Heat Losses In A Cook Pot at Constant Temperature

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Introduction

During simmering or cooking the task of the cook stove is to maintain a constant cooking temperature in the pot. In order to accomplish this goal, enough fuel is used to offset the energy losses from the pot.

These energy or heat losses are due to three main mechanisms; evaporation, radiation and convection. The goal of this study is to quantify the relationship of these mechanisms and to attempt to find means to minimize these losses when possible.

Methods

The pots used in the study are WFP standard pots used in the evaluation of various cook stove designs. They are pictured in Figure 1. The pots measure 25 cm in diameter and 16 cm in height and are made from stainless steel. They have a capacity of a little more than 7 liters. The tests were all done with 5 liters of water. One of the pots was used in a number of cook stove tests and its outer surface is blackened with soot. The other has never been used in testing and has the characteristic shiny surface of a stainless steel pot.

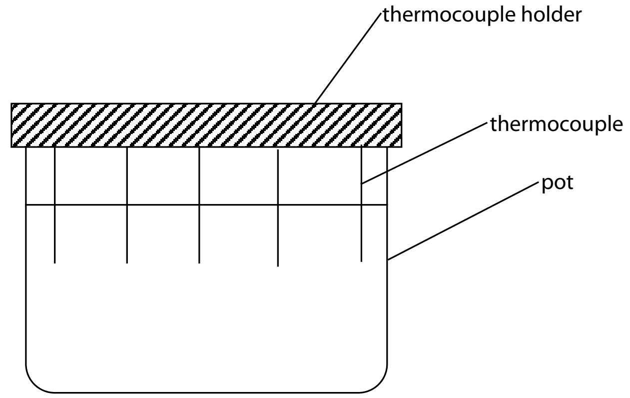
Figure 1

The former is much more likely to be found in a typical third world kitchen. The expectation is that these pots will have very different heat radiating characteristics and that is the motivation for using two pots.

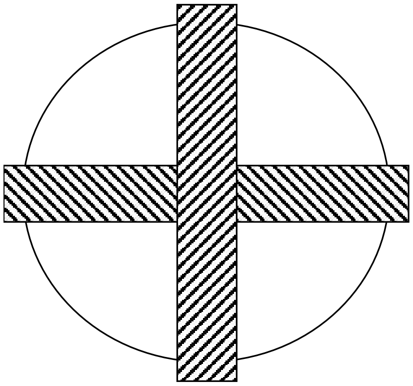
All of the tests were done on an electric range rather than a wood-fired cook stove. It is a much simpler task to hold the pot at a constant temperature on an electric range.

The temperature data was obtained using a thermocouple A/D data logger with an 8 channel capacity. It was a Picolog TC-08 model from Pico Technology Ltd. The data was fed into a Dell laptop computer with installed software that allowed for tracking the temperature histories over a variety of preset times and sampling rates. Excel worksheets were then used in data reduction and for graphing.

Before gathering data some preliminary runs were done with an array of thermocouples placed in various locations in the experimental pot to see how well they tracked when the pot was taken from room temperature to boiling. Fig. 2 shows the thermocouple setup. 7 thermocouples were used in the initial runs. The object was to ascertain if there was an appreciable distribution of temperatures in the pot during this process. Fig. 3 shows the results of one of these runs. The results showed that there was a uniformity of temperatures to within one or two tenths of a degree Celsius throughout the water volume. The local altitude of the laboratory where the tests were made is approximately 400 ft. above sea level. The boiling point for water at this mean altitude is 99.60 C.

