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Visualization and Analysis Studies of Hollow Cone Spray under low Air Cross Flow Velocity under Atmospheric Condition

Ban K. Abed Jabar* [a] *and Ahmed Majho Jabar* [a]

[a] *Faculty of Engineering – University of Al-Qadisiyah-Iraq*

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ABSTRACT

This study deals with the atomization of hollow cone spray water with low air cross flow. The visualization of the hollow cone spray by shadowgraphy, from the nozzle exit. The diameter of the nozzle allows observing different modes of breakup and structures (ligaments, helices, ...). The treatment of these images makes it possible to determine the drop size distribution of the spray droplets in function of length scales of the downstream flow. In the measurements of water hollow cone spray with injection pressures of 25kPa and air velocity of 10 m/sec. The calculations at the exit of the injector, in two planes perpendicular, and the average droplet sizes in the presence of air low cross flow conditions. The high- speed imaging is used to capture the final spray. These images are analyzed by using the image software. The structure and characteristics of the whole and sectional body of the spray are investigated at different times. The results show the droplet trajectory profile of the liquid droplets is in a good an agreement with analytical solution.

1. Introduction

The hollow cone spray in cross flow is a very simplified configuration of a fluid, usually, fuel in liquid or gaseous form injected into a cross flow. It was in the 1930s that the first studies on jet in cross flow appeared. Their purpose is to evaluate the dispersion, but also the consequences on the environment of the spray dispersion from the injector. Since then, many works are related to the study of the hollow cone spray in cross flow and present the different characteristics of the spray cross flow. Most of them relate to the trajectories and increases in the velocity of the main flow and the average behavior of velocity fields. In Chul Lee et al [1] used the spray jet penetration and drop size distribution to study experimentally the of liquid jets in subsonic cross-flows. David Sedarsky et al [2] had been used the image processing technique located in the far field to investigate the breakup of a liquid jet in cross flow. They observed by using particle imaging measurements (PIV). Sudeepta Mondal et al [3] improvement of the mixing process in a jet cross flow configuration in a confined environment is one of the primary objectives. The use of methods such as changing the shape of the injection port (section orifices squares, ovals, etc), the addition of a triangular protuberance or the rotation of the flow of the jet would increase the mixture significantly. Schadow et al [4] studied the influence of a jet cross flow with triangular section, the injection being performed at the corners, and compared the levels of pressure fluctuations with a jet with a circular section. They found the formation of coherent structures circular section, while small-scale turbulence is generated at corners of the triangular injection. The amplitude of the fluctuations is then estimated at 10% of the average pressure while it amounts to more than 30% for the circular injection**.** Surya et al [5], studied the influence of

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* *Corresponding author.*
E-mail address: ahmidkadhim@yahoo.com (Ahmed Abed Al-Kadhem Majhool)

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Nomenclature

Y	Mass fraction.	St	Strouhal number.
d	Liquid jet diameter(m).	*Greek symbols*	
q	Liquid to air momentum-flux ratio.	ρ	Density kg/m^3.
We	Weber number.	σ	Surface tension N/m.

fluid jet injection entrance environments on the construction of liquid jet in cross-flow. The momentum ratio of the liquid to air is directed in a range ($Q\sim 3-100$) and the Weber number in a range ($We = 17-89$). High-speed imaging and Shadowgraphy and high- speed imaging are utilized to investigate the drop size and the trajectory of the consequence spray. Anubhav Sinha et al [6], investigated exploratory examinations on the structure of air-blast spray. The atomizer is at a higher weight than encompassing and the air-blast gas is required to display includes commonly found in under-extended gas planes. They used Proper Orthogonal Decomposition (POD) for the examination has been done utilizing these pictures.

