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Performance Investigation of Oil-Based Sensible Thermal Storage System for Cooking Applications

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ABSTRACT

This paper presents a performance investigation of a sensible thermal storage (STS) system for cooking applications. The system consists of a cooker and storage units. The cooker unit supports the pot and the storage unit stores heat from heated Duratherm-630 oil. The system's thermal performance was tested by cooking beans and boiling water. A 1,800W heating element was used to heat the oil to 220 °C. It took 2 hours and 50 minutes to cook beans while charging and 160 minutes to boil 40 litres of water during discharging. The temperature that remained in the storage unit after completing the cooking while discharging process was 120 °C, this temperature range can be used to cook other types of food.

Keywords: thermal storage, charging and discharging, Duratherm-630 oil, temperature, cooking unit, performance

NOMENCLATURE

Abbreviations	
PCM	Phase Change Material
TC	Thermocouple
TES	Thermal Energy Storage
STS	Sensible Thermal Storage

1. INTRODUCTION

Energy is required for global economic and social advancement to raise living standards. Nevertheless, supplying energy to the population in the world should be done responsibly and with a determination to expand and exploit available resources effectively [I]. Energy is vital for global progress and its responsible use can improve living standards. Currently, 2.6 billion people in developing countries rely on biomass for cooking and due to population growth with no clean energy measures, reliance may rise to 2.7 billion by 2030 [2]. Tanzania's National Energy Policy of 2015 encourages the use of clean cooking methods, speeding up the country to shift from biomass fuel to modern energy sources to improve the quality of life of people [3, 4].

Several clean cooking alternatives particularly solar cookers, have been reviewed and developed. Based on their mode of operation, these can be classified as direct or indirect solar cookers [5, 6]. These cookers use solar energy from the sun, replacing non-renewable fuels like kerosene and charcoal. However, they face limitations in use due to the intermittent nature of sunlight, necessitating thermal energy storage for extended cooking times [7, 8, 9, 10].

Sensible heat storage, latent heat storage and thermochemical storage are the types of thermal energy storages (TES) that utilise inexpensive, chemically stable materials like water, rocks, iron and oil for thermal energy extraction [11, 12].

Thermal performance of solar cookers based on an evacuated tube solar collector and flat plate collector with PCM storage; and charging the heat storage coupled with a parabolic trough collector for cooking purposes and stored energy over 200 °C are among the investigation performed by the past reseachers [13, 14, 15]. TES systems charge energy when there is an energy surplus and extract thermal energy stored when there is a shortage or high energy demand [16, 17, 18, 19].

2. MATERIALS AND METHODS

2.1 System Configuration

A sensible heat storage tank with a capacity of 0.098 m3 was filled with Duratherm 630 oil and rock pebbles for testing. A single-pot solution was chosen to observe heat transfer and temperature distribution. The system

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includes a charging unit, cooking unit, connecting pipes, storage unit and data collecting devices as arranged in the laboratory and illustrated in Fig 1.

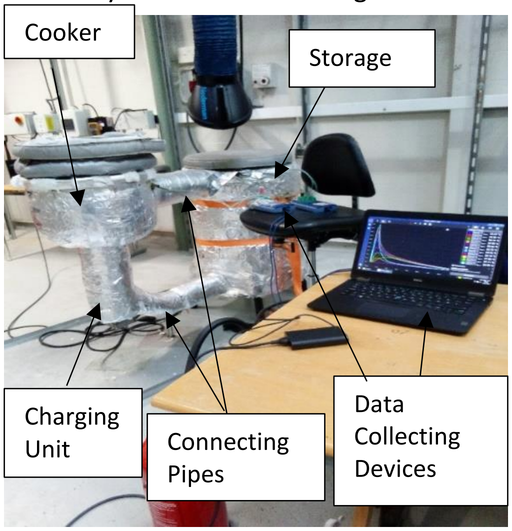

Fig. 1. STS System Arrangement in the Laboratory

2.2 Experiment procedures

The systems tests involved manually adjusting the valve position to maintain constant overflow temperature during discharging. Fire risk was reduced by keeping the charging temperatures below 229 °C. Experiments were conducted to test the system's cooking capacity and performance behavior by using beans and water.

