dish that was capable of cooking bread, pizzas etc[28].

2. The Blazing Tube Solar Appliance[29] comprises a triple cavity vacuum tube containing vegetable oil, a trough shaped Compound Parabolic Curve high efficiency reflector and a heat retention cook box. The compound parabolic curve surrounds the vacuum tube which is attached to the cook box. The Blazing Tube Solar Appliances were supplied by UNHCR to refugees in the Goudoubo Refugee Camp in Burkina Faso[30]. Unfortunately other there was initial adoption of the technology the use of the stoves were not continued by the women using them for a number of reason which will be discussed later.

3. The Devos Cooker is another type of solar cooker[31]. This comprises a parabolic concentrator and a table where food can be prepared as well as cooked. This was also trialled by the UNHCR at the Goudoubo Refugee camp but was rejected by the refugees[32]. The reason is not given.

26 https://solarcooking.fandom.com/wiki/Category:Parabolic_solar_cooker_designs
27 https://www.crses.sun.ac.za/files/research/completed-research/eppei/OOCraig.pdf
28 Low cost solar oven – Summary, Keno; https://www.fastcompany.com/3033624/a-cheap-solar-powered-oven-that-bakes-bread-without-pollution
29 http://www.blazingtubesolar.com/
30 https://blogs.lse.ac.uk/internationaldevelopment/2018/01/12/the-broken-promise-of-solar-cooking-the-case-of-goudoubo-refugee-camp/
31 https://solarcooking.fandom.com/wiki/Devos_Solar_Cooker
32 https://blogs.lse.ac.uk/internationaldevelopment/2018/01/12/the-broken-promise-of-solar-cooking-the-case-of-goudoubo-refugee-camp/

4. Indirect solar cookers use the energy gathered by the parabolic concentrator to heat up a heat transfer medium such as oil filled pipes. The advantage so these structures is that the cooking can be done at a distance from the heat collection source[33].

5. GoSun Fusion has a parabolic reflector which concentrates the sun's rays onto a vacuum tube. The vacuum tube also works as an insulator. However to cook a full meal there is also the need to use a 12V battery to power a thermal heating element in the base of the cooking tray. This cook-stoves retails at about $500[34].

6. SunFire Solutions Solar Stove is a plastic injection moulded box with a reflective lining and a clear perspex lid. It can cook and bake stews and soups but it only has a small capacity (one 2 litre and one 4 litre pot). It takes 60mins to boil 1 litre water and can cook a chicken stew for 4 people in 3.5 hours[35]. It costs 850 South Africa Rand.

7. SunFire parabolic solar cookers focus the suns rays on a pot stand which is part of the design. The cooking pan it then put onto the stand to cook the food. It is available in 3 sizes and can boil a 1 litre of water in 12-4 mins depending on size. The sizes range from 1.2-1.8m diameter and cost 1,500-2,500 South African Rand. The parabolic dish needs to be adjusted every 30-40 mins[36].

Photovoltaic cookers

As the cost of solar photovoltatic panels has decreased so the feasibility of using them for cooking has increased. The solar panels can be connected directly to the electric stove to provide the energy required. However like other energy collection methods relying on solar power they are not usually used in isolation and need some method of storing the energy for use when the sun is not shining. There are 2 main methods of doing this – using a battery or Thermal Energy Storage (TES).

33 Solar Energy Storage, Bent Sørensen, published by Academic Press
34 https://www.cnet.com/news/gosun-shows-off-new-solar-oven-at-ces-2019/
35 https://www.sunfire.co.za/product/sun-stove/
36 https://www.sunfire.co.za/product/solar-cookers/

Stand alone PV cookstove

Work has been done in USA and Uganda looking at using PV panels alone to power an eCook stove. They concluded that the insulation was the key to the design. With little or no insulation too much heat was lost to the atmosphere and the required temperatures for cooking could not be reached. The solar energy is converted into electricity which is then used as the energy source. They used the boil and simmer technique for cooking as it is a long slow cook[37]

Battery storage

Until recently the cost of the battery has been a barrier to household use for cooking but recent advances in technology and reduction in cost has made the use more of a reality[38]. The battery can be charged during the sunlit hours and then the stored energy used when required.

5 Other eCook stoves

Battery powered eCook stove

A local entrepreneur in Democratic republic of Congo has produced a battery operated brazier stoves that costs as much as one bag of charcoal and runs on two batteries cheap batteries. It still requires some charcoal but the amount is reduced to about one tenth and can use charcoal dust rather than lump charcoal[39].

Cooking using phase-change material

Calfornia Polytechnic State University (Cal Poly) have devised an eCook stove that uses the phase change material erythritol as a form to store heat. The phase change material is in an insulated box. The material is heated by PV during the day which melts. When the material changes phase back to a solid it releases energy and heat which is then used for cooking[40].

Sun Buckets uses a parabolic reflector in conjunction with phase change material. The “Bucket” containing the phase change material is charged using a parabolic reflector. This is them removed and the bucket taken to the place of cooking. It has an aluminium top cooking surface. The business model that they are looking at is to have a central charging point where householders can swap spent units for fully changed ones[41].

37 Watkins et al, Development Engineering, 2 (2017), 47-52
38 Energy Research & Social Science, 40 (2018), 257-272
39 https://globalpressjournal.com/africa/democratic-republic-of-congo/fueled-passion-eliminating-deforestation-congolese-entrepreneur-debuts-battery-powered-cook-stoves/
40 https://solarcooking.fandom.com/wiki/Category:Photovoltaic_cooker_designs
41 https://solarcooking.fandom.com/wiki/Sun_Buckets

Issues that need to be considered

There are a number of problems and issues that need to be addressed before an eCook stove can be implemented.

Uncertain/unreliable power supply

Before the use of eCook stoves will become widespread in Sub-Saharan Africa there has got to be a reliable power supply. If firewood is still needed as a back up the change to eCooking will be very slow although there is evidence that fuel stacking is becoming more widespread[42].

Cost

The upfront cost of buying an eCookstove is cited as one of the biggest barriers to changing to an eCook stoves[43]. It is estimated that in sub-Saharan Africa only 50% of households pay for fuel with the remaining 50% gather firewood locally for free[44]. The ability to spread the cost by having monthly payment terms and/or microloans will aid the buying of eCook stoves.

Taste

Food taste different when cooked on a wood-fire. Compare the taste of a sausage cooked on a barbecue compared to one cooked on a grill. This will require a change in habit and is not something that can be designed into an eCook stove.

Changing cooking techniques

There may need to be a change in cooking techniques. Rather that cooking as we would a stew on top of a cooker as slow cooker approach may be needed where the food is heated up then left to cook in an insulated box.

Adaptability

Like Western cooking more than one cooking method is often used when preparing a meal. The cook-stove should therefore ideally be able to be used for multiple cooking techniques eg stews, boiling, frying, grilling[33].

Barriers to change in refugee camp

There were also a number of other reasons cited as to why the Blazing Tube Solar Appliances were not adopted by UNHCR to refugees in the Goudoubo Refugee Camp in Burkina Faso[45].

Misleading size

It was assumed that as the solar cook stove was significantly bigger than the rest of the cookstoves in the camp it was able to cook bigger portions. However the pots that fitted it were too small and households with over 5 people had to cook in at least 2 shifts.

42 https://energypedia.info/wiki/Cooking_Fuels

43 Brown and Sumanik-Leary, A review of the behavioural change challenges facing a proposed solar and battery electric cooking concept, 2015, DOI:http://dx.doi.org/10.12774/eod_cr.browneetal

44 Beyond fire: How to achieve electric cooking. Couture, T D and Jacobs, D, May 2019

45 https://blogs.lse.ac.uk/internationaldevelopment/2018/01/12/the-broken-promise-of-solar-cooking-the-case-of-goudoubo-refugee-camp/

Fuel expenses and reliability

Cloudy weather in the refugee camp meant that the solar cookers were not reliable enough for the refugee women to reduce their biomass fuels consumption, and consequently, their expenses. This contrasted with the women who received Liquified Petroleum Gas (LPG) cookstoves and who reduced their biomass dependency by 50 percent.

Climate Change considerations

Most women's worries about environmental issues only concerned deforestation. They acknowledged their firewood collection practices had negative effects to the environment but the y all shared the same perception that solar cookers were less environment-friendly than LPG stoves.

Food taste and preparation time

Women's constant inability to cook food items, such as beans, meat or maize, was a fundamental barrier. Refugee women reported feeling comfortable with solar cooker when cooking rice or sauce, otherwise they reported spending too much time preparing a meal.

Intra-household conflicts

Refugee women spouses' dislike the taste of food prepared with the solar cook-stove which prompted marriage problems and even divorce threats.

Conclusion

There are many types of eCook stove being developed and tested that may be suitable for rural Sub-Saharan Africa. The pros and cons of these need to be examined in conjunction with user requirements to develop an eCook stove that not only works but is also acceptable to the people who will be using it.

Appendix 2

Simplified Guide and Review of

Phase Change Material

Contents

A SIMPLE GUIDE TO PHASE CHANGE MATERIAL

What is "phase change"

The "phase" of a material is that physical state that it is in, ie whether it is a solid, a liquid, or a gas, at a given temperature. Phase change is when it goes from one state to another when the temperature changes, eg when water becomes ice (liquid to solid) or water becomes steam (liquid to gas).

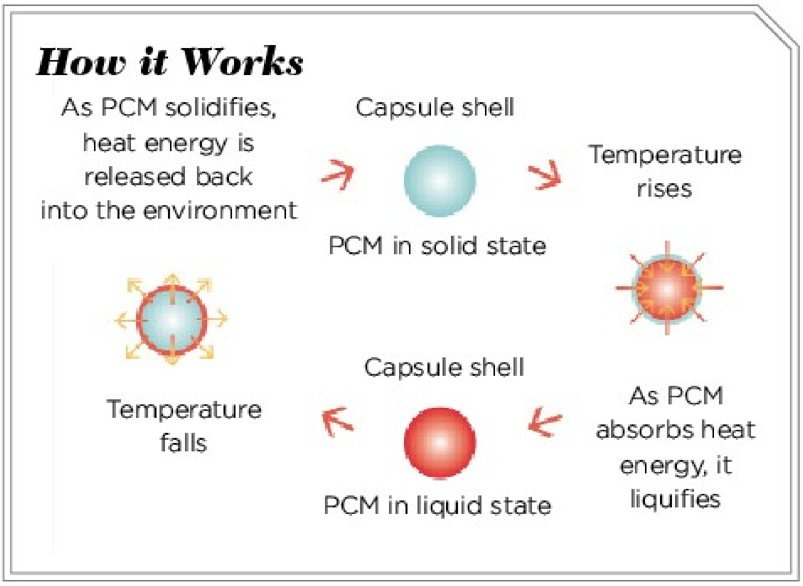
What is a phase change material

Phase change materials (PCMs) are substances which absorb or release large amounts of 'latent' heat when they change in their physical state, ie from solid to liquid and vice versa. This makes them capable of storing heat energy. They also need to be chemically stable and be able to change from on phase to another many times without altering physically or chemically.

How does phase change material work

When a material changes from one physical state to another it either needs energy or it gives off energy. For example water requires energy to transform it into steam. A PCM is normally a solid at ambient temperature. As energy is supplied by heating it up, it absorbs that heat and turns into a liquid ie melts. As the material approaches the melting point it can absorb a large amount of heat at an almost constant temperature until all the material is melted. The material will then retain that heat as long as the temperature remains constant or above the melting point.

When the temperature falls the material will release the stored heat to the surrounding area and will turn back into a solid.



Use of phase change material in an eCook stove

The phase change material will be used as a type of battery to store the energy from the solar panel until it needs to be used for cooking.

During the day the solar panel absorbs the heat from the sun and creates electricity. This electricity is then fed to the PCM in the eCook stove where it heats up the PCM turning it from solid to liquid.

The PCM is held in a sealed vessel which is enclosed in an insulated layer. This insulation ensures that the temperature around the PCM is kept at or above the melting point of the material. When the cook stove needs to be used the lid is taken off the stove and a pan is placed on the stoves hot plate. As the temperature of the pan is colder than the PCM melting point, the PCM starts to solidify, releasing its heat into the pan and its contents and thereby cooking the food.

Review of PCM materials

The use of PCM as heat storage systems are used in a number of different areas. There are also used as cooling solutions too. Example applications are:

- Hand warmers
- Transportation of food
- Drinks cooling
- Transportation of medicines and vaccines
- Water heating
- Waste heat storage
- Building passive cooling
- Heat pumps
- Automotive cooling systems
- Marine refrigeration

PCM can be organic or inorganic compounds and are divided into low-temperature heat storage (less than 120°C), medium-temperature heat storage (120–300°C), and high-temperature heat storage (more than 300°C)[1].

The inorganic PCM are primarily composite salt hydrates[2] whereas the organic PCM are usually hydrocarbons, primarily paraffins, lipids or sugar alcohol[3]

1 Qianjun Mao, Ning Liu, and Li Peng, *Advances in Materials Science and Engineering*, 2018, https://doi.org/10.1155/2018/9410560
2 Murat M.Kenisarin, Renewable and Sustainable Energy Reviews, 14 (3), 2010, https://doi.org/10.1016/j.rser.2009.11.011
3 The 6th International Conference on Applied Energy – ICAE2014, Polyols as phase change materials for low-grade excess heat storage, Saman Nimali Gunasekara, Ruijun Pan, Justin Ningwei Chiu and Viktoria Martin

Wikipedia has a very comprehensive table of the thermophysical properties of phase change materials[4] giving not only the common chemicals but also commercially available PCM.

The table gives melting points of the PCM which enabled the narrowing down of suitable materials on the range that we required. However finding out what PCM materials are being currently used for heat storage in cook stoves does not seem to be published. Sun Bucket use 10kg of PCM which can reach temperatures of 400°C but which PCM they are using is not known apart from it being an inorganic salt.

SOWTech in collaboration with Cal Poly learnt through personal communication that they were using erythritol, a sugar substitute. We therefore chose to use this as it was a medium temperature PCM and, as it was a food stuff, was safe to use and handle and available in bulk quantities at reasonable cost.

4 https://en.wikipedia.org/wiki/Phase-change_material#cite_note-9

SOWTech

Appendix 3

Report of initial user-centred design visit to Blantyre area of Malawi

9-16 October 2019

Contents

Report of initial user-centred design visit to Malawi

Purpose of visit

A visit was made to the Blantyre area of Malawi from 9-16 October 2019 by Lynn McGoff of SOWTech C.I.C. as the initial consultation in the user-centred design process for the developing of an eCook stove using solar pv as the stoves energy source.

The visit was made in conjunction with that of Josie Charter, UK trustee of Aquaid Lifeline who run a number of educational establishments for boarders and day pupils in southern Malawi including Namisu Children's Village. The Children's village was the base for the visit being close to the city of Blantyre but also located in a rural setting.

The objectives of the visit were:

- to observe the current status of cooking in rural Malawi
- to introduce the concept of a solar powered eCook stove to the women in local villages
- to obtain feedback as to what is important for a cook stove
- to investigate the availability of solar panels in Malawi
- to find out about buying behaviour
- to establish if there were any social or cultural issues that could effect the buying of an eCook stove.

Location of visit

The visit was to Namisu, a rural village near Blantyre, in the south of Malawi. Namisu comprises a primary school for boarders and day pupils, Namisu Children's Village run by the UK charity Aquaid Lifeline, and a rural village where the workers at the orphanage live independent from the charity with their families. These workers include kitchen staff, cleaners, maintenance men, farmers/gardeners and other low paid workers as well as teaching staff. There is also a police station and a centre for handicapped people in the village.

The school has around 200 day pupils. The boarders are housed in separate buildings with dormitories for up to 4 children. Each boarding house is home for up to 15 children.

Methodology

A series of in-depth interviews were held with ladies involved with the cooking of meals in different situations in and around the area of Namisu.

These included:

- in the main kitchens at the schools in Namisu and Khombwe
- in the boarding houses in Namisu
- in village houses in Namisu

The interviews were conducted using local interpreters. Open questions were used to provide a framework for discussions that centred around the objectives of the visit where possible.

A practical lesson on the cooking of Nsima was giving by one of the village ladies to show how this staple food stuff is cooked. This was done on an LPG cooker so not as to use anyone's wood supply.

A solar panel supplier in Blantyre had been identified before the visit. An appointment was made and discussions were held with him regarding the cost and availably of panels in Malawi.

In addition to the primary purpose the visit, there was an opportunity to be involved in a debate with secondary school children at Gormani on "The impact of technology on the new generation". The initial debate centred around mobile phones and internet but this was broadened to include their views on the sustainability of wood as a fuel and the use of a solar-powered eCook stove to replace wood and charcoal cook stoves.

Findings

Objective 1 – the current state of cooking in rural Malawi

Current stoves in use

There are a number of stoves in use in various situation.

<u>Large stoves at the day school</u>

The school uses large purpose built rocket stoves. These stoves are large vessels which the cooking pot is lowered into. This sits on a pedestal with a fire at the bottom. This type of stove uses less wood than a conventional fire. They also use large 3 stone fires.

Stoves in the boarding house

These stoves are built to cook meals for around 15 people. They appear to be an *in situ* clay built structure with an L shaped hole. The fire is built inside with a stoke hole to feed wood in and a hole at the top over which the pan sits. These are double stoves so that two things can be cooked at the same time. The stoves are located within a building and when the fire is lit the room is filled with smoke. The walls of the building are blackened with smoke.

Cooking fires in village houses

The village houses use 3-stone cooking fires. These fires are outside of the houses. The pot sits on top of the stones and the wood is fed in between the stones. Long pieces of wood are used with the fire lit in the middle. The wood is then pushed in as the fire burns. While they are cooking they do other chores and come back to the fire about every 20 minutes to look after the fire.

Improved cooking stoves

In the market a different type of stove was being made and sold. These were two pots, one on top of the other, with holes between them. They had moveable supports on the top to hold big and smaller pots. These were for burning charcoal rather than fire wood.

Firewood and charcoal

It appears that firewood is the fuel of choice in rural areas and charcoal in urban ones. In Malawi it is forbidden for motorised vehicles to bring charcoal into the town. It therefore comes in on bicycles for the charcoal ovens in the hillsides. The men travel 70-80km all through the night to bring in the charcoal.

The firewood is bought by the ladies in the village. They walk up to 6km to fetch it and they spend about 500kwacha/day. It was unclear if this was bought everyday or how many meals were cooked on a day's worth of wood.

Last year they were spending 400k/day. This price can go up in the rainy season to 1,000k/day due to a lack of available wood.

The cost of charcoal is about half as much again but it burns for longer.

Meals cooked

There are three main types of food cooked:

Maize flour – this is made into porridge or nsima and is the main staple food

Protein – this is normally red beans (kidney beans) but can also be meat or fish

Relish – this is a vegetable mix of green leaves, Chinese cabbage, cabbage and pumpkin leaves are grown locally and used. Tomatoes and onions can then be added. Tomatoes are also a popular crop locally grown.

The number of meals cooked per day depends upon the circumstances of the people. The ladies interviewed said that they cooked three meals a day, breakfast, lunch and dinner but this did not appear to be the norm. Breakfast is porridge which is just for the children before school. Cooking of the meal starts about 4am and is served at 6am. Lunch is nsima. Cooking starts at 11am and is served at 12noon. Dinner is nsima, beans and relish. Cooking starts at 6pm and, depending on what is being cooked, is served at 7-8.30pm.

It appears to be more normal to have just one meal a day. It might be that the ladies wanted to appear that they ate better than they actually did.

The family size of the people interviewed was 5-8 people. They put the water onto boil for the nsima first and that is the first thing they cook. They then cook the red beans and finally the relish. After finishing cooking, once a day, they put a metal pail of water on to heat up with they use to wash themselves with. They wash clothes in cold water.

In the school the boarders have two meals a day. They have porridge for breakfast and then the main meal of nsima, beans and relish at 3.30pm when school ends. The cooking for this meal starts around 9.30-10am.

The red beans take the longest to cook as they need to boil for around 2 hours.

The time taken to cook the nsima depends on the quantity to be cooked. The meals for the main school takes 75-90mins to cook whereas in the boarding houses it takes 45-50mins and for the families 30-45mins.

Pots used for cooking

There are two types of pots used by the local people. The first is made locally in a scrap metal area and the second is imported from South Africa.

<u>Local pots</u>

The pots are made by hand in an area that appeared to be a scrap yard. A circle of metal is worked first (the sides of the pan). The base of the pan was then added. The pans come in a variety of sizes from small household ones to large ones for institutions but between the makers they appear to be fairly uniform in size. The Children's Village at Namisu uses these locally made pots. They do not have lids but handles can be fitted, either two curved ones or a single one like a saucepan.

<u>Imported pots</u>

These are imported from South Africa and come with handles and a lid. The village ladies use these pots because, although they are more expensive, they last longer (4 years) than the locally made ones which rust and last only 1-2 years.

The pots used in the household were of 2 sizes. The smaller pot was 12 cm high and 22cm diameter giving a volume of approx 4.5 litres. The larger pot was 16cm and approx 30cm diameter giving a volume of 11 litres.

The cost of the bigger imported pot is 7,000k compared to a similar sized local one which would be about 5,000k.

Objective 2 - to introduce the concept of a solar powered eCook stove to the women in local villages

The ladies in the village were familiar with solar power as the children's village uses solar power to pump the water up from the borehole. They got very excited about being able to use it to cook with. They appreciated that they would have to buy the stove initially as opposed to the free 3-stone cooking method but this outlay was preferred to the ongoing expense of having to buy firewood.

Objective 3 - important design features for a cook stove

The input from the local ladies was limited when open questions were asked. It is unclear whether this was due to translation issues or not knowing what sort of information was required. When were closed questions were asked it invoked more discussions.

The time needed to cook the food was one concern to some of the ladies. Although some would be prepared to start cooking earlier there was a preference for the cooking time to be no longer than it is a present. Normal cooking involves using only one pot at a time. If the cook stove could incorporate 2 pots then this would reduce overall cooking time.

Although the kitchens are undercover in separate rooms in the school and boarding houses, the fires are outside of the village houses. The houses are not large enough to accommodate the cook stove so it would have to remain outside. Concern was expressed about the security of the solar panel if left unattended outside of the house.

The cook stove would have to accommodate two sizes of pan. These are normally 10 L and 5 L pans and are used to cook the different parts of the meal.

Objective 4 - the availability of solar panels in Malawi

Discussion with Power-Aid Ltd

Power-Aid Ltd is a UK registered company with offices in Blantyre, Malawi. It is a supplier of solar panels. The company is run by Brett Pallister and his wife Katherine and is a sponsor of the NGO Making Friends Malawi.

The solar panels supplied by Power-Aid Ltd are imported from China and have an aluminium frame and a 2mm toughened glass cover. They are available from 10W to 455W. The panels up to 200W are available as 12V or 18V. Above 200W a 36-38V panel is available.

A 100W solar panel will cost 38,000 K. Recently solar panels have been made VAT exempt in Malawi.

In addition to the solar panel there is a requirement for MC4 waterproof connectors which are 3,500k /pair and aluminium sleeved single core DC cable to run from the panel to the stove. This costs 900k /m.

Power-Aid are interested in setting up a manufacturing company to be able to make the panels locally. The solar cells would still be imported in and they would then be mounted locally possibly in recycled plastic frames.

Ideas for production included

- modular panels so more could be added when needed
- an add-on package to be able to charge mobile phones

- an add-on night package with a battery for powering lighting
- mounting the solar panel frame with legs so that they can be taken indoors for security.

Objective 5 - buying behaviour

Purchasing issues

Any purchasing decision would be made in discussion with their husbands but they thought that their husbands would be in favour of the cook stove as it would be cleaner and healthier.

Saving up to buy something is not an option due to the low wages. The ladies interviewed said that they would be willing to pay up to 80,000k for a solar-powered eCook stove and that they would take out a loan to pay for it.

Objective 6 - social or cultural issues that could affect the buying of an eCook stove.

The ladies in the villages could see the advantage of not using wood. They were aware of the health issues of using wood. They were also aware of the available wood getting scarcer. However their concerns were not about deforestation and the environmental effects but not being able to find/buy wood for cooking and having to use maize stalks and husks which don't burn so well and they would need more of them.

The possible implication of solar power taking longer to cook the food was discussed. Some thought a longer time would be a disadvantage whereas others just aid they would start cooking sooner.

The main concern was the solar panel being stolen and that they would have to move it into the house when there was no one around.

There was a preference to have the cook stoves made locally if possible rather than to import them. The ladies would be interested in being part of an initiative to make them.

Mobile phones

Mobile phones were in evidence everywhere. They are a status symbol. It is mainly the young men that have them but some ladies have them also. They have to take them to a charging station where it cost 100k to charge the phone.

They said that a mobile phone charging unit attached to the solar panel would be a good idea.

Discussion with secondary school children

On a visit to Gormani the secondary school children were debating the impact of technology in the new generation. Primarily this was about mobile phones and the internet. After the main debate I was introduced and I explained what I was in Malawi to do. The discussion was then opened up to include solar-powered cooking. They were all very enthusiastic about the possibility of using solar-power to cook with. They were aware of deforestation and the impact of it.

They discussed the pros and cons of using solar energy.

Pros:

- It would save wood
- it would use a sustainable energy source
- there would be less contamination in the food
- it would be more healthy
- it would be cleaner

Cons:

- the cost of the stoves
- food might taste different
- it might take longer to cook the food

Overall they agreed that using solar to cook with was a good thing.

Results

There is a need and an appetite for a solar-powered cook stove in Sub-Saharan Africa. People are aware of the dwindling wood supplies and are in principal ready to embrace new technology.

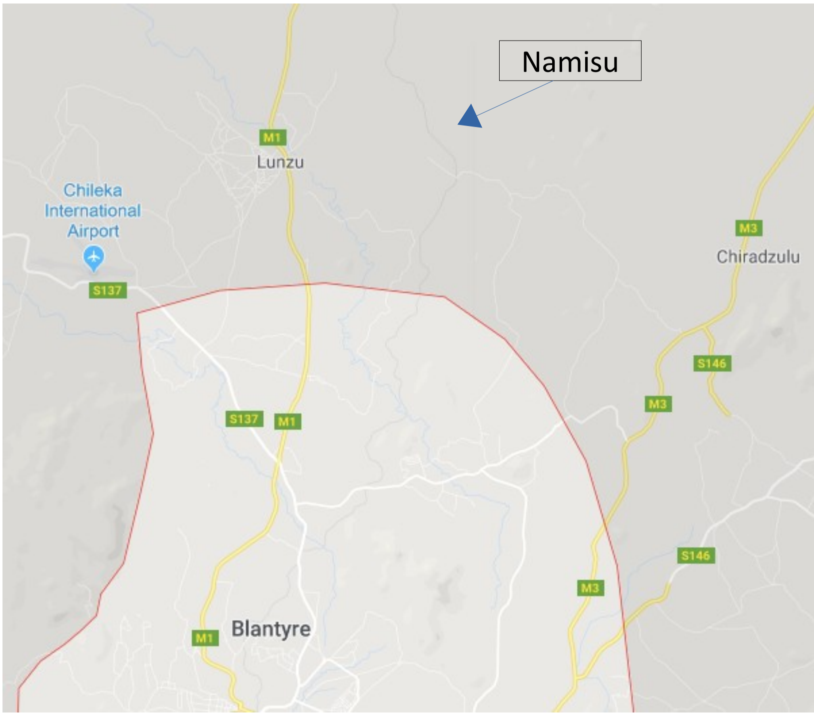
It was difficult to talk about design issues and what the people wanted from their cooking. This was partially due to having to use an interpreter and also asking what was wanted when they had no experience of anything other than wood fires. They did however want something that was cleaner and healthier than wood but were concerned about the security of the panel and any increase in cooking time.

The ladies in the rural village were willing to try the new cook stoves and volunteered to try them out.

Appendix 1 – Area of Malawi surveyed

The ladies interviewed for this report were located in Namisu Children's Village and Namisu village. They are located just outside Lunzu to the north of Blantyre in the Shire Highlands region of southern Malawi.

It is a very rural location accessed by dirt track roads that are soon to be tar-maced. There is no electricity supply. Although pylons have recently been put in to the children's village (but not the people's village) it has not yet been switched on and there is no indication of when this might happen.



Local village

Namisu school

Appendix 2 – Financial considerations

Wages in Malawi (October 2019)

A cleaner at Namisu Children's Village earns 35,000 K/month

A young waiter in Blantyre earns 50,000 K/month

A casual labourer can earn 500 K/day

Example prices of food and household items (October 2019)*

Tea bags (box of 25)	315 K
Maize flour (ready ground) 2 kg	1,060 K
Maize flour (ready ground) 5 kg	2,480 K
Punnet of carrots	386 K
Punnet of green beans	239 K
Tomatoes (1 kg)	1,000 K
Onions (1 kg)	775 K
Bananas (1 kg)	1, 000 K
Milk (1 L)	830 K
Beef mince (1 kg)	3,006 K
Fruit squash (1 L)	595 K
Tin of baked beans (410 g)	795 K
10 L cooking pot (locally made)	5,000 K
10 L cooking pot (South African import)	7,000 K

* Source – local information and https://www.numbeo.com/cost-of-living/country_result.jsp?country=Malawi

Appendix 3 – Recipe for Nsima

For 3 people

1250 ml water

750 ml maize flour

1. Put the water onto heat until bubbles just start to from

2. Slowly add about ¼ -1/3 of the flour with stirring to give a runny constituency

3. Leave to boil, stirring occasionally.

4. For porridge the cooking is stopped at this stage, salt added and the dish served.

5. For nsima boil for 5-10 mins. When it begins to thicken add the rest of the flour stirring vigorously.

6. Beat vigorously using a motion of pulling the nsima to the edge of the pan and scrapping it up the side until the mixture is smooth.

7. Remove from the heat and put portion sized spoonfuls into the serving dish (as would serve scoops of mashed potato). This is then kept until ready to eat.

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Appendix 4

Technical Report

Design and Construction of the

SOWTech UK Prototype eCook Stove

Contents

Preface

Context

The Appendix gives an account of the design and fabrication of the UK prototype of an eCook stove. Other appendices give more details of other technical aspects of the programme. These are as follows:

- *The development of the heating elements of the stoves*
- *The development of the Power Optimisation Device (POD) to manage the power generated by the photovoltaic (PV) panels*
- *The field trials of the Malawi eCook stove prototype*

This work was undertaken as part of a programme called Modern Energy Cooking Services-Technology Research for International Development (MECS-TRIID) managed by Loughborough University and funded by DIFD. The objective of this initiative was to fund research into developing new solutions and approaches which may improve the performance and delivery of modern energy cooking services and which will provide tangible and impactful benefits.

These appendices have been written to provide a full account of the work undertaken so that it may be disseminated and shared. The report includes pictures and diagrams explaining what has been undertaken but the technical text has been kept to a minimum. The account seeks to convey the areas where things have not gone according to plan as well as those that we are pleased to report, so that the full learning experience can be passed on.

The structure of the report

The work will be described as a series of discreet work packages with each package having a section which describes the what problem or challenge is being investigated. We see the path to our objective being achieved through a series of hurdles which needs to be overcome. These “hurdles” could also be referred to as steps on a pathway, or experiments, or research topics or tasks. In this report we will call them TASKS. Following the statement of each task there will be an account of the work undertaken. The work undertaken will contain a brief description of what was done. This is then followed by a short conclusion and comment on the implications arising from that work. The Implications may be conclusions or outcomes from research, further questions to be addressed or decision regarding what to do next.

The aim to make these accounts short and discreet so that they are easier to cross reference and to make it as easy as possible for easier for the reader to follow the evolution of the project.

Task 1:- To identify the design requirements for the eCook stove

Introduction

The task is to interrogate the information obtained from literature research, the user-centred design work of this project and from technical discussion to determine the design parameters for this project.

Work undertaken

Meetings were convened within the project team which were used to establish a consensus regarding the execution of the project.

The work undertaken during the user centred design study were used as the basis of the conclusions. A review of energy storage options was undertaken.

