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An Enhancement of the Thermal Efficiency of House Hold Domestic Cook Stove

Ibrahim Hussain Shah
Department of Mechanical Engineering
Institute of Engineering & Technology, Devi Ahilya Vishwavidyalaya, Indore, India

Abstract: *Now a days gas stoves are very common in all houses counting urban and remote areas. The main power source for gas stoves is LPG. Liquefied petroleum gas (LPG) is usually used as a cooking fuel because it has higher energy content and produces lower emissions compared to other traditional fuels. Due to immense demand for LPG, aside from its limited reserve, performance improvement of the LPG cook-stoves is important. LPG plays a significant role in the transition towards a more safe, sustainable, and competitive energy model. The major source of the LPG is fossil fuels, so its huge consumption will definitely lead to its shortage in the future. Considering the limited fuel resources, energy conservation, environmental issues, increase within the demand of LPG in near future, it's necessary to explore the ways to further improve the thermal efficiency and therefore the emission characteristics of the domestic LPG cooking stoves. In the present work, performance parameters of the LPG stove such as parameters affecting thermal efficiency and CO emissions are studied. Various parameters affecting thermal efficiency of a burner such as distance between burner and pot, material of the burner, size of injector, swirl effect, pan support modification are determined. The paper is aimed to spotlight the latest add in this field and also, the areas needed to be addressed are discussed.*

Keywords: Domestic Cook Stove, Emission, Liquefied Petroleum Gas, Thermal Efficiency, etc.

I. INTRODUCTION

The burners are widely used for heating and cooking purposes in domestic and industrial applications owing to their simplicity, low cost, and simple usability. This common utilization causes a huge portion of total energy consumption via cookstoves in present. The performance of a stove or burner is usually represented by its thermal efficiency, which is defined because the ratio of the rate of heat transferred from the burned gas to the product of the rate of supplied fuel and its calorific value. The combustion efficiency of the LPG stove remains very high, and any longer improvement within the same is usually difficult to realize. However, the thermal efficiency of a standard domestic LPG cookstove is 68%, as quite 31% of the entire energy released from the fuel gets lost within the flue gas.

The loss can be minimized by improving the rate of heat transfer from the impinging flame to the load. Thus, the performance of an LPG cookstove can be significantly affected by the heat transfer efficiency of the impinging flame. The heat from the flame is mainly transferred to the impinging surface of the cooking vessel by forced convection, though the radiative part of heat transfer plays only a small role due to the low emissivity of the flames established on the burner [1].

Therefore, any work toward improvement in the overall efficiency must aim toward enhancing the convective heat transfer rate from the flame to the load. An improvement in the efficiency of the stove contributes toward both sustainability and cleaner production. More efficient stoves help to reduce the fuel consumption and higher efficiency contributes to reduced emission of carbon dioxide and other toxic gases to the environment and lessens the degradation in air quality. However cleaner and efficient combustion of LPG in the stove, improves the ambient condition in the kitchen and reduces the associated health hazard. In countries like India, where the LPG supply primarily depends on import, improvement in cookstove efficiency helps to conserve foreign exchange.

The overall efficiency of a cook top burner depends on the design of the burner, stove and the pot. In recent years, several studies have been conducted with the household gas stoves to achieve the desired objectives. Junus considered the effects of the burner cap design on flame stability in natural gas fired cookstoves. They observed that lift off occurs at high

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thermal inputs above certain levels of primary aeration, while flash back occurs at lower thermal inputs. They aimed for a design that offered a stable flame over a turndown ratio of at least 5, along with 60% primary aeration to curtail the pollutant emission from the burner. The burner cap design was optimized to achieve the desired turndown ratio and primary aeration [2].

In a further work, Junus reported that a circular ring insert at a suitable place of the burner could aid in improving the thermal efficiency and reducing the NO2 emission significantly at all loads. Since NO2 imposes more serious indoor air pollution than the other oxides, its reduction received special attention in the design of domestic burners [3].

There are effects of variations in gas composition on the performance of domestic gas stoves. Larger heating value of gas led to a lower thermal efficiency and higher CO emission. Although the above studies were extensive, they overlooked the fact that burner efficiency and emission could be significantly improved by decreasing the gas pressure, increasing the primary aeration, selecting proper thermal input, and adjusting the optimized heating height [4].

