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Entrained Air around a High Pressure Flat Jet Water Spray

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Abstract

An investigation was conducted to analyse the pattern of entrained air around a high pressure flat jet water spray with emphasis on the determining inter-dependency on droplet velocities, droplet size, and the air velocities around a flat jet atomiser. Applications of spray and its surrounding air interaction based on the aerodynamic properties have been very common in the area of combustion, spray painting, spray dryer, however, fewer research have been conducted on high pressure surroundings especially for flat water jets, which until recently other applications in the cleaning oil and gas production systems using high pressure water jets.

While other research concentrates on using fuel such as diesel and iso-octane for entrained-air measurements, this research utilised the water flat spray jet. The air flow pattern around a fan jet spray in both downstream and radial components of the entrained-air velocities and its effect on the atomization process as the droplets moves from the nozzle exit was investigated using both Phase Doppler Anemometry (PDA) and Hot Wire Anemometry (HWA). Findings from this research provide an envelope of the spray characteristics at range of high pressure up to 10.0MPa, at various downstream and radial positions through the flat spray, which identify the rate of air entrained in the region of primary and secondary atomization.

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Introduction

Spray jet propagation and dynamics has substantially been used for several industrial purposes, such as combustion, spray painting and aerodynamic systems for effectively utilising high area coverage and subsequent behaviour of the spray characteristics, until recently, spray jet dynamics and surrounding air envelope are closely related not only to the food-processing and spray-drying but also for cleaning purposes in oil and gas facilities, where deposit such as wax are found along pipelines, and particular attention has been given to flat jet spray for their characteristics high impact on the targeted surfaces. Consider the profile of a single flat jet nozzle, which has proved to have higher entrainment efficiency than nozzles assembly[1], propagating through aerodynamic forces along an atmospheric chamber, which enable measurement to be taken from the nozzle exit to a considerable distance downstream for Sauter Mean Diameter (SMD), droplet mean velocities, entrained air velocity for both within and outside the spray width until where the entrained-air velocity decays to local air velocity, unlike the previous measurement done to ascertain the total entrained-air volumetric flow rate[2], which the variation of the air velocity was difficult to ascertain from one point to another, the current research undertake a grid pattern for the chamber as shown in Fig. 1 below, in which measurements are closely monitored using a combination of Phase Doppler Anemometry and Hot Wire Anemometry.

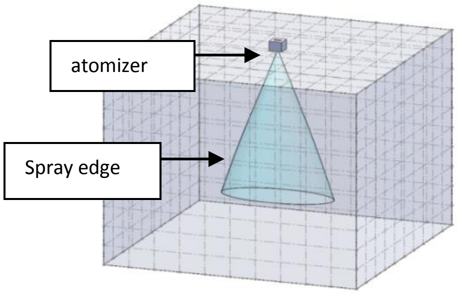


Figure 1. Flat jet spray 3D envelope

Experimental Set up

Droplet Mean Velocities and SMD measurement

The experimental set up involved measurement of droplet size velocities and droplet size diameter using Phase Doppler Anemometry (PDA) for single flat jet spray, at 25^o spray angle. High pressure pump was used for supplying range of liquid flow rate loading through the flat jet atomizer at 4.8, 6.0 and 10.0MPa corresponding to 0.130, 0.145 and 0.188kg/s respectively as shown in Table 1. Particles mean droplet velocities as well as diameters measurement have been investigated using Phase Doppler Anemometry as shown in Fig. 2 above, A high pressure pump of 50MPa rating was used to deliver the required pressure head to the atomiser. The pressure was closely monitored at both the pump outlet, and at the atomizer inlet using pressure gauges.

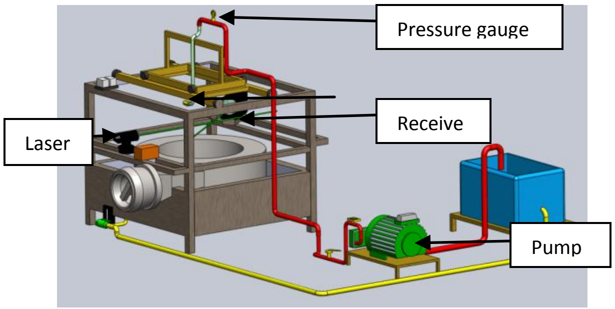


Figure 2. Experimental rig

Property	Value
Spray angle	25^o
Spray Nozzle code	2505
Flow rate at 10MPa	0.188kg/s
Flow rate at 6.0MPa	0.145kg/s
Flow rate at 4.8MPa	0.130kg/s

