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Research Paper

Effect of burner configuration and operating parameters on the performance of kerosene pressure stove with submerged porous medium combustion

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HIGHLIGHTS

- A kerosene pressure stove with porous burner is studied.
- Burner is made of Al_2O_3 and SiC.
- Burner size, fuel and air flow rate are optimized.
- Improved emission characteristics are observed.

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ABSTRACT

The use of porous burner in combustion appliances finds widespread attention due to its inherent nature of low emission and high efficiency. This paper presents a finding on the effects of the porous medium (PM) configuration and operating parameters on the performance of a kerosene pressure stove equipped with Silicon Carbide (SiC) and Alumina (Al_2O_3) operating in the submerged combustion mode. The study covers three different diameter burners: 60 mm, 70 mm and 80 mm, and their thermal performances are assessed through thermal efficiency, emissions and radial temperatures at different air and fuel flow rates. The best performance is observed in the case of 70 mm diameter burner with a minimum of 44 ppm CO (carbon monoxide) and NOx (oxides of nitrogen) ~1.5 ppm. An air flow rate range of 120–130 lpm is found optimum.

1. Introduction

Kerosene is an important cooking fuel in many developing countries, including India; especially in the urban areas, where biomass needs to be purchased, and Liquefied Petroleum Gas (LPG) being expensive is accessible only to the higher income groups [1–3]. For rural communities however, biomass is the primary fuel, while kerosene is used as a supplementary fuel for it is available at a subsidized rate [4].

Typically, kerosene is burnt in two kinds of stoves viz., wick stoves and pressure stoves. The wick stoves rely on the capillary transfer of the fuel and the pressure stoves work with a vapor-jet nozzle that aerosolizes the fuel using a manual pump. Between the two categories, the use of wick type is more prevalent due to the lower initial cost, while the pressure type exhibits better thermal performance with an average thermal efficiency of ~40–45% [5–7]. The main reason for the lower thermal efficiency of the kerosene stoves with respect to the best category stove: LPG (thermal efficiency: ~60%) is associated with its design. Further, kerosene stoves generate many health-damaging pollutants such as carbon monoxide (CO), oxides of nitrogen (NO_x), and sulphur dioxides (SO_x) [8,9]. However, the attention received by the kerosene stove is still small. It is interesting to note that in spite of the large penetration of LPG in the Indian market, still 22% urban households depend on kerosene and this situation is predicted to remain same in the foreseeable future due to the desire for clean fuel and unaffordability of LPG.

Efficiency improvement in LPG stoves has been the subject many researchers for ages and a newer kind of burner called porous burner (PB) is a recent topic of interest [10–17]. The working of PB is based on a new concept of combustion called porous media

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combustion (PMC), wherein the combustion takes place either within or at the surface of a highly conductive and radiative solid porous medium (PM). Radiation is the main mode of heat transfer, while the convection and conduction are improved due to the large surface area and high conductivity of the PM. Unlike this, in a conventional burner (CB), convection becomes the dominant mode of heat transfer for gases having low thermal conductivity and poor radiative properties. Further, the reaction zone in the CB is thin and there is a large temperature gradient. PB has large reaction zone due to the superior thermal properties of the solids, and a strong energy feedback mechanism makes the temperature gradient across the burner uniform [18–20].

In recent times, the research on PMC is gaining momentum, and many practical burners with high efficiency and low emissions are conceptualized. Mujeebu and co-workers [21–24] have updated the progress of the technology through a series of review papers focusing on diverse topics, such as state-of-the-art materials, applications, burner configurations, performance with various gaseous and liquid fuels etc. Among the liquid fuels, kerosene has received wide attentions and many burners having industrial utility are reported [25–32]. The low wattage burner for domestic stoves has however failed to have a wide international attention. There have been a few reports where PM were used as the radiative inserts in the kerosene stoves and they are reported to perform better over their conventional counterparts [33–35]. Complete combustion within the PM is yet to be well explored. This study reports the optimization strategy adapted to arrive at a new configuration of the stove with PB and based on the knowledge of this baseline study, the investigation is further extended [36]. The following section describes the current experimental setup, followed by the results, discussion and conclusion at the end.

2. Methodology

2.1. Experimental setup

In the present work, a conventional kerosene pressure stove was used with some suitable modifications in the burner parts to accommodate a PM within it and to act as a burner. The description of the conventional stove, its burner parts and working can be found in other published reports of the authors [36]. Fig. 1 shows a schematic of the experimental setup.

