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SWIRL DIRECT COMMON RAIL INJECTION SYSTEM: REMARKABLE DIMENSION IN DIESEL FUEL TECHNOLOGY

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ABSTRACT

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With the increasing demand of diesel internal combustion engine worldwide, the need for fuel economy resulted in the development of diesel fuel injection system take place in modern research. The latest common rail injection (CRI) mechanisms are making a combination of the high performance of the petrol engines and superior fuel economy characteristics of diesel engines. A lot of studies have been conducted on the improved technology, and it is now definite that the advantages of CRI systems are undeniable. Its outstanding advantages in technical, economical, and environmental fields, Swirl direct CRI systems are superior to previous engine technologies. This system is a modern variant of direct fuel injection system for internal combustion engines. In diesel engines, a high pressure fuel rail feeding individual solenoid valves is featured. As opposed to low pressure fuel pump feeding unit injectors or high pressure fuel line to mechanical valves controlled by cams on the camshaft; this system is efficient due to variant of direct fuel injection system. The key component of the system is the solenoid valve controlled injector and the development of the injector nozzle with several mechanical modifications (especially helical gear type swirl spray unit and injector cap) results to deliver the outstanding idle quality, unparalleled flow consistency and unrivaled durability essential for high performance fuel injection. The technology ensures the injection spray patterns and mixing of fuels with the intake air at a good ratio which results good combustion inside the engine that leads to improvement in engine efficiency, fuel economy etc. The result shows, at high pressure the swirl nozzle refers to maximum volume of fuel consumption, which is important for burning inside the engine that ensures improvement of driving performance and higher fuel economy which is important for efficient common rail injection technology.

Key words: *Common Rail Injection (CRI), Injector, Swirl, Diesel engine*

INTRODUCTION

Rapid progress in fuel injection technology over the years has played a key part in contributing to the development of engines with higher fuel efficiency and lower emissions. In diesel engines, common rail injection system features a high-pressure fuel rail feeding individual solenoid valves, as opposed to low-pressure fuel pump feeding unit injectors, or high-pressure fuel line (rail pressure sensor is located that gets connected with the electronic control unit, ECU) to mechanical valves controlled by cams on the camshafts. Here fuel is led to the common rail, a high-pressure reservoir built as a pipe with pressures in the area of $1200 < P < 2000$ bar. From there the fuel is regulated and led to each cylinder (Gunter *et al.* 2006). Third-generation common rail diesels now feature piezoelectric injectors for increased precision; with fuel pressures up to 26,000 psi. Fig. 1 and fig. 2 shows the general common rail injection system that available in diesel engines and the internal arrangement of a common rail injector respectively (Arthur 1989).

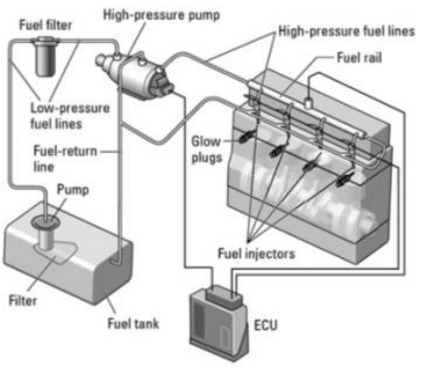


Fig 1. Common rail injection technology

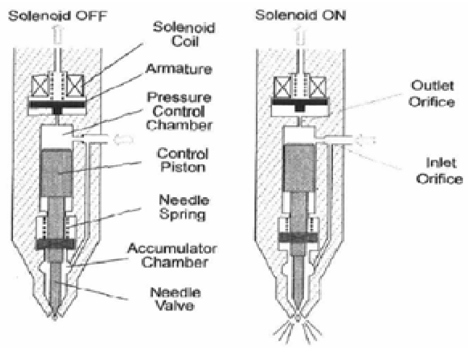


Fig 2. Common rail injector

BASIC WORKING PROCEDURE

In the common rail injector, the valve has two main holes inlet hole (Z) and outlet hole (A). The red tinted zone is called valve control chamber. The nozzle and the valve are fueled by two high pressure channels. Fig. 3 shows the valve holes and the valve control chamber and Fig. 4 shows the two high pressure channels. One channel fuels the nozzle and the other one fuels the valve.

