

Performance analysis of porous radiant burners for cooking applications

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Abstract

A new trend of utilizing the porous burner technology for the application of domestic cooking was observed because of its high efficiency and low emissions. This research work presents the experimental analysis of three types of porous burners having uniform diameter of 90 mm, 70 mm and divergent shape burner having the top diameter of 90 mm and bottom side diameter of 70 mm respectively. The fuel used for all the experimental trials was, Liquefied Petroleum Gas (LPG). Porous burners consist of two zones i.e. preheating zone and combustion zone. The test piece preheating zone was filled with steel balls of diameter 6.5 mm and in combustion zone porous matrix of SiC foam of 10 ppi was used. Height of combustion zone was kept constant for all the three burners at 25 mm. Burner was operated at different equivalence ratio ranging from 0.10-0.60. The maximum efficiency of 79 % was observed for porous burner of diameter 90 mm at equivalence ratio (Φ) of 0.49 and 0.84 kW power.

Keywords: Porous Radiant Burner; LPG; Cooking Applications; Thermal Efficiency.

1. Introduction

India is the second largest LPG consuming country [1]. Indian government, is spending huge amount of money on subsidizing LPG cylinder. In India, the current price of subsidized LPG cylinder of 14.2 kg is Rs. 466.50 and non-subsidized is Rs. 737.50. It is creating a huge financial burden on Government of India (GOI) as the rest of money for the oil companies is to be paid by them. For reducing this economic burden from GOI, one has to find alternative fuels for cooking applications or to increase the thermal efficiency of a domestic burner. In the present work efforts are being made to test porous burner technology (PBT) for LPG fired burners for cooking applications.

In porous burner technology, porous medium is used for combustion. This is also known as Porous Medium Combustion (PMC) and Porous Radiant Burner (PRB). PMC is divided into two zones i.e. preheating zone and combustion zone. The first one is preheating zone, filled with metal balls made of low porosity and other is the combustion zone, filled with SiC ceramic matrix. The reason for choosing low porosity in preheating zone is to avoid combustion and the resulting flashback [2]. Fig.1 shows a schematic diagram of a two-layer porous burner. Air fuels mixture, first preheated in the preheating zone then combustion takes place in the combustion zone. Heat is transmitted in all the directions by the conduction, convection and radiation mode of heat transfer. PMC is giving better thermal efficiency and low emissions as compared with domestic burners available in market. Various researchers are working to increase the thermal efficiency and to reduce the emissions of burner.

Isabel Malico et al. [2] presented a review paper on the porous media combustion for household application. Porous burner for cooking applications was discussed in detail.

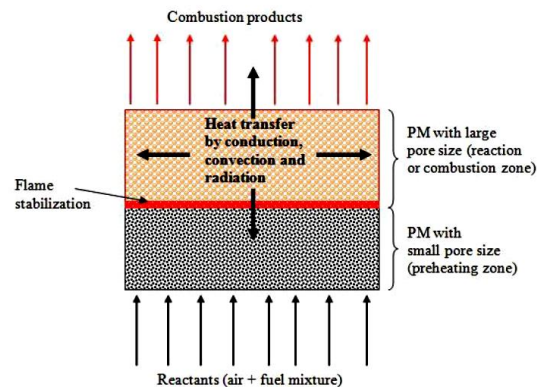


Fig. 1: Schematic Diagram of A Two-Layer Porous Burner [2].

M.A. Mujeebu et al. [3] presented a review paper on the various applications and materials which can be used for porous burner. In their paper, authors presented research and development in PMC.

P Muthukumar et al. [4] developed a domestic cooking porous burner for LPG. Burners were tested at different porosities, i.e. 80%, 85%, 90% for different equivalence ratios and wattages. In the experimental setup, SiC foam of 80-90% porosity was used in combustion zone and 40% porosity in preheating zone. Efficiency achieved for this setup was 75% which was 10% better than the domestic burner available in Indian market.

