Abstract

Globally, the major share of energy requirement is met by conventional combustion devices working on fossil fuels. Depletion of fossil fuel reserves, and ever increasing environmental imbalance caused by pollutants from combustion devices, has become a great concern. This has, thus necessitated the need to search for alternative sources of energy, and also some design modifications in the existing devices. The main focus of the design modifications is to conserve energy to the maximum possible extent, and to minimize the emissions. Hence, a continuous effort on improving the performance of combustion devices has remained a paramount task for the policy makers and researchers dealing with energy conservation and environmental pollution.

A conventional combustion device is characterized by free-flame in which the combustion takes place in the open air environment, and convection is the main mode of heat transfer. As compared to heat conducting solids, gases have very low thermal conductivities and emissivities, in conventional combustion devices, contributions of conduction and radiation from the post flame to pre flame zone is insignificant. Thus, due to poor heat transport, these devices are less efficient, and they have undesirable features such as low flammability limits, low power density, high level of pollutant emissions, etc. Conventional liquefied petroleum gas cooking stoves fall under this category.

In India and many other countries, for cooking stoves, LPG is the most commonly used fuel. In these stoves, a premixed air-fuel mixture combust in the gaseous environment and the flame stabilizes over the perforated metallic burner head. The free-flame combustion in these burners is similar to that of the Bunsen burner. In free-flame combustion, the reaction zone is very thin, and because of which, the temperature gradient across the flame is very high. The measured thermal efficiencies of the conventional domestic LPG cooking stoves (1 — 3 kW) available in the Indian market are in the range of 60-68%, and that of the medium-scale (5 — 15 kW) are in the range of 30-45%. These efficiencies are low. Due to the aforesaid reasons, the free-flame combustion is not desirable for the LPG cooking stoves. India is the fourth largest consumer of LPG, and it ranks third in the domestic sector. The total domestic consumption of LPG in India is almost **comparable** to other petroleum products used in industrial applications. According to the 2014 Annual Report, "Basic Statistics on Indian Petroleum & Natural Gas" the number of the domestic LPG consumers in India is increasing year by year, and the total number of LPG consumers in 2014 was about 150 million. Analysis of the consumers' data of previous years shows a steady growth of about 10%. Due to increasing number of consumers, the demand of LPG is also increasing. The total LPG requirement during 2016-17 is projected to be 21.83 MMT which is 1.66 times more than India's indigenous production. To meet the demand, therefore, India has to import LPG, and for this, a huge amount of foreign exchange is paid. As consumers cannot afford the actual price of LPG,

the Government provides a substantial amount of subsidy. In the year 2014, the total subsidy on LPG for cooking stoves given by Government was (INR) 483.62 billion.

Apart from inefficient utilization of energy in the existing LPG cooking stoves, and expenditure of the foreign exchange, huge amount of pollutant emissions is a serious concern. CO and NOx emissions from conventional domestic LPG cooking stoves (1 — 3 kW) are in the range of 220 ppm to 550 ppm and 5 ppm to 25 pprn, respectively. The same for the medium scale (5 — 15 kW) LPG cooking stoves are 355 ppm to 1165 ppm and 28 ppm **to** 110 ppm, respectively. These emissions levels are above the current standards of World Health Organization. Thus, curtailment of CO and NOx emissions further necessitates development of the efficient burners for cooking applications.

Instead of combustion in the gaseous environment, like in the conventional burners, if a fuel is made to combust in a conducting and radiating porous matrix, thermal efficiency goes up, and emissions of CO and NOx come down. This is owing to enhanced heat transfer. This combustion in the porous matrix utilizes the principle of excess enthalpy combustion. By preheating **the** premixed fuel-air mixture, even the lean mixture and low calorific value fuel can be combust in the porous matrix. This preheating in combustion in the porous matrix is realized due to the manifestation of the volumetric thermal radiation. Apart from preheating of the incoming premixed fuel-air convection owing to higher surface area per unit volume mixture, volumetric radiation, conduction and increased of the porous matrix, homogenization of temperature, and hence the volume of the reaction zone gets elongated. These all lead to a higher thermal efficiency and reduced emissions.

