Experimental Thermal and Fluid Science 99 (2018) 211–218

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Experimental study of diesel fuel atomization performance of air blast atomizer

H.M. Gad*, I.A. Ibrahim, M.E. Abdel-baky, A.K. Abd El-samed, T.M. Farag

Mechanical Power Engineering Department, Faculty of Engineering, Port Said University, Port-Said, Egypt

ARTICLE INFO

Keywords:
Airblast atomizer
PIV
Spray
Atomization

ABSTRACT

In this study, the spray performance of airblast atomizer is experimentally investigated under different operating conditions and different internal atomizer geometry. The used airblast atomizer is designed so that, the atomizing air is issuing from the atomizer with swirling motion. The swirling of the air blast is formed as passing the through a vane swirler fixed around the fuel exit. The investigated parameters are: the atomizing air swirler angle, the atomizing air to fuel mass ratio and the distance between the fuel nozzle exit and the atomizing air exit orifice. Four air swirlers with vane angels: 0°, 15°, 30°, and 45° are used. The distance between the fuel nozzle exit and the atomizing air exit orifice is changed from 0 to 3 mm. The fuel spray characteristics are studied then represented as spray shape and spray droplets intensities which are photographed using digital camera of particle image velocimetry (PIV). The radial spray concentrations are measured by using the tubes patternator technique. The spray cone angle is also measured under different operating conditions. The fuel used in this study is commercial diesel oil. The results indicate that, the spray cone angle increases with increasing the atomizing air to fuel mass ratio and also by increasing the atomizing air swirler angle while it decreases by increasing the distance between the fuel nozzle exit and the atomizing air exit orifice. The results also show, the spray concentration have its maximum values at the center line and decreases by moving radially outward. The spray intensities are clearly radially decreased. The spray cone angle is increased by about 142% (17°), 120% (18°), 123% (21°) and 120% (24°) for atomizing air swirler angle of 0°, 15°, 30° and 45°, respectively at constant value of the distance between the fuel nozzle exit and the atomizing air exit orifice ratio of zero.

1. Introduction

The atomization of liquid fuel from liquid bulk to small droplets with different diameters and numbers is an important process in combustion and industrial systems. By atomizing, droplets formed and its surface area is increased which increases the rate of evaporation and hence decreases the time required for evaporation. For liquid-fuel spray combustion applications such as liquid fuel injectors in gas turbines, industrial furnaces, rocket engines, etc., the good mixing between fuel and oxidant is an important process which enhances the chemical reaction rate to reach the complete combustion [1,2]. In order to achieve the favorable combustion system requirements such as the higher combustion efficiency, lower exhaust emission, wider stability limits and uniform temperature distribution, the study of the spray characteristics of fuel atomizers is found to be very important [3,4].

Twin fluid atomizers such as airblast atomizer can be used instead of the single fluid atomizers which require high pressures [5]. Airblast atomizer is a twin fluid atomizer where the air is used as a gas phase fluid and water or liquid fuel is used as a liquid phase fluid. The principle of operation of the airblast atomizer is concerned of the relative velocity between the air stream and the liquid fuel velocity, where the air has a relatively high velocity and the liquid fuel has low velocity [3–8]. The airblast atomizers have many clearly advantages over the other liquid fuel atomizers, especially in their applications in the gas turbine engines such as low fuel pressure and finer spray, creating good mixing between fuel and air which results in low soot formation [9–12].

The operating condition for the twin fluid atomizers such as atomizing air to liquid mass ratio is an important parameter for the investigation of the air blast atomizers. The effect of the air to liquid mass ratio was studied over a range of 0.2 to 2.7 [5]. Also, Rizk [13] studied the effects of the air velocity and the liquid fuel properties on the spray characteristics using an airblast atomizer, where it is found that, the spray distribution became more uniform and the droplets sizes became finer by increasing the air velocity or decreasing the liquid flow rate. The spray characteristics were investigated under different pressures of air and liquid by Rui Ma et al. [3]. Their results showed that, the liquid

---

* Corresponding author.
E-mail address: hamada_zzdd@eng.psu.edu.eg (H.M. Gad).

https://doi.org/10.1016/j.expthermflusci.2018.07.006
Received 23 October 2017; Received in revised form 1 July 2018; Accepted 10 July 2018
0894-1777/

Nomenclature

ALR	atomizing air to liquid fuel mass ratio
AASA	atomizing air swirler angle, degree
L	nozzle-Orifice distance, mm
D	fuel nozzle diameter, mm
L/D	nozzle-orifice distance to fuel nozzle diameter ratio
D_o	atomizing air exit orifice diameter, mm
$\dot{m}_f$	fuel mass flow rate, g/s
$\dot{m}_{a.a}$	atomizing air mass flow rate, g/s
PIV	Particle Image Velocimetry

pressure has negligible effect on the spray angle while the air pressure has a clear effect on the spray angle.

In addition to the operating conditions of the airblast atomizer, the atomizer design is found to have a significant effect on the spray characteristics. Many researchers investigated experimentally and numerically the effect of the airblast atomizer design on the spray and combustion characteristics [12,14–18]. Feras et al. [14] and Marek [15] studied the design of the airblast atomizer combined with pressure swirl nozzle while Hai et al. [16] investigated the effect of liquid jet diameter on the twin-fluid atomizer. The internal and external mixing between the atomizing air and liquid fuel in the air blast atomizers were also studied [17,18].

