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Improvement of the Domestic LPG Cooking Stoves: A Review

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Abstract

Objectives: The objective of this review was to study various works that have focussed on the improvement of the efficiency and emission features of the LPG (Liquified Petroleum Gas)cook-stoves. **Methods:** The major focus of the review was on the LPG cook-stoves, though a variant in the form of Biogas was also studied. Parameters like performance, efficiency and emission features of various cook-stoves were taken into account. The design factors of the burners used in these cook-stoves was also one of the major factors that was strongly emphasized in this study. Findings: It was found that if the efficiency of a stove needs to be improved, the focus must be on the improvement of the specifications, design and material of the burner. For better efficient burners, the air preheating can be considered as a factor. As in the case of porous media, the thermal efficiency of the burner increases and the CO and NOX emissions reduce drastically**. Application:** Material of the burner also plays a pivotal role in the performance of the stove. Burners made up of have been found to be more efficient than their counterparts iron burners. Also, the shape of the burner is one factor that can help improve the performance of the stove.

Keywords: Burners, LPG cook-stoves, Performance, Thermal Efficiency

1. Introduction

In the common understanding, the gas burner is used to create a flame of fire, that heats any desired product, by making use of gas fuels such as C_2H_2(acetylene), CNG or propane. To make a complete combustion, a number burners involve inlet for the airto facilitate the mixing of gas and air. Commonly, acetylene is used with oxygen. A naturally aspirating gas-fired, Bunsen burner is applied for laboratory purposes. A propane burner with natural drag is used to melt the metals that have low melting points up to 1100°C, such as copper and some noble metals. For direct combustion, LPG stove has proved to be relatively simple appliance. Operating at atmospheric low-pressure the LPG stove has a burner that is premix and multi-holed type. The typical LPG gas stove comprises of a supply tube for fuel, gas injector jet, air openings, throat, gas mixing manifold, burner head, orifices in the burner, and supports for a vessel.

The efficiency of a cook stove has been categorised broadly in two; burning efficiency and overall efficiency. Burning efficiency is related to the capacity of the stove in order to convert the chemical energy of the fuel into heat. Whereas, the ability of the stove to transfer this heat to the heat absorbed by the object, that isto be heated, is the overall efficiency.

Other works,that calculated the efficiency for various stoves, were studied. It was found that the overall efficiency of the stoves was largely dependent upon numerous factors namely pressure, surrounding temperature, air velocity, the conductivity of the vessel, shape, size and weight of the vessel, and the amount of specimen used. Thus, for the same stove it was possible to achieve different values of efficiency. Calorific value of the fuel used, is the input energy for the cooking stove, thus in all the measurements of the efficiency its value was accounted in.

A summary of the conclusions made by their work includes-

The efficiency for a given stove for a given fuel can vary with conditions. The surrounding conditions and the quality of fuel hold as the major factors for this variation. Under controlled conditions maximum efficiency can be achieved, though in common usage, this value is lower than

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that achieved in controlled conditions. The following are the conditions that the efficiency of a stove depends upon:

- Environmental conditions.
- Shape, size, weight and conductivity of the vessel.
- Size of the burner and the surface area of the bottom of the vessel.
- Calorific value and quality of the fuel.

A research institute in Bangladesh developed and studied two improved cookstoves. One of the cookstoves was to use biomass as its fuel whereas the other used natural gas. Two parameters were taken into consideration for the study. One was the type of cooking vessel used (round-bottomed pot and flat-bottomed pan) and two the flow rate of the fuel i.e. the gas. Higher efficiencies were obtained in all the cookstoves where the pan was used as the cooking vessel. In the case of power, the efficiency was found to first increase with an increase in the gas flow rate but declined as the flow rate was increased further. Also in their experiment, they found that perforated shields made up of sheet metals may be used around the flame and a portion of the cooking vessel. As in the study, several factors were found to be responsible for the overall efficiency of the cookstoves. In the case of natural gas burners, the design of the burner head, design of the cooking vessel and the rate of flow of the gas were the major factors. The study further concluded that improvements in the efficiency of the cooking systems are possible by

- Using burners with optimum design
- Using vessels with flat bottoms
- Operating at flow rates that provide the highest efficiency.

