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Performance Analysis of Modified Cookware Geometry for Efficient LPG Utilization in Domestic Kitchens

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Abstract

The following experimentation work focuses on determining the most suitable geometry of cooking utensil to be used for day-to-day specific cooking activity for example milk heating which is a widely found daily task in many houses. For our work, we consider families consisting of 8-10 members (joint Indian families).The quantity of milk and various conventional cooking utensil used for heating is noted as per need of 8-10 members, which depends on the generalized survey conducted in seventeen joint families in nearby locality which is the traditional size of Indian households in rural areas. Four different H/D ratios of simple utensils and utensils with modified bottom geometrical structure are selected for this study and they are tested against three different flame conditions of a domestic gas burner LPG stove for example high, medium and low. Overall thermal efficiency and performance characteristics of each utensil is calculated and compared on graph. Based on the experimental data, conclusions are drawn. Highest efficiency of 51.5% is found to be with utensil P1 at low flame condition. The lowest efficiency of 32.5% is observed with utensil P3 at high flame. It can be deduced that more than 15.2 kg of LPG which is equivalent to one LPG cylinder can be saved annually by just using utensils of optimum aspect ratio, at low flame condition for heating of milk.

Keywords: Energy Conservation, Heat transfer enhancement, modified cookpot

1. Introduction

Out of the total Population of India, 13.6 % of the rural and semi urban population were mainly accessing LPG as primary source of cooking compared with Induction/electrical cooking methods [3]. When we consider the open pan cooking process which is still widely used in many countries like hotels, restaurants we found that because of the open surface of food contents directly to the atmosphere there are a majority of losses which are categorized in two types i.e. convection and radiation losses[6]. Also we can found that the actual positioning height of utensil above burner, i.e., distance between burner top and cooking utensil bottom is a crucial aspect which affect overall efficiency of the gas stove because majority of heat energy get lost while travelling from flame to utensils [11]. This loss contributes to diminishing efficiency of utensils and hampers overall performance resulting in high LPG consumption. As per the Bureau of Indian Standards (BIS, 2002): IS 4246, the thermal energy efficiency of LPG burner shall not be less than 64% for open pan cooking during a water boiling test [7], to make it economical, subsidy on LPG alone will not be helpful but we also need to utilize LPG efficiently so that the same quantity of fuel will last longer and no fuel get wasted in entire process [2]. The present work aims at studying and calculating consumption of domestic LPG fuel for specific cooking activity and corresponding thermal efficiency during its use for same cooking processes such as milk heating.

1.1 Methodology

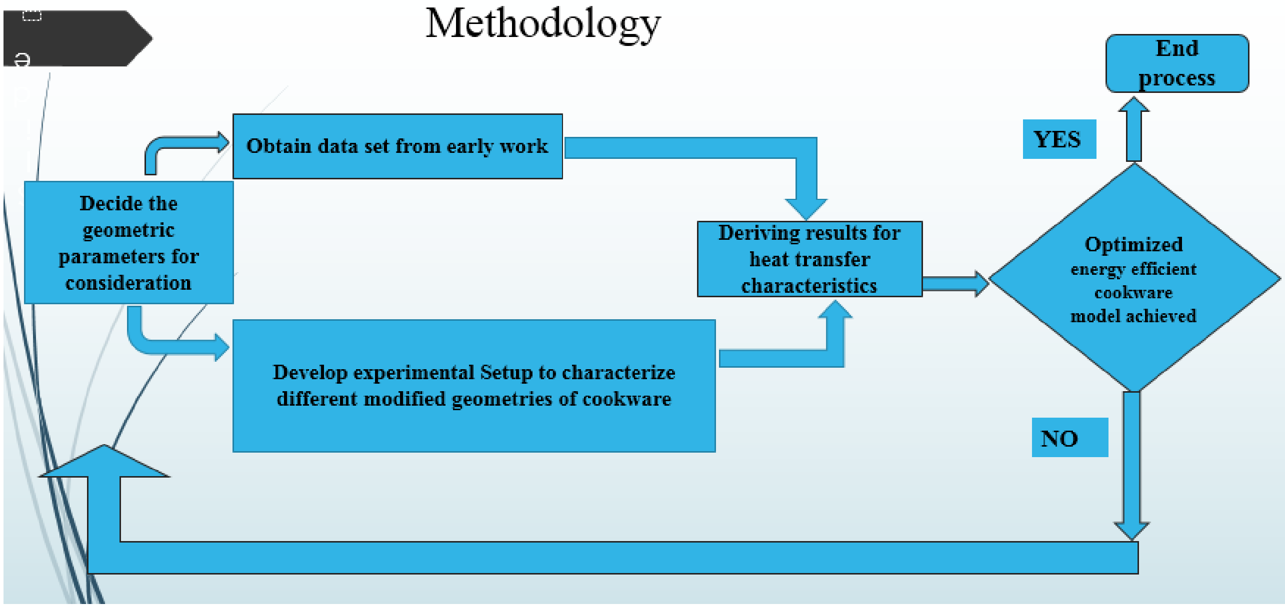

Fig.01 overall diagram summarizing the different parts of the study being conducted step-wise

