VISUALIZATION OF DIESEL JETS THROUGH FUEL INJECTOR NOZZLE

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Abstract: The fuel injector nozzle break fuels into droplets, form the spray pattern, and propel the droplets into a combustion chamber. The nozzles determine the amount of spray volume at a given operating pressure, the travel speed, and spacing of the jets of fuel. In fuel injection, the smallest possible droplet size is wanted for the most flow. This work presents an opportunity to use the Schlieren arrangement as a visualization method to view the flow of fuel from an injector nozzle which cannot be seen by the naked eye. The jet flow of Diesel Fuel through a three-hole fuel injector nozzle was investigated by Schlieren photography. A test rig was designed and constructed to accommodate the nozzle; optical mirrors were arranged according to Schlieren specifications in order to allow the jet to be photographed. The breakaway pressure of the nozzle was set at 80bar. A three-hole fuel injector nozzle in which each hole is 0.26mm in diameter and 120° apart was used; the third jet could not be seen from the images because the camera took x-y dimension images. The spray pattern observed from the two dimensional images of the jets developed were seen to be well dispersed. Su et al [3] found that emissions could be reduced in diesel engines if the injector nozzle produces smaller and more dispersed droplets.

Keywords: diesel, jet, nozzle, Schlieren, visualization

1.0 Introduction

The nozzle determines the amount of spray volume at a given operating pressure, the travel speed, and spacing of the jets of fuel. In fuel injection, the smallest possible droplet size is desired for best combustion. Su et al [3] found that reduction in emissions from diesel engines can be achieved if the injector nozzle produces smaller and more dispersed droplets.

In agricultural sector, selecting nozzles that produce the largest droplet size while providing adequate coverage at the intended application rate and pressure can minimize drift [2]. Drift in this context means that some droplets of fertilizers/pesticides were moving away from a common direction of flow. It is important to select a nozzle that develops the desired spray pattern.

Flow Visualisation is very useful in basic fluids research for discovery, exploration, qualitative insight, and quantitative measurement. Schlieren and Shadowgraph photography allows for the visualisation of the density gradient (Schlieren) or the second derivative of density (Shadowgraph) of the gas in a compressible flow.

Schlieren and Shadowgraph methods are closely related, but there are several distinctions. Schlieren methods require a knife-edge or some other cut-offs of the refracted light, where no cut-off is used in shadowgraphs.

The Schlieren image is an optical image formed by a lens, and thus bearing a conjugate optical relationship to the Schlieren object. The illuminance level in a Schlieren image responds to the first spatial derivative of the refractive index in the Schlieren, e.g. $\delta n/\delta x$. The shadowgraph however responds to the second spatial derivative or laplacian, e.g. $\delta n^2/\delta x^2$. [1]

Both Schlieren and Shadowgraph are integrating optical systems that project line of sight information onto a viewing screen or camera focal plane. Light propagates uniformly through homogeneous media; it slows upon interacting with matter. [1]

The refractive index, n= c_0 /c of a transparent medium indicates this change, where c is the speed of light in the medium and c_0 is the speed of light in a vacuum usually given as $3x10^8$ m/s. For air and other gases there is a simple linear relationship between the refractive index and the gas density ρ given by [1] below as:

$$n-1= k\rho \quad (1.1)$$

The Gladstone-Dale coefficient, k, is about $0.23cm^3/g$ for air at standard conditions (1 atm; 273K) using white light. For other gases, it may vary roughly from 0.1 to 1.5.

The refractivity (n-1) of a gas, from equation 1.1, depends upon gas composition, temperature, density and the wavelength of illumination. In many cases, the temperature, density and pressure of gases are further related by the simple perfect gas equation of state

$$P= \rho RT \quad (1.2)$$

R is the specific gas constant usually given as 287J/kg.K for air

Compressible flows may arise from temperature differences, high gas speeds or large pressure gradients. These possibilities lead to gas disturbances that refract light, and can be visualised because of this refraction.