2. Insight into the Recent Improvements

2.1 . Type of Burner

In a study, it was found that swirl burners have a significant effect on the thermal efficiency that is about 15% higher than that achieved when conventional burners are used. The study has thus suggested the replacement of the conventional burner with the swirl burner in domestic appliances as no major modification needs could be found in the conventional burners.[1]

Natural gas burners have been a part of the cooking system for a while now and this lighter fuel works at different pressures as compared with the most conventional LPG, the burner requirements for the natural gas are very different from that of the LPG. The burner performance gets strongly affected by the heating value of the fuel, which further depends on its composition. Usage of the same gas stoves to burn natural gas with various heating values may become dangerous and inefficient due to probable incomplete combustion, lift-off, flashback and lack of heat input. The study also professed that the fuels with higher heating values than that of the natural gas, when used in the same burners will result in decreased thermal efficiency and increased CO emissions.

2.2 Flame Height and Temperature Distribution

Temperature distribution depends on the structure of the flame, that is attributed to the variations in the heating height. The flame height also depends on the methane concentration and the velocity of injection.

The results of the experiment showed that the optimum heating height of the burner, that gives the widest range of high temperature and best thermal efficiency, was achieved with a Type-C flame. In this flame, inner premixed and outer diffusion flame are open and diverge.[2,3]

2.3. Design Improvements

In an experiment it was found that the increase in the diameter of the ports that admit the fuel-primary air mixture along with drilling holes obliquely, to add an impact of swirl to the flow, helps in increasing the efficiency and reduce emissions. The smaller orifice in the nozzle for fuel injection was also found to improve the performance by decreasing burner loading.[4-5]

Eight factors were studied to have effects on either the maximum primary aeration for stable flames at 3.3kW or the turn down ratio. Varying the angle under the cap and overlap, effects detected were mostly due to the variation in the angle under the cap.[6-9] The study postulated the following preferred combinations of factors:

- Burner top angle: 15^{o}
- The angles under the cap and overlap: 15^{o}
- Indent under the cap

It was found that this cap and burner combination was optimum for the satisfactory operation at up to 61% primary aeration at 3.3kW and had a turndown ratio of 5.3.

3. Case Studies

In this case study the authors focussed on the gas burners and its design. In order to fulfil this, they developed an atmospheric gas burner. In order to facilitate testing methods, they also developed apparatus. In their work, flow of the gas was studied through different types of orifices. The study also involved the laws that governed the rate of flow of air insidethe burner, the detailed design of injecting tube, consumption of the fuel by the ports of different area at various rates, and the impact that is established with various adjustments of the air shutter. It was found that the rate of discharge of gas through different types of orifices varied greatly as the angle of approach and the length of tube of the orifice underwent variations. Also the ratio of the momentum of the gas stream to that of the stream of air-gas mixture that enters the burner, for any given burner, was found to be constant. This relation, as stated in their work, enables readily calculations of the effect on the air volume that enters when there is a change in the pressure, rate, or specific gravity of the gas.[10-12]

Performance of burner was tested on various strategies in their work. A number of burner orifice were designed and optimised for their study. Also, a number of injection tube models were designed. Positons of the orifice were changed for experimental purposes and injector with best results was selected. In their work, Walter et al used a correlation among the tube and the ports of the burner to achieve the features that of an optimum burner which would have been satisfactory. As a part of the experiment the team also found that with the ports of smaller size, it became possible to turn the rate of flow of the gas lower without any signs of flash back. The reason for this absence of the flash back was considered to be the cooling effect of the secondary air upon the flames that are small, and this helped in the reduction in the speed of propagation of the flame.[13-14]

