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Experimental Study of liquid fuel spray characteristics and atomization

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ABSTRACT

Gas liquid two-phase flows broadly occur in nature and environment, such as the falling of raindrops and various spray processes. Atomization, referring to the conversion of bulk liquid into a collection of drops (i.e. a spray), often occurs after the liquid passes through a nozzle. Atomization and spray process is a typical gas liquid two-phase flow of great practical relevance in internal combustion engines. The combustion performance and emissions are mainly influenced by the atomization of the liquid fuel, the motion and evaporation of the fuel droplets and mixing of fuel with air.

Laser diagnostics system is now emerging as a powerful tool for the investigation of unsteady fluid mechanics. At the same time, the study and optimization of in-cylinder flow processes in automotive Internal Combustion (IC) engines is of increasing importance in the design of improved combustion systems with lower emissions and favorable power and efficiency characteristics.

Proper atomization of fuel always leads to proper combustion, but before this process takes place there are certain parameters which need to be studied. In this work, the effect of these fuel parameters on non-reacting spray such as sauter mean diameter (SMD), velocity of fuel droplets and spray cone angle of liquid fuel spray at various pressure ranges and various mass flow rates is studied with the help of laser diagnostics system i.e. Particle image velocimetry and Shadowgraphy.

This study is helpful to understand the droplets dynamics in liquid fuel combustors. This work is helpful in many industrial applications such as aircraft engines, diesel, gasoline internal combustion engines, and gas turbine.

Keywords— Non reacting spray, spray cone angle, sauter mean diameter, particle image velocimetry, Shadography.

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I. INTRODUCTION

The internal combustion engines are spread to the extent that they represent the main cause of pollutant production. Nevertheless, it is well known that the stocks of fuels traditionally used in this kind of engines will be able to satisfy the world's needs for few more decades. This explains the huge

Injection concepts in order to either replace the traditional ones or obtain a more efficient and clean combustion. The pollutant emissions from the combustion of the fossil fuels for power generation

and propulsion systems have been negatively affecting the environment. MILD combustion processes evolve in a temperature and concentration range outside the sphere of interest of standard combustion processes, with the aim of lowering the

maximum temperature of the whole process below the value at which substantial pollutant formation

occurs. It represents a trade-off between optimizing fuel conversion in terms of energy saving and pollutant

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abatement, and maintaining the configurations of traditional processes. The stability, near-homogeneous temperature and concentration profiles, reduction and abatement of pollutants, and very specific oxidative structures, which differ from the traditional thin flame, make. Mild combustion is a unique process in terms of environmental sustainability.

The process of injecting a diesel fluid into the thermodynamic behavior of a working fluid (air or gas) has been a priority in the research of the phenomena that occur in combustion systems. Due to technological improvements it's possible in present times to characterize the injection fuel process in such conditions that match those happening when the engine is running under standard conditions, hence the purpose of these studies, which focus in the achievement of a perfect mixture between the working and active fluids; as a result of this, a series of consequences are triggered that lead to an optimum combustion, and therefore in the improvement of the engines capabilities. In diesel engines the combustion process basically depends on the fuel injected into the combustion chamber and its interaction with the air.

The injection process is analyzed from this point view, mainly using as basis the structure of the fuel spray in the combustion chamber, making this study

of high importance for optimizing the injection process, and therefore reducing the pollutant emissions and improving the engines performance.

The diesel spray can be defined with the following physical parameters.

