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.

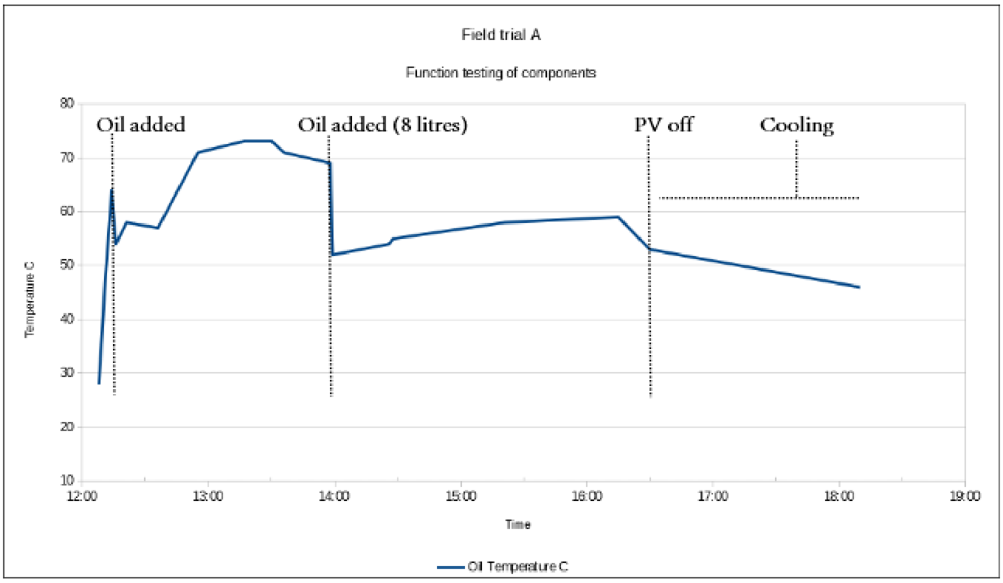
Our Aquaid partners reported no difficulty in the manufacture of the units. They felt that in the light of this prototype experience, there would be considerable potential to reduce the costs of fabrication with more time to negotiate better labour rates and using cheaper alternative materials. For example, 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.

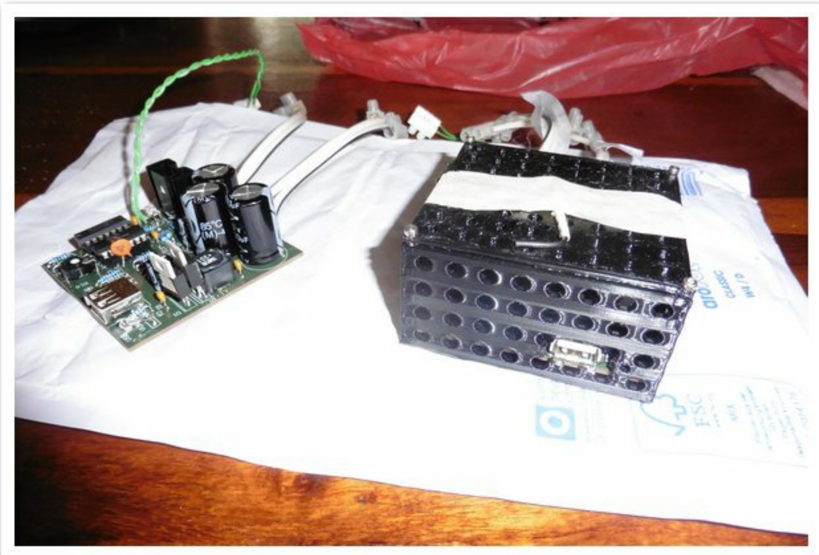
A temperature drop from 59°C at 16.15 to 46°C at 18.10 showed that the heat retention within the oven was poor.

