International Journal of Thermal Sciences 109 (2016) 362–373

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

A comparison of the thermal and emission characteristics of co and counter swirl inverse diffusion flames

Ashraf Kotb*, Hany Saad

Department of Mechanical Power Engineering, Faculty of Engineering, Ain Shams University, Cairo, Egypt

ARTICLE INFO

Article history:
Received 7 November 2015
Received in revised form
5 June 2016
Accepted 6 June 2016
Available online 21 June 2016

Keywords:
Inverse diffusion flames
Burners
Co swirl
Counter swirl

ABSTRACT

In this work the influence of co-swirl and counter-swirl burners on the inverse diffusion flame (IDF) characteristics has been studied using liquefied petroleum gas (LPG). The flame shape of the co and counter IDFs were compared. The momentum exchange between the air and fuel jets for swirled IDF burners effects on the produced flame length and stability. The analysis of the results showed that the co-swirling IDF is shorter and more stable than the counter swirling one. The influence of the air jet Reynolds number (Re) consequently the primary equivalence ratio (Φ) on the flame centerline temperature and exhaust gas emissions were examined. The results showed that for the co swirling IDF the centerline temperature profile is higher than the centerline temperature profile of the counter swirl IDF for all values of Φ used in this study. The CO and NOx emissions comparison were made for the two swirled burners. It was found that Re and swirl directions are two key factors for reducing CO emissions. This study indicates that the CO emission is decreased by using co-swirl IDF.

© 2016 Elsevier Masson SAS. All rights reserved.

1. Introduction

Inverse diffusion flame (IDF) is a kind of diffusion flame with an inner air jet being surrounded by outer fuel jets in either confined or unconfined conditions shows no flashback, less soot loading than normal diffusion flame (NDF), low NOx and has a wide range of flammability [1–11]. Glassman [26] investigated the effect of flame temperature, fuel structure and fuel concentration on soot formation in laminar inverse diffusion flames of methane, propene and butane. The IDF configuration was chosen due to its lower soot loading and minimum sample probe clogging as compared to NDF. Kailashnath [27] analyzed numerically the flow field to characterize the effects of exiting fuel–air jets on soot formation in laminar IDF and NDF configurations using methane as a fuel and observed a reduction in the peak soot volume fraction in Inverse diffusion flame as compared to normal diffusion flame.

The IDF can exhibit both the characteristics of partially premixed flame and diffusion flame Sze Lip Kit, [5]. These features make the use of IDF burners feasible and are becoming of growing interest in domestic and industrial applications, but few studies have been performed using the swirled IDF configuration compared to the non-swirled IDFs literature [1–12]. These studies covered the flame structure, its thermal characteristics and the exhaust gas emissions.

Swirled combustion is widely employed in many practical combustion devices such as swirl combustors, cyclone combustors, and swirl burners to control the stability and intensity of combustion and both the size and the shape of the flame. Swirled combustion provides a good momentum exchange ways to stabilize the flame, increase the combustion efficiency, and enhance the heat and mass transfer [13]. Different types of swirl generating devices have been used to impart a swirl to the flow field. In order to achieve enhanced mixing between the fuel and the air and flame stability in a modern gas turbine combustor, double swirl vane were used to supply either co or counter swirling air flows [14,15].

The swirl combustion benefits strongly depend on the formation of a toroidal recirculation zone (RZ) which allows the flame to be stabilized and occurs in a relative low velocity regions where the flame speed and the unburned flow velocity can be matched, assisted by the recirculation of chemical species and heat flow [13–16]. The dimension and shape of the recirculation zone are strongly affecting the combustion process. This is because the RZ carries the active chemical radicals backwards and hot combustion products which supply ignition energy for the incoming reactants [14]. It was noted that the shear stresses produced by the swirl

* Corresponding author.
E-mail addresses: Ashraf_Ibrahim@eng.asu.edu.eg (A. Kotb), Hany.Elsayed@eng.asu.edu.eg (H. Saad).

http://dx.doi.org/10.1016/j.ijthermalsci.2016.06.015
1290-0729/© 2016 Elsevier Masson SAS. All rights reserved.

Nomenclatures

Re_{air}	Air jet Reynolds number, dimensionless, $(\rho_{air} \cdot v_{air} \cdot d_{air})/\mu_{air}$.
Re_{fuel}	Fuel jet Reynolds number, dimensionless, $(\rho_f \cdot v_f \cdot d_f)/\mu_f$.
ρ_{air}	Air Density, kg/m^3.
ρ_{fuel}	Fuel Density, kg/m^3.
μ_{air}	The air dynamic viscosity, Pa.s.
μ_{fuel}	The Fuel dynamic viscosity, Pa.s.
H	Vertical flame distance measured from burner tip, m.
D	The outside air jet diameter, m
G	The momentum flux, kg/m.s
H/D	The flame height to outside air jet diameter ratio
Φ	The equivalence ratio, dimensionless which is the ratio between the stoichiometric air to fuel ratio to the actual air to fuel ratio, $(\Phi = \frac{(A/F)_{stoic}}{(A/F)_{Actual}})$.
Θ	Swirl vane angle, degree.
m^o	The mass flow rate of the fluid, kg/s
S	The swirl number
Q_{air}	The air volume flow rate, L/min
p_∞	Stagnant ambient air pressure away from the jets, Pa
v_{fuel}	The fuel velocity, m/s

occur in both the tangential and axial directions and as swirl in the air flow increases, the combustion becomes more intense and flames are shortened [17,18].

