Fuel 124 (2014) 141–150

Contents lists available at ScienceDirect

Fuel

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

Design modification of the air diffuser in the burners of a fuel oil power plant. Part II: Interaction with the liquid spray

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HIGHLIGHTS

- The design of the current diffusers in a fuel oil power plant has been modified.
- Interaction between primary air and liquid spray has been analyzed.
- Droplet velocity field has been measured using SPIV.
- Horizontal toroidal structures of the flows have been found at exit of the burner.
- Optimized design increases swirl and decreases axial velocity.

ARTICLE INFO

Article history:
Received 1 October 2013
Received in revised form 23 January 2014
Accepted 29 January 2014
Available online 11 February 2014

Keywords:
Swirling flows
Diffusers
SPIV
Heavy fuel oil

ABSTRACT

Standard fuel oil industrial burners normally include an air diffuser to condition the air flow so that it satisfies the requirements for combustion. Primary air has to mix efficiently with the fuel droplets, confining them in a defined volume and ensuring their complete consumption in a determinate residence time. A widely used technique to achieve these objectives is to induce a swirling motion to the co-flowing air to create a recirculation zone. This work analyzes how a modification in the original design of the diffuser currently in use in a Cuban power plant, already studied in the first part of this investigation and consisting in the addition of a finned swirler ring, modifies the interaction of the air stream with the liquid spray. To this end, experiments were performed in a wind tunnel with a 1/3 scaled down burner model. To simulate the burner nozzle, a commercial air-assisted hollow cone one was used. Droplet Sauter mean diameter (*SMD*) was measured with laser diffractometry, and the three components of the average velocity of the droplets without and with co-flowing air were calculated with stereo particle image velocimetry (SPIV) in a complete diametric plane, divided in seventy 35 mm × 26.5 mm zones. The analysis of the results indicates that the presence of the swirler ring improves the performance, enhancing the rotation of the air flow, reducing the axial velocity and recirculating a fraction of the droplets closer to the exit nozzle.

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1. Introduction

The vast majority of industrial fuel oil burners, in particular those installed in power plants, are formed of a nozzle to atomize the fuel, and a diffuser to condition the primary air coflow. Normally, the nozzles are "Y"-type twin-fluid so that they can be operated at moderate pressures, (typically 5–6 bar) using steam as the atomizing gas. The diffuser is responsible to condition the primary air flow required for combustion, enhancing the mixing and dispersion of the droplets, regulating their residence time in the reaction zone in order to ensure a complete combustion, and confining the flame in a determinate volume. To perform all these tasks in the best possible way, the diffuser has to be designed taking into account the fuel spray characteristics.

Due to economic restrictions, light fuel oils previously used in the boilers of most Cuban power plants have been progressively replaced by native crude petroleum that is formed by a mixture of several compounds, each with different boiling temperatures [1]. In Cuban crude petroleum the values of some of the parameters with major influence on the atomization and combustion processes such as the kinematic viscosity and the asphaltene contents [2] are out of the ranges recommended by boiler manufacturers. Both evaporation and low temperature oxidation reactions [3] are

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http://dx.doi.org/10.1016/j.fuel.2014.01.094
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decreased so that reducing the size of the droplets and increasing their residence time in the flame reaction zone are required to maintain the combustion efficiency. In consequence, to operate the plants with these untreated fuels, burners (nozzle and diffuser) have to be modified. To achieve a correct atomization, our research group has designed new nozzles specifically conceived for high viscosity fluids [4–6]. A reduction in the mean droplet diameter was confirmed even for highly viscous fuels reaching values as low as 40–50 μm. However, to complete the study, the diffuser performance has also to be revised, in order to confine the droplets and, if possible, to increase the residence time in the high temperature reaction zone.

A widely used technique to stabilize the flame and to limit its length is to surround the fuel spray by a swirling co-flow [7–9] that creates a recirculation zone (RZ) to confine the droplets. In the particular case of power plant combustion chambers, this configuration is convenient to prevent the flame from reaching the opposite combustor wall, avoiding potential damage to the heat exchanger tubes. At the same time, physical contact of the flame with the comparatively cold walls of the combustion chamber usually produces a temperature reduction in the reaction zone that can contribute to flame extinction. This situation is especially critical in rich or lean mixtures where temperatures are lower. In these cases, reaction times become larger than mixing times and local flame extinction results in the formation of poly-cyclic aromatic hydrocarbons (PAH) that finally leads to soot emissions [10].

