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Sensible heat bean cooker

Casiana B. Lwiwa[†] and Ole J. Nydal
Norwegian University of Science and Technology, Kolbjørn Hejes vei 1, 7491, Trondheim, Norway
[†]Corresponding email: casiana.b.lwiwa@ntnu.no or lwiwacasiana@gmail.com

ABSTRACT

Alternative cooking energy to replace wood fuels is needed in the African context. Liquified Natural Gas (LNG) is a solution but is still based on burning fossil fuel. Electrical cookers can be an alternative as well. However, for off-grid systems this means electrical batteries are required, as the solar electricity from Photovoltaic (PV) panels is intermittent, and as cooking is also to be made after sunset. Heat storage technologies can provide solutions where available energy is stored in the form of heat for cooking when needed. The challenge is then to develop systems which are robust, safe, and technically simple. A very simple small-scale solution is demonstrated here, for the particular case of cooking beans. An insulated iron cylinder is heated, either in a solar concentrator or by PV-powered heating elements. The stored heat can then be calibrated to the cooking of a given volume of beans. After the cylinder has reached the calibrated temperature during the charging, the pot can be placed and left on the top of the cylinder. When the energy is depleted, the beans should be ready cooked.

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INTRODUCTION

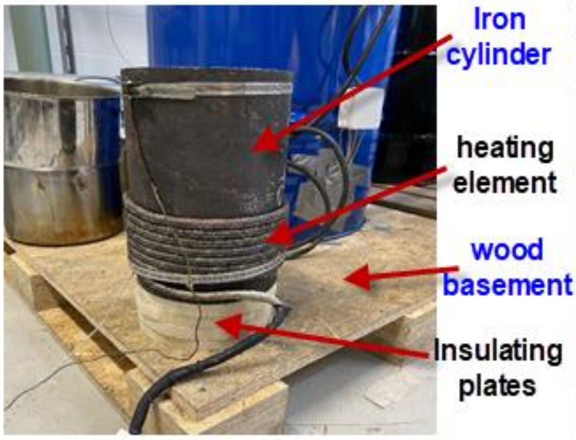
The energy required for cooking accounts for nearly 95% of all the domestic energy needs in sub Saharan Africa (Energy & Agency, 2022). The access to clean, cheap, effective, reliable and safe cooking energy systems is important, particular in the African context, as more than 80% of households rely on biomass for cooking (Energy & Agency, 2022). Switching from unclean to clean cooking fuels will ensure improvements in human health and reductions in environmental impacts caused by burning of biomass (Gordon et al., 2014). The choice of the cooking energy is determined by its availability, price and cleanliness level. Alternative cooking energy to replace fuel woods should preferably have high energy efficiency and high combustion efficiency as the combustion of unclean cooking fuels results in emissions of household air pollutants. Besides, high heat transfer efficiency with appropriate heat control methods should also be taken into consideration.

Solar box cookers for direct cooking in the sunshine are well developed. The solar funnel cookers for concentrating solar energy and convert it into heat for cooking (Apaolaza-Pagoaga et al., 2021; Carrillo-Andrés et al., 2022; Ruivo et al., 2021) are easy to build, handle, safe and low-cost solutions. However, as the sun is intermittent in nature, and since cooking needs also to be done after sunset, heat storage technologies can provide solutions where available energy is stored in the form of heat for cooking when needed. In the literature, a few heat storage technologies for cooking using sensible heat (Mbodji & Hajji, 2017; Mussard & Nydal, 2013; Schwarzer & Da Silva, 2003) and latent heat (Buddhi et al., 2003; Sharma et al., 2000) have been reported, but there is still potentials for innovation in this area. This paper demonstrates the use of a robust, clean, safe and simple system for storing heat for cooking during off-sun hours. The designed system can replace the traditional use of biomass and is demonstrated for the particular case of cooking beans.