1. Spray tip penetration
2. Spray angle
3. Break up length

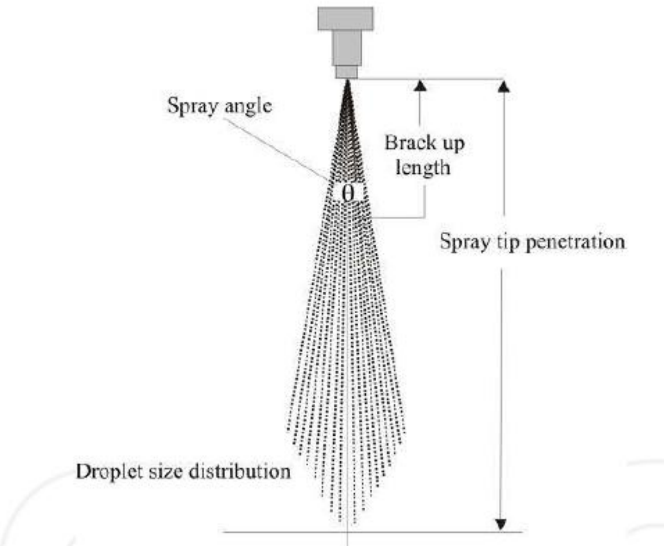

Fig 1. Physical parameter of a diesel spray

II. EXPERIMENTAL METHOD

Construction

It consist of a nitrogen cylinder of capacity 47 liter in which the gas occupied volume is 7 cum. Fuel tank of capacity 14 liters , pressure gauges of various range, non-return valve, fuel nozzle from 1.87 kg/hr. to 7.22 kg/hr. , a movable stand. A CCD camera imager pro sx 5m having resolution 2448 x 2050 pixel, an Nd: YAG double cavity laser, laser controller in which the coolant is their which need a temperature around 23-26 ^{0}c, diffuser light for shadography purpose, and at last a traversing system on which a fuel nozzle is mounted for proper location of fuel nozzle, it have a stepper motor due to which it is able to move the nozzle in X and Y direction with a fine accuracy. Also there is a glass chamber circulated around the nozzle to avoid the dispersion of fuel.

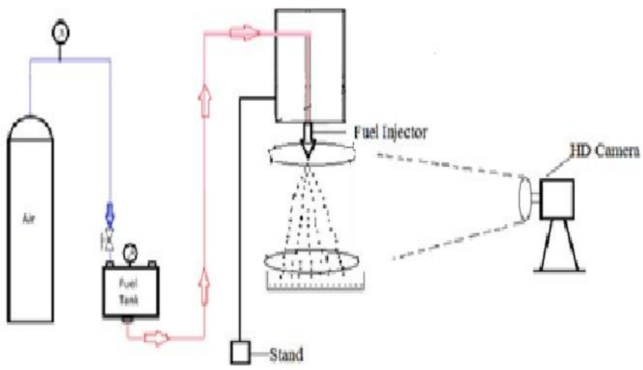

Fig 2. Schematic Diagram of the Experimental Setup For atomization of fuel

Working

Initially we poured the fuel in tank and pressurized it as per the requirement with the help of pressure regulator. The fuel are design in such a way that it can sustain pressure up to 14 bar. We can measure the pressure of fuel with the help of fuel pressure gauge. This fuel is supply to the nozzle which is mounted on a traversing system. This system is able to move in a horizontal as well as vertical direction.

Fuel is filled in a fuel tank and it is pressurized up to required pressure, in my case say up to 4, 6, 8 bar of nozzle 5.84 kg/hr. i.e. 1.5 gallon/hr.

Once the fuel supply is started simultaneously the laser as well as camera should be start to capture the images. After capturing the images we need to process that image which gives us the sauter mean diameter of fuel droplet, break up length of that dispersion, velocity. Same procedure is for PIV as well as Shadography. Remaining droplet is collected in a pan. This process is repeated for different pressure shown above and if we get the break up length of dispersion up to pan, then this is the final pressure at which it will work effectively.

