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Usability of porous burner in kerosene pressure stove: An experimental investigation aided by energy and exergy analyses

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ABSTRACT

Porous media combustion (PMC) is relatively a new concept, and due to its inherent characteristics of high efficiency and low emissions, it has found wide applications in many practical systems like internal combustion engine (IC engine), water heater, LPG (Liquefied Petroleum Gas) stoves, etc. In this study, the concept of PMC has been employed in a kerosene pressure stove, and the usefulness of the media consisting of alumina (Al_2O_3) and silicon carbide (SiC) in terms of efficiency and emissions is investigated. Further, the conditions for optimum efficiency and emission are brought out through a systematic analysis with different burner geometry and exergy calculation. The major highlight of this study is that the highest efficiency of the stove with porous media is found to be ~10% higher than the average thermal efficiencies of the stoves available in the Indian market.

1. Introduction

Kerosene is an important cooking fuel in India, especially, for the middle income urban locale who aspires for clean fuels but cannot afford Liquefied Petroleum Gas (LPG) due to its higher cost, and poor distribution network, in some cases [1,2]. While, in rural areas, biomass still dominates [3], but larger majority uses kerosene as supplementary cooking fuel [4]. There are two kinds of stoves currently available for kerosene to burn: one is wick stove, which relies on capillary transfer of fuel, and the other type is pressure stove with vapor-jet nozzles that aerosolizes the fuel using manual pumping. The use of wick type is more prevalent due to the lower initial cost, however, the pressure type exhibits better thermal performance, with the average thermal efficiency varying between 40 and 45% [5–7]. Inappropriate burner design is the main cause responsible for this lower thermal efficiency in comparison to LPG stoves (~60%) [8]. However, surprisingly, not much effort has been put to improve the performance. In the existing configuration, the maximum reported efficiency is ~55% [9,10]. However, the use of porous media (PM) is found to result in better efficiency through thermal radiation, while the complete concept of kerosene combustion within the porous media is yet to be studied [11–13].

Porous media combustion (PMC) is relatively a new concept where the entire combustion takes place in a radiatively participating, solid porous material having high surface area. Unlike, the conventional burner (CB) where convection is the dominant mode of heat transfer, and the contribution of conduction and radiation are minimal; the flame in a porous burner (PB) is submerged. The use of solid medium promotes better heat transfer from the burned gases to the unburned reactants making the system more efficient than a conventional system that works on free-flame. The PM being highly conductive and radiative, the contribution of conduction and radiation heat transfer in a PB is significant. Radiation occurs as the porous material takes up sensible heat of hot gases and converts it to radiative energy. Besides, high surface area of the porous material results in efficient convective heat transfer between the solid and gases, and this makes the reaction zone to extend with a uniform temperature profile across the burner [14,15]. On the other hand, in CB, the reaction zone is thin, resulting in high NO_x and CO emissions due to the sharp temperature gradient. Fig. 1(a) shows the heat transfer mechanism in a CB and (b) a PB where radiation dominates.

In recent years, PMC has attracted a great deal of attention as it offers several advantages, and the concept has been employed in many practical systems like internal combustion engine (IC engine),

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gas turbine, water heater, etc. [16–18]. Domestic applications are however still limited, but good performances are observed when replacing the CB in LPG stoves [19–25]. In kerosene stove also, the use of PM is found beneficial, especially in improving the emission characteristics. A two-layered PB made of silicon carbide (SiC) and Alumina (Al_2O_3) is found to have good thermal performance, however, in conclusion, authors' expressed the scope for its further improvement through better heat management [26]. The current study is an extension to [26] and it adopts the optimized version of the burner reported with modification in the burner enclosure to minimize the heat loss. The enclosures tested in this study consist of three different configurations, and for each configuration, emission and efficiency measurements at different air and fuel flow are investigated. Further, an exergy analysis is carried out to evaluate the scope for recoverable heat. The formulation used for exergy analysis and a brief description is presented in Section 2 of this paper. In general, the paper is constructed in the following order. First, the experimental setup is described, followed by the methodologies adopted and then the results. Finally, based on the discussion on the results, a suitable conclusion is brought out and presented at the end.

