A Comparison of Functions and Safety Features on the Thermo Pot Water Boiler

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Introduction

The Addis Thermo Pot uses electricity to boil, and then maintain, the temperature of hot water for instant availability in drinks and in cooking. The user selects the maintenance temperature of 40°C, 50°C, 60°C, 85°C or 98°C. When boiling, the power demand is 680W. When keeping warm, the Thermo Pot cycles between 2W and 100W. Its power demand is therefore substantially lower than a conventional kettle. The Thermo Pot is double walled to reduce heat loss rate and reduce the energy demand when maintaining a temperature.

In the context of the MECS project, the Thermo Pot may provide a means of slowly pre-heating hot water during the day, thereby storing energy as heat, and relieving the energy demanded from a battery. In the cooking diaries, a substantial number of heating events are only for hot water, and pre-heated hot water would be beneficial to reduce the cooking times of many foods.

The Addis Thermo Pot is available in sizes of 3.5 litres or 5 litres and is sold in the UK for between £60 and £100. Similar products include the Perma-Therm sold by Neostar Electronics, and the Bredeco Thermo Pot.

1. Functions and Features

The Thermopot starts to boil as soon as it is connected to the electricity supply. It initially displays the internal water temperature in °C on a red-lit LCD display. At any point after that, the user may select or change the keep-warm temperature using a button on the top display panel. The default is 98°C. However, the Thermopot always boils the water before allowing it to cool to the selected keep-warm temperature. Once boiled, the backlight on the LCD display changes to green and the water temperature is maintained to the selected temperature of 40°C, 50°C, 60°C, 85°C or 98°C. The water may be re-boiled at any time after that at the press of a button.

Physically, the Thermo Pot is a tall cylinder with a rebate under the spout for cups and other vessels to be filled, Figure 1. The body has a brushed stainless-steel surface but the top and lid are composed of black plastic. The spout is at the front of this top section. Control buttons and the LCD display are above the spout. The pump lever switch is to the right-hand side of the spout. The lid contains a large push button at its centre for manual dispensing of hot water. The Thermo Pot is filled by lifting the lid. At the rear of the top is a vent through which steam is released during boiling.

The Thermo Pot includes the following features:

- A water level indicator on the front
- Soft touch buttons for Reboil, Clean, Temperature Setting and Unlock
- Clear LCD display
- Three methods of dispensing water: auto, cup and manual
- Dry boil protection
- Automatically switches off when not used for 72 hours
- Safety locks for both manual and auto dispensing
- Self-cleaning cycle with citric acid supplied to minimise scaling
- Swivel base for turning the whole body of the Thermo Pot
- Carry Handle

Figure 1. Addis Thermo Pot, top and front views

2. Safety Features and Internal Components

The Thermo Pot includes the following safety features:

- Dry boil protection
- Thermal fuses with an operation temperature of 129°C +/- 2°C.
- Thermostat in base with operational temperature 130°C
- Temperature sensor on the outside of inner cylinder

The overall circuit diagram is shown below.

3. Examination of the Thermo Pot

The large central button in the lid has a lock-unlock lever to prevent spillage when not in use. The large central button may be depressed for manual dispensing of hot water but does not always work well.

A stainless steel lever in the lid enables the lid to be opened for refilling and tipping out residual water. A push lever at the rear of the lid enables the lid to be completely removed from its hinge. The lid contains an air gap of approximately 4cm for reduction of heat loss.

The inner cover is held in place by 3 small screws. The base sits on a plastic ring of 167mm diameter upon which the whole Thermo Pot rotates. Removal of this ring from its clips enables access to the larger retaining screws of the base.

There is a thermal shielding metal plate between the inner cylinder and the bottom circuit board. 5 screws hold this base plate, including one next to the water pump.

The inner cylinder diameter is 160mm. Its height is approximately 200mm.

The circuit diagram is shown in Figure 2.