III. LASER DIAGNOSTICS SYSTEM

Particle Image velocimetry

We have number of techniques to measure velocity in the flow field but all these techniques require a sensor which has to be positioned in the flow field. As such, these procedures are prone to position error. Also the instrument will disturb the flow field and it will sense only a small region of flow field. And hence it is not possible to measure the instantaneous velocity field. Therefore a new technique was evolved which used laser and optical system to measure the velocity field by tracking the individual particle in the flow field. For continuous flow it is necessary that the flow field should have proper number of particles that can illuminate the laser light and it should be small

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enough to keep the flow field invariant. These particles, called seeding particles, are externally mixed with the flow.
This technique is called Particle Image Velocimetry (PIV). It works on a simple principle. For example, to find the velocity of a river, we put a light weight object on the river and measure its displacement in a given time interval. Similarly, in PIV, we take two images back to back in a given time interval and then find the displacement of the individual particle and hence the velocity field is determined. If the PIV is to be used for measuring velocity of droplet in a liquid spray, then the external seeding of particle is not required, because the droplet of the liquid will give enough illumination to be captured by camera.

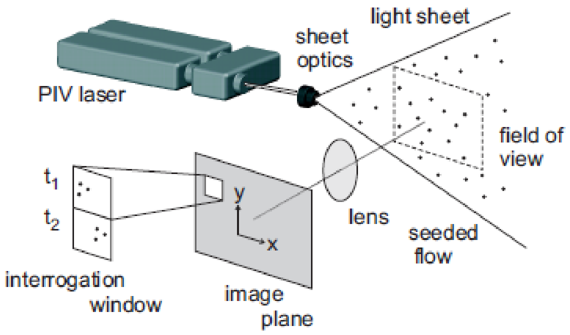

Fig. 3.1: Setup for PIV

Shadography
Another technique which is used for measuring the fuel parameters is shadography. The shadowgraphy technique (backlighting) is used to visualize particles (e.g. droplets from a spray or bubbles in liquid). The technique is based on high resolution imaging with pulsed backlight illumination (see Fig.3.2) the measurement volume is defined by the focal plane and the depth of field of the imaging system. This technique is independent of the shape and material (either transparent or opaque) of the particles and allows to investigate sizes down to 5 µm using an appropriate imaging system and light source. [6][7]

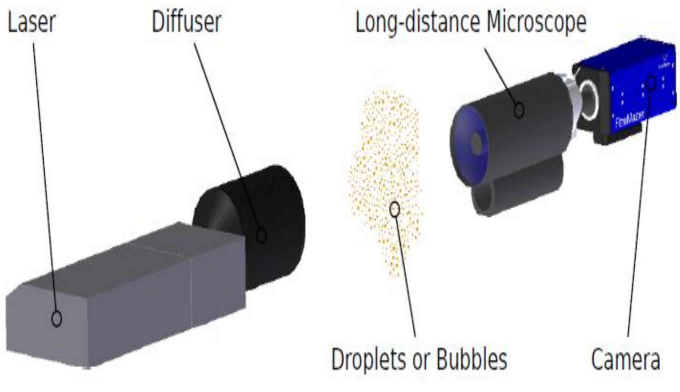

Fig. 3.2: Shadowgraphy setup

IV. Results and Discussion

The following figures show the PIV raw image of kerosene spray at 4, 6 and 8 bar pressure which explain the variation in spray with the injection pressure. The Image explain that the spray cone angle increase from low injection pressure to high
injection pressure. The size of the window covered by PIV is 12 cm X 10 cm. At every individual pressure we captured 200 images and the outcome will be the mean of that images.

