Side-by-side testing to assess the benefits of adding insulation to a commercial electric pressure cooker using the 'Aobosi YBW60' 6 litre.

Authors:	Dr Nigel Monk, Dr Richard Blanchard, Dr John Barton
Author Affiliation:	Centre for Renewable Energy Systems Technology (CREST), Loughborough University
Status:	Final
Type:	Working Paper
Version:	1.0
Date:	4th June 2020
Location:	Wolfson School shared workspace, MECS_Technical folder

This material has been funded by UK aid from the UK government; however, the views expressed do not necessarily reflect the UK government's official policies.

Introduction.

This shortened report briefly discusses a programme of tests in the CREST Renewable Energy for Development laboratory at Loughborough University. A full report will be produced in due course.

Reducing the costs of cooking is one of the enablers to improve access to MECS (modern energy cooking services). Electric pressure cookers (EPCs) already compare favourably against conventional stoves, and very favourably against biomass cooking, in terms of energy consumption, but have evolved to satisfy wealthy consumers' expectations which don't necessarily match the needs of the global south.

One of MECS' ongoing mandates is to critically examine embedded decisions in product specifications to identify innovative solutions with a relevant emphasis in contrast to the emphasis on elaboration over efficiency.

One prevailing belief at the outset of the MECS' programme was that adding insulation to an EPC would reduce energy consumption. Indeed, for traditional pans like a *sufuria*, the so-called 'wonder bag', a cloth bag made from quilted insulation with a tie-drawn opening popular across Africa, is very successful at keeping a pan of food hot enough to remain self-cooking for considerable time, significantly reducing the energy needed to cook beans or tough meat, for example. Could an EPC be similarly improved? Clearly there could be some cost incurred, so the theory required testing accurately.

Although the wonder bag has attractive benefits – cheap, local manufacture, simple to use (raise your lidded pan of food to cooking temperature, remove from – and turn off! – the heat source, place in wonder bag, tightly close the bag and leave to self-cook) - it needs to be fully enclosing to be effective. Unfortunately, enclosing an entire EPC in an insulating cover would not be safe; the function of the pressure-limiting steam valve would be compromised and access is required to the control panel buttons.

Further, the direct equivalent when using an EPC would be to remove the pan and contents from the cooker once up to temperature, losing the advantage of cooking at higher pressure. Instead, it should be possible to install a layer of insulation internally between the chassis and the outer skin, including within the lid. Previous testing had impressed us with various design features of the Aobosi 6 litre cooker, see figure 1. In particular, the lid has an additional, plastic outer cover which creates an air gap of c.1.5 cm above the metal pressure-vessel lid. Using this space meant we could control insulation positioning, avoiding the control mechanisms, making the Aobosi an ideal test appliance.

Experiment.

To test the theory, using the best insulation would allow the best chance of producing the most benefit. It is widely known that the aerogel class of materials offers the greatest insulation resistance available, but application can be challenging because it is semi-rigid once manufactured. Although not yet commonplace, granulated and powdered forms are available along with aerogel-impregnated mineral wool blankets and boards. Aspen Pyrogel XTE™ is a compressed mineral wool impregnated with aerogel intended for steam pipe lagging. It is highly hydrophobic so naturally resistant to absorbing moisture. It is supplied in several roll thicknesses as a dense layer similar to viscose felt and can be cut to shape.

For the Aobosi, a single 10mm layer top and bottom and double layer around the sides required roughly $1m^2$ at a cost of c.£80, see figure 2. An equivalent application of viscose felt would cost nearly double. Installation during production as pre-prepared pieces might add only a few minutes to factory production time.

