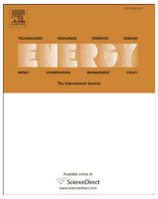
Energy xxx (2014) 1–10

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy



Parametric assessment of a low-swirl burner using the exergy analysis

M.E. Feyz*, S.I. Pishbin, M. Ghazikhani, S.M.R. Modarres Razavi

Department of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad 91775-1111, Iran

ARTICLE INFO

Article history:
Received 1 March 2014
Received in revised form
1 September 2014
Accepted 26 October 2014
Available online xxx

Keywords:
Low swirl burner
Exergy destruction
Premixed combustion
Flame regime

ABSTRACT

The performance of a low-swirl burner (LSB) operating on natural gas is experimentally examined. Due to the unique features of the LSB, many studies have been previously conducted to specify the design limits. However, this study aims to employ the exergy analysis to highlight specific design preferences within the combustion stability ranges. The assessed parameters in this work are fuel–air equivalence ratio, burner recess length, swirl number and thermal input rate. Based on the stream characteristics, two main flame regimes are distinguished. Tracing of entropy generation reveals the significance of fuel exergy destruction in the attached flame regime in comparison with the lifted flame. Also it is declared that for all the examined recess lengths, the irreversibility ratio depicts the same minimum value when the burner is operating at $\Phi = 0.68$. Interestingly, unlike the ordinary diffusion flames, decreasing the swirl number of LSB slightly contributes to the reduction of irreversibility. In the present combustion system on the average basis, only 34.5% of total fuel exergy is destroyed which marks the merits of LSB premixed combustion over swirl-induced diffusion burners.

1. Introduction

During the recent years, strict emission standards in power generation and industrial applications urged the utilization of lean, premixed combustion as a desirable clean combustion technology. This combustion mode exhibits low NO_x and CO emissions without steam injection. Thus, lean-premixed combustion is the basis of the current dry low emissions (DLE) gas turbine combustion systems. When operating on natural gas, CO and NO_x emissions can drop even below 50 and 25 ppm, respectively (corrected to 15% O_2) with the aid of the DLE combustion system [1–3].

Although lean-premixed combustion exhibits several merits in terms of efficiency and emissions, the premixed combustion stability is quite challenging issue due to the flame structure and flame propagation velocity. Swirl-stabilized combustion is widely used as a flame stabilization technique in premixed combustions [4,5]. It promotes the flame stability via creating recirculation zones in the flow field that transport heat and radicals of the products into the reactants which can enhance the flame propagation velocity. Nevertheless, the circulation zones provide the hot spots with high residence time that act as thermal NO_x generators [3].

In order to terminate the drawbacks of high swirl stabilization, researches in the last decade introduced a new technology which reduces the need for recirculation zones in order to stabilize premixed flames. Originally developed at the Lawrence Berkeley National Laboratory, Low Swirl Combustion (LSC) is identified as one of the most promising strategies for premixed combustion stabilization. The low swirl burner (LSB) was initially proposed by Chan et al. [6] and mainly developed by Cheng and others [7–9]. Low-swirl combustion has been commercialized for industrial process heaters and is being employed in gas turbines [10].

The main operating principle of LSB lies within the propagating nature of turbulent premixed flames. In LSBs, the “standing flame front” is accomplished by producing weak swirl which leads to a divergent downstream flow. Original study [11] clarified that unlike the flames stabilized by high amounts of swirl, LSB flames do not rely on flow recirculation for stabilization. The main feature of the LSB is the unique design of swirl injector (Fig. 1), which provides slight swirl flow and facilitates downstream divergent flow where the flame front can be settled.

Several projects have been pursued to adapt LSB to industrial and commercial heaters. Accordingly, the efforts have been made to offer design instructions by which the limits of geometric parameters are defined [12,7].

With recent comprehensive studies on the stability mechanisms and structure of LSB [13], this technology still lacks attempts for further Thermodynamics studies in order to have a better understanding of its nature. In the past two decades, second law of Thermodynamics introduced an effective concept for evaluation of the thermal system deficiencies named “Exergy/Availability” or

---

* Corresponding author. Tel.: +98 915 307 5611; fax: +98 513 7636425.
E-mail addresses: mo.feyz@alumni.um.ac.ir, m.e.feyz@gmail.com (M.E. Feyz).

http://dx.doi.org/10.1016/j.energy.2014.10.074
0360-5442/

Please cite this article in press as: Feyz ME, et al., Parametric assessment of a low-swirl burner using the exergy analysis, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.10.074

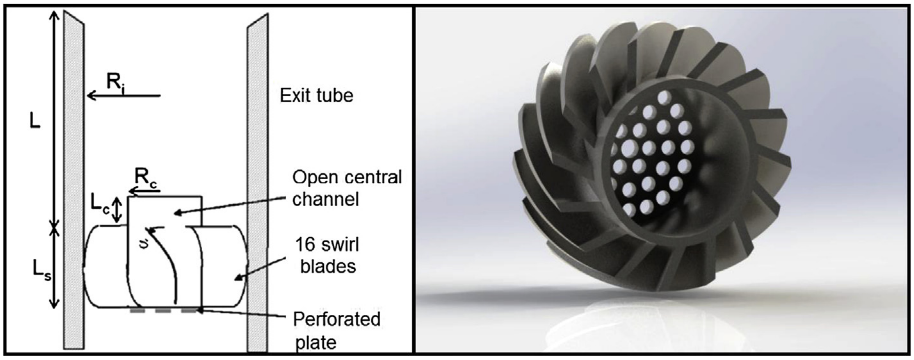


Fig. 1. The schematic diagram of LSB swirl injector; inner radius (R_i), core radius (R_c), recess length (L), swirl length (L_s), channel length (L_c), blade angel (α).

maximum attainable work [14]. In the field of power generation, it is known fact that combustion is always associated with considerable exergy destruction due to the complexity of the process [15].