Table 1.Flat atomizer characteristics

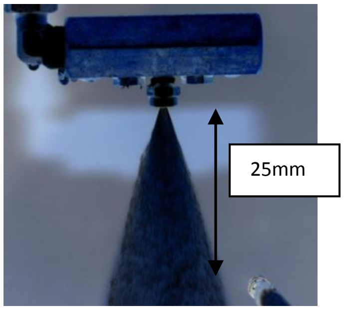


Figure 3. Spray jet

The measurement were then taken at 25, 50 and 75mm positions of the grid spray system as shown below, both droplet mean velocities and SMD were conducted along the spray width, however, entrained air measurement were limited to only regions outside the spray, this is to ensure the hot wire anemometer was not exposed to regions of damage as well as cooling effect due to direct contact with water spray.

Entrained-air set up and procedure

The measurement of the entrained air velocity was performed by mounting the hot wire part of the Hot Wire Anemometry around the flat jet spray edge line at

25mm as shown in Fig. 3, and hence Fig. 4b for 2D sketch, such that the tip sensor is almost touching the spray, ambient temperature were also recorded at the beginning and at the end of each measurement as shown in the display screen of the Hot wire in Fig. 4a. Subsequent measurement were taken at 5mm distance away until the air velocity decays to almost zero. The investigation was then repeated at 50mm and 75mm axial position of the spray. During the measurement, fluctuations were observed at digital entrained-air velocity readings displayed, however, 5 to 15seconds were allowed to achieve fewer fluctuations, and hence results were recorded.

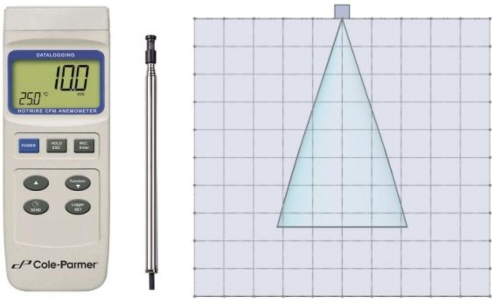
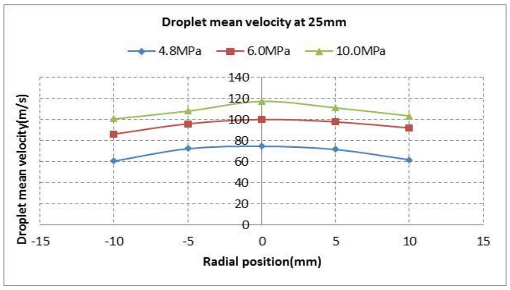


Figure 4(a). Hot wire Anemometer[3] **(b).** Spray jet grid

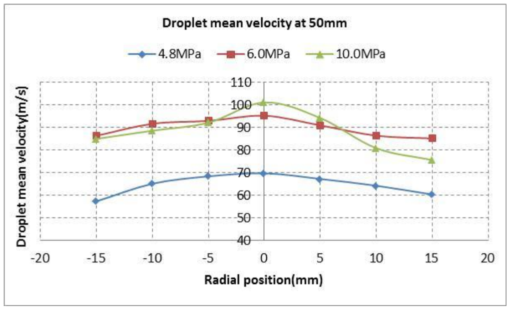
Results and Discussions

Droplets mean velocities and SMD Measurement

Droplet mean velocities and SMD were investigated as part of the envelope of the entrained measurement plane at three positions downstream of the nozzle exit, at three different loadings which matches the entrained-air measurement. Fig. 5(a, b, and c) below indicate increases in droplet mean velocities with increase in liquid loadings from 4.8MPa till 10MPa,with their corresponding velocity distributions in Fig.6(a,b,and c) corresponding to various findings [4], and also general decrease in SMD for all scenarios of liquid loadings as shown in Fig. 7.Though liquid loadings makes a finer spray [5], but the finer particles distribution were observed to be non-symmetrical as in Figure 6.



(a)



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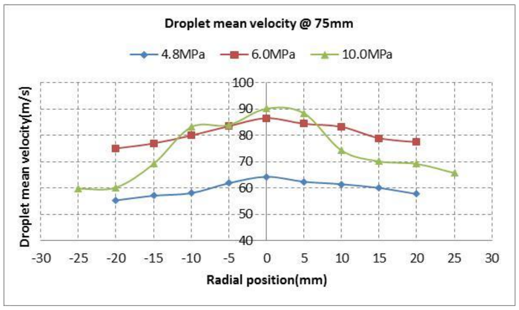
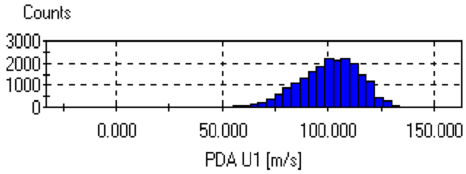
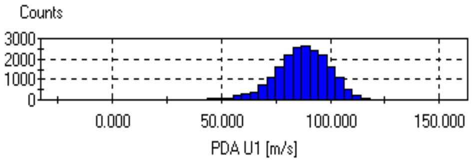