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

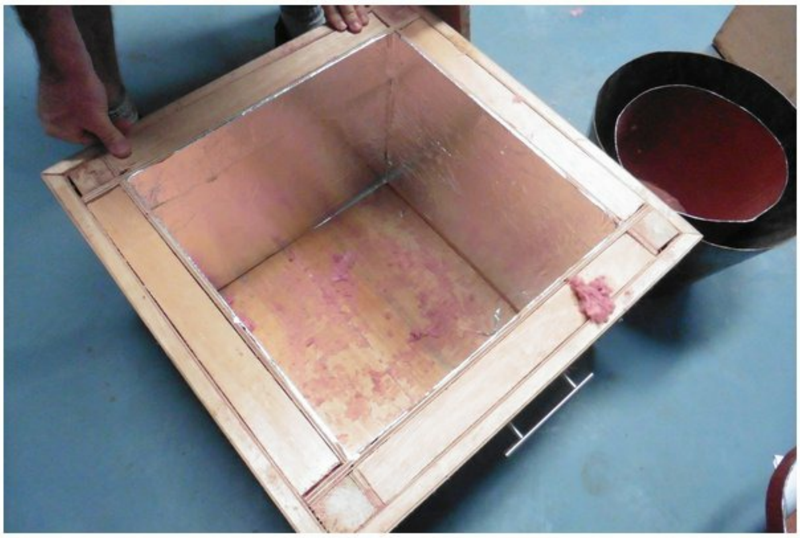
#4 Erythritol phase change material (PCM) for trials

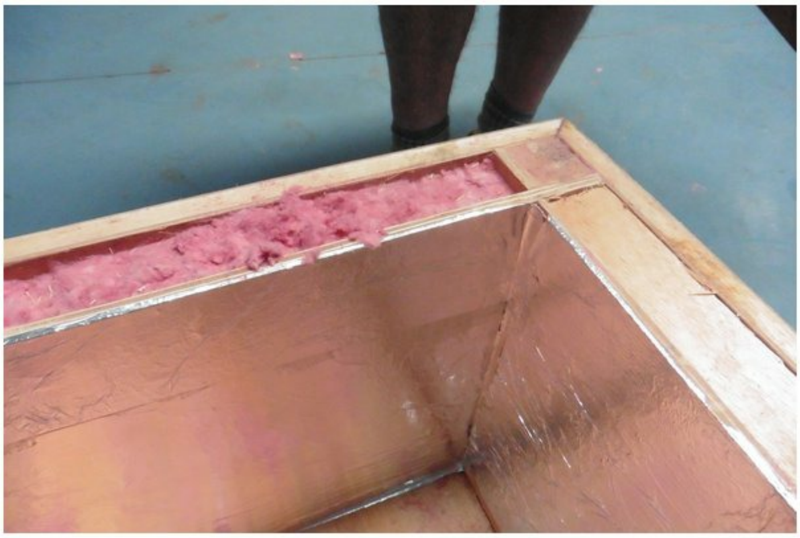
#5 Two oven thermometers used for the trials

#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.

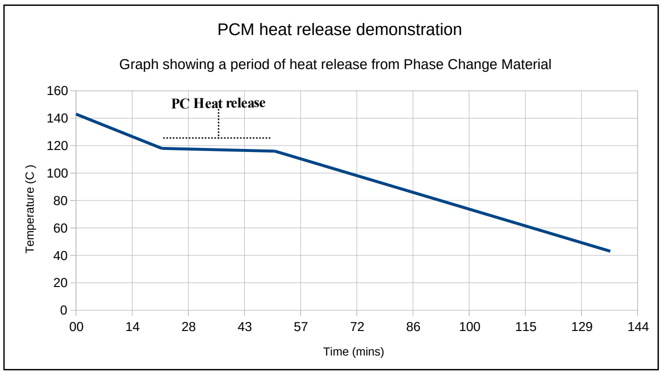


Photo illustration

#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.