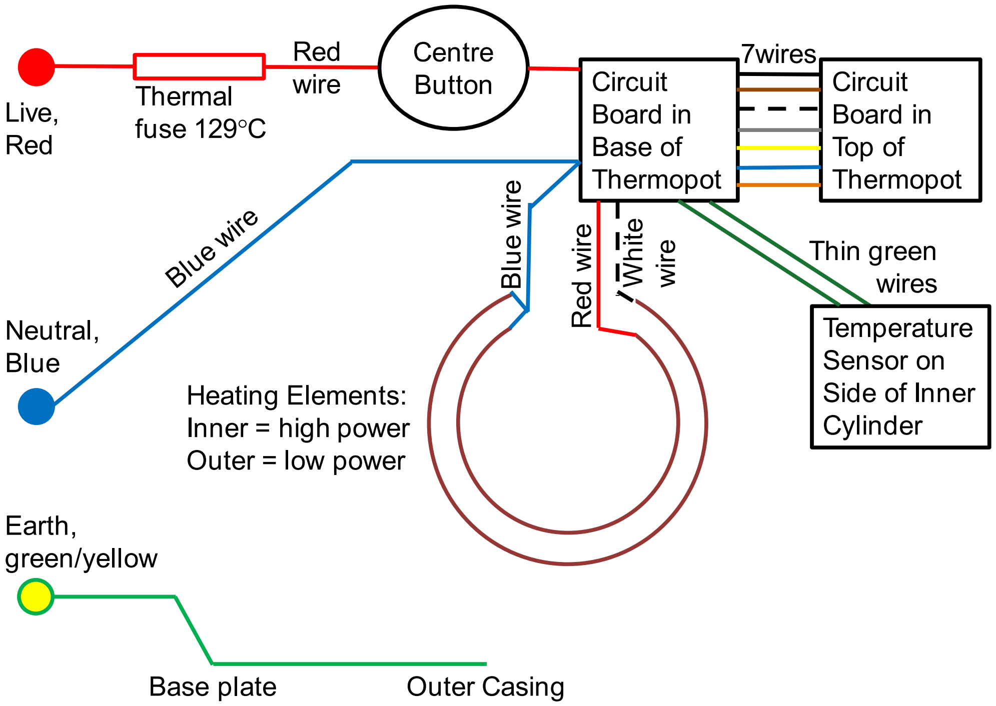


Figure 2. Circuit diagram of main components of Thermo Pot

4. Potential Problems in Normal Use

The body of the Thermo Pot is made of thin stainless steel. When carried onboard a vehicle, especially on the back of a bicycle, it is very easy to buckle or dent this outer skin. In most cases, the dents may be partially removed by careful manual pressure, but some permanent damage remains, as clearly visible on the left hand side of the Thermo Pot in Figure 1. In countries of the developing world, it is virtually certain that the Thermo Pot will be similarly damaged when carried on small vehicles along rough roads.

The metal dispensing lever in the lid is located very close to the right-hand side of the spout. There is a risk of steam scalding when operating this lever.

The actual volumetric capacity of the Thermo Pot, up to its full line, is only 4.76 litres, not the nominal 5 litres advertised. At this full point, boiling caused some spitting of boiling water from the vent.

5. Modifications

Modifications have been made to reduce power and energy use, with the aim of making the Thermo Pot more suitable for solar powered and daytime water heating.

Firstly, the boiling power of 680 watts is higher than the average daytime power output of even four standard 250Wp solar PV modules, and beyond the capability of an imagined solar home system that includes electric cooking. Internal examination of the Pot revealed the presence of two heating elements of different powers, Figure 2 above. Resistance measurements showed that the outer element would produce 100 watts of heat (the keep-warm power) and the inner element would produce 680 watts (the boil and re-boil power). By swapping one wire from the high-power element to the low-power element, the Thermo Pot can be made to never consume more than 100 watts. When filled with 4.76 litres of water and heated from 20°C to 100°C, the energy required is estimated at 1600 kJ or 0.44 kWh. With a power rating of 100 watts, this heating may be spread over 5 hours and be timed to take place when solar power is most abundant, or when grid electricity is cheapest or most reliable. Wires from both relays Figure 2 were placed on the low-power heating element, Figure 3.

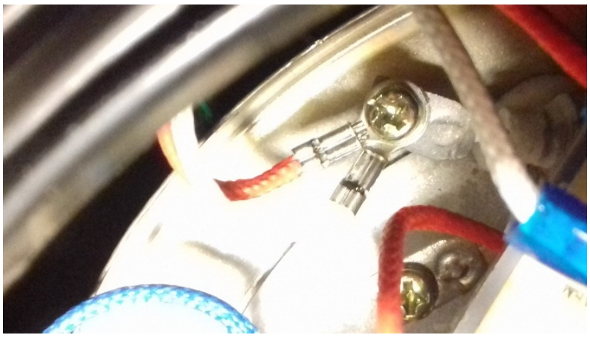


Figure 3. Output of both relays, red and white wires placed on the outer, lower-power heating element

Note that if either of the wires are carelessly positioned, it is very easy to create an earth short by bringing the sleeves of the connectors into contact with the body of the inner cylinder, Figure 4.

