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Application of spray impingement technique for characterisation of high pressure sprays from multi-hole diesel nozzles

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ABSTRACT

An attempt has been made to study and characterise the performance of two multi-hole nozzles of different nozzle hole geometry using the impingement technique. The technique was able to characterise the nozzle geometry and the near nozzle spray characteristics. The transients of the needle motion, dynamics of the pressure fluctuations were all reflected in the momentum flux measurements. The impingement distance had no significant effect on the derived injected fuel mass and the nozzle discharge coefficient. The momentum of the spray was observed to be strongly dependant on the fluctuations of the injection pressure but the average nozzle discharge coefficient for an orifice was not significantly influenced by different injection pressures. Numerous transients were observed to occur in the spray parameters over a single injection cycle and the transients in the spray were unique for an orifice and varied from one orifice to another in the same nozzle. This technique proves to be a vital tool for predicting the transient performance of high pressure nozzle flows.

1. Introduction

Emissions from engines have caused concerns due to global warming, degradation of environment and adverse health effects. In response to climate change phenomena, governing bodies in United States and Europe have proposed stringent emissions regulations on the automotive industries to meet targets in the foreseeable future. The key parameters that contribute to air pollution from engines are nitrogen oxides (NO_x), carbon monoxide (CO), hydro carbons (HC) and particulate matter (soot). These emissions are the consequence of inefficient combustion and have an undesirable effect on public health and the environment. Automotive industries are seeking different solutions to meet the stringent emission regulations. One of the preferred methods is to find a solution by controlling the combustion process and making it as efficient as possible. Solutions via after treatments tend to be overlooked by some engine manufactures, as they lead to increased components and hence high cost of production, maintenance and regeneration. The production of CO_2 is inevitable in engines as it is a product of combustion, but the stringent steps taken to meet the regulations contributes to the reduction in CO_2 emissions. However after treatment, additives and alternative fuel prove to be a better solution to reduce CO_2 emissions. In addition to complying to the emission regulations, the other important criteria that the industry tries to achieve is to improve the fuel consumption. Any reduction in fuel consumption has a significant effect on the maintenance cost of the vehicles and the fuel economy.

The ability to control the quantity of fuel injected into the combustion chamber in diesel engines opens the door for extensive research in optimising the combustion process. Research has lead to technical developments which have resulted in state of the art injection systems and engine control systems which combine to produce efficient combustion system with low emissions and fuel consumption. The common rail diesel fuel injection system is a typical example which has lead to controlled combustion and significant reduction in emissions and fuel consumption. The system is capable of generating very high pressures and also having a significant control over the injection quantity and injection timing. The common rail injectors possess significantly smaller orifice area and hence increased number of orifices in the nozzle. The characteristics of the injector together with ability of producing very high pressures, in the range of 2000 bar, increases air entrainment and enables better mixing of fuel with air.

Characterizing the behaviour of the spray inside the combustion chamber and the significance of orifice geometries has become a prime importance in recent years as it determines the fuel-air mixing and the spray combustion process. Various techniques are being used to study the spray mixing phenomena. The most extensively used application is the optical method where the spray is injected into a nitrogen filled combustion chamber, which is illuminated using laser

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as a light source. The scattering signal from the fuel droplets in the spray is imaged using the state of the art high speed digital cameras, which can be analysed further. In order to correlate the spray patterns with the emissions, the injectors are tested under the same conditions in a conventional diesel engine. Flow rigs are another type of application which characterises the spray and orifice geometries by measuring the mass flow rate of the injectors.

The impingement technique is the most simplified application used to characterise spray and nozzle geometries. This technique is based on measuring the instantaneous force (momentum flux) of the injected fuel jet on a normally mounted sensor. The momentum of the spray strongly influences several important factors such as spray penetration, spray cone angle and air entrainment [1]. Spray momentum provides information about the mass flow rate and the flow exit velocity and it also controls the fuel-air mixing process [2]. The discharge coefficient can also be evaluated from the momentum flux measurements and is considered to be the most important functional parameter that governs the nozzle flow of an injector over the entire operating range [3]. The discharge coefficient (C_d) is defined as the ratio between the actual flow passing through the orifice to the flow that would pass through the same orifice at that pressure drop if the flow is frictionless and without any contraction or phase changes. The discharge coefficient depends on the properties of the flow and that of the fluid and of the nozzle geometry [3].

The impingement technique has been successfully used in the past by other authors [2–5] to determine the spray momentum flux, orifice discharge coefficients, injection rates, jet velocities, spray penetrations and the transients that exist during an injection cycle. However, limited work has been done to determine the momentum characteristics of multi-orifice nozzles with different geometrical configurations. Thus, this work will extend the database of the existing literature to characterise the nozzle geometry effects on the sprays that are injected from two multi-orifice nozzles for different fuel injection parameters.

