Applied Energy 91 (2012) 82–89

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Pollutant emission and noise radiation from open and impinging inverse diffusion flames

Y.S. Choy *, H.S. Zhen, C.W. Leung, H.B. Li

Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong, China

ARTICLE INFO

Article history:
Received 11 January 2011
Received in revised form 1 September 2011
Accepted 8 September 2011
Available online 5 October 2011

Keywords:
Inverse diffusion flame
LPG/air combustion
Emission index
Combustion noise

ABSTRACT

This paper reports an experimental investigation of the pollutant emission and noise radiation characteristics of both open and impinging inverse diffusion flames (IDFs), produced by five burners of different air port diameter (d_{air} = 5, 6 and 6.84 mm) and air-to-fuel spacing (S = 8, 11.5 and 15 mm). The effects of d_{air}, S, overall equivalence ratio Φ and nozzle-to-plate spacing H on the pollutant emissions of CO and NO_x and the noise radiation are examined.

The results show that at fixed air flow rate, a smaller d_{air} curtails NO_x emission but augments noise radiation, indicative of a role played by turbulence, which tends to decrease pollutant emission and increase noise radiation. A larger S reduces NO_x emission but increases noise radiation, indicating that different flame zones may be responsible for pollutant emission and noise radiation. When the IDF is under stoichiometric Φ = 1.6, both the NO_x emission and noise radiation are highest, as a result of maximum heat release rate. A comparison of $EINO_x$ for the open and impinging IDFs shows that the impinging IDFs emit more NO_x probably due to the absence of NO reburning. The impinging IDFs have higher noise radiation than the corresponding open IDFs. A higher level of noise radiation from the impinging IDFs is observed as the target plate is brought closer to the burner.

1. Introduction

Inverse diffusion flame (IDF) is a kind of flame with an inner air jet surrounded by an outer fuel jet. The advantages of inverse diffusion flames (IDFs) and their potential domestic and industrial applications have motivated a number of studies [1–9], ranging from the investigation of flow and flame structure [1,5–9], flame stability [2,9], flame temperature and pollutant emissions [3–9] of open IDFs, to the heat transfer characteristics [7–9] of impinging IDFs, because IDFs are able to exploit the advantages of both diffusion and premixed flames, in regard to operational safety, acceptable pollutant emission levels, and flame stability [5–9].

Most of the previous studies were carried out to study open IDFs in confined [1,2] and unconfined conditions [3–6]. Wu and Essenhigh [1] mapped out six different types of IDFs according to their different flame appearance and stability. Clausing et al. [2] examined the stability characteristics of IDFs and a modified Peclet number was applied to correlate the IDF stability data. Wentzell [3] measured the flame temperature and flame length at different air and fuel jet diameters. He discovered that for the IDF at high Reynolds number, diffusion is not the main transport mechanism while turbulent transport of the oxidizer and fuel streams governs air/fuel mixing. William et al. [4] reported both the flame temperature and in-flame NO concentration. It was shown that most of the IDF-attributable NO is generated at the tip of the flame. Sze et al. [5] developed a novel IDF with a central air port surrounded by a number of individual fuel ports and observed better mixing of air and fuel in this IDF than the traditional co-axial IDF. Later, Dong et al. [6] performed a detailed investigation of such IDFs with individual fuel ports in terms of their flow pattern, flame structure and pollutant emission characteristics.

It is not until recently that impinging IDFs to a flat surface have been investigated. Sze et al. [7] studied the heat transfer characteristics of an impinging IDF under different combinations of three parameters of air flow rate, fuel flow rate and nozzle-to-plate spacing. They revealed that the heat transfer from the impinging flame to the surface is greatly affected by these three parameters. A comprehensive study of the flame structure, static wall pressure, and heat transfer characteristics of the IDF with individual fuel ports was presented by Dong et al. [8]. Later, a similar study of a swirling IDF was conducted by Zhen et al. [9].

Despite a growing body of literature on the open and impinging IDFs, it is found that the pollutant emissions of impinging IDFs have been less explored. Moreover, noise radiation from impinging IDFs has been unexplored. For industrial usage of a flame, the noise radiation from the flame may deteriorate human health and communications in the working area. Therefore, considerable studies have been carried out on the spectral characteristics of sound emitted by premixed and non-premixed flames [10–12], and different

* Corresponding author. Fax: +852 23654703.
E-mail address: mmyschoy@polyu.edu.hk (Y.S. Choy).

0306-2619/$ - see front matter Crown Copyright © 2011 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2011.09.013

Nomenclature

d_{air}	diameter of air port, mm	Φ	overall equivalence ratio
d_{fuel}	diameter of fuel port, mm	H	nozzle-to-plate spacing, mm
L	length of air or fuel port, mm	f	frequency, Hz
S	air-to-fuel spacing, mm		
Re	air jet Reynolds number		

noise generation mechanisms from various modes of combustion have been developed theoretically [13]. However, there is no previous research of the noise radiation characteristics of IDFs under either open or impinging conditions. Further, the relationship between the pollutant emission and noise radiation from IDFs has not been studied. Thus, the objective of this study is to investigate the pollutant emission and noise radiation characteristics of a particular IDF with individual fuel ports under both open and impinging conditions. This paper reports the preliminary results, including the effects of the burner configuration (air port diameter d_{air} and air-to-fuel spacing S), overall equivalence ratio (Φ) and nozzle-to-plate spacing (H) on the pollutant emission and noise radiation of the IDF. The work also aims to provide some insight into the relationship between the pollutant emission and noise radiation behaviors of the IDF.