Figure 4. Both wires on the connector to the outer element. The sleeve of one wire creating a short circuit to earth.

Secondly, when kept warm for several hours, the heat loss is very significant. As shown in the test results section, with an ambient temperature of 22°C and a water temperature of 96°C, the heat loss rate is about 50 Watts. Over a period of 10 hours, this would amount to 0.5 kWh which is more than the energy originally required to heat the water from 22°C. External insulation was therefore applied to the Thermo Pot, Figure 5. In the developing world situation, the felt used in the laboratory tests could be replaced by, for example, a suitably shaped Wonderbag. Note that external insulation cannot address all areas of heat loss, because the spout and vent must always remain unobstructed. The spout area also contains a circuit board that is likely to be damaged by higher temperatures created by external insulation. The vent must remain open to allow steam to escape. Engineering insulation internally at the factory could address these issues.

Figure 5. Externally insulated Thermo Pot. Front and rear views. Spout, handle and vent remain exposed.

Finally, the Thermo Pot was tested at reduced voltage. Without modification, a reduction in voltage from 230V to 115V would reduce the boiling power from 680 watts to 170 watts. However, it would also reduce the keep-warm power from 100 watts to 25 watts.

6. Discussion and Conclusions

The Thermo Pot looks promising for pre-heating water and thereby reducing the energy demand from batteries. This pre-heating is recommended as a use of surplus solar PV power. Battery charging should take priority over this water heating.

A modification to only use the low-power heating element was simple and effective but removes the option of rapid boiling.

A future alternative modification would be to bypass the initial boiling function on start-up, causing the Thermo Pot to move straight to keep-warm mode. This will require a more in-depth examination of the control system.

In its as-supplied state, the heat loss rate of a Thermo Pot is only about 50 watts. In the conext of a strong electricity grid, this is a small and affordable energy penalty but in a stand-alone electricity system, such a loss impacts significantly on the size of other system components required such as solar PV and batteries. External insulation reduced the heat loss rate of a Thermo Pot from 53 watts to 40 watts. However, over a period of several hours, the heat loss is still very significant.

Internal insulation is a promising option for further reducing heat loss, but heat conduction losses are still likely to be significant.

Power reduction by voltage reduction is only effective down to 120V AC. Below that, the Thermo Pot fails to heat water. A more reliable voltage level to ensure normal function would be 150V AC. However, at that voltage, the boiling power demand would be about 300 watts using the larger heating element, and this is likely to exceed any surplus solar PV power at most times of day at domestic scale.

7. Appendix: Specifications of Components and Test Results

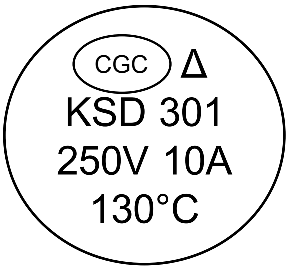
Thermocouple positions in the Thermo Pot

These positions are very similar to positions on EPCs tested earlier.

1. Between the base centre button and the inner cylinder to get as close as possible to the temperature of the water.
2. Adjacent to the thermal fuse, inside its sleeve.
3. On the electronic circuit board in the base.
4. Top of the outside of the inner cylinder.
5. Top of the outside of the external casing, on the stainless steel.
6. Bottom of the outside of the external casing, on the stainless steel.
7. On the lid.
8. Bottom of the outside of the inner cylinder, on the side wall.

Button in base of inner cylinder

This is held in place by 2 screws. Thermal contact with the inner cylinder is maintained by a white paste that is liquid at room temperature. Removal of the screws enables the button to be removed examined. The hidden face shows the identification marks:



Thermal fuse

The thermal fuse, in a glass fibre sleeve, has the following identification marks:

“SEFUSE SF129E PS1E10A”

RS-Online gives the specification:

- Rated functional temperature 133°C
- Operating temperature 129°C +/-2°C
- Holding temperature 118°C
- Max. temperature limit 159°C

Heating elements

Resistances were measured using a hand-held multi-meter.

The inner heating element is connected by the red wire and has a resistance of 77.7Ω. When a voltage of 230V is applied, the expected power dissipation is $(230)^2 \div 77.7 = 681$ watts. This is inferred to be the boiling heating element.

The outer heating element is connected by the white wire and has a resistance of 523Ω. When a voltage of 230V is applied, the expected power dissipation is $(230)^2 \div 523 = 101$ watts. This is inferred to be the keep-warm heating element.