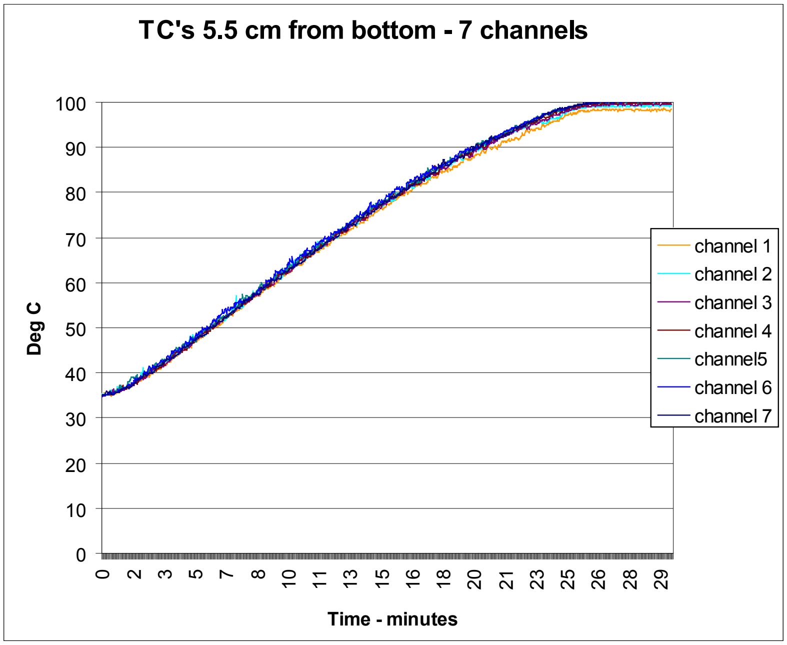


Side View



Top View

Figure 2



TC's 5.5 cm from bottom - 7 channels

Figure 3

Figure 4 shows the results of another measurement done to ascertain the uniformity of the temperature distribution in the vertical direction. 5 thermocouples were distributed vertically in the center of the pot. The top most thermocouple was located one cm below the top surface while the one at the bottom was positioned one cm above the bottom surface. The other three were located at 2 cm intervals in between. The Figure shows how closely they tracked one another. From these results it was decided that a single thermocouple placed in the center of the pot equidistant from the top and bottom surfaces of the water would be sufficient for temperature measurements.