Batteries for electricity

Plus points	Negative points
Familiar technology	Not suitable for deep cycles (full to empty)
Widely distributed	Cost
	Potential theft risk

Thermal storage in steel

Plus points	Negative points
Scrap steel available	Difficult to construct
"AGA Stove" model to emulate	Difficult to standardise
Cost	

Thermal storage in concrete

Plus points	Negative points
Familiar technology	Low heat transfer
Widely distributed	Hard to reach high temperature
`	Carbon footprint of concrete

Thermal storage in Phase Change Material

Plus points	Negative points
Known temperature output	Track record of use limited
Potential for scale	Availability in the short/medium term
Space efficiency of heat storage	
Low health hazard to users	
Positive reports from other projects	

Conclusions

The following summarise the design criteria to be used.

- *Cooking takes place during the day but two meals are prepared when PV power would not be readily available, breakfast and evening meal*
- *The foods that require most cooking resources are Nsima, (made from maize flour) and African beans. Nsima requires hot/usually boiling water and African beans require boiling water for toxin denaturing before being cooked for a significant length of time.*
- *It would be desirable to have two cooking plates so that both Nsima and beans could be prepared at the same time*
- *The possibility to charge mobile phones as part of the cooker facility would be a major asset with respect to market acceptability.*
- *Heat storage will be required to fully meet the objectives as solar energy is not available at the times when cooking is undertaken.*
- *The following table summarises the evaluation energy storage study*

TASK 2:- CHOOSING A PHASE CHANGE MATERIAL

There are many Phase Change Materials and the project needed select one to take forward for prototype trials.

Work undertaken

Phase Change Materials (PCMs) are substances which absorb or release large amounts of 'latent' heat when they change in their physical state, ie from solid to liquid and vice versa. This makes them capable of storing heat energy. They also need to be chemically stable and to be able to change from on phase to another many times without altering physically or chemically.

There are many compounds which meet this definition and they all have different properties. We undertook a review of scientific papers and Internet information which promote the use such materials for energy storage. (See Appendix 2). One option that we considered was high temperature paraffin wax but this was not the final choice.

The review identified a body of work which had been led by Prof Pete Schwartz of California Polytechnic Sate University (Cal Poly). It was not obvious from the reports which PCM was used, but personal contact confirmed that a compound known as Erythritol had been used. We decided that we should build on this work and use the same material in our trials. The Cal Poly work has been documented in You Tube as well as in scientific papers.

Conclusions

Erythritol was chosen as the PCM for the following reasons.

- *The heat emanating from the solidifying material is above the boiling point of water at around 118°C; a temperature which is higher than the boiling point of water.*
- *It is a mass produced product used as a weight control sugar substitute.*
- *It is readily available at a reasonable cost in retail quantities for trials and in bulk quantities if required.*
- *It is produced by fermentation so has the potential for local production.*
- *It is a registered food additive. It is safe to ingest so contamination of food by the PCM during cooking has no health risk implications.*

There is one possible drawback to the use of Erythritol. It is known to have the potential to supercool. That means that it looses its heat and gets colder than its melting point, but it remains liquid. (Wang et al, 2017 Supercooling suppression and thermal behaviour improvement of Erythritol as phase change material for thermal energy storage. Solar energy materials and solar cells, vol 171. Pg 60-71)

The implication of this conclusion was that practical assessment of the risk of supercooling was required to ensure that we could use it as a PCM in the eCook stove.

Task 3:- To determine if Erythritol would supercool in use

Introduction

There are references in the literature that Erythritol can sometimes behave as a supercool liquid. This means that it can cool below its melting point without solidifying. If this were to occur it would prevent the Erythritol from releasing its latent heat so it would not serve as a heat store. The outcome of this task was to find out if this would happen in our application.

Work undertaken

500g of Erythritol was placed in a pan and this was heated on a low heat using a domestic gas ring. The form of the Erythritol was a sugar like crystalline material. The crystals started to melt and form a transparent liquid. This melting then continued to spread through most of the pan.

A handheld infrared temperature probe was used to monitor the temperature in the pan. The pan chosen for the trial was a brown enamel so that it would give a better infra red reflection than a shiny stainless steel surface.

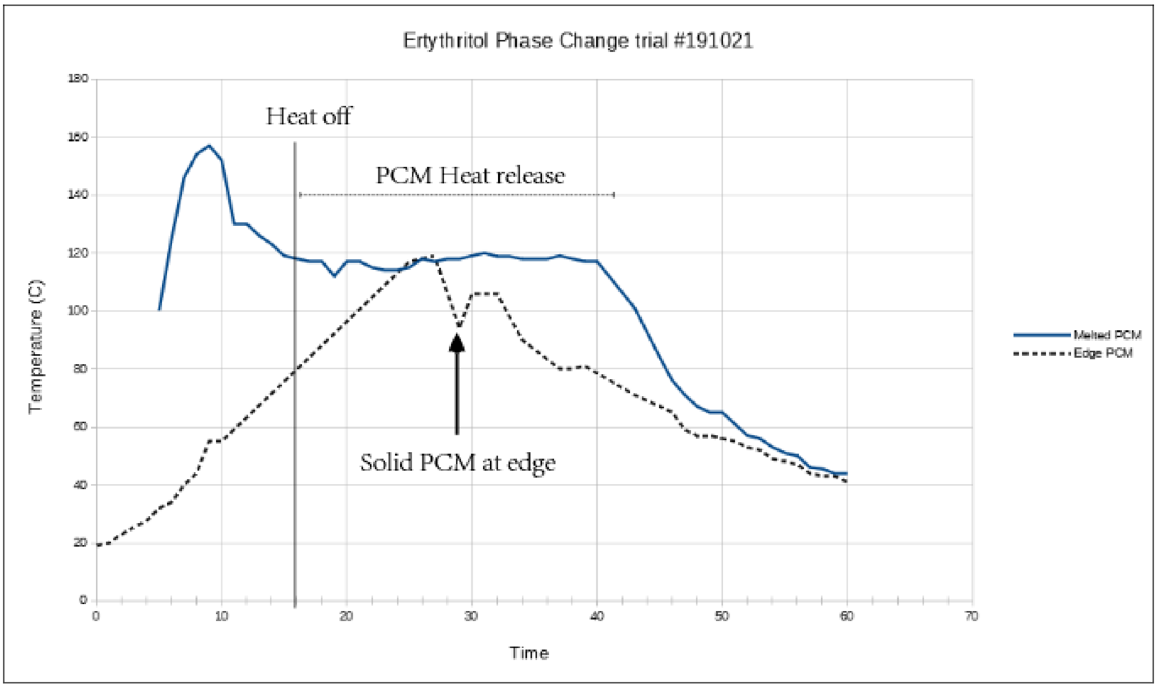
The material started to become hot (160°C) before some of the Erythritol at the edges were molten. The heating was terminated at this point and the liquor monitored as it cooled. The table below shows this trial data. Photo illustrations are also shown.

These temperature data show that during the cooling process there was a steady release of heat over a period of 25 minutes at temp 118°C. The temperature data are shown in the graph below. Photos are also included to show how the PCM melted in some places but not others.

Conclusions

The Erythritol cooled and solidified at a temperature around that of the melting point. There was no evidence of supercooling. The implication of this trials were that it was reasonable to continue to study the use of Erythritol as a PCM.

A further observation from this trial was that the PCM could be hot in one location and that only a centimetre or so away, the temperature could be over 50°C less. Heat transfer within the PCM could be an issue.



Graph showing the PCM change during heating and cooling. The flat line illustrates the period of heat release from the PCM. Photo below shows unmelted PCM alongside melted PCM at 150°C .

Task 4:- To conduct heat from PCM to the hotplate

Introduction

The initial trials showed that heat transfer capability would be a key part of the design of the eCook stove. The following account describes trials to explore how the PCM and the hotplate can be constructed to achieve effective conduction of heat.

Work undertaken

The work comprised of a series of "look see" trials which took place on a domestic induction hob. The following photos illustrate the trials. A brief account is given below

The first trials reproduced the experience of the initial experiments and confirmed the practical implication of the lack of heat conductivity within the PCM itself.

The second trial put two steel bolts from the centre to the edge to assess the use of a bolt to transfer heat from the hot centre to the cooler sides. The impact of the bolt in the unmelted PCM was limited to a few millimeters but it did melt it.

The third trial showed that a pan directly floated in the PCM could boil water. Whilst efficient this approach was provisionally rejected as PCM would be lost when the pan was removed from the eCook stove. In use there would also be a scald risk as the PCM was at 118°C.

The fourth trial used gravel as a support for the pan. Whilst the gravel did serve to ensure that all the PCM melted as heat was being transferred from stone to stone, it did not provide a good contact surface for a hotplate tile or the pan.

The use of sand was the fifth trial and that showed that the pore spaces within the sand were not large enough to allow sufficient PCM into the mix to provide the necessary heating capacity. The use of hot sand as a hotplate surface was interesting but not as a co-mix with the PCM.

Conclusions

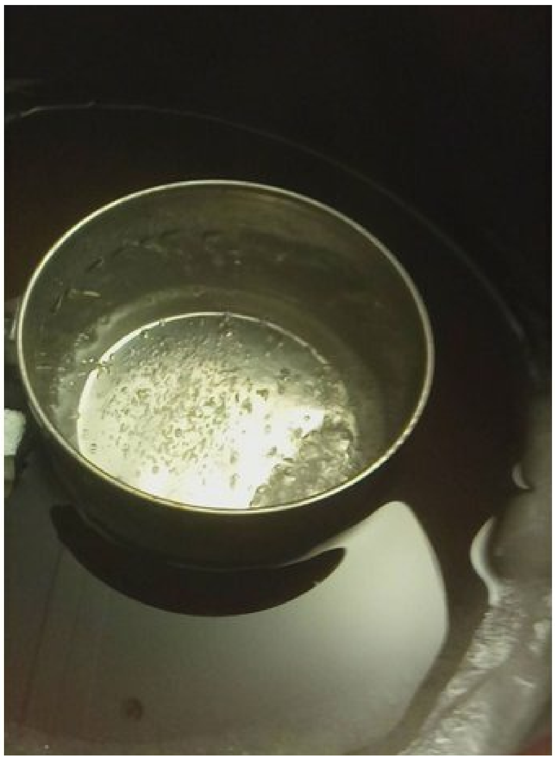
Although none of the approaches gave a clear indication of the best approach, it was decided that metal rods were the most promising approach to heat conduction to the hotplate.

Photo illustrations of Heat to Hotplate trials

#1 PCM melted in middle but not edges

#2 Steel bolts added as heat transfer rods

#3 Bolts had minimal impact to surrounding PCM

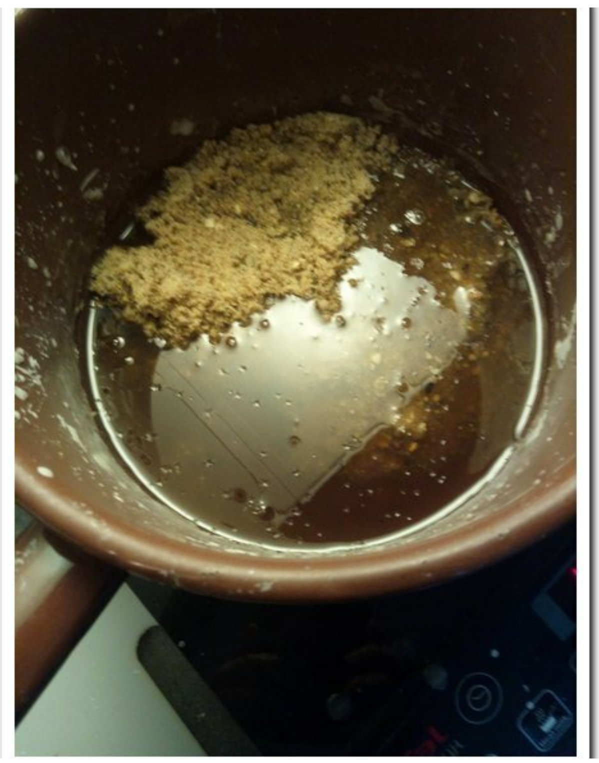


#4 Direct heating of bowl on top of PCM resulted in boiling water

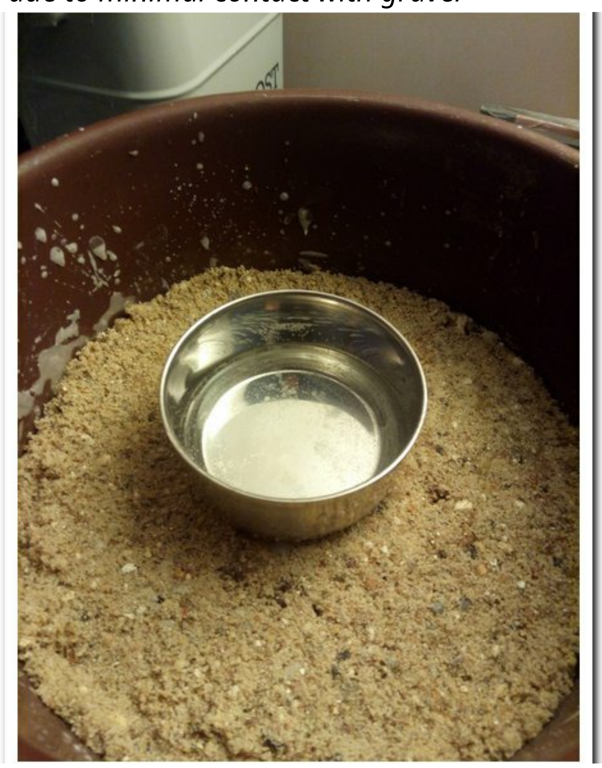
Photo illustrations of Heat to Hotplate trials cont.

#5 Gravel added a support for hotplate

#6 Tile on top of gravel was poor conductor due to minimal contact with gravel



#7 Sharp sand would make better contact with pan but pore spaces reduced PCM too much



#8 Bowl on dry sand with PCM below. Not enough PCM for heating

Task 5:- To assess if towers made of cans can transfer heat

Introduction

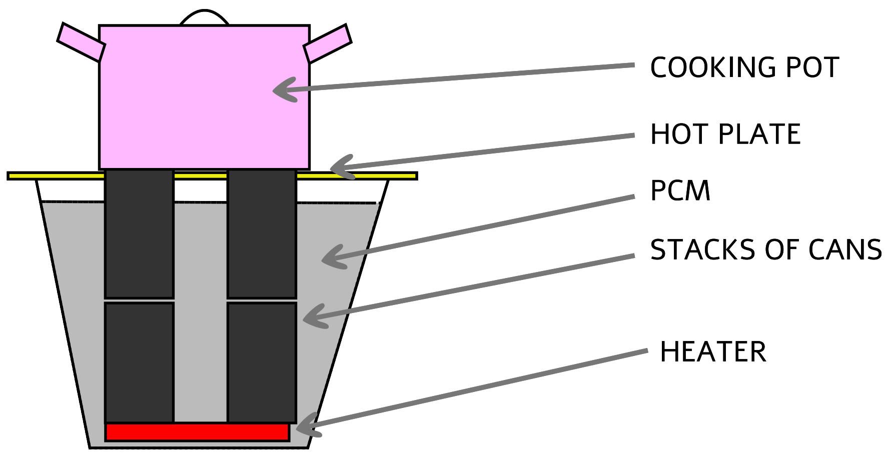
One of the ideas for “metal rods”for conduction of heat from the PCM to the hotplate considered was the use of steel food cans from the household waste. Old cans could be built into pillars and being metal would conduct heat. Waste food cans are widely available but they are limited in the volume of metal they contain, nevertheless it was felt worthy of investigation.

Work undertaken

Three towers of cans were constructed. The top three cans had their base removed and the tower assembled using fire-cement to join the cans together. They were tested as watertight, but were later found to be rather fragile. The three towers of two can each were used as the mount for the upturned frying pan which served as a hotplate.

The photo illustrations below show the method of assembly.

The diagram below illustrates the arrangement.



The can towers were then tested on the heaters to assess the capacity of the metal to provide a pathway for the heat. Once on the heated plates the cans were photographed using an infrared camera.

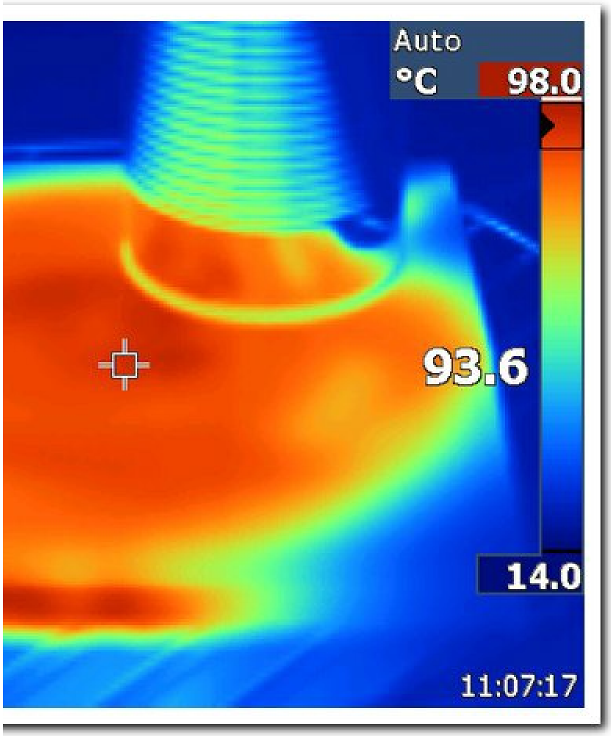
Conclusions

The conclusion from this work was that this was not a good option to pursue for two reasons. Firstly, although as a support for the hotplate they were strong, the pillars were structurally weak at the join and would need welding to made secure. The heating tests demonstrated that as conductors they were poor.

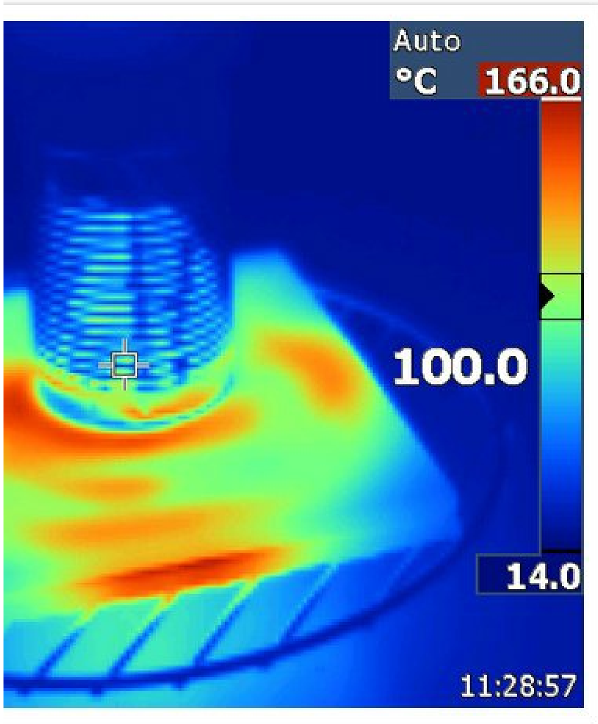
Photo illustrations of "can towers" trials

#1 Concept of can towers

#2 Three towers being water tested



#3 IR photo of can on heater tile showing that the heat transfer upwards is very limited.



#4 Second photo showing cool upper parts of cans

Task 6:- To design the UK prototype eCook stove

Introduction

Prior to building a the UK prototype eCook stove it was decided to prepare designs on the computer. The early trials had indicated that water could boil if it is in close proximity to molten PCM but the trials also showed that the PCM can be difficult to heat due to low heat conductivity. The trials have also highlighted the design challenge of getting the heat to the base of the cooking pot.

Work undertaken

Using Solidworks 3D computer aided design (CAD) an insulated box structure was designed. SOWTech sought advice during this process from its Malawi partners regarding access to materials to avoid using any materials that would not be suitable or available.

During the design phase there was consultation and discussion regarding the outcome of the user-design process undertaken earlier. For example, whilst a two hob cooker was desirable it was not felt necessary to include it in the design at this stage as a second hob could be incorporated later with minimal changes once the concepts had been established. Other issues such as mobile phone charging could be included now as they would be harder to incorporate later.

The output from the design process was some 3D visualisation drawings and a full pack of "for construction" drawings. This design pack was shared with the team. The illustration below shows one of the images from the design pack. It is not clear from the drawing but the upper part of the structure is a removable box lid. The lid void is big enough to house the pans commonly used in Malawi.

Conclusions

The response to the design pack was positive and it was considered appropriate to move into construction phase.

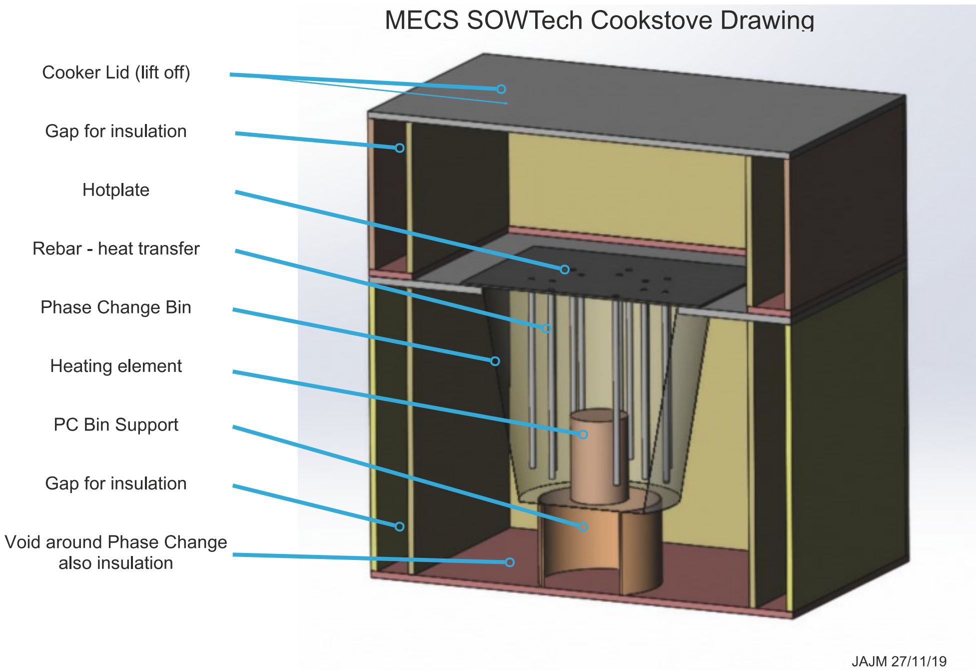
Comment

The issue of the form of insulation was challenging. Insulation materials in the UK are readily available, whereas in Malawi they are not. Furthermore the material that might be suitable for insulation in Malawi, such as rice husks, are not available in the UK. This challenge could not be resolved quickly so it was felt appropriate to progress using readily available UK insulation products and address the issue in Malawi during the field testing.

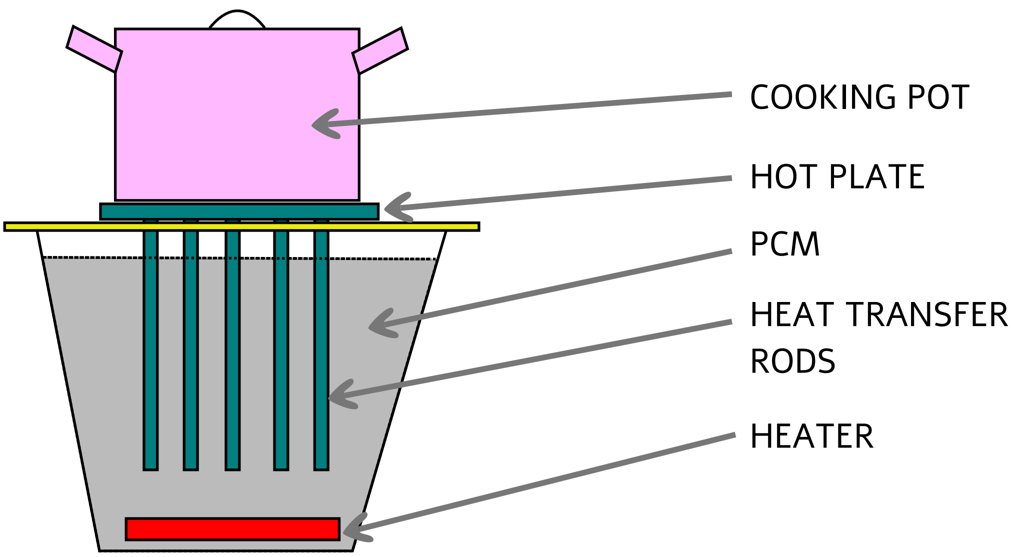
The development of the heaters meant that plate heaters would be used not can heaters but it would not cause significant changes to the overall layout.

The following photos illustrate the process of construction of the UK prototype.

Design drawings:- Photos overleaf



#1 Illustration of the 3D visualisation from the design drawings package



#2 Diagram showing the use of a plate heater instead of a can heater

Photo illustrations: building the structure

#1 OSM board and square section used to make the base box

#2 Metal waste bin used as the PCM vessel

#3 Rockwool wrapped around for insulation

#4 Photo of base assembly

TASK 7:- TO ASSESS HEAT TRANSFER USING COPPER TUBE PILLARS

Introduction

Metal rods to conduct the heat from the PCM to the hotplate was considered a good approach. The use of steel cans was discounted. Tubes made from old copper tube was tested next. The following trial was run to observe the performance of the arrangement.

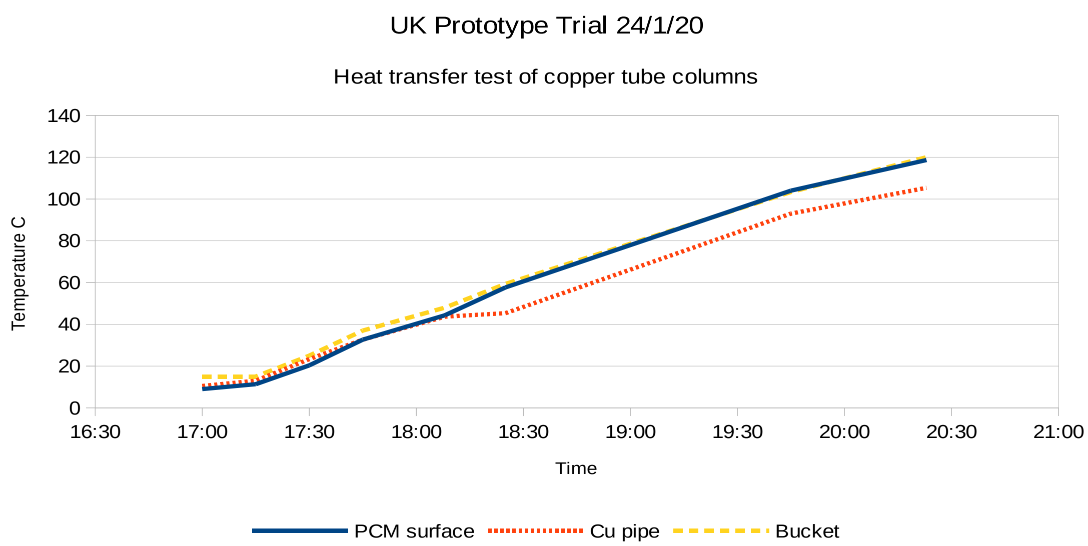
Work undertaken

The base unit of the cooker was assembled

Temperature readings were taken using the IR thermometer on the PCM surface, the surface of the bucket just above the PCM and the top of the copper pipe.

The graph of temperature readings show the close correlation between the heating of the PCM and the temperature at the top of the copper tube pillars.

These trials used the clay tile heaters and the power optimisation device (POD). Both units are subjects of separate appendices.

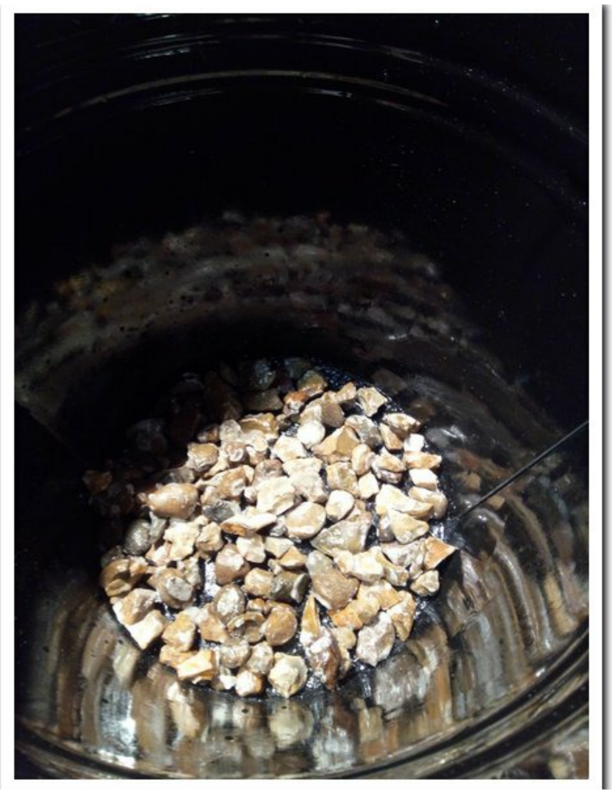


Conclusions

The close correlation of temperature between the PCM and the top of the copper pipe towers was encouraging. It was decided that further work would be undertaken with the arrangement as a stove. A further trial using the hotplate and a cooking pot was to be the next step.

The Power Optimisation Device (POD) and the clay heater tile worked as planned.

Photo illustrations of copper tube pillars



#1 Gravel used as spacer underneath the heater

#2 Clay heater tile on top of gravel

#3 Copper tube pillars held together with cable ties

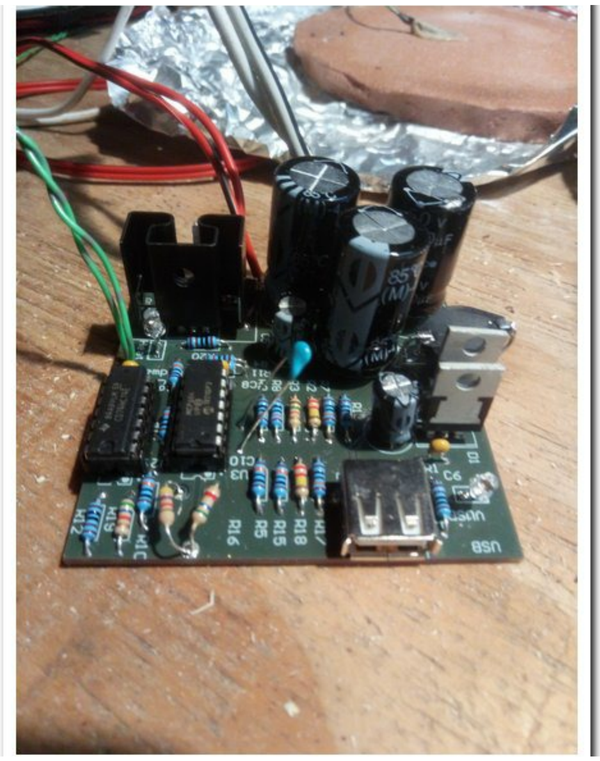
#4 Pipe pillars with gravel filled cant holding the copper pipes in position

Photo illustrations of copper tube pillars cont.

