International Journal of Emerging Technology and Advanced Engineering
Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 126-130
An ISO 9001:2008 certified Int. Journal, ISSN 2250-2459, available online at www.ijetae.com

Performance Tests on Medium-Scale Porous Radiant Burners for LPG Cooking Applications

N. K. Mishra, P. Muthukumar*, Subhash C. Mishra
Department of Mechanical Engineering
Indian Institute of Technology Guwahati, Guwahati – 781039.
*Email: pmkumar@iitg.ernet.in

ABSTRACT

The principle of operation of the porous radiant burner (PRB) is based on porous medium combustion (PMC) in which the combustion of fuel and air mixture takes place inside a matrix of open cavities in the presence of an inert solid surface. Since the porous matrix has high thermal conductivity and high emissivity, the contributions of conduction and radiation in the PMC are significant. In the present paper, performance tests on PRB used for medium - scale cooking applications of capacity 5-10 kW are presented. The PRB chosen for the study is SiC-based porous burner of diameter 120 mm and 90% porosity. Liquefied petroleum gas (LPG) is used as a fuel. Effects of different heat inputs in the range of 5 - 10 kW on the thermal efficiency and emission levels of PRB are investigated. For the conventional LPG burner of 5-10 kW capacity, the measured value of thermal efficiencies is in the range of 30-40%, and the CO and NOx are in the range of 350-1145 ppm and 40 - 109 ppm, respectively. These emissions levels are well above the world health organization standards. Within range of parameters tested, the SiC- based PRB yields the maximum thermal efficiency of about 50%, which is about 25 % higher than the conventional stoves. The measured emission levels are also much lower than the conventional stoves.

Keywords: Combustion, LPG cooking stove, Porous radiant burner, Energy saving

1. INTRODUCTION

The conventional combustion devices are characterized by a free flame, where the convection is the only mode of heat transfer. Thus, the poor heat transport makes the conventional combustion devices less efficient and result in increased CO and NOx emissions. The LPG cooking gas burner is one such device that goes well with this category of high emission levels and low thermal efficiency. In order to overcome these difficulties of the free flame combustion, another means of combustion was discovered known as porous medium combustion (PMC).The principle of operation of the porous radiant burner (PRB) is based on PMC. PMC offers high power density, high power dynamic range and very low NO and CO emissions, owing to the high levels of heat capacity, conductivity and emissivity of the solid matrix, compared to a conventional combustion devices.

The improvement in the living standard of the mankind and the rapid industrial growth demand the abundant use of fossil energy which leads to the diminution of fossil fuel resources and also cause environmental pollution. The issues related to the environmental pollution can be minimized by improving the efficiency of the combustion devices. The thermal efficiencies of the current LPG commercial stoves (5-10 kW thermal load range) available in the Indian market are in the range of 30 - 40% and at the same time the CO (350 - 1145 ppm) and NO_x (40 - 109 ppm) emissions levels are above the world health organization standards.

Pantangi *et al.* [1] implemented the idea of the PMC in a liquefied petroleum gas (LPG) cooking stove for the improvement in thermal efficiency. They investigated the efficiency, emission and energy cost for the conventional domestic LPG cooking stoves with and without the usage of various porous media likes metal balls, pebbles and metal chips. With the usage of porous media, the maximum thermal efficiency of the stove was found to be 73% which was 8% higher than conventional burner. They reported energy saving of about 10%. With LPG as a fuel, Dongbin *et al.* [2] investigated the combustion phenomenon in a porous ceramic stove doped with rare earth elements. The increased emissivity due to the addition of rare earth elements to porous ceramic was attributed to the special valence shell of rare earth elements. Akbari *et al.* [3] carried out a study to investigate the lean flammability limits of the burner and the unstable flash-back/blow-out phenomena. Flame stability showed that the inlet firing rate and matrix porosity were two main parameters which influence the lean flammability limit of a porous burner. Mujeebu *et al.* [4]

developed two compact premixed LPG burners based on submerged and surface combustion modes in porous medium. They compared combustion and emission characteristics of these burners with the conventional burner. Keramiotis *et al.* [5] developed two-layer rectangular porous burner with an Al_2O_3 flame trap and a 10 ppi SiSiC foam. They operated the burner with methane and LPG both as a fuel. They measured gas phase temperature with the help of a thermocouple. For solid phase temperature distribution, they used IR camera.