1.2 Experimental Analysis

Before directly starting experimentation work on random utensils, a detailed survey was done for knowing conventional utensils with varying capacity (vol) used for heating milk on a daily basis for various purposes like making tea, feeding to children and infants as well as elderly people. This survey was done in rokadiya nagar area of Shegaon and kisan nagar area of Khamgaon India, among 17 households where LPG cook stoves are mainly used as a primary cooking source. A suitable questionnaire form is prepared and circulated among these households to get information about frequency of refilling LPG cylinder, use of cooking utensils for heating of milk, size (in liters) , dimensions of utensils ,and daily quantity of milk boiled per day[8]. From the survey, major findings obtained are that for the family size of eight members, 2.5 lit of milk is required over the entire day, the frequency of refilling of LPG cylinder is varying from 27 days to 30 days. Four different utensils are used for milk heating as per availability and washing routines.
Depending on the above data, lab experiments are conducted on LPG stove for heating of milk (2.5 l or 2600 g). Four different H/D ratios of utensils with modified bottom geometry for heat test of milk are used. During each experiment trial, time required for the final point of boiling (in minutes) and amount of LPG utilized (in grams) is measured by stopwatch and digital weighing machine respectively [1].

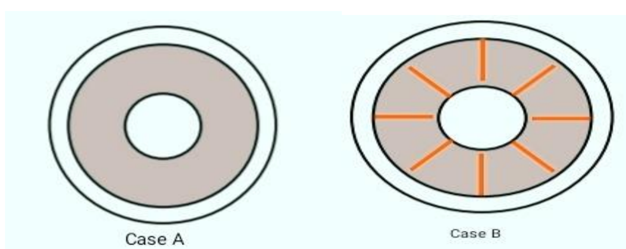

Fig.01 Plain Bottom of Cooking Utensil Rectangular extended attachments at utensil bottom

LPG gas consumption is measured by a digital weighing machine (Make: Hesley)[4] of 200 kg capacity and 1 g accuracy-type thermocouple are used to measure temperature of surrounding air, cold milk that is before test as well as the final product that is heated milk. Thermocouple were attached with a digital temperature indicator (DT-80, Make: Omega). A stopwatch (accuracy: 1 s) is used to measure the time required to heat the milk up to a certain decided temperature. Three different conditions of burner flame of a domestic LPG stove viz. Low flame, medium flame and high flame are employed [5].

Thermal energy efficiency of each cooking utensil is calculated as per the guidelines given in Bureau of Indian standards, IS 4246[9] & Water Boiling Test norms and rules. Thermal Energy efficiency is the ratio of output and input energies. To calculate input energy given to the milk, the mass of LPG consumed during each experiment is multiplied by the calorific value of LPG [8]. The output energy during each experiment is calculated by adding the sensible heat and latent heat contents. The sensible heat transfer to both utensil material as well as contents in the utensil is considered. Following equations are used for calculation of thermal efficiency of a process:

Energy (input) = Mf × CV (fuel)………… (1)

Energy Output = Sensible energy of utensil + sensible energy in milk + latent energy

It is assumed that utensils contents i.e. milk and the utensil material are at thermal equilibrium during experiment. Hence, the final temperatures of milk and utensil material are assumed to be the same for calculation of sensible heating of both utensil and the milk. Initial mass of milk for each experiment is 2.6 kg. The specific heat of milk is considered to be 3.77 kJ/kg K. The specific heat of aluminum utensils is taken as 0.903 kJ/kg K.

For calculation of latent energy during milk heating, the mass of milk lost is considered to be in terms of water. Hence, E(latent) is calculated by multiplying lost mass of milk with latent heat of vaporization of water i.e. 2257 kJ/kg, where lost mass of milk is the difference between initial and final mass of milk during experiment [6]. Based on this data, thermal efficiency is calculated. As per assumptions, it is found that when low flame condition is employed i.e. at lower value of gas flow rate, the time required for heating the milk is more.