A relation was observed amongst the throat area of the injecting tube and the burner area. After aseries of test results it was seen that for better performance the throat area should be 43 per cent of that of the burner ports. A guideline was provided that may help in choosing a burner for any condition. Based on the preceding tests and calculations a series of tables were compiled, that gives of the rate at which the burners, of various sizes for varying pressures and air-gas ratios, consume the gas. it was found to be difficult to make tables that would have been generally applicable to various types of burners, as the rate of consumption of burners, with no injecting tubes, increases with increasing port area. Also it was professed that, for burners with an injecting tube the consumption rate increases so much that it becomes necessary to have a pipe that is of larger area when compared to that of the port, as the results were not found to be up to mark as the velocity past the first ports was already too high. The findings of this study was concluded with the acceptance of the burners with simplicity, low cost and reliability. Such burners have already found their way into the domestic and smaller industrial usage, so it was put forward that if the range of these burners is widened, they can be made to operate with better efficiency without any adjustments.[15]

The experimental work carried out included the designing, construction and evaluation of performance of a burner that uses biogas as its fuel. The work mainly aimed at the enhancement of the efficiency of these stoves. The conventional method of boiling water test was used to evaluate the performance of the stove. Efficiency of 21% and 60% were recorded for boiling water and cooking rice respectively. In addition to this analysis of the flue gases was also conducted in order to bring out the emission characteristics of the stove. The flue gas analyser recorded the efficiency of the burner to be 86.9%. Selection of the perfect material was also the agenda of this study. The prime design parameters under consideration in the study were:

- Smoothness of the gas inlet pipe
- Jet diameter
- Mixing pipe length
- The diameter and number of the port holes
- Elevation of the head of the burner

The design considerations of the study were:

- Specific gravity of the gas
- Calorific value
- Composition of the gas
- Pressure of gas
- Volume of the biogas
- Flame speed

With the extensive implementation of the design parameters, a burner was fabricated, and a performance evaluation was carried out. With the addition of the flue gas analyser the following results were obtained:

- Regulation of the air-gas mixture was assumed to maximize the potential of the stove.
- On all the three burners tested in the study the emission characteristics analysis done by the flue gas analyser showed a constant presence of oxygen, carbon dioxide and air.

The authors were able to give some advice on the future work:

- It was found that by displacing of the injector to and fro in the mixture chamber, the effect of the air-gas regulating mechanism could be improved.
- By comparing the two flame and single flame burners, the authors professed the design and development of the two flame burners.[16,17]

In this study the authors were studying the self-aspirating burners. The effects of changes in the flame structure and the temperature of the combustion air were the prime investigating points. Studies for combustion air with or without preheat case were performed. An increase in the level of the primary air entrainment was observed when the heat input was increased. In the case of preheating, lower primary aeration was found than that in the without preheat case. The reason for this was found that the preheating effect was making the fluid inside the mixing tube more viscose. By preheating the air temperature, a yellow tip flame was also observed pertaining to the decrease in primary aeration. These findings were, as per the author, were crucial information that will aid in the future development of high-performance burners.

In the current study under review, LPG was used as the fuel in the conduction of the experiments. To measure the concentration of oxygen, oxygen sensors with an accuracy of .05% were used. An uncertainty analysis, by a method proposed by Kline and McClintock, using a 95% confidence level was carried out. The maximum uncertainties in the primary aeration was found to be 3.3% and the minimum was 1.6%.

For the measurement of the primary aeration, a set up was installed using oxygen sensor. This was applied to both the cases i.e. with and without preheat. A self-aspirating burner was used. A selection of four preheated air temperatures (50^{o}C, 100^{o}C, 200^{o}C and 300^{o}C) was made. The water manometer was used to measure the static pressure.got the following results to share from their study:

The primary aeration in both the cases, i.e. with and without preheat, increases rapidly in the early stages when the heat input is increased. After the rapid increase, it gets stabilised and is found to no longer dependent on the heat input. The reason for this was stated to be the limitations of the mixing tube and the size of the burner ports. At the preheated temperature of the air of T=300^{o}C, a lower value of about 14% was detected as compared to that in the case of without preheat. This was found due to the increase in the viscosity of the mixture, that resulted from the preheating effect that causes the mixture expand. In the preheat case the pressure distribution was found to be greater than that in the without preheat case. As the preheated air temperature was increased the pressure distribution was also found to increase.