Hayashi *et al.* [6] presented a three-dimensional numerical study of a two-layer porous burner for household applications. They solved the mathematical model using CFD techniques which accounted for radiative heat transport in the solid, convective heat exchange between solid and fluid. Talukdar *et al.* [7] presented the heat transfer analysis of a 2-D rectangular porous radiant burner. Combustion in the porous medium was modeled as a spatially-dependent heat generation zone. A 2-D rectangular porous burner was investigated by Mishra *et al.* [8]. Methane–air combustion with detailed chemical kinetics was used to model the combustion part. Farzaneha *et al.* [9] investigated numerical predictions of the flow, heat transfer and combustion in a 5 kW porous burner. The effects of excess air ratio on the temperature profiles and pollutant emissions were studied.

Pantangi *et al.* [10] investigated the thermal efficiency and emission characteristics of two layered PRBs at various equivalence ratios and thermal loads. Result showed that maximum efficiency of the PRB was about 68% and the measured CO and NO emissions were significantly low in PRB than the conventional LPG cooking stoves. Muthukumar *et al.* [11] investigated the performance of the burner at different equivalence ratios and power intensities. The results showed that the maximum thermal efficiency of the PRB was about 71% at 1.24 kW, equivalence ratio of 0.68 at an ambient temperature of 31°C. They also observed that CO and NOx emission of PRB was very low compared to the conventional burner.

Muthukumar and Shyamkumar [12] optimized the PRB. The thermal efficiency of PRB was found to be 75%. For a given wattage of 1.7 kW and equivalence ratio of 0.54, the efficiency of PRB was found to decrease from 75% to 71% when the porosity of PRB decreased from 90% to 80%. Thermal efficiencies of all the tested PRBs gradually decrease with increase in the equivalence ratios and power intensities. Sharma *et al.* [13] investigated the effect of porous radiant inserts in conventional kerosene pressure stove. The found that using porous insert, the efficiency of the conventional stove increases from 55% to 62%. Sharma *et al.* [14] modified conventional kerosene pressure stove. They used ceramic (ZrO_2) insert in the combustion zone and a ceramic (Al_2O_3) heat shield surrounding the burner. The maximum efficiency was found to be 70%, which was 15% higher than the efficiency of a conventional kerosene pressure stove.

It is observed from the literature that most of the researchers explored the use of porous medium combustion in cooking application for low thermal load in the range of 1-2 kW. It is also found that no researcher tested the PRBs with the capacity range of 5- 10 kW for medium-scale cooking applications. Hence, in the present work, the authors have explored the application of PRB for medium-scale LPG cooking applications.

2. EXPERIMENTAL SET UP AND TEST PROCEDURE

A schematic of the experimental set-up used for testing the performance of PRB is shown in Fig. 1. The fuel and air flow rates are monitored using the coriolis flow meters with suitable valves. Air–fuel mixture moves to the burner through a mixing tube made of Teflon. Adjustable stand has been attached with a radiation shield. The PRB used for the present work is based on two-layered PMC. The two layered PRB consists of a combustion zone and a preheating zone. Combustion zone is formed with high porosity (90%), highly radiating SiC porous matrix, and the preheating zone consists of low porosity (40%) ceramic matrix of 120 mm diameter. Inside the burner casing, a wire mesh is provided to support the ceramic block. The burner casing was fabricated at IIT Guwahati using alumina powder and sodium silicate binder. The schematic of the burner casing is shown in Fig. 2.

Thermal efficiencies of the LPG cooking stoves were estimated by conducting the water boiling test as per the guidelines described in Bureau of Indian Standard (BIS):4246:2002. Procedure is briefly described in the following section.