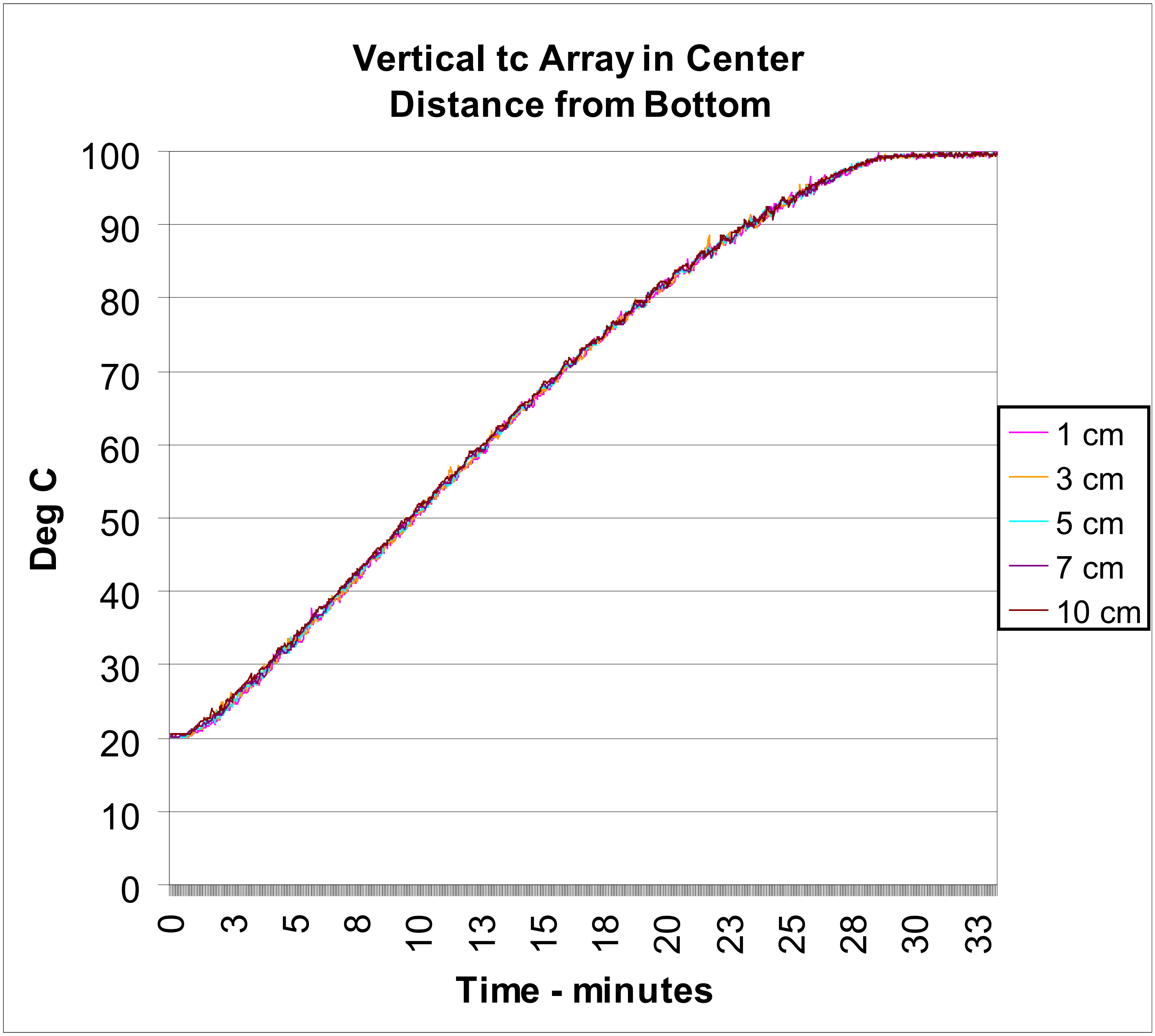


Figure 4

Results

The first set of runs were done to quantify the water lost through evaporation at various fixed liquid temperatures. Runs were made at 10 degree intervals from 50° C to 90° C and at 2 degree intervals from 90° C to 98° C. Figure 5 shows the results in gm/hr of liquid lost and Figure 6 shows the results in equivalent energy lost in watts. The values in Fig. 6 were obtained by multiplying the numbers on the vertical axis of Fig. 5 by the enthalpy change in vaporizing water, 502.5 watt-hrs/kgm.

Runs were also made to ascertain the results in evaporation losses when 1) a thin layer of olive oil was floated on the top surface of the water and 2) a lid was placed on the pot. These results are shown in Figure 5 for a water temperature of 98° C. The olive oil film was 100% effective in inhibiting the losses due to evaporation while the pot lid was 92% effective. The latter result was valid as long as the lid was undisturbed during the entire run. If it were lifted to examine the pot contents or to stir the food, the loss due to evaporation would be greater.

The effectiveness of the oil film in inhibiting evaporative losses exceeded expectations. Apparently the oil film forms a potential barrier which the water molecules cannot penetrate. Any cooking oil or viscous liquid would probably have the same result.

Figure 7 shows temperature histories of a pot taken from room temperature to boiling with and without an oil film. Both runs were made without lids. The run without an oil film has a constant slope until it reaches temperatures when the losses due to evaporation become significant. At that point the slope continually decreases in magnitude until it reaches the boiling point. By comparison the run done with the oil film shows a constant slope until boiling is reached. This illustrates the relative magnitude of the heat loss due to evaporation. The pot with the oil film reaches boiling in 23 min. while the pot without the oil takes 27 min to reach boiling.