Relays on bottom circuit board

There are two relays on the bottom circuit board, each driving one of the heating elements. The two relays are identical and have the following markings:

JCQ – 3F – 12VDC
10A / 120VAC
10A / 24VDC
7A / 250VAC

Water pump

A water pump draws in water from the base of the inner cylinder and delivers it to the spout. Its markings are:

"ZHONG SHAN YIBAO 8-12V DC"

Testing

Five tests have been conducted as described in Table 1.

Table 1. List of heating experiments on the Thermo Pot

Date	Volume of water	Voltage	Heating elements used	Added Insulation
1st July 2019	2 litres	230V grid	680W boiling, 100W keep-warm	None
1st July 2019	5 litres	230V grid	680W boiling, 100W keep-warm	None
14th August 2019	1 litre	230V grid	100W boiling, 100W keep-warm	None
14th August 2019	5 litres	230V grid	100W boiling, 100W keep-warm	None
16th August 2019	1 litre	230V grid	100W boiling, 100W keep-warm	External insulation
23rd August 2019	1 litre	0V to 230V then 230V to 0V	100W boiling, 100W keep-warm	External insulation

Uninsulated Energy Performance

The initial boiling temperature rise of the Thermo Pot, as indicated by the LCD display, is shown in Figure 6. The average rate of increase in temperature was 0.087°C per second. Using the specific heat capacity of water, the average heat flow to the 2 litres of water was 658 Watts compared to an electrical power consumption of 696 Watts.

Approximately 95% of the electrical energy is absorbed by the water during the boiling phase. This indicates that the thermal mass of the pot itself is only approximately 500J/K. This is less than the thermal capacity of an EPC, making the Thermo Pot a more efficient way of heating water.

The average energy consumption after boiling, in the keep-warm phase was 52.7 Watts, while the average internal temperature was 95°C and the laboratory temperature was 22°C. The thermal conduction (coefficient of heat loss) was therefore 0.72 J/K.

Some energy was lost in boiling before the thermostat switched off. This energy varied from test to test and was estimated at 9kJ with 2 litres of water but 27kJ with 5 litres of water.

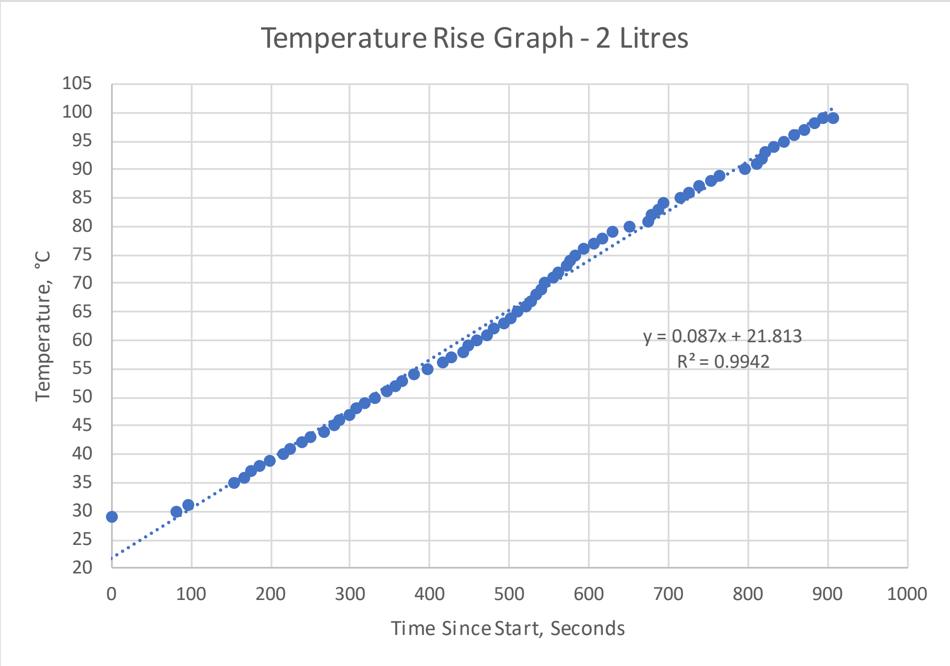


Figure 6. Initial temperature rise of the Thermo Pot when filled with 2 litres of water