#5 The pillars in position in PCM bucket

#6 Pillars surrounded by PCM which has just started to melt

#7 Base assembly under test with temporary insulation on the top



#8 Showing the Power Optimisation Device (POD) providing power to heater

Task 8:- To test eCook stove using copper tubes pillars

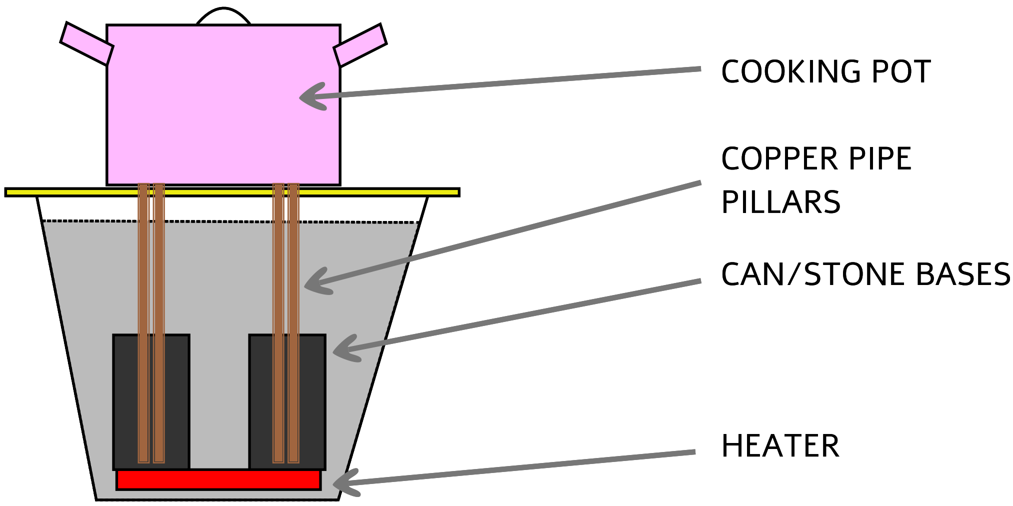
Introduction

The UK prototype cooker was constructed with few changes to the drawn plans. There were two exception to this. The use of rockwool meant that the double wall of the original design was not required. The double wall being necessary for loose fill insulation such as rice husks or vermiculite.

The second exception was that the rod based hotplate was not easy to build in the time available so an alternative using copper pipe rods and an upturned frying pan was used instead.

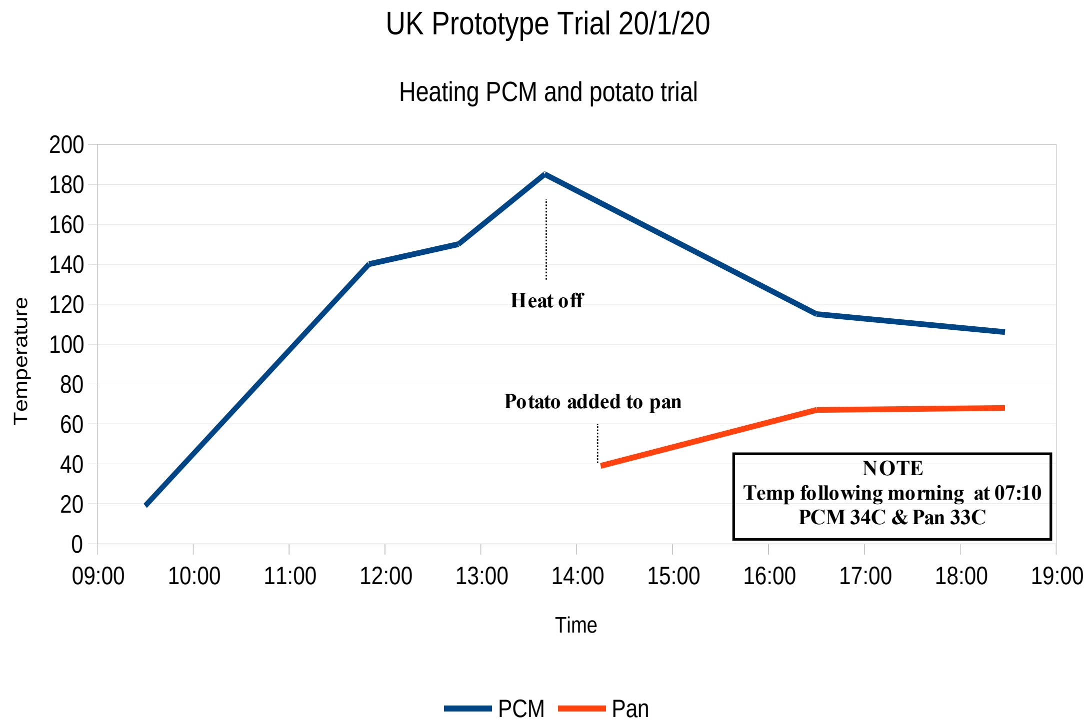
Work undertaken

The description of the assembly of the eCook stove structure is illustrated by the photos below. The trial used the copper pipe pillars as tested in the previous trial. A sectional diagram is given below.



The eCook stove was powered using the transformer and the POD as no solar power was available.

The temperature was monitored using oven thermometers - one in the oil and one in the pan. Inside the pan was placed a few potatoes to assess the cooking potential.



The temperature of the PCM was a cause for concern. The upper limit of the temperature should have been around 150°C but when it reached 180°C it was decided to terminate the heating. Subsequent investigations showed that the POD lights had been turning on/off as planned but the power to the heater had not been doing so. This was traced back to an earlier incident when the POD had been subjected to an accidental short and this had caused the component failure.

The other key important lesson arising from this trial was that it was also found that the heater plate had failed after being switched off. This then left the heater plate “icebound” in the PCM vessel and unable to be removed.

Conclusion

The outcome of the trial was a number of key lessons for future design.

The failure of the POD to accurately check the temperature mean that a second line of protection should be used. A thermal break would be included in heater wiring, which would melt at a preset temperature.

Once the PCM had cooled it became very difficult to recover the failed heater. Given that the heaters would be one of the most vulnerable components, it would be necessary to bring the heater out of the PCM by design, so that it could be recovered at will. The implication of this to the design was significant.

The potatoes which were placed in the eCook stove overnight were cooked the following morning. The eCook stove had no electrical power and the only heat was that released from the PCM.

Photo illustration of the copper tube cooker trial

#1 Hotplate temperature being recorded using IR thermometer

#2 Geotextile fabric being tested to absorb condensation and improve seals

#3 eCook stove lid and cooking pot on top of base unit

#Small potato used for trial. Cooked overnight in unheated eCook stove using only PCM heat

TASK 9:- TO ASSESS AN OIL BATH TO HEAT THE PCM VESSEL

Introduction

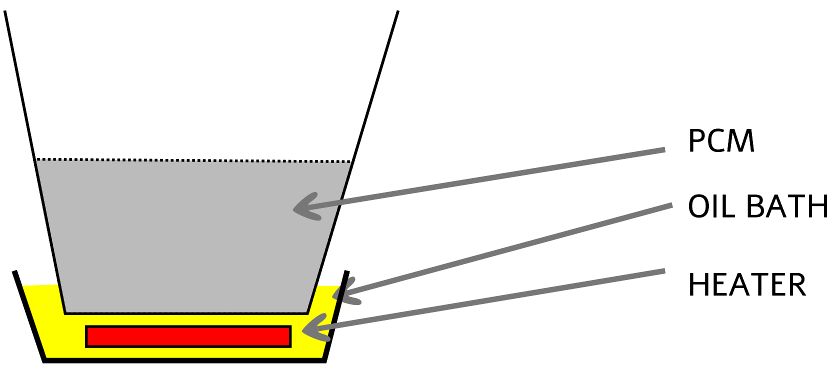
The risk of getting a heater trapped in solidified PCM requires an alternative arrangement to be developed. This trial is to assess the idea that a tray of oil might be an appropriate manner in which to conduct heat from the heaters to the vessel containing the PCM. The heater is in oil which in turn heats the base of the PCM vessel.

Cooking oil is readily available in Malawi.

Work undertaken

A washing up bowl was lined with fibreglass insulation and a stainless steel bowl mounted within the bowl. The PCM bucket bottom had a lip which would form an air lock when the stainless steel (SS) bowl was filled with oil. A tile and fire cement was used to fill this void so that the base was flush. The PCM vessel was placed into the SS bowl filled with a heater tile between the PCM vessel and the SS bowl. The thermistor was located in the vicinity of the heater tiles. The SS bowl was then filled with sunflower oil to a depth of approx 100mm.

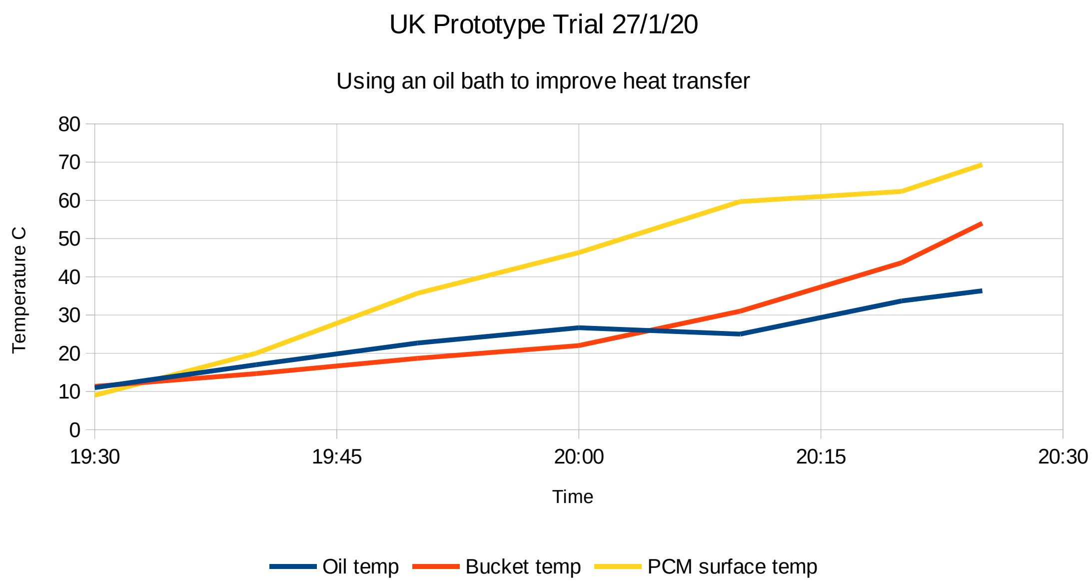
The diagram below illustrates the arrangement under test.



The near IR thermometer was used to measure the temperature of the PCM vessel just above oil level and the surface temperature of the PCM.

The following observations were made during the trial.

- *The oil boiled in the immediate vicinity of the heater plate. This was due to exposed wires remaining within the heater plate due to the method of construction*
- *The oil bath led to the PCM melting from the edges first, rather than from the middle when heated directly from beneath.*
- *The impression was that the oil bath was a big improvement on the heat transfer to the PCM vessel as shown by the speed and way the PCM melted.*



The trial of the oil bath was successful in transferring heat to the PCM vessel. Further ideas were developed during the trial and these led to an extension from the original objective. As oil and PCM are both immiscible and non reactionary, it might be possible to surround the PCM in oil and thereby enhance the overall heat transfer arrangements. So after some checks regarding the chemical properties of the two materials it was decided to investigate this further. The following actions were taken.

- *Some molten PCM was transferred to a clean food can. Vegetable oil was then added to the top of the molten PCM to determine if the two materials were immiscible. The relative bulk densities would indicate that this would happen, but a chemical interaction between the two compounds might occur.*
- *The observations were that the two liquids were highly immiscible. The PCM started to solidify below the oil level due to the cooling effect of the oil which was at approx 11°C .*
- *To test the use of vegetable oil as a heat transfer medium further, approx 600ml of sunflower oil was then added to the PCM in the bucket. This was then observed. The added oil on the surface of the PCM clearly facilitated the melting of the PCM on the surface of the vessel.*

Conclusions and implications

The oil bath improved heat transfer to the PCM vessel.

The thermistor needs to be mounted in a manner which retains the connection to the wire whilst being resistant to heating in oil.

The use of oil on the surface of the PCM improves the heat transfer into the PCM and aids in achieving consistent heating of the PCM.

The heater plate should not have exposed resistive wire or the exposed wire causes localised boiling of the oil.

The use of vegetable oil as a heat transfer media seems advantageous but the impact of the oil on the materials used to make the heater plates needs to be further investigated.

The oil and PCM are immiscible and do not react, leaving the option to fully enclose the PCM in oil.

The implication of this trial was that a oil bath outer vessel would effect heat transfer to the PCM. A twin vessel is now required, one which holds the PCM and one which holds the oil. This trial also suggested that oil not only below the PCM would be work, but perhaps the oil could completely cover the PCM. Could the PCM be covered on all sides, including the top. The bulk density of the PCM is higher than oil, but we needed to ascertain if the two materials interacted or reacted. If they did not react the use of a fully oil-enclosed PCM would ensure efficient heat transfer between materials.

Photo illustrations Oil being used as heat transfer mechanism

#1 Mortar filling the lipped to prevent an air pocket insulating the PCM bucket

#2 Tile heater trimmed to fit the base of the PCM bucket

#3 Spacers and tile heater placed in oil bowl and bucket placed on top

#4 Cooking (sunflower) oil added to the bowl

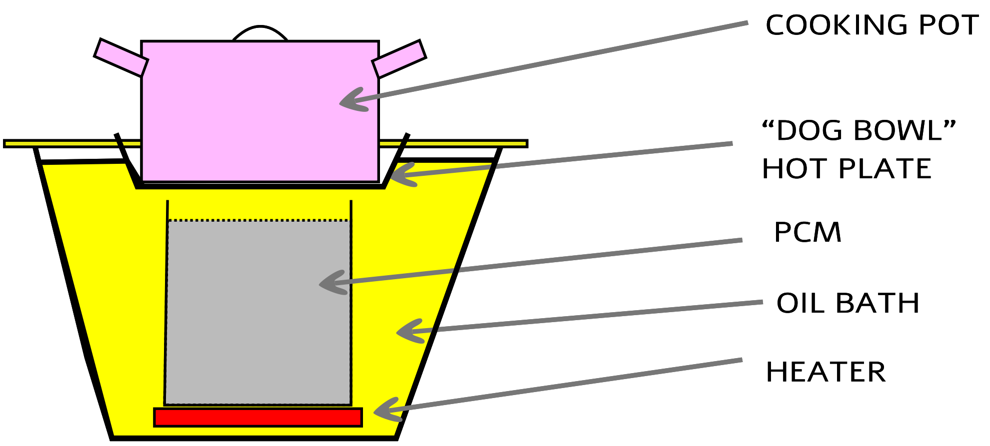
TASK 10:- TO IMPROVE THE HEAT TRANSFER USING AN OIL IMMERSED HOTPLATE

Introduction

The purpose of this trial was assess the use of an oil immersed bowl as the hotplate for a cooking pot. The oil fully encapsulates the PCM which means that it can function as the heat transfer media for both the melting phase of the PCM and the freezing phase.

Work undertaken

A new arrangement for the internal core of the cooker was built and assembled as per the diagram below. The photos below illustrate how this was undertaken.



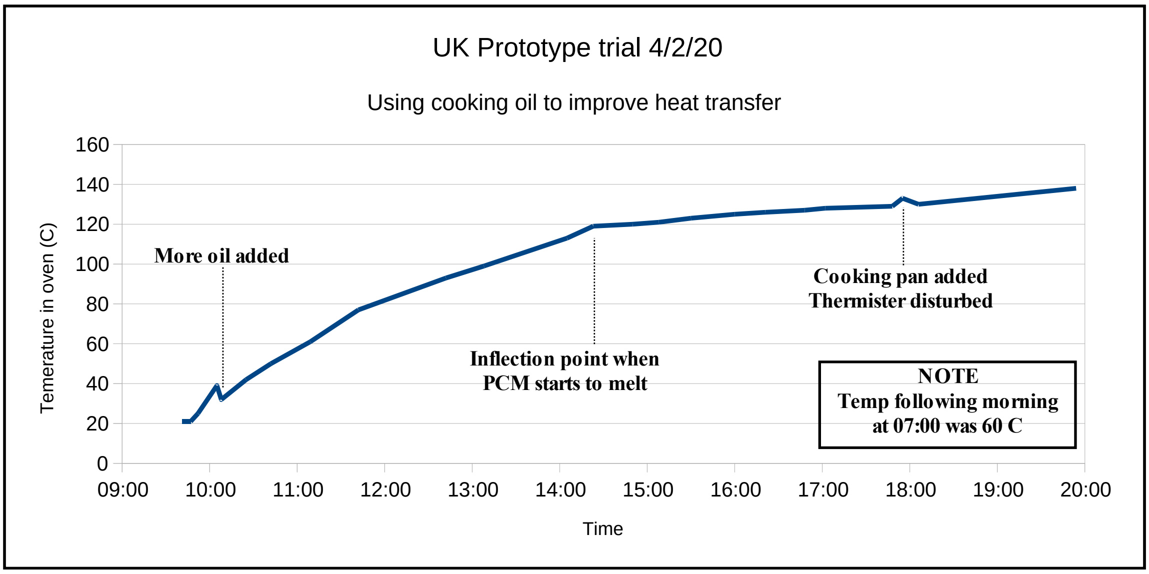
The only metal PCM vessel which could be procured was smaller than desirable but it did contain 2kg of PCM. The large volume of oil, (5 litres) meant that it took a significant period of time to heat up.

The graph below illustrates the temperature records.

At 6pm the cooking pan was added to the assembly which caused a disturbance in the oil giving rise to the blip in the heat profile.

The PCM did completely melt. The POD worked as planned and controlled the upper temperature.

The graph shows a clear inflection point where the PCM starts to melt and the rate of temperature increase drop as the heat is absorbed by the PCM.



Conclusions

The trial showed that PCM could be melted and to absorb heat, within 12 hours using the POD as the power source.

The POD temperature control feedback appears to be working as planned.

The use of oil stabilised the heat transfer process and gave rise to not "overheating" in the vicinity of the heater.

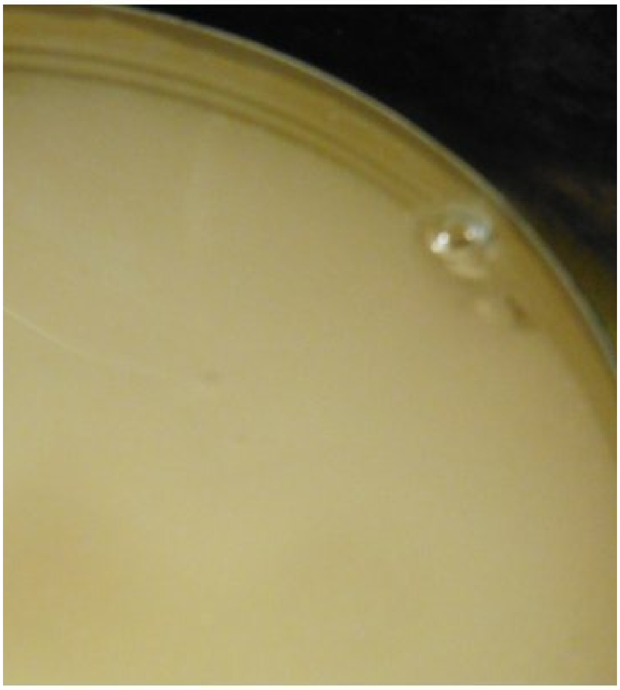
The oil immersed dog bowl has been the best approach used to date for heating the hotplate.

Photo illustrations

#1 Heater tile on spacers to allow oil circulation. PCM can on top of heater

#2 PCM being weighed into PCM vessel

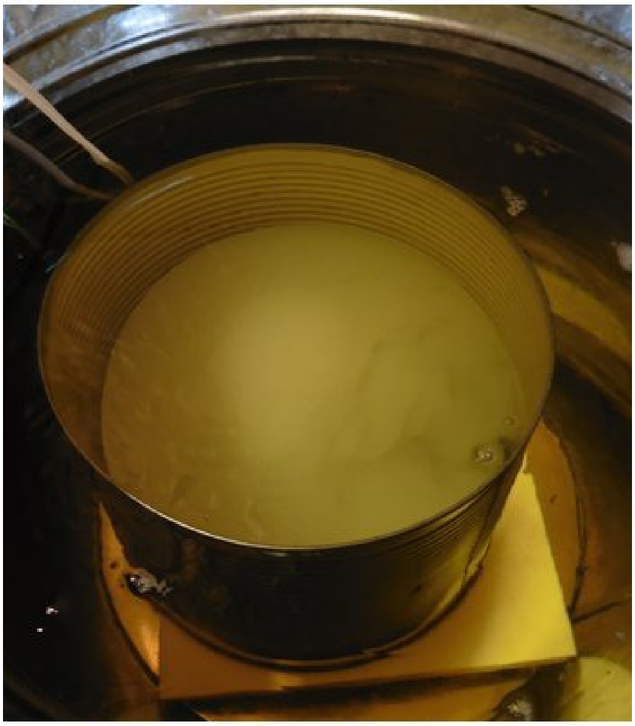
#3 PCM vessel within oil bath.



#4 Air being displaced by oil from the PCM. Top up oil needed after displacement

Photo Illustrations cont.

#5 PCM as filled for comparison with #6



#6 PCM partially melted - white powder visible below the melted layer (transparent) of PCM

#7 "Dogbowl" hotplate resting on PCM vessel within oil bath vessel.

#8 Boiling droplets of water on hotplate to illustrate temperature of hotplate

TASK 11:- TO TEST THE OIL IMMERSED HOTPLATE USING MAIZE FLOUR

Introduction

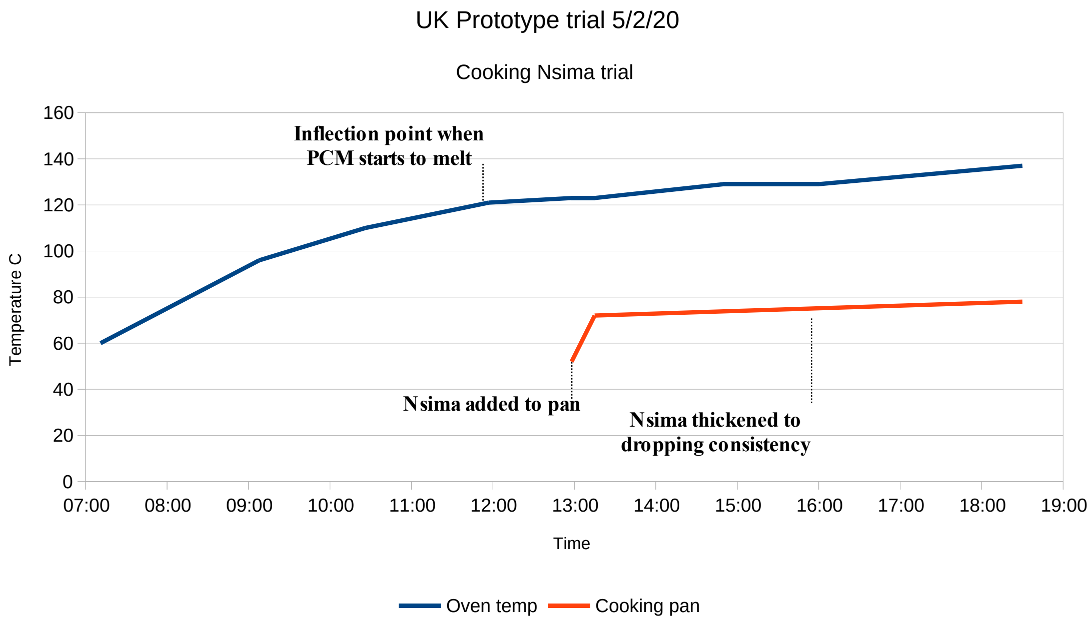
A key objective of the project is to be able to cook the type of food products eaten by the low income communities. Maize flour, which is turned into Nsima in Malawi, is one such staple foodstuff. This trial uses some Malawi maize flour and the apparatus described in the previous trial was used to heat the flour and water.

Work undertaken

The eCook stove was started whilst the oil was still at 60°C. The represents the retention of heat overnight. The eCook stove arrangement was the same as shown in the previous section.

When the eCook Stove was at an oil temperature of 123°C, a mix of flour and water was added to a lidded pan on the hotplate.

The following graph illustrates the temperatures of both the oil and the flour water in the pan.



Conclusions

It showed heat retention overnight with the temperature of the oil the following morning being 60°C and the cooking pan was 58°C. This is a temperature used for slow cooking which indicates that the oven could be used in this way overnight.

The use of the oil immersed hotplate did produce a temperature in the pan which was capable of changing the nature of the flour water mix to that of a solid.

The temperature that was achieved in the pan was disappointing. At the peak temperature of the oil (c 140°C) the pan temperature was still a lot lower at approx 80°C. Whilst this is well above the minimum temperature required for meat to be safely cooked, it is still well below the temperature required to boil beans.

This trial would indicate that the design can achieve a cooking temperature overnight, ie when un-powered. In other words the use of PCM delivered long term heat intput to the eCook stove. It can also achieve stable heating and oil temperatures which could be used for oil immersed cooked, ie deep fat frying.

The requirement to boil water for certain foodstuffs such as African beans has meant that the stove is currently unable to cook such products. However, we recognised the potential of the heater plates developed for the stove as potential hotplates for direct PV powered boiling of such food. Similarly we have also discussed the possibility of having a powered heater above the PCM as well as below it. Such an option would not dramatically increase the price but it could make a large difference to the potential of the unit to meet the needs of the market.

The following task was an initial test to explore this possibility. Further work along these lines was also undertaken during the field trials in Malawi. (See Appendix 7)

See overleaf for photo illustrations.

Photo illustration of the "Immersed bowl" trial.

#1 Pan in "Dogbowl" hotplate - insulated raised for the photograph

#2 Photo illustrating the lift off insulated lid above the base unit.

#3 Photo of the cooked maize flour showing the transformation of the starch into a solid texture.

TASK 12:- TO EXPLORE THE USE OF THE PLATE HEATERS AS A STAND ALONE COOKING HOTPLATE

Introduction

The objective of the project is to generate an eCook stove option which is made locally and which provides a means to cook the food eaten by those on low incomes. One of the foods which our target beneficiaries need to cook are African beans. These beans contain a toxin which needs to be boiled before it is safe to eat. After a period of boiling it is then cooked for a considerable period of time but boiling for this stage is not required.

This trial was a first "look see" to explore the idea that we could make a hotplate suitable for boiling water using the heater components which we had already developed, namely the POD to control the PV output and the heaters. This first trial is reported below

Work undertaken

The trial was started at 2pm on a winters day when there was some weak sun. The heater used to start the trial was a concrete tile heater as it has a flat surface suitable to good contact with a pan. However the tile was not oil conditioned and may have contained some residual water. At 97°C it "blew" the concrete so it was replaced with a clay tile, shown in the illustrations below.

The clay tile was placed on a piece of insulation board and a pan containing 300ml of cold water was placed upon it. After 50 minutes the water in the pan was at 60°C and the hotplate was approx 156°C .

The trial was terminated at this time as there was no further sunshine.

Conclusions

This little test gave encouraging results and indicated that a direct sunshine heated hotplate may be one way to achieve boiling. In this way the beans could be boiled during the day for the period of at least 10 minutes that are required to remove the Phytohaemagglutnin toxin but then be transferred to a slow cooking oven for the duration of the long cook which is over a matter of hours.

The following procedure has been recommended by the PHLS (Public Health Laboratory Services, Colindale, UK) to render kidney, and other, beans safe for consumption:

** Soak in water for at least 5 hours.*

** Pour away the water.*

**** Boil briskly in fresh water for at least 10 minutes**.*

The hotplate used in daytime sunshine could be a early simple system for achieving this critical cooking requirement.

Photo illustrations Hotplate trial

#1 Clay heater tile placed on insulation to act as hotplate

#2 Pan on tile which contains 300ml of water

#3 Solar panel in late afternoon winter sun (06/02/2020). Note plate heater is covered in fibreglass insulation to reduce heat losses. The oven thermometer display is visible on the fibreglass. The open POD is visible in the plastic box alongside.

Appendix 5

Technical Report

Power control, thermodynamics and PV panels

SOWTech eCook stove

Contents

Preface

Context

This appendix covers three topics regarding the cooking power topics relating to the project.

There are three discreet topics covered below, but they all pertain to providing the power needed for cooking which is derived from the solar energy.

- *The development and use of a Power Optimisation Device. A means to control and optimise the PV power derived from the panel*
- *The thermodynamic calculations which formed the basis of the power requirement*
- *A brief account of the PV panel specification issues options identified during the procurement of PV in Malawi.*

This work was undertaken as part of a programme called Modern Energy Cooking Services-Technology Research for International Development (MECS-TRIID) managed by Loughborough University and funded by DFID. The objective of this initiative was to fund research into developing new solutions and approaches which may improve the performance and delivery of modern energy cooking services, and which will provide tangible and impactful benefits.

These appendices have been written to provide a full account of the work undertaken so that it may be disseminated and shared. The report includes pictures and diagrams explaining what has been undertaken but the technical text has been kept to a minimum. The account seeks to convey the areas where things have not gone according to plan as well as those that we are pleased to report, so that the full learning experience can be passed on.

The structure of the report

The work will be described as a series of discreet work packages with each package having a section which describes the what problem or challenge is being investigated. We see the path to our objective being achieved through a series of hurdles which needs to be overcome. These “hurdles” could also be referred to as steps on a pathway, or experiments, or research topics or tasks. In this report we will call them “tasks”. Following the statement of each task there will be an account of the work undertaken. The work undertaken will contain a brief description of what was done. This is then followed by a short conclusion and comment on the implications arising from that work. The Implications may be conclusions or outcomes from research, further questions to be addressed or decision regarding what to do next.

The aim is to make these accounts short and discreet so that they are easier to cross reference and to make it as easy as possible for the reader to follow the evolution of the project.

TASK 1:- BUILDING A CONTROLLER TO OPTIMISE PV POWER OUTPUT

Introduction

Heat is the energy which is needed to cook food. The source of the energy to be used in this project is solar power captured by photovoltaic (PV) panels. Prior work by others had used diodes to convert the electricity from solar panels to heat. This approach was reviewed by our technical consultants who concluded that the method of preference for this project would be the use of resistive wire to generate the heat. Both approaches have similar technical merits but the primary reasons for this choice was cost of production at scale and the reduced risk of failure due to reducing the number of parts and connections.

In order to optimally use power from a PV panel some form of controller is needed to manage the amount of current drawn from it. If this demand is not managed and too much or too little is taken from the panel it causes the system performance to be compromised. The task is to devise the best method to achieve this power control at an affordable cost.

Work undertaken

The first step in taken was a review of existing devices to determine if an appropriate unit was readily available. No "off the shelf" equipment was judged to be available that was basic enough or cheap enough to justify buying. The next step was to specify and design a unit that would meet the requirements of the project. The requirements included the following:

- *suited to provide power to the heaters being planned*
- *suited to PV panels that are readily available in Africa*
- *suitable for construction in Africa with low cost components*
- *additional capability of charging mobile phones*

The technical consultants to the project developed plans for such a unit based on a double sided printed circuit board with through hole components. The description used for this design was "technology from the 1960's and could be built by school children". The key point about the design is that it does not use modern methods of manufacture which require complex factory based equipment. It is acknowledged that "in quantity" the printed circuit boards and components would probably come from China, but the assembly of the units could be undertaken in somewhere like Africa without recourse to sophisticated manufacturing facilities.