Y.H. Zhu et al[7], investigated the primary separation of a beat fluid stream in supersonic cross-flow is numerically researched. A two-stage stream ***L***arge Eddy Simulation (LES) calculation is created for reproductions of fluid fly atomization in a supersonic gas stream. Zhanbo Si et al [8], investigated the effects of cross-flow and flat divider impingement on the shower advancement and scattering. The spray was infused by ***a*** valve covered orifice (VCO) nozzle under different cross-flow speeds and surrounding weights. A. Rajabia et al [9], examined an ethanol fluid jet exposed to mix of an air cross-flow and a typical electric field. The fluid stream direction was found as a component of two non-dimensional amounts; the fluid stream to the cross-flow force proportion and the electroinertial number. The electroinertial numbers defined as the proportion between the fluid fly specific energy and electric power. Su and Mungal[10], evaluated the scalar concentrations for two cross flow streams: one classic, the other protuberant. They then estimated the lengths of penetration and the jet openings. They show that adding a triangular protrusion inside the outflow of the jet implies a better efficiency of the mixture. Liscinsky et al. [11] protuberances do not generate significant vorticity factitious compared to that caused by a transverse flow. In addition, they observe the penetration of the jet decreases with the increase in the number of swirls. There are many studies referring to jets not perpendicular to the flow principal, that is, inclined relative to the normal to the main flow. The jets forced are the subject of many investigations.

Therefore, the present paper. had as an objective to evaluate spray trajectory, the drop size distribution and spray intensity over the whole and three zones of spray liquid injected into low air cross flow velocity. Past investigations of fluid injection in crossflow incorporate examinations of liquid atomized at various conditions. One of the key purposes of these examinations is the investigation of the spray dispersion. Because of the way that cross stream fuel infusion is broadly utilized in gas turbine combustors, it is imperative to comprehend the components that control the spray separation, penetration, and transmission inside the cross stream. Generally , the effectiveness of a spray in a cross flow is identified with its scattering in the flow. A comprehension of spray conduct in cross flow is essential for an effective control of the spray. Spray structures in the bead system have for the most part been examined as far as spray infiltration .Schetz et al [12] played out an energy examination on greatest infiltration height and found that the most extreme penetration tallness is the separation required to divert the fluid jet infusion momentum fluctuation to the air stream course. Inamura et al[13] examined the widths spray, they utilized a photographic strategy and recorded pictures from the highest point of the spray field. A connection of spray widths was observed to be a component of q and x/d. .Schetz et al [12] utilized a minuscule photography technique to quantify bead sizes for injectors of different geometries. The injector geometry was found to significantly affect the normal bead estimate. Past research examinations that are relevant to the issue are those on spray in still air. Ghosh et al [14], in their analysis described how the prompted air flows in spray planes have numerous likenesses with the air flow in tempestuous jets, and can be examined utilizing ideas and models first proposed by Morton, et al [15]. The present tests measure the adjustments in splash structure with a uniform cross-stream speed of 10 m/s. Previous estimations [16,17], have demonstrated that cross-stream because of tumble might be up to 25 m/s right off the bat in the acceptance stroke and between 5 and 10 m/s. late in the pressure stroke. The fire structure continues as before with elective infusion lengths for the period over which the valve is completely open [18].

