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Diesel Fuel Spray Momentum Distribution for Air Blast Atomizer

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Abstract: *In the present work, the spray momentum of airblast atomizer is determined under different operating and atomizer geometrical conditions. The airblast atomizer the atomizing air entering with a swirling motion given by a centrally atomizing air swirler. Four different atomizing air swirlers with atomizing air swirler angle (AASA) of 0º, 15º, 30º, and 45º were used. The axial distance between the fuel nozzle exit and atomizing air exit orifice is investigated and taken as 0, 1, 2 and 3 mm to give the ratio of distance between the fuel nozzle exit and the atomizing air exit orifice to fuel nozzle diameter (l/D) of 0, 1, 2, and 3, respectively (taking the fuel nozzle diameter as 1 mm). Also the atomizing air to liquid ratio was studied and changed from 2 to 8. A modified air blast atomizer was designed and constructed to study the different parameters. An experimental test ring with the required measuring instruments for the study was constructed. The radial spray concentrations are measured to determine the spray momentum distribution using the commercial diesel oil as atomized fluid. From the experimental results, by increasing of ALR the peak value of the spray momentum decreased and shifted radially outward for all AASA and l/D. For shorter but wider combustion chambers, it is recommended to use higher AASA and smaller l/D and vise versa.*

Keywords*: Airblast atomizer, spray concentration, atomizing air swirling, spray momentum.*

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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
$D_{a.a}$	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
ρ	Fuel density
u	Spray velocity
A	Patternator tube cross sectional area
M	Spray momentum
$\delta\dot{Q}$	Volume flow rate at each tube, cm^3/s
$\dot{m}$	Fuel mass flow rate at each tube, g/s

I. Introduction

The liquid fuel atomization is very important process in liquid fuel combustion and industrial applications. Atomization is done by disintegrate the fuel from bulk liquid to very fine droplets to enhance the rate of evaporation by increasing the surface area of the fuel. This increase in the evaporation rate leads to increase in the mixing quality and consequently increases the possibility to reach the complete combustion [1 and 2].

There are three main types of fuel atomizers; pressure atomizer which depends on high fuel injection pressure using small diameter holes for fuel exit in spray form, rotary atomizer which is using a rotating disc with high speed of rotation to generate the centrifugal force and the liquid is thrown out in sprayed form and the twin-fluid atomizer which depends on the relative velocity between the atomizing fluid and fuel [3-5].

The airblast atomizer is one type of twin-fluid atomizer types which has many clear advantages over the other types of 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 [6-8]. The investigations and studies of spray characteristics for the airblast atomizer modifications and amendments progressed in recent years due to its importance and advantages. The measured and studied spray characteristics are classified into two main basic groups; the first is macroscopic, which involve spray penetration, spray cone angle and the break up length [9–11], the second is microscopic, which involve droplet velocity, distribution and size distribution and mixture strength distribution [12-14]. The diesel fuel spray performance of a modified design of airblast atomizer was experimentally investigated under different operating and geometrical conditions by Gad et al. [15].

In combustion systems, the fuel spray momentum is a very important parameter because it affects on the spray penetration inside the combustion chamber and also on spray cone angle depend [16]. So spray momentum distribution of liquid fuel could be a good indication of spray penetration and spray cone angle which indicate the mixture distribution and control the condensation due to impinging with the surfaces inside the combustion chambers. The spray momentum was investigated and measured by directing the fuel spray onto a fixed plate connected with a force sensor to measure the force of the spray impact on the plate [16-18]. May et al. [19] studied the effect of ambient pressure on an airblast spray injected into a cross flow. It was observed that the airblast pressure drop, fuel flow rate, and cross flow velocity were held constant, an increase in ambient pressure decreased spray jet penetration but increased breakup.