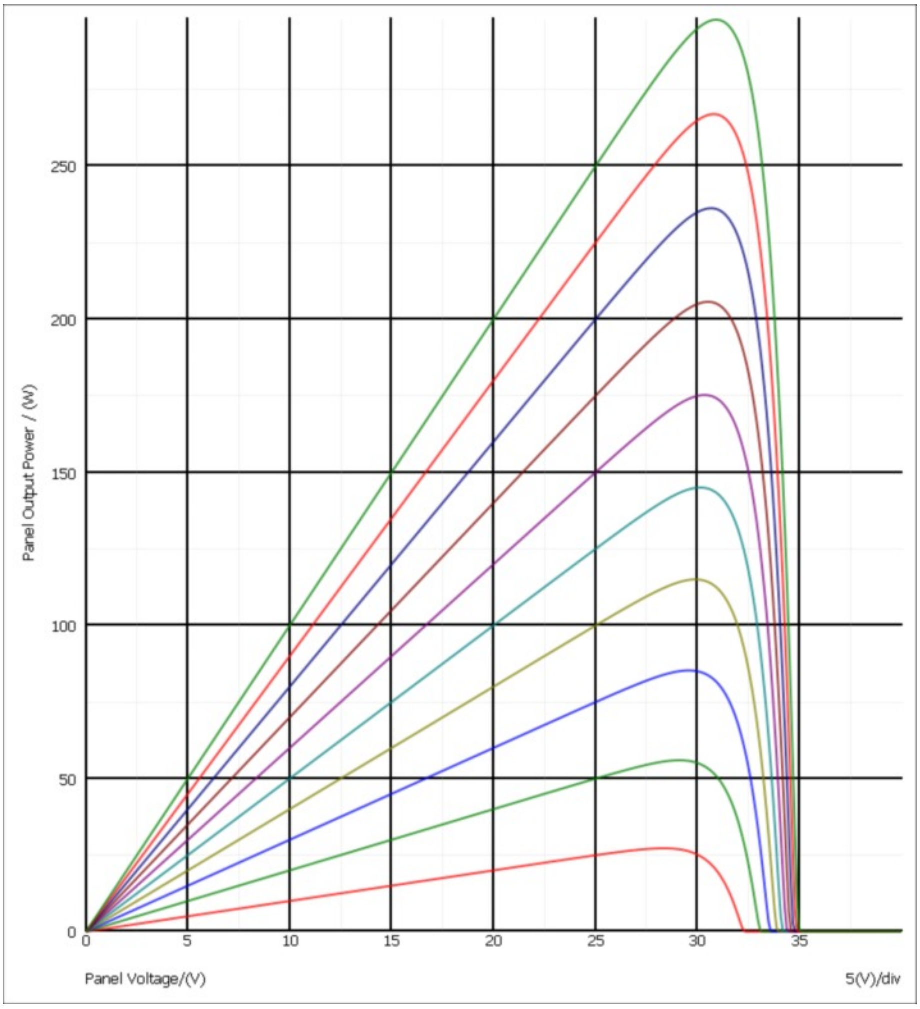
The efficiency of the circuits designed are estimated to be better than 97% efficient with overall system efficiency being greater than 90%. Improvements would be possible with more design cost and complexity.

The design of the circuit is to function in a manner similar to that used by Maximum Power Point Tracking (MPPT) controllers.

This is the design built into the majority of inverters tied to the grid. It enables the panels to work at maximum efficiency no matter what the environmental conditions. The MPPT controller works by adjusting the current drawn out of the panel so that the panel's "maximum power point" is maintained.

In the case of our project the principle is similar to the MPPT controllers used on grid/battery projects. However, in our project, the power is controlled by varying the average voltage delivered to the heaters so that a constant voltage on the panel is maintained, close to the maximum efficiency point.

The graph below shows a simulation of the PV performance at different levels of solar irradiation. From this graph it can be seen that the optimum power points on the panel are around 30V. Slightly higher in bright sunshine and lower at low light levels. The task of the Power Optimisation Devise is to maintain the panel voltage as close as possible to this optimum voltage. A true MPPT system would track the small variations, along with similar variations with temperature. However, for simplicity we use a constant voltage.



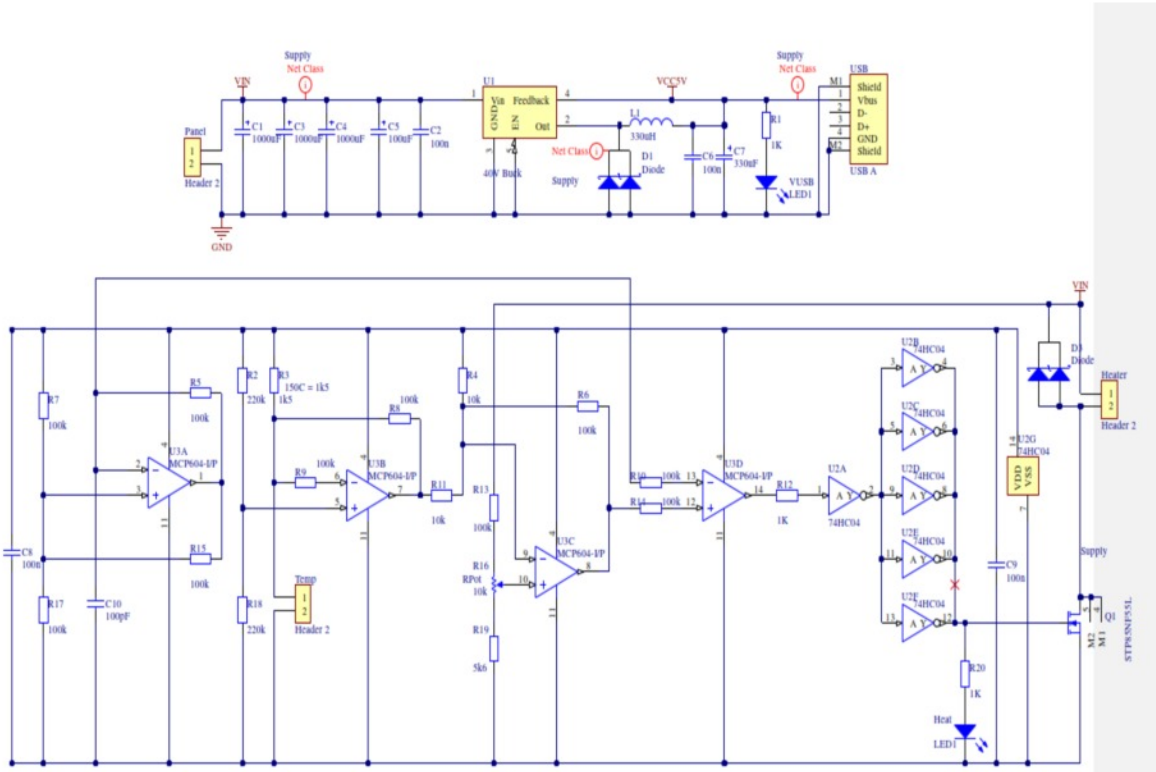
Using the resistive wire heaters and a controller means that there are no power variations to deal with as the heaters warm up, compared to the significant variation experienced with diode heaters.

Once the maximum desirable temperature is reached the power supply to the heater is reduced to maintain a constant temperature.

Part of the assumptions made regarding the project was the amount of power that we estimated was needed to provide the cooking function being sought. The conclusions were that we would use a PV panel with approximately 300W peak output. The thermodynamic calculations used to arrive at this are described in a separate task.

The design of the circuit is a resistive heater fed by a pulse width modulation (PWM) signal to match the average resistance to the current available from the solar panel. The circuit monitors the voltage on the panel and adjusts the PWM ratio and hence the right average current to maintain the desired voltage on the solar panel. The current is smoothed by a large capacitor. It had been hoped that the heater coil self inductance might be enough, but unfortunately it was not the case. The circuit consisting of a quad opamp and hex inverter is shown below

The design of the circuit to achieve this is reproduced below.



The circuit consists of:

- *A triangle wave generator based around U3A. A temperature error amplifier based around U3B, Temp is a 100k (at 25°C) thermistor. A voltage error amplifier based around U3C which measures the voltage on the solar panel . The solar panel working voltage is adjusted by varying R16.*

- *The voltage reference is shifted by the output from the temperature error amplifier, so the temperature control is achieved by moving the solar panel working voltage away from the optimum.*

- *The gain around U3C can be adjusted to provide 'super optimum' control of the solar panel voltage i.e. allowing the voltage on the solar panel to fall slightly as the current drops. We have only roughly optimised the gain.*

- *The voltage error signal is compared with the triangle wave by U3D to give the PWM signal which is cleaned up the logic invertors, U2 before switching Q1 which drives the heater. D3 is to prevent damage to the electronics by any inductance in the heater.*

- *C1-C5 are is the smoothing capacitors*

With respect to the design of this circuit it is similar to a preset MPPT circuit. The panel voltage is set by resistors/potentiometer. Whilst this can be close to optimum, PV panel temperature and operating light levels move so the optimum operating points vary slightly. However we estimate that this is only a few % efficiency loss. A future development of the unit could include a microcontroller to continuously optimise the operating point.

The control electonics run at 5V so using an underrated power supply unit allows simultaneous operation as a USB charger. The power supply unit can deliver 1.5 Amps to the USB socket.

One of the key design parameter for the unit is cost. The unit cost of the POD manufactured in bulk is very hard to estimate because costings are very sensitive to quantity orders and assembly costs. As a guide however, the unit costs of the prototype POD's components has been of the order of £5 unit. Given volume production the unit cost could be affordable for application within the target communities.

Having built the POD unit it was necessary to protect it. A ventilated box unit with apertures for wire input and outputs and the USB port was designed. The design also needed to allow for the two indicator LED lights to be seen outside the box. Two of these boxes were 3D printed for the project. The ventilation holes are important to ensure the components do not overheat. A secondary protection would also be required in a consumer version to prevent water ingress. The drawing of the POD case is shown below together with photo illustrations.

One of the constraints was the lack of sunshine for UK testing. In order to emulate the power from a PV panel a transformer was built which delivered 50V. The early trails of the POD were undertaken using this surrogate for the panel.

During one of these functional tests a clay heater panel was observed to heat to 200°C in 5 minutes with a resistance of 7.7 ohms (3 Ohms would be a more optimal value when the system is connected to a 30V Solar panel) so it was being powered by 325 watts.

Once in use in the field trials data was obtained with illustrates the control function of the POD. The following pages illustrate some graphs of the input and output voltages from the POD. It can be seen from the data due to the overcast conditions the maximum power output from the panels was rarely experienced. Further details of these particular trials are contained in the "Field Trial" appendix 7.

Conclusions

The development of the POD has been everything we sought. The unit is inexpensive, it could be constructed with basic facilities and modest skill levels.

The POD delivered controlled power to the heaters as can be seen on the graphs below. It did its job.

It was adaptable to different voltages with minor changes to potentiometer settings.

There are many ways the unit could be refined. For example, the POD could be adapted to serve two heater plates. One which can be used as a daytime hotplate specifically for achieving boiling temperatures and the other for heating the heat battery PCM material for slow cooking at times when sunshine is limited.

The POD can also be evolved to be able to automatically adjust or be user adjusted to solar panels optimised for different voltages.

The unit has attracted the attentions of other developers in the field and a unit has been sent to Cal Poly in California to assist with their work in this field. The feedback received to date indicate it is working as required.

During development some operator errors caused the POD unit to be shorted-out by tinfoil. This led to damage to one of the components. Repairs to the POD were made by using a soldering iron to remove the damaged component and replacing it with a new one. This work was undertaken in a domestic UK kitchen using DIY tools. This experience suggests that repairs and maintenance will be achievable within the community, subject to suitable training and facilities being available.

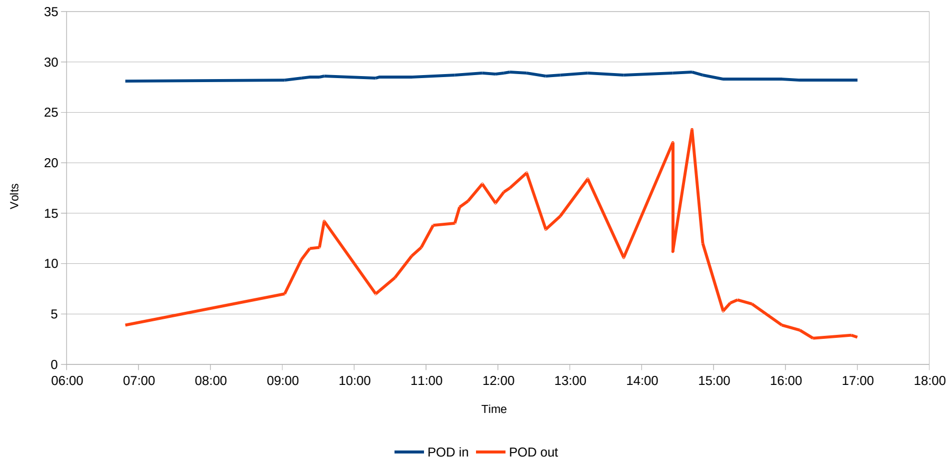
There were a few minor issues with the current design during assembly. For example, the printed circuit board design had a couple of footprint errors which made it more difficult to assemble than it should have been. These can be rectified in any future builds through minor changes to layout.

The development of the POD is significant achievement of the project.

Graph illustration of POD controlled voltages

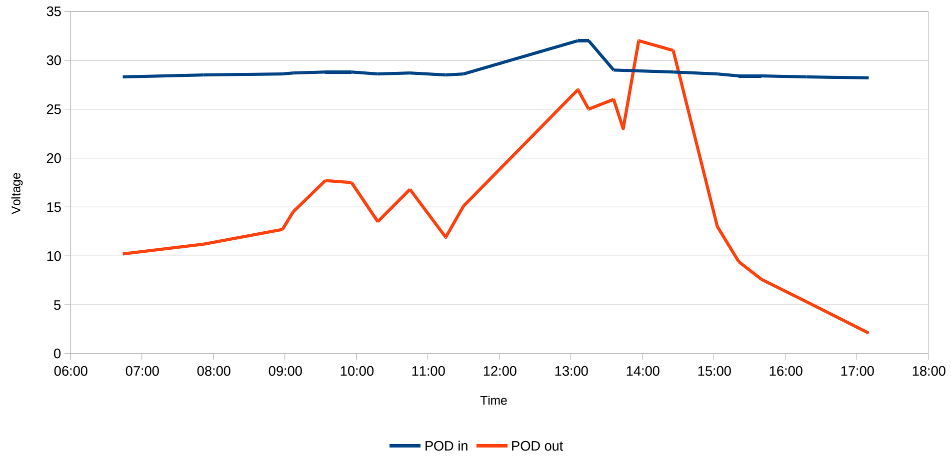
POD I/O volts 11/2/20

Relation between POD input output voltage



POD I/O volt 12/2/20

Illustration of the voltage in and out of the POD



POD I/O volts

POD voltage input output 13/2/20

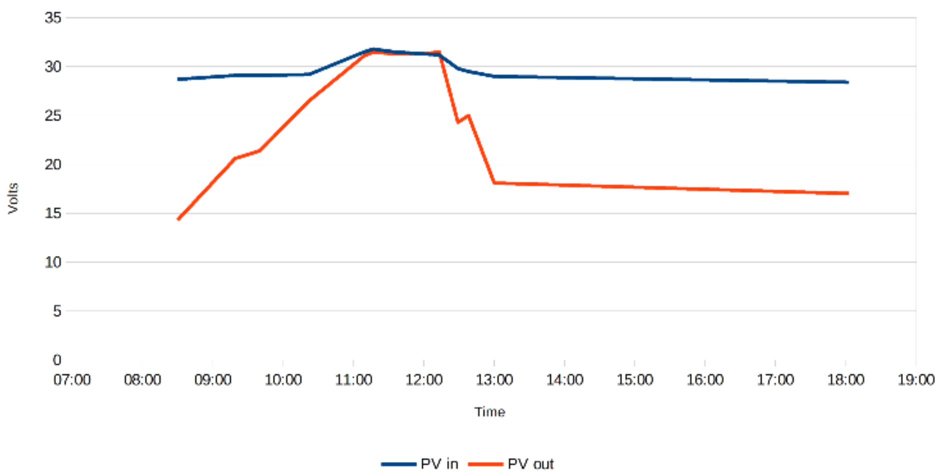
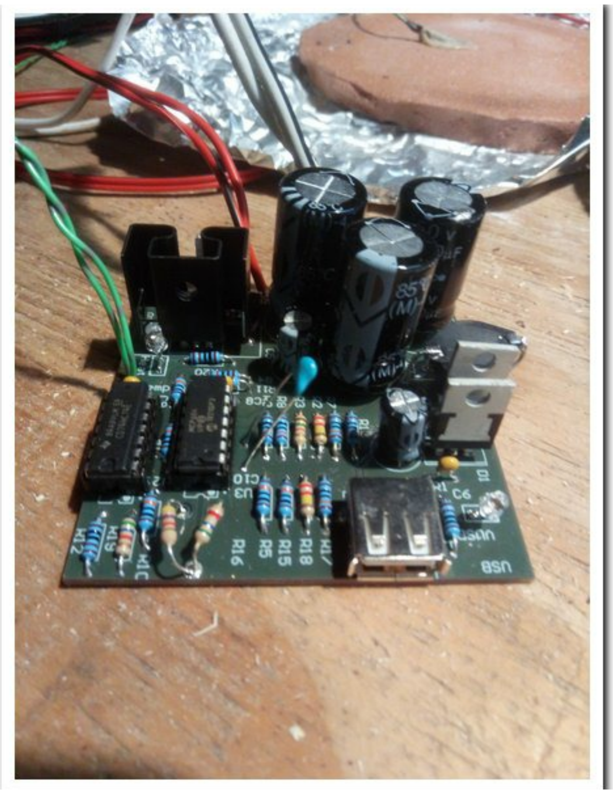
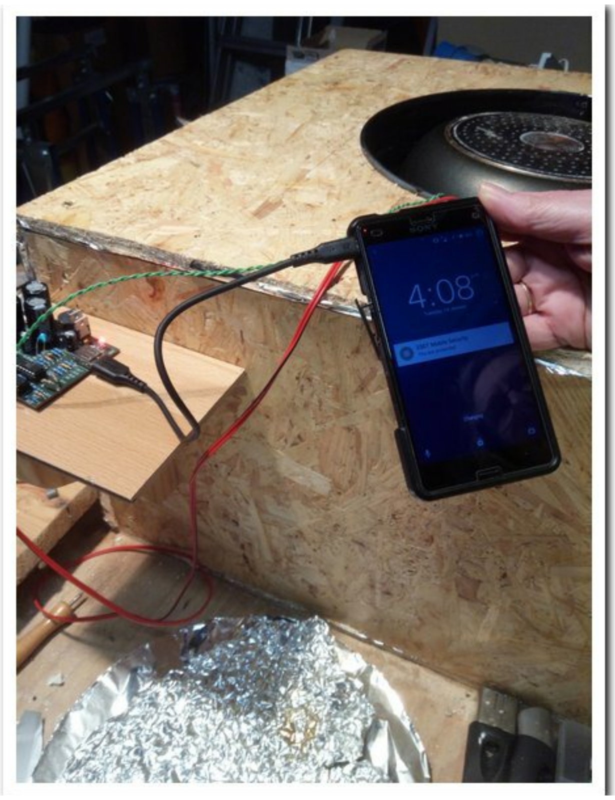


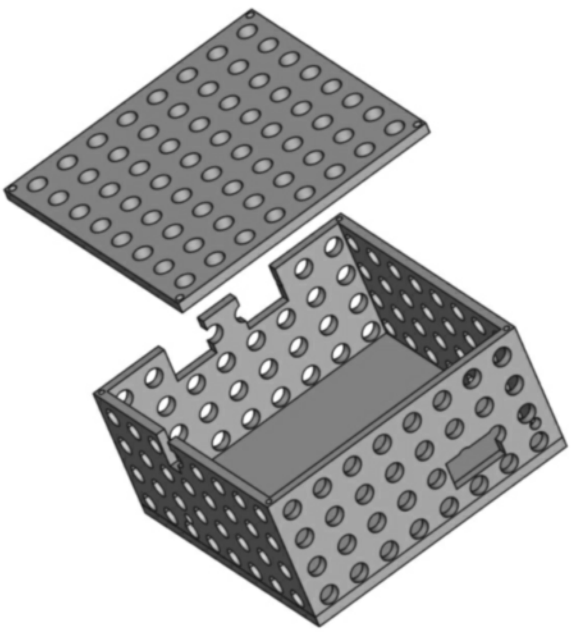
Photo illustrations of the POD



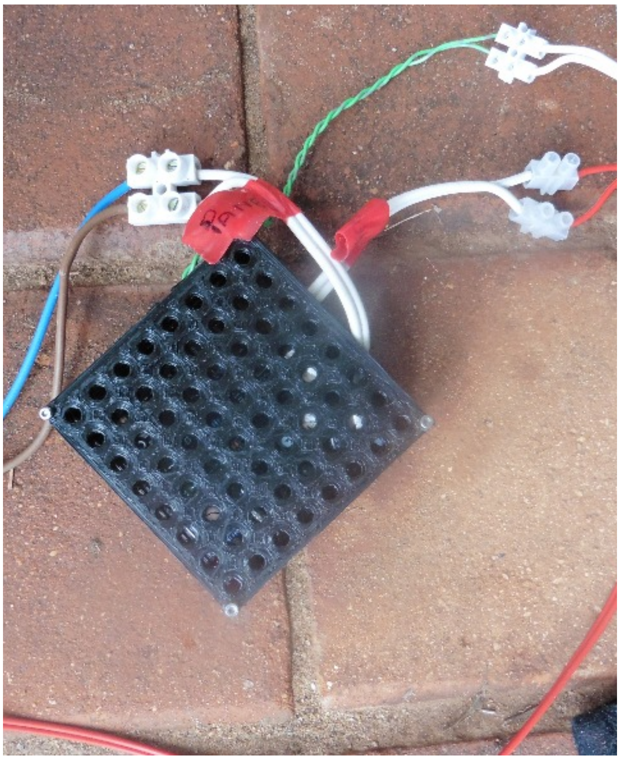
#1 Power Optimisation Devise (POD) assembled



#2 POD shown charging a mobile phone



#3 The drawing of the case to mount the POD for use. Weather protection not shown.



#4 Photo of the POD in use in Malawi

TASK 2:- THERMODYNAMIC CALCULATIONS

Introduction

One of the key design questions which had to be faced is just how big is the task. In other words what scale of cooker is required to meet the cooking expectations. Finding the long term answer to this question will be something which experience and circumstances will determine. There are many variables which cannot be readily determined will include heat losses from the cooker, the food to be cooked, the volume of food to be prepared. Nevertheless, this project had to prepare some best estimates of the cooking demand. This section illustrates the calculations that have been included and which formed the basis of the subsequent design.

Work undertaken

The factor which influenced the decision re the scale of the project was the power that a given type of solar panel could generate, so the maximum daily energy that a 300W PV panel could generate was estimated. This calculation was then down rated for loss of efficiency with age and sub-optimal conditions of operation. Having established what level of energy could be obtained this was then translated into the amount of water that could be boiled. This capability was then assessed to determine if it sounded realistic with respect to the possible heating requirement. The user-centred design work produced an indication of the cooking requirement. This process was undertaken on an iterative basis until a consensus was achieved within the team on the best guess for building the prototype.

The phase change material (PCM) of choice was Erythritol and the literature provided key thermodynamic information that was needed. This enabled a calculation to be made which determined the amount of PCM that the eCook stove would need have.

The calculations illustrated below show the detailed assumptions and calculations that were used.

Conclusions

Given the assumptions used the practical implications were calculated as follows:

- *To store all the energy from a 300W panel would require a theoretical total of 27kg of PCM. This figure was discounted to 20 kg of PCM due to expected PV inefficiencies.*
- *This volume of PCM would have enough stored energy to bring 10 litres of water to 100°C from 20°C*

These calculations formed the basis for deciding on the volume of PCM to be used in the prototype eCook stoves.

Illustration of the Thermodynamic calculations

Erythritol

$MolecularMass := 122.12 \quad \frac{g}{Mol}$

$Tmelt := 121.5 + 273 \quad K$

$Tcold := 120 + 273 = 393 \quad K$ Temperature in morning, worse case for volume calculation is near melting point

$Density := 1451 \quad \frac{Kg}{M^3}$

$HeatOfFusion := 15420 \quad \frac{J}{Mol}$

$SpecificHeatOfFusion := \frac{HeatOfFusion \cdot 1000}{MolecularMass} = 1.263 \cdot 10^5 \quad \frac{J}{Kg}$

$HeatCapacity := 166.50 \quad \frac{J}{Mol \cdot K}$ up to 177.80 user lower value as worse case

$SpecificHeatCapacity := \frac{HeatCapacity \cdot 1000}{MolecularMass} = 1.363 \cdot 10^3 \ \frac{J}{Kg \cdot K}$

Water

$WaterSpecificHeatCapacity := 4186 \quad \frac{J}{Kg \cdot K}$

$WaterSpecificHeatVaporisation := 2260 \cdot 10^3 \quad \frac{J}{Kg}$

$Tboil := 100 + 273 = 373 \quad K$
$Tcoldwater := 20 + 273 = 293 \quad K$

SolarPanel

$HeaterPanelPeakPowerNew := 300$

$HeaterPanelPeakPower := HeaterPanelPeakPowerNew \cdot 0.8 \quad Watts$

$HeaterPanelPowerAverage := \frac{HeaterPanelPeakPower}{2} \quad Watts$

$TimeSunshine := 8 \cdot 3600 \quad s$

$Tcoldwater := 20 + 273 \quad K$

$EnergyPerDay := HeaterPanelPowerAverage \cdot TimeSunshine \quad J$

$MassWaterBoil := \frac{EnergyPerDay}{(Tboil - Tcoldwater) \cdot WaterSpecificHeatCapacity} = 10.32\,Kg$ or litres

Illustration of the Thermodynamic calculations cont

Calculate volume of Erythritol to store energy

$$EnergyToHeatPerKg := (Tmelt - Tcold) \cdot SpecificHeatCapacity = 2.045 \cdot 10^{3} \quad \frac{J}{Kg}$$

$$EnergyToMeltPerKg := SpecificHeatOfFusion = 1.263 \cdot 10^{5} \quad \frac{J}{Kg}$$

$$MassErythritol := \frac{EnergyPerDay}{(EnergyToHeatPerKg + EnergyToMeltPerKg)} = 26.934 \quad Kg$$

$$VolumnErythritol := \frac{MassErythritol}{Density} = 0.019 \quad m^{3}$$

$$VolumnErythritol \cdot 1000 = 18.562 \quad l$$

Task 3:- Selection of PV panels for trials

Introduction

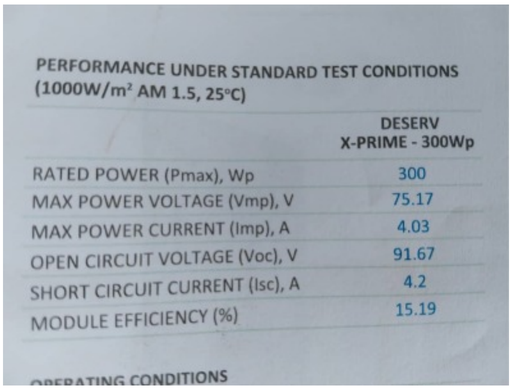
There are many different sizes and types of PV panel which are available on the market. This task was to determine which panel to buy and establish what was available in Malawi, the location of the field trials. This brief comment illustrates how this was approached and the reasons and options that were considered.

Work undertaken

One of our original partners in Malawi was a PV specialist. However, for reasons unknown to us and our other Malawi partners, they become uncontactable. However, we were able to pursue two other channels to resolve the issues. Firstly, a company supplying PV had approached us and provided an account of the equipment which he could provide. Details listed below for reference.

Secondly Aquaid Lifeline have previously purchased a number of PV panels for water pumping applications and their contact was able to offer suitable panels at a competitive rate. The MD of the business (Kim Gardner Jacobsen), expressed a keen interest to discuss the project with SOWTech so Dr Mullett met him during the fieldwork trip. The company is currently the main dealer for Grunfoss in Malawi and therefore they execute many PV powered pumping projects. The reason for his interest was that he had been involved in solar cooking trials earlier in his career when PV was far more expensive. He saw the potential and wanted to support the development of the concept. One of the practical ways in which this happen is through the dedicated import of PV panels from China. He currently imports PV panels for his existing business by container load, so doing the same for solar cooking would be a real option once it is known what is needed.

One supplier offered the following panel (see insert). However the voltage was above normal “safe” level and too high for the POD as built.



PERFORMANCE UNDER STANDARD TEST CONDITIONS (1000W/m² AM 1.5, 25°C)

	DESERV X-PRIME - 300Wp
RATED POWER (Pmax), Wp	300
MAX POWER VOLTAGE (Vmp), V	75.17
MAX POWER CURRENT (Imp), A	4.03
OPEN CIRCUIT VOLTAGE (Voc), V	91.67
SHORT CIRCUIT CURRENT (Isc), A	4.2
MODULE EFFICIENCY (%)	15.19

OPERATING CONDITIONS

Other panels of 100W 18V and 100W 36V were also considered. These units could be arranged to work with the proposed system. An extract of the suppliers email is reproduced below to illustrate what is readily available in country and at what price.

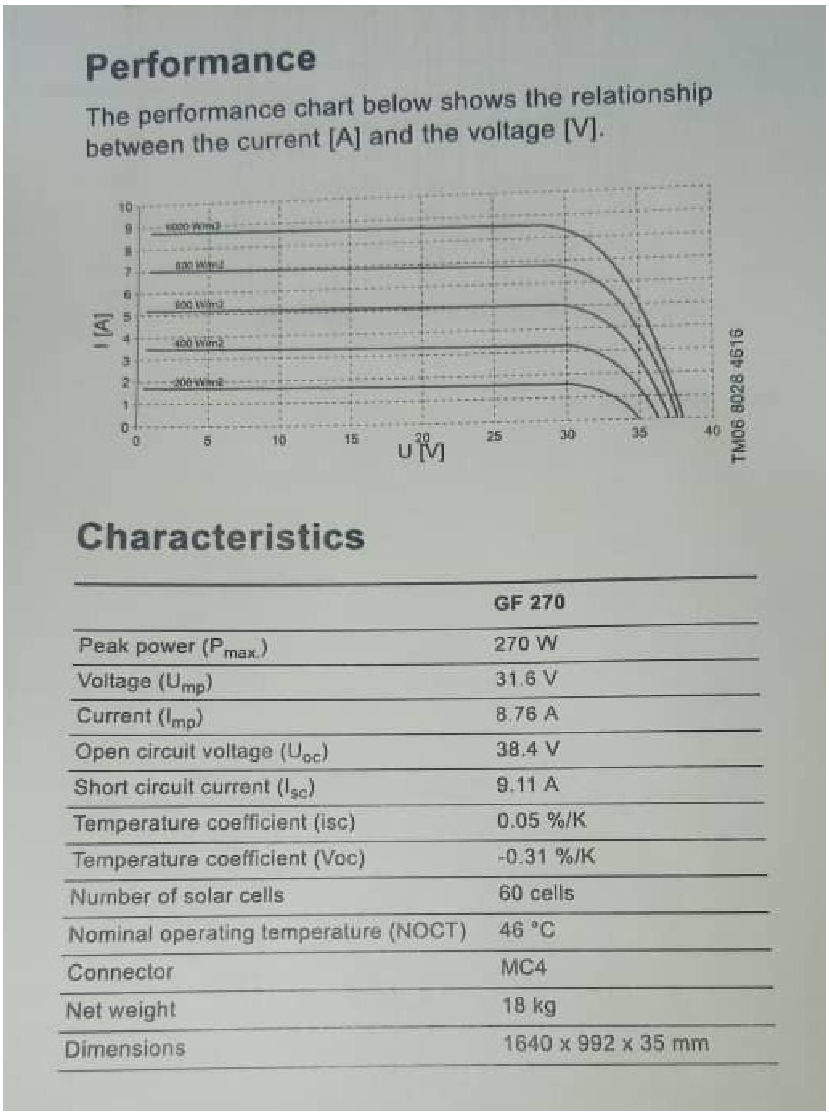
Extract of potential suppliers email *“The most prominent and high quality brand in Malawi so far is Enersol which is low voltage solar panels (100W, 18V,5.56A) and Aquasol which is high voltage solar panels(100W, 36V, 2.78A). The solar panels are very easy to buy as they come from South Africa, I have them in my shop and I sell 100W Enersol solar panels at K55,000 (57 GB pounds) and 100W Aquasol solar panels at K60,000 (63GB pounds). Please find attached datasheet for the solar panels mentioned.*

For this project, you might also need to consider solar panels supporting structure (aluminum type) which is about K80,000, (84 GB pounds). I am sure that the products (prototype) have build in batteries and charge controllers.