Purna et al. [5] developed a self-aspirating porous radiant burner and conducted the experiment for different velocities (i.e. 3.0 m/s, 3.6 m/s and 0.4 m/s) and calculated thermal efficiency and temperature distribution analysis for the burner. Thermal efficiency was found to be 64.16 % for velocity of 3.6 m/s and

55.46 % for gas velocity at 3.0 m/s and 36.52 % for gas velocity at 0.4 m/s.

Layrisser Iral et al. [6] performed a study on the induced air porous radiant burner for domestic applications at high altitude. Burner was tested for three different power units (i.e. 370 kW/m^2 , 480 kW/m^2 and 670 kW/m^2) and emissions and thermal efficiency of the burner were also measured. A maximum thermal efficiency of 50% for 370 kW/m^2 was observed.

Byeonghun Yu et al. [7] developed different types of porous media burner to check which one to use with a condensing boiler and also calculated the thermal efficiency of the burner. Three types of porous media; metal fiber (MF), ceramic (CM) and stainless steel fin (SF) were utilized. Thermal efficiencies of burner at different wattages and equivalence ratio were analyzed, and it was observed that MF burner at 25 kW and $\Phi = 0.95$ have highest efficiency at 86.7%, while SF burner has lowest efficiency at 15kW and $\Phi = 0.80$ i.e. 81.6%.

Wasan Yoksenakul et al. [8] built up a self-aspirating porous burner for small and medium-scale enterprises. Experiments were conducted for power in the range of 21- 44 kW and height was varied from 75-125mm and LPG was used as fuel. It was found that with the increase in the height, thermal efficiency decreases except the burner at 34 kW. Highest thermal efficiency calculated was 57.64% for SPMB.

Jugjai et al. [9] developed porous burner for kerosene. In experimental setup instead of spray atomizer, fuel was supplied from the top side, and combustion takes place at the lower side where it was mixed into the air. Combustion properties were calculated inside the burner by calculating temperature profiles and emission characteristics. It was observed that burner showed a stable combustion with low emissions of pollutants at the equivalence ratio in range of 0.37-0.55 and power in the range of 2.62-3.49 kW.

Sharma et al. [10] performed an experiment on porous inserts in conventional kerosene pressure stove. It was observed that by using porous insert, the efficiency of the stove increased from 55% to 62%.

Jaguajai and Sanitjai [11], designed a new porous burner for domestic applications i.e. porous radiant reticulated burner (PRRB). It has been observed that porous radiant reticulated burner was efficient than the other burners in terms of efficiency, combustion stability and emission characteristics.

V. K. Patangi and P. Muthukumar et al. [12-13], developed a porous burner for cooking application for LPG, and did an experiment by varying the porosities, power and equivalence ratio. Efficiency was 72 % and 71 % which was 7% and 6 % respectively better than the domestic burner.

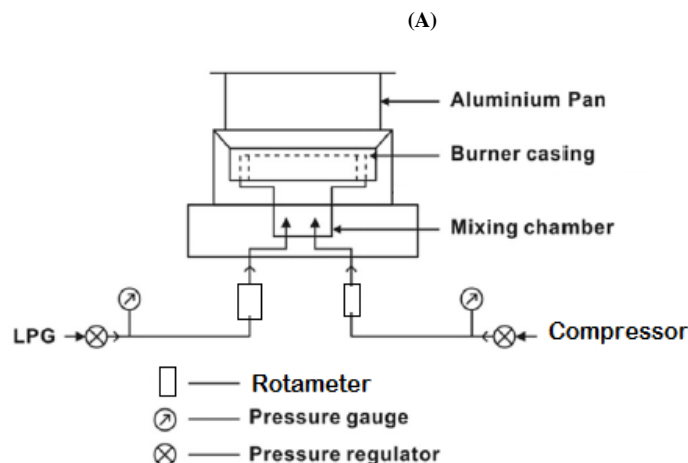
From literature survey, it is observed that porous burner technology (PBT) is not limited to one field. PBT can be used for