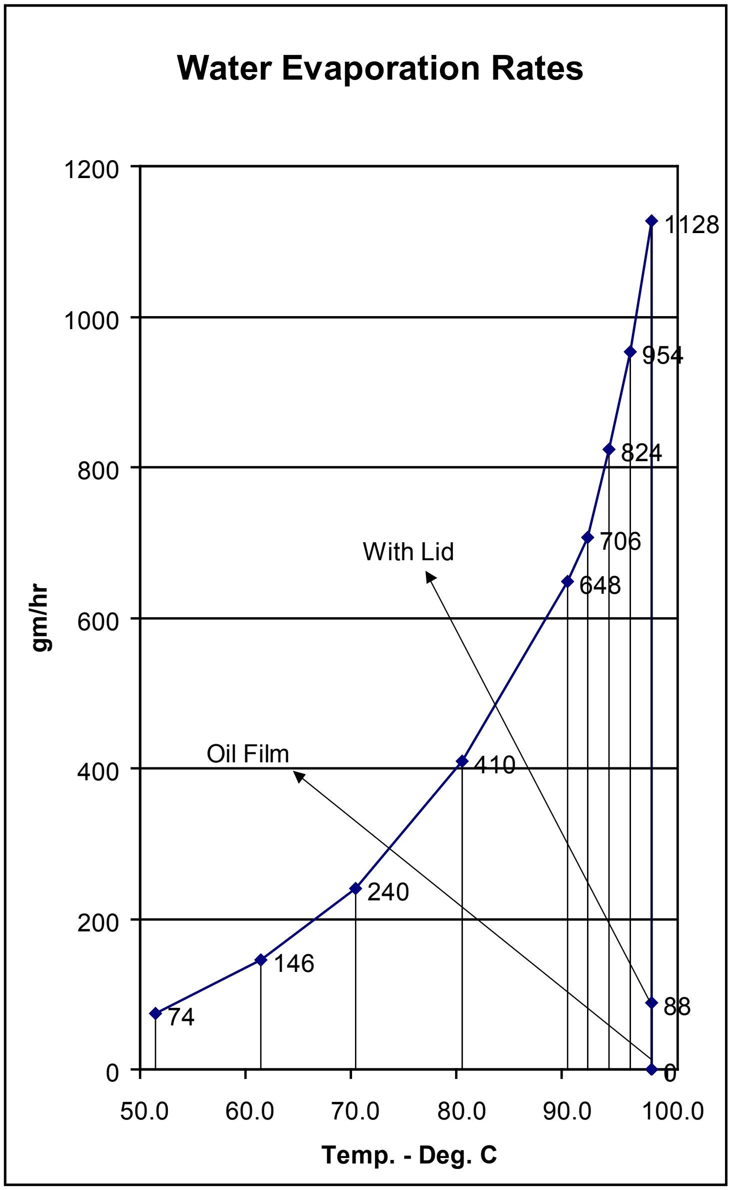


Figure 5

Having a means to completely inhibit the evaporation process makes it possible to quantify the various mechanisms of heat loss during the cooking process. The next part of the study involved the use of a meter which quantified the amount of electrical energy in kw-hrs used by the electric range in each experimental run. All of the measurements were made after the stove had been on steadily for anywhere between 30 minutes and an hour. This allowed the stove body to reach a steady state condition. Runs were made with and without an oil film as well as with a lid with the pot at a constant temperature of 98° C. This provided a relative number for quantifying the heat loss due to evaporation as well as the heat loss from radiation and convection combined. Next runs were done with an oil film at the same temperature but in each pot (blackened and shiny). This gave a relative quantity for the heat loss from radiation from the sides of the pot. Finally if each of these pots can be assigned a coefficient of radiation which approximates the actual values, then an approximate value for the heat loss due to radiation from the sides of the pot can be assigned to each pot. Table 1 below gives the total energy input to the stove in watts for each of the runs described above.

