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Emission characteristics and axial flame temperature distribution of producer gas fired premixed burner

P.R. Bhoi[a,*], S.A. Channiwala[b,1]

[a]Department of Mechanical Engineering, L&T-Sargent & Lundy Limited, L&T Energy Centre, Near Chhani Jakat Naka, Baroda 390 002, India
[b]Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Deemed University, Ichchhanath, Surat 395 007, Gujarat, India

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ABSTRACT

This paper presents the emission characteristics and axial flame temperature distribution of producer gas fired premixed burner. The producer gas fired premixed burner of 150 kW capacity was tested on open core throat less down draft gasifier system in the present study. A stable and uniform flame was observed with this burner. An instrumented test set up was developed to evaluate the performance of the burner. The conventional bluff body having blockage ratio of 0.65 was used for flame stabilization. With respect to maximum flame temperature, minimum pressure drop and minimum emissions, a swirl angle of 60° seems to be optimal. The experimental results also showed that the NO_x emissions are inversely proportional to swirl angle and CO emissions are independent of swirl angle. The minimum emission levels of CO and NO_x are observed to be 0.167% and 384 ppm respectively at the swirl angle of 45–60°. The experimental results showed that the maximum axial flame temperature distribution was achieved at A/F ratio of 1.0. The adiabatic flame temperature of 1653 °C was calculated theoretically at A/F ratio of 1.0. Experimental results are in tune with theoretical results. It was also concluded that the CO and UHC emissions decreases with increasing A/F ratio while NO_x emissions decreases on either side of A/F ratio of 1.0.

1. Introduction

During combustion NO_x formation occurs by three fundamentally different mechanisms: thermal NO_x, fuel NO_x and prompt NO_x. Thermal NO_x results from the thermal fixation of molecular nitrogen and oxygen in the combustion air. Its rate of formation is extremely sensitive to local flame temperature and, to a lesser extent, to local oxygen concentrations. Fuel NO_x derives from the oxidation of organically bound nitrogen in fuels such as coal and heavy oil. Its formation rate is strongly affected by the rate of mixing of the fuel and air. Prompt NO_x is produced by formation first of intermediate hydrogen cyanide (HCN) via the reaction of nitrogen radicals and hydrocarbons in the fuel, followed by the oxidation of the HCN to NO.

Characteristics of partially premixed turbulent flames are investigated using a burner design that allows for a variation in the level of premixing between fuel and air. Velocity and mixing characteristics of co annular streams have been measured, which show a region of enhanced turbulence and mixing in the shear region, and indicate that an increased partial premixing with increasing inner tube recess ($\Delta x/D_i$) [1]. The reverse flow carries the combustion products back towards the burner mouth, providing a continuous and stable source of energy for flame ignition, thus dispensing with a need

* *Corresponding author*. Tel.: +91 265 2452830; fax: +91 265 2452928.
E-mail addresses: prb_29677@yahoo.com (P.R. Bhoi), sac_svr@hotmail.com (S.A. Channiwala).
1 Tel.: +91 0261 2227334, +91 9879104416 (mobile); fax: +91 0261 2228394.
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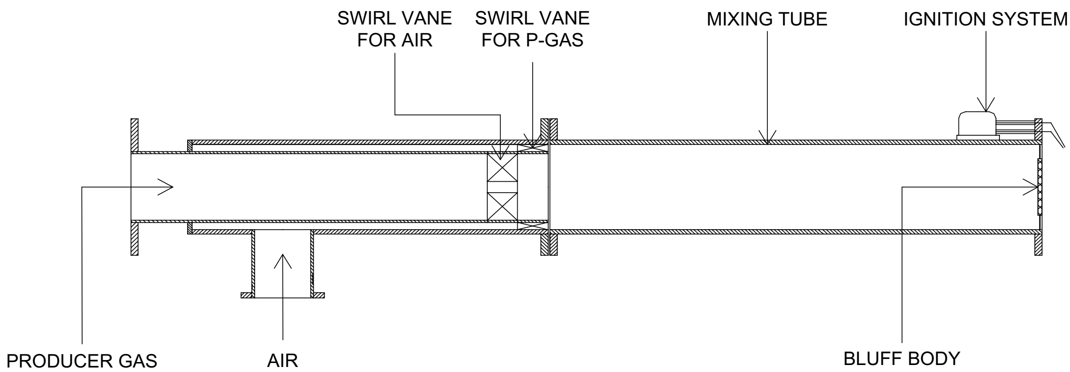