A 19.5 kg LPG commercial cylinder was connected to a regulator and then with a coriolis flow meters (accuracy± 0.01 g) between to the burner. The fuel flow rate was monitored using the coriolis flow meters with suitable control valves. Aluminium vessel along with lid and stirrer for the experiment was selected and filled with known amount of water (5-10kg) at room temperature. Weight of the vessel and water were noted with the help of a weighing balance (accuracy ± 0.5 g). Initial temperature (T_1) of the water was measured using glass in mercury thermometer (accuracy ± 0.5°C). Once the flame stabilized in the burner, vessel was kept above the burner. Water was heated up to 80°C, and for uniformity in temperature, stirring was started and continued until the end of the test when the temperature of water reached (T_2) 90± 0.5°C. Then the burner was switched off. The time taken to raise the temperature of

Int. J Emerging Technology and Advanced Engineering
ISSN 2250-2459, *Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 126-130*

the water from initial temperature to 90°C was also noted. In each case, experiments were repeated at least three times and the average of three was taken for the analysis.

The percentage of thermal efficiency η_{th} of the stove was calculated based on the following formula:

$$\eta_{th} = \frac{(m_w \times C_w + m_p \times C_p)(T_2 - T_1)}{m_f \times CV}$$

To compare the thermal efficiencies of conventional burners with PRB, a market survey was carried out to get the various types of burners used in conventional commercial LPG cooking stoves. Mainly three types of burners are used in India (Fig. 3). The efficiencies and emissions of PRB and conventional burners were calculated using the same procedure.

The CO and NOx emissions were measured using TESTO 350 XL portable flue gas analyzer. The sampling was done as suggested in the BIS: 4246:2002.

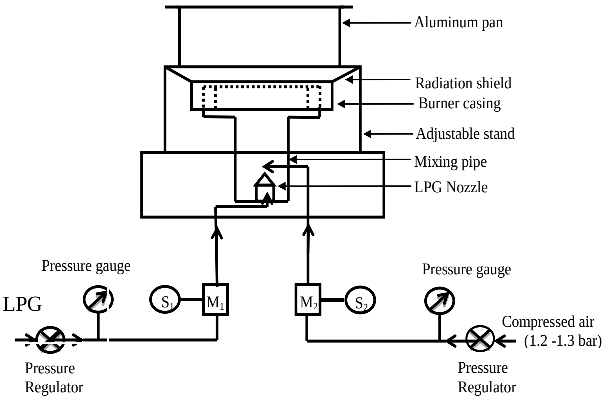

Fig. 1. Schematic of the experimental set-up.

3. RESULTS AND DISCUSSION

In the following pages, we compare thermal efficiencies and emissions for the conventional commercial burner and porous radiant burner.

Thermal efficiency

Thermal efficiency was measured for conventional burners at different thermal loads. Thermal efficiency was found in the range of 30-40%.Whereas for porous radiant burner was found in the range of 40-50%. These results are shown in Fig. 4. The maximum improvement in thermal efficiency is about 34.3 % at 10 kW thermal load. For the chosen configuration of the PRB, with increase in the thermal load, the observed trend of lower efficiency is attributed to the fuel rich mixture and increased heat loss.

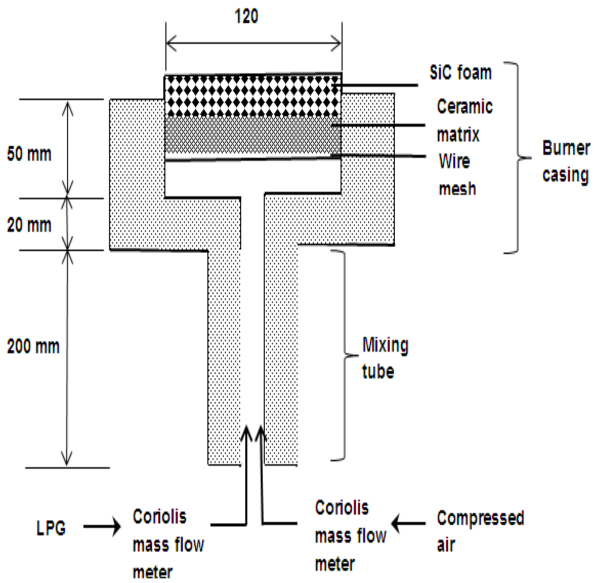

Fig. 2. Schematic of porous radiant burner(PRB).