For other accessories, we can include DC cables 6mm which cost K1500 (1.57 GB pounds) per metre, MC connectors which is K4500 (4.7 GB pounds) per pair. Flexible conduit Ultraviolet (UV) adapted for outdoor use is k2500 (2.61 GB pounds) per meter, cable trunking is k2500 (2.61 GB pounds) per meter. We might also solar panel mounting screws, with rubber hole prug for sealing holes against rain water which cost K20,000 (20.89 GB pounds) per panel with 4 screws. I have all the necessary materials that might be needed for this project.

Conclusion

The panel chosen for use in the trial was 270W 31.6V. The specification of the panel which was readily available and competitive is given below. As the supplier offered two panels at a competitive rate, these were used in parallel during the project. This was helpful given the dull and overcast conditions experienced during the trials. Unfortunately, we had no option but to undertake our trials in the rainy season.



Performance

The performance chart below shows the relationship between the current [A] and the voltage [V].

Characteristics

	GF 270
Peak power ($P_{max.}$)	270 W
Voltage (U_{mp})	31.6 V
Current (I_{mp})	8.76 A
Open circuit voltage (U_{oc})	38.4 V
Short circuit current (I_{sc})	9.11 A
Temperature coefficient (isc)	0.05 %/K
Temperature coefficient (Voc)	-0.31 %/K
Number of solar cells	60 cells
Nominal operating temperature (NOCT)	46 °C
Connector	MC4
Net weight	18 kg
Dimensions	1640 x 992 x 35 mm

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Appendix 6

Development of

PV powered heaters

for the eCook stove

Contents

Preface

The development of the eCook stove required heaters to be developed which would be powered by photovoltaic cells. One of the requirements was that they should be suitable for local manufacture. This appendix summarises the steps taken which led to the development of two types of heater. Both types of heater can be made locally to the end user as they are simple to make and require the minimum of bought in components.

The aim to make these short accounts discreet so that they are easier to cross reference and to make it as easy as possible for easier for the reader to follow the evolution of the project.

Abstract

This appendix gives an account of the evolution of the heaters used in this project. Each iteration of development is described as a Step. Later in the project two different paths for heater fabrication were developed in parallel.

The development of a heater which could be fabricated within the low income community was a key part of our overall objectives. Simple tools, low cost and locally available materials (as far as possible) were considered essential.

Step 1: Evaluation of prior work

Introduction

Prior work led by Prof Pete Schwartz at California Polytechnic State University (Cal Poly) had demonstrated that heaters could be made using diodes. The alternative option for generating heat was the use of heater wire. A review of both approaches was required.

Work undertaken

The consultants to our project, Dr Euan Smith and Dr Paul Routley, considered both options and also had communication with the Cal Poly team.

The following exchange is a sample of the communications we have had but it illustrates the nature of this collaboration.

To Pete, Matt,(Cal Poly)

Euan here, I've been helping Paul and John in some of the discussions.

Have you looked at the reliability of the diode chain? I would have suspected that the failure mode of a diode would be open circuit, as I would think that a failure of one of the connections (wire bond to the semiconductor, solder joint, etc) would be more likely than degradation to the semiconductor itself, and unless they are well sealed then moisture could accelerate the corrosion of such joints. A single diode chain represents a lot of such contacts in series and would be susceptible to a single point of failure.

Euan. (SOWTech team)

To Euan, Paul, (SOWTech)

Euan: Exactly what we are dealing with. Moisture is infiltrating the area surrounding the diode chain, and allowing corrosion on either the first connection (copper wire to tin coated copper diode lead) or the last (same as above).

Paul: How are you able to get a PWM for $4? Sounds awesome. Is this something you are buying, or building? Thanks for the well organized diagram. This makes resistive heaters more attractive, but there is still the issue of ease of construction/manufacturing. I also am confused: the goal of the PWM is to extract maximum power from the panel AND to provide maximum power to the heater. Are you providing maximum power to the heater? What kind of losses do you expect? I have a personal solar system, and pwm charge controller by Renogy that claims 99% efficiency in drawing power from the panel and 98% conversion efficiency, for example.

…......................I applaud you for heading that direction and suggest you keep going.

Matt

This collaborative discussion and exchange has continued through the project.

Conclusions

The outcome of the review was that our technical consultants understood that the hot diode approach was workable, but on balance we decided to pursue the resistive wire approach. The reasons for this included:

- *Lower unit cost at scale*
- *More resilient to corrosion issues*
- *More operational and control flexibility*

Step 2: Tin can heaters

Introduction

The tins in which canned food is sold are available in household waste in Malawi. The first heaters we made used these cans.

Work undertaken

Resistive wire (Constantin Ni Cu) was measured to an appropriate length to give a resistance of approximately 10 ohms. This was wrapped around a can and then held in place using fire cement. The expectation was that the metal can would provide a radiant heat source. The wire has an insulating layer so it requires that layer to be stripped to make the connections. A transformer and rectifier were assembled to provide a power supply which would mimic, as far as possible, a PV panel supply.

The trial failed as the heater wire burnt off the insulation on the wire and the metal can then shorted the circuit.

The following photo illustrates the heater.

Conclusion

The can being conductive was not suitable as a heater element. A glass bottle might make an alternative which would not be electrically conductive, but which would be capable of withstanding heat, and be readily available in low income communities.

Step 3: Using Glass food bottles as heaters

Work undertaken

Using pasta sauce bottles, various heaters were made and tested. The resistive wire is difficult to hold in place with fire cement due to it's "spring" so glue gun and heat resistive self adhesive tape were used. The wrap around a bottle was easy to make once the ends were secured to the bottle.

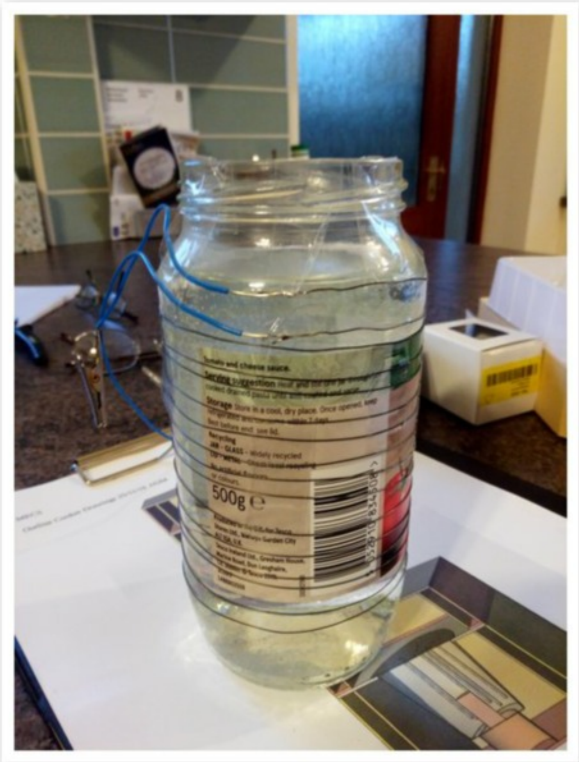
The following photographs illustrate the approach:

Conclusions

Whilst a bottle worked well as a support it was felt that we should develop a more robust heater structure.

Photo illustrations

#1 Heater wire being wound onto jar



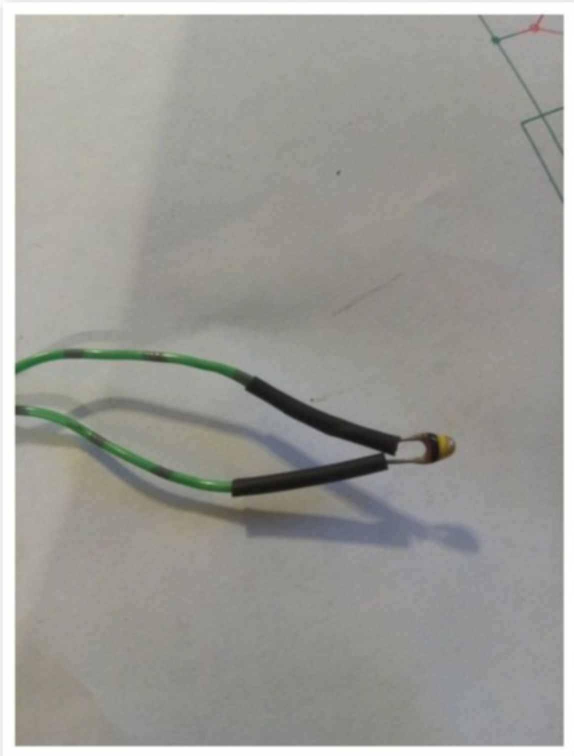
#2 Heater wires soldered to power wires

#3 Heat resistant tape being used to hold wires

#4 Wire encased with fire cement

Photo illustrations cont

#5 Fire cement being cured on stove



#6 Thermistor used on bottle to control max temperature

#7 Heat resistant tape holding thermistor

#8 Jar heater under test - note thermometer

Step 4A: Development of ceramic tile heaters

Introduction

A flat heater was felt to be the most flexible shape which was likely to be the most robust. The heater project followed two different strands of development.

One approach was to use ceramic tiles as the heat-conducting support structure. We established through our partners that ceramic tiles are readily available and in Malawi.

The second approach was to make heaters in clay. Clay bricks are manufactured within the low income communities for house building. To seek to mimic this situation, we joined a pottery workshop in Cambridge. These two initiatives ran concurrently. The ceramic tile approach will be described first in this report.

Work undertaken

White ceramic tiles, 150mm by 150mm were used to make the heaters. The method used to make the heaters evolved so this report briefly outline this process.

The first heaters were made using NiCu wire. The wire was cut to length and then wound in a double spiral on the surface of one tile. Various methods of holding the wire in place were tried, but a dab of hot glue gun worked well. Once the wires were held in place fire cement was used to make a sandwich with a second tile.

Initially the fire cement was used to just hold the two tiles together, but once we started using oil as a heat exchange material, the exposed heating wire boiled the oil. It was therefore necessary to fully enclose the heater wire.

We had some failures with the point of connection between the heater wire and the wire delivering power to the heater. Various methods such as push connectors, solder and shrink tube were used. Eventually the method found to be the most satisfactory was “chocolate block” connectors with the plastic stripped off. The used of a hot blade rope cutters worked for this task.

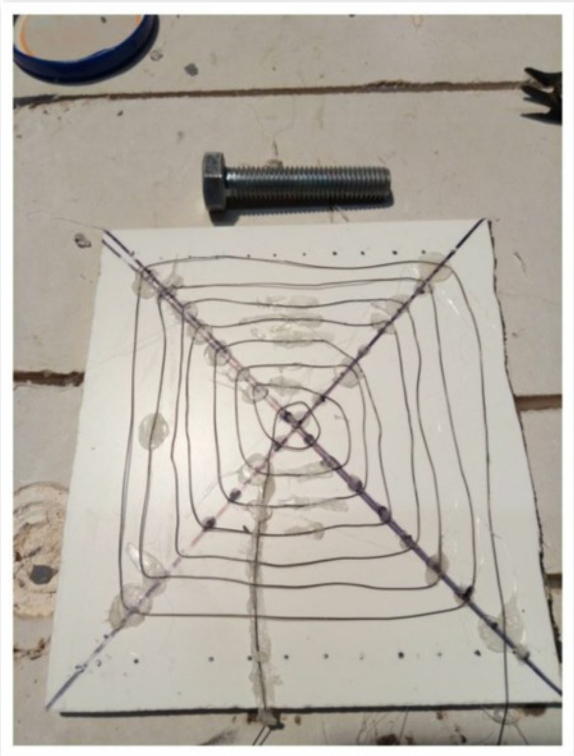
Later in the project we used cement to create thicker tiles. The cement stuck best to the smooth ceramic surface rather than the clay back. We consider this to be a result of the porous and weak surface texture of the tile. This however, will be useful if trying to mould concrete only heaters without retaining a tile.

If the concrete is not oven heated to dry out the heater fails when put to use. This is a result of the vaporisation of the moisture by the heater. This vapour is unable to escape and the resulting pressure causes the cement to blow apart. One of the other options is to “condition” the heater in oil. By putting the heater in oil, the temperature rise is controlled as the oil dissipates the heat, and the moisture vapour is released into the oil slowly and the resultant void filled with oil. This approach seems promising and worth testing further.

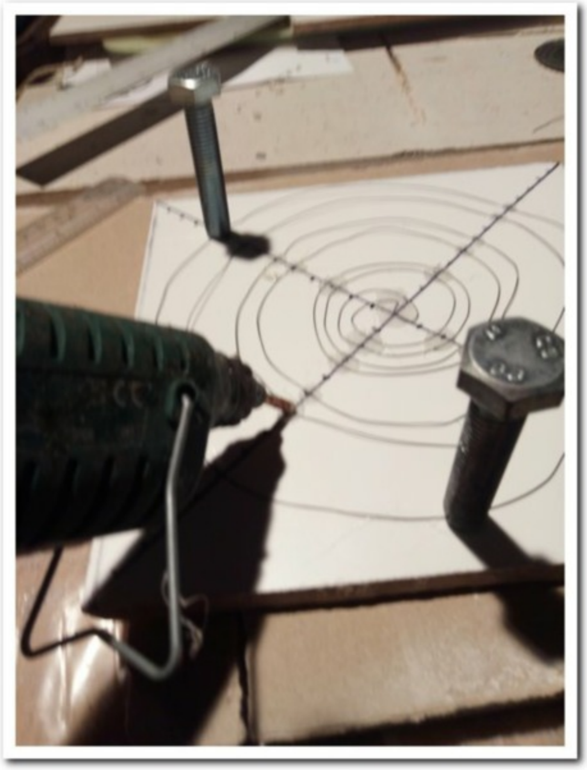
A small framework helped to shape the tile heater. Once we started fully encasing the heater wire in cement, the second tile was left off to allow for drying and vapour release.

The following photographs illustrate the processes described above.

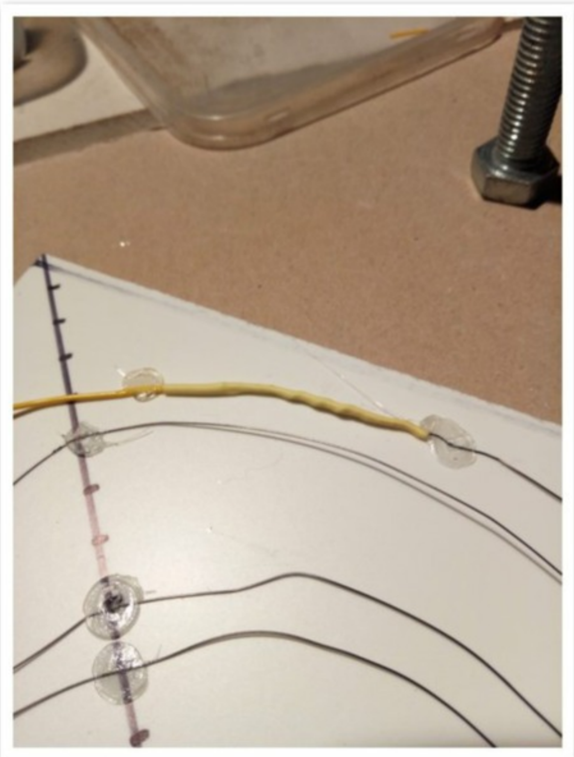
Photographs illustrating the development of the tile heaters



#1 First tile heater - overlapping wires

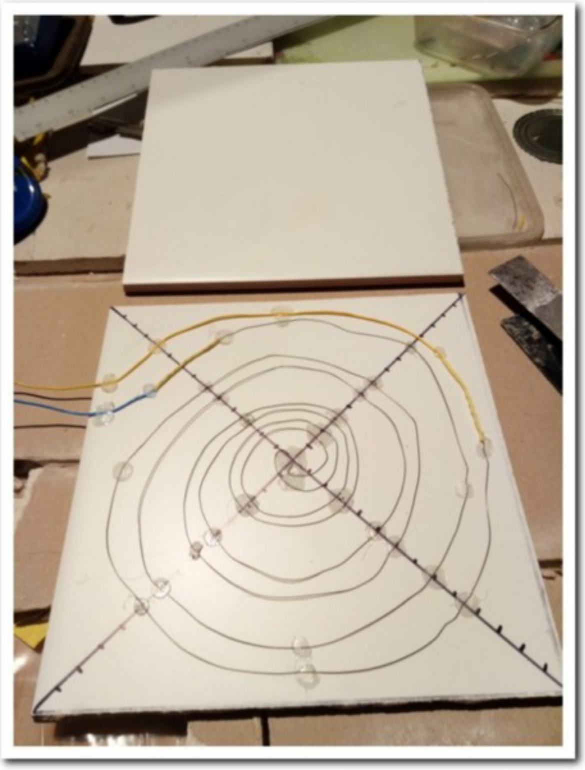


#2 Double coil wire layout - Bolts and glue gun



#3 Shrink wrap joining heating wire to power wire

#4 Fire cement used to join tiles



#5 Fabrication - Lay down the heat wire

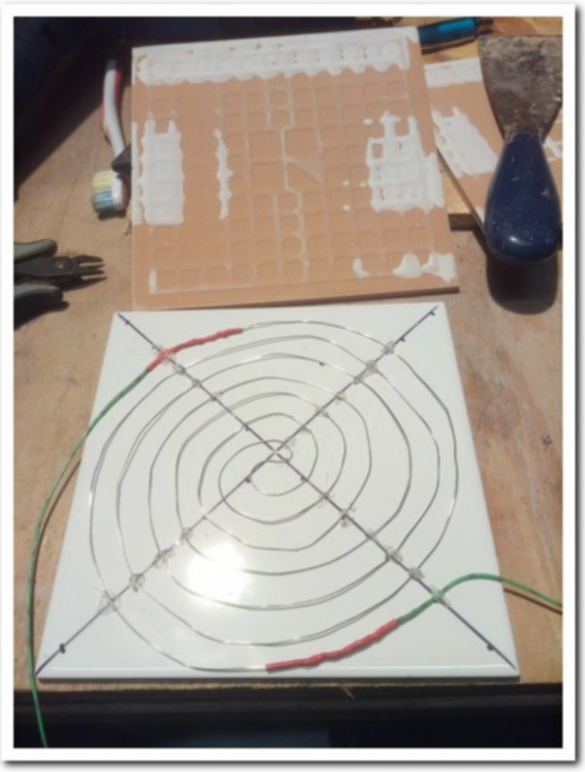
#6 Fabrication - Apply fire cement

#7 Fabrication - Spread fire cement avoiding

#8 Fabrication - Apply fire cement to second tile and apply to the first tile

#9 Start of cement/mortar trials

#10 Dabs of cement/mortar used as per wall tiling

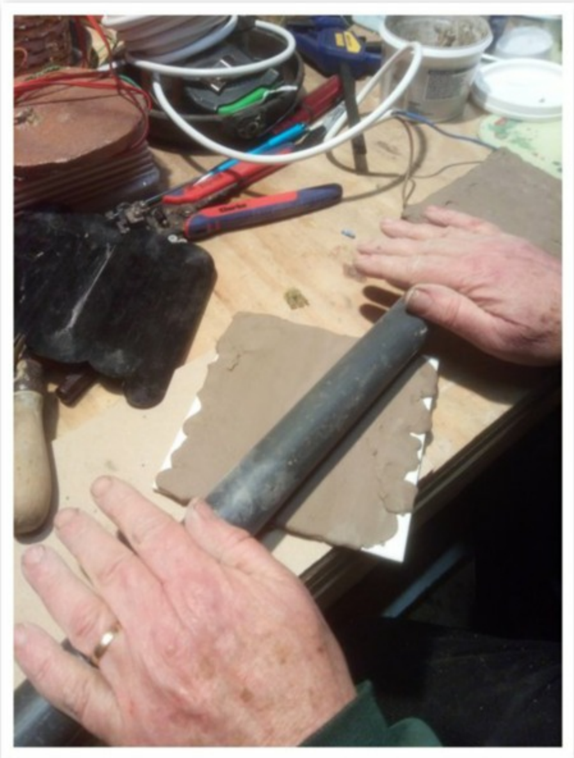


#11 Heating wire changed to Nichrome wire

#12 After fabrication always test the wires

#13 Use of 3D printed profile to mark wire path in a clay

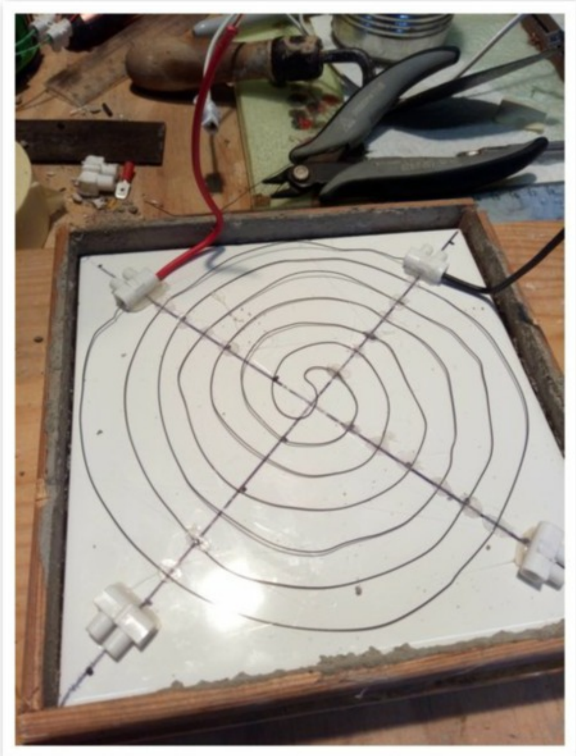
#14 Wire squeezed into clay to hold wire in place



#15 Top sheet of clay rolled out

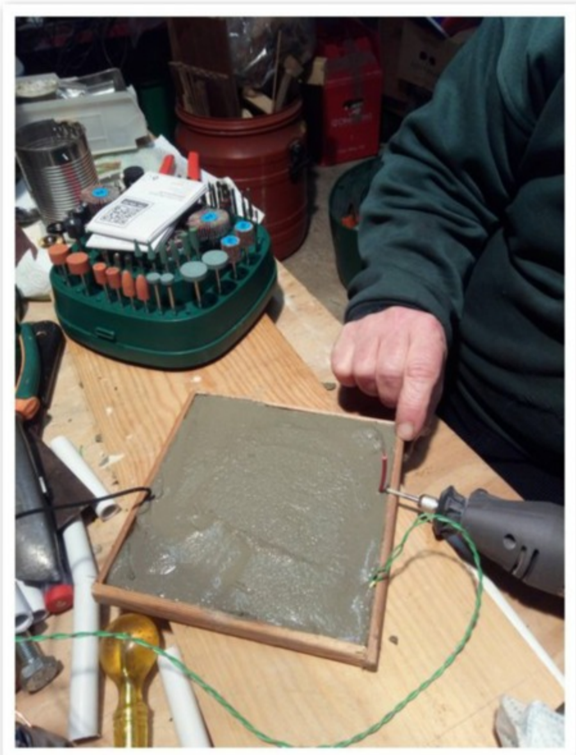
#16 Top sheet applied to wired clay

#17 Dried clay shrunk after drying. Tile weak and unserviceable due to exposed wires



#18 Wooden frame used to hold cement and experimentation with choc block connectors

#19 Heating wire being held together using masking tape



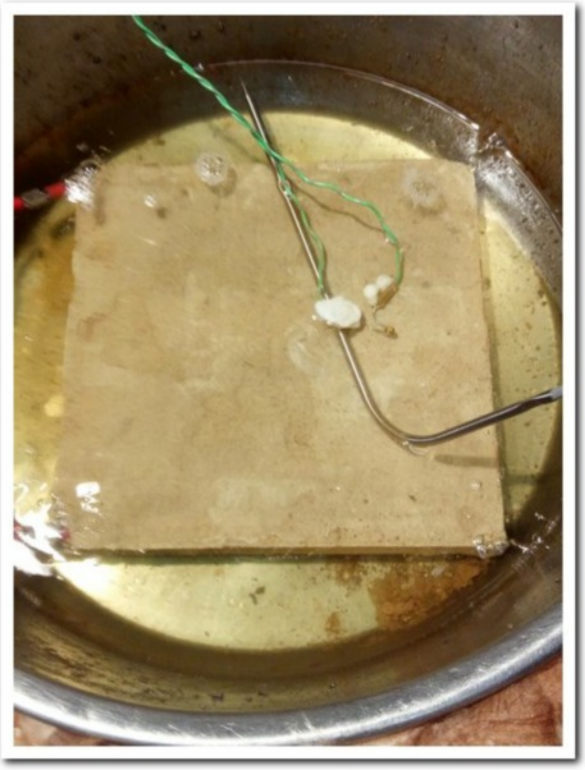
#20 Mould filled with cement. Channel being grooved for cables

#21 External choc block as connector

#22 Push fit connector being encased in cement

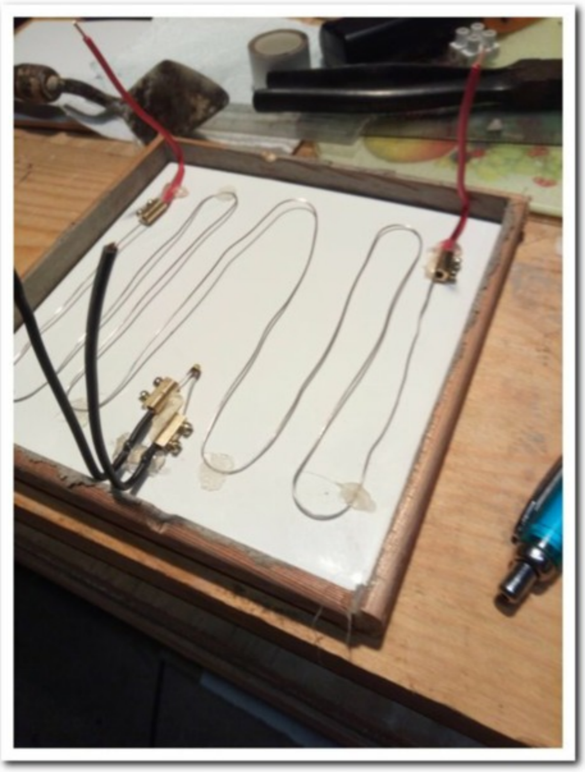
#23 Cement tile blown by heating with retained moisture - A

#24 Cement tile blown by heating with retained moisture - B



#25 Oil bath being used to condition cement

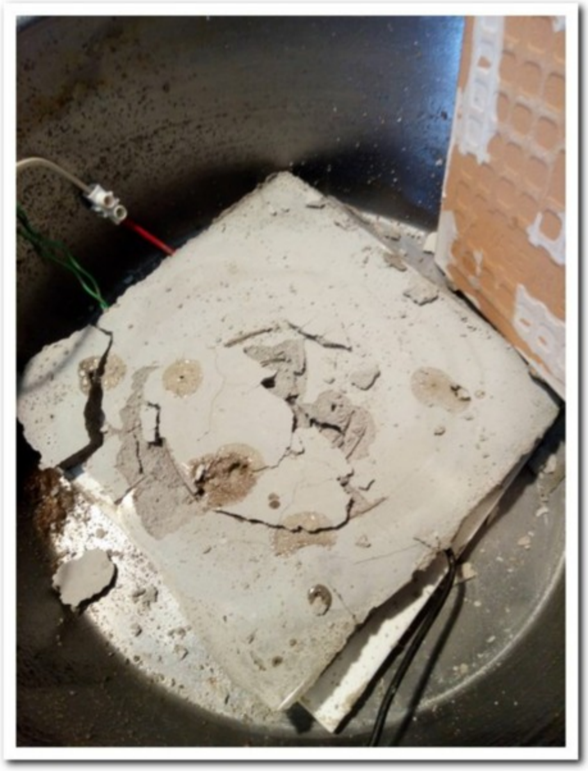
#26 Revised wire-shaping framework with shorter distances



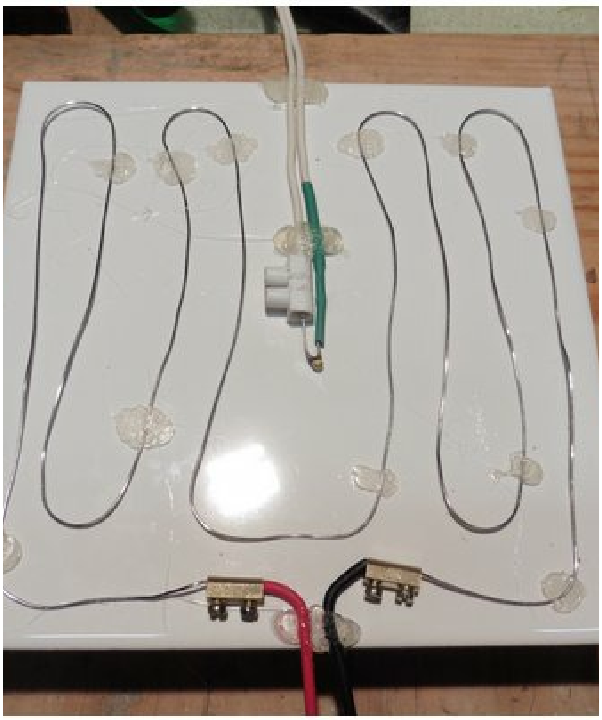
#27 First version of mould showing wires coming out in the vertical plane

#28 Revised mould to allow wires to protrude in a horizontal plane

#29 Stripped choc block shown as internal connection to power/sensor wire



#30 Thermistor connection using a choc block to provide tension support once in cement



#31 Wire arrangement to allow for horizontal emergence

#32 Clamps being used to hold tiles whilst setting

STEP 4B: DEVELOPMENT OF CLAY TILE HEATERS

Introduction

The use of clay to make bricks is a familiar process to most rural economies in low income areas. To make heater tiles using clay is a good fit with our objective of developing a locally manufactured eCook stove. In order to explore this option we joined a workshop in Cambridge which offers facilities for pottery making. (https://www.kilncambridge.com/)

Dr Paul Routley, our technical consultant undertook this experimental work and he was given assistance from Dr Bilgin Soylu, one of the owners of the facility.

Work undertaken

The first trials with the clay was undertaken using Constantin (Ni Cu) heating wire. The wire was pressed into the clay in the shape of a double loop. This clay was then dried and fired. The shrinkage of the clay during firing of the clay was enough to cause the heater wire to become exposed. The temperature of the kiln was hot enough to cause the heater wire to fail. Photos are included below to illustrate this issue.

The conclusion from this work was that a more robust heater wire should be used. The Constantin wire has a melting temperature of 1200°C and this was subsequently changed to Nichrome wire which melts at 1500°C

Further tiles were made with the new heater wire. The method of assembly was changed.

A wire path template was developed and printed on a 3D printer in plastic. This template was then used to press a depression into the clay tile which corresponded to the predrawn path of the heater wire. Once the wire was in place, a second disk of clay was applied onto the first disk of clay, thus encapsulating the heater wire.

The heater wire was left exposed during firing so that the power supply wires could be attached later. During firing, the clay did shrink and in some instances the clay cracked. The heater wire circuits were not broken so some cement paste was used to fill the cracks.

As the Malawi field trial arrangements progressed, the resistance of the heater wire was changed from around 8 ohms to 3 ohms, to accommodate the type of PV panel which was to be used.

There were instances during the trial where the point of connection between the power supply wires and the heater wires was vulnerable. As exposed heater wire became a source of boiling oil in the later trials it was necessary to further cover the heater wire on the tiles after firing with cement paste.

Conclusions

The clay tiles worked well and were very robust. They remain a workable proposition for local fabrication, but refinement of the process is needed to overcome identified weaknesses. One downside for the clay tile was that it is not easy to creating a smooth surface which can act as a hotplate for cooking.