(c)

Figure 5. Droplet mean velocities at (a) 25mm, (b) 50mm, (c) 75mm downstream



(a)



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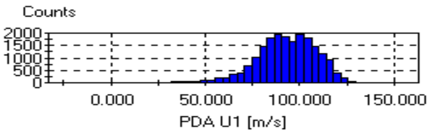
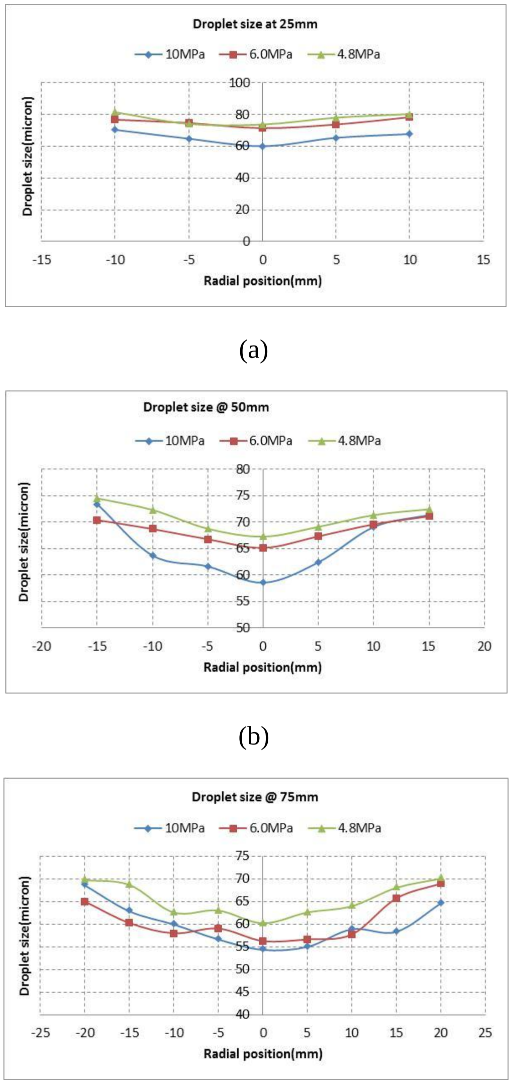


(c)

Figure 6. Droplet mean velocity distribution at (a)25mm, (b) 50mm, (c) 75mm



(a)

(b)

(c)

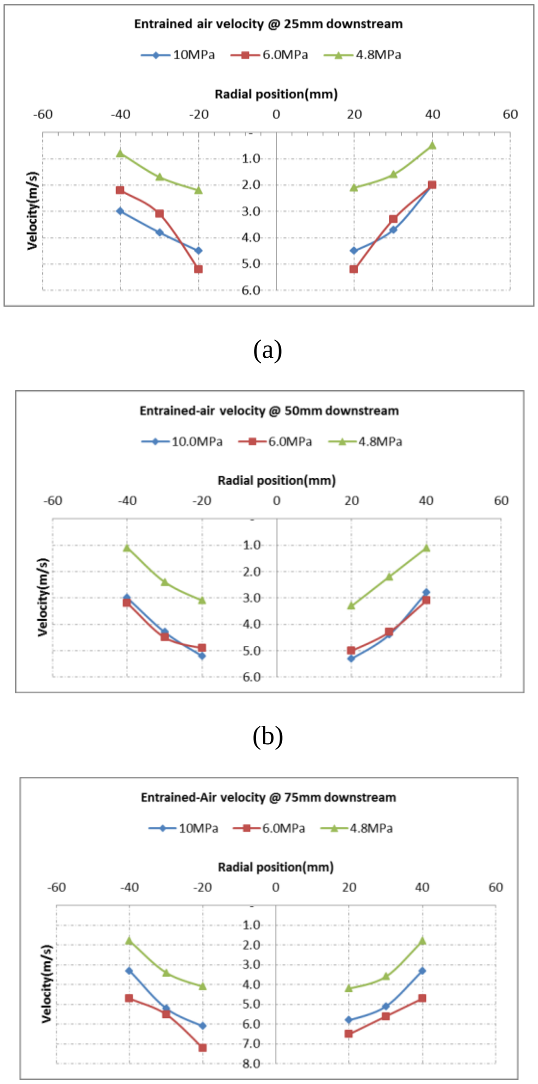
Figure 7. SMD at (a) 25mm, (b) 50mm, (c) 75mm