2. Experimental facility and methods

In this section, the apparatus that are used to characterize the single hollow cone spray in cross flow is presented. **Fig. 1.** shows the schematic diagram of hollow cone spray visualization setup of equipment First, the general characteristics of the hollow cone spray in cross flow are provided: the average representation of a spray trajectories based on velocity and scalar, the length of penetration or the rate of flow of the spray constitute the spray intensity in this study. Then an analysis of the unsteady aspect is invested. The main structure of spray drop size distribution is highlighted in many works and presented; the dynamics of the hollow cone spray is highlighted and the frequencies of passage structures are evaluated. All these results come from times of experiences.The injector is a prototype for hollow cone spray for water injection. This is an injector ”Single hole” with a diameter of 1mm. The needle lift is controlled by mechanical ring system. The most likely source of error comes directly from the capacity of the injector produce repeatable data. The use of an injection system brings its share of variability. Since he is turbulent flow, a series of successive streams can not be exactly the same. **Fig. 2.** shows the water hollow cone spray injector used in the tests. In order to quantify this source of error, a series of tests were carried out. The test consisted of hollow cone spray (P inj = 25kPa, V gas = 10 m/sec) repeatedly and observe the trajectory curve. In total, three trials are conducted. This repeatability test is not presented, which puts into question the relevance of the data. Although the number of tests performed in the present case seems little, the result of this exercise will come, at a minimum, to quantify the existence of an experimental variation in the tests. It presents the curves of the repeatability test. The low number of repeatability tests is due to a break in the high speed camera at the end of the experiments. The images are acquired by a digital CCD camera with fast shutter (casio exilim 1280 * 1084 12 bits, 8 Hz), allowing fast double exposure. This camera presents sensitivity and dynamics well suited to PIV acquisitions. A PC is needed to control the operation of the light source and the camera. **Fig. 3.** shows the CCD intense image Camera with an ultra-zoom lens. The installation of this experimental device makes it possible to obtain the velocity field of the gas phase around the spray for the study of training. Visualization of the phase Spray liquid is also achieved by using this camera.

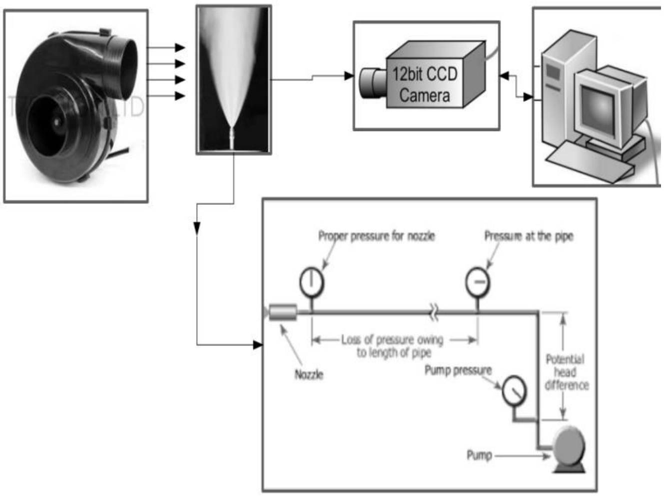


Figure 1: Schematic diagram of hollow cone spray visualization setup.

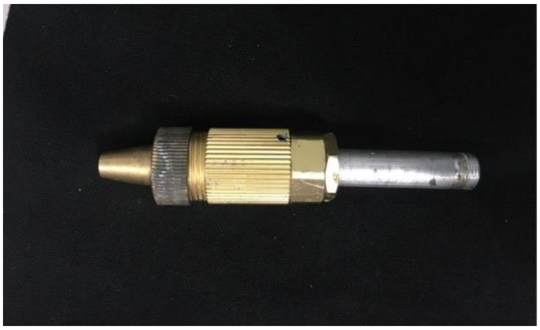


Figure 2: Zoomed image of hollow cone nozzle.

Figure 3: Zoomed image of camera observation direction.

3. Results and discussion

3.1. Experiment validation

The characterization of the trajectory of the hollow cone spray has been the subject of much research and publications. As part of this study, it will limit to those carried out for the case of a low injection liquid spray, opening transversely into a low air cross flow uniform velocity. **Fig. 4.** shows a comparison between the experimental result and the analytical method used by In Chul Lee et al., [19] where the influence of parameter q (momentum ratio) on the spray trajectory length.

$$\frac{Y}{d} = q^{0.75} We^{-0.07} \exp\left(\frac{0.057}{St + 0.036}\right) \tag{1}$$

Where We is Weber number and St is Strouhal number is taken to be zero because it represents oscillating flow mechanisms

$$We = \frac{\rho v u}{\sigma} \tag{2}$$

The agreement is good because in general, the parameter (We) has a great direct influence on the trajectory of the spray, however, according to its range of values, it defines the primary atomization regime of the spray. But in each different atomization regime, the deformation of the spray is not the same, which has an influence on its trajectory.