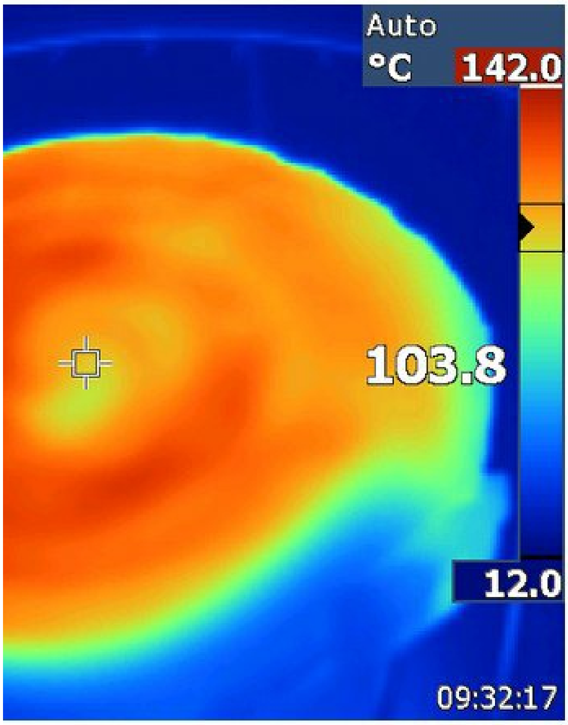
Photographs to illustrate the development of the clay heater tiles

#1 First attempt at clay heaters. Burnt out wire shown as brown flecks

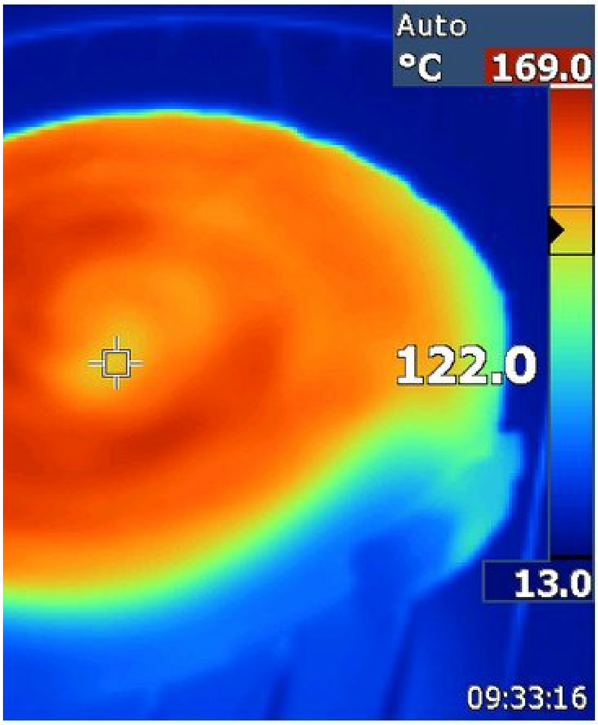
#2 Close-up of damaged heater wire

#3 Version of clay tile under heating load. Infra red photos of this tile below.

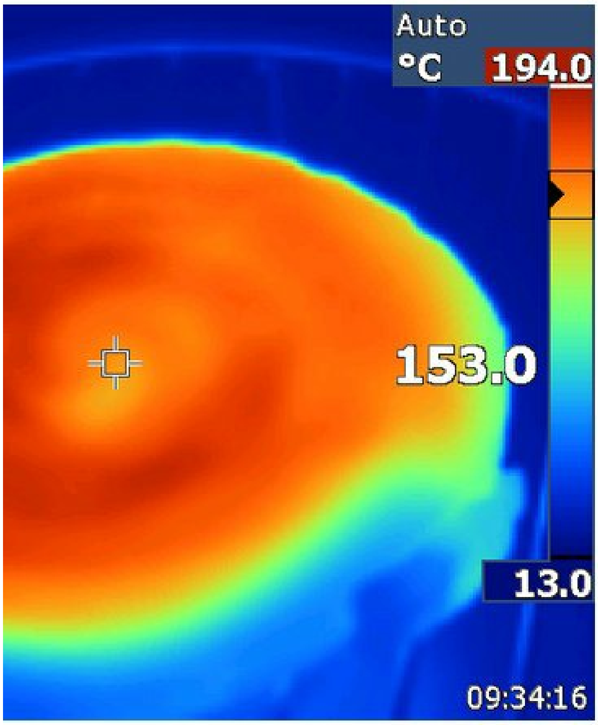
 # 4 Clay tile having been used in PCM. Reinforcements of cable showing on right



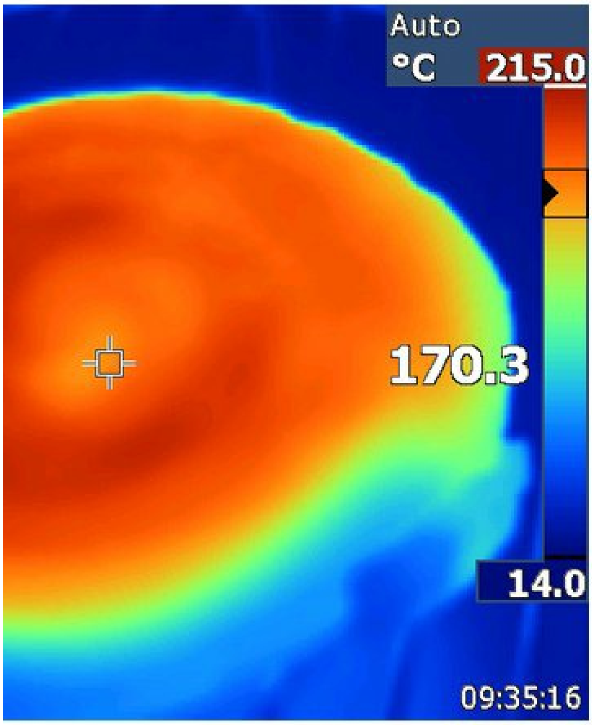
#1 Series of Infra red photos of heater plate trial. Max temp shown at top right.



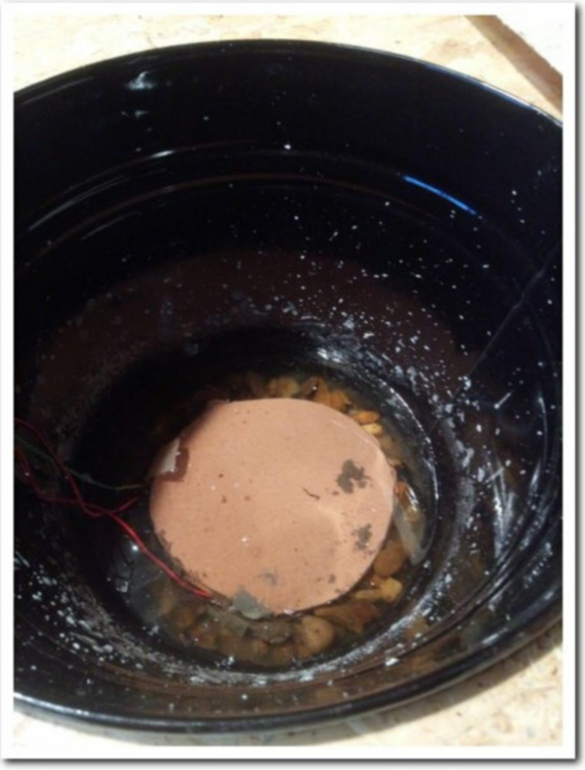
#2



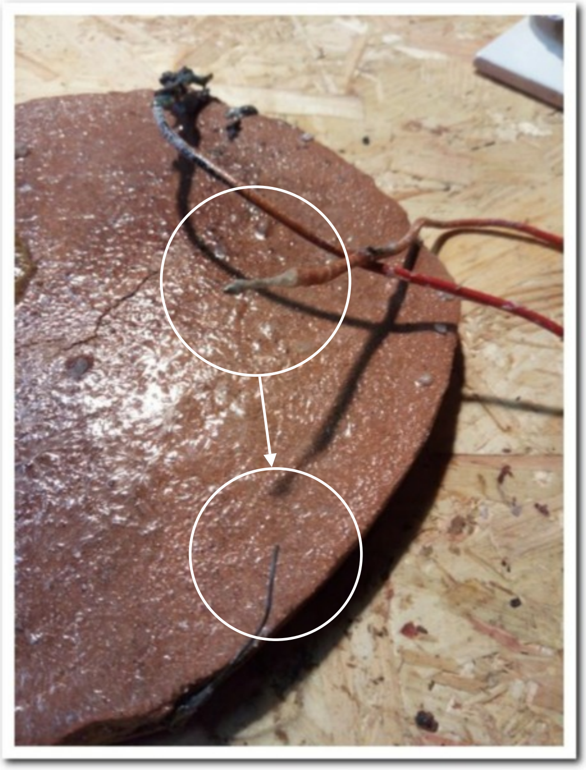
#3



#4 Max temperature shown as 215 C



Clay heater in molten PCM. Gravel used to raise the heater above the base of the bucket



Power cable to heater cable failure. This failure resulted in heater beina frozen in PCM

3D printed template for heater wire in clay heater plate

Hotplate trial showing pan on top of clay tile.

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Appendix 7

Technical Report

Field Trials

Malawi Prototype

Contents

Preface

This appendix gives an account of work undertaken in conjunction with partners Aquaid Lifeline, at the children's village at Namisu, near Blantyre, Malawi. The work was undertaken between the 10-14 February 2020

The report is divided into discreet work packages described as tasks. Each task is introduced to set the context and the tasks are given in chronological order.

SOWTech received substantive support from its local partner Aquaid and this support and assistance is acknowledged. A special thanks goes to the General Manager, Angus Gaisford.

The Task: Functional test of eCook stove components in Malawi

Introduction: Field Trial A

This was the first field trial of the eCook stove in Malawi. We selected a location outside the guest house as the centre for the trials. The reasons for this being: ease of access at all times, access to a kitchen, proximity to place of work of a local cook and 24 hour security cover for the equipment.

The objective of this trial was to assemble the equipment which had been locally made and to functionally test all the equipment.

Work undertaken

The prevailing conditions were overcast so two PV panels were wired in parallel. The power optimisation device (POD) was connected to the PV. A thermal break was fitted to the heater power circuit as a secondary cutout for the heater.

The structural elements of two eCook stoves had been made locally. SOWTech had provided technical drawings to partners Aquaid Lifeline. They had used local labour to build the structures.

The eCook stove units included an insulated base unit, a hotplate support and a top cover. Into these components are placed an outer steel vessel and an inner steel vessel. Onto the top of the vessels fits the steel hotplate with heat transfer rods welded to the base.

For insulation of the boxes a limited amount of fibrous insulation had been obtained and this was used to fill the outer voids in the base units and the lids. The inner void between steel buckets and outer insulation was filled with clothes and other fabrics.

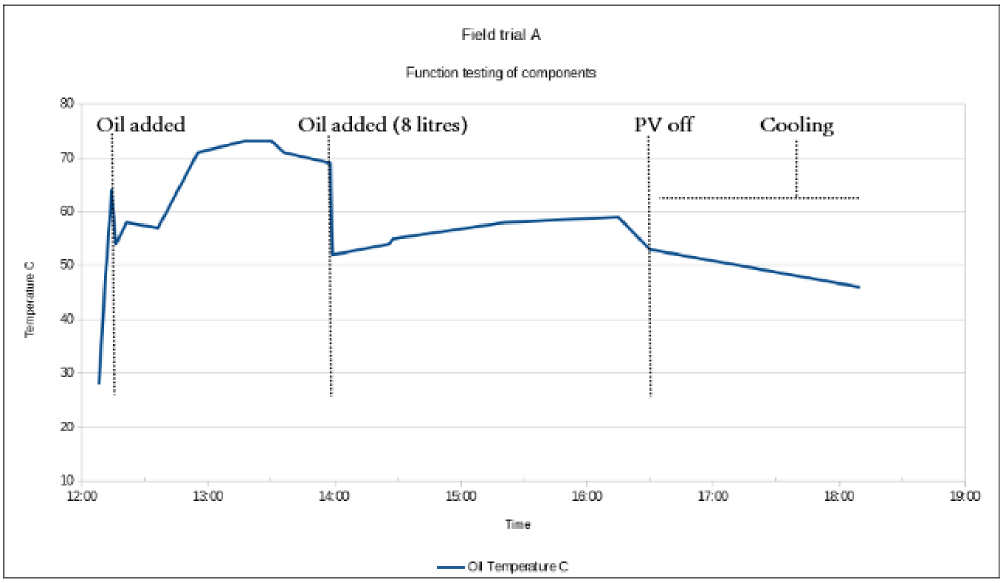
Our Aquaid partners reported no difficulty in the manufacture of the units. They felt that in the light of this prototype experience, there would be considerable potential to reduce the costs of fabrication with more time to negotiate better labour rates and using cheaper alternative materials. For example, blockboard was used as the sheet timber, but there are cheaper alternatives which could be considered for future projects.

Photographs of the eCook stove components are shown below.

The first step was to make all of the connections and to add a small quantity of cooking oil and to monitor temperature to check if the heater plate was working.

Once the equipment was assembled it was filled with approximately 8 litres of cooking oil and 5 kg of Phase Change Material (PCM).

The heating trial commenced at 12:08 local time. The graph below shows the data collected and the “events” during the heating trial.



Conclusions

All of the electrical elements were shown to be functioning:

- The PV panels were generating electricity.
- The POD was controlling the voltage of the solar panel and delivering power to the heater.
- The heater was functioning and elevating the temperature of the surrounding cooking.

The maximum temperature achieved during this trial was 73°C in the oil. The voltage delivered to the heater varied between 4.2 and 8.3V It was clear from this that the overcast conditions would severely curtail the output of the panels.

The volume of oil (8 litres) was considerable and in future iterations of the design reductions in this volume should be a design objective.

A temperature drop from 59°C at 16.15 to 46°C at 18.10 showed that the heat retention within the oven was poor.

Protection of the wires from being damaged by the top of the metal vessels was noted for improvement. The PV connectors became disconnected so these need to be improved.

Photo illustrations

#1 Clay heater tiles brought from the UK for trials

#2 Ceramic tile heaters brought from the UK. A coil of resistive heater wire also shown

#3 Two Power Optimisation Devices (POD) brought from the UK. One POD is mounted in a ventilated case. Wire connections are PV power in, power to heater and thermistor controls. USB phone charge connection visible on the front left of the unboxed POD

Photo illustrations cont

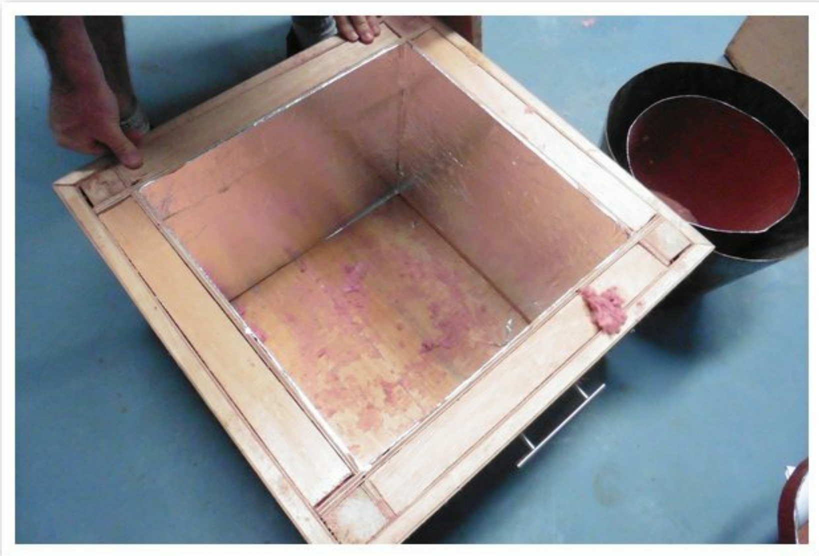
#4 Erythritol phase change material (PCM) for trials

#5 Two oven thermometers used for the trials

#6 Electrical meter used for measuring voltages and various power and sensor cables & connections.

Photo illustrations cont

#7 eCook stove base unit made in Malawi

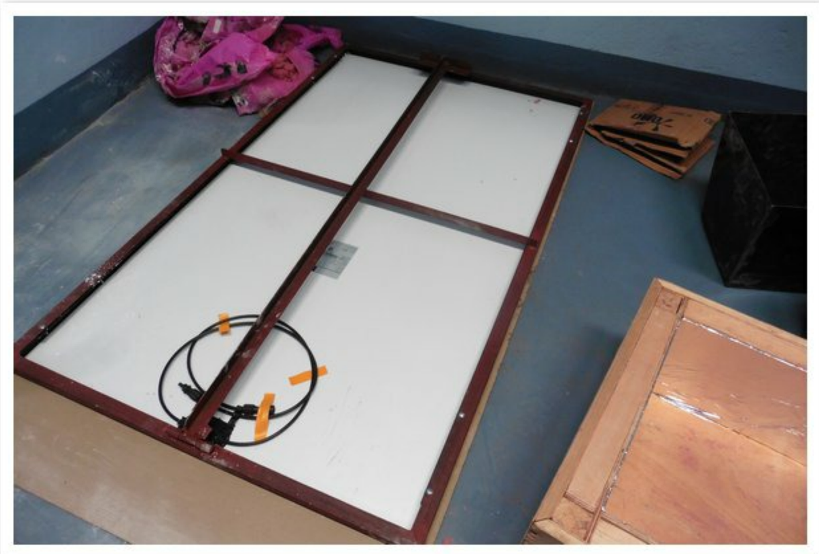


#8 Flock fibreglass insulation obtained in Malawi and fitted between the double walls of the base unit

#9 Steel vessels made in Malawi for the eCook stove. The original specification was modified just before the trials started to facilitate the oil based heat transfer arrangements. Two eCook stove structures were made, one with round vessels and the other with square

Photo illustrations cont

#10 Steel hotplate with rod heat conductors. Two plates like this were made, both made in Malawi



#11 Steel support structure for the PV panel constructed to facilitate movement of the PV unit for the trials. Frame made in Malawi

#12 eCook stove being assembled. Old fabrics and clothes being packed around the PCM vessel for provide insulation

The Task: Demonstration of the phase change process to our African partners

Introduction

The assumption behind the main approach of this work is that a chemical heat battery will be used to extend the heating period so that cooking can be achieved when PV is not generating any energy. The objective of this task was to show our partners and potential users of the system how phase change material stores heat. Erythritol, the phase change material selected for this project, would be melted and then subsequently cooled so that it became solid again. The continuous release of heat during the cooling process would be demonstrated. The explanation of the chemistry for the release of energy during solidification is challenging. This task was a way to "show and tell". Illustrating the process in real life was used to convey the concept of the storage of heat energy.

Work undertaken

The process which follows was observed by both our partners in Aquaid, (Angus and Josie) but also by one of their Malawian staff, Eviness.

A quantity of granular phase change material (approx. 500g) was placed in a small cooking pan. The guest house LPG cooker was used to gently heat and melt the PCM. The melting was observed by the participants, and particular attention was drawn to the fact that part of the PCM could be molten whilst a few centimetres away unmelted PCM was at a completely different temperature. An oven thermometer was used to demonstrate that the molten material was at a temp of 155°C whilst the unmelted material was only at 75°C.

This task also illustrated to the team the change of appearance of the PCM after cooling.

The following graph contains the temperature decay data/graph. The following photos show Eviness, a young mum who works in the charity, being shown the process. Further, less technical explanations were later given to many of the younger generation!

Conclusions

The task helped the Malawian partners to appreciate the function of the PCM. Considerable surprise of the heat release properties of the PCM were expressed. It is of note that even after 2 hours of cooling the temperature of the PCM was 43°C.

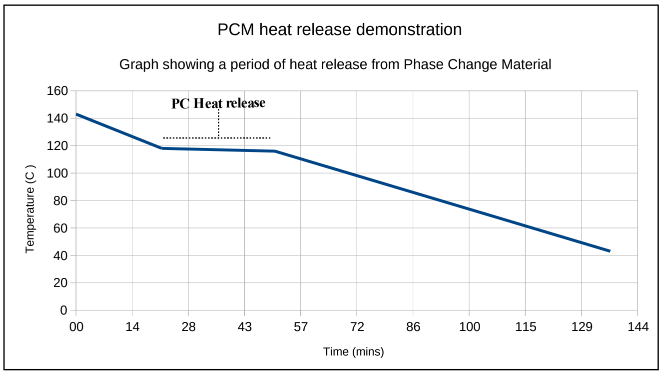


Photo illustration

#1 Local Mum and employee of Aquaid, Eviness, being shown by John Mullett how the Erthritol melts and then solidifies with the release of heat

#2 Photo of the pan showing the partially melted Erythritol. The steel probe of the oven thermometer is also visible in the pan

#3 Josie Charter, a trustee of Aquaid Lifeline, shown chatting to some of the orphans which the charity supports. Questions about our trials were among the many topics of conversation with the youngsters

The Task: Observations on the first day of operation

Introduction: Field Trial B

This trial was undertaken over the first full day of the field trials. The objective being to observe what heating could be achieved with the eCook stove as built.

The work undertaken

The eCook stove PV panels were set up at 06:49 and oil temperature reading as voltage readings commenced. After setting up the equipment a visit was made other parts of the centre. During the time away, there was a period of heavy rain. During this time, the PV panels were brought undercover by Eviness as a precaution. After the rain the PV panels were reinstated.

The conditions were overcast for almost all of the time but when there was mild sun, the PV readings reflected this. (See table below at 09:35).

Observations made during this trial identified that there was considerable heat loss between the main elements of the structure. In particular, air gaps were visible between the three parts of the eCook stove structure (the base unit, hotplate support and the top cover).

Similarly is was noted that there had been significant heat losses overnight. It was resolved to undertake as much additional insulation work as possible. Foam tape and blankets were requested. During the day these materials became available and were fitted as soon as it was possible. The added insulation events are illustrated on the graph below.

During the period of this trial, our partners introduced our work to a pupil, Lupactio Mwandenga, who had completed his secondary education and was going on to University . He expressed considerable interest in the trial and engaged in discussion as he was fluent in English. Another older man who was employed as a guard then engaged with Lupactio in Chichewa. The photos below illustrate the unplanned but significant local engagement with the project.

By early afternoon, our partners had procured blankets and foam tape to assist with improvements to the insulation of the unit. These changes are noted below.

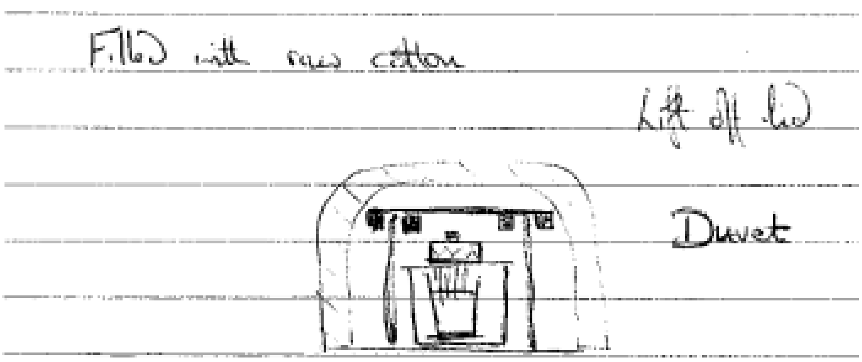
By mid afternoon, the oil temperature had achieved 85°C despite the overcast conditions. A pan with water and maize flour (ratio of 1:2 v/v) was then put onto the hotplate (and covered using the lid).

A repeat of the concern regarding loose wires on the PV connectors was observed. At the end of the afternoon the PV connectors were rewired to achieve a more secure fitting. (Note the standard PV ML4 fittings are not designed for repeated disconnection as required by the situation of the trial.) Some of the spigots of the connectors were removed to aid the disconnection. The disconnection was required to be able to move the panels for added security overnight. (Armed police patrol the site overnight as the risk of intruders is significant.)

Conclusions

The heat losses from the structure are too high. Added insulation is improving the situation. Further work on forms of local insulation is needed. Options discussed with our Malawi team include raw cotton which is grown locally, multilayer tinfoil fabric structures which could be made locally, and the use of the "fluff" from disposable nappies which is also available locally. The duration and seasonality of this field trip did not permit these concepts to be built and tested on this occasion. A lightweight shaped "duvet" style cover for the eCook stove would probably be an effective option if combined with a lift off lid and a single unit structure.

The pan with the flour/water was showing some thickening at the bottom of the mix. This observation indicates that the heat being transferred through the hotplate to the pan was poor. Further investigation of this is required.



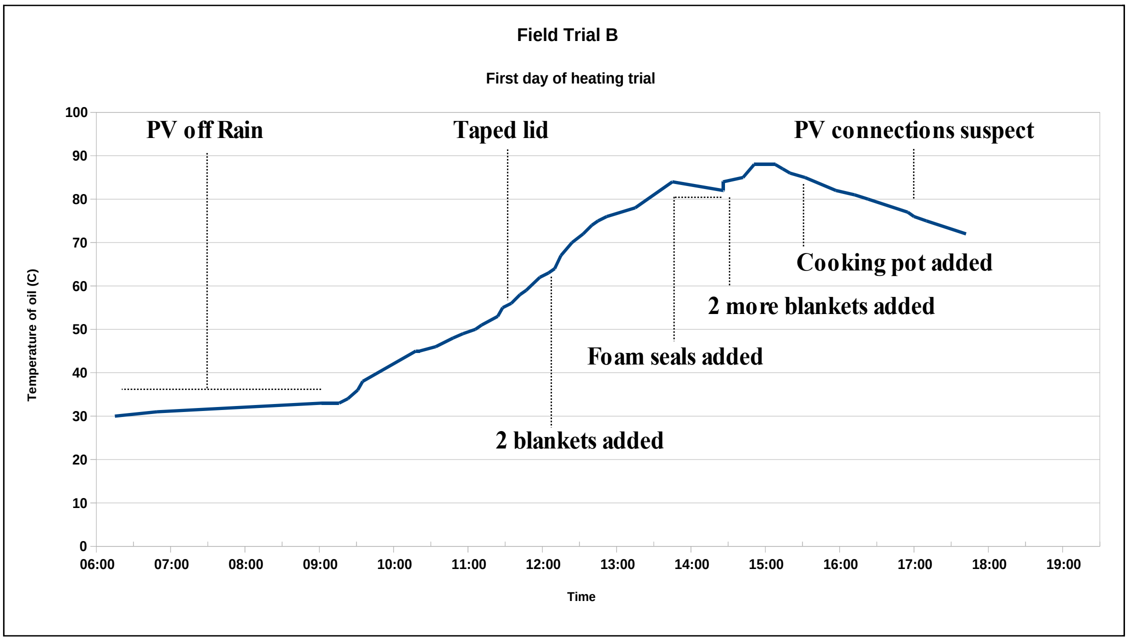


Photo illustrations

#1 Two PV panels being used to collect solar power. Each panel is rated at 290 watts

#2 This photo shows the stoves in preparation for use. The area was undercover and close to a kitchen within the guesthouse of the children's village

#3 Photo illustrating the spacers used below the outer vessel. The purpose of the spacers is to raise the vessel off the base to improve insulation

Photo illustrations cont

#4 Outer oil vessel placed inside the base structure

#5 Filling the void between between vessel and base with used bed fabrics and clothes

#6 Hotplate support being placed onto the base frame. One of the issues to cause concern is the seal between the base and the hotplate support. In this instance a fabric was used to close the gap

Photo illustrations cont

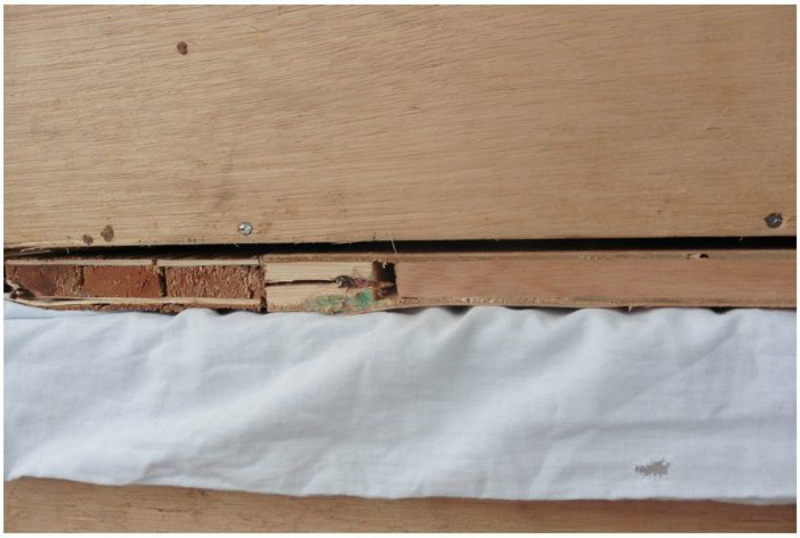
#7 Spacers, heater and thermistor cables visible. Small amount of cooking oil in the base visible

#8 A detailed issue which would needs a refinement is the protection of the heater cables as they emerge from the vessel to prevent damage to the cable

#9 This photo shows the two vessels - one inside the other one for oil and one for PCM

Photo illustrations cont

#10 The PCM shown in the centre vessel



#11 Photo illustrating the difficulty of sealing the lid and the base. This gap allows heat to escape from the oven

#12 Foam sealant being applied to the inside edge. This approached stopped the air path out from the vessel, but this issue needs further attention

Photo illustrations cont

#13 Lupactio Mwandenga is shown in this picture. He is the pupil from the orphanage with the highest exam score. He spent time with John Mullett, and showed a significant interest in the experiments. This was possible because Lupactio spoke very good English

#14 This photo captured an exciting moment. Rager, the man on the right was a guard on the site. He had watched the trials and helped out when needed. Rager does not speak English. He approached Lupactio and he spent time asking and learning what the experiments were about

#15 The interest sparked by the trials meant that the children were often present in significant numbers. Their curiosity seems about something new may prove an important element in the pathway to change

Photo illustrations cont

#16 Eviness preparing the mix of Maize flour and water that is used to make Nsima

#17 Stirring the nsima in the pot within the eCook stove

#18 The eCook stove achieved a thickened paste resembling Nsima. However there were taste differences reported by Eviness and others. The most probable explanation is that the mix was not heated to a high enough temperature

The Task: To observe the impact of improved insulation

Introduction: Field Trial C

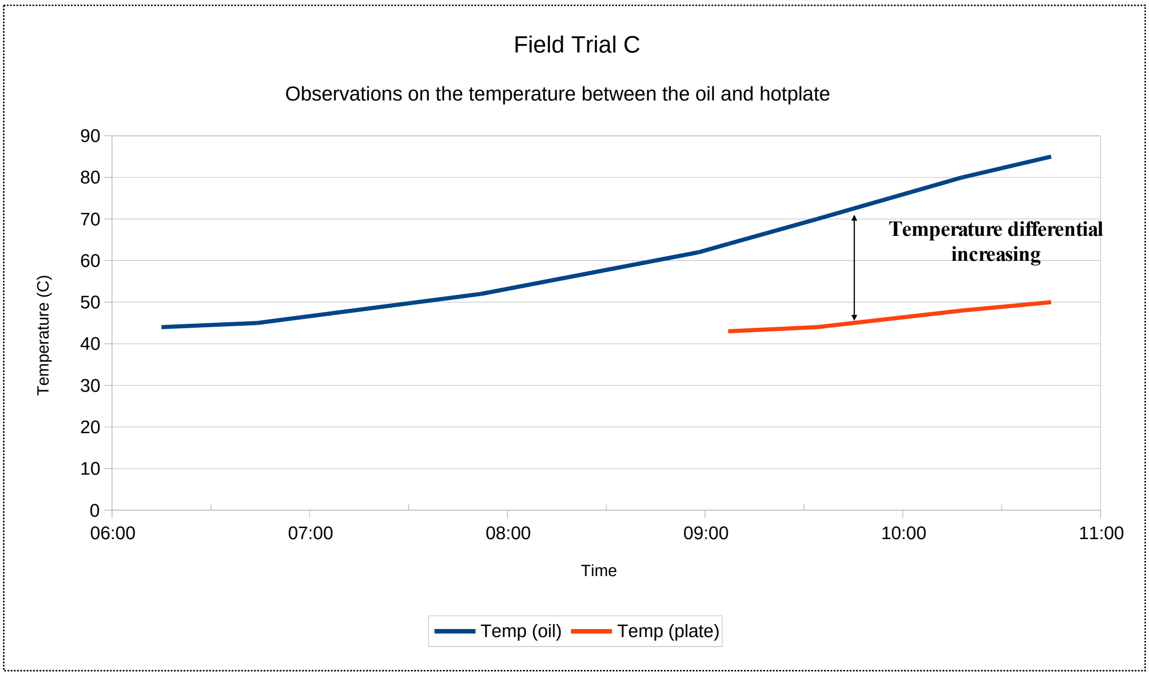
The observations made during the previous task indicated that whilst there is a reasonable level of heat being generated in the oil, the heat is not being transferred to the hotplate and cooking pan. This trial sought to try and investigate the effects of improved insulation and to investigate the temperature difference between the oil and cooking pan.

