Experimental Investigation for Enhancement of Boiling Heat Transfer of Pots having Surface Modification with Flue Tube

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ABSTRACT

Several modified surfaces have been developed for the enhancement of boiling heat transfer where distilled water is used as the test fluid at atmospheric pressure. These surfaces have either with modified surface geometry or by finned bottom surface or by insulating the skirt. Effect of modified bottom surface with flue tube arrangement on boiling heat transfer has been investigated. Three different modified bottom surfaces with flue tubes have been used and their thermal efficiencies are compared with standard flat bottom pot. The pot with modified bottom with a tube gives 9-10% higher efficiency than that of the flat bottom pot. Also in case of modified bottom pot with flue tube, the boiling point is reached earlier compared to other pots. Amongst different diameter flue tubes the concave shaped bottom with a flue tube is the most conducive condition for enhancing the boiling heat transfer.

KEY WORDS: Boiling pot, Heat transfer enhancement, and Thermal efficiency.

1. INTRODUCTION

The contact surface of the boiling pot with the flame is very important when it comes to fuel conservation. The thermal efficiency improves with the shape of the pot itself and its ability to transfer the heat without obstruction. The flame under the boiling pot should make direct contact with the pot with least unutilized flame escaping through the edges of pot. Excess flame that travels up the side of the pot skirt is lost to the atmosphere, which decreases efficiency. The round bottomed pots are more stable because their centre of gravity is deeper. However, nowadays in many places flat-bottom vessels are used, which became common under European influence. WHO defines efficiency is a combination of combustion efficiency and heat transfer efficiency. The geometry of the pot bottom could be one of the major roles in heat transfer efficiency. Most of the authors investigated about the efficiency of stoves but least experiments on the boiling pots and the impression is that a flat pot bottom is considered as “standard pot”. While Baldwin mentions pot efficiency but he does not referred specifically to the geometry of the pot and its relation between pot design and heat transfer efficiency. When assessing the overall efficiency of new system elements, the stove and the pot both have to be taken into consideration. Researchers also investigated boiling efficiency by pool boiling using different geometric parameters. Kang (2007), experimented with annular tube at few degrees of inclination submerged in saturated water and found that at a given heat flux the heat transfer coefficient was increased with inclination angle. Researchers have been done in improving stove design to enhance the heat transfer. Rahman (2014), experimented on structured surfaces and found that boiling heat transfer is increased greatly using structured surfaces Sharma (1990), studied the thermal performance of the wood cook stove with different power input. Hannani (2006), carried out the mathematical modeling of the thermal efficiency by varying pot diameter, pot height and edge radius have been studied.

Most of the research works done in increasing thermal performance of cooking stoves on pool boiling using electrical heater. However, the present work is focused on the boiling pots of modified bottom surfaces with vertical flue tubes for heat transfer enhancement.

Geometric Configuration: All the vessels are of cylindrical bottom and the heat transfer occurs mainly through the bottom surface and also through flue tubes. The schematic diagram of different pot bottoms are shown in Figure 1. The different pots are as follows:

Pot-1: standard pot with flat bottom without flue tube
Pot-2: flat bottom with a central flue tube having internal diameter 1.4 cm.
Pot-3: flat bottom with a central flue tube having internal diameter 2.0 cm
Pot-4: concave bottom with a central flue tube having internal diameter 1.8cm

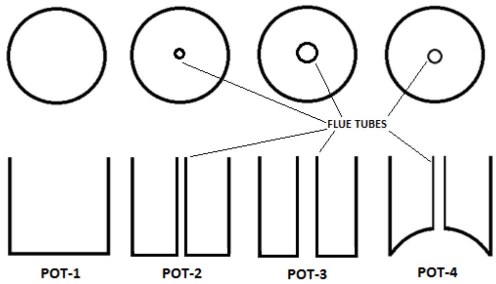

Figure.1. Schematic diagram of different pots

Figure. 2(a) Side view pot-1 **Figure. 2(b)Bottom view pot-1** **Figure. 2(c) Top view pot-1**