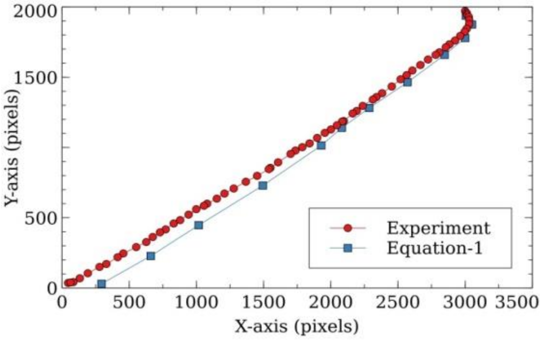


Figure 4: Comparison of predicted spray trajectory with the experimental data.

3.2. Whole body structure

The height represents the percentage of spray droplets that are in this range, for an unpressurized discharge of spray injection water. Normally the type of graph representing the size distribution of droplets gives a graph like the one of contentious distribution. Through the characterization of hollow cone spray according to the intrinsic structure. In the cross flow system, all experimental work is carried out on the average structure of the spray in a cross flow through concentration measurements. The gas velocity is constant. The four cases obtained are shown in **Fig. 6.** at different time. The time interval among them is (5 sec). The spray droplets have only a main trajectory in the cross flow (**Fig. 6** a and b). Moreover, with the increase of time, the jet tends to align horizontally in the cross flow as shown in **Fig. 6d**. This phenomenon is related to the predominant momentum of the spray compared to that of the main flow. They identify the streams with single and multiple trajectories. The transition between these four types of spray trajectories is defined with the increase for dispersion as shown below.

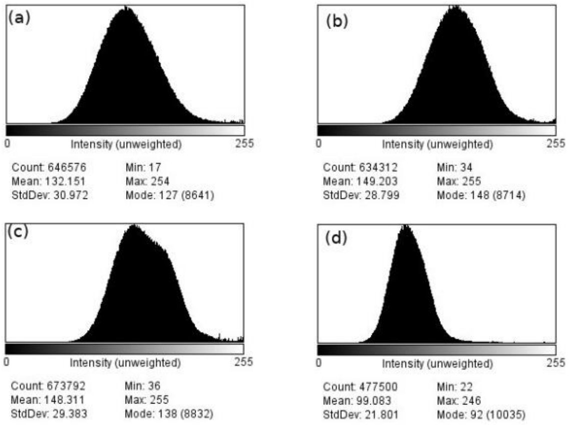


Figure 5: Histogram of droplet size at the air flow velocity of 10 m/sec at different time.

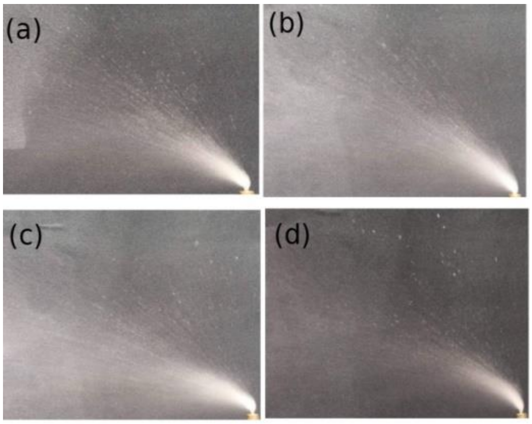


Figure 6: Histogram of droplet size at the air flow velocity of 10 m/sec at different time.

From image processing software which is used here to show droplets dispersion. Spray dispersion in the sense used here of mixing the droplets with them and the surrounding gas. The gas phase velocity can be reached on the one hand via the relative velocity of the droplets. The dispersion of the hollow cone spray, in contrast to a translation of the spray, requires here, that different droplet sizes that have different relative velocities to the gas phase.