Figure 1 Aobosi 6 litre EPC before and…

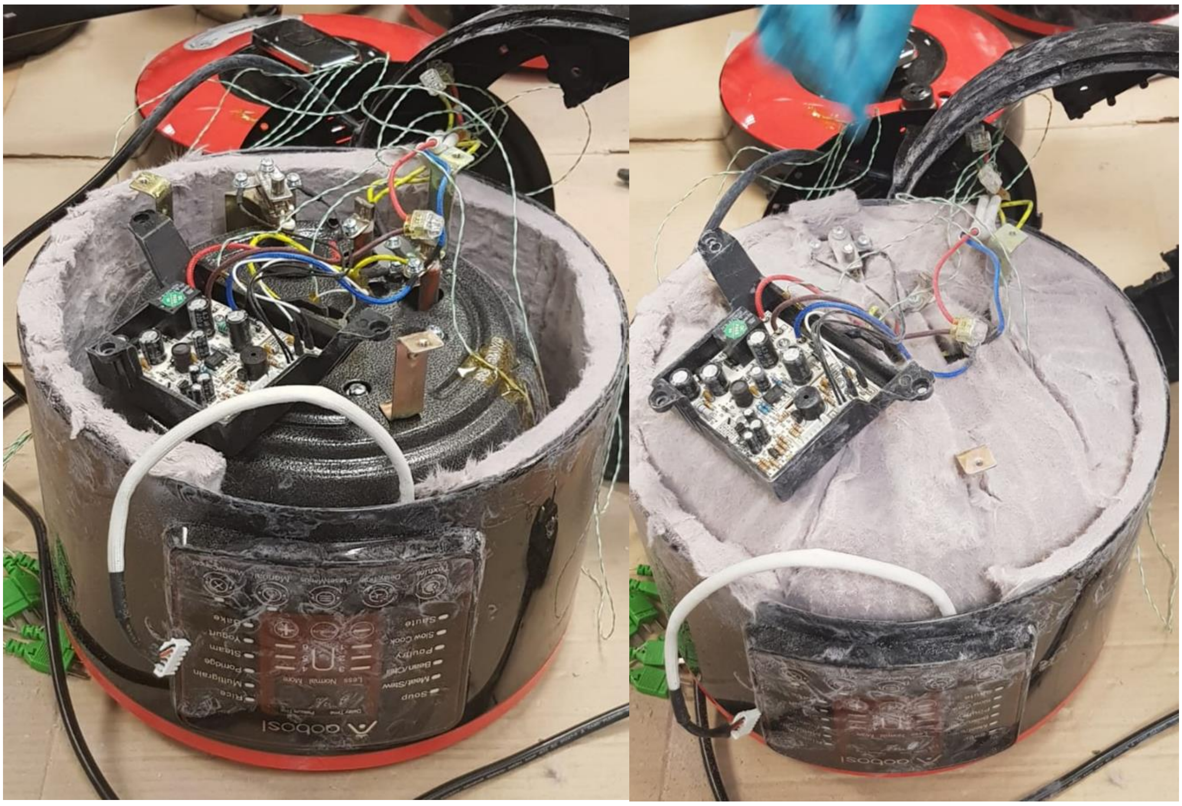

Figure 2 During installation. Handling Pyrogel XTE insulation required full PPE - photographs of view from beneath the EPC with base support and cover removed. Other Aspen Aerogels products have different handling qualities.

One significant parameter outside our control that can introduce a source of inconsistency during testing is the mains voltage available in the lab. There are other large loads in the vicinity. Although variation is only a few percent, the effect would be that consecutive tests might produce inconsistent results. Thus, two identical cookers were tested simultaneously, one with added insulation, one as bought, so that power input and environmental temperature variations did not affect the comparison. We have now obtained AC bench supplies so the AC voltage can be controlled precisely; the lab temperature remains a different matter but is generally consistent within a season.

A series of water boiling tests were undertaken. Water boiling tests (WBT) are the most effective tool to accurately assess appliance efficiency and behaviour and avoid the issue of wasted food from other types of tests. The tests were repeated at different volumes and different voltages (to represent different quantities of food and differently rated appliances), while measuring internal water temperature and 8 external temperatures, with the two cookers placed side by side.