From the previous review, the importance of studying the airblast atomizers for different operating conditions and atomizer geometries is clearly observed. For combustion application, it is noticed that, the spray cone angle is very important in increasing the mixing rate of fuel droplets with combustion air. Therefore in this study, the atomizing air is swirled around the fuel exit in order to increase the spray cone. Preliminary experimental runs have been done in order to choose the proper operating and design conditions. The spray performance of the airblast atomizer is investigated for the following different operating conditions: ALR is taken as 1, 2, 3, 4, 5, 6, 7 and 8, the distance between the liquid fuel nozzle exit and the atomizing air exit orifice is changed from 0 to 3 mm for the atomizing air swirler angles (AASA) of 0°, 15°, 30°, and 45°. The spray shape, spray droplets intensities, spray concentrations and spray cone angle are studied for the above different operating conditions using commercial diesel oil as atomization liquid with the properties shown in Table 1.

2. Experimental test rig

In order to investigate the effects of changing ALR, AASA and L/D on the spray performance, an experimental test rig consisting of atomizing air line, fuel line, airblast atomizer and the spray chamber is constructed. The layout of the experimental test rig is shown in Fig. 1. The atomizing air line comprises of the air compressor (1), air control valve (2), pressure gauge (3), air rotameter (4), and control valve (5). The compressed air, which is operated at a pressure about 6 bar, passes through the control valve and pressure gauge then passes through the air rotameter which is used to indicate the mass flow rate of the atomizing air, then it passes through the control valve which controls the mass flow rate of the atomizing air. Finally, the atomizing air passes through the airblast atomizer and discharges into the spray chamber.

The fuel line contains the fuel tank (11) which is located at vertical stands at height of about 6 m, fuel filter (8), U-tube manometer (18), fuel orifice (19), fuel valve (15) and control valve (20). The fuel flows by gravity from the elevated tank to the control valve by static pressure head, then the fuel passes through the fuel filter and the fuel orifice, which is calibrated to determine the fuel mass flow rate. Then the fuel passes through the control valve, which is used to control the mass flow rate of fuel before entering the airblast atomizer. The fuel enters the air blast atomizer from the fuel port and flows axially through the internal fuel tube to pass through the fuel nozzle. The atomizing air enters the airblast atomizer through the atomizing air port and passes through the atomizing air swirler which possesses the air a swirling motion before exiting from the orifice. The air blast atomizer is centrally located in the spray chamber (22). The spray is collected in the lower fuel tank (6) and returned back to the elevated fuel tank by fuel pump. The dimensions and construction of the used airblast atomizer are shown in Fig. 2. The distance between the fuel nozzle exit and the atomizing air orifice (L) is changed by the adjusting thread on the internal fuel tube to be 0, 1, 2, and 3 mm. At a distance of 0 mm the fuel nozzle and the atomizing air orifice are at the same exit plane. The fuel nozzle diameter (D) is taken constant as 1.0 mm and the ratio between the distance (L) and the fuel nozzle diameter (D) is (L/D) is taken as 0, 1, 2 and 3. A detail dimensions and a photograph of the atomizing air swirler are shown in Fig. 3(a) and (b), respectively. There are four atomizing air swirlers with different angles (AASA) of 0°, 15°, 30° and 45°.

Fine spray droplets are generated inside the vertical cubic spray chamber which is of dimensions $50 \times 50\,\text{cm}^2$ with height of 70 cm as shown in Fig. 4. One side of the spray chamber is transparent to allow observation and taking images for the spray by the digital camera and the Particle Image Velocimetry (PIV). The transparent side is movable to allow setting the spray patternator in a specified position inside the spray chamber in order to investigate the spray concentration and distribution pattern. The spray patternator consists of 21 tubes located at a specified vertical distance of 20 cm from the atomizer exit which is selected after conducting many preliminary experiments. The spray pattern of a fuel atomizer is a key factor in the mixing of the fuel with the air. The arrangement of the measuring system, using Dantec Dynamics dual camera PIV is illustrated in Fig. 5. This system utilizes two Charge-Coupled Device (CCD) cameras and Neodymium-doped Yttrium Aluminum Garnet (Nd-YAG) laser.

3. Experimental results and discussion

In this section, a series of experimental runs are carried out to investigate the effect of changing, in turn, ALR, AASA and L/D on the spray characteristics which includes spray shape, spray cone angle, spray droplets intensities and radial spray concentration.

3.1. Effect of changing the air-liquid ratio (ALR)

As previously indicated, the ALR is taken as 1, 2, 3, 4, 5, 6, 7 and 8. The ALR is varied by changing the atomizing air mass flow rate by keeping the fuel mass flow rate constant of 1 g/s. In the following sections, the effects of changing the ALR on spray droplets intensities, spray shape, spray cone angle and spray concentration will be investigated keeping AASA and L/D constants.

(i) Spray droplets intensities

The spray droplets intensity is defined as the number of droplets at a specified defined area in the spray cone. In the present study, the spray

Table 1
The diesel fuel properties.

Fuel property		Units
Kinematic viscosity at 40 °C	1.3–4.1	mm^2/s
Density	850	kg/m^3
Carbon	87	wt%
Hydrogen	13	wt%
Cetane Number	40–55	