Thermal Efficiency Enhancement of Domestic Cooking Pots

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Abstract - In this paper, the thermal efficiency of domestic cooking pots is investigated with the water boiling test (BWT). The domestic cooking pots are fabricated from the aluminum and stainless steel with different sizes of 20, 22, 24 cm. The tests are all done with water 2/3 capacity of the pot at the atmospheric pressure by using LPG gas stove as fuel. The testing was monitoring the water temperature, pot surface temperature, exit flame temperature and LPG consumption at the several times until the boiling point temperature. The results obtained from the modified cooking pot are compared with those from the standard cooking pots. It is found that the modified cooking pot required 15-20% less energy than the standard cooking pot to bring water to boiling. The results of this study are of technological importance for the efficient design of domestic cooking pots to enhance performance.

Keywords-Thermal efficiency; cooking pot; heat transfer enhancement

1. INTRODUCTION

In order to obtain the energy for heating or cooking processes in the household, the world's human population burns biomass or fossil fuels. The combustion processes release harmful chemical compounds, greenhouse gases, and particulate matter into the air. All products have significant effects on both human health and global climate and ecology changes. In order to decrease the harmful effects of biomass combustion, thermal efficiency of the combustion process should be improved. Over the years great studies have been done in improving cook stove technology. Sharma et al. [1] studied the thermal performance of the wood cook stove at different power outputs. The cook stove has been designed for an optimum power output for a wood-burning. Tremeer and Jawurek [2] considered the thermal efficiency and emission harmful of five rural wood-burning cooking devices. Gupta et al. [3] studied the emission factors and thermal performance of cooking stove. Sharma et al. [4] devaluated the thermal performance of the solar cooker. Bhattacharya et al. [5] considered effects of the various parameters on thermal performance and emission of the cook stoves. Kumar [6,8] presented the simple test procedure for considering the thermal performance of box type solar cooker. Ozturk [7] experimentally determined the energy and exergy efficiency of the solar parabolic-cooker. Desale et al. [9] considered the cooking pots erosion wear. Hannani et al. [10] studied the mathematical modeling of cooking pots thermal efficiency using a combined experimental and neural network method. Neural network results, the variations of the thermal efficiency with various parameters have been studied. Lahkar and Samdarshi [11] reviewed the thermal performance parameters of box type solar cookers and identification of their correlations.

To the best of author' knowledge, there are many paper presented on the improvement thermal performance of the various cooking stoves. However, the paper presented the improvement thermal efficiency of the cooking pots by enhancement of heat transfer process have not mentioned. The objective of this paper is to present the improvement thermal efficiency of cooking pots by water boiling tests using LPG as fuel. The tests are done with different sizes and different materials of the standard cooking pots.

2. EXPERIMENTAL APPARATUS AND METHOD

2.1 Test loop

A schematic diagram of the experimental apparatus is shown in Fig. 1. The test loop consists of the test pots, LPG fuel consumption system and data acquisition system. Due to constant heat input on the cooking pot, all of the tests are done on an LPG fuel. The standard cooking pots and the modified cooking pots fabricated from the aluminum and stainless steel with three different diameters of 20, 22, 24 cm are tested with the water boiling test (WBT) at atmospheric pressure. The flow rates of the LPG fuel consumption are controlled by adjusting the regulator valve and measured by the digital weight scale and the stop watch. To decrease the convection heat loss and increase heat transfer rate, the modified cooking pots with two layers are tested. The MP1 is represented the two layers surface cooking pot. The MP2 is represented the cooking pot with the insulation at the inner surface of the outer layer while the MP3 is represented the cooking pot with the helically coiled aluminum strip as shown in Fig. 2. Inlet and outlet frame temperatures are measured with six type-T copper constantan thermocouples. Three and four type-T copper constantan thermocouples are applied to measure water temperature in the pot and the pot surface, respectively. All type-T copper constantan thermocouples with an accuracy of $\pm 0.01\%$ are pre-calibrated with dry-box temperature calibrator.