The structure of the flame, as shown in Figure 1 and 2, for a partially aerated burner was found to have two distinct regions; the inner and outer cone flames. As described in their study, the inner core flames burn with the entrained primary air and are thus rich premixed flames. Whereas, in the case of the outer cone flames that burn with unburnt fuel and secondary air, the flames are non-premixed flames. Yellow tip flame was found to occur in the inner cone flames as the heat input was decreased. Whereas, an abundance in the levels of CH and C was evident from the greenish-blue colour in the inner cone flames when the heat input was further increased. However, yellow tip flame was observed in the periphery of the cone flames, pertaining to the fact that the secondary air has no way to move in from the surrounding that is just on the plane of the burner. As understood from prior information, the flame stability is affected by the thermal input and aeration mechanisms, it was detected that a slight increase in the heat input is able to facilitatea higher flame height. Reason for this increase in the height of the flame is attributed to the velocity of the gas mixture that increases with increase in the thermal input. The high preheated temperature was found to be responsible for the low primary aeration and increased burning velocity. Thus, it was noted that the flame height remains constant and does not depend on the temperature of the preheated primary air.

Figure 1. Effect of the heat input on the structure of the flame[18].

Figure 2. Effect of air preheating on structure of the flame at q=8.41kW[18].

They have concluded their work with the following remarks:

The level of the primary aeration, in both the cases, one that involvespreheat and another that does not, is increased rapidly at the early stages when the supply of the heat is increased. Hereafter, the primary aeration stabilizes and is further independent of the heat supply. This is attributed to the critical limits of the tube for mixing and the port size of the burner. Also, a yellow tip flame was detected when the air temperature before entrainment, i.e. preheat temperature, is increased, because the primary aeration is decreased.

Incomplete combustion leads to the increase in the CO levels. Increase in the rate of combustion prevents the flame height from getting affected. For the achievement of a burner with higher efficiency a factors such as the preheating of the air can be taken into consideration.[17-18]

The study was carried out in order to test the performance of a porous radiant burner used in LPG domestic cook-stoves. Due to its eco-friendliness and high thermal efficiency, the porous media has attracted a decent attention in the recent past. In the construction of the burner, two-layered porous media was used to attain the maximum advantages. Combustion zone was designed using SiC (Silicon Carbide) and Al_2O_3 (Alumina).Burners of a given diameter were analysed for various equivalence ratioand thermal loading. The parameters analysed were again the thermal efficiency and emission characteristics. As prescribed in the BIS (Bureau of Indian Standard),2002, the water boiling test was conducted in order to determine the thermal efficiency of both the conventional and PRB cook-stoves. Efficiency the PRB was detected to be 68% which was 3% more than the best efficiency generated by any traditional LPG cooking stoves. The reaction zone was detected in close vicinity of the other two. This was evident from the axial temperature distribution. At higher thermal loads, the reaction zone started to move towards the downstream. A constant temperature on the surface was measured in case of the PRB.

In case of the two-layer PRB the combustion zone was fabricated using SiC porous matrix. 5mm balls of Al_2O_3 were used to form the preheating zone. A schematic diagram is shown in the Figure 3. With a porosity of 90%, the PRB had a thickness varying from