Work undertaken

The trial commenced at 06:15 with an oil temperature of 44°C. The enhanced insulation has elevated the starting temperature by over 10°C. This is an improvement. The data for the days trial is given below in the table.

A new probe to measure cooking pot temperature as well as oil temperature was installed at 08:58. This shows a differential of approx. 20°C. At 09:05 the two temperature sensors were cross checked for consistency and were exactly the same.

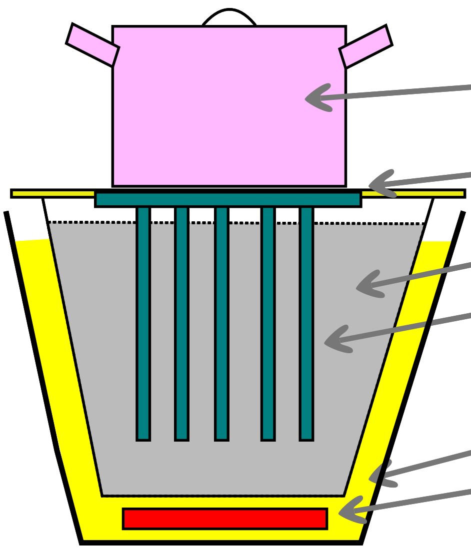
The observed temperature differential between the cooking pot and oil increased as the temperature of the oil increased so that by the time the oil temp was 85°C the pot temperature was still only 53°C, a differential of 32°C.



Conclusions

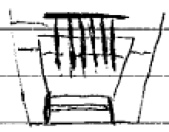
The above data led to a review of the overall arrangement between the PCM and the oil.

The original concept was to heat the PCM directly with no oil involved. This plan was amended to include cooking oil to help transfer heat from the heater to the PCM using a second vessel as the oil aided heat transfer into the PCM. This is the configuration used in the trial above. However given the delay in the heating of the pot this situation was reviewed.



The use of the PCM was in fact blocking the heat pathway from the oil to the hotplate and pot. As has been shown, the PCM is actually a very poor conductor of heat. It was decided that one option was to reverse the location of the PCM and oil. Put the oil and heater immediately below the hotplate and the PCM around the outside. This would improve the rate at which the heat was transferred to the hotplate and the PCM would act as an effective insulation until it melted. The day's trial was halted at 10:45 to effect this change. At this point the differential was 32°C. The decision was taken not to put PCM in the outer vessel, as the lack of sunshine and therefore power was depriving the scheme of enough temperature to melt the PCM. The impact of making this change is given in the following task report.

Issue



PCM is keeping hotplate cold
Option
A Put oil into PCM vessel + use oil
to convey to rods. Need a lot of oil
vessel + may not have it + not hot enough to melt

The Task: To reduce the temperature differential between oil and pot

Introduction: Field Trial D

The previous task showed that the elevated oil temperatures were being insulated by the PCM from reaching the hotplate. The arrangement of the experimental cooker was changed so that the heated oil could be in direct contact with the hotplate and the heat transfer rods.

This task commenced at 11:15 and the initial temperature differential was 40°C due to the hotplate being air cooled to 34°C during the changeover.

Work undertaken

Having put the oil that was in the outer vessel into the inner vessel the PV heating was restarted and recording made. Again the PV was only able to deliver a low voltage power due to the overcast conditions. The data obtained is below.

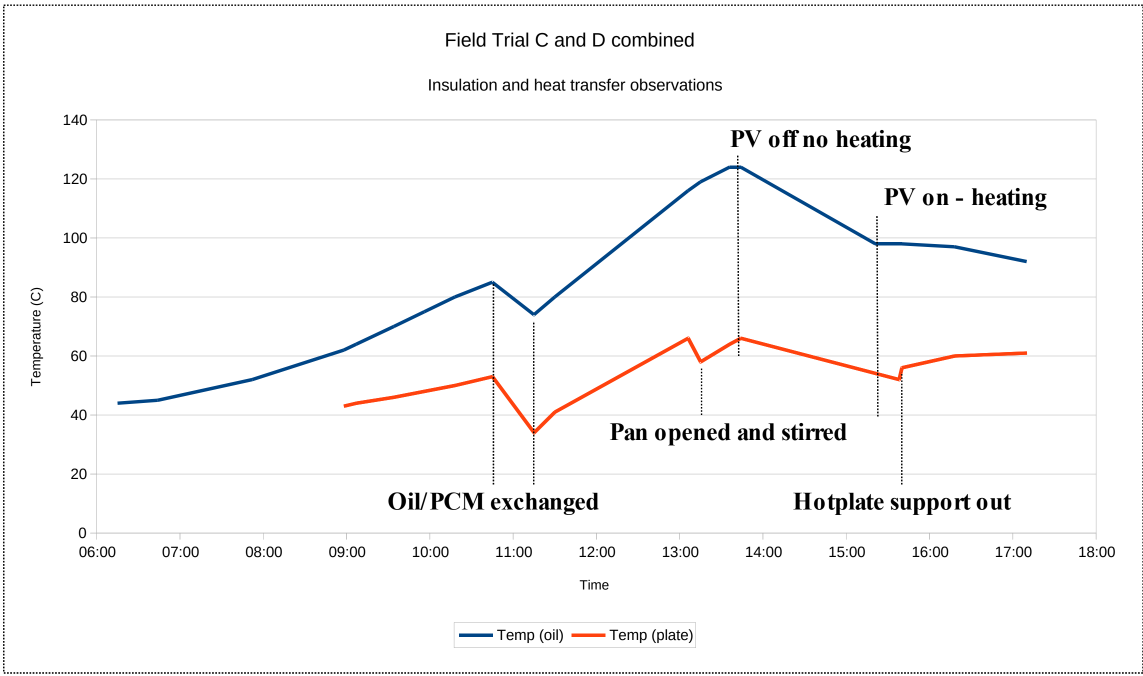
From this data it is possible to see that the temperature of the oil rose to 119°C by 13.15 but the temperature in the pot did not rise at anything like the same rate, being at 58°C at that time. This is a differential of 61°C. This results indicates that further improvements to improve heat transmission the hotplate are required.

At this time a further assessment of the flour water mix in the pot was made. It showed that the flour was not hot enough to achieve full thickening.

By 13:36 the temperature of the pot was still only 64°C whilst the oil temperature was 124°C.

The Task was suspended in order to use the PV power for a trial of a hotplate. The measurement of oven temperature was continued whilst the PV power was disconnected.

By 14:26 the internal temperature of the oven had cooled from 124°C to 109°C. The rate of cooling indicates that there should be further effort made to improve the insulation. This would benefit all aspects of cooker performance.



Conclusions

The placing of the heater into the oil and the oil being in direct contact with the hotplate rods did not achieve the big improvements in heat transfer that were hoped for. However the slope of the two temperatures, oil and hotplate did track better than before the change was made.

Heating of the eCook stove was resumed at 15:21 when the oil temp had fallen to 98°C.

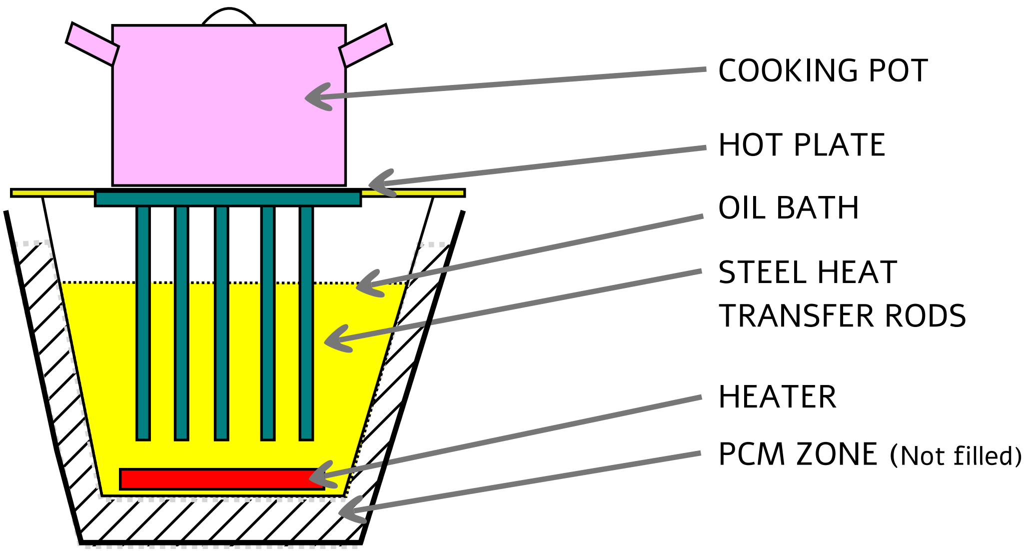
At 15:38 the pot was found to contain a thicken flour paste. See previous photo. It showed that the flour had cooked but the time taken was long. The taste of the paste was metallic which is probably a reflection of the duration of cooking.

Given the challenge of getting the heat transfer from the oil to the hotplate, it was decided to undertake a cooking trial directly on a heater tile. This concept would give a direct heating to the pan from the tile without the medium of oil.

The heat transfer needs to be improved. The level of oil in the base container was significantly below the top of the vessel so adding more oil could bring the hot oil into closer contact with the hotplate. This improvement is tested in the next oven trial.

Photo illustrations

#1 Rager assisting with the task of removing the oil from the outer vessel and transferring it into the inner vessel as part of the new arrangement



#2 Diagram of the new arrangement with the oil in contact with the heater rods

The Task: To test the heater tiles as a cooking plate

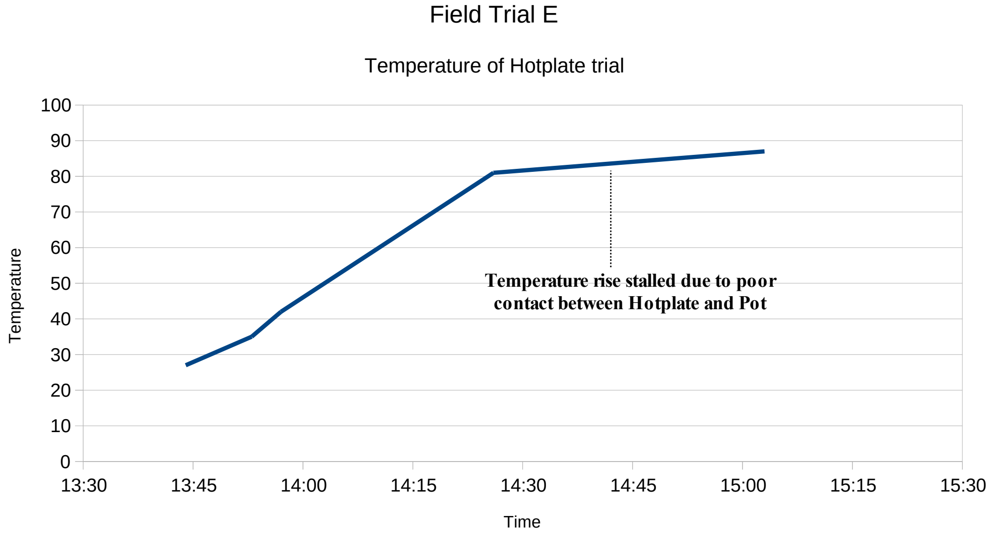
Introduction: Field Trial E

The use of the heaters developed for the eCook stove may have potential as a plate heater used directly below the pan. A small initial trial with the clay heaters showed that the undulating surface of the clay made it difficult to get a good contact with the pot. However the heaters we made which are based on the ceramic tiles would be flat enough to give good contact with a pan. A second trial during one of the periods of hazy sunshine it was decided to try this out.

Work undertaken

The first trial was carried out with a clay tile.

The results of the heating was made by recording the temperature in a small pan placed on the tile. The heating commenced at 13.44 with a water temp of 27°C. The data for the temperature in the pan is shown below.



The second trial was made with a ceramic tile heater. The output from the POD was connected to a tile heater with the smooth ceramic face being in contact with the pan. The tile was placed on a piece of tile to insulate it from the paving stones below. A pot of water was placed on the tile with 300ml of water in it.

During the water heating period a Malawian lady called Beata, who had spent time with me the previous day, came by and I passed the process of cooking to her. When she judged the water hot enough she added a spoonful of Nsima flour. This was then subsequently stirred at intervals. It did thicken and boil to the stage of making porridge. Further flour to make the Nsima paste was not added because the power from the PV was insufficient for this stage.

Temperature reading were not taken during this trial as both the thermometers were in use on another trial. The cooking process was used as a guide to the performance of the tile hotplate heater.

Various photos of this trial are shown below.

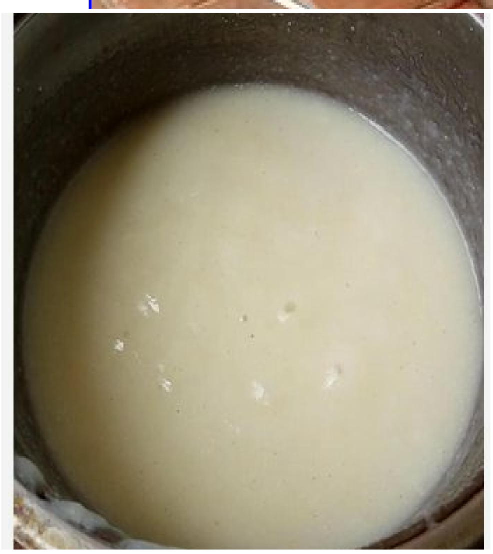
Conclusions

The results and observations of the first trial indicated that the approach had potential but a better contact between the heater and the pan was required. The clay tile being uneven would not achieve this contact so a further trial with a ceramic tile heater was undertaken.

This trial showed that direct heating by PV to a heater tile is a viable way to offer a hotplate option if there is sufficient sunshine to produce the power required. We achieved a boil of flour and it thickened to produce a porridge. (Video available)

Refinement of the plate heater would include underside insulation and the possible use of windbreak sides as found in camping stoves to reduce heat losses from around the pan.

Photo illustrations



#1 Top right photo

PV powered Hotplate heater with pan

#2 Middle photo

Beata with her son cooking some Nsima

#3 Bottom left

Close up of boiling Nsima in the pan. Weather overcast no shadows visible. (Video shots of this available.)

The Task: to reduce the temperature difference between the oil and pan

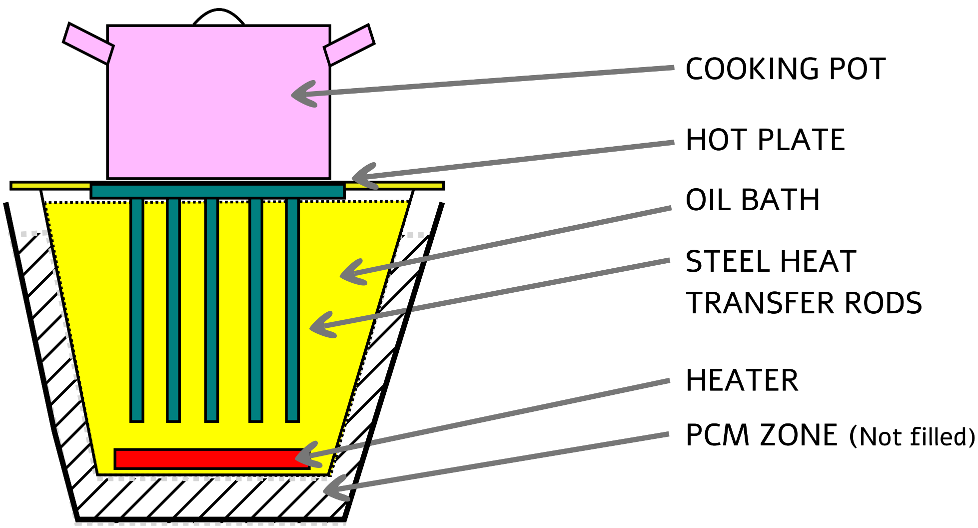
Field Trial F

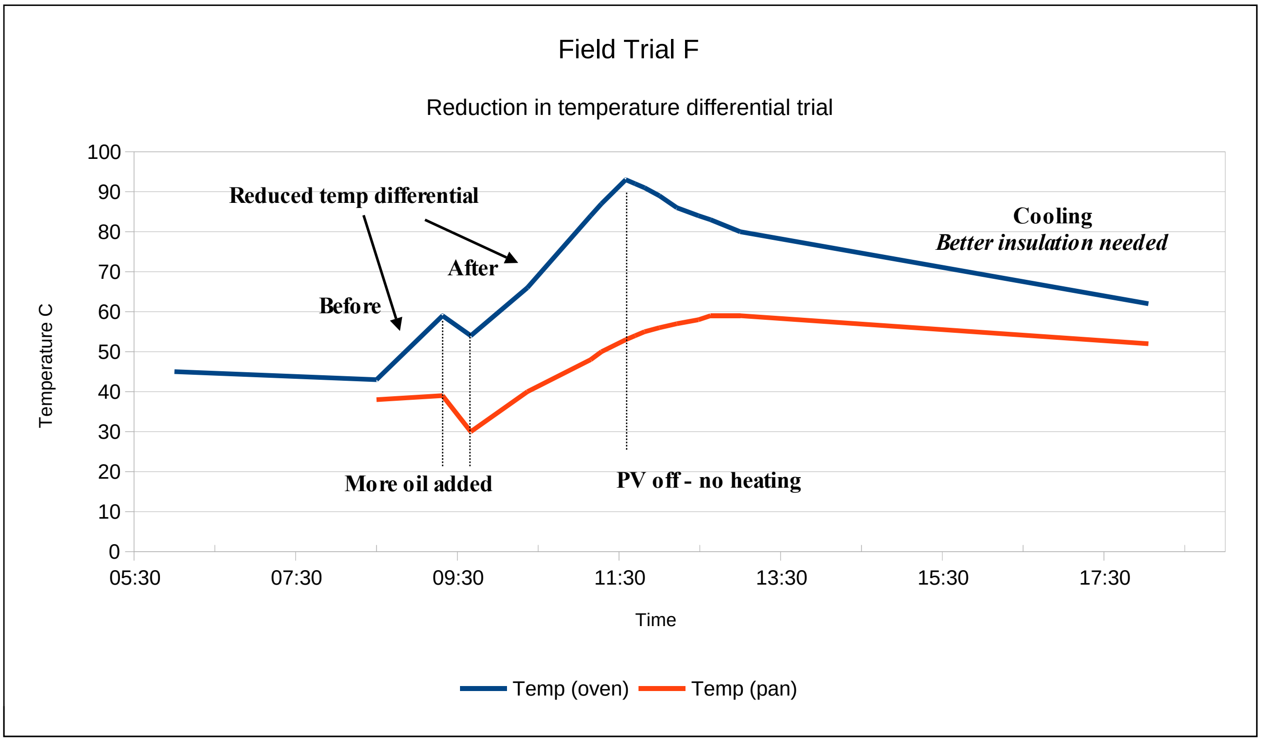
The purpose of this task was to find out if a full oil vessel can reduce the temperature differential between the oil and the cooking pan on the hotplate. The temperature differential between the pan and the oil

Work undertaken

To reduce the distance between hot oil and the hotplate further cooking oil, approx. 6 litres, was added to the vessel. This brought the level of the oil to the top of the vessel. Temperature and voltage records were taken. Due to plate cooking tests, the heat was withdrawn from the cooker at 11.35. Also limited data during the afternoon as absent to attend a meeting with Mary's Meals.

The new arrangement is illustrated and the temperature data is graphed below

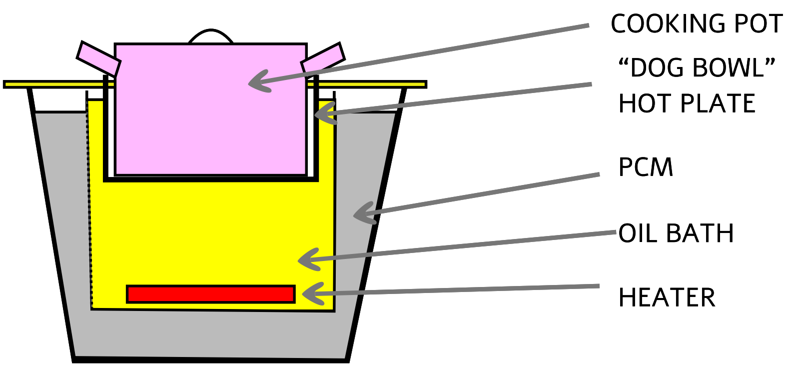




Conclusions

The added oil did not make an obvious improvement to the rate at which the pot on the hotplate responded to the temperature in the oil. The implication of drawn from this trial was that the temperature transfer rods alone did not give the temperature transfer required. Further developments of heat transfer concepts need to be tested. A promising design, which in some way mimics the successful rocket stove found in Malawi, and tested in the UK, is the use of inverted top-hat to bring the oil level up to the base of the hotplate and up the sides. The dog-bowl design is a term we have coined to describe the concept as a dog bowl was used for the first version of the cooking pot holder - see diagram below. This entire structure would be covered with an insulated lid.

The diagram below indicates the proposed next steps to improve heat transfer into the hotplate.



Appendix 8

Dissemination Report

Contents

Preface

Objective

The work done in this project needs to be conveyed to a wider audience for a number of reasons including:

- *Ensuring that the eCook stoves proposed are required and are acceptable for the intended use*
- *Sharing and exchanging expertise so as not to "reinvent the wheel"*
- *Informing interested parties of the work we are undertaking*
- *Sharing information with our partners so that they can understand the principals of the project*
- *Explaining the concept to local people for them to see how they could use the eCook stove*
- *Teaching and training others to build the eCook stove in country*

The method used for the dissemination will vary with the type of information and the audience.

INITIAL DISSEMINATION OF THE ECOOK STOVE CONCEPT TO LOCAL MALAWIAN PEOPLE

Objective

The local people who will use the eCook stove need to made aware concept of the solar powered cook stove as a replacement for wood fuel. It needed to be ascertained that it was something that they would want and it would be something that they would use. They also needed to have their input into the design of the cCook stove including what was acceptable and what wasn't.

Methodology

Initial communications were with our potential partners, Aquaid Lifeline, in Malawi. This was by e-mail, Skype and Whatsapp to discuss the concept of the project and to see if it was something that they would be willing to be a partner in. Face to face meetings were also held with the UK trustee of the charity.

There was a field trip to Namisu, Malawi to talk to the local ladies directly about the eCook stove and to get their feedback and input.

Part of the field trip included taking part in a debate with secondary school children on the impact of new technology on the younger generation where the solar powered eCook stove concept was introduced and explained to them.

Results

The feed back from Aquaid Lifeline was that they were very conscious of the deforestation caused by the overuse of wood as a fuel source. They had been looking at ways to reduce their wood usage including the purchase as use of more fuel efficient Rocket stoves and by trying to grow bamboo as a fuel source.

> *All the Aquaid Centres are in a rural setting, in villages and firewood is the only source of cooking fuel. All meals are cooked in the more energy efficient Rocket Stoves, no meals are cooked on open fires.*
> *Aquaid Lifeline has made significant steps in establishing its own woodlots to reduce the demand for locally provided wood fuel and tries to use this wood as efficiently as possible.*
> *However, we believe that we need to take further steps to reduce our dependency on wood as deforestation and the environmental impact throughout Malawi is significant. The declining supply of available firewood is also becoming noticeable and the cost of obtaining firewood is steadily increasing.*
> *We believe that changing habits starts from a young age, and we are in a privileged position where we can influence young minds and the next generation to do things differently.*
>
> *Aquaid Lifeline is very excited about the MECS SOWTech cookstove as we see this as a possible alternative and sustainable solution to what is a huge problem not only in Malawi but many African and less developed countries.*
> Angus Gaisford, General Manager, Aquaid Lifeline

During the first field trip to Malawi there was the opportunity to speak to many local people. The concept of the solar power cook stove was explained. People were aware of the diminishing wood supply which manifests itself most obviously to them with the increase in wood prices.

The ladies in the village. Buy the firewood for their home cooking They walk up to 6km to fetch it and they spend about 500kwacha/day. Last year they were spending 400k/day. This price can go up in the rainy season to 1,000k/day due to a lack of available wood.

Firewood is the fuel of choice in rural areas and charcoal in urban ones. In Malawi it is forbidden for motorised vehicles to bring charcoal into the town. It therefore comes in on bicycles for the charcoal ovens in the hillsides. The men travel 70-80km all through the night to bring in the charcoal. The cost of charcoal is about half as much again but it burns for longer.

The ladies were excited about having a solar eCook stove. They had input into the design of the stove (see Appendix 3: Report of initial user-centred design visit to Malawi).

We were able to take part in a debate on the impact of technology on the new generation with secondary school children at Gormani. Primarily this was about mobile phones and the Internet. After the main debate I was introduced and I explained what I was in Malawi to do. The discussion was then opened up to include solar-powered cooking. They were all very enthusiastic about the possibility of using solar-power to cook with. They were aware of deforestation and the impact of it.

They discussed the pros and cons of using solar energy.

Pros:

- It would save wood
- it would use a sustainable energy source
- there would be less contamination in the food
- it would be more healthy
- it would be cleaner

Cons:

- the cost of the stoves
- food might taste different
- it might take longer to cook the food

Overall they agreed that using solar to cook with was a good thing.

SHARING AND EXCHANGE OF INFORMATION WITH OTHER PROFESSIONALS IN THE FIELD

Objective

It is known that there are other teams looking into solar cook stoves. By sharing information between the teams we can learn from each other and avoid known pitfalls. The information exchange will enable the project to proceed more rapidly.

Methodology

The MECS team put SOWTech in contact with Prof. Peter Schwartz and his team at California Polytechnic State University (Cal Poly). They are working on a similar eCook stove using phase change materials.

There have been many email exchanges between the Cal Poly team, SOWTech and Dr Paul Routley, SOWTech's consultant.

Results

There has been a very fruitful exchange and dissemination of information between the two teams especially regarding the electrical components cumulating in SOWTech supplying Cal Poly with one of the Power Optimisation Devices that we have developed.

Below is an example of the type of correspondence between us.

RE: Introduction from the UK re solar cookers

Peter V. Schwartz pschwart@calpoly.edu via cpslo.onmicrosoft.com

20 Dec 2019, 06:59

to mattwalker175@yahoo.com, Paul, John, me, Grace, Owen, Euan

Thanks Matt!

Here's the flat diode. I bought 2000 of them. I think we sent 700 to Ghana.

Pete

From: matt walker <mattwalker175@yahoo.com>

Sent: Thursday, December 19, 2019 10:52 PM

To: Peter V. Schwartz <pschwart@calpoly.edu>; Paul Routley <prroutley@outlook.com>; John Mullett <johnajmullett@gmail.com>

Cc: Lynn wk McGoff <lynnm4ad@gmail.com>; Grace Isabel Gius <ggius@calpoly.edu>; Owen Hugh Staveland <ostavela@calpoly.edu>; Euan Smith <euan1971@yahoo.co.uk>

Subject: RE: Introduction from the UK re solar cookers

Paul,

Matt Walker here, one of Pete's research students. Hoping to clarify something.

We currently use 1N5408 doides (3A silicon rectifier). The data sheets and pricing can be found online. We have no problem running 6A or more through them if they are properly heat sunk. They cost about 4 cents a piece when you buy 1000-2000.

The flat diodes cost a significant amount more. I'm not familiar with them yet and don't have the part number. We have done only a small fraction of our work using these diodes so far. Any results we have published are from the round 1N5408 diode based heater.

Matt

On Thu, Dec 19, 2019 at 10:22 PM, Peter V. Schwartz <pschwart@calpoly.edu> wrote:

Paul,

Thanks for the explanation.

For 100 W, we would run a chain of 19 or 20 diodes costing $0.80. This would be for a nominally 18 V, 6 A solar panel. Thus each diode would dissipate about 5 W.

Pete

From: Paul Routley <prroutley@outlook.com>

Sent: Thursday, December 19, 2019 1:23 PM

To: Peter V. Schwartz <pschwart@calpoly.edu>; John Mullett <johnajmullett@gmail.com>

Cc: Lynn wk McGoff <lynnm4ad@gmail.com>; Grace Isabel Gius <ggius@calpoly.edu>; Owen Hugh Staveland <ostavela@calpoly.edu>; mattwalker175@yahoo.com; Euan Smith <euan1971@yahoo.co.uk>

Subject: RE: Introduction from the UK re solar cookers

Peter

The circuit does function as a MPPT controller but by maintaining the voltage on the solar panel, the average voltage on the heater is what is varied to extract the maximum current from the panel before the panel voltage starts dropping. The average heater voltage will vary from a maximum, under bight sunshine, of the voltage on the panel (about 30V in our case) to zero as the amount of sunlight falls. Heater resistance is about 3Ohms for 300W, I.e. about 10A heater current. 280C max sounds about right for Silicon diodes. The heater wire should be good to over 1000C.

We had some good experiments today with John's heaters made from two ceramic tiles with heater wire between stuck together with clay.

Just checking your pricing for he diodes; We are looking for a total heater power of about 150W to 300W. The diodes I was looking at dissipate about 1W so 300 diodes would be needed costing $12 for the round ones or $63 for the flat ones, using your prices. Prices proportionally lower for lower powers.

Regards

Paul

From: Peter V. Schwartz <pschwart@calpoly.edu>

Sent: Thursday, December 19, 2019 7:46:48 PM

To: Paul Routley <prroutley@outlook.com>; John Mullett <johnajmullett@gmail.com>

Cc: Lynn wk McGoff <lynnm4ad@gmail.com>; Grace Isabel Gius <ggius@calpoly.edu>; Owen Hugh Staveland <ostavela@calpoly.edu>; mattwalker175@yahoo.com <mattwalker175@yahoo.com>; Euan Smith <euan1971@yahoo.co.uk>

Subject: RE: Introduction from the UK re solar cookers

Paul!

Nice to meet you and thanks for the communication.

I think what you're presenting to me is a device that will maintain 5 V output under all solar intensities by imposing a duty cycle of the output and holding energy in a capacitor or inductor. This will function as a low cost MPPT controller. I think it's a great idea, and have thought about it as well, but never investigated it.

I agree with what you say about the shortcomings of diodes… except the price. We purchase the diodes we use for $ 0.04 per diode for the round ones, and $0.21 for the flat ones. I'm reasonably sure that we can get them for considerably less if we manage a sale directly from China. But it's not important because as is the cost is less than $4 per pot. Additionally, while your device costs about the same, you haven't provided the heater yet.

However it is not my intention to poo poo your direction. I'm FULLY in support of it, and I think it needs to be done! And there's an important concern about diodes you didn't mention: the temperature limitations. 280 C seems to be the maximum temperature the diodes can withstand. And while this is reasonably hot for cooking, it imposes a power limitation because at high power the diodes will be considerably hotter than the food.