The importance of studying the effects of different operating and atomizer geometrical conditions for a modified design of airblast atomizer on spray momentum is clearly observed. In the present study the spray momentum distribution measurement is carried out in a simple method; the measuring method depends on measuring of spray mass distribution which used to determine the spray momentum distribution. The spray momentum distribution of the airblast atomizer is investigated for the following different operating and geometrical conditions: ALR which taken as 2, 4, 6, and 8, the ratio of distance between the fuel nozzle exit and the atomizing air exit orifice to fuel nozzle diameter (l/D) which changed from 0 to 3 mm and the atomizing air swirler angles (AASA) which varied as 0°, 15°, 30°, and 45°. The commercial diesel oil is used as atomization liquid and has the properties shown in Table 1.

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. %
Centane number	40-55	

II. Experimental Test Rig

In order to investigate the effects of changing ALR, l/D and AASA on the spray momentum distribution, an experimental test rig consists of an atomizing air line, diesel fuel line, a modified design for airblast atomizer, the spray chamber was manufactured for this purpose. A tubes patternator is attached with the spray chamber to measure the spray concentration in order to determine the spray momentum distribution. The detailed layout of the used experimental test rig is shown in Fig. 1 while the detailed construction and dimensions of the modified air blast atomizer is shown in Fig. 2.

The atomizing air to liquid ratio is changed the flow rate of the atomizing air keeping the liquid fuel mass flow rate constant. The axial distance between the liquid nozzle exit and the atomizing air orifice (l) can be varied as 0, 1, 2 and 3 mm and the liquid nozzle diameter (D) is kept constant at 1.0 mm. A tangential motion is introduced to the atomizing air using four different swirlers with blades angles of 0°, 15°, 30° and 45°. The detailed dimensions and photograph of the atomizing air swirlers are shown in Figs. 3 and 4, respectively.

The used spray patternator consists radially of 23 scaled glass tubes with inner and outer diameters of 12 mm and 14 mm, respectively. These tubes are connected in horizontal straight line, the patternator is located at a height (h) of 20 cm below the atomizer exit which is examined and selected after running many preliminary spray experiments.