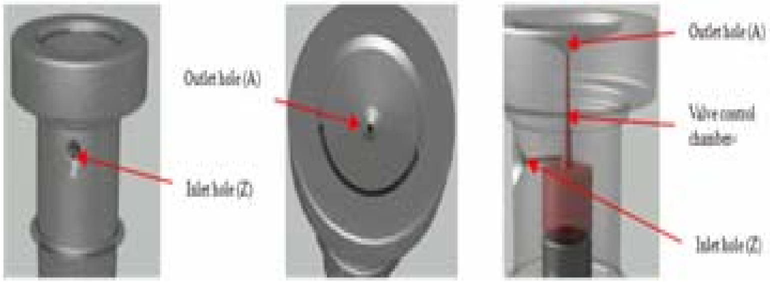


Fig 3. Valve holes and valve control chamber

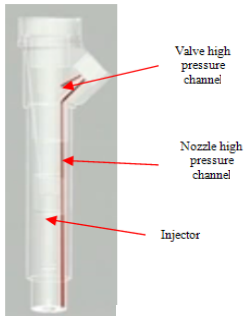


Fig 4. Valve and nozzle high pressure channel

Overflow diesel oil gets out through the top. Moreover, this low pressure flow cools the entire system. The injector opening and closing is due to a balance of forces. An elastic force caused by the nozzle spring. A force caused by the pressure of diesel oil on nozzle needle. Last force is caused by the change of volume in valve control chamber. This variation controls opening and closing. When diesel oil goes out, pressure in valve control chamber decreases. So valve control plunger modifies its position. The armature is a two piece design. So when injector closes, the force on the valve is reduced. Injector opens when the solenoid valve is energized. This technology allows precision diesel oil injection.

IMPROVEMENT FEATURES OF SWIRL DIRECT COMMON RAIL INJECTOR

The concept of the swirl direct injection system is developed to take consideration of uniform combustion inside the engine. The fuel spray pattern of the system creates swirl inside the engine and the fuel droplets are small in size. Therefore, the fuel mixes with the compressed air and ignites quickly that results good combustion which leads better efficiency. Incorporation of swirl effect in the common rail injector activates a new dimension in the diesel technology.

Improvement of Injector Components

Design of injector components mainly develops with some modification in the injector nozzle. The injector nozzle, helical gear type swirl spray unit with 14-holes and injector cap arrangement is the major concern. Application of these arrangements results to deliver the outstanding idle quality, unparalleled flow consistency and unrivaled durability essential for high performance electronic fuel injection. Fig. 5 shows the characteristics of the nozzle of the swirl direct common rail injector.

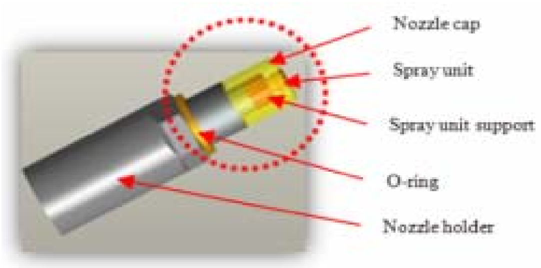


Fig 5. Nozzle characteristics

Flow/Discharge Coefficient

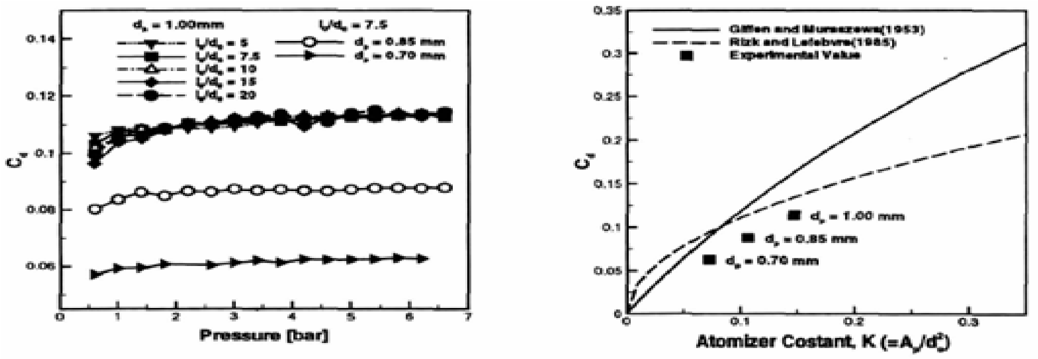
Typically, the flow coefficient determines the spray pattern. The swirl spray through the injector nozzle characterized depending on the low value of the air core. The viscosity and the flow co-efficient influence the film thickness. Generally, flow co-efficient of Re 3000 is irrelevant. *Giffen and Muraszew* offered theory by the following expression was induced in this regard,

$$C_d = 1.17[\frac{(1-X^3)}{1+X}]^{0.5}$$

Where, X is the exit area and at maximum flow conditions, the injector according to the shape of X is directly related to the variable condition. Therefore, the flow coefficient is determined by the injector geometry. *Lefebvre* also suggested the following expression of injector flow rate coefficient by the shape of the variable.