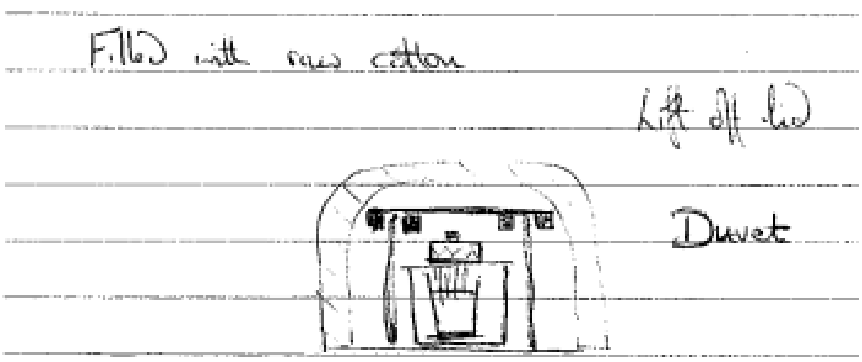
By mid afternoon, the oil temperature had achieved 85°C despite the overcast conditions. A pan with water and maize flour (ratio of 1:2 v/v) was then put onto the hotplate (and covered using the lid).

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.



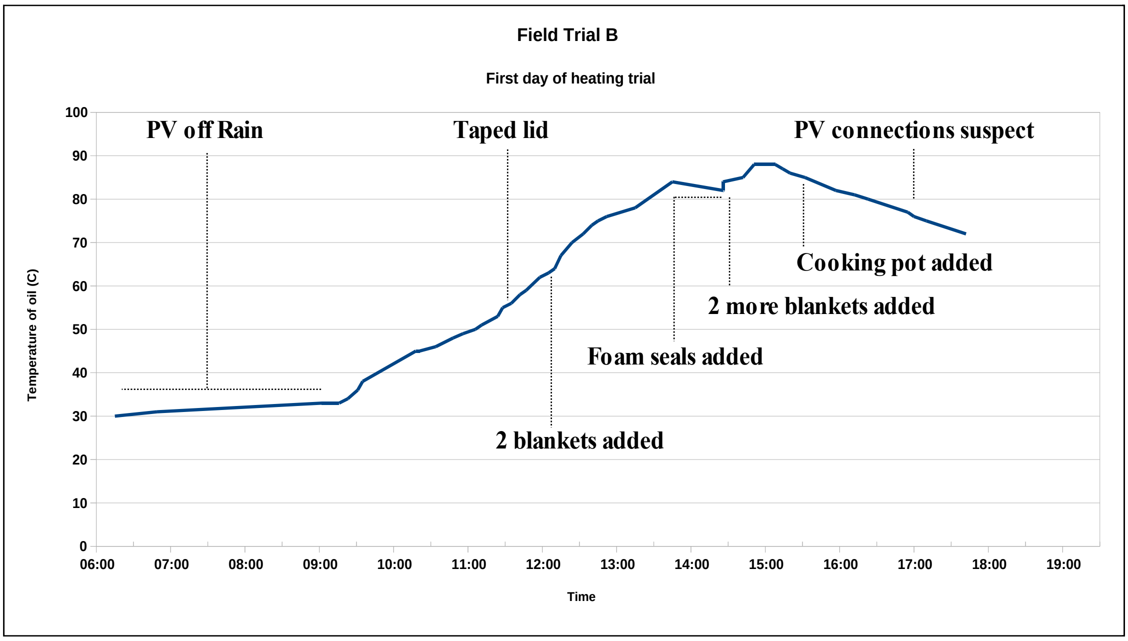


Photo illustrations

#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

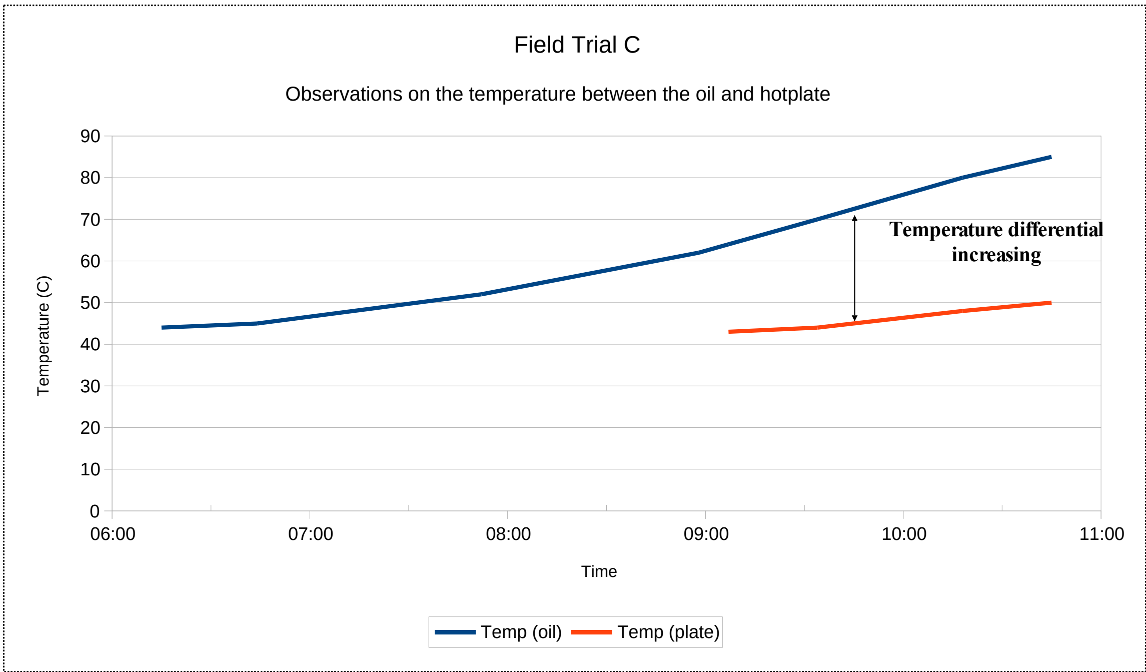
The observations made during the previous task indicated that whilst there is a reasonable