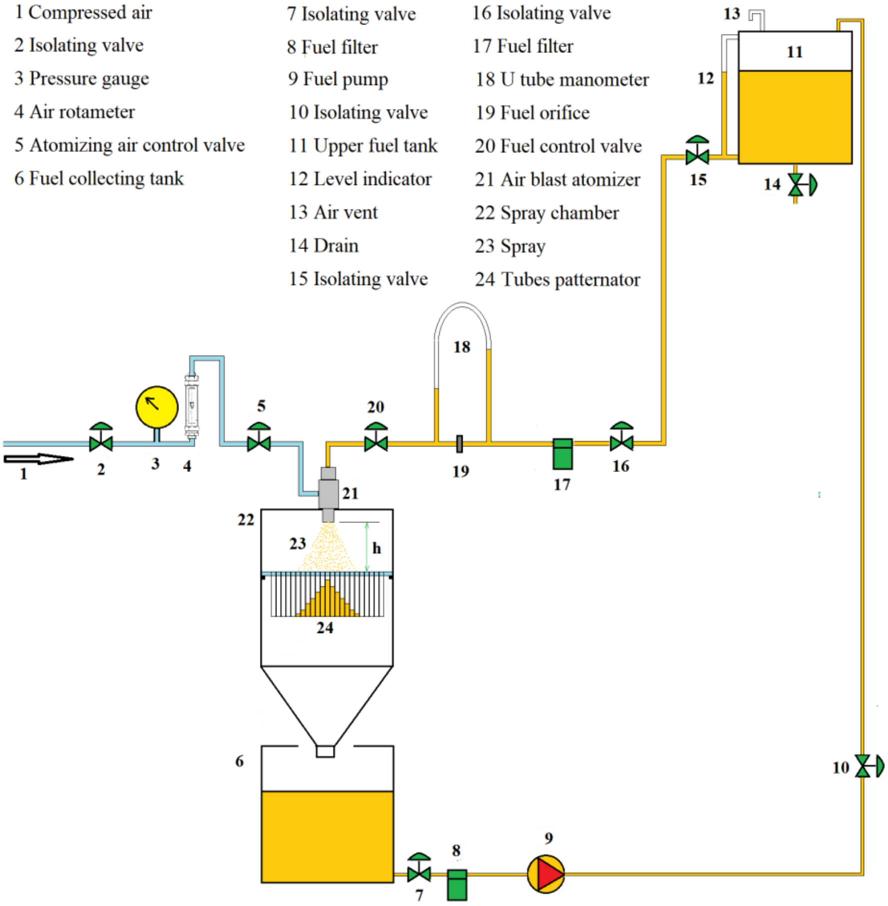

Fig. 1 The detailed layout of the used experimental test rig

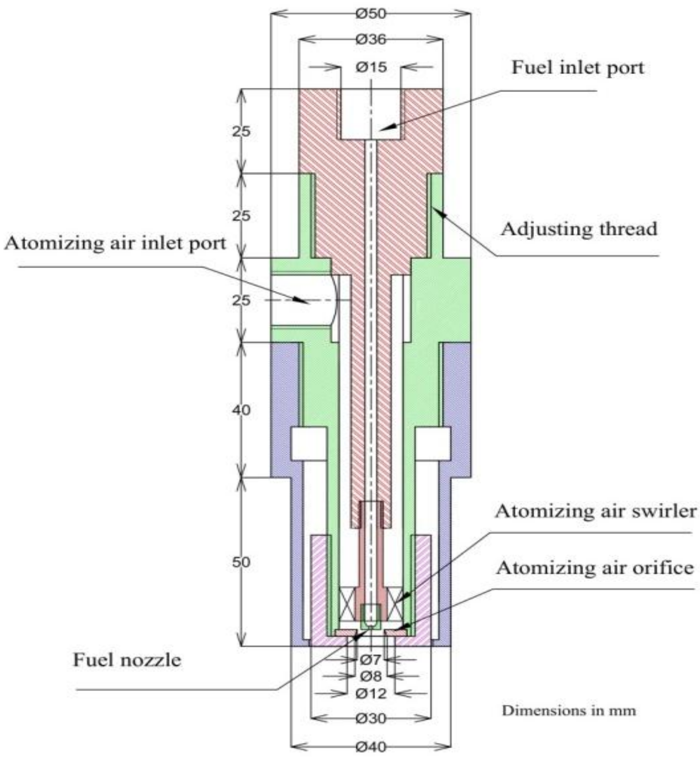

Fig. 2 The detailed construction and dimensions of the modified air blast atomizer

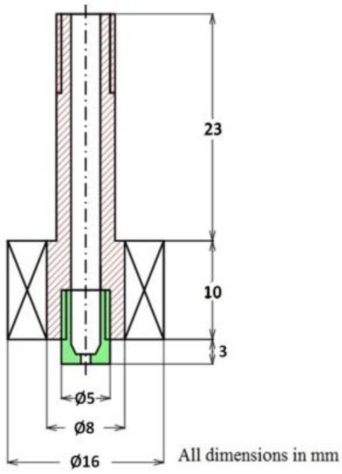

Fig. 3 The detailed dimensions of the atomizing air swirler

Fig. 4 A photograph of the atomizing air swirlers

III. Experimental Results And Discussion

In the present work, a series of experimental runs were carried out to investigate the effects of changing the atomizing air to liquid mass ratio (ALR), atomizing air swirler angle (AASA) and the ratio of distance between the fuel nozzle exit and the atomizing air exit orifice to fuel nozzle diameter (*l*/D) on the radial spray momentum distribution at constant fuel mass flow rate of 1.0 g/s, fuel nozzle diameter of 1.0 mm, atomizing air orifice diameter of 7 mm and vertical distance between fuel nozzle and the patternator location (h) of 20 cm.

The intersection between the obtained spray cone and the horizontal plane which passing through the patternator tubes inlets produces a circle, the center of this circle is the same as the center of the patternator. The area of this circle is divided into a centralized circle and a number of rings, the centralized circle area is equal to a single patternator tube cross sectional area and the area of each ring is integrated to evaluate the total radial spray concentration.