We would expect the energy and time required to raise the EPC and water temperature to be increased by a small amount, and the average energy input rate during cooking to be reduced by an amount. The former is best measured via 'proportion of pre-heat energy absorbed heating the water' where any increase in parasitic thermal mass will reduce this basic efficiency. The reduction in cooking energy required is directly measured via 'average energy input rate during cooking'.

Results.

The parasitic thermal mass of a typical EPC is c. 80 Wh, see figure 3. This is calculated from measured energy consumption data. The Sayona is roughly the same size as the Aobosi EPC. This represents the total energy absorbed during the pre-heat phase by raising the temperature of the EPC and insulation itself. However, the temperature rise is not precisely known and varies throughout the cooker so that a figure for Wh/K cannot be calculated from this figure.

As an alternative approach, the Pyrogel XTE material added 0.16 Wh/K thermal mass, equal to 7.2 Wh if an average temperature rise of 45 K is assumed, see figure 4. In comparison, 1 litre of water requires 116 Wh of energy to rise 100 K. Therefore, at a simplistic level, the Pyrogel XTE adds between 3.7% overall increase in thermal mass for a 1 litre volume of water and 1.2% increase for 5 litres load. From figure 5, this can be seen to fall within experimental variations between repeated tests.

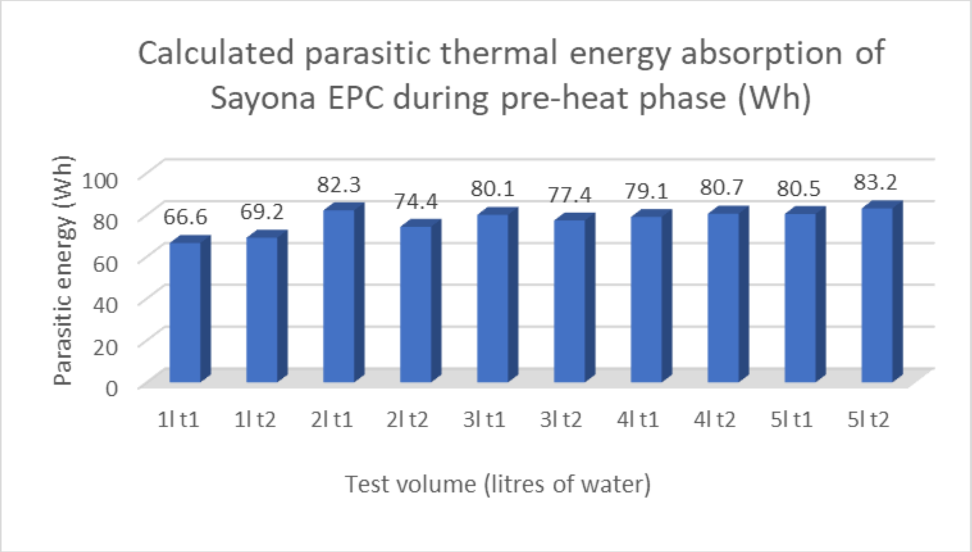

Figure 3 EPC thermal mass evaluated from WBT data. Report available here: An Investigation into the Functionality and Efficiency of an Electric Pressure Cooker bought in Kenya intended for the Domestic Market: 'Sayona PPS 6 litre'