many applications such as heat exchangers, IC engines cooking applications, etc. It is observed from the literature survey that in order to increase the efficiency and reduce the emissions optimized shape, need to be analyzed. In the present work, PMC is divided into two zones i.e. preheating zone and combustion zone. The first one is preheating zone, filled with metal balls of diameter 6.5 mm made of low porosity and other are the combustion zone, filled with SiC ceramic matrix. The reason for choosing low porosity in preheating zone is to avoid combustion and the resulting flashback. Temperature distribution and thermal efficiency were investigated.

2. Experimental approach and procedure

The Porous radiant burner (PRB) used for experimental setup in this research work is shown in fig.2 (a). The mass - flow rates of air and fuel were measured by rota-meters (make JTM). The air-fuel mixed with each other in a Y-Shaped mixing chamber made up of steel, then reaches the combustion zone for combustion as shown in Fig. 2 (f). The burner consists of two zones i.e. preheating zone and combustion zone. Combustion zone is filled with SiC ceramic foam having 10ppi and thickness 25 mm. Preheating zone was filled with steel balls having diameter 6.5 mm each.

Thermal efficiency and temperature distributions were measured for both the burners (domestic and porous burner). Efficiency was calculated by water boiling test. As shown in Fig. 1 b. LPG from a 5 kg cylinder equipped with a controller supplied to the burner by means of a rota-meter. The fuel flow rate is measured by utilizing the rota - meter. Aluminium pans along with lid were utilized for the testing. The pan was filled with a known amount of water (0.5-1 kg) at ambient temperature (23-25°C). Amount of the water is varied from 0.5–1 kg to check the repeatability and also to measure the effect on efficiency by varying the weight of water. Weight of the pan with water was measured by a weighing balance (precision ± 0.5 gm). Initial temperature (T1) of water is measured. Initial weight of the cylinder is measured. The pan was kept over the burner once the flame becomes stable. Water was heated up to 80°C. At this stage, the burner was turned off. The final weight of LPG cylinder was measured once again. The time which burner took to raise the temperature of the water from initial temperature (T1) to 80°C is also noted. In every case, readings were taken at least three times, and the average of three were taken for the final result. As per the IS 4246:2002 standards [14], the thermal efficiency of LPG fired burners is calculated from the following formula:



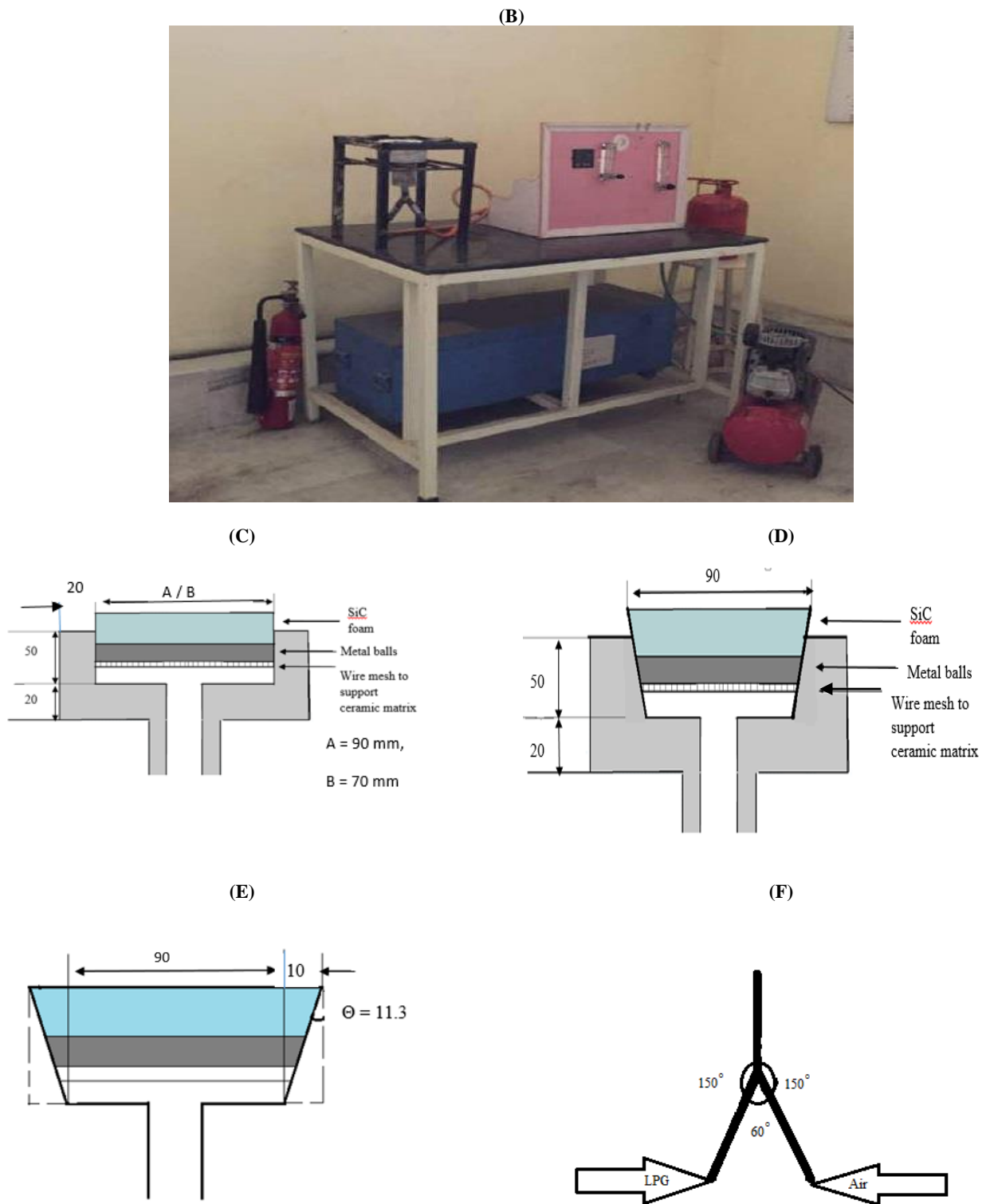


Fig. 2: (A) Schematic Diagram of Experimental Setup (B) Experimental Setup (C) Porous Burner (D) Divergent Burner (E) Dimensions of Divergent Burner (F) Schematic of Y-Shaped Mixing Tube.

$$\eta_{th} = \frac{100(W + P)(T_2 - T_1)}{m_f \cdot CV} \quad (1)$$

where W is the mass of water, P is mass of the pan along with lid made up of aluminium and m_f is the mass of the LPG consumed and CV is the calorific value of LPG.

P. Boggavarapu et al. [15] have also used the above formula for the calculation of thermal efficiency of LPG and PNG fired burners

The burners were operated at different equivalence ratio(Φ).

Equivalence ratio can be defined as the ratio of actual air fuel ratio to the stoichiometric air fuel ratio.

$$\phi = \frac{(air / fuel)_{actual}}{(air / fuel)_{stoichiometric}} \quad (2)$$

Actual air fuel ratio tell us about the actual air fuel being used for the combustion or the actual amount of air or fuel being used to raise the desired temperature of water. Air flow is measured using rota meter and from the rota meter we will get the value of actual air being used for combustion and fuel was measured using

weighing balance that will give us the value of actual amount of fuel used for combustion or for raising the temperature of water. And stoichiometric air fuel ratio was taken as 15.6 (used by V.K. Patangi) [12].