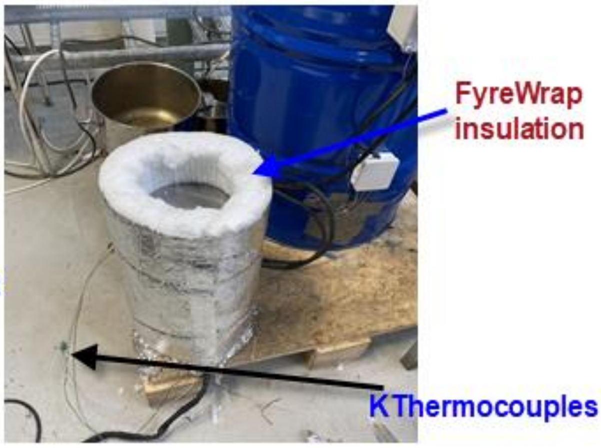
DESCRIPTION OF THE SYSTEM

Experimental setup

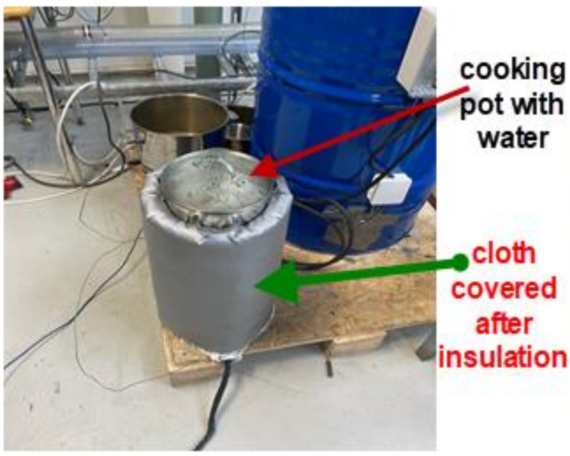
An insulated iron cylinder is heated by a grid-powered heating element (1090W power and maximum temperature of 450 °C) wrapped around the cylinder. When a set temperature is reached, the power is shut off and a waiting period is allowed until the cylinder has close to homogenous temperatures. Two cooking cases were then considered: boiling of water (3 or 2 liters) and cooking of beans (1 kg beans and 2 liters of water). Figure 1 shows the setup for the experiments.



(a) An iron cylinder covered with heating element plus insulating plates on the bottom



(b) Insulation supplemented to the iron cylinder



(c) The case of boiling water (2 liters) on heat storage

(d) The case of cooking beans (1 kg of beans and 2 liters of water)

Figure 1: Set up for the experiment for the bean cooker.

DESCRIPTION OF THE HEAT STORAGE

The iron cylinder has 20 cm diameter and 30 cm length. After insulation, the diameter is 29 cm, and the length is 46 cm. On the bottom of the iron cylinder, 4 flat insulation plates have been placed, that withstands higher temperatures. Their diameters are the same as the iron cylinder.

High temperature insulation is applied (type FyreWrap) to reduce the heat losses from the cylinder as well as from the cooking pot to the surrounding. The insulation was wrapped in heat resistant cloth, which also helps to reduce convection heat losses from the cylinder surface. Good insulation will result in considerable energy savings during cooking and will reduce the time needed to reach the set temperature of the cylinder during heating.

TEMPERATURE MEASUREMENTS

The temperature measurements as a function of time were recorded through the heating and cooking experiments by using a Digital PicoLog data logger. Three thermocouples, (type K) were installed, and named “Top”, “Bottom” and “Water”. The Bottom thermocouple measures the temperature at the heating element, which is wrapped around the cylinder. The Top measures the temperature on the top of the heat storage. Water measures the ambient temperature before cooking started and was then moved into the water to give the water temperature during cooking.

EXPERIMENTAL PROCEDURES

The experiments were carried out in the Department of Energy and Process Engineering at the Norwegian University of Science and Technology. After the cooking experiments, the PicoLog was normally left to continue the data logging for about 24 hours. This gives the data for the evaluation of the insulation properties, showing the capacity of the storage to retain heat.

In the morning of each test, before setting up each experiment, the designated volume of water or/and beans were measured and placed into the cooking pot. This volume ranged from 2 liters of water to 1 kg of beans and 2 liters of water. The values for the heat capacity of the water and the iron storage are taken from the public domain.

The insulated iron cylinder was heated until the Bottom sensor reached about 312 ^{o}C (the maximum temperature tolerance of the heating element is 450 ^{o}C). During the heating period, the top of the cylinder is insulated with three insulation pads. The power was then shut off and the cylinder left to obtain homogeneous temperatures. After the Bottom and Top temperatures became analogous, the insulation pads on the top were replaced with the cooking pot to start the boiling or cooking. The Water thermocouple was placed inside the cooking pot, to record the temperature of the water. The tip of the sensor was placed about 5 mm from the bottom surface of the cooking pot. The time, ambient temperature, and temperature on Bottom and Top were also recorded manually during the experiments, to give reference point for each test.

After completing the experiment, the pot was left on top of the heat storage and the data logging continued overnight. The elapsed time (in seconds) and the corresponding temperatures were recorded each second. For comparative tests, the temperature versus time for both cases, boiling water (2 or 3 liters) and boiling beans were plotted.