Fig. 7. shows the atomization process at a different time. **Fig. 7a** shows the relative speed may be at an entry velocity, approximately lower than other cases due to the injection process at the earlier interval. That is maybe increased in **Fig. 7b** based on spin-induced centrifugal forces. On the other hand the spray dispersion also occurs turbulence, if the droplets are light enough to follow the turbulent vortex movements of the gas as shown in **Fig. 7c** and **d** due to gas interment.

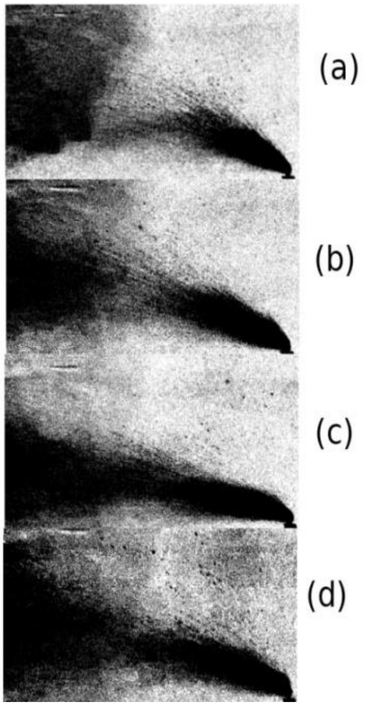


Figure 7: Hollow cone spray atomization mechanisms in microscopic view at different time.

The visualization of the hollow cone spray at the outlet of the injector is done through the method of shadow. The resulting images are then processed numerically. In order to extract the parameters interesting characterizing the hollow cone spray, the images must be of good quality. The saturation of an image is the most important aspect of its quality. The images taken by transmission are subjected to two possible saturations, in the light, and in the dark. Saturation in the clear is due to strong light power and the one in the dark is caused by opacity and the size of the photographed motif. A saturated image is losing information, so it is necessary to evaluate this aspect according to the light intensity of the source as well as the size of the photographed motif. **Fig. 8.** shows the hollow cone spray intensity along its trajectory at different times. For this the light intensity of 66% of the power is chosen in order to quantify the saturation of the bright pixels. The work is done on the images of the records of the test pattern taken with a resolution of 3.45 m / pixel. In a hollow cone spray configuration, the injection is performed by means of a liquid sheet annular, sheared between two layers with fast moving gas cross-flows. **Fig. 9.** shows surface area distribution of the two sheets at different times in such injection of the liquid, as well as the associated with atomization processes. In **Fig. 9a** and **b** show, the mechanism of instability of the hollow cone spray sheared with air cross flow, which is apparent clearly. While at **Fig. 9 c** and **d** this is no longer appeared due to the wide dispersion of droplets with time.

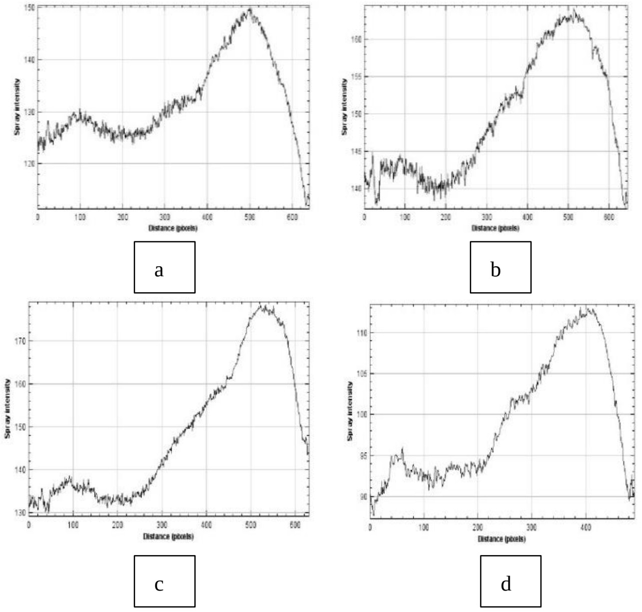


Figure 8: Hollow cone spray intensity along the traveling distance at different time.