I'm curious how this will work. 5 V is a rather low voltage indicating the need for high current. 150 W would require 30 A. So the resistance of the heater would have to be pretty low… well under an Ohm, and the lead wires to the cooker would have to be VERY low resistance… but they could be short if the modulation unti is close to the cooker.

I look forward to our future communication.

Pete

From: Paul Routley <prroutley@outlook.com>
Sent: Wednesday, December 18, 2019 8:24 AM
To: John Mullett <johnajmullett@gmail.com>; Peter V. Schwartz <pschwart@calpoly.edu>
Cc: Lynn wk McGoff <lynnm4ad@gmail.com>; Grace Isabel Gius <ggius@calpoly.edu>; Owen Hugh Staveland <ostavela@calpoly.edu>; mattwalker175@yahoo.com; Euan Smith <euan1971@yahoo.co.uk>
Subject: RE: Introduction from the UK re solar cookers

Hi Peter

I am Paul Routley the electronics engineer working with John.

With regards to the diode heating, the diode string does the right thing, by maintaining a constant voltage on the solar panel (approximately) irrespective of the current being produced. There are a couple of shortcomings though:

Power diodes are not cheap, I think about $20 for 150Watts worth of diodes

The voltage is temperature dependant

Changes to the solar panel optimum working voltage require a change to the heater design

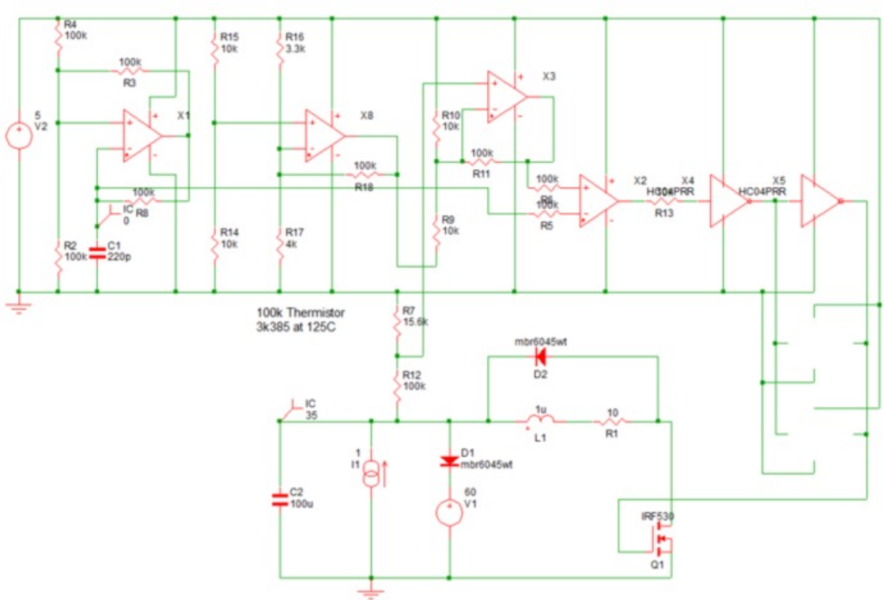
The solution we are working with is a resistive heater fed by a PWM signal to match the resistance to the current generated by the solar panel. The circuit monitors the voltage on the panel and adjusts the PWM ratio to get the right average current. The current is smoothed by a large capacitor (could be inductive, and I had hoped the heater coil self inductance might be enough, but unfortunately not. Capacitors seem to be more cost effective). The circuit consisting of a quad opamp and hex inverter is shown below and the simetrix file attached (you can get a free simulator to run it from https://www.simetrix.co.uk). Only three invertors are on the schematic as there is a component limitation on the free version of simetrix

The circuit consists of:

A triangle wave generator based around X1

A temperature error amplifier based around X8, R17 is a 100k (at 25C) thermistor.

A voltage error amplifier based around X3 which measures the voltage on the solar panel modelled by D1, V1, I1. The working voltage is adjusted by varying R7.



The voltage reference is shifted by the output from the temperature error amplifier so the temperature control is achieved by moving the solar panel working voltage away from the optimum.

The gain around X3 can be adjusted to provide 'super optimum' control of the solar panel voltage. I.e. allowing the voltage on the solar panel to fall slightly as the current drops. We have not done the experiment to optimise the gain yet.

The voltage error signal is compared with the triangle wave by X2 to give the PWM signal which is cleaned up the logic invertors, X5, X5 etc, before switching Q1 which drives the heater modelled by L1, R1. D2 is to prevent damage to the electronics by any inductance in the heater.

C2 is the smoothing capacitor. About 3000uF in real life but 100uF for the simulation so things settle faster.

Cost of components is about $4 + $2 for a 5V smps convertor that generates 5V from the solar panel output. The 5V can also be used to charge a phone. Wire for the heater costs about 50c.

Regards

Paul

From: John Mullett

Sent: 12 December 2019 15:34

To: Peter V. Schwartz

Cc: Lynn wk McGoff; Grace Isabel Gius; Owen Hugh Staveland; mattwalker175@yahoo.com; Paul Routley; Euan Smith

Subject: Re: Introduction from the UK re solar cookers

Hi Peter

Great to have heard more of your experiences.

Re heaters. We are still at early days but resistive wire on bottles has worked so far. We cover the wire with morter in thin layer of heat resistant mortar, as used in fireplaces. This is cured by placing on the top of a wood stove to just warm through. We are also trying a unit made with the wires in clay, but not tried this yet. Having issues with the clay shrinking and then exposing the wire. We are also experimenting with different wire thickness and types of wire.

Re the diodes, I can ask my electron partners if they have any comment, that sort of issue is outside my paygrade...

Re the supply of Erythritol, as far as I know its made by fermentation using a specific micro-organism (I would need to look up the name again). Perhaps subject to another project once we have proved its the right PC material.

Re condensation. would I be right in thinking it is the steam being released from the cooking pot into the insulation. I will review our designs with this in mind. If it is, then we must consider the internal structure of the cooking chamber to ensure its damp resistant and maybe have a drainage /venting arrangement.

Useful to have your input. Hope to be able to share more of our experience as we gain it!

Thanks

John

On Mon, 9 Dec 2019 at 18:08, Peter V. Schwartz <pschwart@calpoly.edu> wrote:

John,

This is great. Already we are helping each other:

Thanks to you, we have more confidence in our past experiments indicating supercooling is not a concern.

We can tell you about our (mis)adventures making resistive heaters… It was a bit of a mess trying to find an electrical insulator that is thermally conductive. We went with the industry standard of MgO, but man, what a mess… and trying to compress it? You can see videos online about how they make standard electrical heaters. It's hard to emulate. It may (… most certainly) be best to contact a factory and have them make the heaters for you, and you can just bend them around the cookers, or put them in the cookers…. Or better yet, design a cooker that can use a conventionally-available heater.

You can import lots of Erythritol rather inexpensively from China. If you buy a lot, it's cheaper. I actually don't know how it's made, but I agree that what we want to do is make loads of it cheaply in Africa with low low low standards of quality because no one's going to eat it. If you can contact a company in China, we could *get them to do it. However, Africa is tomorrow's China for manufactured goods, so we might as well get that started.*

Issues? Condensation! You can run a small vent to the pot as we did in our "baking" video. However, you'll still get some condensate in the insulation and it will accumulate… like after ~ 30 tests in the making of the "Hot Diodes!" paper, I was surprised to find pools of water in the bottom of two of the three buckets. What did I find in the bottom of the third? A crack. So, I drilled a bunch of holes in the bucket I use at home and the difficulty is only acute… meaning after I cook, everything is wet, it might be a little wet, but the moisture is largely driven off by the heat…

Looking forward to our future communications.

Pete

From: John Mullett <johnajmullett@gmail.com>

Sent: Monday, December 9, 2019 2:47 AM

To: Peter V. Schwartz <pschwart@calpoly.edu>

Cc: Lynn wk McGoff <lynnm4ad@gmail.com>; Grace Isabel Gius <ggius@calpoly.edu>; Owen Hugh Staveland <ostavela@calpoly.edu>; mattwalker175@yahoo.com

Subject: Re: Introduction from the UK re solar cookers

Hi Pete

Thanks for getting back to me and so quickly.

We will certainly let you have our feedback on the resistive heating elements.   We are undergoing modest testing with them right now.

RE the students in Austin. I have misled you. The mentoring I do is via skype calls to engineering students who are undertaking projects in biological waste treatment for emergency aid. (nothing to do with solar cookers ... yet).

I know the head of sanitation for the International Red Cross in Geneva who happens to be an Austin Uni Alumni. He suggested I could help out the students which is how it has come about. This work is all pro bono, so I just do it by skype as and when Prof Janet Ellzey (of Austin) requests it.

I have read some of stuff on hot diodes, but not sure which if I have read the particular paper you allude to. Happy to do so if you could point me to it. (Also reviewed the videos of making them - very helpful)

I was aware of the supercooking issue from the literature, but like you we have not encountered this problem with our trials to date. Our early trials gave off heat at around 115 degrees C which was pretty much what we expected. Are there other phase change options you would suggest we should consider?

Do you have any knowledge of where it can be purchased at the lowest cost. I am using catering/food grade material as its easy to buy but I feel sure there must be cheaper options. One day I hope we can ferment our own in Africa but that is a way off yet! That does call for biology!

Would love to chat over the issues you are encountering too. Will keep you posted on how we get on.

Thanks again.

John

On Thu, 5 Dec 2019 at 19:27, Peter V. Schwartz <pschwart@calpoly.edu> wrote:

John,

I receive your introduction enthusiastically.

I think it is a great idea that you are pursuing the resistive heater direction. I am interested to know what we can learn from each other.

Have you read the "Hot Diodes!" paper? It outlines the advantages of diode heating… more efficiently extracting heat from the solar panel. However, there are significant disadvantages as well… and all the diode advantages can be realized if you have a "smart" system connecting the solar panel to the heater… Such "intelligence" is ever decreasing in cost… and we really should get on it and develop this… requiring collaboration with electrical engineering.

The other thing is that Erythritol exhibits super cooling… that you don't get the latent heat of fusion back until the temperature drops well below a cooking temperature… I've read about this, but we haven't experienced this problem… I invite you to collect cooling curves and see if things work well for you too.

We are running into other challenges, and slowly chipping away at them. I look forward to our future communication.

As for Skype, etc. I'm open to this, but likely we have more information to share. If you have students in Austin, I think it may be appropriate to visit each others' labs… particularly in summer… For instance, we could host a research student for a month… just a thought.

Pete

From: John Mullett <johnajmullett@gmail.com>

Sent: Thursday, December 5, 2019 9:17 AM

To: Peter V. Schwartz <pschwart@calpoly.edu>

Cc: Lynn wk McGoff <lynnm4ad@gmail.com>

Subject: Introduction from the UK re solar cookers

Hi Pete

We have not been in touch before. My normal territory is biological waste management such as composting and AD. However, we got the opportunity to participate in a solar cooking initiative being hosted by Loughborough University (UK). During our initial discussions with Simon Batchelor the issue of heat batteries came up. I already have heat batteries in my house (27kwh worth) using kit from Sunamp. Simon introduced me to your work which I have read with great interest. I should explain that after a lifetime of building large waste recycling plants for the developed world, I and two other colleagues spun out of our business a social enterprise for working in low income countries with the catchy little name of Sustainable OneWorld Technologies cic. We have been involved with novel digesters and biogas cookers in various African countries but feel that solar and heat storage is good way to stop cutting down trees. So we are looking to build on your expertise and are building a pv powered cooker using Erthritol as the phase change. We are currently building a prototype in the UK and plan to do another in Malawi in the next two months. We have opted for resistive wire rather than diodes as the heating element. The plan is for local manufacture to facilitate acceptability, low cost and "ownership". In fact much as you have been doing.

We would welcome any tips you might care to offer. We will be open source about the project once we have something to say, and look forward to trying to crack this really difficult cooking problem. Being a biologist by training and background, the physics is all a mystery to me. However, organic matter, the soil and the need to conserve trees is my world, and as a PhD in algae and as an ex worm farmer, I have some empathy for permaculture too.

Would be good to connect. I do skype /whatsapp/ viber if appropriate and you might be interested to know I am currently a mentor for some student projects in a Uni of Texas at Austin programme. Any help or tips much appreciated.

Kind regards

John

Informing interested parties of the work that we are doing

Objective

The work that we have been doing has been disseminated to the wider public who are interested in the fields of sustainable living, deforestation, WASH and health.

Methodology

This has been done through three main channels:

1. Articles in Lynn's Letters, a newsletter that is send out by SOWTech to a wide range of international recipients including senior officers in international Charities and NGO, workers in the health and WASH fields

2. Bulletins on the SOWTech website www.sowtech.com

3. Conversations with interested people

Results

We have had some positive feedback from our communications.

John R <rutahiwajohn12@gmail.com>

Mon, 2 Dec 2019, 13:09

Hello Lynn,

Thanks so much for sharing me this email, am so interesting with this project please if you will need any assist from Tz am Keen to work with you more in this project.

Cheers

John

From: director@grassrootsafrica.org <director@grassrootsafrica.org>

Sent: 26 October 2019 18:47

To: 'Lynn McGoff' <lynnm4ad@gmail.com>

Cc: 'Charlie Knight' <crhknight@hotmail.co.uk>

Subject: RE: Grant to design an ecookstove

Dear both,

Can I put the two of you in touch with one another?

Charlie has been working with an organisation promoting smart stoves in Malawi. You might have common grounds.

Regards,

Benny

David Little <david.i.little@btinternet.com>

Fri, 6 Dec 2019, 14:26

Lynn,

Thanks for the letter from Malawi, sounds like a great idea for the replacement of polluting stoves. The mitigation of deforestation for wood fuel is also essential. In the DRC a few years ago, we saw boys riding their bikes out of town, not into town as you might expect for work. Eventually we worked out, when we once saw the same boy in the evening, that they had spent all day gathering wood and tying it to their bikes to push back into town. I suppose they were lucky to be in the fresh air, unlike the girls and women doing the cooking?

Cheers,

David

Example Lynn's letter

Subject: SOWTech visit to Malawi

Hi

I recently had the privilege of going out to Malawi as part of the ecookstove project. I was the guest of Aquaid Lifeline at their Children's Village at Namisu where I was met and hosted by Josie Charter, one of their trustees from the UK.

The purpose of my visit was to find out first hand how and what the women cook in rural communities and to get their input into the design of our ecookstove. I spoke to a number of ladies both in the villages and in the Children's village. The staple food is nsima, a thick porridge made from maize flour. This is normally eaten with boiled red kidney beans and a vegetable relish. In the villages they cook on three-stone wood fuelled fires that are outside of their houses. The ladies get up at 4am to light the fires and cook a maize porridge for the children before they go to school. The ladies buy in all their wood fuel which is a big expense for them, 30-40% of their income, especially as the cost of the wood can double in the wet season.

Some of the design outcomes from my visit was that solar power stoves would be welcome. The stoves would have to mimic their current stoves as the stirring of the nsima is important so an enclosed oven type stove would not work. A stove that had more than one hotplate would be an advantage as it would allow the nsima and kidney beans to be cooked at the same time cutting down on the actual time spent cooking.

I also visited a number of schools with Josie. At one of these schools the older students held a debate on the impact of new technology. It was initially focused on internet and mobile phones but after they were told why I was there they discussed using solar power for an ecookstove. They were very enthusiastic about especially as they were very aware of the problem of deforestation. The other advantages they highlighted were less contamination in the food, money saved from not buying wood, it would be cleaner and more healthy. Their concerns were the initial cost of the stove, the food might taste different and that it might take longer to cook.

Another highlight of my visit was being taught how to make nsima. My attempts to beat the nsima to make it smooth caused much amusement but, with help, I succeeded. It even tasted alright too. We ate some of it and gave the rest away to a local family.

The information I brought back will now be used as part of the User-Centred Design process as we go forward with the project designing the ecookstove and building a prototype.

Regards

Lynn

PS If you not longer wish to receive Lynn's Letter please drop me an e-mail and I'll take you off the mailing list.

Lynn McGoff

Director
SOWTech

Explaining and demonstrating the concepts to our partners and local people

Objective

One of the most important purposes of information dissemination is informing our partner in Malawi, Aquaid Lifeline what we are trying to do and why so that they will be full onboard with the ideas and be able to turn it into a reality.

Methodology

We spoke with and emailed Aquaid to explain the concepts of the eCook stove and sent the team in Malawi production drawings and reports to keep them up to date with the things we were doing.

When in Malawi the working of the Phase Change Material (PCM) was demonstrated by heating the PCM and showing how it melted and took in heat which it then released when it solidified.

We were able to demonstrate how the eCook stove to some of the local people and they were able to try using it.

Results

By disseminating the information to Aquaid Lifeline in Malawi they were kept fully informed as to where we were in the project.

Sending them the production drawing in advance enabled prototype components to be made in Malawi ready for the field visit to trail the prototype eCook stove.

The local people were interested in what we were doing and were eager to try out the eCook stove.

The results of the PCM demonstration can be found in the section “Demonstration of phase change process to partners”

Illustrations

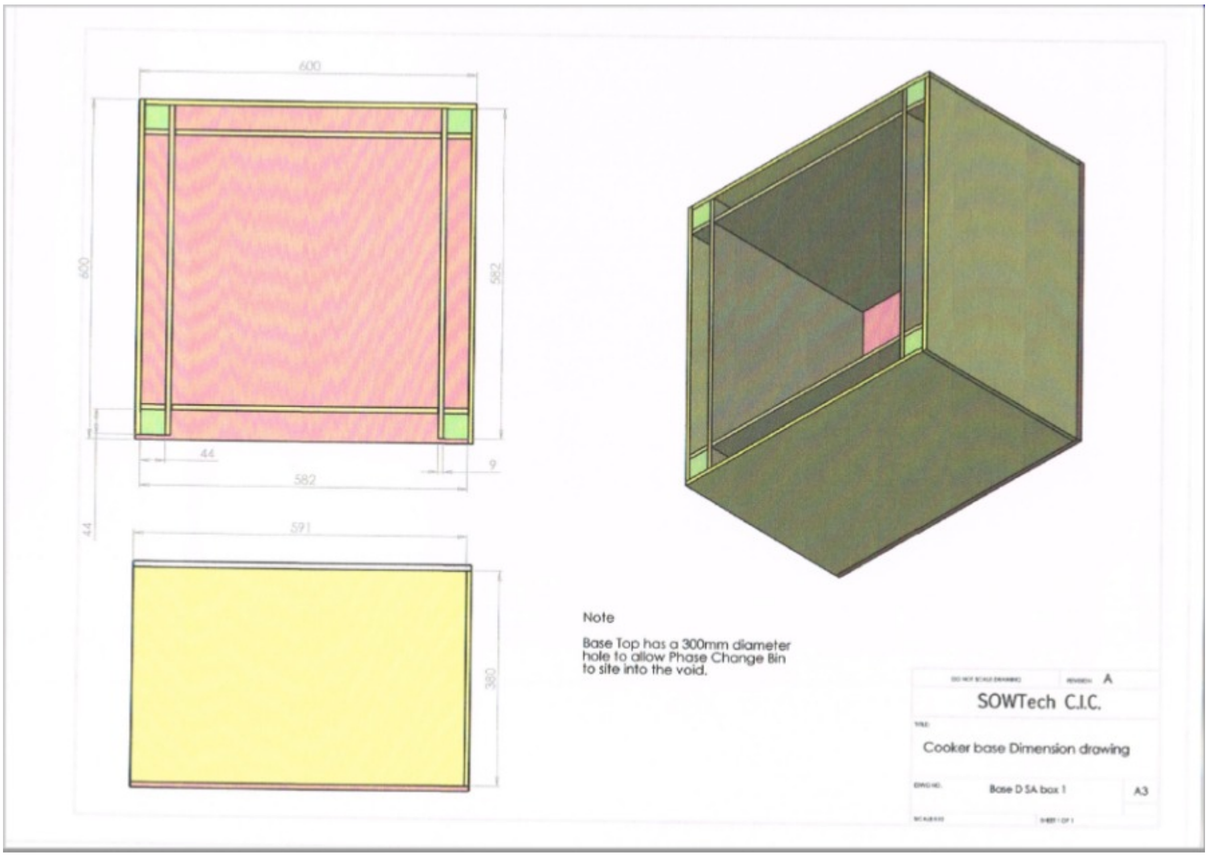


Illustration of one of the design drawings sent to Malawi

Photo illustrations

#1 Local lady cooking nsima in eCook stove

#2 Local lady cooking nsima in eCook stove

#3 Local children taking an interest in eCook stove

#4 Local lady cooking nsima on eCook stove hotplate

DEMONSTRATION OF PHASE CHANGE PROCESS TO PARTNERS

Objective

The objective was to show how the Erythritol Phase Change Material (PCM) material melted and then subsequently became solid again with the continuous release of heat. The explanation of the chemistry for the release of energy during solidification is challenging. This task was used as a “show and tell” exercise.

Methodology

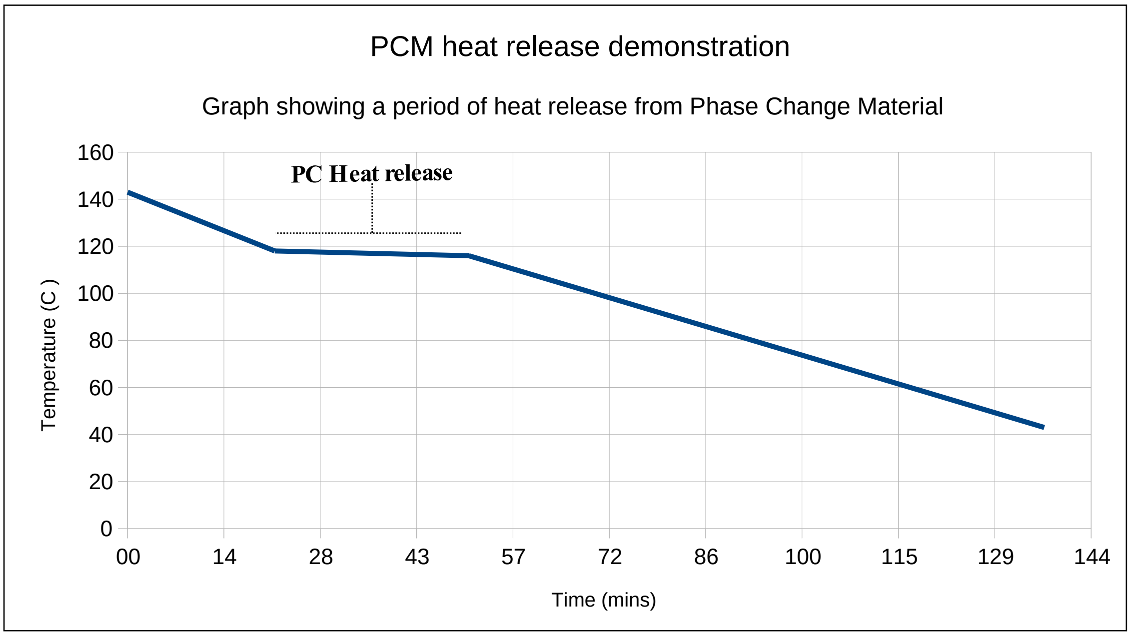
The demonstration was observed by both our partners in Aquaid, (Angus and Josie) and also one of their Malawian staff, Eviness.

Approximately 500g of granular phase change material was placed in a small cooking pan. The LPG cooker in the guest house was used to gently heat and melt the PCM. The change of appearance of the PCM after cooling was also shown to the team.

Results

The melting was observed by the participants, and particular attention was drawn to the fact that part of the PCM could be molten whilst a few centimetres away there was unmelted PCM at a completely different temperature. An oven thermometer was used to demonstrate that the molten material was at a temp of 155°C whilst the unmelted material was only at 75°C.

The following graph contains the temperature decay data/graph.



The demonstration helped our Malawian partners to appreciate the function of the PCM. Considerable surprise of the heat release properties of the PCM were expressed. It is of note that even after 2 hours of cooling the temperature of the PCM was still at 43°C.

The following photos illustrate show Eviness being shown the process.

Demonstration of the melting of the Phase Change Material in Malawi

Discussion of eCook stoves with potential partners for roll out

Objective

For this project to be successful there needs to be a conduit for the roll out of the ecCook stoves within Malawi and beyond.

We are therefore looking at potential partners who would be able to undertake this.

Methodology

When in Malawi John met with Wessie Tenthani and Winfore Ng’ambi who are Senior Regional Managers at Mary’s Meals. Mary’s Meals is a UK based charity which works in 18 countries across Africa, Asia, Latin America, Eastern Europe, and the Caribbean. They aim to provide a cooked meal to every child in education in some of the most impoverished countries in the world and are now feeding 1,667,067 children every school day worldwide. Malawi is Mary’s Meals largest school feeding programme as it is one of the poorest countries in the world and faces huge challenges in education, access to healthcare and widespread child malnutrition. They provide meals to 30% of primary school aged children across the country. Since the start in 2002 1,019,335 children in Malawi have received Mary's Meals. Locally supplied wood is what is used to cook these meals. The fires are lit at 3am so that the porridge is ready before the start of school. This cooking task has is probably the biggest single use of wood fuel on any given day amongst the poorest in the community. The porridge mix and the methods of cooking are standardised throughout the programme. In Malawi this cooking task is around 260,000 litres of porridge a day.

We are also talking to Sandile Mtetwa and Admire Baudi of Bolsan, an entrepreneurial organisation based in Zimbabwe. They are looking for novel sustainable products that they can make using supported local manufacturing in Zimbabwe.

Results

Mary’s Meals Malawi operates out of Blantyre in southern Malawi and has around 114 employees who manage, deliver and monitor their school feeding programme. They provide meals of maize and soya porridge locally referred to as likuni phala, fortified with essential vitamins and minerals

During the meeting Mary’s Meals expressed concern about the sustainability of future of wood fuel supplies. They have now passed the responsibility of procuring the wood in rural areas to the individual sites rather than supplying it direct. In urban areas they supply briquettes. A proposal by Mary’s Meals to explore bamboo as a fuel source had failed to secure funding.

The concept and working of the solar eCook stove was explained and discussed with them. They expressed a desire to be involved in future work to trial the eCook stove and to work with SOWTech on a scale up project.

Sandile and Admire from Bolsan are graduates who are looking for ways to support their local communities in Zimbabwe. They are looking to start to fabricate and install Interseasonal Rainwater Harvesting systems in schools in rural Zimbabwe and on farms. They have expressed an interest in the eCook stove as they are very conscious of the effects of deforestation in their country and are looking at ways that they can mitigate this. Sandile is currently studying at Cambridge University in the UK and we have held face to face meeting with her as well as Skype calls with both her and Admire.

Photo illustrations

#1 Bags of flour used to make meals

#2 Firewood for use in cook stove

#3 Cooking the meals

#4 Children being fed by Mary's Meals

Potential of supporting individuals setting up in business

Objective

Much of the local rural economy in Malawi is built on individuals running small businesses selling goods and produce much of which is home grown or home made. Those that bake to produce goods do so on a small scale on three stone wood burning fires or ovens. There is the potential for such individuals to use an eCook stove as an alternative and the feasibility of the idea was explored.

Methodology

A local women, Beata, was visited by SOWTech when in Malawi. She makes a living by making mandasi, a type of doughnut, which she sells for MK 50 (about 5p). SOWTech had explained and demonstrated the solar powered eCook stove to her when she visited Namisu selling her mandasi.

She also has a bread oven and makes and sells bread during the dry season as the wood is too expensive in the wet season to make a profit. In the dry season she pays MK1000 for firewood to make a batch of 230 Mandasi. In the wet season this rises to MK3,000.

Results

SOWTech were invited to Beata's home to see how she makes mandasi. To make a batch of 230 Mandasi she uses 10kg wheat flour which costs MK5,200, sugar costing MK850 and salt costing MK50. The dough made is fried in 3 litres of oil costing MK2,000. In the wet season she therefore makes virtually no profit.

Cost to produce 230 Mandasi

	Wet season	Dry season
Wood	3,000	1,000
Wheat flour	5,200	5,200
Sugar	850	850
Salt	50	50
Oil	2,000	2,000
Total	**11100**	**9100**

	Wet season	Dry season
Cost to make 1 Mandasi	48.3	39.6
Profit per Mandasi	1.7	10.4
Profit per batch	**400**	**2400**

Discussions were held about the eCook stove and the benefits that could be had from using solar power instead of wood fuel.

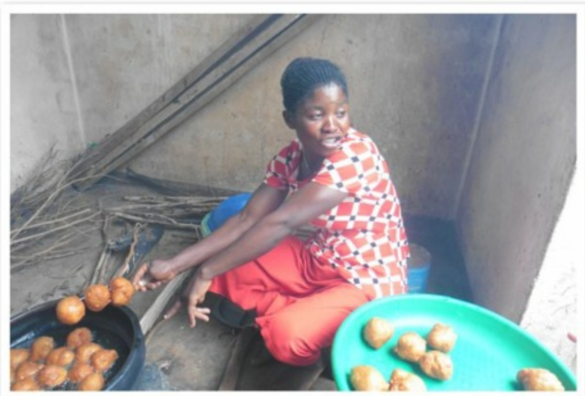
Photo illustrations

#1 Beata using the eCook stove

#2 Preparing the batter for mandasi

#3 Forming the batter into mandasi balls

#4 Frying the mandasi



#5 Finished mandasi

#6 Bread oven

Training of potential fabricators in Malawi

Objective

One of the key rationales of the eCook stove is that it can be manufactured locally in country. To be able to to this the local people need to be given the training and skills to do so.

Methodology

When in Malawi John met with Lupactio Mwandenga, who was the star pupil of the year last year. He was very interested in the eCook stove and especially the electronics as he hopes study medical engineering. John explained the workings of the eCook stoves including the electronics.

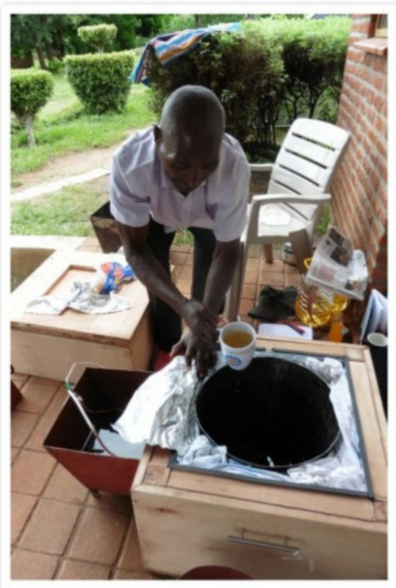
Results

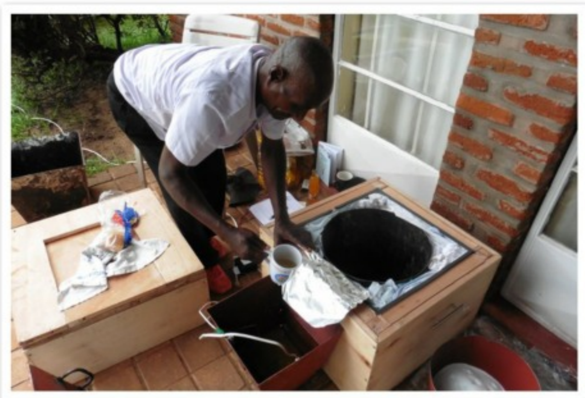
Lupactio was very receptive of the information and learned fast, understanding how and why everything worked. He was then able to explain to other Malawians about the eCook stove and how it worked in their own language.

Lupactio spending time with John Mullett to learn about the eCook stove

Photo illustrations

Lupactio explaining the concept and electronics to locals in their own language





Local man learning about the fabrication of the eCook stove and helping to make adaptations to it

Future dissemination plans

Objective

To enable the eCook stove project to continue and to go into production information about the stove needs to be spread more widely.

Methodology

There needs to be a number of routes of dissemination. These will include:

1. Further articles in Lynn's Letter
2. Bulletins on website
3. Discussions with people who are interested in building and selling the eCook stove
4. Continued collaboration with Cal Poly
5. Publication of reports on SOWTech website and direct sharing of the reports with interested parties