1.3 Results & Discussions

1.3.1 Milk heating process

For carrying out heating of milk, 2.5 l i.e. 2600 g of milk at 24 °C ± 1 °C is used (room temp). The milk is heated in four different aluminum utensils of four H/D ratios viz. P1, P2, P3, P4 at three flame conditions viz. low, medium and high flame of LPG stove [10]. The final temperature of milk is set at 92 °C ± 1 °C. The lowest LPG consumption is found at a low flame with 3.2 l capacity utensil (P1) whereas the highest LPG consumption occurred at high flame condition with 4 l capacity utensil (P3).

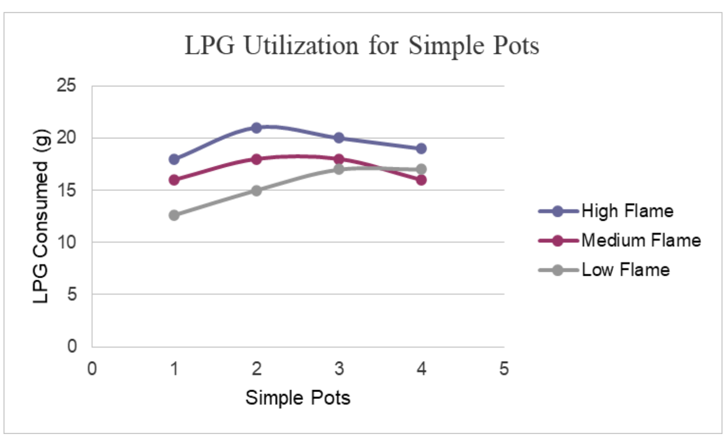

Fig.03 LPG Consumption during heating of milk for Simple cookpot

LPG consumed percentage gets higher values for high flame conditions in case of simple pots. Whereas other values remains at intermediate level

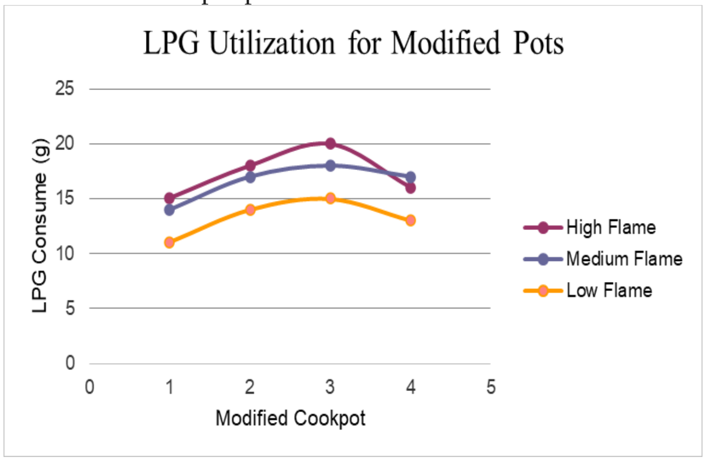

Fig.04 LPG Consumption during heating of milk for Modified cookpot

Yellow line indicates a lower trend of LPG consumption for modified pots which is the conventional behavior for various pots available in the market when we increase flame size, the radiation heat losses increase. Hence, during most of the experiments, highest LPG consumption occurs with high flame of the burner. With increase in utensil size, there is increase in LPG consumption as surface area for heating increases. It is connected with the increased radiation and convective heat losses from the larger utensil exposed surface. Thus, the optimum utensil size for heating of 2.5 l milk is a utensil (P1) of 3.2 l capacity.

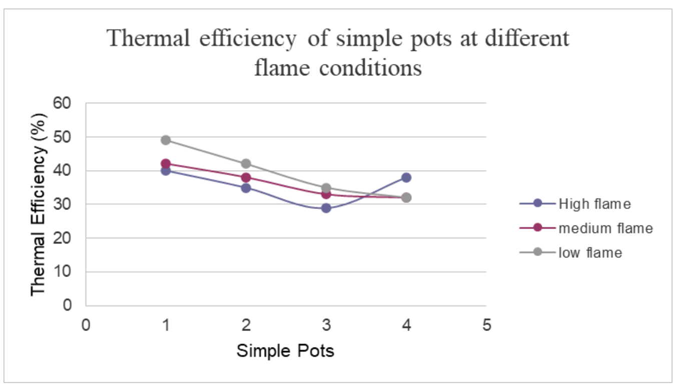

Fig.05 Thermal efficiency comparison for Simple pots at different flame conditions