The cooker unit remained insulated during the cooking process to minimise heat losses to the environment. The insulation comprised three layers of 50 mm Fyrewrap insulation piled on top of the other and covered with aluminium foil. To reduce air circulation, the lid of the cooker was also insulated and when cooking/boiling was required, the cooking pot was immersed inside the cooking unit.

Fig. 2. Variable Voltage Transformer

The heating element was enabled to generate 1800W of electricity at 230V or 580W at 130V to ensure consistent power delivery across various energy sources.A variable output transformer regulated the voltage supplied to the heating element with a range of 10-230 V; this is shown in Fig 2.

2.3 Experimental set-up

The system used Type K Thermocouples TCs and a pico logger to monitor the system temperatures, which were plotted using PicoLog 6 software and a TC-08 type pico logger [20, 21]. Fig 3 displays a condensed system representation, with the installed TCs highlighted in blue.

The TC 1-7 as the temperature control units of the system were used to monitor temperature distribution, energy content and thermal stratification while TCs 4, 4', and 4" were placed to measure radial temperature changes in the storage.

TC A and TC B placed to monitor the natural circulation in the system while TC D, TC E and TC F placed to measure the cooking pot temperatures during cooking/boiling. A TC W was placed to monitor the temperature of the cooking/ boiling food or water during the experimental process.

3. RESULTS AND DISCUSSION

Three categories of experiments were conducted: charging, cooking, and discharging.

3.1 Charging experiment

The behaviour of the system during charging was tested through several experiments. The first experiment started when the initial temperatures were 23 oC and 24 oC in the cooker and storage respectively. After powering the heating element, the duratherm-630 oil in the cooking unit was heated up to the boiling temperature which initiated the flow of oil from the cooking unit to the storage unit. Thermocouple in the cooker at the top left side position (TC-Top-Left), top middle position (TC-Top-Midle) and top right side position (TC-Top-Right) in the cooker represented by letters D, E and F respectively in Figure 4; this shows that the overflow of oil from cooker to the storage unit started when the temperature reached 98 °C.

The thermocouple in storage at the top position (TS-Top) represented by number 7 in Fig 4 shows the temperature change in the storage after overflow due to natural circulation in the system. The temperature rise at point 7 shows that the oil has expanded leading to natural circulation.

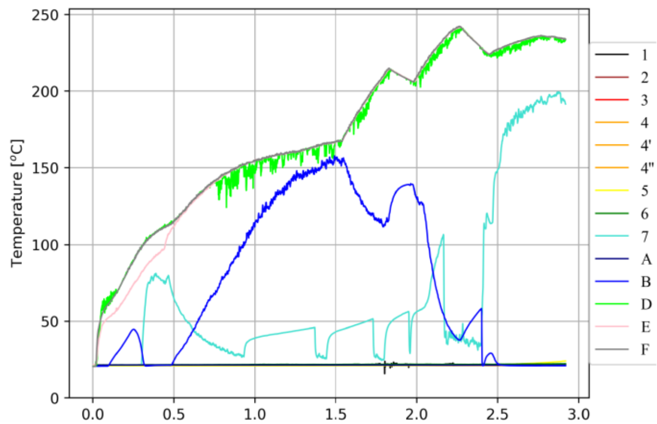

Fig .4.Temperature Distribution During High Power Charging on the system

3.2 Cooking while charging

The second category of experiment aimed to test the capability of the system to cook while charging. The charging process led to a significant increase of the temperature in the cooking unit. The temperature increase in the storage depended on the mass flow due to fluid expansion in the cooking unit. The temperature increase in the cooking unit enables beans to be cooked easily. It took 30 minutes to charge the STS system and attain the temperature of about 102 °C when the beans started boiling as shown in Fig 5. The experiment results show that cooking two kilograms of kidney beans took 2 hours and 50 minutes and the temperature in the cooker was raised to 180 °C.