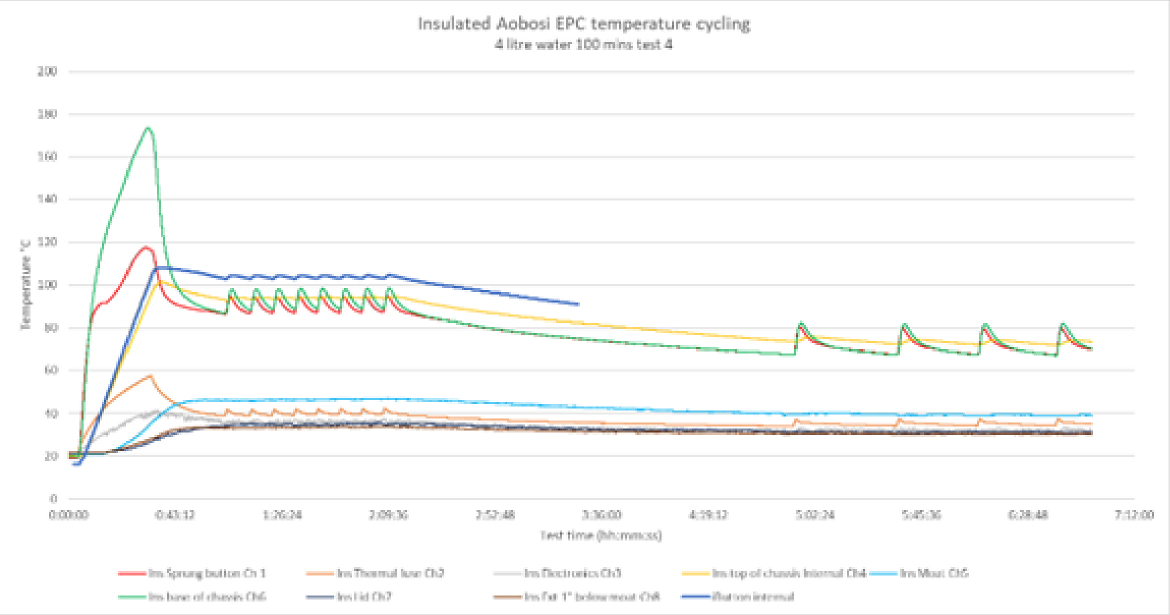

Figure 4 WBT temperature graph, Aobosi with added insulation. The Pyrogel is sandwiched around the sides between the chassis temperature (ch4) and external case temperature (ch8) which reach 100°C and 30°C respectively resulting in an average rise of 45°C above the starting temperature of 20°C.

Pre-heating phase.

During the pre-heating phase, energy efficiency, defined as input energy absorbed by the water, varies from 65 - 84% between 1 litre and 4.5 litres of water, see figure 5. The loss that might be reduced is therefore 35 – 16 %. However, within these losses is the constant parasitic thermal mass of the cooker itself. The remaining energy lost to the environment comprises 4% of the total preheat energy input for all volumes of water. Adding the Pyrogel XTE reduced the latter by 22% (see figure 6) producing an overall improvement of 0.9%. The improvement is offset by the larger increase in parasitic thermal mass. During the tests, there was no visible difference between the two cookers that could not have been ascribed to experimental variation, see figure 5.

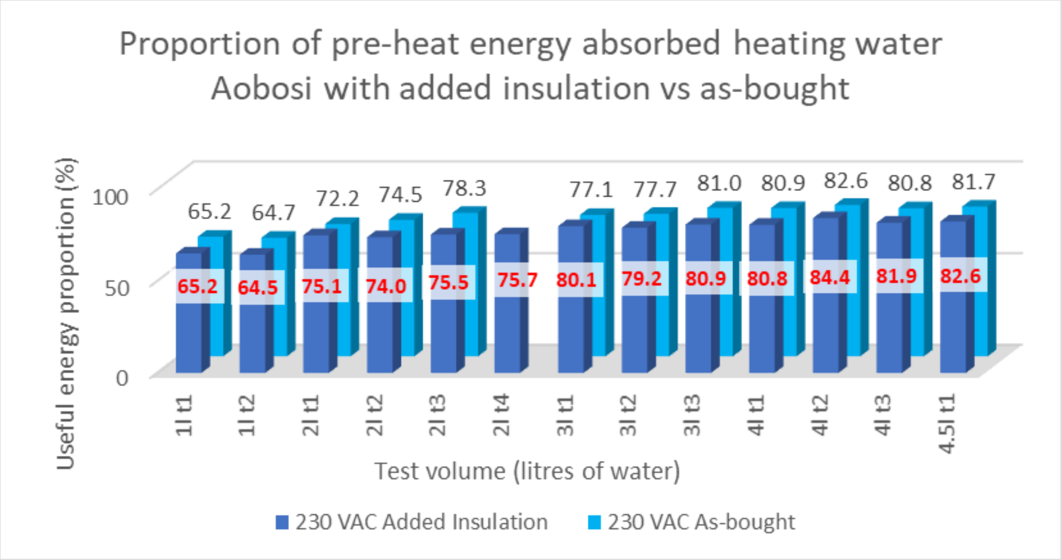

Figure 5 proportion of pre-heat energy absorbed heating the water. (Note: 1l t1 represents 1 litre test 1, etc.)