Fig. 3. Different types of commercial burner available in Indian market chosen for comparison.

Exhaust gas analysis

The pollutant formed from the combustion process effects the environment and health in many ways. The CO and NOx emissions from the conventional burner and the PRB are shown in Fig. 5. At all thermal loads, both CO and NOx emissions were found lower for the PRB.

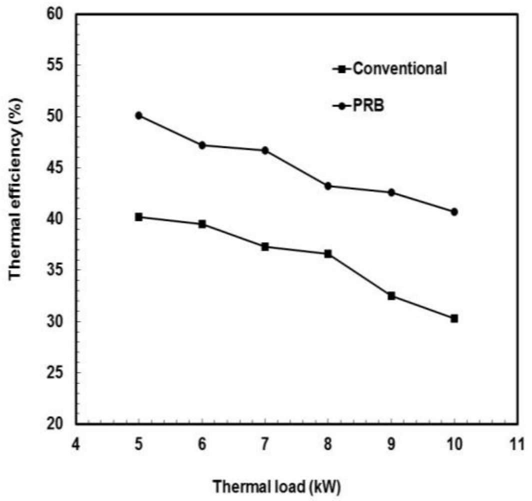

Fig. 4. Thermal efficiency of different burners.

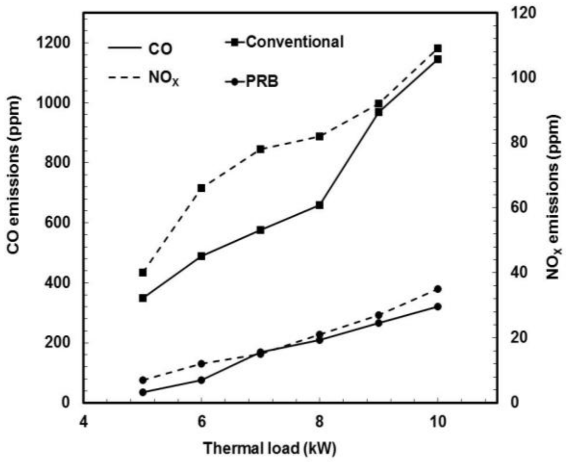

Fig. 5. Comparison of CO and NOx emissions for different thermal loads for PRB with conventional burner.

4. CONCLUSIONS

Performance of the PRB for commercial LPG cooking stoves was tested. For different thermal loads thermal efficiencies, CO and NOx emissions were investigated. Thermal efficiencies of the PRB gradually decreased with increase in power intensity. PRB with 5 kW thermal load yielded the maximum thermal efficiency of about 50%, which was about 25% higher than the efficiency of the conventional burner. At the thermal load of 10 kW, the PRB yielded the maximum improvement in thermal efficiency of about 34.3 %. The measured emissions of CO and NOx were much lower than the conventional commercial burner.