Figure. 3(a) Side view pot-3 **Figure 3(b)Bottom view pot-3** **Figure 3(c) Top view pot-3**

Figure. 4(a). Side view pot-4 **Figure 4(b)Bottom view pot-4** **Figure 4(c) Top view pot-4**

The standard pot and the modified pots (Figure 2 to Figure 4) are made up of galvanized iron sheet of 0.125 cm thick having diameter of 15 cm and height of 15 cm. Pot-2 is of same material and dimension as that of pot-3 with the flue tube diameter of 1.4cm. To reduce the convective heat loss, the modified pot-4 is brazed with 10 mm flue gas obstructer at the bottom side of the skirt to restrict the flue gas to escape along the edge of the pot. Also vertical flue tube of 15 cm height internal diameter is fabricated centrally at the bottom of the pot-2, 3 and 4 for passage of flue gas.

2. EXPERIMENTAL SETUP AND METHOD

Test set up: The schematic diagram of the experimental set up is shown in the Figure.5. The set up consists of the test pots, LPG cylinder with attached stove, weighing machine and thermocouple. To supply constant heat flux LPG fuel is supplied at a fixed fuel flow rate. Then a filled LPG cylinder with attached stove is kept on the digital

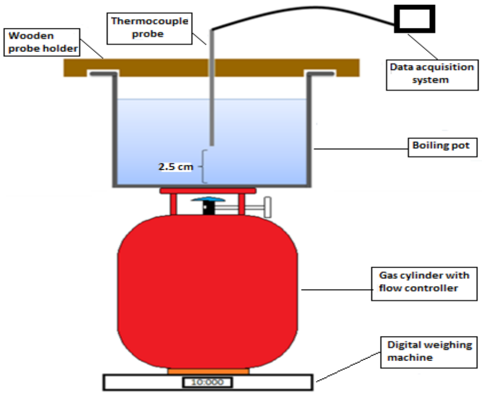

Figure.5. Schematic diagram of experimental setup

Weighing machine having least count 0.002kg weighing machine. Pot containing specified quantity of distilled water is place over the stove. Wooden probe is used to hold the type-T such a way that the thermocouple tip is positioned 2.5 cm above the bottom of the pot. The thermocouple is connected with a data acquisition system to record the transient temperature.

Methodology: Each boiling pot is cleaned, dried and its weight is measured then filled with 1.5 kg of distilled water. It is placed over the LPG cylinder attached with stove then whole arrangement is placed over the digital weighing machine. The weight and the temperature of water are noted. Gas stove is ignited and the constant gas flow rate is maintained by setting the flow controller. Readings of weighing machine as well as thermocouple is noted at an interval of one minute. The experiment is conducted till the boiling point attained. Then the boiling pot is removed and the weight of the gas is noted without disturbing the gas flow rate. A set of similar experiments are conducted for other pots with same gas flow rate.

Thermal Efficiency: Thermal efficiency is the fraction of heat generated by fuel to raise the temperature of water to its boiling point. The remaining heat is lost to the atmosphere. While heating water from initial temperature T_1°C to the boiling point temperature T_2°C water receives sensible heat by the combustion of fuel. Subsequent supply of heat known as latent heat of vaporization utilized to evaporate. Input energy is calculated by fuel consumption.

Thermal Efficiency is calculated by the following formula:

$$\eta = \frac{m_w C_p (T_2 - T_1)}{CV_f m_f} \text{x}100\%$$

Where η is thermal efficiency of boiling pot, m_w is weight of water in each pot (kg), C_p is specific heat water at constant pressure (4.186 kJ/kg°C), T_1 is initial temperature of water (°C), T_2 is boiling temperature of water (°C) CV_f is lower heating value of fuel (LPG) consumed (49 MJ/kg); m_f is the quantity of gas consumed (kg).