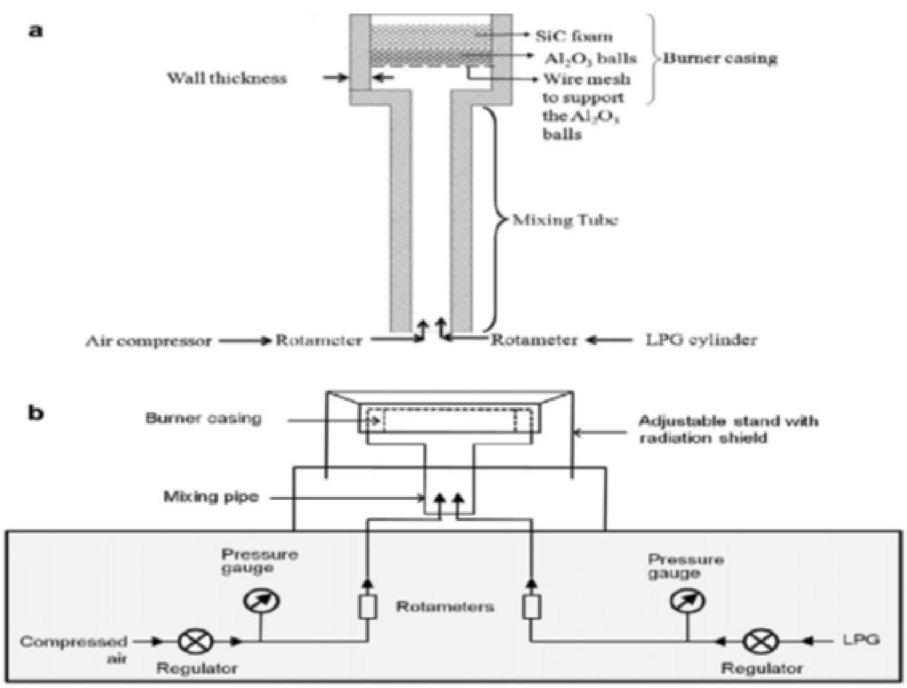

Figure 3. Schematics of the PRB and the experimental setup[19].

1.5 cm to 2.0 cm. Using alumina powder and sodium silicate binder, the burner casing was fabricated. Casing was made to undergo sintering at high temperatures to sustain high thermal stresses. The PRB consisted of a zone of combustion, preheater, mesh made of wire, a burner casing and Teflon mixing tube. Using different combinations of measurements of diameter and thickness of the burners, a series of experiments were conducted. Five different burners, namely B_6, B_7, B_8, B_9, and B_{10}, were used in the investigation. The experimental setup that was used to test the performance of the PRBs included:

- Monitoring of the fuel-flow and air-flow rates using rotameters with control valves.
- At 3.0 kN/m^2, the compressed air and the LPG were taken to the mixing pipes through their respective rotameters.
- Water boiling test as prescribed in the BIS, 2002, helped in the calculation of thermal efficiency.
- A distance of 5.0 cm was maintained between the burner surface and the bottom of the pan.

In their study, Pantangi et al used the Testo 350 XL portable gas analyser in order to measure the CO and NO_X emissions. The sampling of the same was done as prescribed in the BIS, 2002. Because the observations made for the thermal efficiency were made at different equivalence ratios, the results showed that the air requirement for each burner was different. At a lower equivalence ratio, the thermal efficiency is higher for any given burner at a given wattage. And that, this thermal efficiency decreases with increase in the equivalence ratio. As for example, in the experiments, the B_6 burner at 1.3 kW the efficiency was found to decrease from 63.0% to 50.0%, whereas the equivalence ratio increased from 0.41 to 0.51.

In the case of the two-layered PRB, the experimental investigation included five different combinations of thickness and diameters of the combustion zone. The distribution of the axial and radial temperatures of the burner were measured for different wattages as well as different equivalence ratios. Thermal efficiencies and the CO and NO_X emissions were obtained for all the burners. Through the measurements of the axial temperature it was revealed that at higher wattages, there was a shift in the reaction zone towards the downstream of the burner. At higher wattages the radial temperature was found to be uniform. This is a desirable feature for any efficient burner. A maximum efficiency of 68% for the B_8 burner was achieved that is almost 3% higher than that of the conventional LPG cooking stoves. The thermal efficiency increased from 62% for B_6 to 68% for B_8 burners. B_8 and B_9 were found to have almost the same maximum thermal efficiency of 68%. However, due to the loss of heat radiations the maximum thermal efficiency was found to decrease. For the emissions, the CO and NO_X in case of the PRBs were found to be in the range of 25e^{350} mg/m^3 and 12e^{25} mg/m^3. These values were much below the prescribed values (CO: 400e^{1050} mg/m^3 and NO_X: 162e^{216} mg/m^3) for the conventional domestic cooking stoves.[19]

The research was carried out in order to implement the concept of the Porous Medium Combustion (PMC) into the Porous Radiant Burner (PRB). In the case of the PMC, the combustion of the fuel occurs inside a set matrix of open cavities, where an inert solid surface is present. With high thermal conductivity and high emissivity, the porous matrix facilitates heat transfer through conduction and radiation. In their experiments, they conducted tests for performance on the PRB that is used in applications of capacity of 5-10 kW; typical of medium-scale cooking.