3. Result and discussion

Burner was operated at different equivalence ratio (0.10 - 0.60) and power wattages (0.4-1 kW). In the following sections, results of temperature distribution and efficiency of the porous burner and domestic burner have been discussed. Two parameters were varied to measure the temperature distribution ;

- i). Equivalence ratio
- ii). Air flow rate

3.1. Temperature distribution

Temperature of surface of PRB and conventional burner (CB) were measured using K-type thermocouple. The output of the thermocouple was acquired by using data acquisition system (make Ambartronics TC - 900). The burners were operated for almost 1 hour. Temperature of all the burners were measured at different equivalence ratio. Every burner attained a different maximum temperature (298 - 650°C) at different equivalence ratio (0.11 - 0.16).

In Porous burner with 90 mm diameter, it was observed that at constant equivalence ratio ($\Phi = 0.16$) as the time increases, the temperature increases and after 65 minutes the maximum temperature attained by the burner was 460°C. It was also observed from the Fig.3 that, as the mass fuel consumption increases by 5 % the temperature increases by 150°C. At equivalence ratio of 0.11, the maximum temperature observed was 327°C and minimum temperature at the start of combustion was 225°C.

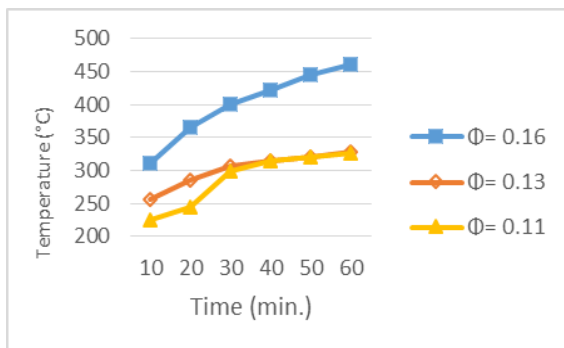


Fig. 3: Variation of Temperature W.R.T. Time (Minutes) of Porous Burner 90 Mm at Different Equivalence Ratio.

Fig. 4 shows the variation of surface temperature of porous burner of 90 mm diameter w.r.t. air to fuel ratio. It was observed temperature increases with the decrease in air to fuel ratio (increase in fuel consumption). The maximum increase of temperature was observed from (301 to 491°C) when air/fuel ratio decreases from 3.47 to 2.14 (38.3 %). It was also observed that as the air/fuel ratio decreases beyond 1.32 to 1.13, the temperature increase was less (630 to 638°C) the reason for the same may be due to saturation of heat within the porous medium.

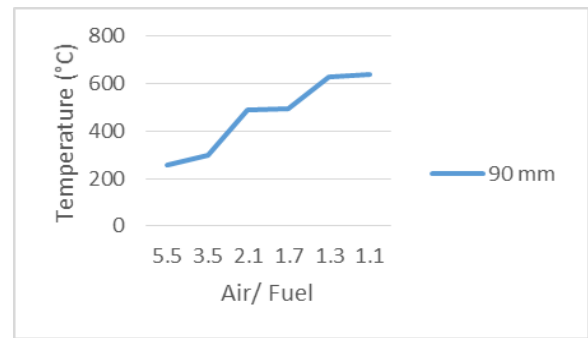


Fig. 4: Variation of Temperature W.R.T. Air / Fuel Consumption of Porous Burner 90 Mm.

In Porous burner with 70 mm diameter, it was observed that at constant equivalence ratio ($\Phi = 0.47$) as the time increases, the temperature increases and after 65 minutes the maximum temperature attained by the burner was 480°C. It was also observed from the Fig.5 that, as the mass fuel consumption increases by 3.5 % the temperature increases by 23°C. At equivalence ratio of 0.27 the maximum temperature observed was 398°C and minimum temperature at the start of combustion was 295°C.