Impressed with the performance of the devices based on porous medium combustion in diverse applications, recently, some researchers have extended its usage to LPG cooking stoves. They have reported enhanced thermal efficiency and reduced emissions. A critical review of previous studies reveals that their developments lacked utility for domestic cooking as well as cooking for a mass, as these required the supply of compressed air. The supply of compressed air is not feasible, and it is also unnecessary for the cooking applications. The present work, addresses this issue through the development of self-aspirated two-layer porous radiant burners for LPG domestic as well as medium-scale cooking stoves.

The present work, therefore, is aimed at the development of the LPG cooking stoves that utilizes the principles of porous medium combustion. For the domestic cooking, the burner power of the range 1-3 kW is developed. With cooking for a large number of people (say 50 or 100) in hostels, hotels, community centres in mind, a medium scale burner with power range 5 — 15 kW is also developed. The developed cooking stoves with porous radiant burners are stand-alone systems. Unlike the burners of other researchers, for their operation, these burners do not require supply of any external air. Making the developed stoves independent of external air, the design has been substantially changed. The changes are discussed in detail in the thesis.

The work contained in the thesis has been carried out in three parts. In the first part, the performance analyses have been carried out for the medium-scale LPG cooking stove with a porous radiant burner. Though working on external air supply, the objective of the first study has been to understand the stability range of the burner, and to fix the geometric and operating parameters. The second part of the study is dedicated to the development of self-aspirated domestic LPG cooking stove with a porous radiant burner (PRB). The development of self-aspirated medium-scale PRB for LPG cooking stoves is the third study. To compare the improvements in terms of thermal efficiency and emissions in the developed LPG cooking stoves, experiments were also performed with that of the conventional LPG cooking stoves of the same power input available in the market.

In the first part of the study, the burner input power range considered was 5-10 kW. For the two-layer LPG cooking stove with a PRB working on external air, performances have been investigated at power inputs in the range 5-10 kW. And, for the stable combustion, the equivalence ratio was found from 0.54 to 0.72. The combustion behaviour within the burner has been also studied by measuring radial and axial temperature distributions. The temperature measurement has been done using both thermocouple and IR camera. For different power inputs, the thermal efficiency of the PRBs were found in the range 42 — 58% and the respective values for the conventional burner was in the range of 35 — 45%. This increase in thermal efficiency is attributed to improved combustion in PRB. Also emissions were lower than the conventional burner. As mentioned before, the LPG cooking stove with PRB operating on external air lacks utility, the two studies address the development of self-aspirated LPG cooking stoves with PRB with the input power ranges 1 — 3 kW and 5 — 15 kW.

Placement of porous matrix in the flow path adds to the resistance, and to overcome that in previous studies, researchers had to use compressed air. And, this has been one of the major limitations in using the LPG cooking stoves with PRB for cooking applications. To overcome this limitation, the design modifications in terms of LPG supply pressure, orifice, burner port, mixing tube and burner casing were done. For power input 1-3 kW LPG cooking stove with a pgB, for air entrainment, two slots in the burner port was introduced. The orifice diameter too was changed. The LPG supply pressure was increased to 1.2 bar (gauge). With the improved design of the burner assembly, thermal efficiency, emission characteristics and temperature distribution were studied for power input in the range of 1 - 3 kW. A significant improvement in thermal efficiency (63-75%), and large reduction in emissions (CO: 30- 140 ppm and NOx: 0.2-3.5 ppm) were observed.

For the medium scale (5 — 15 kW) LPG cooking stove with PRB, the design of the burner is completely different from the one with 1-3 kW considered in the second study, and also of the conventional ones of the same input power range (5 — 15 kW). Instead of one burner port in the previous one (1 -3 kW), to meet the requirement of large volume of air, four burner ports with four orifices were incorporated. Each of the four burner port was fitted with an orifice.

All the four orifices were connected to the same LPG supply line. For the better radiant output, the diameter as well as the thickness of the porous matrix for the combustion zone was optimized. The thermal efficiency was found to improve significantly (44 — 55%), and the emissions (CO: 60 — 190) ppm and NOx: 2 — 10 ppm) also reduced considerably.

For both self-aspirated domestic as well as medium-scale cooking stoves with PRB, the measured emissions were found lower than the conventional burner. Significant amount of LPG can be saved by using developed LPG cooking stove with a two-layer PRB. Newly developed burners with PRB showed a steady-state operation without any flashback and blow-off. It was observed that the radial temperature distribution of the burner with PRB was almost uniform. As both developed stoves are self-aspirated, it works on the natural draft. It is ideally suited for LPG cooking applications everywhere.