SiC- based porous burner was chosen as the PRB for the study. Fuel used in the study was LPG. Investigations were made into the thermal efficiency and emission levels of the PRB, by studying the effects of different heat inputs in the range of 5-10 kW. In the case of conventional LPG burners, as shown in Figure 4, with a capacity of 5-10 kW, the thermal efficiencies measured were in the range of 30-40%. The emission tests of the conventional LPG burners gave the CO and NO_X values in the range of 350-1145 ppm and 40-109 ppm, respectively. The given emission values were way above the values prescribed in the WHO standards. The SiC-based PRB, when tested within the range of parameters, were found to yield the maximum thermal efficiency of 50%. This value of the thermal efficiency is about 25% higher than that of the conventional stoves.

Figure 4. Commercial Burners used for performance[20].

In the case of the conventional stoves the combustion is free flame. In such stoves the heat transfer is done by only convection. This makes the conventional combustion devices much less efficient and there is a significant increase in the CO and NO_X emissions due to the poor mode of heat transfer. In order to overcome the disadvantages of the free flame combustion, a new means of combustion was adopted. This was the PMC. PMC is able to deliver high power density, high power dynamic range and low levels of emissions.

The monitoring of the fuel and air flow rates was done by using Coriolis flow meters with suitable valves. A mixture tube of Teflon was used to move the air-fuel mixture to the burner. The radiation shield was installed on an adjustable stand. The PRB used in the experiments was dependent on two-layered PMC, a preheating zone and a combustion zone. Combustion zone was made using high porosity of about90%, highly radiating SiC porous matrix. Whereas the preheating zone consisted of low porosity of about40% matrix made up of 120mm ceramic balls. Inside the casing of the burner, a mesh of wire was provided in order to support the ceramic block. Fabrication of the burner casing was done at IIT Guwahati with alumina powder and sodium silicate binder.

As per the guidelines described in BIS, the thermal efficiency of the LPG cook-stoves was measured. A comparison of the efficiencies of both conventional and PRB was carried o]ut through surveys. Similar methods were applied in order to carry out the comparison between the emission and performance characteristics of both types of burners. The Testo 350 XL portable gas analyser was used, in order to measure the CO and NO_X emissions. The sampling of the same was done as prescribed in the BIS.

The thermal efficiency for a conventional burner at different thermal loads was measured and that it was found to be in the range of 30-40%. On the other hand, the thermal efficiency of the PRB was recorded in the upper range of 40-50%. With the increase in the thermal load, for the given configuration of the PRB, the fall in the trend of the efficiency was related to the rich fuel mixture and the increase in the heat losses. The emissions of CO and NO_X, from both the conventional burners and PRB were analysed for different thermal loads. For PRB, the CO and NO_X emissions were found to be lower at all thermal loads. In another study of slurry pipeline system it was found that such a system offers features that may help reduce environmental pollution. Such features are reduction in air pollution and lesser ecological disturbance along with energy consumption saving.

4. Conclusions

Specific works related to the improvement of the cooking stove performance and efficiency were studied. One of the experiments was based on a different fuel, biogas. But, the underlying objective of the research was similar to other studies. In all the case studies, the burner of any stove plays the pivotal role and was detected the one major factor that affects the performance of the stove severely. Thus, it becomes clear enough that if we have to improve the efficiency of a stove, the focus must be on the improvement of the specifications, design and material of the burner. The Government of India has also promoted the research on the improvement of the LPG stoves.[21,22] The following are some further key points from the review:

- For better efficient burners, the air preheating can be considered as a factor.
- As in the case of porous media, the thermal efficiency of the burner increases and the CO and NO_X emissions reduce drastically.
- Material of the burner also plays a pivotal role in the performance of the stove. Burners made up of have been found to be more efficient than their counterparts iron burners.
- Also the shape of the burner is one factor that can help improve the performance of the stove.
- The results have shown that for maximum efficiency, the injector throat area should be 43% of that of the burner ports.

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