From the radial spray concentration distribution and the integrated area of each cross section, the volume flow rate δQ of each ring in cm^3/s is calculated. The spray momentum can be determined for each radial position corresponding to radial spray concentration as the following:

$$\delta M = \delta \dot{m} \times V$$
$$\delta \dot{m} = \delta Q \times \rho$$
$$V = \frac{\delta Q}{A}$$

Where A is the corresponding area of the δQ

$$\delta M = \delta Q \times \rho \times \frac{\delta Q}{A}$$
$$\delta M = (\delta Q)^2 \times \frac{\rho}{A}$$

From the above equations, with the helping of the radial spray concentration distribution, the radial spray momentum distribution can be obtained and the effects of the studied parameters; ALR, AASA, and *l*/D on the spray momentum distribution will be discussed in the following sections.

3.1 Effect of the air-liquid ratio (ALR)

The effect of changing the air-liquid ratio ALR on spray momentum at constant *l*/D of 0 and different two values of AASA; 0° and 45° will be illustrated and discussed. Figure 5 shows the effect of changing ALR on the spray momentum at *l*/D of 0 and AASA of 0°. It is shown that the maximum spray momentum is located at the first ring at a radial distance of 1.4 cm from the spray cone center line, and it decreased by increasing of the radial distance for all ALR. By increasing of ALR from 2 to 4, 6 and 8 the maximum spray momentum decreased by about 7%, 27% and 29%, respectively, and also the radial distance locations shifted by about 50%, 100% and 100%, respectively. The reduction in the maximum value of the spray momentum is due to the radial distribution of this momentum with the divergent of the spray cone angle and spray concentration. This reduction gives good mixing inside the combustion chambers but short penetration

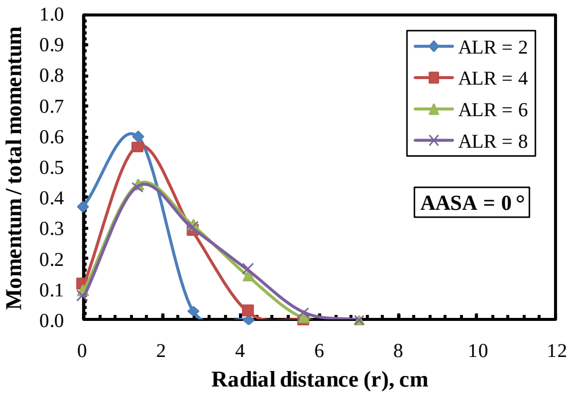

Fig. 5 Effect of changing ALR on radial spray momentum

[AASA = 0°, *l*/D = 0, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

Figure 6 shows also the effect of ALR on the spray momentum at *l*/D of 0 but at AASA of 45°. It is noted that the maximum spray momentum is located at the first ring at a radial distance of 1.4 cm from the spray cone center line for ALR of 2, while shifted radially outward by increasing ALR.

The results show that the peak value of the spray momentum for AASA of 45° is clearly lower than the corresponding values for AASA of 0° due to the dispersion of the spray with increasing AASA as a result of increasing the tangential motion and reduction of the axial motion. Figure 6 also shows that, by increasing of ALR from 2 to 4, 6 and 8 the maximum spray momentum decreased by about 37%, 44% and 53%, respectively.

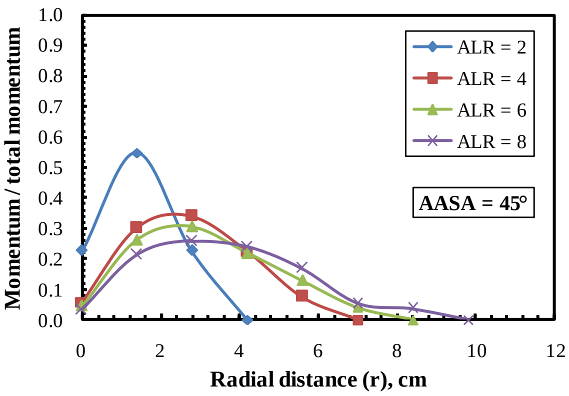

Fig. 6 Effect of changing ALR on radial spray momentum

[AASA = 45°, *l*/D = 0, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

Generally, it is found that by increasing the ALR the projection area of the spray is increased and covered a larger number of patternator tubes which appeared clearly in shifting in the radial position of the peak value of momentum. The increasing of the spray area at a constant fuel flow rate from fuel nozzle led to decrease the fuel flow rate at the patternator center tube and the first ring, and consequently increasing the fuel flow rate at the remaining rings, so, the maximum spray momentum is shifted radially outward by increasing of ALR.