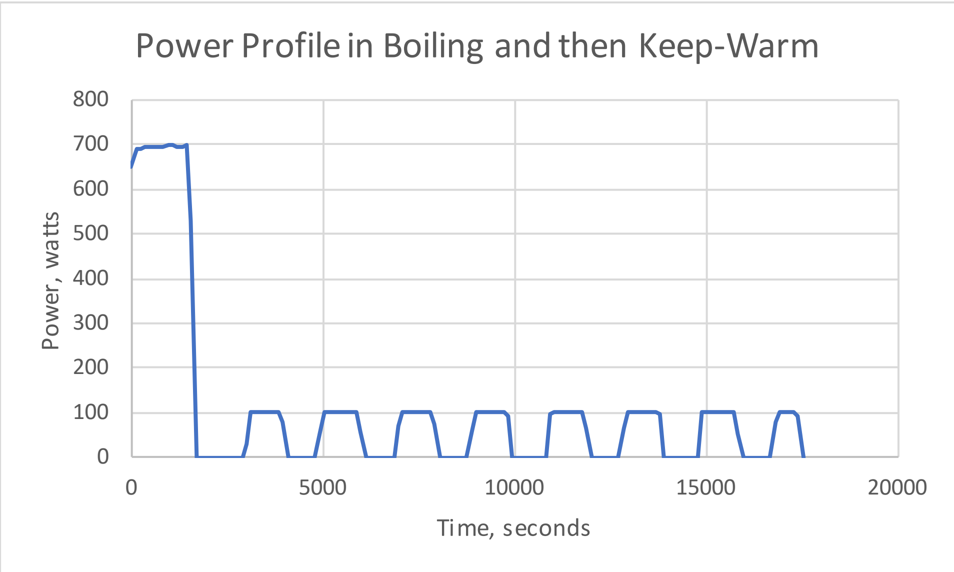


Figure 7. Power consumption profile of the Thermo Pot before modification

Performance after Changing the Heating Element Connections

After connecting the output of both relays to the low-power outer heating element, the initial boiling phase was longer, but also did not result in boiling of the water. The water temperature peaked at 96°C. The measured thermocouple temperatures are shown in Figure 8 for the test with 1 litre of water and in Figure 9 for the test with 5 litres of water. The initial boiling phase lasts about 1 hour per litre of water, making the modified Thermo Pot more suitable for use with excess solar power. Electrical measurements confirm a current of 0.44A at 235V, equal to a power of 103 watts during the initial boiling phase.