level of heat being generated in the oil, the heat is not being transferred to the hotplate and cooking pan. This trial sought to try and investigate the effects of improved insulation and to investigate the temperature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

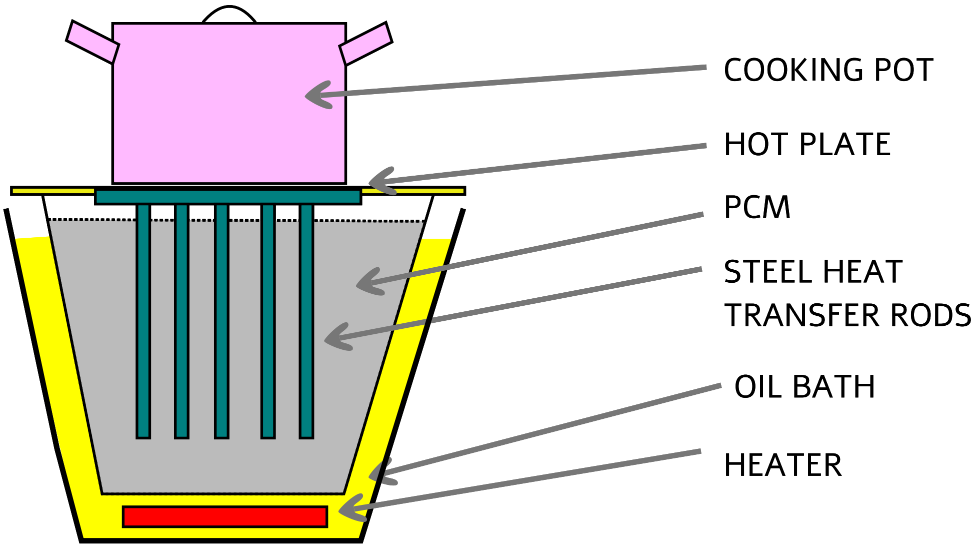
The observed temperature differential between the cooking pot and oil increased as the temperature of the oil increased so that by the time the oil temp was 85°C the pot temperature was still only 53°C, a differential of 32°C.