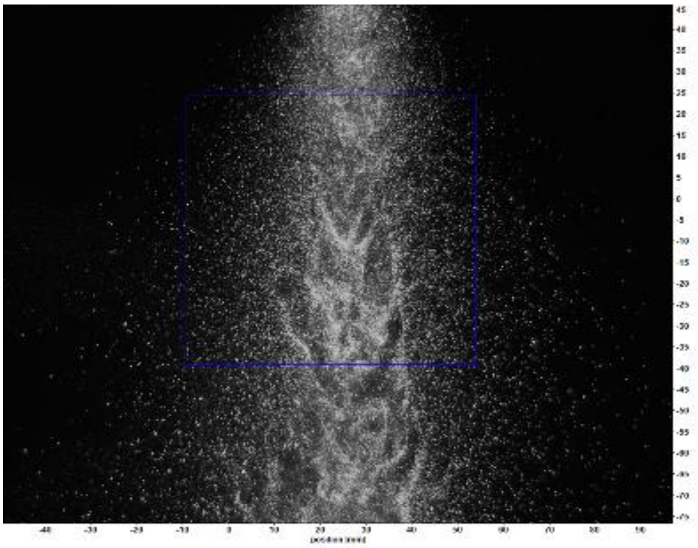

Figure 4.1: Sample Image of kerosene spray from nozzle tip

From the image in Fig. 4.2, it can be observed that the velocity at the axial location is quite high compared to the other region. Also the direction of the vector shows the movement of droplets in the downstream direction. This post processing is done without any kind of masking to understand the effect of spray on the surrounding medium. The PIV result of nozzle spray at 10 mm downstream

shows that the maximum velocity of the droplet is found near the axis of the spray and the magnitude

of the same is found to be 6 to 8 m/s. From the vector length image it can be observed that with the increase in pressure, the width of the high velocity column increases. This shows that the impact of pressure is directly proportional to the number of droplets influenced. In some of the images, the velocity of droplets in the vicinity of the spray is considerably high. This is due to the vorticity of surrounding air.
The post processing of the images is done with the help of Davis software. With the help of this we are able to find the velocity vectors.