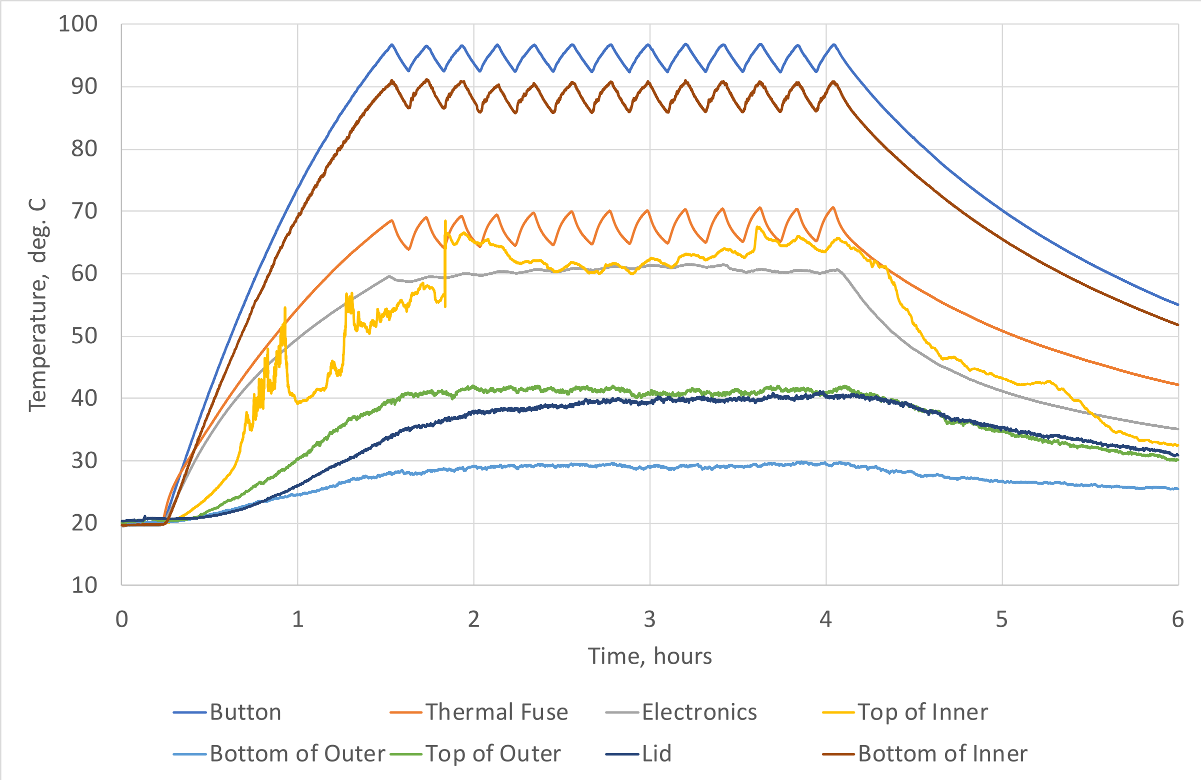


Figure 8. Thermocouple temperatures of the Thermo Pot during boiling and keep-warm with 1 litre of water

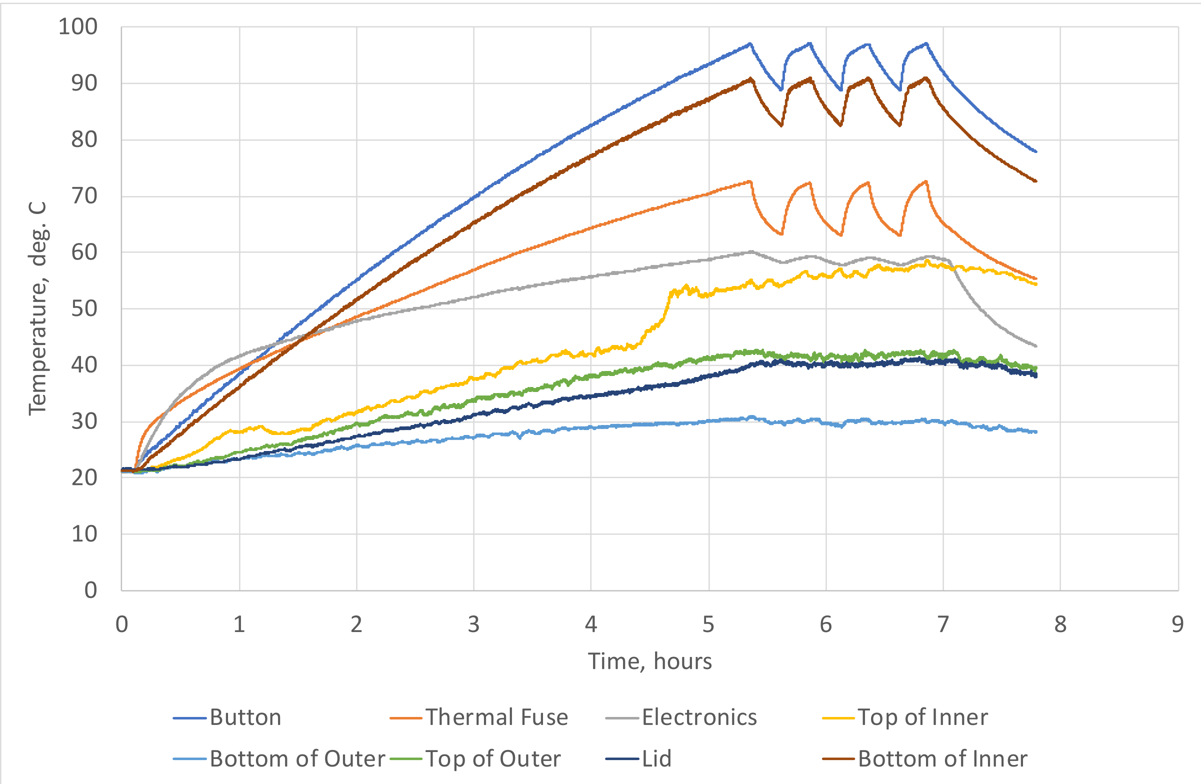


Figure 9. Thermocouple temperatures of the Thermo Pot during boiling and keep-warm with 5 litres of water

Performance with External Insulation

When external felt insulation was added, Figure 5, the energy used to boil and keep warm 1 litre of water was reduced. The boiling and heating phases were almost identical, but the cooling between the keep-warm heating phases was longer and the final cooling rate was slightly slower, Figure 10. During the keep-warm phase, the gaps between heating cycles was longer, Figure 11. The calculated average power consumption during keep-warm was 39.7 watts, compared to 52.7 watts without insulation.