The sensitivity of a measuring instrument is one of its basic characteristics, relating the instrument's output to the input received. In the case of Schlieren optics it is convenient to use the z-type mirror system to illustrate the geometrical optics of Schlieren sensitivity.

2.0 Objective

The aim of this project was to use Schlieren arrangement to visualise the diesel jet flow from a three-hole fuel injector nozzle in order to describe the flow pattern.

3.0 Materials and methods

3.1 Materials

For the experiment, a diesel injector nozzle, hand fuel pump, diesel fuel, two parabolic mirrors, knife edge, light source, camera and the test rig were all required.

3.1.1 Basic description of the test rig.

The test rig was made from mild steel, it consists of four steel rods each threaded (M8) at ends, a drip tray, two steel plates, a steel piece and three window glasses. The four steel rods connects the two plates together, the steel piece hold the injector tightly to one of the plates, the drip tray collects the fuels as they exit the nozzle and the three window glasses prevented the fuels from splashing out of the rig. The figure below shows the exploded view of the test rig.

3.2 Method

The room must be completely dark to take pictures of the Schlieren image. Room ventilation was blocked off and stray air currents were tamed during the experiments, the room was vibration free for the Schlieren imaging. A workbench big enough to accommodate the length of the Schlieren field was used.

3.2.1 Setting-Up/Adjusting the Z-type Schlieren Arrangement

Good Schlieren photographs of high sensitivity can be made only when the system has been properly aligned and adjusted. The first step was to obtain a sharply focussed image of the light source on the first knife-edge. This knife-edge was made from a new razor blade, and it was inserted far enough into the beam at the point of best focus so as to intercept about half the incident light. The first Schlieren mirror was placed exactly one focal length of the parabolic mirror (ninety-one centimetres) away and so positioned as to receive the entire diverging beam from the knife-edge. At first the emergent beam was not parallel; the mirror was repositioned for the reflected beam from the mirror to have uniform parallel rays. This mirror was adjusted until the reflected beam makes the smallest possible angle with the diverging beam from the first knife-edge.

The second Schlieren mirror was then placed so as to receive the parallel bundle of rays from the first mirror, and at least two focal lengths away from the first mirror for convenient field location. By tilting this second mirror slightly, the converging beam coming from it is deflected slightly to one side; the angle was the same as that between the first knife-edge and the first mirror. The second knife-edge was then placed precisely at the focal point of the second mirror and rotated so that its edge is exactly parallel to the sharply defined edge of the light beam. It has the unique advantage that parallel rays of light pass through the Schlieren field, thus producing an image of good resolution. The least permissible separation of the mirrors is about twice their focal length in order to provide space for the Schlieren field between the entrance and exit cones of the light.

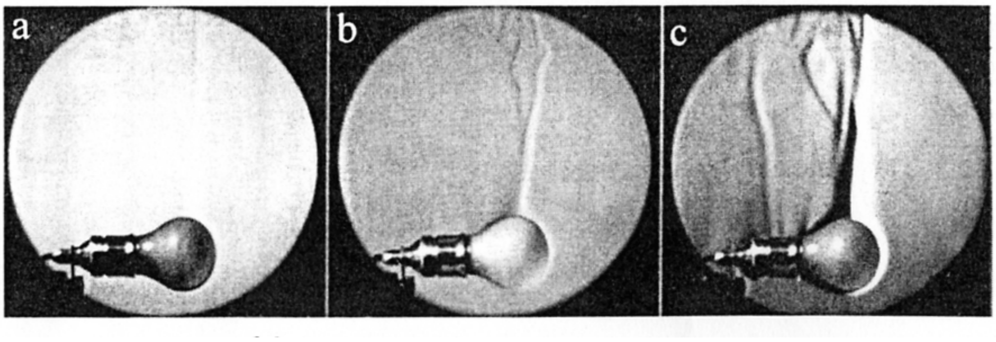

Figure 1: shows Schardin's images of thermal convection from a light bulb with increasing sensitivity settings [1]