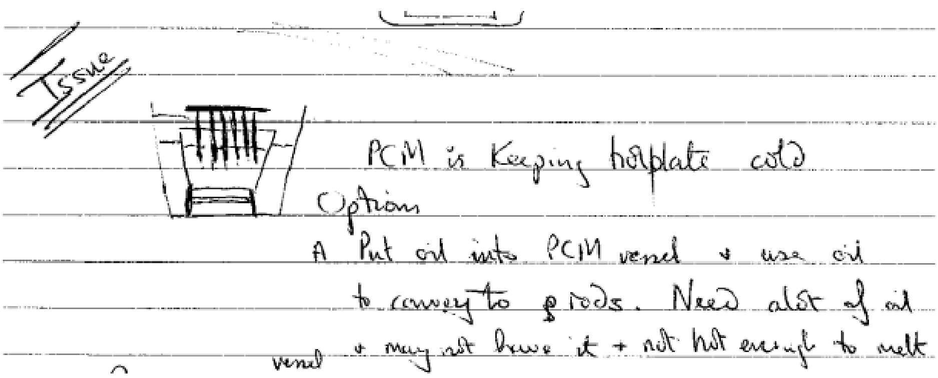
Conclusions

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.



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.

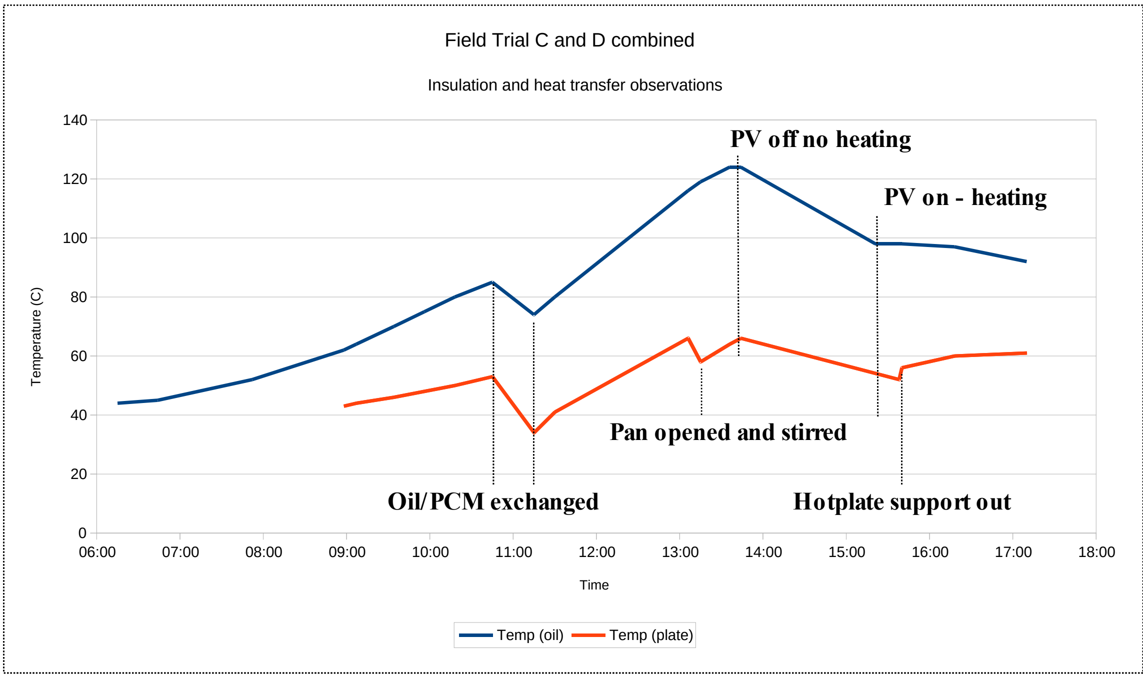
From this data it is possible to see that the temperature of the oil rose to 119°C by 13.15 but the temperature in the pot did not rise at anything like the same rate, being at 58°C at that time. This is a differential of 61°C. This results indicates that further improvements to improve heat transmission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