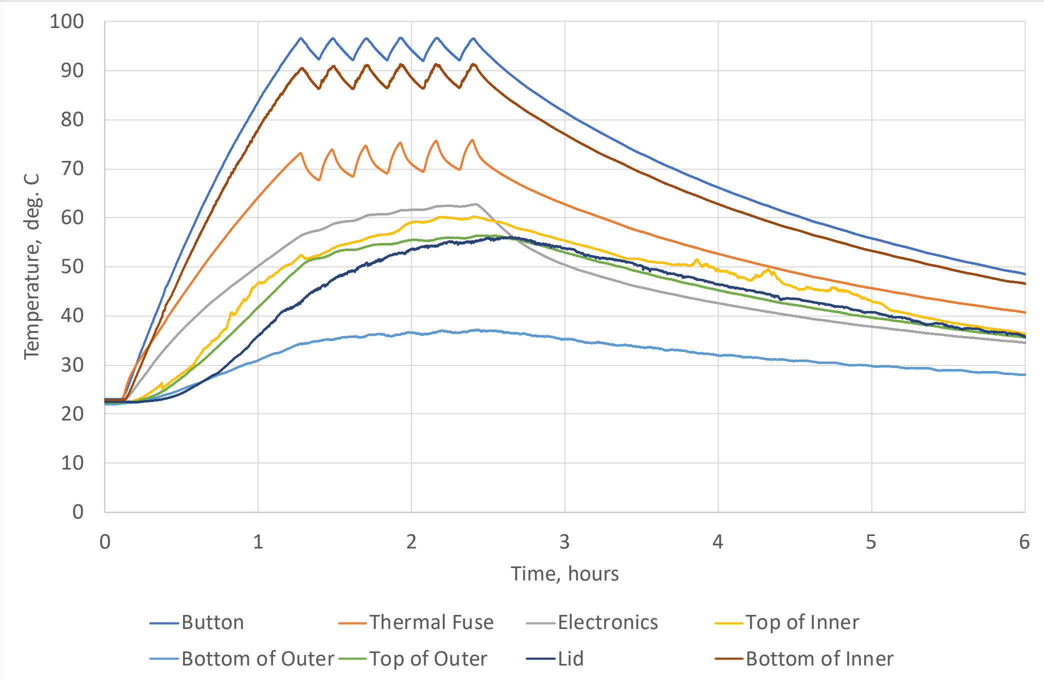


Figure 10. Thermocouple temperatures of the Thermo Pot during boiling, keep-warm and natural cooling, with1 litre of water and external insulation.

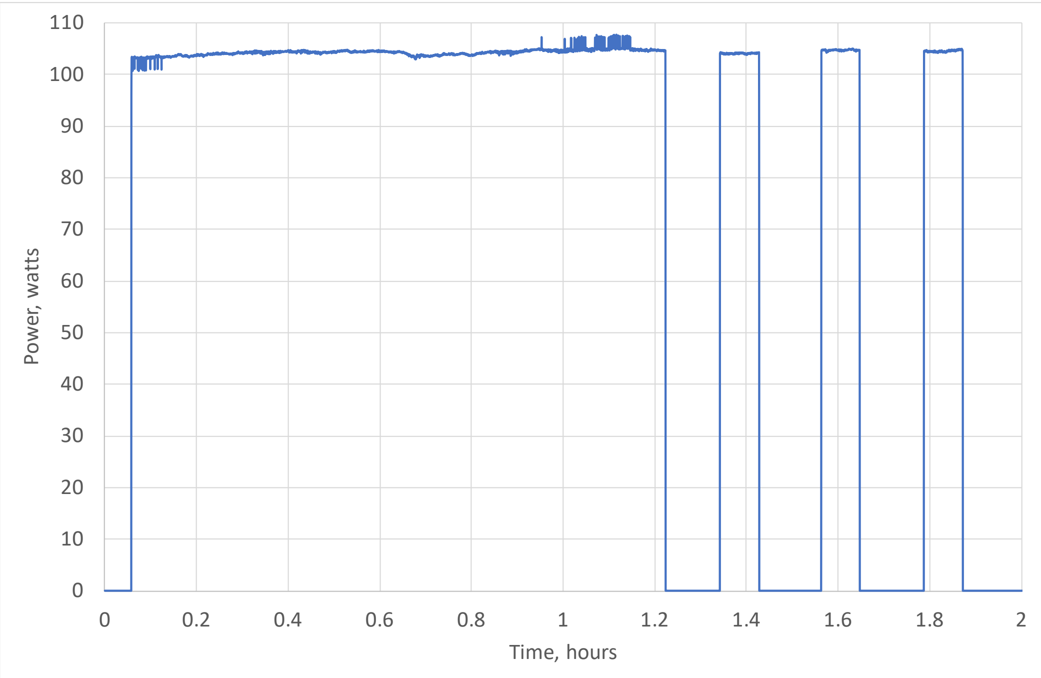


Figure 11. Power used by the Thermo Pot during boiling and keep-warm, with1 litre of water and external insulation.