The effects of ALR on the maximum spray momentum at *l*/D of 0 and for both AASA of 0° and 45° is summerized in Fig. 7. It is clearly observed that as in the above discussion, the maximum spray momentum is decreased by increasing of ALR. The effect of changing ALR on spray cone angle was studied by Gad et al. [15] and the results indicated that the increasing of ALR led to an increase in the spray cone angle. So by increasing of ALR the spray cone angle increases and this led to increasing of the spray projection covering area which causes the decreasing of the maximum spray momentum and shifting outward.

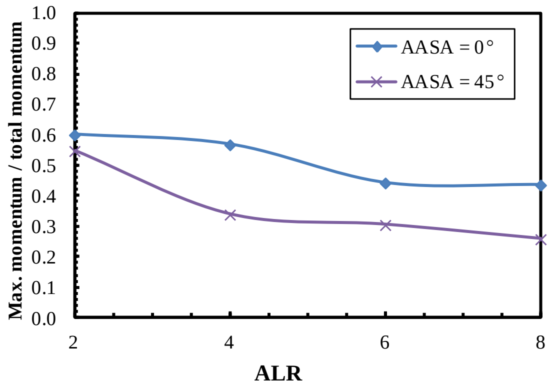

Fig. 7 Effect of changing ALR on maximum spray momentum
[l/D = 0, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

3.2 Effect of the atomizing air swirler angle (AASA)

In this section the effect of changing AASA on spray momentum at *l*/D of 0 and different ALR will be shown. Four different atomizing air swirlers with different angles; 0°, 15°, 30° and 45°, were used to investigate the modified air blast atomizer Figure 8 shows the effect of AASA on radial spray momentum at ALR and *l*/D of 2 and 0, respectively. It is shown that, increasing of AASA from 0° to 15°, 30° and 45° slightly decreases in the maximum spray momentum can be obtained and are about 2%, 4% and 10%, respectively, while the radial location of the peak value remains constant.

It is also shown that, for all AASA at ALR of 2, the spray momentum starts from the spray cone center line with a moderate values then it increased to reach its maximum value then it is radially decreased.

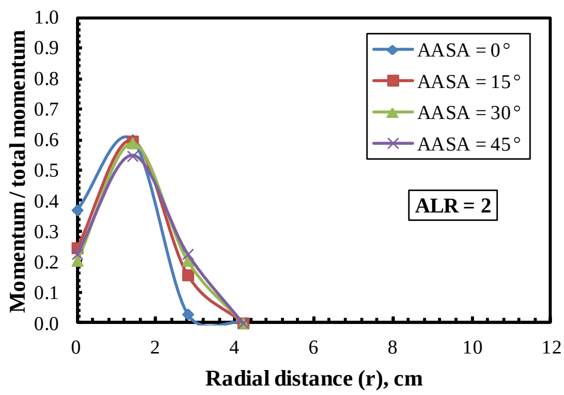

Fig. 8 Effect of changing AASA on spray momentum
[ALR = 2, l/D = 0, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

Figure 9 shows the radial spray momentum distribution at different AASA, ALR of 8 and *l*/D of 0. It is shown that, Increasing of AASA from 0° to 15°, 30° and 45°, the maximum spray momentum decreased by about 14%, 30% and 40%, respectively, and the peak value is shifted radially outward.