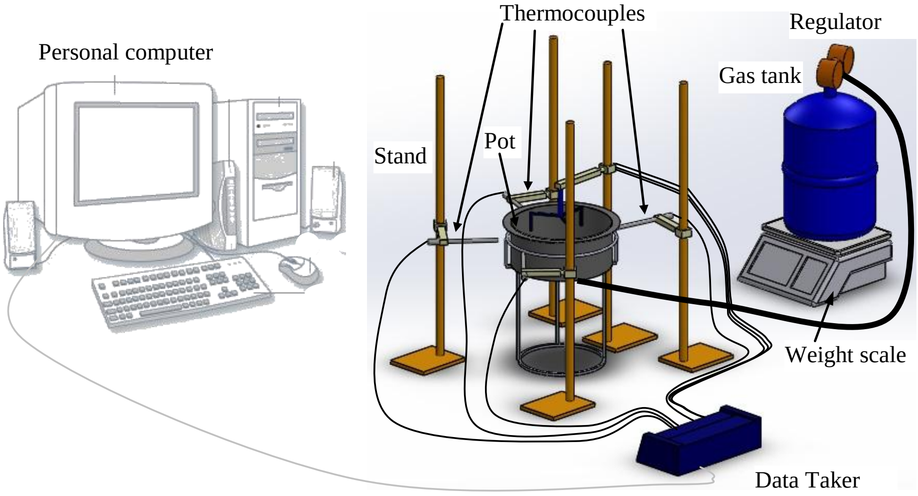

Figure 1: Schematic diagram of experimental apparatus

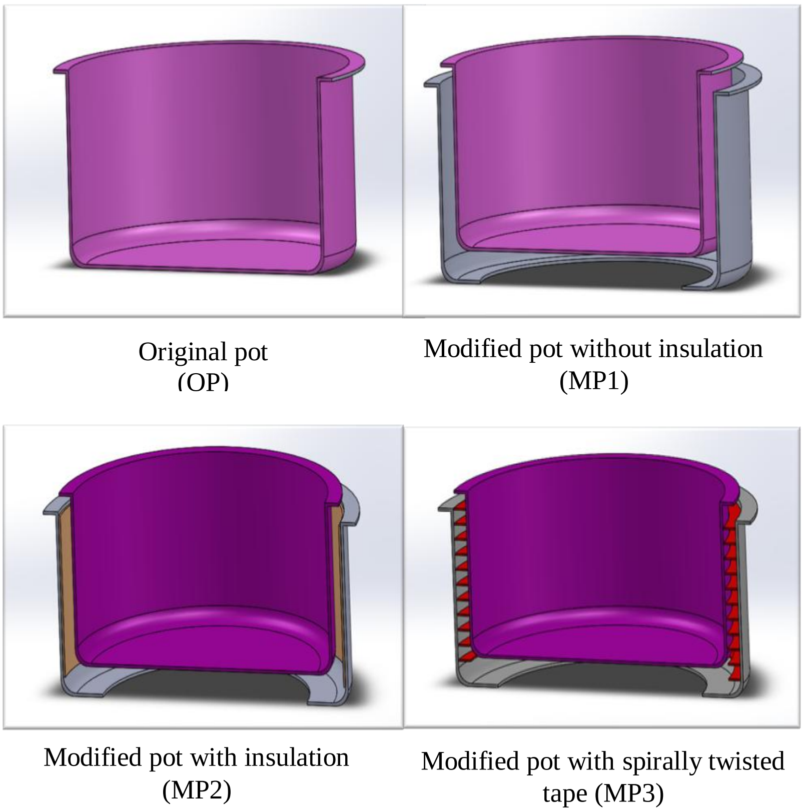

Figure 2: Schematic diagram of modified pots in the present experiment

2.2 Operating conditions

In order to make sure the adequate space and sufficient time to perform the test without being disturbed, the test runs are performed in a test room that is protected from wind, however, it has the sufficient ventilation to vent harmful stove emission. The test runs are carried out with the water volume in 2/3 pot capacity. In order to minimize the variation in fuel characteristics input on the cooking pot, the LPG is used as fuel in the present study. Water temperature is monitored using the three thermocouple located at the center line of the cooking pot and midway between the base and the water surface by the Data Logger DT80 with 40 channels that is connected to a computer displaying the temperature continuously during each run. Each position of the temperatures is recorded three times and the displayed results represent an average of these runs. Temperatures at each position are averaged over the time period. The uncertainty and accuracy of the measurement are given in Table 1.

Table 1: Accuracy and uncertainty of measurements

Instruments	Accuracy	Uncertainty
Thermocouple type T, Data logger, ^{o}C	0.1%	$\pm$ 0.1
Digital weight scale	0.1%	$\pm$ 0.1

3. RESULTS AND DISCUSSION

First of all, the practice tests are done to determine the local boiling point of water. The boiling point of water is the point at which the water temperature no longer rises, no matter how much heat is supplied. The local altitude of the laboratory where the tests were measured is approximately 120 m above the mean sea level. In order to obtain an adequate space, sufficient time to conduct the test without being disturbed, the tests are performed in a room. However, there is sufficient ventilation to vent harmful. Figure 3 shows the boiling point temperature of water obtained from four Type-T thermocouples constantan at the variation positions in the cooking pot. The results showed that there is a temperature uniformity to within one or two tenths of degree Celsius throughout the water volume. It can be seen that the boiling point of water at this mean altitude is 100.25^{o}C.