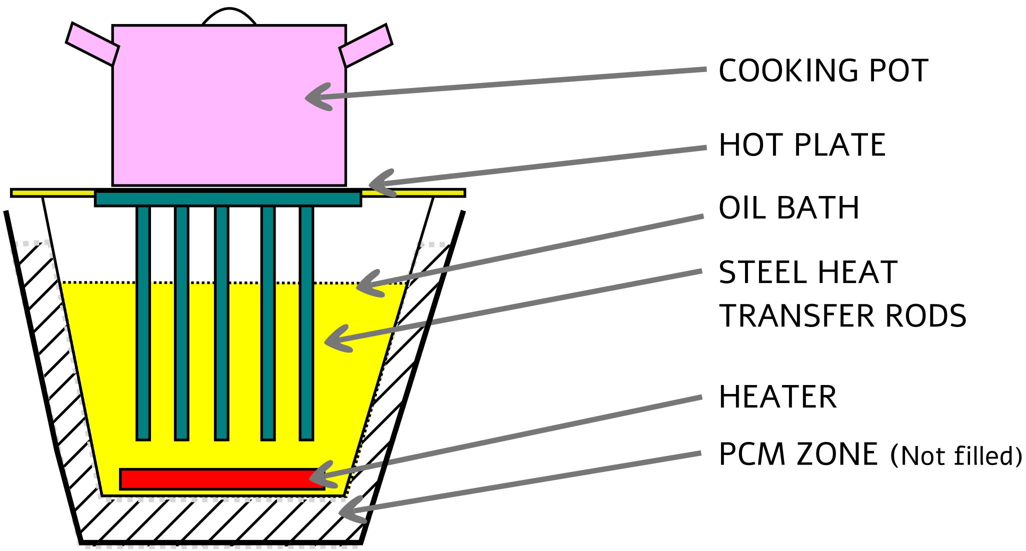
At 15:38 the pot was found to contain a thicken flour paste. See previous photo. It showed that the flour had cooked but the time taken was long. The taste of the paste was metallic which is probably a reflection of the duration of cooking.