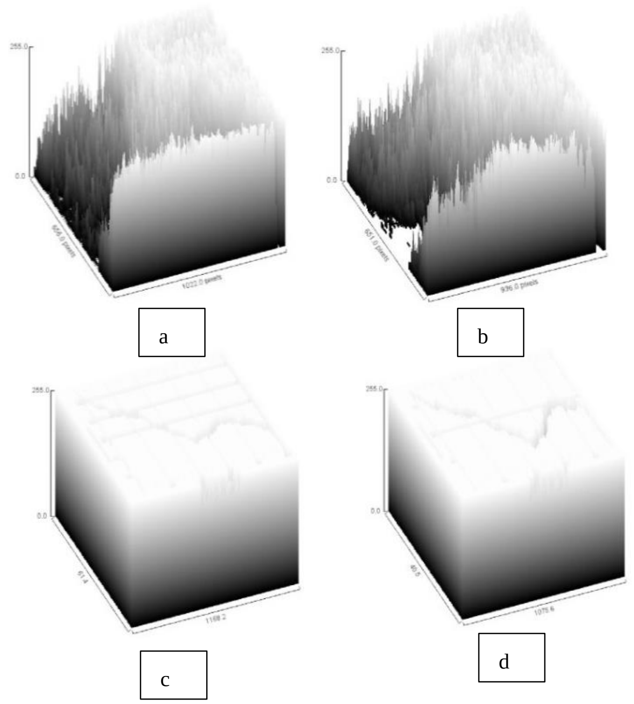


Figure 9: Three-dimensional surface of hollow cone spray at different time.

3.3. Sectional body structure

Fig. 10 shows the results obtained for three sections where the positions are considered in **Fig.10** . It's noted from that, the value of the spray intensity increases with the number of droplets as shown in **Fig.10c**, but also presents a more pronounced more oscillatory behavior than the other two cases. **Fig. 11** shows a histogram of hollow cone spray at different sections. The distribution of total diameters of the drops of the spray obtained by the sectional procedure for measuring regimes 1,2 and 3 are compared in Figure. As expected, it can be seen that the droplets measured for one injection condition may have very large diameters as shown in **Fig.12a**. The droplets of small sizes nevertheless seem large differences as shown in **Fig. 12b** and **c**. These values, corresponding to the position the peak of each distribution, appear relatively insensitive to the experiment. It is still quite surprising to find that the most observed for the highest zone (**Fig. 12a**) where the two spray sheets are meeting.