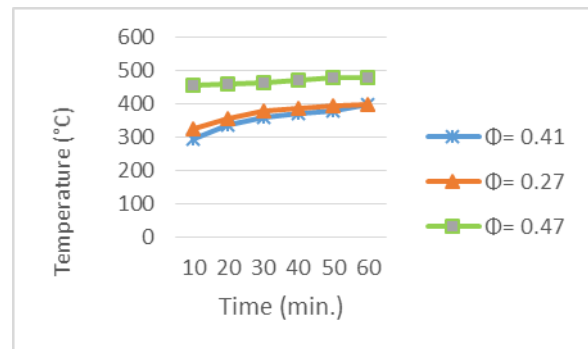


Fig. 5: Variation of Temperature W.R.T. Time (Min.) of Porous Burner 70 Mm at Different Equivalence Ratio

Fig. 6 shows the variation of surface temperature of porous burner of 70 mm diameter w.r.t. air to fuel ratio. It was observed temperature increases with the decrease in air to fuel ratio (increase in fuel consumption). The maximum increase of temperature was observed from (360 to 475 C) when air/fuel ratio decreases from 2.1 to 1.6 (23.8 %).

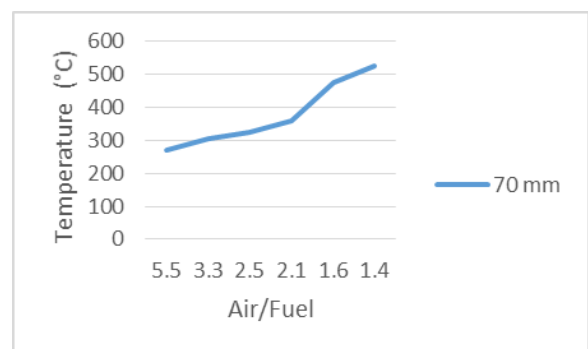


Fig. 6: Variation of Temperature W.R.T. Air /Fuel Consumption of Porous Burner 70 Mm.

In Porous divergent burner with 90 mm top diameter, it was observed that at constant equivalence ratio ($\Phi = 0.63$) as the time increases, the temperature increases and after 65 minutes the maximum temperature attained by the burner was 575°C. It was also observed that in Fig.7, as the mass fuel consumption increases by 1.5 % the temperature increases by 51°C. At equivalence ratio of 0.43, the maximum temperature observed

was 498°C and minimum temperature at the start of combustion was 300°C.

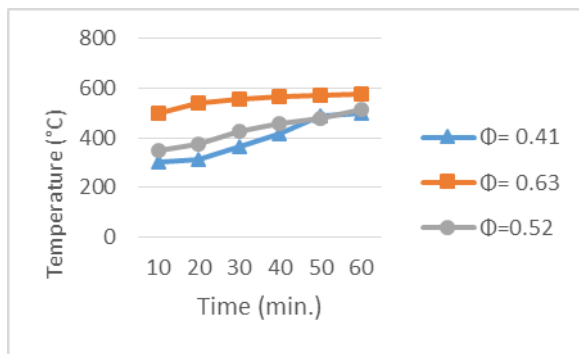


Fig. 7: Variation of Temperature W.R.T. Time (Min.) of Porous Burner Divergent at Different Equivalence Ratio.

Fig. 8 shows the variation of surface temperature of porous divergent burner of 90 mm top diameter w.r.t. air to fuel ratio. It was observed temperature increases with the decrease in air to fuel ratio (increase in fuel consumption). The maximum increase of temperature was observed from (380 to 558°C) when air/fuel ratio decreases from 2.2 to 1.9 (13.6 %).

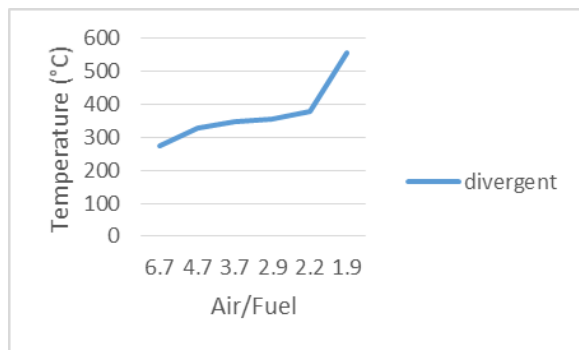


Fig. 8: Variation of Temperature W.R.T. Air/Fuel Consumption of Porous Burner Divergent.