Generally, the well-known Gouy-Stodola theorem establishes the connection between the lost exergy or irreversibility and the entropy generation [16]. Destruction of fuel chemical exergy in multicomponent reacting flows occurs through different sources of entropy generation in combustion phenomena [15]. Major causes of the entropy generation during combustion are introduced in a study by Dunbar and Lior [17] as chemical reaction, heat transfer due to temperature differences, species mass transport and viscous dissipation. Accordingly, Dunbar and Lior introduced heat transfer as the main source of entropy generation.

The dominant entropy generation mechanism seems to be different in premixed and non-premixed flames. In the work of Nishida et al. [18], the comparison is made between premixed and diffusion flame in order to identify the influence magnitude of each entropy process. Also, the operating parameters such as air–fuel ratio and inlet temperature on the entropy generation in a typical premixed flame are studied. They declared that the chemical reaction is the dominant factor of entropy generation in premixed combustion whereas for diffusion flames, it is heat transfer that comprises a major part of entropy generation. They also stated that for methane combustion, the total entropy generation reduces with increasing the equivalence ratio from 0.7 to 1. This is believed to be caused by the effect of equivalence ratio on the combustion temperature and the reaction zone thickness. The overall exergy analysis also confirms the superiority of stoichiometric combustion on reducing the combustion internal irreversibility [19].

There may be a contrasting point while comparing the observations of Dunbar and Lior [17] with the ones of Nishida et al. [18]. Even though, Dunbar and Lior introduced heat exchange as the dominant entropy generation process in premixed flames, Nishida et al. attributes the major entropy generation to the chemical reactions. The reason within the conclusion of Nishida et al. may rely on their assumption of reaction zone, which keeps the temperature gradients outside of the flame extremely low.

Most of the combustion applications involve turbulent reacting flows. The turbulent flow exhibits entropy generation due to extracting energy from the main stream to maintain its fluctuating nature. Stanciu et al. [20] split the sources of fuel exergy destruction into mean and turbulent parts for heat/mass transfer, chemical and viscous components. It turned out that the turbulent viscous, thermal and diffusion entropy are considerably greater than those generated in the mean motion field. In a practical investigation, Yapici et al. [21] conducted a numerical simulation for turbulent diffusion combustion of CH_4-air in which the inlet air passes through swirl injector and enters as co-flow with fuel. The effects of fuel–air equivalence ratio and swirl number are exclusively examined on the rate of entropy generation in the system. The results imply that increasing the swirl number in particular conditions can restrict the entropy generation. Moreover, the investigation of Makhanlall and Liu [22] showed the importance of entropy generation due to radiation for macro-scale combustion systems, while radiation entropy generation is usually neglected in micro-scale combustions [23].

Utilization of diffusion combustion in industries is widespread due to its simplicity and higher safety. Applying the exergy balance to the common applications of diffusion combustion shows the irreversibility values ranging from 44 to 71% of total fuel exergy. The irreversibility production is lower in gaseous fuels and is higher in liquid and solid fuels, respectively [24–26].

The limited number of exergy studies on the premixed turbulent flames usually has not vastly succeeded in providing a practical insight about the effective irreversibility production sources. The introduction of low swirl combustion, as the leading stability mechanism of the modern gas turbines, necessitates the investigation of this technology via exergy approach. In this study, LSB combustion as a perfect example of propagating turbulent premixed flame is examined experimentally and the effects of design and operational parameters on its exergetic performance are studied. The results of the following investigation can provide a better insight for selection of design parameters in a manner that exergy destruction meets its minimum.

2. Test rig and experimental procedure

The main component of the LSB is a swirl injector which is responsible for flame stability. The swirler supplies the air–fuel mixture through two passages: an outer annular region with swirling vanes and a central channel that permits a fraction of the flow to remain unswirled (Fig. 1). In order to control the flow rate allocated to each passage, a perforated plate is attached to the central channel.

The aerodynamic uniqueness of the LSB swirler provides a highly turbulent flow with slight swirl that can promote the divergent flow downstream of the burner exit and avoids the formation of recirculation zone. The swirl number for LSB practice is defined as:

$$S = \frac{2}{3}\tan\alpha \frac{1 - R^3}{1 - R^2 + \left[m^2\left(\frac{1}{R^2} - 1\right)^2\right]R^2} \qquad (1)$$

where from Fig. 1, α is the angle of 16 vanes mounted around the central channel and $R = R_c/R_i$. The parameter $m = m_c/m_s$ is the ratio

Please cite this article in press as: Feyz ME, et al., Parametric assessment of a low-swirl burner using the exergy analysis, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.10.074