2. Experimental apparatus and techniques

The basic configuration of the burner for generating IDFs in this study is shown in Fig. 1. The burner is made of brass and consists of a central air port of diameter d_{air} and twelve fuel ports circumferentially arranged around the air port with an air-to-fuel spacing S between the centers of the air and fuel ports. The length of each port is sufficiently long ($L/d_{air} > 20$, $L/d_{fuel} > 20$), thus fully developed jet flows are formed at the port exit. The fuel used is standard liquefied petroleum gas (LPG) available in Hong Kong, containing 70% butane and 30% propane. Fig. 1 also shows the experimental set-up for measuring pollutant emission from the open and impinging IDFs. The burner was placed on a 3-D positioner so that it could be moved to any position in space. Both the air and fuel flow rates were controlled and monitored by calibrated flowmeters. For open IDFs, a stainless steel hood of 15 cm base-diameter and 15 cm in height was placed over the flame tip to collect flue gases. For impinging IDFs, a copper plate with a surface area of $2 \times 2\ m^2$ and 5 mm thick was horizontally mounted over the flame. The plate was evenly cooled on the backside by a cooling water jacket and the temperature of cooling water was maintained at 38 °C by a thermostat. At the center of the copper plate, a small hole of 1 mm diameter was drilled and by adjusting the 3-D positioner, the flues gases at a distance of 50 mm away from the stagnation point of the impinging flame were sampled. For both cases of open and impinging IDFs, water vapor was condensed and removed before the sampled flue gases entered the NO/NO_x (California Instruments Corporation, Model 400 CLD) and CO/CO_2 (California Instruments Corporation, Model 300) analyzers for simultaneous measurement of the volumetric concentrations of CO_2 and pollutants of NO_x and CO. For all the measurements, the CO concentration was found to be two orders of magnitude lower than that of CO_2. Hence, the following equation was used to calculate the emission index of CO and NO_x.

$$EI_J = \frac{3.7\{J\}MW_J 1000}{\{CO_2\}MW_{C_{3.7}H_{9.4}}} \quad (1)$$

where the bracket indicates volumetric concentration, MW is molecular weight and J symbolizes pollutant species. Note that the molecular weight of NO_2 was used for $EINO_x$ calculation. An uncertainty analysis was carried out with the method reported by

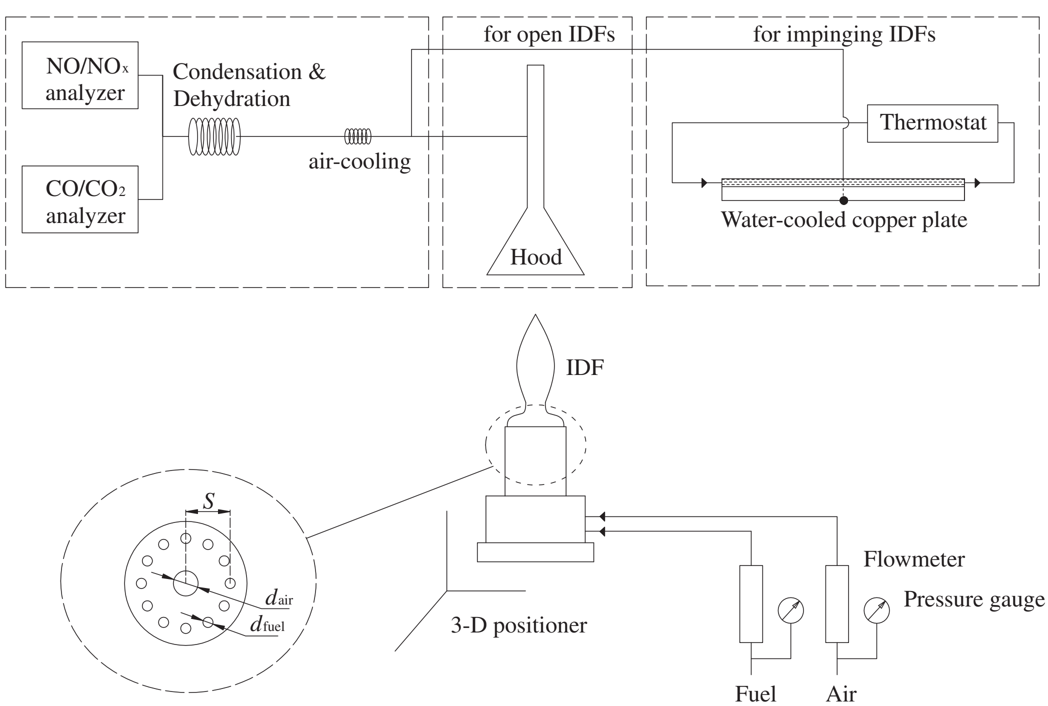

Fig. 1. Burner and experimental set-up.