It was observed from Fig.9, the variation of temperature of domestic burner with LPG fuel consumption. It was observed that as the fuel consumption increases the maximum temperature of domestic burner (with regular burner). At 0.028 gm/sec LPG consumption, the maximum temperature was 271.2°C. It was also observed that at the same fuel consumption, porous burner with 90 mm diameter has the higher value of maximum temperature (6.89 – 20.94 %).

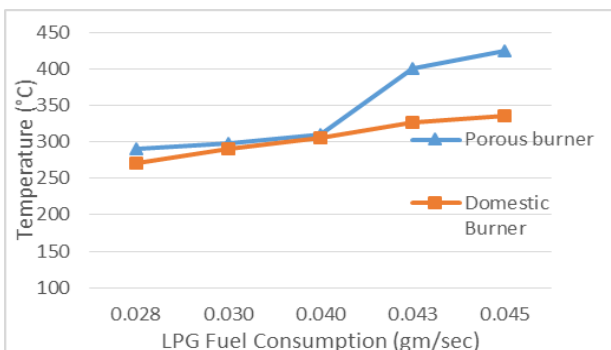


Fig. 9: Variation of Temperature W.R.T. LPG Fuel Consumption (Gm/Sec) for Domestic Burner.

3.2. Thermal efficiency

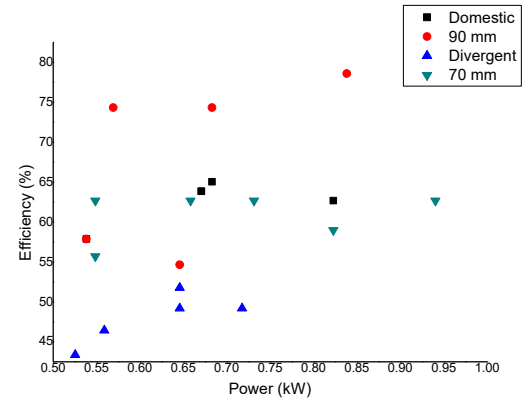


Fig. 10: Variation of Efficiency of Porous and Domestic Burner Vs. Power (Kw).

The Fig. 10 shows the variation of thermal efficiency of porous burner and domestic burner w.r.t. power (kW). It was observed that maximum efficiency was experienced by the porous burner with 90 mm diameter as compared to the other burners. At a constant power of 0.6 kW, the thermal efficiency of porous burner with 90 mm diameter was observed to be 15.67 % , 22.13 % and 30.32 % more than the 70 mm diameter porous burner and domestic burner and divergent burner respectively. The maximum efficiency of 78.58 % was observed for porous burner of 90 mm diameter at equivalence ratio of 0.49 and at power 0.84 kW.

4. Conclusion

An experimental analysis was performed to measure the efficiency of three porous burners (with diameter 90 mm, 70 mm and divergent shape burner with a top side diameter of 90 mm) and constant height of 50 mm. The thermal efficiencies of three porous burner (90, 70 and divergent) were measured and compared with the domestic burner.

Following are the conclusions:

- The maximum efficiency of domestic burner was 65 %.
- It was observed that porous burner with the diameter of 90 mm has the highest efficiency. For porous burner, 90 mm efficiency was found to be 78.58 % which is 13.5 % higher than the domestic burner.
- Porous burner 70 mm has a maximum efficiency of 62.7 % which is 8 % higher than the domestic burner.
- Maximum efficiency for divergent shape porous burner was 51.78 %.
- For porous burner with diameter 90 mm, maximum temperature was 460 °C at an equivalence ratio (Ø) of 0.16.
- For porous burner with diameter 70 mm, maximum temperature was 480 °C at an equivalence ratio (Ø) of 0.47.
- For porous burner with divergent shape having top side diameter of 90 mm, maximum temperature was 575 °C at an equivalence ratio (Ø) of 0.63.