$$C_d = 0.35(\frac{A_P}{D_s d_o})^{0.5}(\frac{D_s}{d_o})^{0.25}$$

Here, the flow rate co-efficient is determined by the injector geometry that depends on the exit area and the maximum flow through the exit area. Fig. 6 represents the flow coefficient of injectors, which has a very low value.



(a) Injection pressure flow coefficient (b) Compare the flow coefficient

Fig 6. Injection flow co-efficient

Sauter Mean Diameter (SMD)

The sauter mean diameter (SMD) is defined as the diameter of a sphere that has the same volume/surface area ratio as a particle of interest. The concept was originally developed by German scientist J. Sauter in the late 1920s. It's (SMD, d32 or D) a common measure in fluid dynamics as a way to estimate the average particle size. SMD is typically defined in terms of the surface diameter (d_s) and volume diameter (d_v). Mathematically,

$$d_s = \sqrt{\frac{A_p}{\pi}} \qquad d_v = \left(\frac{6V_p}{\pi}\right)^{\frac{1}{3}}$$

Where, A_p and V_p are the surface area and volume of the particle, respectively. d_s and d_v are usually measured directly by other means without knowledge of A_p or V_p. The Sauter diameter for a given particle is:

$$SD = D[3,2] = d_{32} = \frac{d_v^3}{d_s^2}$$

If the actual surface area, A_p and volume, V_p of the particle are known the equation simplifies further,

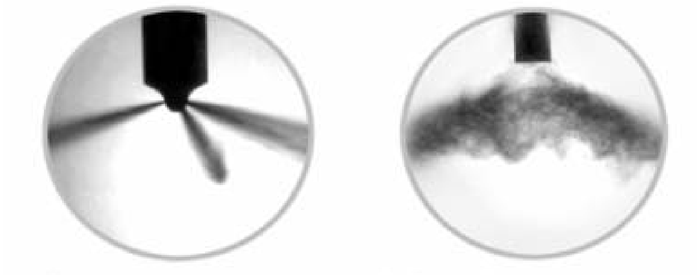
$$\frac{V_p}{A_p} = \frac{\frac{4}{3}\pi(d_{32}/2)^3}{4\pi(d_{32}/2)^2} = \frac{(d_{32}/2)^3}{3(d_{32}/2)^2} = \frac{d_{32}}{6}$$

$$d_{32} = 6\frac{V_p}{A_p}$$

Injection sprays from swirl nozzle through 14 holes results maximum spray angle as well as the measure in fluid dynamics as a way to estimate the average particle size i.e. SMD is 2.5μm whereas the conventional systems followed by 20/25μm (at needle lifting pressure of 600Kgf/cm^2 and spray pressure from the holes to the combustion chamber is 20Kgf/cm^2). Therefore, the combustion process in diesel engines can be improved to lower pollutant formation and enhance combustion efficiency by injecting fuel in the form of finer sprays i.e. smaller mean drop size (Heywood 1988).

Spray Comparison

During injection, the spray angle is one of the important issues. The spray angle determines the mixing of fuel and oxidizer which has a strong influence on combustion performance. Fig. 7 shows (a) conventional injection spray and (b) swirl direct injection spray. Modification is being done in the nozzle structure. Conventional injection sprays from 6 holes whereas the swirl injection sprays through 14 holes which results maximum spray angle.



(a) Conventional injection spray (b) Swirl direct injection spray

Fig 7. Conventional and swirl injection spray

EXPERIMENTAL MACHINE

Fig. 8 shows the experimental machine (Model: Sugwang GOLD-500) set up that is used to evaluate the performance of the injector. The experimental study is carried out with newly developed 14-holes swirl direct common rail injector. Fuel consumption and fuel return is measured at different operating conditions such as pressure, RPM, power etc.