2. Theory and calibration

The main objective of this study is to determine the discharge coefficient, injection rate and the instantaneous velocity of the spray from the momentum flux and injection pressure measurements for two different nozzles of different nozzle hole geometries. The fundamental equations relating these characteristic parameters were obtained from the Newton's Second Law and the Continuity Equations.

According to Newton's Second Law:

$$F(t) = \dot{m}(t)\cdot\Delta V(t) \tag{1}$$

Where $F(t)$ is the instantaneous impingement force, $\dot{m}(t)$ is the mass flow rate, and $\Delta V(t)$ is the change in velocity. In reality the collision of fuel droplets on the impingement transducer is an extremely complex process. In order to make the analysis simpler, the rebound velocity of the spray droplets after impact are assumed to be negligible compared to their injected velocity. So in this analysis the change in velocity is approximated to the velocity $V(t)$ of the spray before impact at that point along the spray axis. Since the momentum of the spray is destroyed at the sensor surface, the forces measured by the sensor can be considered to be equivalent to spray momentum flux. By applying Continuity and Bernoulli's equations at the exit of the orifice of the nozzle, the discharge coefficient can be derived as:

$$C_d = \frac{\dot{m}(t)}{\dot{m}_{\text{theo}}(t)} = \left[\frac{F(t)}{2\cdot A_0\cdot\Delta P(t)}\right]^{\frac{1}{2}} \tag{2}$$

where A_0 is the cross sectional area of the flow and $\Delta P(t)$ is the change in pressure (Injection pressure–back pressure). Detailed derivations of equation (2) are provided in [3–5].

Instantaneous discharge coefficient will provide information regarding the dynamic changes that are occurring in the nozzle flow during the short injection time period of few milliseconds. In addition to capturing the dynamic changes in the nozzle flow, information regarding the nozzle internal geometry can also be inferred through the nozzle discharge coefficient. Thus, the impingement technique will provide information regarding the nozzle discharge coefficient, injection rate and the instantaneous velocity of the spray at any time (t) and the cumulative mass flow from an orifice, per injection cycle.

A piezo-electric pressure transducer, Kistler (Type-601A), was used for the impingement measurements and the output from the transducer was amplified by a Kistler charge amplifier (Type 5009). The transducer was mounted on a test bench with its diaphragm protruding, in a horizontal vise and it was force calibrated. Calibrated weights of 0.5 N, 1 N and 2 N were used for the calibration process. These weights were chosen as they are in the same range as the forces exerted by a single injector spray [1,2,5]. A total of 50 readings were obtained for each calibrated weight and their mean values were used for calibrating the transducer for the momentum flux measurements. The principle of the spray impingement technique is shown schematically in Fig. 1.

3. Experiments

The schematic of the developed spray impingement test rig together with the high pressure common rail fuel injection system is shown in Fig. 2. The fuel system compromised of a fuel tank, fuel lift pumps and a motor driven high pressure common rail pump. The injection system is capable of generating pressures up to 1500 bar. The lift pump was used to supply fuel to the high pressure pump as the fuel tank was at the lowest point in the hydraulic system. An instrumentation rack consisting of a computer and an injector driver unit was used to drive the injector in the impingement rig. The Em-tronichs programme was used to control the pump and the injector driver unit. A separate computer with an integrated data acquisition system was used for data acquisition. The data acquisition system consists of a high speed data acquisition card, SCB-68 and Lab View programme was used as the driver software. Lab View was programmed to acquire the input signals and collate the acquired data. The injection signal, impingement signal and the pressure transducer signals were measured using the

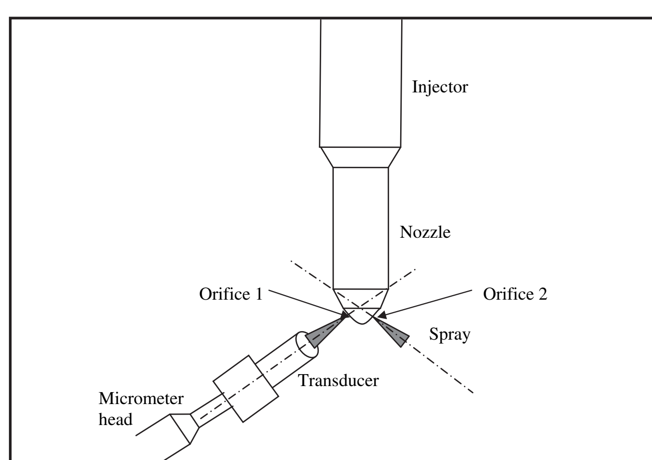

Fig. 1. Schematic of the spray impingement technique.