2. Methods and materials

The present experimental setup was constructed in a conventional kerosene pressure stove with suitable modification in the burner parts to support PMC. For familiarity, a schematic of the conventional stove is presented first, followed by the current experimental setup. Fig. 2 (a) illustrates the various components of the stove in general, and (b) details of the burner parts.

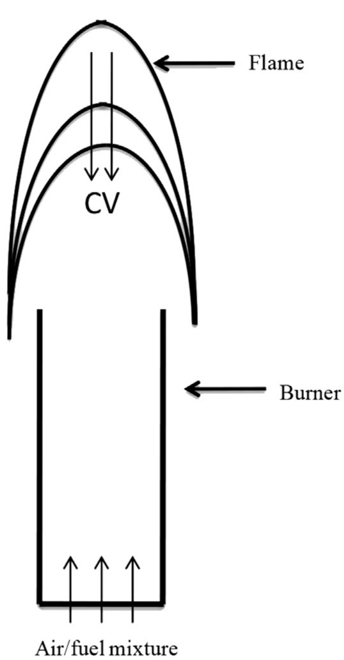
As marked in Fig. 2 (a), the stove consists of a fuel tank/oil container with a hand operated plunger, a spirit cup, a vapor burner, a fuel regulator (pressure release valve), a flame holder (flame ring), a heat shield and a pot holder. The vapor burner consists of one rising, two ascending and two descending tubes, and a flat circular chamber at the top, called vaporizer (Fig. 2b). Vaporizer is an important component of the conventional stove, and it was used in the current configuration too to generate the hot kerosene vapor however the burning is completely submerged within the PM. Fig. 3 shows a schematic of the current 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 [14,28].

Al_2O_3 is put below the SiC layer with a wire mesh support to prevent the downstream heat transfer (it is low emissive and conductive than SiC), while the thickness was optimized to receive sufficient convective heat for 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.

The parameters that had been measured in this study are air flow rate, air pressure, kerosene flow rate, gas and solid temperatures, and CO and NO_x emissions. Air flow rate was measured by a calibrated rotameter having range of 0–400 L 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. Temperatures at various locations were measured using K type thermocouples, and the details of the temperature measurements are provided below.

As seen in Fig. 4, for radial temperature measurements, the burner surface is divided into six equal parts, and the distance between each division is 10 mm. In the plot showing temperature



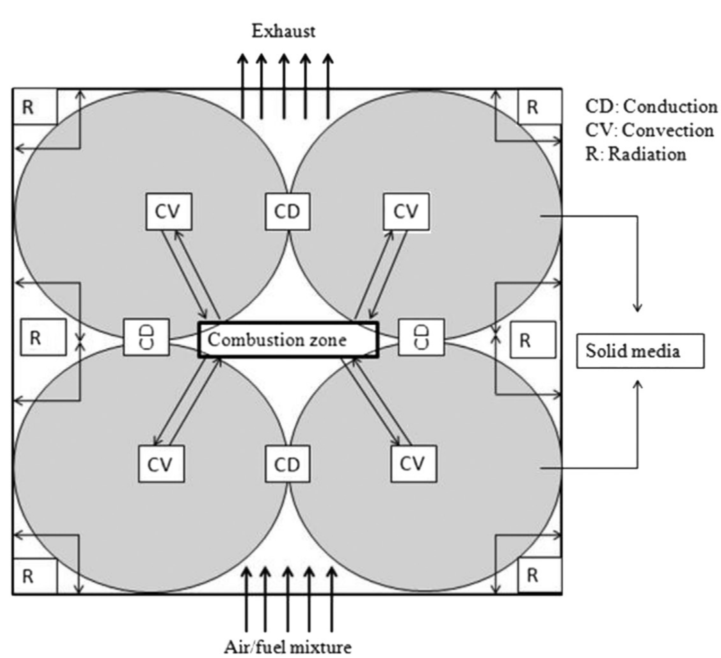


Fig. 1. (a) Convection dominated free-flame in CB (b) radiation dominated PB.