II. PERFORMANCE PARAMETER OF LPG COOKSTOVE

THERMAL EFFICIENCY

Thermal efficiency of LPG stove is defined as the ratio of the amount of heat transfer from the impinging flame to pot to the amount of heat supplied through fuel. There are several parameters that affect the thermal efficiency of cook stove some of which are discussed below:

LOADING HEIGHT

Loading height is the distance between the top surface of the burner to the bottom surface of the vessel or pot. In many studies it is found that the loading height affect the thermal efficiency of the LPG cook stove, it is obvious that the amount of heat transfer will vary if we change the distance between source of heat and the surface of vessel, at lower loading height there is less entrainment of cold air and hence heat transfer is more whereas at higher loading height the entrainment of the cold air is more and hence the heat transfer reduces at this height. Rohit Singh Lather [5] conducted an experiment on ―Performance Analysis of an LPG Cooking Stove for Improvements‖ in which he observed the effect of loading height on thermal efficiency, gas consumption and flue gas emission. For changing the loading height of the utensil on the LPG cookstove, the loading height mechanism was fabricated and installed on the cookstove. The change in the loading height was measured by a measuring scale attached.

He observed the variation in thermal efficiency by varying the loading height. With an increase in the loading height, increased thermal efficiency was observed. After reaching a maximum, a drop in the thermal efficiency was seen. The trend is attributed to the fact that loading height changes the shape of the flame, resulting in cooler core and wider higher temperature zone, leading to higher heat transfer and thermal efficiency. The highest thermal efficiency was measured for 5 mm loading height and lowest was measured for 7.5 mm loading height. He observed the lowest gas consumption for 5 mm loading height and the highest was observed for 7.5 mm height. It is noteworthy that, higher thermal efficiency is observed for higher loading higher in comparison to the original loading height provided by the gas stove manufacturer [5].

Agung Sugeng Widodo [6] conducted an experiment on ―Efficiency of Household Gas Stove by Optimizing Gap of Pan and Stove Cover in which the Efficiency of the household gas stove has been investigated by changing the gap between pan and stove cover. The efficiency was analyzed by measuring combustion energy produced by LPG, cover surface, and water temperature used in cooking process. The ceramic cover was used since this cover showed the best efficiency compared to other materials. The gap between pan and stove cover was varied in 1 mm to 7 mm with increment of 1 mm. When compared to a conventional stove the results were that efficiencies tend to low at the initial condition because the energy produced from the combustion process is absorbed by any materials in the stove including stove cover and pan [6].

SIZE OF INJECTOR

Basu et al. [7] investigated the performance improvement of LPG cook stove through the different design of burner cap and fuel injection nozzle. The nozzle of diameters 0.7-0.83 mm was considered for the study. Four different sizes of injectors were considered along. The thermal performance study of LPG cook stove was done in two ways, with modification in fuel injector size or nozzle size and also modification in burner cap material.

It is found that the increase in the diameter of fuel injector which means admitting the fuel-primary air mixture is more and more, to enhance the performance of cook stove. The smaller holes of fuel injector improve the performance of cook stove and reduced emissions at the expense of decreasing burner loading. While using larger holes, the fuel flow rate is maximum and also increases convection heat transfer between hot combustion product and pot which is less than the heating losses to surroundings. Due to this phenomenon the thermal efficiency of the cook stove gets reduced. The optimum size of fuel injector is obtained at 0.77 mm for both the burners. This can be attributed to the optimum gas flow and enhancement of effective heat transfer and impinging resident time of hot flue gas onto the pot. With the increase in fuel injector size, the thermal efficiency of cook stove first increases then decreases. The optimum nozzle size gives higher thermal efficiency at minimum power input. The variation of thermal efficiency is due to the different primary aeration. For a smaller nozzle, the primary aeration is more than the fuel flow rate, this lowers the thermal efficiency. For a bigger size of nozzle, the fuel flow rate is higher than the primary aeration, so heat losses are more as compared to the smaller nozzle.

Performance of LPG cook stove, improves by the fuel injector nozzle size. Injector size is neither too small nor too large, the optimum size gives the maximum thermal efficiency and low heat losses to surroundings. When injector size is small, more resistance to fuel flow rate and complete combustion of fuel which gives better performance as vice versa. It has been observed that the maximum thermal efficiency of domestic cook stove is 68% for Brass burner and 64% for Cast Iron burner at the same fuel injector size of 0.77 mm [8].