Cooking phase.

During the cooking phase, the 22% saving will apply to the whole energy input, see figure 6. However, because the EPC power is cycling on and off at a duty ratio c.10% (see figure 4), absolute saving is the product of these at c.2% of the nominal power rating. This is observed as a lengthening of the cycle period for the EPC with added insulation.

The net effect is thus, for 1 hour of cooking, independent of the water volume, the added insulation will save c.20 Wh of energy.

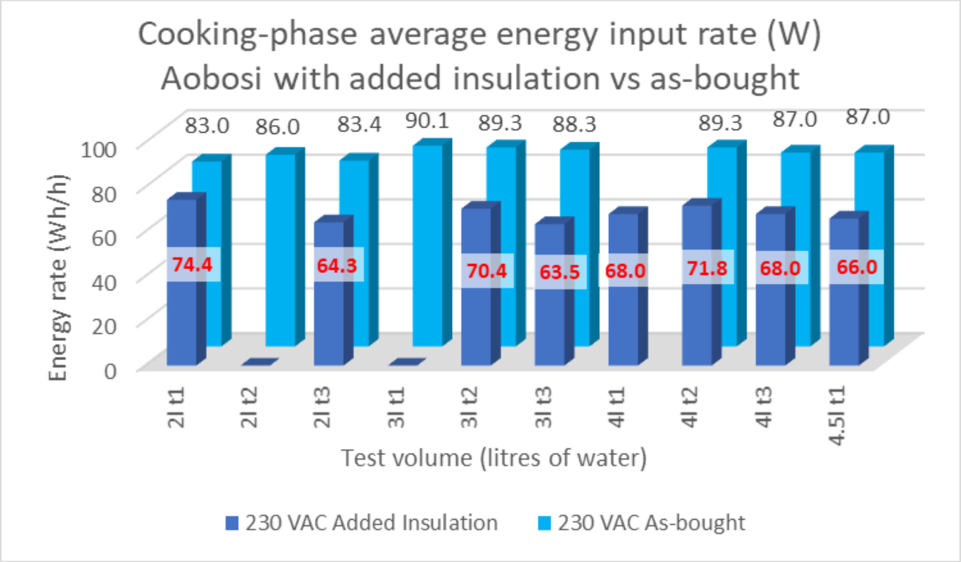

Figure 6 average energy input rate during cooking. Adding insulation in place of air reduced energy loss rate by c.22%.

Discussion.

In simple terms, adding insulation reduces thermal conductivity or heat loss rate through this layer by 22% compared to air but increases parasitic thermal mass by the equivalent of 0.136 litres of water, or 1.2% compared to 4.5 litres of water plus the EPC itself.

Installing the Pyrogel added 0.7kg to the cooker with parasitic thermal mass 0.16 Wh/K (compared to 1.16 Wh/K for 1 litre of water, for example). Installation displaces 4.75 litres or 6g of air with thermal mass 1.6×10^{-3} Wh/K and thermal conductivity = 0.59 W/K, calculated for a representative hollow cylinder the same shape as the added insulation. However, the cylinder of insulation is calculated to conduct 0.46 W/K, a reduction of 22%. The thermal conductivity reduction is relatively low because air is also an excellent insulant provided convection is minimal.

The measured energy input rates during cooking confirmed the 22% reduction in heat loss rate. This can save around 20 Wh per hour of cooking duration. This is a small amount and the benefits of extra insulation in an already efficient device can be seen to be negligible. The results confirmed negligible difference in the energy performance of the two EPCs.