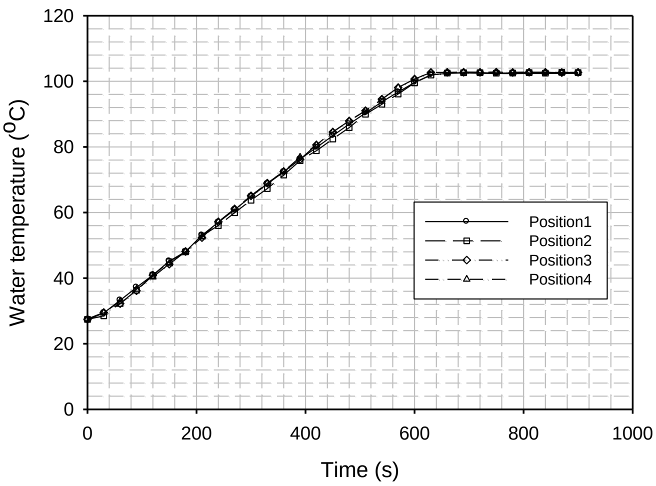

Figure 3: Local boiling point temperature of water

Figures 4, 5 show the variation of water temperature taken from room temperature to boiling point temperature for aluminum and stainless steel cooking pots, respectively. It can be seen that the results obtained from the conventional cooking pot has a constant slope and then slightly increase until it reaches boiling point temperature. This is because the evaporation loss has significant effect to the temperature variation. As compare to the results obtained from the modified cooking pot, the water temperature tend to increase until boiling temperature is reached. The conventional cooking pot reaches boiling temperature in 840 sec. while the modified cooking pots take 640-650 sec. to reach boiling temperature. This means that the convection heat losses for the modified cooking pot less than those from the standard cooking pots. For the modified cooking pots, the energy from the hot gas is transferred to the inner and outer layers of the cooking pot. Due to insulation, the heat transfer to the inner layer for MP2 tends to increase. Therefore, the boiling point temperature of the MP2 is reached faster than that of the MP1. For the MP3, the helically coiled strip is applied to enhance time of heat transfer from the hot gas to the cooking pot layer. It can be seen that the boiling point temperature obtained from the MP3 is reached faster than the other modified cooking pots.

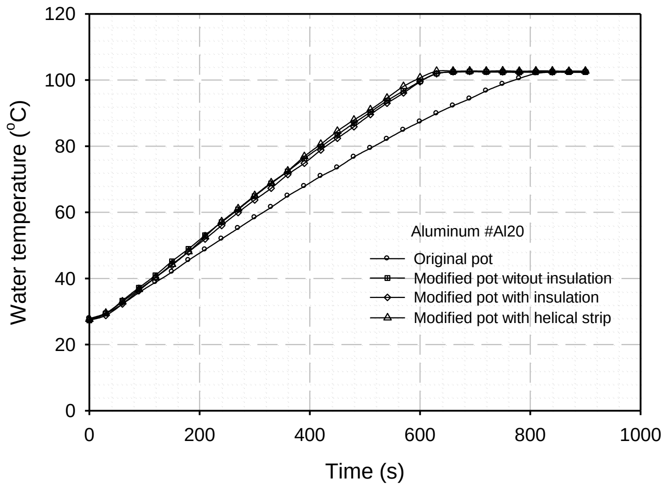

Figure 4: Variation of the water temperature with time for aluminum pots

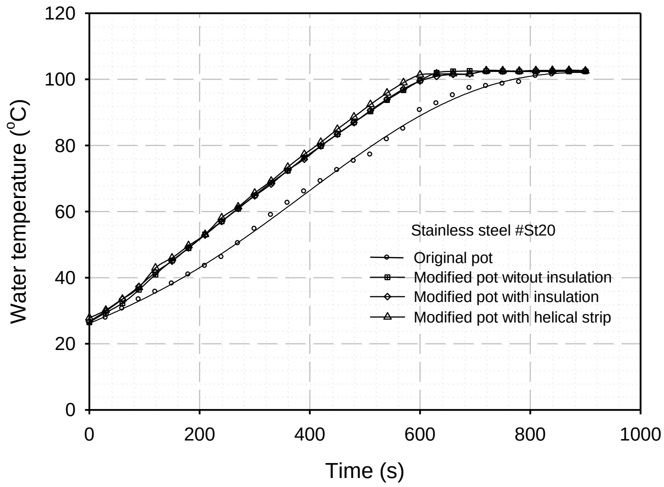

Figure 5: Variation of the water temperature with time for stainless steel pots

In general, the cooking pot heat losses are due to three main mechanisms; evaporation, radiation and convection. The goal of this study is to minimize these losses as possible as. The thermal efficiency was determined by carrying the standard water boiling test (WBT). The thermal efficiency of the cooking pot is defined as the ratio of the energy entering the cooking pot to the energy content of the fuel consumed. The energy entering the cooking pot produces two measurable effects: raising the temperature of the water form the room temperature to the boiling point and evaporating water. In the standard WBT, a known quantity of water is heated on the stove. The quantity of water evaporated after complete burning of fuel is determined to calculate the efficiency by using the following formula:

$$\eta = \frac{m_{w,i} C_{p,w} (T_{w,b} - T_{w,i}) + m_{w,evap} h_{fg}}{m_f \left(LHV_{fuel} \right)}$$

where $m_{w,i}$ is the mass of water initially in cooking pot, $C_{p,w}$ is the specific heat of water, $m_{w,evap}$ is the mass of water evaporated, m_f the mass of fuel burned, $T_{w,b}$ is the temperature of boiling water, $T_{w,i}$ is the initial temperature of water, h_{fg} is the latent heat of water vaporization, and LHV_{fuel} is the lower heating value of fuel.

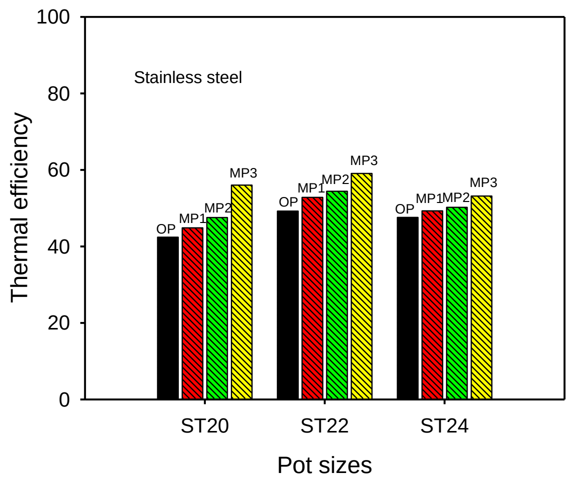

Figure 6: Comparison of thermal efficiency for stainless steel pots with various types

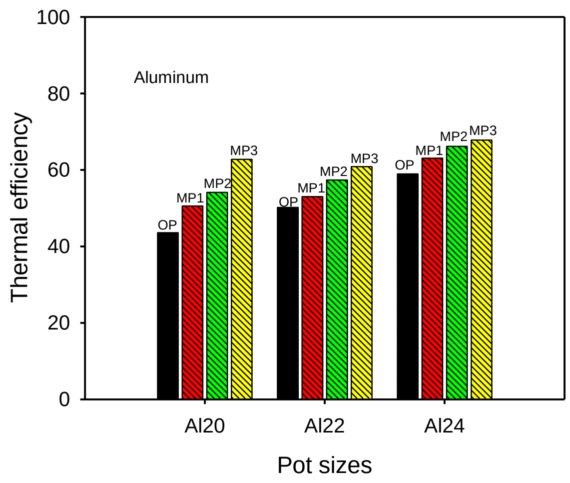

Figure 7: Comparison of thermal efficiency for the aluminum pots with various types

Table 2: Comparison of energy consumption and payback period the various types

Pot types	Used fuel (kg/hr)	Used fuel for 30 days				Modified costs/Break event point	
		kg	Tank	Fuel cost (Bath)	Decrease fuel cost (Bath)	Modified cost (Bath)	Payback period (Day)
OP	0.2	144	10	2900	-	-	-
MP1	0.18	129.6	9	2610	290	700	73
MP2	0.17	122.4	8	2320	580	1000	51
MP3	0.15	108	7	2030	870	1500	52

The effects of the different pot sizes on the thermal efficiency of the pot were investigated. The size of the cooking pots has slightly effect on the efficiency of the cooking pots. As shown in Figures 6-7, the thermal efficiency values remained nearly unaffected when the size of the pot was varied. Although the larger pots have more heat absorbing surface at the bottom and the sidewall, this seems to be offset by the greater heat loss by the larger cooking pot than the smaller ones due to a larger surface exposed to the surroundings. Due to increase heat transfer to the water, the thermal efficiency obtained from MP3 is the highest among the modified cooking pots. Table 2 shows the comparison of energy consumption and payback period of the various modified cooking pots. Although the MP3 has the highest modified cost, however, MP3 gives the fastest payback period among the modified cooking pots.

4. CONCLUSIONS

In the present study, the modified cooking pot is done to decrease the convection loss. The heat transfer efficiency is defined as the percentage of heat contained in the hot gases that gets transferred to the substance being cooked. Improved the cooking pots are constructed with two surfaces and modified flow directions that reduce the amount of heat drawn away from the combustion gases giving rise to higher flow temperatures and higher heat transfer efficiency than traditional methods. It can be seen that the gas flow direction and decreasing convection heat losses have significant effect on the thermal efficiency cooking pot.

5. ACKNOWLEDGEMENT

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