POROUS RADIANT BURNER

Porous medium combustion has attracted more attention due to its clean and high combustion efficiency. To have these advantages they constructed the burner was with two-layer porous media. The combustion zone was made from silicon carbide, and alumina balls were used to form the preheating zone. For a given burner diameter, the performances of the burner, in terms of thermal efficiency and emission characteristics, were analyzed for various equivalence ratios and thermal loads. The water boiling test as prescribed within the BIS: 4246:2002 was used to calculate the thermal efficiency of both the traditional LPG cooking stoves and therefore the porous radiant burner. The maximum thermal efficiency of the LPG cooking stoves with a porous radiant burner was found to be 68% which is 3% higher than that of the maximum thermal efficiency of the conventional domestic LPG cooking stoves. The axial temperature distribution within the burner showed that the reaction zone was on the brink of the interface of the two zones and at a better thermal load, it shifted towards the downstream. The surface temperature of the porous radiant burner uniform [9].

The combustion zone of the two-layer porous radiant burner was made of silicon carbide porous matrix. Alumina balls of 5 mm diameter form the preheating zone. The porosity of the porous radiant burner was 90% and its thickness varies from 1.5 cm to 2.0 cm. The burner casing was made by using alumina powder and sodium silicate binder. To sustain high thermal stresses, the casing was sintered at high temperatures. The PRB consists of a combustion zone, a preheating zone, a wire mesh to support the preheating zone, a burner casing, and a mixing tube made up of Teflon. The experiments were performed with various diameters and thicknesses of the combustion zone. Five different types of burners were used in the study. The experimental set-up used for testing the performance of the porous radiant burner. The fuel flow and airflow rates were measured using the rotameters with control valves. The compressed air and the LPG were taken through their respective rotameters to the mixing pipe. The water boiling test as per the guidelines of the IS: 4246 was employed for evaluation of the thermal efficiency of the LPG cooking stoves. The distance between the burner surface and the bottom of the pan was kept at 5 cm.

In every case, the maximum thermal efficiency has been observed at different equivalence ratios, and this is for the reason that for different burners, for flameless conditions, the air requirement was different. For a given burner at a given wattage, the thermal efficiency is higher at a lower equivalence ratio and found to decrease with an increase in equivalence ratio. Such as for the B6 type burner efficiency decreases when the equivalence ratio increases at 1.3kW. For the two-layered porous radiant burner, the investigation was made for five different combinations in terms of thicknesses and diameters of the combustion zone made of SiC. The axial and radial temperature distributions of the burner were measured for different loads and equivalence ratios. For all the burners thermal efficiencies and CO and NO2 emissions were calculated.

The axial temperature measurement revealed that at higher wattages, the reaction zone shifted downstream of the burner. For higher wattages radial temperature was found to be more uniform, which can be a desirable feature of any burner. The maximum thermal efficiency of the B8 type burner was about 68%, which is 3% higher than the maximum thermal efficiency of the traditional LPG cooking stoves. The thermal efficiency of the porous radiant burner was found to increase. The maximum thermal efficiencies of B8 and B9 type burners were found to be almost the same. However, the maximum thermal efficiency of the B10 type burner was found to decrease due to the higher radiation heat loss. The CO and NOX emissions of the porous radiant burners were much low compared to the traditional stove [10].

MATERIAL OF BURNER

Burners of different material were used to study the effects on LPG stove performance. It was experimentally found out that thermal efficiency of stove using flat and flower face brass burners were higher as compared to regular cast iron burner. The burner head was removed and replaced by different design. Different burner head designs used in this work. Thermal efficiency was found out as per the BIS. It is observed that thermal efficiency of LPG stove improves by using flat and flower faced burners. When flower face burner was used, thermal efficiency of LPG stove was found to improve. The thermal efficiency of flat face brass burner was found to be maximum of 58%.

The thermal efficiency of LPG stove for regular cast iron burner was found to be 48%. When flat and flower face burners were used, thermal efficiency of LPG stove improved. When flat face brass burner was used maximum thermal efficiency of 58% was achieved. While thermal efficiency of 50% was observed when face brass flower burner was used. Further, it was experimentally found out that thermal efficiency of LPG stove using regular brass burner was 4% higher as compared to regular cast iron burner.

The technique of replaced of burner head is simple and safe. It can be easily implemented in domestic LPG stove for fuel conservation [11]. With various researches carried out regarding improvement of efficiency it was found out that a brass burner can give an efficiency of up to 68% and with conventional burner its efficiency is as low as 51%. So, for better performance of cook stove the material of Brass burner cap would be preferred. The thermal efficiency using the brass burner cap is approximately 4% higher than the cast iron burner for each nozzle size. The cost estimation on monthly basis, we can save the money if we use Brass burner in place of CI burner [8].