However, many variables such as burner geometry, Reynolds number and equivalence ratio, method of swirl generation, exit nozzle design, swirl number, fuel injection geometry, can be significantly affect the combustion process [13] and [20].

Olivani et al. [14] conducted an experimental investigation on two swirl stabilized non-premixed flames formed at the end of two concentric pipes. A comparison between two flames with co-axial fuel injection and radial fuel injection at the same flow of swirling air and equivalence ratios (Φ), which is given by the stoichiometric A/F ratio normalized by the actual A/F ratio were carried out. The analysis of the results showed that, the fuel injection method plays an important role on mixture formation and flame stability in the primary mixing zone although the mixing process and the flame structure are governed by the swirl motion imparted to the air flow.

Terasaki et al. [21] developed a direct fuel non-premixed injection burner equipped with a double air swirl for the combustors of gas turbine and compared the produced NOx emission of that double air swirl burner with those of conventional air swirl burners. The analysis under non-burning conditions of the air and fuel mixing process showed that in the double swirler burner the mixing of directly injected fuel and air is more rapid than in the conventional burner. The improved mixing in the combustion region is very effective in suppressing NOx formation.

Terasaki stated that the conventional (or single air swirl) burners are commonly used in industrial burners but it was found that the swirl intensity in the single swirl burner decays exponentially in the axial direction. The double air swirler which is composed of two coaxial swirlers is used to control the pollutant emission [21].

Therefore, the work presented in this paper is to investigate the characteristics of co and counter swirling fuel and air jets for IDF. The influence of the air jet flow rate, Q_{air} and consequently the air jet Reynolds number, Re on the flame shape, flame temperature and CO and NOx emissions are investigated while keeping both of the total fuel flow rate and the fuel jets velocity unchanged. The experimental results from comparing the thermal and emission characteristics of a swirling co and counter air and fuel jets for IDF is presented in this paper.

2. Test rig and experimental procedure

The objective of the presented two burner designs in this study is to enhance the fuel and air mixing through high entrainment of fuel jet momentum air.

Fig. 1 shows the construction of the swirled IDF burners used in this study. Two sets of IDF burners were used. One is co-swirl for both air and fuel jets and the other is counter swirl. Each set consists of IDF burners that have the same pitch circle radii, the number of the fuel ports which equal 12 fuel ports (2 mm each). The outlet air flow swirl angle is fixed using helical gear with angle 15°. The outside and inside diameter of the gear is 15 and 8 mm respectively. While the fuel flow swirl angle (which kept constant at 30°) is changed to be in the same direction as the air flow direction to be co swirl burner or in opposite direction to form counter swirl burner as shown in Fig. 1.

Gaseous fuel LPG, (analysis carried out by Misr Petroleum 60% C_4H_{10} and 40% C_3H_8 by volume) was fed into the gas burner from a bottle at a gauge pressure of (5000 $\pm$ 100) Pa, after passing through a pressure regulator valve fitted in the LPG bottle outlet. This regulator is used to keep the outlet fuel pressure at 3000 Pa. The feeding fuel line is equipped with a calibrated pressure gauge, 6000 Pa maximum pressure and placed after the pressure regulator valve which used to control the fuel flow rate. The fuel delivery line is connected to a calibrated fuel stainless steel frame Omega rotameter with flow rates up to 6 L/min used to measure the fuel flow rate. Air is forced into the swirled IDF burner from a 1000 L size compressor tank. The air mass flow rate is measured using a calibrated Omega rotameter with flow rates up to 120 L/min. The supply air pressure is controlled and kept constant during all experiments. The gaseous fuel supplied to the burner issues from it through a number of equal diameter inclined fuel ports with a swirl angle 30° as shown in Fig. 1. The fuel ports of the two burners are equally spaced around the air port on the same pitch circle. The inlet temperature of the air and the fuel are measured by two pairs of calibrated thermocouples type J which is placed in the inlet section of the IDF burner.

The appearance of the IDF under different operating conditions was obtained using a digital camera with 16 Mega pixels, 50 frames per second imaging rate. The position of the used camera relative to the flame position was the same during all shots in order to keep the height and size scales the same for all shots. The temperature of the flame was measured using type S (Pt-Pt Rh 10%) thermocouples. The type S thermocouple wire diameter is 0.1 mm. The diameter of the ceramic tube in which the thermocouple wires were enclosed is 3 mm and its bead size is almost 200 μm to minimize flame disturbance during measurements. A data acquisition system whose sampling rate is 30 scans per second is connected with thermocouple extension wires. The thermocouples signals are recorded by using a universal serial bus-4719 transmitter with 16-bit resolution and 4–20 mA accuracy. The data acquisition system provided with cold junction compensation. During the experiments, the thermocouple was aligned with the burner such that it can be moved to obtain the flame temperature distribution in axial direction. The thermocouple bead was aligned co-axially with the air jet centerline each time before measurement. The temperatures

Download English Version:

https://daneshyari.com/en/article/668949

Download Persian Version:

https://daneshyari.com/article/668949

Daneshyari.com