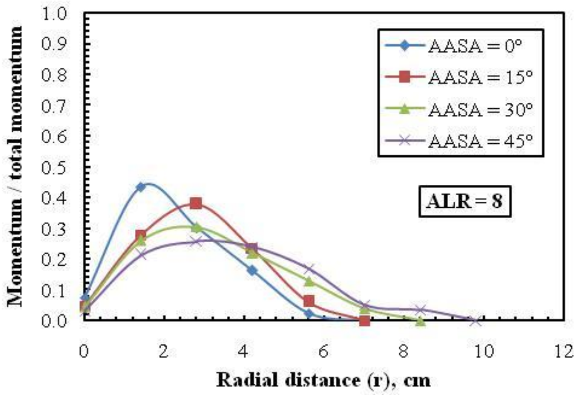

Fig. 9 Effect of changing AASA on spray momentum

[ALR = 8, l/D = 0, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

It is shown that by increasing the AASA the tangential motion of the spray increase increasing the spray cone angle and consequently, the projected area of the spray increased which increases the radial spray concentration distribution. The increasing of the spray distribution area at a constant fuel flow rate led to decrease the fuel flow rate distribution and radially increased compared with the lower AASA. So the maximum spray momentum is radially shifted outward by increasing AASA to 15°, 30° and 45° at ALR of 8.

Figure 10 shows the effect of AASA on the maximum spray momentum at l/D of 0 and for both ALR of 2 and 8. It is observed that, the maximum spray momentum is slightly decreased by increasing AASA at ALR of 2 while this reduction is clearly appeared for ALR of 8. The effect of the atomizing air swirler angle on spray momentum is clearly obtained for higher ALR which increases the cone angle and spray envelope. The reduction in peak value of the spray momentum with increasing AASA is suitable for application in shorter but wider combustion chambers.

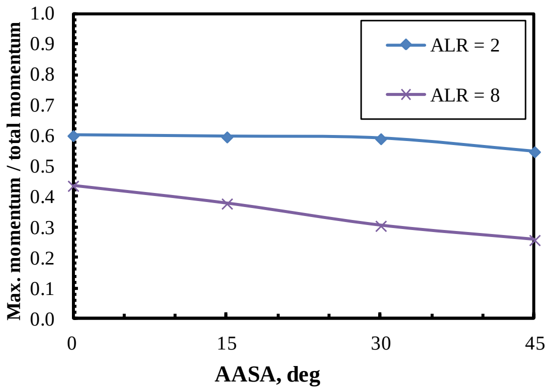

Fig. 10 Effect of changing AASA on maximum spray momentum

[l/D = 0, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$= 1 g/s, and h = 20 cm]

3.3 Effect of *l*/D ratio

The effect of changing l/D on spray momentum at AASA of 45° and different ALR will be shown and discussed in this section. The axial distance between the fuel nozzle exit and atomizing air exit orifice is investigated and taken as 0, 1, 2 and 3 mm to give the ratio of distance between the fuel nozzle exit and the atomizing air exit orifice to fuel nozzle diameter (l/D) of 0, 1, 2, and 3, respectively. Figure 11 shows the effect of l/D on the radial spray momentum distribution at AASA of 45° and ALR of 2. It is observed that, increasing l/D from 0 to 1, 2 and 3 mm, the maximum spray momentum increased by about 4%, 6% and 13%, respectively. The peak value of the spray momentum is slightly shifted radially inward with increasing l/D.

By increasing l/D the spray cone angle clearly decreased resulting in decreasing the covering area of the spray which decreased the radial spray distribution. The decreasing of the spray projection area at a constant fuel flow rate from fuel nozzle led to increase the fuel flow rate at the patternator center tube and the first ring, and decreasing the fuel flow rate at the remaining rings. So the maximum spray momentum is shifted radially inward.