SWIRL EFFECT

A. A. Moustafa conducted tests on three patterns of flow orientation Swirl flow, Star pattern swirl, with the radial flow as a benchmarking burner in the swirling effect on a single ring gas domestic burner. As the changing conditions, the influence of the pan height on the flame front and Reynolds number has been introduced.

LPG was used as the testing gas for the examination of these burners in order to study how to improve future domestic gas burners by increasing thermal efficiency while lowering CO emissions. For the ignition discharges, burners that contained the swirling movement gave lower outflows, the three burners created emanations as follows Radial burner 0.09%, Swirl 0.08%-star design was the least with 0.01% emanations and this is expected the bigger violent power created by these whirl flares, the Star design burner likewise permits adequate measure of air to pass and arrive at the blazes openly which diminished obviously the burning outflows generally to different burners plans.

From the warm effectiveness imminent the whirl burner gave the most noteworthy warm productivity coming to practically 60.4% followed by the outspread burner 58.8% and the Star design burner 51.97%, and this leads us to the swirling movement improves the proficiency of the burner as a result of empowering the flares from connecting for a more extended timeframe with the lower part of the warmed skillet, truly we may reason that this occurs because of the way that the whirl will in general make a concentrated swirling activity alongside rakish energy to empower the warmth to be moved to the warmed burden, and the most noteworthy thermal efficiencies for all burners where kept up at the least pot height and greatest Reynolds number.

So, at long last to have as a trade-off for an upgraded effectiveness and brought down ignition discharges the Swirl burner would be promising to concentrate more, and more cases should be intended for the star design burner adding a tendency point to improve the contact between the blazes and the warmed burner [12].

DESIGN OF PAN SUPPORT

Mithun Das [13] suggested that the cook-stove design be tweaked to increase overall efficiency. A metal annular plate (referred to as the insert) is attached to the pan support (on which the cooking vessel is placed) in the modified cook-stove design to guide the flow of air and the burned gas. The insert's width is 40 mm, and its inclination angle with the horizontal is 13 degrees. In addition, we have also modified the spill-tray by closing the gap between the burner periphery and spill-tray (GBS). The design changes are incorporated into the 12-degree sector of the physical domain (placement of insert and GBS closed). The insert height (Hinsert) in the modified design is defined as the vertically measured distance between the vessel's bottom surface and the top edge of the insert. While optimising the modified design, Hinsert is varied from 6 to 12 mm, and the load height (Hload=distance between spill-tray and vessel bottom) is kept constant at 28 mm. The distance between the burner top and the vessel bottom is kept constant at 16 mm in these conditions.

The Spill-Tray and the Gap between the Burner and the Spill-Tray were demonstrated in this setup. The gap between the burner and the spill-tray in a traditional cook stove allows secondary ambient air to enter from the stove's backside. The secondary air aids in the completion of the fuel combustion process. However, because it is entrained from a colder environment, the flame temperature is reduced slightly. As a result, the rate of heat transfer from the flame to the vessel slows down, lowering the thermal efficiency. If the spill-tray is not connected to the burner, more cold air enters the flame through the GBS, lowering the flame temperature and resulting in a reduction in efficiency. Radiative heat loss through the GBS reduces the efficiency even more. As a result, in addition to installing the insert, our approach to burner design modification includes closing the GBS.

III. CONCLUSION

LPG is most widely used fuel for household cooking in India and it's is still the most rapidly growing source of fuel in terms of usage as people from rural places in India are still switching from coal towards cleaner and hassle-free source in the form of LPG. So, in this paper we aimed to study for higher efficiency by modifying the existing design which is affordable as well as increases the efficiency.

Following conclusions can be drawn from this study:

Fuel injector which is neither too small nor too big i.e., the optimum size (0.77mm) increases the efficiency of LPG stove as it gives maximum thermal efficiency and low heat losses to surroundings. Brass burner caps give approximately 4% higher thermal efficiency than cast iron burner for each nozzle size. Brass burners with the same fuel injector (0.77mm) gives efficiency of 68% while cast iron burners gives the efficiency of 64% at the same setting. Swirl burners which are already used in industries, slightly increases the efficiency with designs in burners but are slightly expensive. Closing the gap around burner prevents cold air to enter from the bottom of the stove. This results in increase in thermal efficiency.

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BIOGRAPHY

Author Ibrahim Hussain Shah is working as Assistant Professor, Mechanical Engineering Deptt., IET DAVV, Indore (MP). He has 25 years of experience in Thermal Engineering Field.