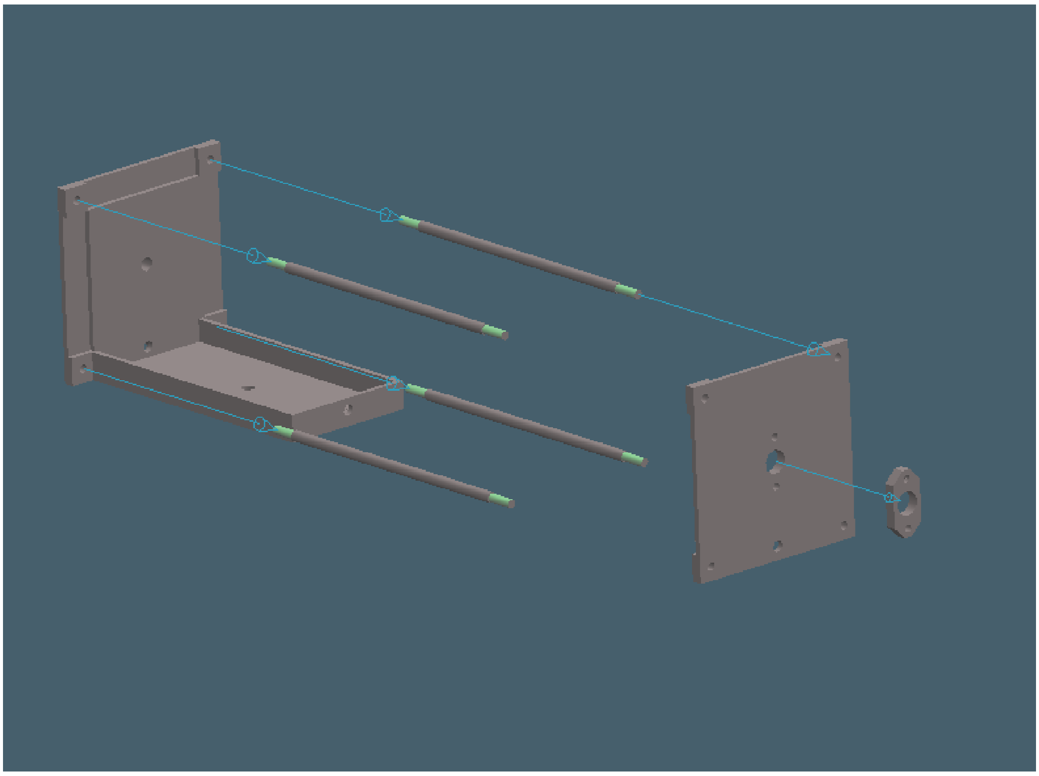

Figure 2: Exploded view of the test rig

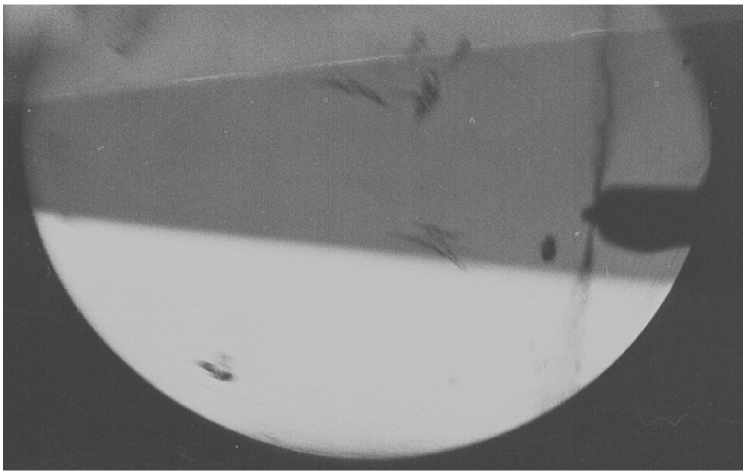

Figure 3: Image 1

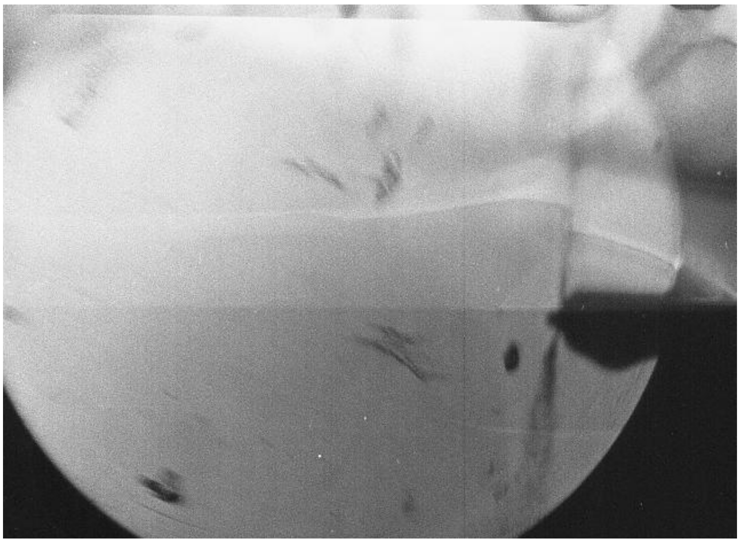

Figure 4: Image 2

Figure 5: Image 3

3.2.2 How the technique works

The fuel flow from the pump through a delivery line, the pressure at which the fuel is flowing in the line was seen on the display unit. The pressure transducer in the arrangement could only handle a maximum pressure of 100bar, by loosening the threaded end of the injector, the breakaway pressure was set to 80bar. The signal from the transducer was also viewed on the oscilloscope. After several attempts of trying to see how many times the fuel exits the nozzle at a particular pressure, a trigger position was indicated on the oscilloscope. And it was noticed that there was always a rapid pressure drop whenever the fuel exits the nozzle.

As the pressure on the fuel line increases, there was always a fallen signal from the oscilloscope. As the fallen signal get closer to the trigger position on the oscilloscope, a bellow or air release connected to the camera was squashed in order to open the shutter, the SGLS button on the oscilloscope was then pushed and the light source was triggered within 1 –2 seconds to take the Schlieren image in sight and the bellow was now released to close the shutter. After each shot, the camera was wound and set to take another shot.

4. Results and discussion

The aim of the project was to visualise the jet flows through diesel injector nozzle. It can be seen from the pictures that jets of high velocity were achieved when the breakaway pressure was set at 80bar. A further adjustment of the breakaway pressure to about 60bar was done and what came out of the nozzle were no longer jets but pool of fuel.

The Schlieren image 1 can be seen from the tip of the three-hole nozzle, the image shows two jets, one in upward direction and the other one in the downward direction. The sensitivity of this image is very good. The upward flow of the image could be seen to a significant length and that the flow started diminishing at about halfway in the downward direction.

The image 2 is quite similar to image 1 except that the upward flow here is not as visible as in image 1, this may be due to the time the picture was taken. This picture is definitely taken at a later time compared with image 1.

The Image 3 a good Schlieren image taken from the experiment. The jets look very sharp. Though, a three-hole nozzle was used to inject the fuel, two jets can be seen on all the images. The jets shown are almost at 180° apart, but the nozzle used was a three-hole which are 120° apart.

5.0 Conclusion

It can be concluded that a significant reduction in the breakaway pressure of a three-hole nozzle from 80bar to about 60bar significantly affects the spray break-up of diesel. It has also been established that the process developed in this study was able to visualise and describe the jets of diesel through a three-hole nozzle.

For further study, a research that will use the process developed in this study to visualise jets of di-methyl ether (DME) through a three-hole and a four-hole injector nozzles should be conducted, in order to compare the jets of both fuels.

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