The Thermocouples were positioned in Storage (S) and in the cooker (C) as follows: Thermocouple in storage bottom position (TS-Bottom), thermocouple in storage top position (TS-Top), thermocouple in storage middle position (TS-Middle), thermocouple in the cooker top right side position (TC-Top-Right), thermocouple in the top middle position (TC-Top-Midle) and thermocouple in the cooker at top left side position (TC-Top-Left). The performance behavior of charging and meeting the requirements for cooking applications was investigated. The maximum temperature in the cooker unit was 219.49 °C but this shout after removing the cooking pot from the cooking unit . The performance behavior of the cooker and storage unit is presented in Fig 5.

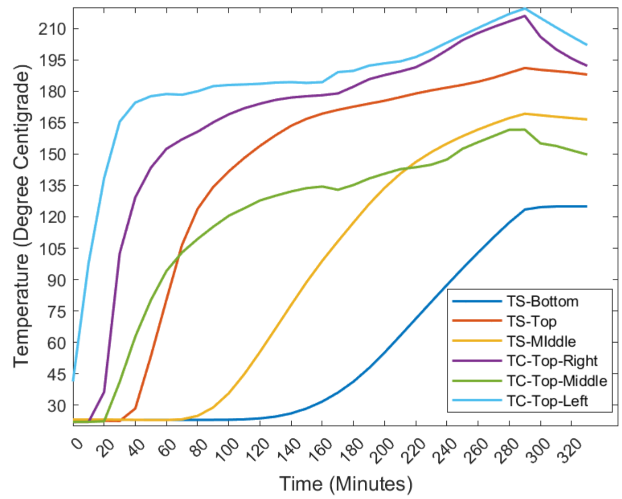

Fig. 5. Temperature Distribution During Charging and Cooking

Fig 6 and Fig 7 shows the cooking pot and beans during the cooking process and after completing the cooking process.

Fig. 6. Coocking process in the cooking unit

Fig .7. Cooked Beans

3.3 Discharging experiment

The discharge test aimed to determine how well the system worked to accomplish cooking while discharging. The system took 35 minutes to charge entirely, reaching a temperature of 185 °C. This experiment involved boiling water to determine the number of cooking and temperature remains in the storage after cooking. Four litres of water were boiled ten times, and 40 litres were boiled to 100 °C. The number of experiments took 160 minutes and the temperature remaining in the storage unit was above 120 °C. Natural circulation of the oil from the storage facilitates the cooking process in the cooking unit. Fig 8 shows the heat flow in the STS system.

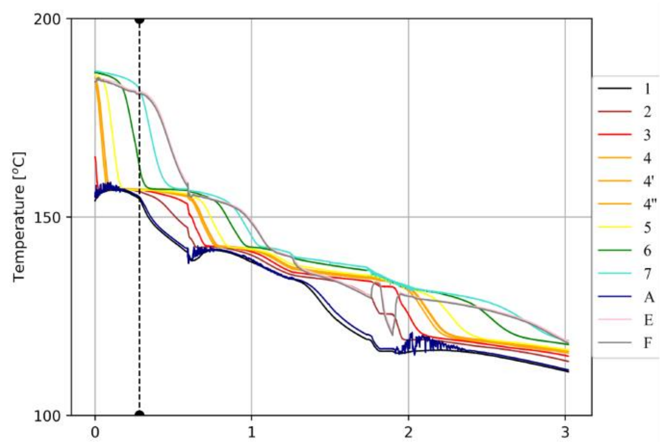

Fig. 8. Temperature distribution when dischrging

4. CONCLUSIONS

Testing reveals natural heat circulation between storage and cooking units within the flashpoint of durathermo-630 oil sufficient for the cooking application. The system provides adequate cooking during charging and non-charging times. Two kilograms of kidney beans were ready within a temperature of 185 oC for two hours and fifty minutes; this shows that it is possible to cook other types of food which can be prepared at a temperature below 219 °C. Also, the results show that the system can cook after stopping the charging process and store heat for a long period. However, uncertainties remain a challenge in the STS system, the performance of the system has some limitations such as being expensive for small household applications.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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