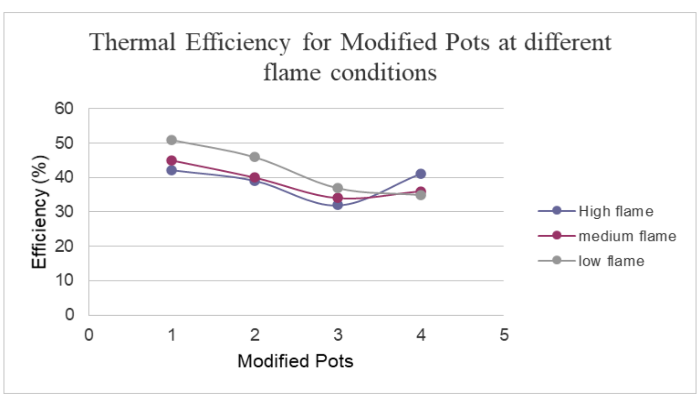

Fig.06 Thermal efficiency comparison for Modified pots at different flame conditions

With increase in utensil size, there is decrease in thermal efficiency as surface area for heating increases. It is connected with the increased radiation and convective heat losses from the larger utensil exposed surface

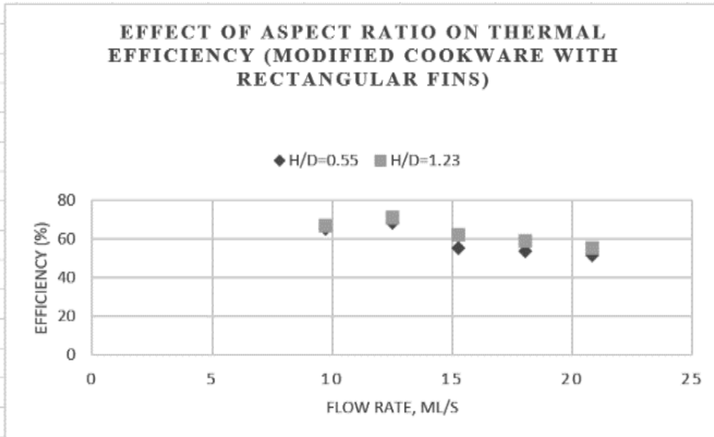

Fig 07. Effect of variable aspect ratio on thermal efficiency of BIS standard cookpot and modified cookpot.

This graph indicates general trend with rectangular fins for conventional cook pots.

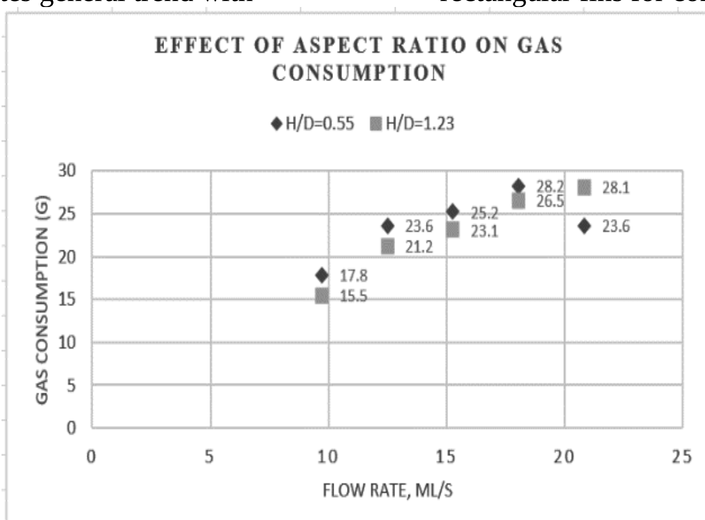

Fig 08. Effect of variable aspect ratio on gas consumption of BIS standard cookpot and modified cookpot

1.4 Conclusion

The highest efficiency of 51.5% is found to be with utensil P1 at low flame condition mainly due to the lowest LPG consumption. With increase in size of utensil irrespective of the flame size, there is decrease in average thermal efficiency due to increased area for heating. The lowest efficiency of 32.5% is observed with utensil P3 at high flame. This indicates that irrespective of flame condition, size of utensil plays a crucial role in determining efficiency. There can be improvement in efficiency by just changing the utensil size and the cooking routines (i.e. use of low flame condition when not urgently required in spite of high flame condition). Thermal efficiency of the milk heating process using the utensils except P1 at different flame conditions are in the range of 32.5–44%. It can be deduced that more than 15.2 kg of LPG which is equivalent to one LPG cylinder can be saved annually by just using utensils of optimum aspect ratio, at low flame condition for heating of milk.

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