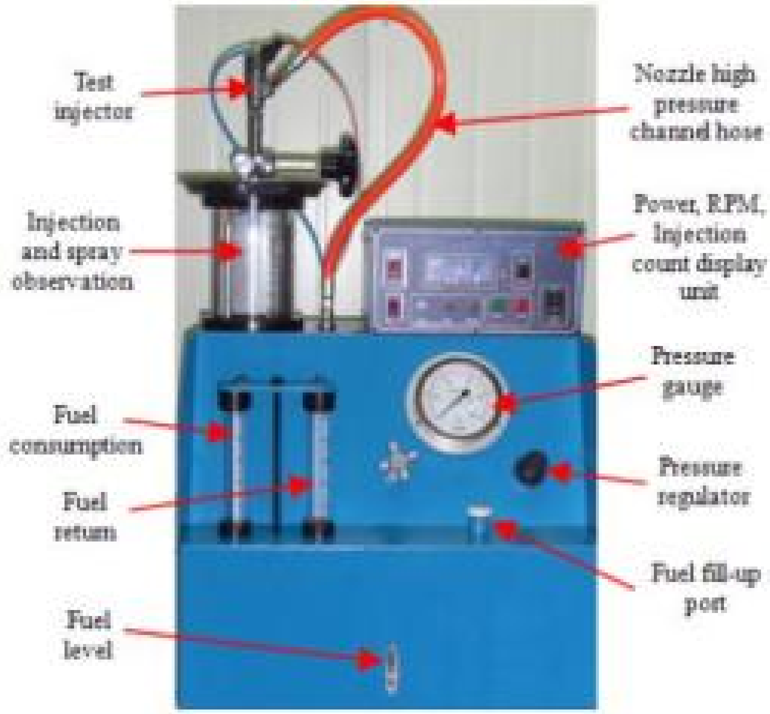
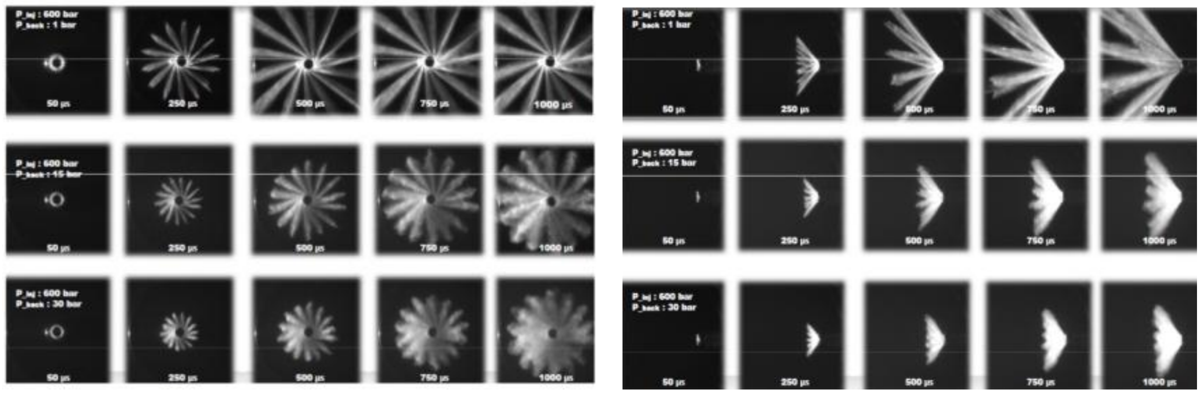


Fig 8. Experimental machine

FINDINGS AND DISCUSSION

From the experimental study, it is found that, at high pressure and motor power the rate of fuel consumption and return results good combustion that is duly characterized by short length obtained from pilot injection. This is also important for reducing the combustion noise(Giffen and Muraszew, 1953).

Fig. 9 shows, the combustion characteristic of a swirl direct common rail injector at injection pressure of 600 bar and back pressure of 1, 15 and 30 bar respectively. Improvement of injector nozzle with main injection/pilot injection (and spray) results the structure of the complete combustion.