The porous burner technology was tested experimentally for the domestic applications and it was observed that with the same fuel consumption, the thermal efficiency of porous burner with 90 mm diameter was 78.58 % was highest among all the burners. The computational analysis of the work will be done in future.

References

- [1] <http://timesofindia.indiatimes.com/business/india-business/india-becomes-second-largest-domestic-lpg-consumer/articleshow/57008531.cms>
- [2] Isabel Malico, and M. Abdul Mujeebu, "Potential of Porous Media Combustion Technology for Household Applications", International Journal of Advanced Thermo fluid Research Volume 1, Issue 1, 2015
- [3] M. Abdul Mujeebu , M.Z. Abdullah , M.Z. Abu Bakar, A.A. Mohamad , M.K. Abdullah, "Applications of porous media combustion technology – A review", Applied Energy 86 (2009), 1365–1375 <https://doi.org/10.1016/j.apenergy.2009.01.017>.
- [4] P. Muthukumar , P.I. Shyamkumar, "Development of novel porous radiant burners for LPG cooking applications ", Fuel 112 (2013) 562–566 <https://doi.org/10.1016/j.fuel.2011.09.006>.
- [5] Purna C et al. " Performance improvement of self-aspirating porous radiant burner by controlling process parameters" Int. Journal of Engineering Research and Applications , Vol. 3, Issue 5, 2013, 978-984
- [6] Layrissir Iral, Andr_es Amell, "Performance study of an induced air porous radiant burner for household applications at high altitude", Applied Thermal Engineering 83 (2015), 31-39. <https://doi.org/10.1016/j.applthermaleng.2015.02.044>.
- [7] Byeonghun Yu , Sung-Min Kum, Chang-Eon Lee, Seungro Lee, "Combustion characteristics and thermal efficiency for premixed porous-media types of burners" , Energy 53 (2013), 343-350. <https://doi.org/10.1016/j.energy.2013.02.035>.
- [8] Wasan Yoksenakul and Sumrerng Jugjai, "Thermal efficiency of self-aspirating porous medium burner for Small and Medium Scale Enterprises (SMEs)", The Second TSME International Conference on Mechanical Engineering, (2011), 19-21
- [9] S. Jugjai, C. Pongsai, "Liquid fuels-fired porous burner", Combust. Sci. Technol. 179 (2007) 1823-1840. <https://doi.org/10.1080/00102200701260179>.
- [10] M. Sharma, S.C. Mishra, P. Acharjee, "Improvement of thermal efficiency of a conventional pressure stove using porous radiant inserts", Int. J. Energy Res. 10 (2009) 247-254.
- [11] S. Jugjai and S. Sanitjai, "Parametric studies of thermal efficiency in a proposed porous radiant recirculated burner (PRRB) a design concept for the future burner", RERIC International Energy Journal, 18(2), (1996), 97-111.
- [12] V.K. Pantangi, Development and performance analysis of porous radiant burners for cooking applications. Ph.D Thesis. Department of Mechanical Engineering, IIT Guwahati, 2010.
- [13] P. Muthukumar, Piyush Anand, Prateek Sachdeva, "Performance analysis of porous radiant burners used in LPG cooking stove" International Journal of Energy and Environment Volume 2, Issue 2, (2011), 367-374.
- [14] Indian standard, IS 4246, Domestic gas stoves for use with liquefied petroleum gases specification (fifth revision); 2002
- [15] Prasad Boggavarapu, Baidurja Ray, R.V. Ravikrishna, "Thermal Efficiency of LPG and PNG-fired burners: Experimental and numerical studies", Fuel 116 (2014) 709–715. <https://doi.org/10.1016/j.fuel.2013.08.054>.