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

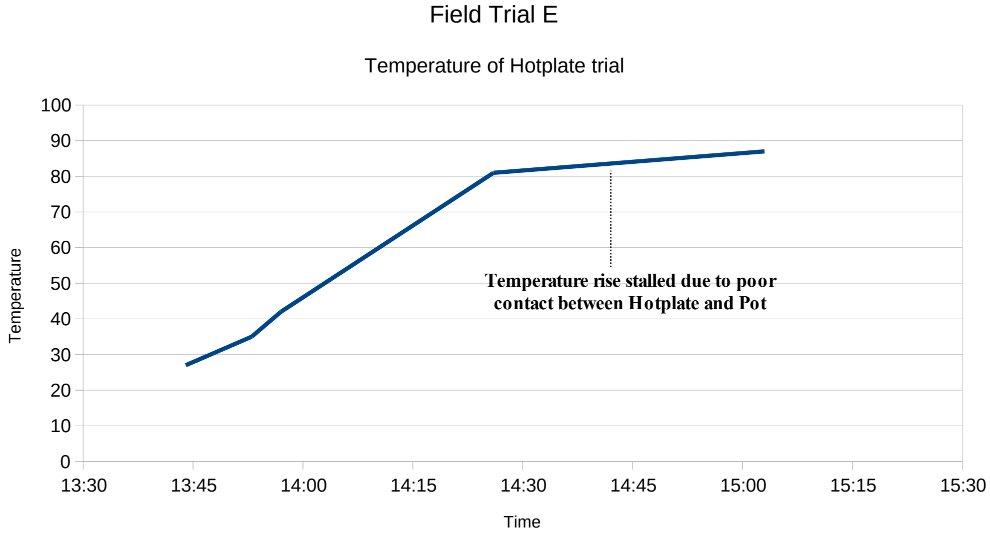
Introduction: Field Trial E

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

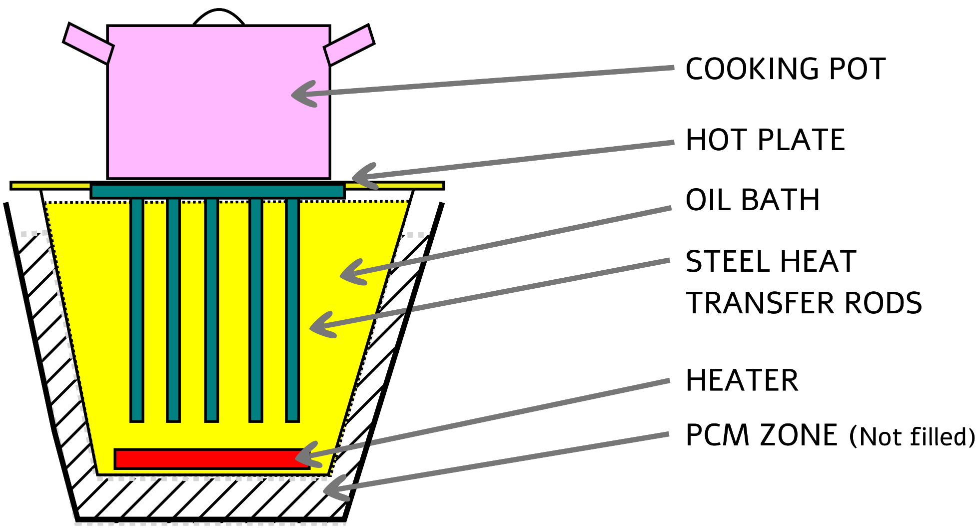
Field Trial F

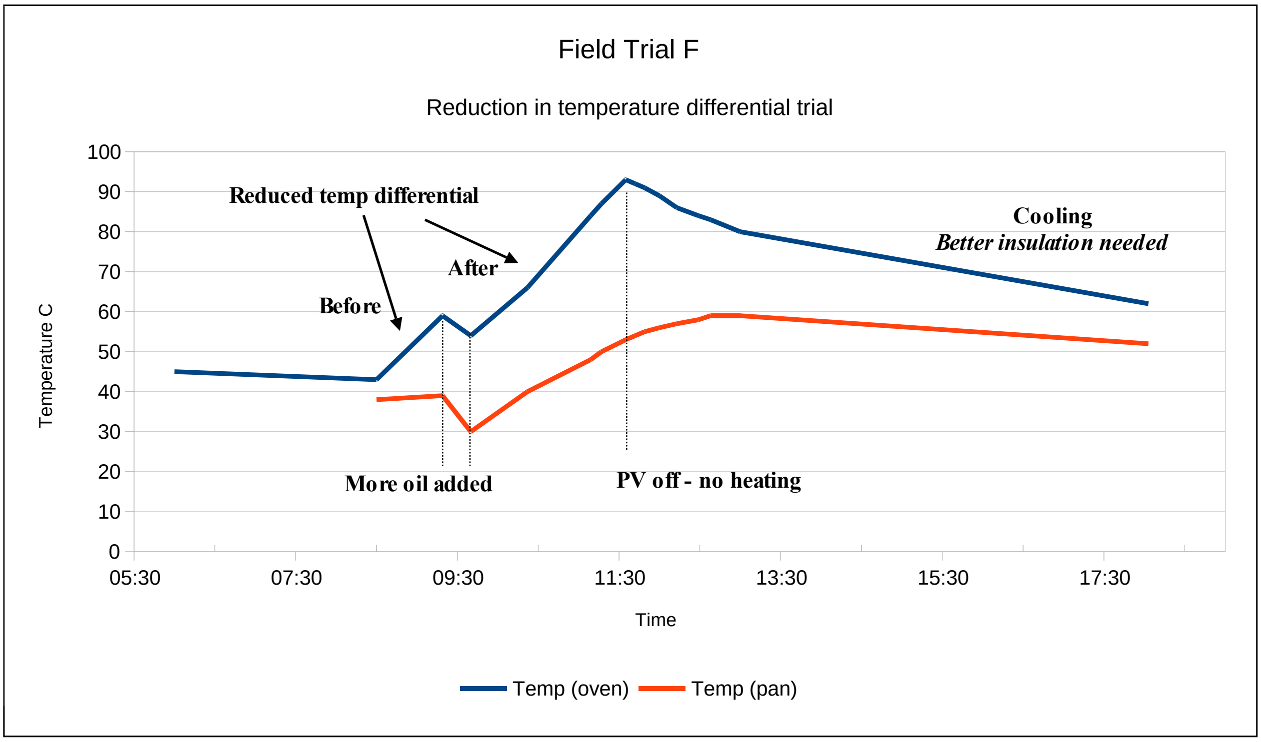
The purpose of this task was to find out if a full oil vessel can reduce the temperature differential between the oil and the cooking pan on the hotplate. The temperature differential between the pan and the oil

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.