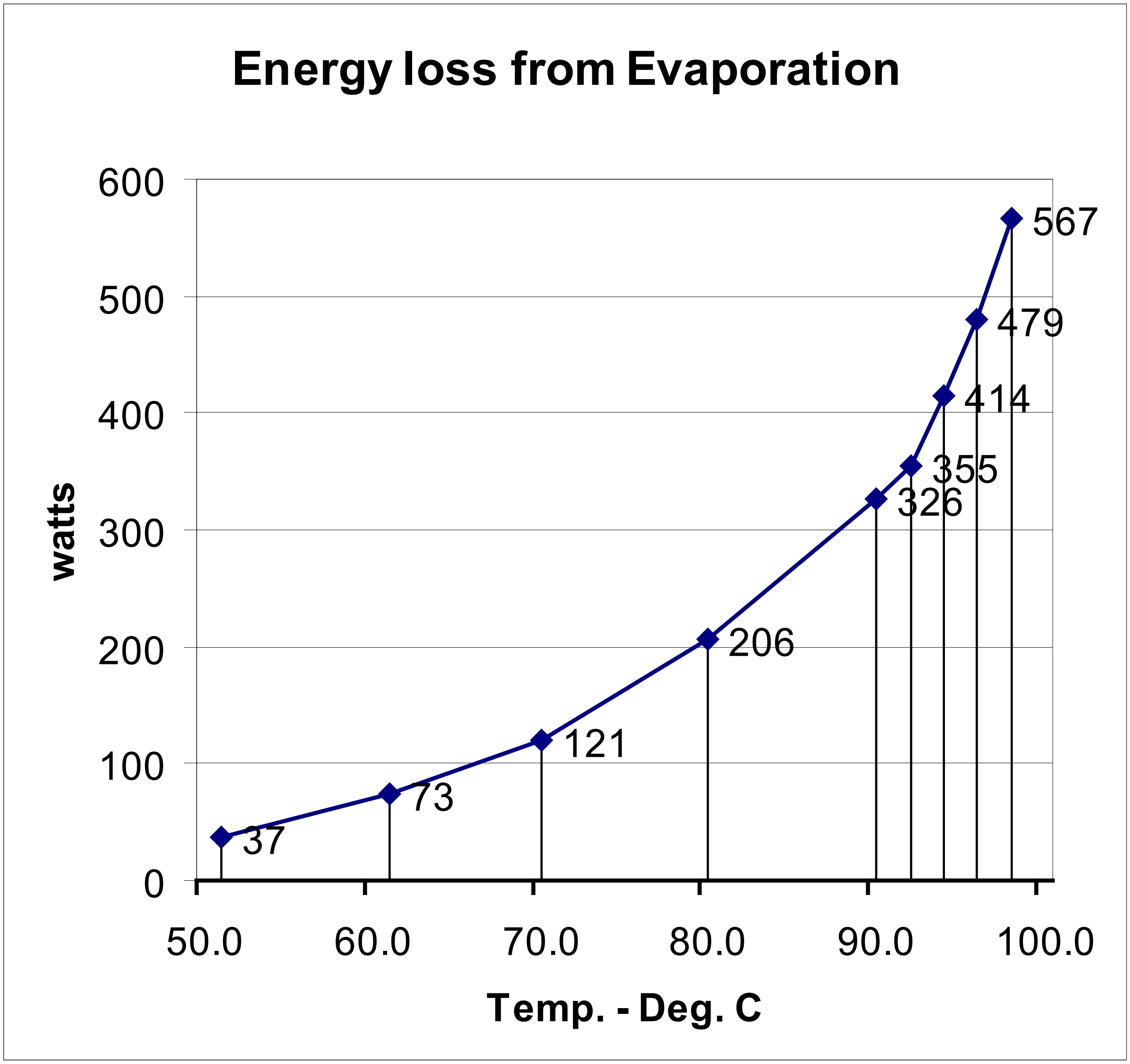


Figure 6

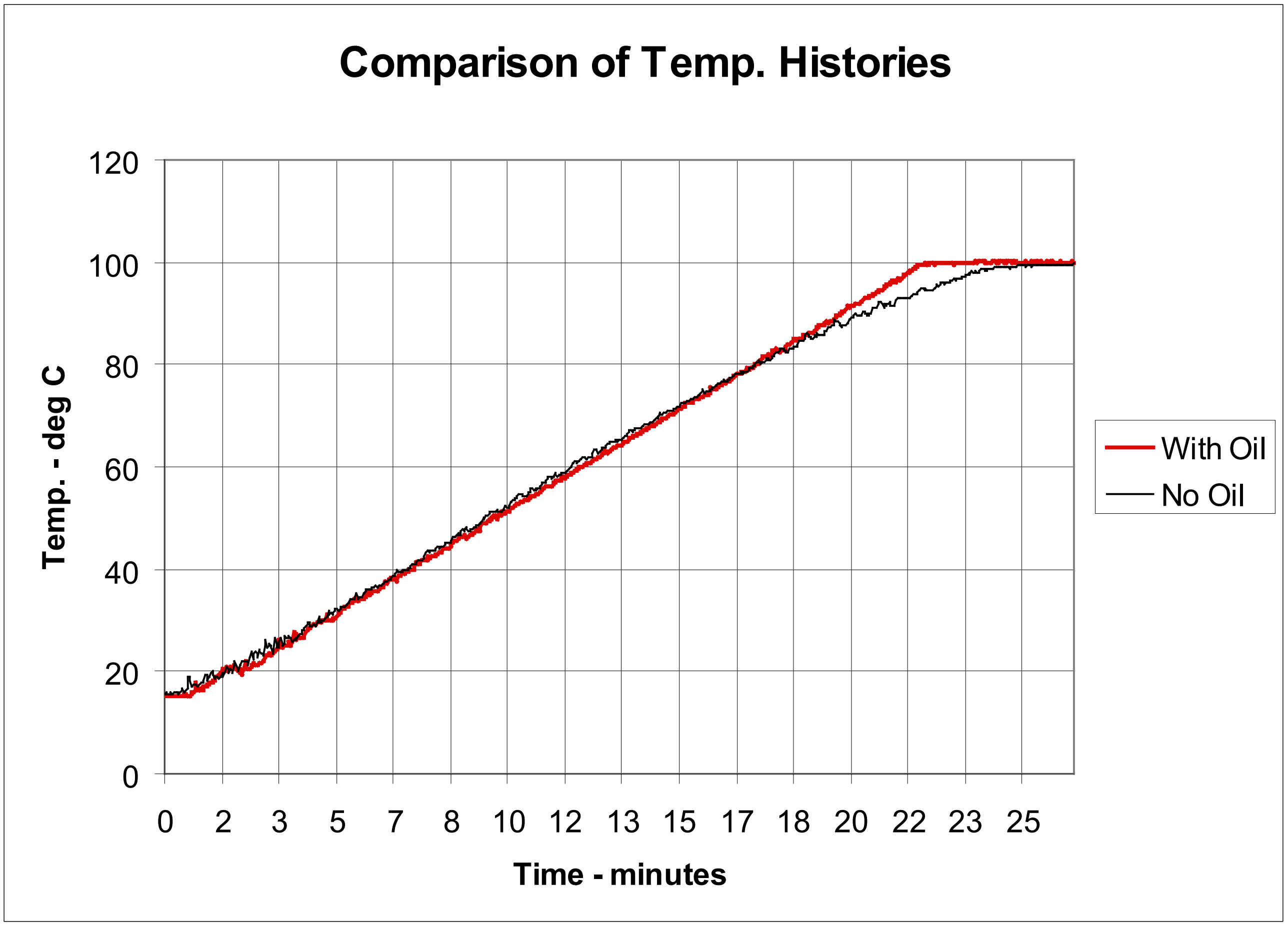


Figure 7

Table 1 below gives the total energy input to the stove in watts for each of the runs described above.

Description	Black Pot	Shiny Pot
No Oil	1080	990
With Oil	230	140
With Lid	270	180

Table 1

The difference in energy input between the runs without oil and with oil represents the savings in energy when evaporation is eliminated plus a small difference between heat loss by radiation from the water surface and that lost from the olive oil surface. This difference is 850 watts. From Fig. 6 the actual value of the energy savings at a temperature of 98° C is given as 567 watts. Water has a greater radiation emissivity than olive oil by a small amount. Thus the difference between the runs with oil and without oil due to radiation losses from the pot liquid surface is 3 watts. In the section below dedicated to radiation losses the details of how this figure was derived will be explained. The total energy saved when the oil is added to the pot is given by: 567 + 3 = 570 watts. By dividing this number by the total energy difference supplied to the stove, the result gives the thermal efficiency of the stove. In the present case this efficiency is 67%. Table 2 below gives the actual rate of energy in watts supplied to the pots by multiplying the values in Table 1 by the stove thermal efficiency.