REFERENCES

1. Pantangi, V.K., Kumar, ASSRK., Mishra, S.C. and Sahoo, N., 2007, "Performance analysis of domestic LPG cooking stoves with porous media", Int. Energy Journal; 8: 139-44
2. Dongbin. Z., Jinsheng, L., Guangchuan, L.,Yan, D., Gang. X. and Lihua L., 2007 "Effects on combustion of liquefied petroleum gas of porous ceramic doped with rare earth elements", J Rare Earths; 25:212-25
3. Akbari, M. H., Riahi, P. and Roohi, R., 2009, "Lean flammability limits for stable performance with a porous burner", Applied Energy; 86:2635–43
4. Mujeebu, M. A., Abdullah, M.Z., and Mohamad, A. A., 2011, "Development of energy efficient porous medium burners on surface and submerged combustion modes", Energy; 36: 5132-5139
5. Keramiotis, C., Stelzner, B., Trimis, D. and Founti M., 2011, "Porous burners for low emission combustion: An experimental investigation", Article in press December,) in Energy.
6. Hayashi, T.C., Malico, I. and Pereira, J.C.F. , 2004,"Three-dimensional modeling of a two-layer porous burner for household applications", Computers and Structures; 82:1543–50
7. Talukdar, P., Mishra, S.C., Trimis, D. and Durst, F., 2004, "Heat transfer characteristics of porous radian burner under the influence of a 2-D radiation field", Journal of Quantitative Spectroscopy and Radiant Transfer,;84: 527-537.
8. Mishra, S.C., Steven, M., Nemoda, S., Talukdar, P., Trimis, D. and Durst, F., 2006, "Heat transfer analysis of a two-dimensional rectangular porous radiant burner", Int. Communications in Heat Mass Transfer,; 33: 467-74.
9. Farzaneh, M., Ebrahimi, R., Shams, M. and Shafiey. M., 2009, "Numerical simulation of thermal performance of a porous burner", Chemical Engineering and Processing; 48:623–32
10. Pantangi, V.K., Mishra, S.C., Muthukumar, P. and Reddy, R., 2011, "Studies of PRBs for Cooking Application", Energy,;36:6074-6080
11. Muthukumar, P., Anand, P. and Sachdeva, P.,2011, "Performance analysis of porous radiant burners used in LPG cooking stove". Int J Energy and Environment;2:367-74
12. Muthukumar, P. and Shyamkumar, P.I.,2011, "Development of a novel porous radiant burner for LPG cooking applications". Article in press (DOI: 10.1016/j.fuel.2011.09.006) August, in Fuel.
13. Sharma, M., Mishra, S.C. and Acharjee P.,2009,"Improvement of thermal efficiency of a conventional pressure stove using porous radiant inserts", International Journal of Energy Research,; 10: 247-254,

ISSN 2250-2459, *Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 126-130*

14. Sharma, M., , Mishra, S.C. and Mahanta P., 2011, "An experimental investigation on efficiency improvement of a conventional kerosene pressure stove", International Journal of Energy for Clean Environment; 12: 1-15

NOMENCLATURE

m_w	mass of water, kg
m_p	mass of pan along with the lid and stirrer, kg
m_f	m_f is the fuel consumed to raise the water temperature from T_1 to T_2, kg
C_w	specific heat capacity of water (C_W = 4.1826 kJ/kg-K)
C_p	specific heat capacity of aluminium (C_p = 0.8959 kJ/kg-K)
CV	calorific value of the fuel, (CV = 45780 kJ/kg)

AUTHORS' BIOGRAPHIES

Niraj Kumar Mishra holds B.Tech degree from MIT Purnea, (2008) in Mechanical Engineering and M.E (2010) with specialization in Heat Power from the Department of Mechanical Engineering at BIT Mesra. He is a Research Scholar in the Department of Mechanical Engineering at IIT Guwahati. He is currently doing research on porous medium combustion at IIT Guwahati.

Palanisamy Muthukumar received PhD degree in Mechanical Engineering from IIT Madras during 2005. He joined at IIT Guwahati as Assistant Professor in January 2006 and he became Associate Professor in January 2010. He received DAAD research fellowships during September – December 2000, June-July 2008, and June - July 2010. He is the recipient of IEI Young Engineer Award - 2010 in Mechanical Engineering from Institute of Engineers (India). He is the reviewer of many international journals in the area of hydrogen energy, energy storage, refrigeration, and heat transfer. He has published over 80 research articles in various international journals and conference proceedings. His area of interests are hydrogen energy storage, metal hydride based thermal machines, coupled heat and mass transfer in porous medium, porous medium combustion, sorption heating and cooling systems, etc.

Subhash C. Mishra holds BSc (Engineering) from BIT Sindri Dhanbad (1989) and MTech (1992) and PhD (1997) in Mechanical Engineering from IIT Kanpur. Prof. Mishra joined IIT Guwahati as a Senior Lecturer in December 1996. He became Assistant Professor in April 1997, Associate Professor in May 2000 and Professor in October 2004. Prof. Mishra is the recipient of the research fellowship of the Alexander von Humboldt Foundation, Germany and a Fellowship by Invitation of the Japan Society for Promotion of Science. He is the reviewer of many journals and conferences in the area of heat transfer and has about 200 research papers to his credit. He is a fellow of the Indian National Academy of Engineering and American Society of Mechanical Engineers.