The net effect can be visualised through the thermographic images in figure 7. Although there are obvious differences, the external temperatures for both EPC’s are far below the internal temperature of the water, except at the junction of the lid and body, where the ‘moat’ forms a thermal bridge. Adding insulation within the cooker will never address this issue, which could require re-engineering of the component. A lid that covered the joint might be an alternative approach and should not require a wholesale redesign of the EPC per se.

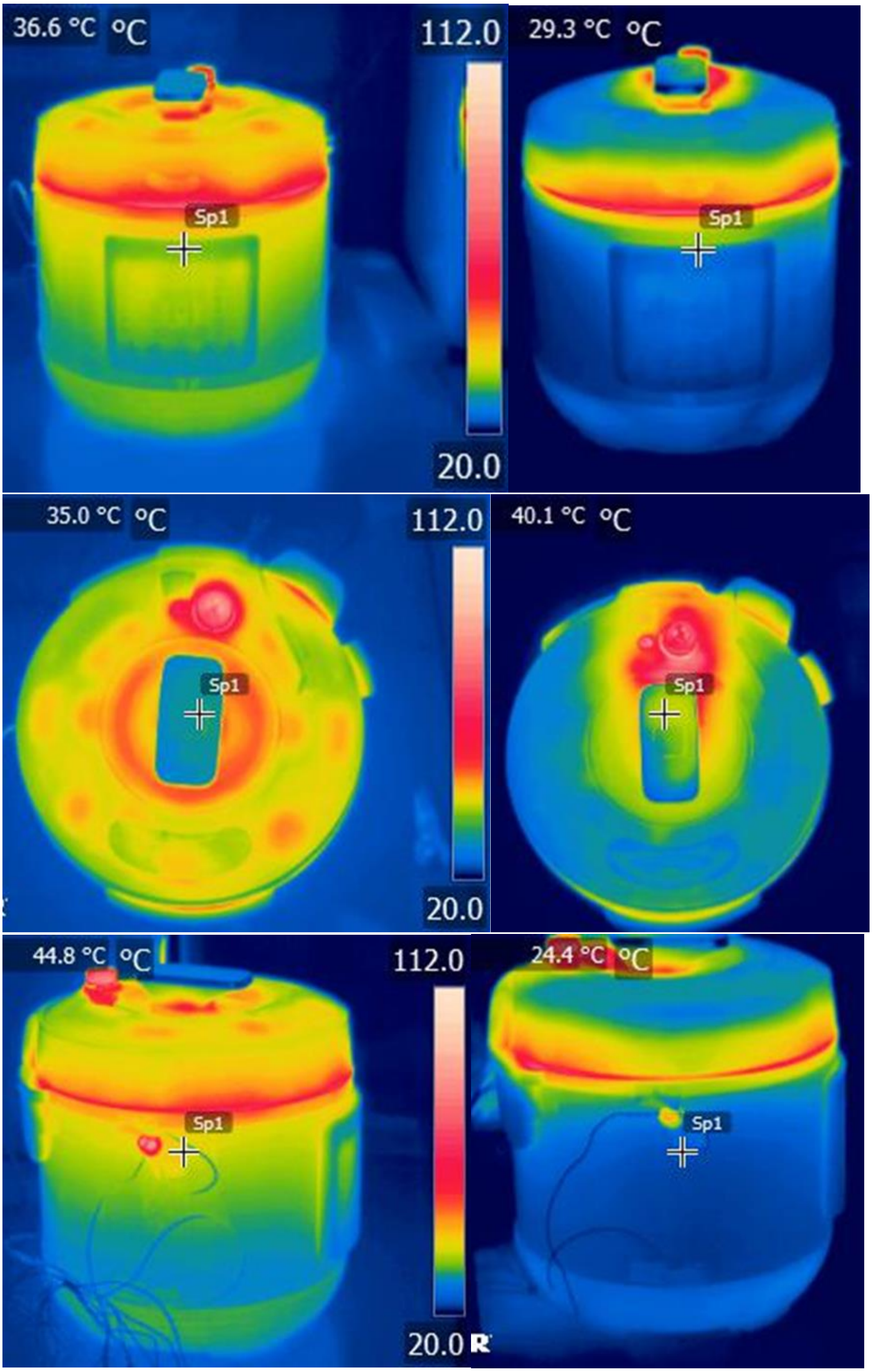

Figure 7 Thermographic images of EPC front, lid and side views during cooking phase with 3 litres water: as-bought Aobosi left and Aobosi with added insulation right (side views partially obscured by cables). The images have been post-processed so that the colours represent the same temperature range in each image. Note the effect of the ‘moat’, the plastic ring that joins lid to base and inner pan to chassis to outer skin; the moat creates an effective thermal bridge. The image of the insulated lid shows the effect of the ‘pie-slice’ of insulation omitted to avoid the steam vent and interlock mechanisms. [Images courtesy of Baptiste Rabut]

Choosing an EPC with an air-gapped lid provided the opportunity to replicate how a factory might install insulation, but displacing trapped-air insulation can be seen to provide limited benefit. This also demonstrates that improving something that is already high performing provides diminishing returns. In contrast, a poorly designed EPC may benefit to a greater degree. Figure 8 shows an equivalent thermal image of an EPC where the lid is a single layer of stainless steel.