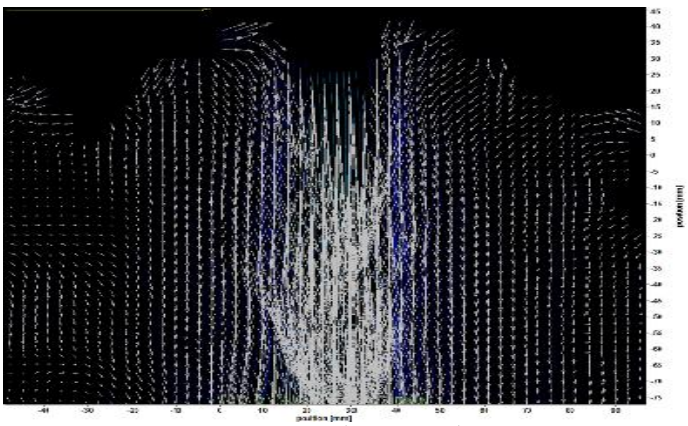

Figure 4.2. Sample vector field image of kerosene

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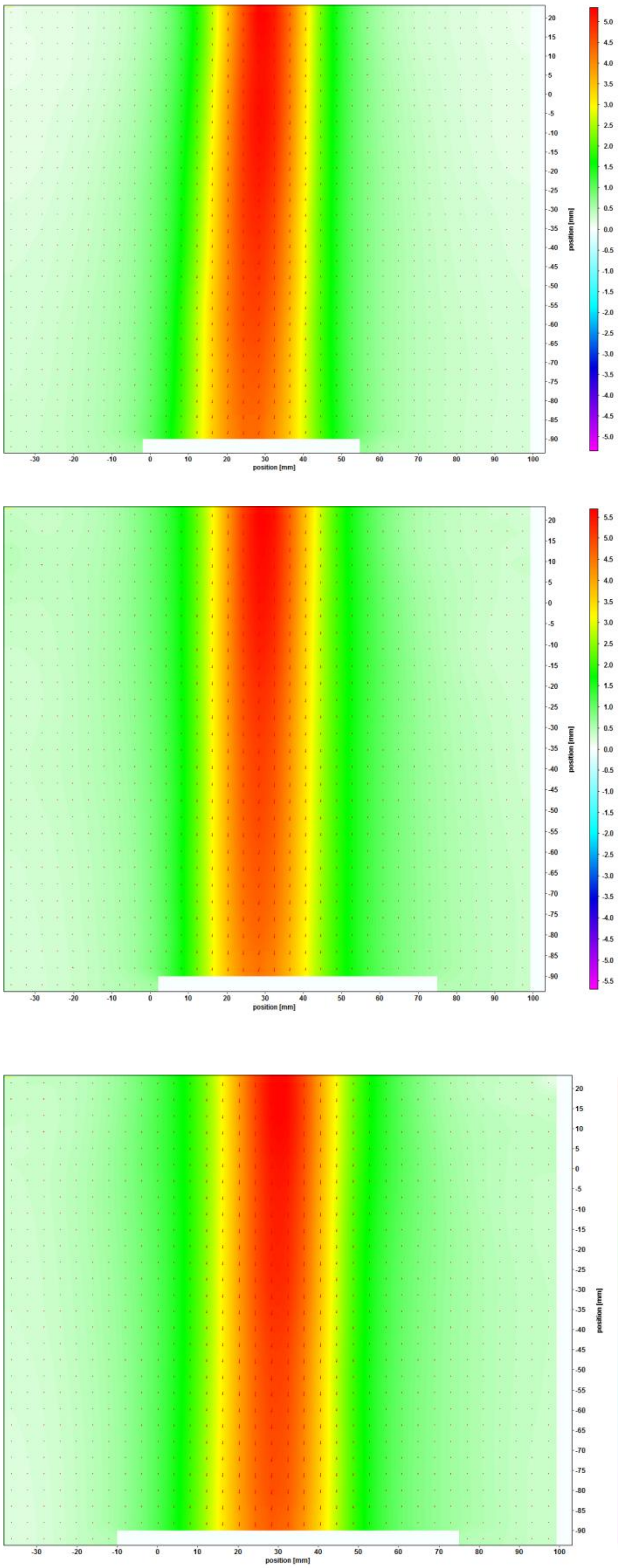

Figure 4.3. Vector length at 4, 6 and 8 bar from 10 mm from nozzle tip.

To analyse the droplet size i.e. SMD, similar images get captured.