Low Voltage Test

The Thermo Pot was powered via a variac to test its behaviour at low voltage. The voltage was swept from 0V to mains grid voltage (230V AC) and back down to 0V. The Thermo Pot was filled with about 1 litre of water and only the initial boiling phase was tested. The test was too short to give the thermal performance. The control electronics and switching relays were being tested to discover if the Thermo Pot might operate at reduced voltage as an alternative to modifying the heating element connections.

Power use over time is plotted in Figure 12 and current is plotted against applied AC voltage in Figure 13. The Thermo Pot switches on its heating element at 120V and switches off at about 63V. The LCD display began to operate at a voltage somewhat lower than 120V. Thus the minimum voltage for certainty of operation is a little over half grid voltage, and the minimum operating power (with the lower power heating element) is 30 watts. If the higher power element were used, then the power draw would be reduced from 680 watts to about 200 watts.

A reliable voltage of at least 120V cannot be achieved from a conventional North American 110V to 120V inverter.

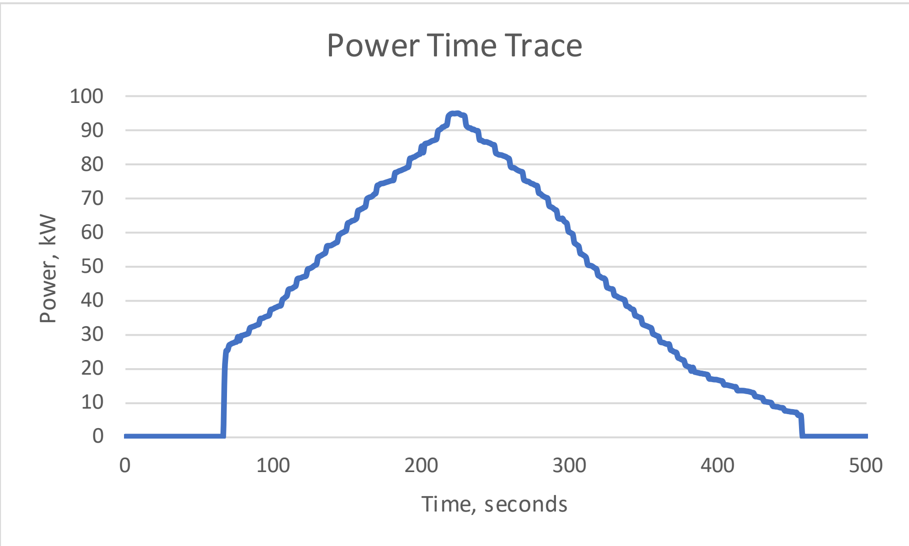


Figure 12. Power increase and decrease of the Thermo Pot as the voltage was swept

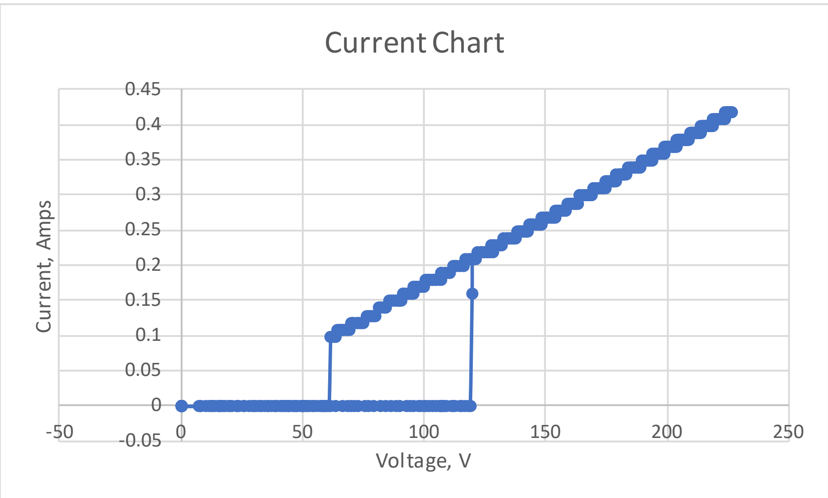


Figure 13. Thermo Pot current vs. voltage during an up and down voltage sweep, showing hysteresis of minimum voltage