Fig. 1 – Cross sectional view of producer gas fired premixed burner.

for a pilot flame. In addition, swirl extends the curved shear layer and produces extra shear promoting turbulence generation, which enhances mixing and combustion intensity. The major practical benefit is the broadening of the range of the working parameters at which the burner can operate in stable regime. This makes it possible to maximize the flow rate of the co-current primary air and thus to reduce the flame length and formation of nitrogen oxides, without causing the flame to blow out [2]. Swirl can be imposed in various ways. The most common and simplest ways are the tangential inflows and use of guide vanes [3]. Designers of industrial burners and gas turbine combustors use swirl vanes, a central bluff body, or both, to achieve needed flame stability, heat release profiles and the desired flame length. Swirl vanes are typically placed racially outside of a central fuel injectors and the large diameter face of the injector acts as a bluff body. The bluff body and the swirl vanes produce a large-scale recirculation zone, which can improve the fuel-air mixing rates and thereby significantly shorten the flame. The recirculation vortex can increase mixing rates and reduce combustor length, which is desirable. The recirculation vortex can also increase the flame stability limits by a factor of as much as five over those values associated with simple jet flames [4]. Bluff body and swirl stabilized flames are similar in that they represent, in simplest terms, the fundamental interaction between a fuel jet and a surrounding toroidal vortex. The vortex in this case is recirculation vortex, which affects the properties of the flames. It is found that the two most important fundamental parameters that govern both types of flames are (1) the vortex circulation (Γ) and (2) the fuel jet momentum [5]. Nitrogen oxide (NO_x), flame structure and burning velocity for Egyptian natural gas – air flame have been investigated experimentally and computationally for a laminar premixed flame. Experimentally, CO, O_2, and NO_x concentrations as well as the gas temperature were measured throughout a flat flame on a matrix burner at an equivalence ratio, Φ of 0.5, atmospheric pressure and initial temperature of 300 °C [6]. NO_x emissions from all the LSBs were found to be independent of thermal input and were only a function of the equivalence ratio. However, emissions of CO and unburned hydrocarbons were strongly coupled to the combustion chamber size and can be extremely high at low thermal inputs. The emissions from a large vane-LSB were very encouraging. Between 210 and 280 kW and $0.8 < \Phi < 0.9$, NO_x emissions of $<15^\circ$ ppm and CO emissions of $<10^\circ$ ppm were achieved. A low-swirl burner (LSB) developed for laboratory research has been scaled to the thermal input levels of a small industrial burner. The purpose was to demonstrate its viability for commercial and industrial furnaces and boilers [7].

In the combustion of low-grade gas in which the slow velocity of propagation of flame makes it difficult to keep the flame from blowing off the burner, the provision of a strong swirl to air or gas will keep the flame anchored at a much higher velocity [8]. This technique is also an advantageous for rich gas burners in shortening the flame and giving better control.

From the available literature on swirl flow, it is concluded that total pressure requirement of the axial plus tangential entry swirl generator is higher than the other systems and with direct rotation, method only weak swirl can be generated. Hence, commercial burners have tended to adopt the guided vane system, where vanes are so positioned that they deflect the flow direction [8]. Swirl vane was selected to generate swirl to analyze burner performance at different swirl angle. Theoretically, the swirl should be given to the component of greatest volume but, since in the present study the air/gas ratio for producer gas is about unity, it was decided to give opposing swirl to both gas and air to ensure perfect mixing and flame stabilization. Deans et al. showed that nitrogen content of *Prosopis juliflora* of 2–5 cm diameter is 0.56% [9].

A considerable amount of work on emission characteristics of conventional fuel fired burners is reported in the literature. The aim of the present work is to study the effect of swirl angle and A/F ratio on emission characteristics of producer gas fired premixed burner. During the study emissions like oxides of nitrogen (NO_x), carbon monoxide (CO) and unburned hydrocarbon (UHC) from producer gas fired premixed burner was measured at swirl angle ranging from 0° to 75° in step of 15°. For each swirl angle flow rate was varied at the scale of 60, 80, 100, 120 and 131 $Nm^3\,h^{-1}$ and for each flow rates A/F ratio was varied at the scale of 0.8, 0.9, 1.0, 1.2 and 1.5 [10].

2. Experimental methods

2.1. *Burner details*

The cross sectional view of the premixed burner of 125 $Nm^3\,h^{-1}$, i.e., 150 kW is shown in Fig. 1. The present burner is a concentric tube burner where the air is supplied through