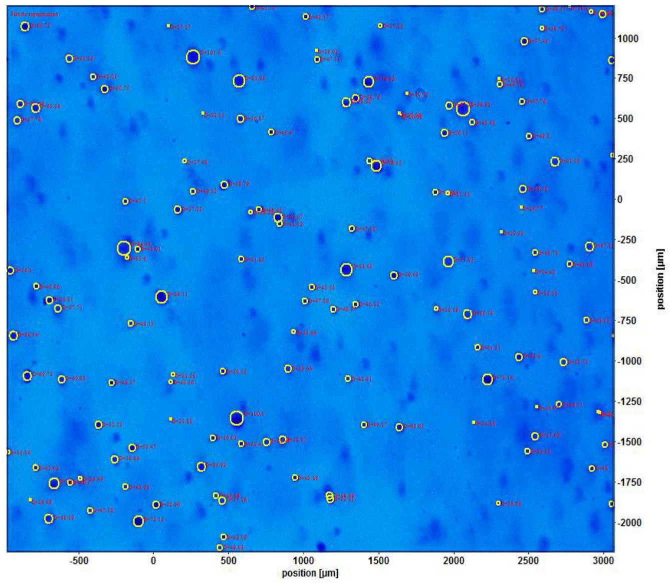

Figure 4.4: Processed image of shadow graph

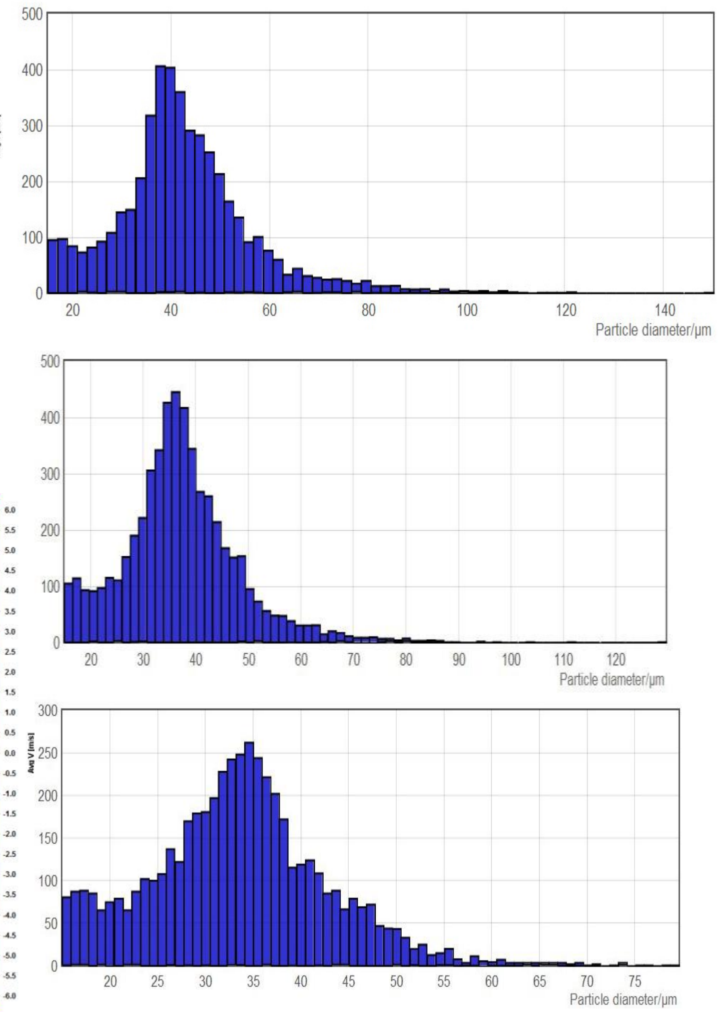

Figure 4.5: Diameter histogram at 4, 6 and 8 bar injection pressure

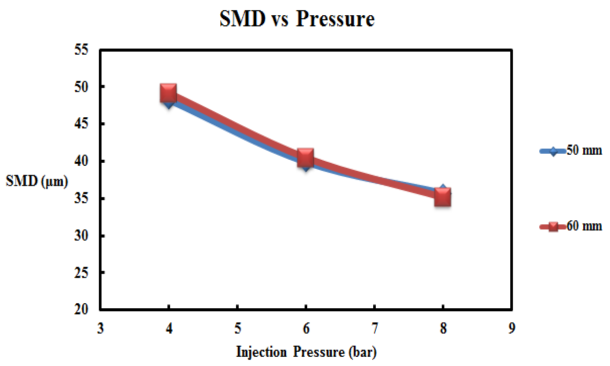

Figure 4.6: SMD variation with location and pressure

V. CONCLUSIONS

It is observed that PIV results have shown that the velocity of the droplet does not change considerably with increment in the injection pressure from 4 bar to 8 bar. However, the spreading of spray is found to increase with increase in injection pressure, with respect to the raw image of the spray of figure 4.1.

In figure 4.3 and figure 4.4, one can observe that the width of the reddish zone (i.e. high velocity zone) in PIV result is increasing with pressure, showing more number of formation of droplet with high velocity in the range of 6 to 7 m/s. From the observation of the shadowgraphy results have shown that the size of the droplet for kerosene spray change considerably with increment in the injection pressure from 4 bar to 8 bar. This shows that the pressure swirl nozzle gives fine atomization with increase in injection pressure without considerably changing the velocity distribution. The SMD of the kerosene spray will be in the range of 35 to 49 um for the given range of pressure and downstream locations and this result are comparable with result found by Reddy et al, [1]. The reason of smaller SMD at 8 bar is due to the spray properly formed at this pressure and this gives fine atomization.

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