The major components of this setup are a PB: made of Al_2O_3 and SiC; a casing to house the burner, a vaporizer; two air entry ducts; a fuel tank and an air compressor. Al_2O_3 is used in the form of balls, while SiC is of honeycomb type with a thickness 20 mm, 10 ppi (pores per inch) pore density and 80–85% porosity. The porosities of Al_2O_3 balls are in the range of 35–40%, and the balls have an average diameter of 7 mm. The idea of selecting two different materials with different porosities was in line with findings of the previous researchers where they showed it to be a better stabilization technique of the combustion zone within the PM due to the variation of the optical properties of the materials [18,19].

Al_2O_3 is put below the SiC layer with a wire mesh support and its thickness is so optimized that it radiates the amount of heat that is required for the continuous functioning of the vaporizer. Initially, the vaporizer receives heat from the spirit cup where a little amount of kerosene is burnt, and once the vapor starts burning within the media, the media becomes radiatively participating and then it transfers heat downwards. The fire in the spirit cup is then put off, and the hot vapor comes out of the nozzle and mixes with the surrounding air. A reaction zone is established within the media and on attainment of the steady state, various measurements are made on three different diameter burners, viz., 60 mm, 70 mm and 80 mm.

The parameters that had been measured in this study are air flow rate, air pressure, kerosene flow rate, gas temperatures, and CO and NO_x emissions. Air flow rate was measured by a calibrated rotameter having range of 0–400 liters per minute (lpm), and the air pressure by a dial type pressure gauge having 0–2 bar capacity. Kerosene flow rate was measured by a strain gauge based weighing balance having least count: 1 g and maximum capacity: 30 kg. The details of the temperature and emission measurements are presented in Section 2.2.

2.2. Experimental details

2.2.1. Porous media configurations

Initial experiments were conducted with only SiC (Fig. 2a) as PM, and the performance was evaluated in terms of complete retention of the flame within it. However, having established the fact that the single kind did not suffice the requirement, further experiments were conducted with a combination of Al_2O_3 and SiC with varying thickness. Fig. 2(a)–(d) illustrates the schematic of the various configurations, and their performances are discussed below.

Configuration 1: In this configuration, a single piece of 20 mm thick, 70 mm diameter SiC PM having the pore density of 10 ppi was used as the porous bed, and the behavior of the stove with this combination was observed for varying air flow rates. Repeated measurements showed that at all air flow rates, a short blue flame hovered over the top surface of the PM, and this confirmed the insufficiency in bed thickness to entrain the flame completely. Hence, in the configuration 2 (Fig. 2b), the thickness of the media was increased to 40 mm while the diameter was kept same (70 mm).

Configuration 2: In this configuration (Fig. 2b) with the increased thickness of the PM there was no free-flame at the top of the PM; rather, the PM became red hot as the enthalpy of combustion released in the gas phase heated it up to the incandescence and the combustion completed in the radiant mode. However, the upstream temperature was found significantly while the design is aimed at higher transferrable heat flux. A new configuration was thus tried to avoid the kerosene burning that took place below the porous media due to high upstream temperature.

Configuration 3: In this configuration to see the effect of PM with different porosity, SiC was replaced by a packed bed of three layered 7 mm diameter Al_2O_3 balls with porosity 35–40% enclosed in a 70 mm diameter casing (Fig. 2c), and visual observation indicated a flame below the Al_2O_3 bed. The reason for gases to burn outside the medium was thought to be due to higher pressure drop resulted on account of increased tortuosity of the porous bed made of balls than honeycomb types. Increased thickness of Al_2O_3 bed might have posed difficulty in overcoming the resistance offered to the moving fluid and hence in the next trial, thickness of the Al_2O_3 bed was reduced.

Configuration 4: In this configuration (Fig. 2d), two layers of 7 mm diameter Al_2O_3 balls and a single piece of 70 mm diameter, 10 ppi SiC were used to construct the porous bed. SiC was placed over Al_2O_3 balls. Putting Al_2O_3 at the bottom and SiC at the top was supported by the fact that Al_2O_3 being low conductive was expected to provide minimum upstream heat loss, and SiC to promote more downstream heat in the direction of load. Besides, it has been also been shown that for better radiant performance, it is essential to have the upstream layer with lower porosity and shorter length, and putting Al_2O_3 at bottom satisfies the criteria [37–38].

The burning characteristics with the configuration 4 were found very close to the expected one. No flame was seen above the PM, and fluid motion was undisturbed for a large range (60–180 lpm) of air flow rates. Air flow rate was measured by a calibrated