EXPERIMENTAL RESULTS ON COOKING TESTS

Boiling of water

An insulated iron cylinder was heated by a grid-powered heating element up to about 200 ^{o}C. After the storage was fully charged, the power was shut down and the temperature decreases until the top and bottom were homogenous, then boiling of water started. Two cases have been investigated: boiling of 3 or 2 liters of water. For the case of boiling 3 liters of water, the heat storage was not able to boil water. The maximum temperature reached was 98 °C, after 3 hours and 35 minutes. However, the cooking pot was left on top of the heat storage for the data to log on overnight as shown on Figure 2. The amount of water was then reduced to 2 liters and the experiment was repeated, Figure 3.

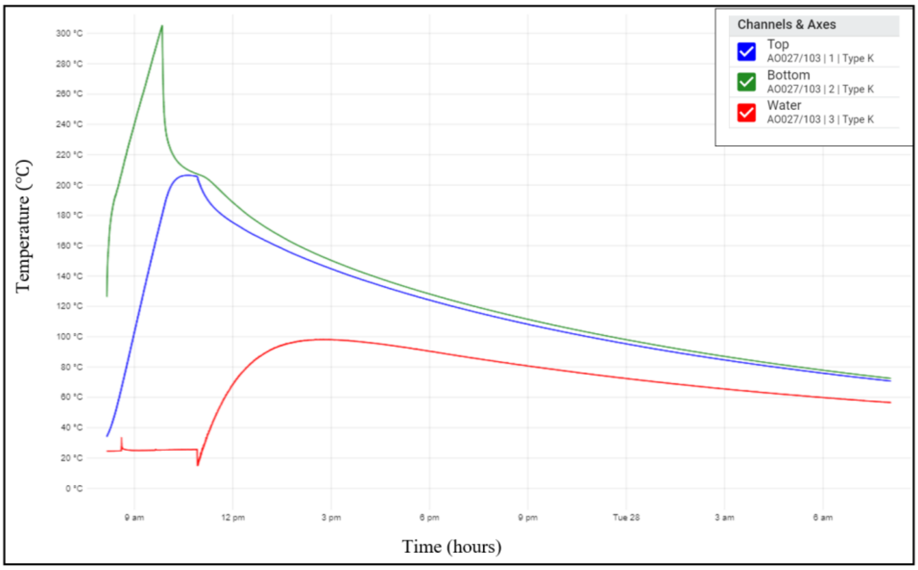


Figure 2: Boiling 3 liters of water.

The thermocouple sensor for the Bottom temperature recordings (green curve in the plots) was positioned in contact with the heating element. The recordings thus show a very rapid initial increase, and a rapid decrease after the power shut off.

For the case of boiling 2 liters of water, when cooking started, water boiled after 26 min, as shown on Figure 3. It maintained the boiling point for 3 hours and 56 minutes, until temperature started to decrease.

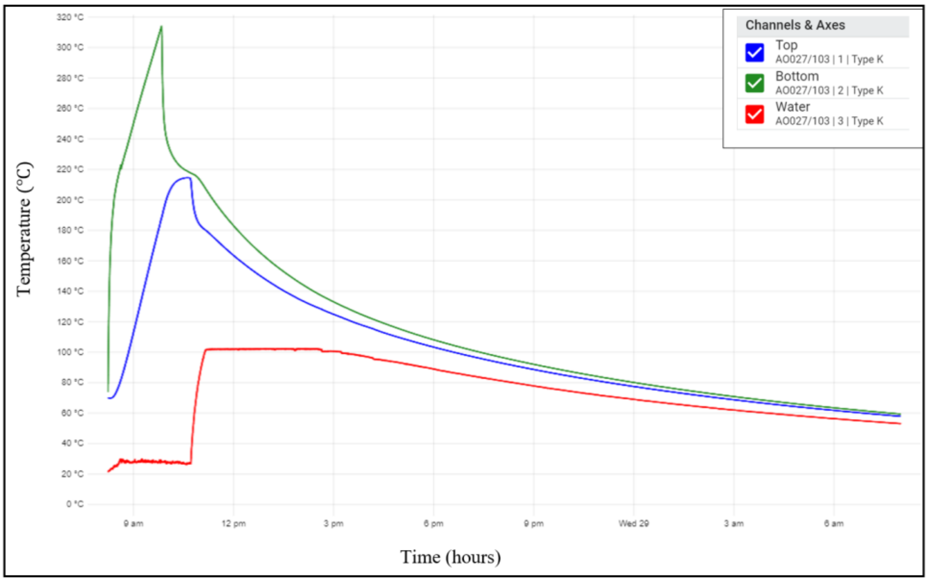


Figure 3: Boiling 2 liters of water.