The objective of this work is to analyze the effect of the addition of an outer finned swirler ring to the diffuser currently in use in a Cuban power plant (see Fig. 1 in [2]). This swirler ring generates rotation in the combustion air in the same direction of that imposed by the swirler plate. This is a modification that can be implemented easily and in an economical way, because it does not require altering the piping already installed in the power plants. For similar reasons, this reasonably moderate variation has been studied so that the flows are not drastically changed in any way that could require further modifications in the combustion chambers. Fig. 1 shows a burner with an old diffuser without swirler ring and a similar burner with the new design already in place.

In a first part of this research the air flow generated with the original and the modified diffuser configurations was studied [2]. In this second part, the research focuses on the air flow interaction with the liquid spray generated by the burner nozzle. Again, experiments have been performed in a wind tunnel with a 1/3 scaled down burner model, measuring the three-component velocity field of the spray droplets. Results obtained with and without the outer swirler ring are compared. The flow has been studied in non-reacting conditions, using air and water as the working fluids. Obviously, combustion will affect the interaction between the fuel spray exiting from the nozzle and the diffuser air flow due to the combined effect of a reduction in density, and an increase in velocity [11,12]. Droplet evaporation will also be influential, as droplet diameter will be reducing with time. However, if the inclusion of the outer swirler ring in the present experiments enhances the swirl and the recirculation zones, promotes the mixing and extends the droplet residence time, it should also be beneficial in the real situation. This extrapolation has already been verified for nozzle designs that were analyzed in our laboratories in water–air experiments and later tested in a real power plant.

2. Experimental set up

Most details of the experimental facility used in this work have been already described in [2]. Some of them will be included here again for consistency. The 1/3 scaled down burner model was attached with a flanged connector to the exit of a wind tunnel, as depicted in Figs. 2 and 3 in [2]. The air flow was generated by a 7.5 kW centrifugal blower fan (Casals AA 70 T2 7.5) whose rotation speed was controlled with a frequency regulator. The flow rate was adjusted to 1200 m^3/h.

The model of the original burner consists of a conical swirler plate (cone angle of 30° with respect to the horizontal) with a diameter of 150 mm, with the nozzle located in its apex. The cone has 12 slanted vanes with a total open area of 630 mm^2 that impose a clockwise rotation and is mounted in a 195 mm inner diameter piece of pipe. In this way, there is a gap of 22.5 mm between the swirler plate and the inner pipe wall. In this work, the addition of a finned outer swirler ring fitted in this gap to also induce a clockwise rotation to the air flow was analyzed. This element is formed by 18 rectangular blades with a dimension of 20 mm × 40 mm and a width of 3 mm, which are tilted 20° with respect to the vertical. Presently, this new diffuser design is not permanently installed in any power plant. Some preliminary field tests were initiated in a real facility, but due to financial problems they were stopped before their conclusion. If the conclusions of these studies indicate that the outer swirler ring improves the fuel oil combustion, its addition would be relatively simple, just welding the fins, without the need to actuate on the main swirler plate or the burner nozzle. A view of the different parts of the downscaled diffuser is presented in Fig. 2.

The Reynolds number, *Re*, of the air flow before the swirler plate, taking as diameter the 195 mm of the pipe is 1.43×10^5. Considering only the area that remains open to the flow once the diffuser is installed, and calculating an equivalent diameter, the Re value increases to 2.02×10^5.

The nozzle initially installed in the power plant was a "Y" type one with 8 exit holes. In previous works [4–6], the nozzle had also been redesigned, replacing the eight Y ducts by a single mixing chamber, while maintaining the external dimensions. A model of the new nozzle, downscaled satisfying geometrical similitude was manufactured, but the resulting spray did not respond to the scaling criteria: spray angle larger than 90°, flow rates over 300 l/h and droplet Sauter mean diameter (*SMD*) below 20 μm. Using this scaled nozzle, the diffuser air co-flow was not capable of confining the droplets in the spray, in contrast with some preliminary tests performed in the power plant where a reasonable confinement had been achieved. After discarding this option, a commercial

Fig. 1. Real burner with an old diffuser without swirler ring and a similar burner with the new design already in place.

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