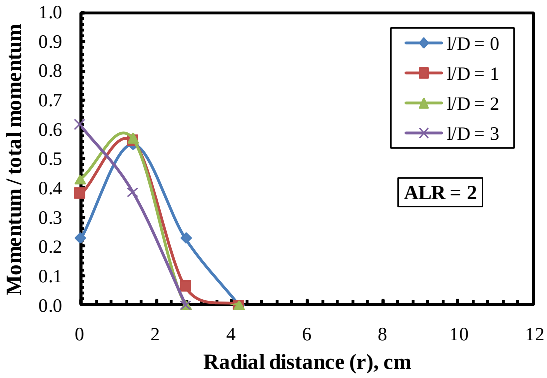

Fig. 11 Effect of changing *l*/D on spray momentum

[ALR = 2, AASA = 45°, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

Figure 12 shows the effect of *l*/D on the spray momentum at AASA of 45° and ALR of 8. It is also shown that, increasing *l*/D from 0 to 1, 2 and 3 cm, maximum spray momentum increased by about 12%, 31% and 42%, respectively, and also shifted radially inward. For longer but narrow combustion chambers, it is preferred to use higher *l*/D to give good penetration of the fuel in the mixture in axial direction but smaller divergent in the radial direction.

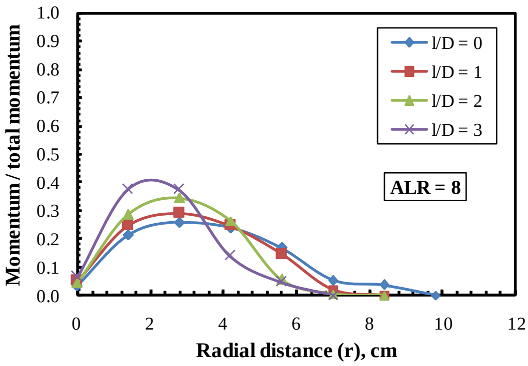

Fig. 12 Effect of changing *l*/D on spray momentum

[ALR = 8, AASA = 45°, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

Figure 13 shows the effect of *l*/D on the maximum spray momentum at AASA of 45° and ALR of 2 and 8. It is inferred that, the maximum spray momentum is slightly increased by increasing *l*/D. the same trend was obtained for ALR of 2 and 8 but with different values as the maximum spray momentum for ALR of 2 is greater than that of 8 as previously discussed.

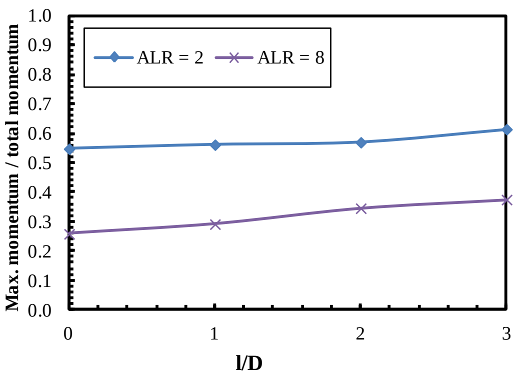

Fig. 13 Effect of changing *l*/D on maximum spray momentum

[AASA = 45°, D = 1 mm, $D_{a.a}$ = 7 mm, $\dot{m}_f$ = 1 g/s, and h = 20 cm]

IV. Conclusions

In the present study, atomizing air to liquid ratio (ALR) varied from 2 to 8 keeping the fuel mass flow rate constant at 1 g/s, atomizing air swirler angle taken as 0°, 15°, 30° and 45° and ratio of distance between the fuel nozzle exit and the atomizing air exit orifice to fuel nozzle diameter (*l*/D) changed as 0, 1, 2 and 3 keeping the fuel nozzle diameter (D) constant at 1 mm, were experimentally investigated on the spray momentum distribution. The following conclusions can be obtained from the experimental results:

- By increasing of ALR the peak value of the spray momentum decreased and shifted radially outward for all AASA and *l*/D.
- Increasing AASA from 0° to 45° the maximum spray momentum slightly decreased and its radial location of the peal value remains constant.
- The effect of the AASA is clearly appeared for higher ALR.
- Increasing *l*/D the maximum spray momentum increased and slightly shifted radially inward.
- For shorter and wider combustion chambers, it is recommended to use higher AASA and smaller *l*/D and vise versa.

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