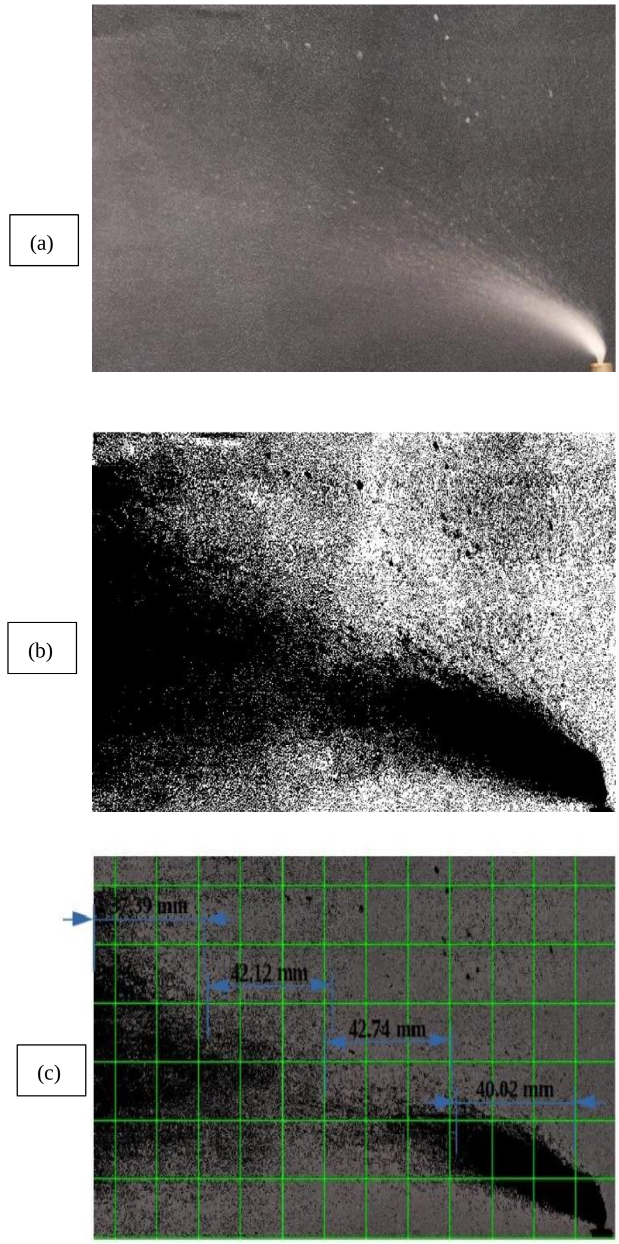


Figure 10: Hollow cone spray images of macroscopic spray shape with selected regimes.