Boiling of beans

As for the case of boiling water, in Figure 4, after charging, the power was shut down and discharging begins on the green loggings (Bottom). The thermocouple connection failed. The thermocouple was connected again, and the experiment continued. Beans started boiling after 39 minutes, as shown on Figure 4. At around 4:30 pm, the lid on the cooking pot was opened to check whether the beans have been cooked, temperature dropped a bit from 100 °C, and the beans were already cooked. The PicoLog was left to record the data overnight.

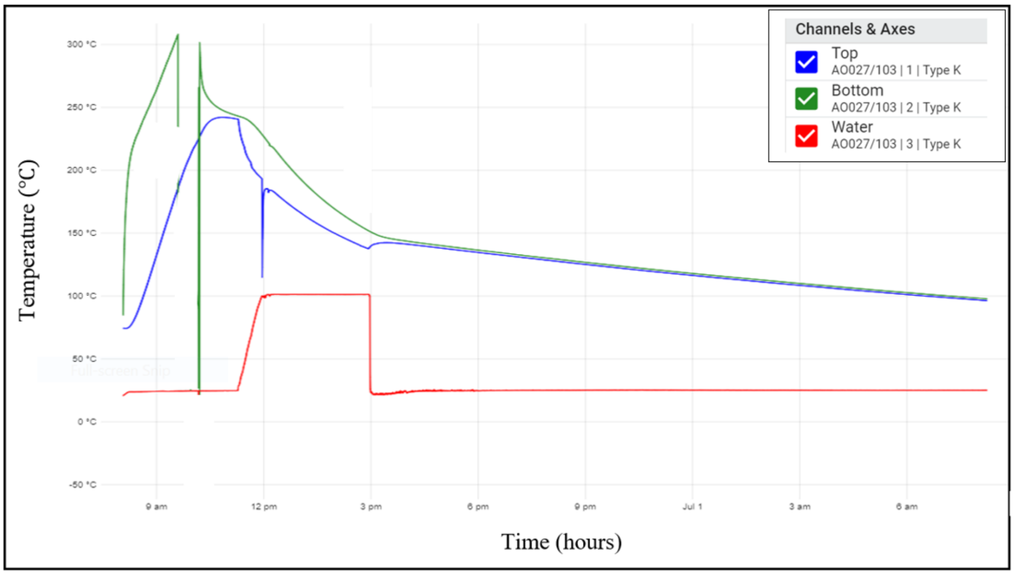


Figure 4: Beans cooking, 1 kg dry beans and 2 liters of water.

DISCUSSION

The two sets of experiments, boiling water with 3 and with 2 liters, and cooking 1 kg beans in 2 liters of water show that the performance of the cooker depends very much on the quality of the contact between the cooker and the top surface. The top surface has been machined carefully to ensure good contact, but in the experiments, there was a risk of having some piece of the insulation cloth between the pot and the top surface. This deteriorates the heat transfer rates to the cooker very much. With good contact, the time to bring two liters of water to cooking is about 30 minutes and the time to bring two liters of water together with one kg beans to the boiling point is about 40 minutes, with starting temperatures of the cylinder between 220-240 °C.

The sensor for the Bottom temperature recording was in contact with the heating element, whereas the Top sensor was only in contact with the cylinder surface. This means that the direct comparison of the two temperature recordings is not possible, as the Bottom temperature also represents the heat in the heating element. However, the cooking experiments only started after the two temperatures had converged to near same values, which will be the initial cylinder temperature for computational study of the process.

The capacity for the insulated iron storage system to retain the heat will depend on the amount of insulation which is applied. For the current study, 5cm FyreWrap insulation, the storage can retain the heat for several hours and can therefore be suitable for cooking during the evening (up to about 3 hours after sunset). After about 24 hours, the retained heat can still be used for warming food.

CONCLUSION

A robust, safe, and technically simple small-scale solution for storing heat for cooking after sunset has been constructed and demonstrated for the particular case of cooking beans. An iron cylinder (20 cm diameter and 30 cm height) heated to about 220 ^{o}C can be used for cooking 1 kg dry beans in 2 liters water. It is important to ensure good thermal contact between the top of the cylinder and the cooking pot. The time to bring the beans to cooking is about 40 minutes. After 3 hours of cooking, the residual heat in the cylinder drops from 150 ^{o}C to 100 ^{o}C in about 12 hours. The decay time can be reduced with added insulation and the time to boiling, as well as the cooking capacity, can be increased with a higher initial cylinder temperature.

The cylinder was heated with wrapped-around heating elements. In the experiments, the grid power was used. The intention in a real application is to use PV power. An alternative heating method can be made by inserting a solar concentrator over the cylinder. After charging temperatures have been attained, the concentrator can be removed, and the cylinder enclosed with insulation.

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