Entrained-air results

The experimental demonstrations was restricted to two major rational of the entrained-air velocity measurements as variation of entrained-air velocity with (i) downstream axial distance from the nozzle, and (ii) the liquid loading obtained at various pressure between 4.8 to 10.0MPa.

i) Axial downstream distance

The first set of results obtained in Fig. 8(a, b, and c) confirms that although higher liquid loadings increases with subsequent pressure increase from 4.8 until 10MPa, which increases the droplet velocity substantially, at given downstream position, entrained velocity continue to rise steadily in all scenarios with liquid loadings , but it clearly shows the drag forces which acted gently upon the larger droplet sizes at lower flow rate[6] due to higher momentum, thus entrained less air which ultimately results in mild deceleration for the droplets, this conforms very well with the observed margins of entrained-air velocities particularly between 4.8MPa and the two others at 6.0 and 10MPa, with much similarity, although the drag force continue to suppress the droplet velocity at the higher liquid loadings, 0.13kg/s(4.8MPa) seems to be a critical flow rate with lesser atomization and breakup[2].Observation from Figure 8(a, b, and c) below also showed the effect of higher drag force on the smaller droplets obtained at higher pressure of 6.0 and 10MPa.



(a)

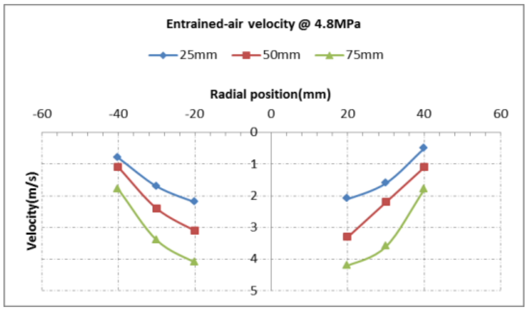
(b)

(c)

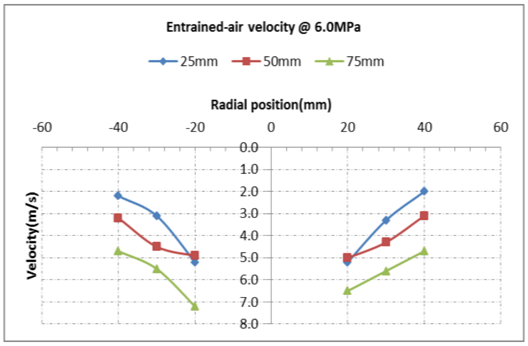
Figure 8. Entrained-air velocity at(a) 25mm, (b) 50mm, (c) 75mm

ii) Liquid loadings obtained at various pressures

Second investigation which then kept the liquid loadings same while varying the downstream distance from the nozzle, while other researchers confirmed similar scenario of free-air jets[7] , their findings agreed very well on the linear increase in mass flow rate with distance downstream the nozzle exit[8].Fig. 7(a, b, and c) relates the variation in the droplet sizes and droplet velocities along the spray jet, in which the droplet size decreases as a results of secondary atomization and break up, leading to more concentration in the smaller droplets, which are affected rapidly by the drag force, and hence entrained more air downstream. Although, velocity was found to decay along the axis of spray by about 20% at 12cm [9], which relates to the velocities within the spray axis, however, velocities measured around the edge of the spray continue to rise steadily with downstream length up to 75mm in this investigation, which confirms increase in mass flow rate with downstream position [8].



(a)



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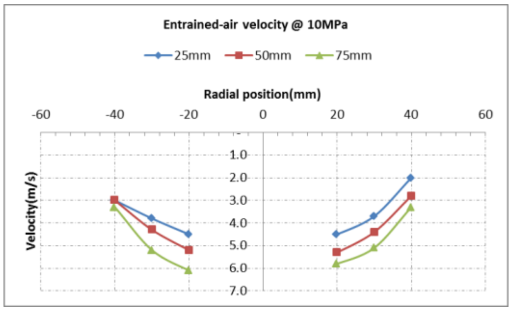

(c)

Figure 9. Entrained-air velocity at (a) 4.8MPa, (b)6.0MPa, (c) 10.0MPa

Conclusion

The investigation presented preliminary results obtained by analysing the entrained air velocity behaviour in ambient non-forced air surrounding, just outside the spray width until where the velocity decays to local air velocity, which findings indicated linear increase in velocity with liquid loadings as a results of pressure increase. Variation in droplet mean velocities and SMD are also observed to affect the pattern in which entrained-air surrounding flat jet sprays behaves.

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