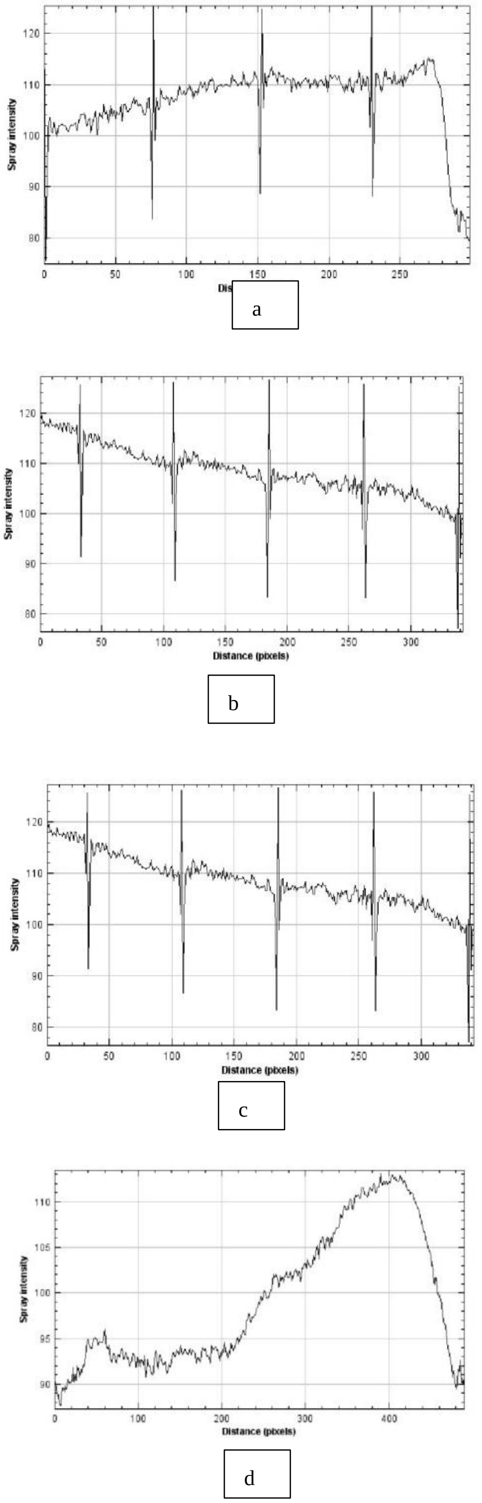
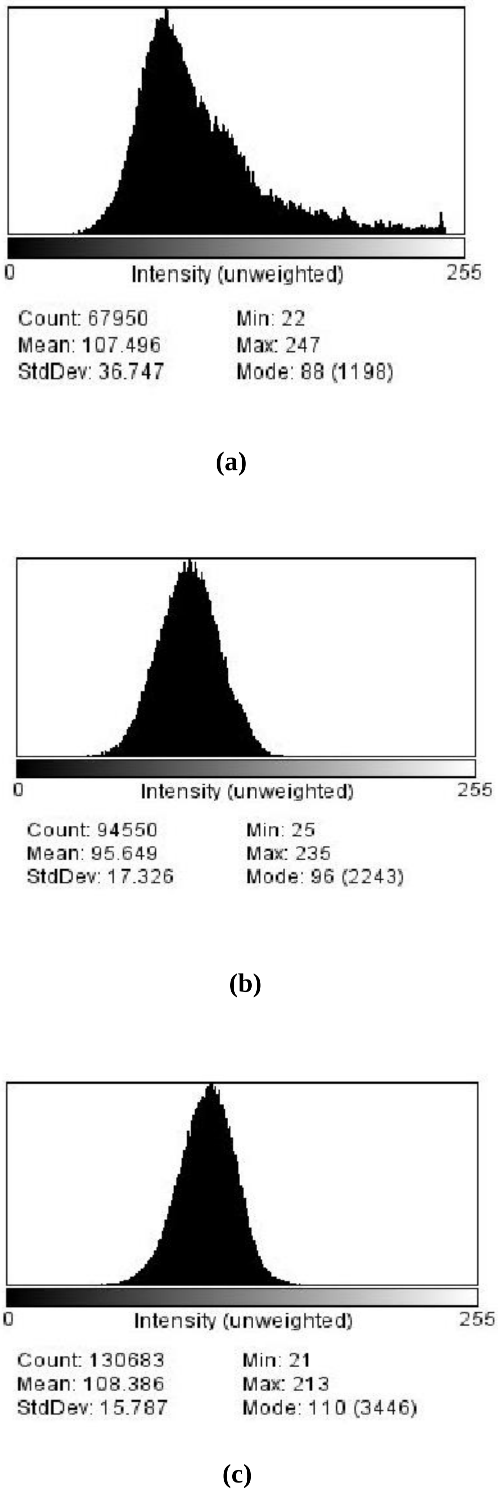


Figure 11: Spray intensity along the traveling distance for different regimes.



(a)
Count: 67950 Min: 22
Mean: 107.496 Max: 247
StdDev: 36.747 Mode: 88 (1198)

(b)
Count: 94550 Min: 25
Mean: 95.649 Max: 235
StdDev: 17.326 Mode: 96 (2243)

(c)
Count: 130683 Min: 21
Mean: 108.386 Max: 213
StdDev: 15.787 Mode: 110 (3446)

Figure 12: Histogram of droplet size at different sections.

4. Conclusion

Spray direction and droplet flight ways of a straightforward jet subject to mixes of cross flow and typical electric power were examined experimentally. The information of the present examination concurs well with the recently estimated information. The infiltration information is reliable, which is consoling thinking about the reality, that the nozzle configuration was marginally unique and extensive contrasts of the fly conduct with little structure. The droplet size and spray intensity are discussed, the distribution of the droplet diameter for all cases are considered. A histogram for all the spray pictures is taken by utilizing the picture handling. The estimation of droplet widths for the utilized range fundamentally relies upon the speed and so: the higher the estimations of speed the littler the droplet distance across. The impact of the liquid momentum transition on the droplet distance across is minimal.

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