Heat gained by water to reach at boiling point = $m_w C_p (T_2-T_1)$ kJ

Energy of consumed fuel = $CV_f m_f$ kJ

3. RESULTS AND DISCUSSION

The experiments have been conducted with four different pots at constant heat flux. Each experiment is conducted using 1.4 kg of distilled water and consumes 0.026kg of fuel in 15 minutes. The efficiency of different pots is discussed.

Variation of water temperature with time: Figure 6 the variation of temperature of water in different pots with time at various fuel flow rates.

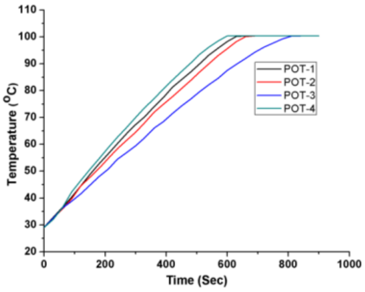

Figure. 6. Variation of temperature with time

In all cases, the water temperature of increases from room temperature till it reaches the boiling point and then the temperature remains constant during boiling. The temperature of water in pot-4 is higher at any time compared to other three pots. Similarly the boiling point of water is also reached earliest in pot-4 than the other pots.

Effect of size of flue tube on efficiency: Comparing between pot-2 and pot-3 the diameter of flue tube in pot-3 is more than pot-2 and the pot-1 has flat bottom with no flue tube. The boiling point reaches earlier in pot-1 than pot-2 and pot-3 hence the thermal efficiency as shown in Figure.7. Also the efficiency of pot-2 is more than that of pot-3. Narrow tube in pot-2 allows less gas to flow through it, so loss of heat is less though the surface area of the tube exposed to water for heating is less compared to pot-3. As the diameter of tube increases flue gas loss also increases accordingly. The heat loss due to escape of flue gas dominates heat transfer through surface area of flue tube. Between pot-2 and pot-3 the efficiency ratio of pot-2 and pot-3 is more than the ratio of their surface area exposed to flame.

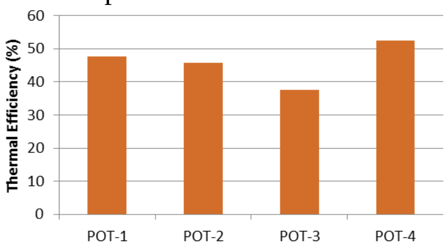

Figure.7. Thermal efficiency of various pots at 1.73 gm/min gas flow rate

Effect of modified bottom on efficiency

Table.1, shows the bottom surface area of different pots and their corresponding thermal efficiencies. In all cases the gas flow rate is 1.73 gm/min.

Table.1. Pots with different surface area and their efficiencies

POT	Flue Tube diameter (cm)	Surface area (cm^2)	Efficiency (%)
POT-1	No tube	176.737	47.71
POT-2	1.4	175.197	45.64
POT-3	2	173.595	37.49
POT-4	1.8	232.161	52.47

It is observed that the thermal efficiency is highest for pot-4 compared to other pots. The bottom of pot-4 is concave shape with a flue tube. The diameter of flue tube in pot-4 is between pot-2 and pot-3. The pot-4 having tube diameter 1.8cm utilizes heat better than the escape of gas compared to other pots. Apart from the size of the tube, bottom surface is also modified to concave shape to increase the surface area and minimizing the gas to flow through sides of the pot. The total surface area of exposed to flame contact in pot-4 is more than the other pots.

4. CONCLUSION

The heat transfer in different pots has been investigated and the conclusions may be made as follows:

- The early attainment of boiling temperature of water in pot having small diameter flue tube compared to pots having large diameter flue tube without bottom modification.
- Surface area and escape of flue gas determines the utilization of heat.
- The efficiency of pots is more with modified bottom surface compared to flat bottom surface. The efficiency is more for the pot of modified bottom surface having more surface area.
- The efficiency of pot having larger diameter flue tube with bottom modification gives higher efficiency than flat bottom pot as well as pots with flat bottom with flue tubes. The improved surface area and flue gas passage area are the detrimental factors for enhancement of thermal efficiency in boiling pots.

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