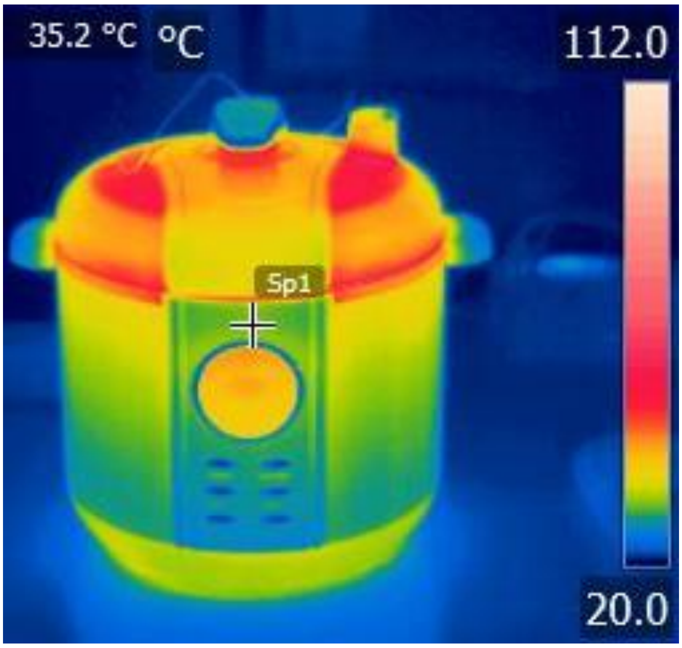

Figure 8 Another brand of EPC with single layer stainless steel lid. Although the emissivity appears to show temperatures around 50-60°C, the surface temperature has been measured at more than 105°C.

Here, the internal steam contacts the underside of the lid where it condenses before falling back into the pan. The lid has been measured to reach over 105°C. Not only will the heat loss be at a higher rate but the exposed metal also poses a risk of scalding. Similarly, the moat can be seen to present a thermal bridge. In this case, an insulating cover might offer a worthwhile improvement. It would need to cover the top half only, past the moat. It will need to avoid obscuring the control panel and it will need to have holes or orifices positioned to avoid the interlock and pressure control steam vents. The control panel cut-out can help position it correctly so that the vent holes are aligned correctly and safely. The cover can be made in-country like the wonder bag at low cost using natural materials.

Further, a number of low-end EPCs have heating elements that are simply bolted to the hot plate instead of being encapsulated to them. In these cases, adding insulation beneath the element would help control energy losses. However, due to the high temperatures involved, the insulation would need to be a technical product such as Pyrogel XTE or Spaceloft board.