Description	Black Pot	Shiny Pot
No Oil	725	663
With Oil	154	94
With Lid	181	121

Table 2

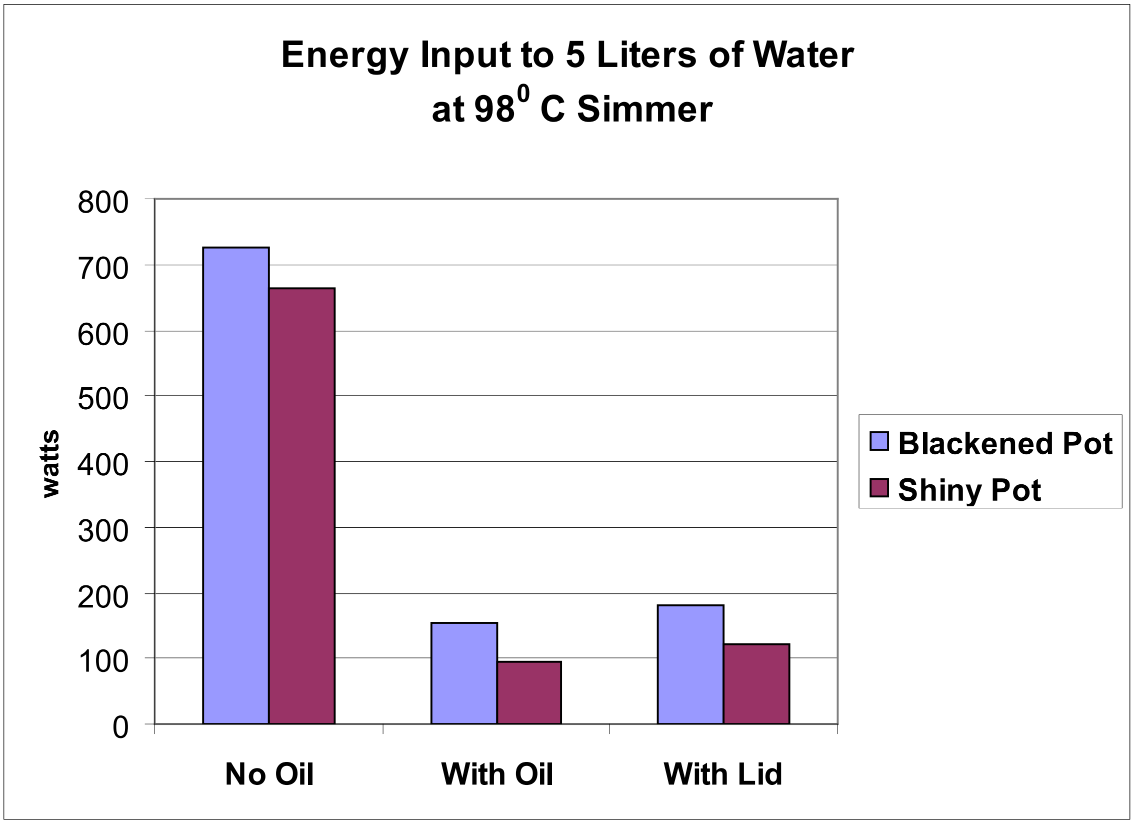


Figure 8

Fig. 8 shows these values in a bar chart. In the runs made with the blackened pot the loss due to evaporation is almost 80% of the energy supplied to the pot. For the shiny pot the evaporation loss is 86% of the total energy loss from the pot.

Radiation Losses

The equation which describes thermal radiation is given by the Stephan-Boltzmann equation below:

$H=\varepsilon\sigma A(T^4_s-T^4_{rm})$
H= Total heat rate loss in watts/hr
ε=emissivity
σ= Stephan-Boltzmann constant = 5.67×10^{-8} W/m^{2}K^4
A= surface area
T= Absolute temperature in deg. Kelvin = deg. Celsius + 273
T_s= Temp. of the pot surface = 98 + 273 = 371^0K
T_{rm}= Temp. of the room = 10 + 273 = 283^0K

The values for the various surface emissivities were arrived at using an infrared thermometer with variable emissivity settings (Westward model 1EZ22). The pot was heated to a constant temperature close to 98° C using a submerged thermocouple to monitor the temperature. The IR thermometer was then used to monitor the pot surface as well as the liquid surfaces. The thermometer emissivity was adjusted so that the IR thermometer reading in each case equaled the Thermocouple reading. The emissivity setting was then used for the calculation in the Stephan-Boltzmann equation. Table 3 below lists the various emissivities.

Soot surface	0.90
Shiny surface	0.25
Water surface	0.94
Oil surface	0.85

Table 3

In all of the measurements done for Fig. 8 (no oil, with oil, or with lid) the difference in the total energy used in heating the blackened pot and the shiny pot was 61.4 watts. It is assumed that this difference is entirely due to the variation in emissivities between the blackened pot and the shiny pot. The pot lateral surface area is given by:

$$A = \Pi 25 \times 16 = 1257 \text{ cm}^2 = .1257 \text{ m}^2$$

Using the above values of emissivity coefficients for the pot surfaces, the difference is: 0.9 – 0.25 = 0.65, the calculated difference in energy loss is 58 watts, a difference of 5% from the actual measured value.

The area of the liquid surface is given by:

$$A = \Pi/4(25)^2 = 491 \text{ cm}^2 = .0491 \text{ m}^2$$

The difference in emissities between the water surface and the olive oil surface is 0.94 – 0.85 = .09
Using the surface area above and inserting this into the Stephan-Boltzmann equation for radiation heat loss yields a value of 3 watts. Adding this to the figure for heat loss from the surface due to evaporation gives a value of 570 watts which was the value used to calculate the thermal efficiency of the stove.

For the shiny pot the radiation emissivity is 0.25. This yields a heat loss rate of 22.5 watts from the pot surface due to radiation. The rate of heat loss from the liquid surface using 0.94 for the value of emissivity is 32.8 watts. Thus the total rate of energy loss due to radiation is 55 watts for the shiny pot.

For the blackened pot using 0.90 for the emissivity from the pot surface, the radiation loss is 80.5 watts. The loss from the liquid surface is the same as the previous calculation, 32.8 watts. Thus the total rate of radiation losses for the blackened pot is 113 watts.

Convection Losses

Using the rule of conservation of energy, the losses due to convection are arrived at by subtracting the total losses due to evaporation and radiation from the total energy input to each pot. The result is:

44 watts for the blackened pot and 41watts for the shiny pot.

These results are summarized in Fig. 9

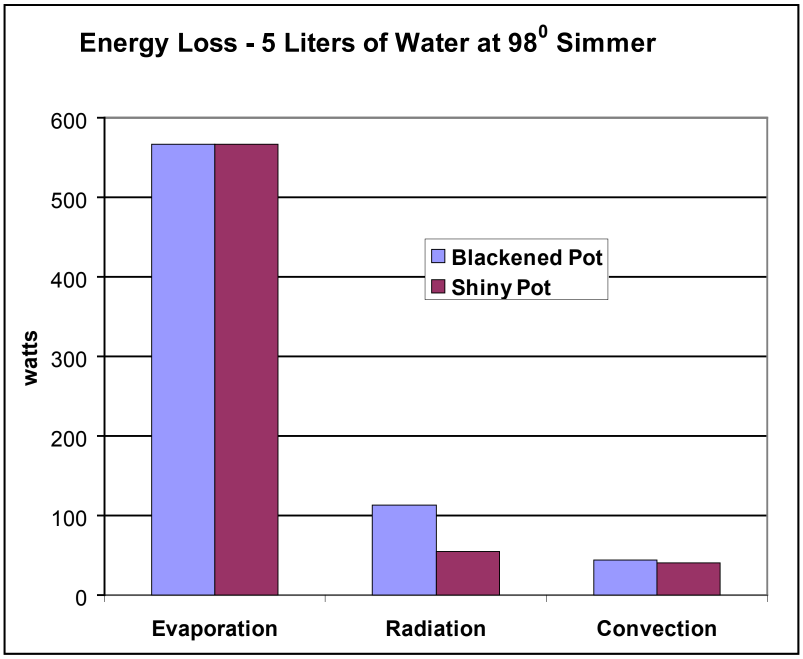


Figure 9

Summary and Conclusions

For a 25 cm diameter pot:

- At typical cooking temperatures, evaporation accounts for the major portion of the total heat losses.
- At a temperature of 98° C evaporation accounts for approximately 78% of the heat loss for the blackened pot and 85% of the loss from the shiny pot.
- A thin layer of cooking oil will entirely eliminate liquid evaporation.
- This not only saves approximately 80% of the fuel used and reduces air pollution by the same amount, but will also save water. At a cooking temperature of 98° C with 5 liters of water approximately 22.5% of the water is lost each hour.
- Using a lid while cooking will achieve roughly 90% of the above savings as long as the lid is not removed during the cook time.
- The heat loss from radiation accounts for 16 % of the total loss for the blackened pot and 8% of the total loss for the shiny pot.
- Convection losses only account for 6% of the total for both pots.
- A quick calculation of thermal efficiency for the electric range used in this study gave a value of 67%.