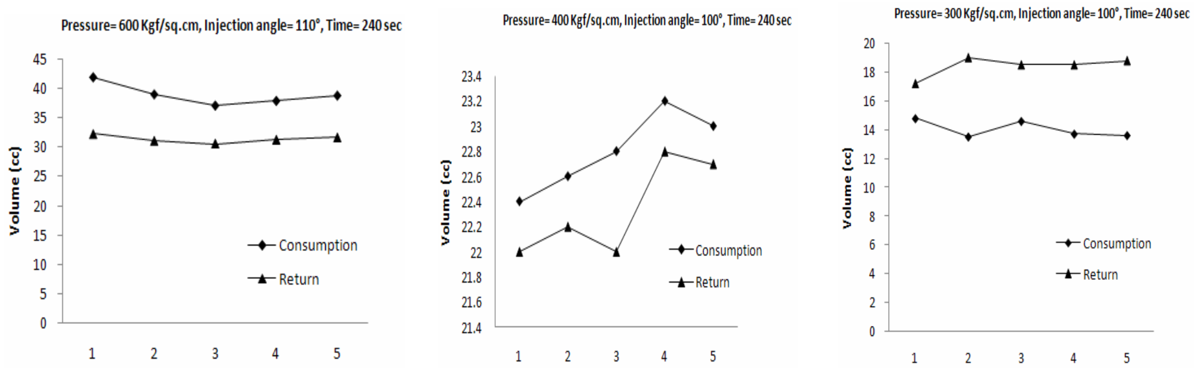


Front view End view

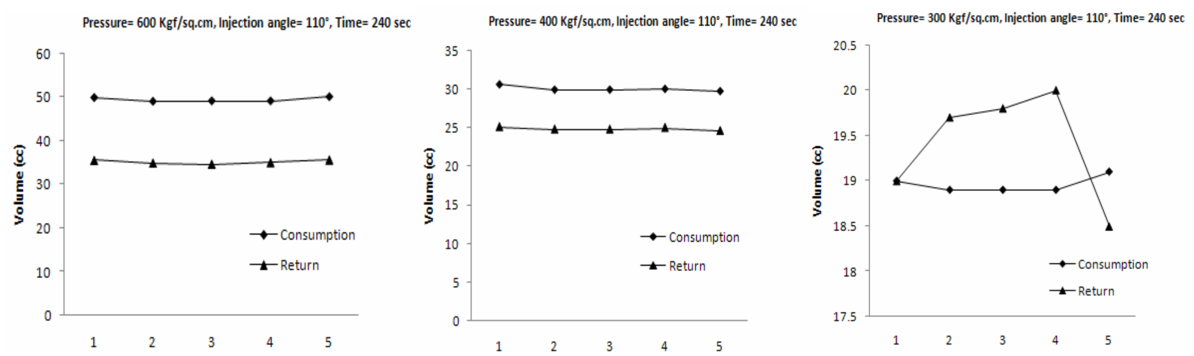
Fig 9. Combustion characteristics (Front and end view)

Fig. 10 shows the performance result of the injector by the experimental analysis. It shows that, the fuel consumption and return at different pressure followed by different power set up. Pressure is set up at 600 Kgf/cm^2, 400 Kgf/cm^2 and 300 Kgf/cm^2 respectively at power 1.0 ms, 1.2 ms and 1.5 ms.

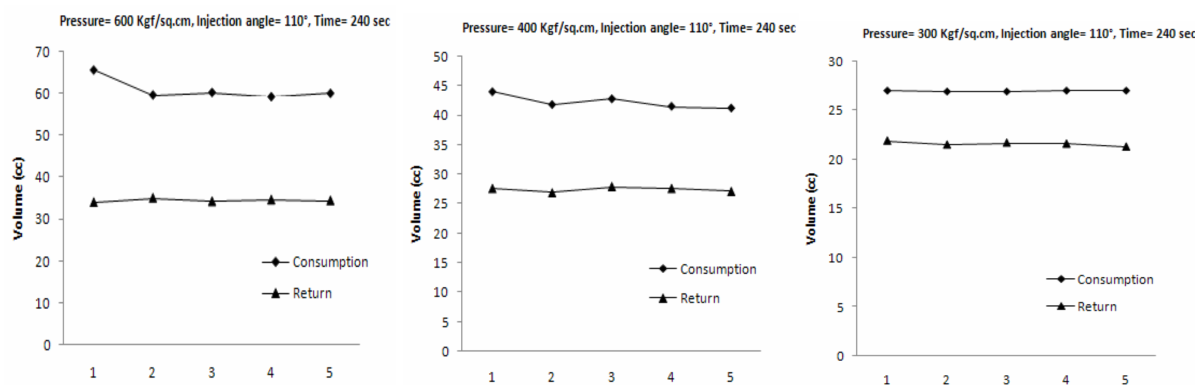
At RPM= 7Hz, power= 1.0ms and injection count= 1000



At RPM= 7Hz, power= 1.2ms and injection count= 1000



At RPM= 7Hz, power= 1.5ms and injection count= 1000



Average fuel consumption and fuel return at different power set up

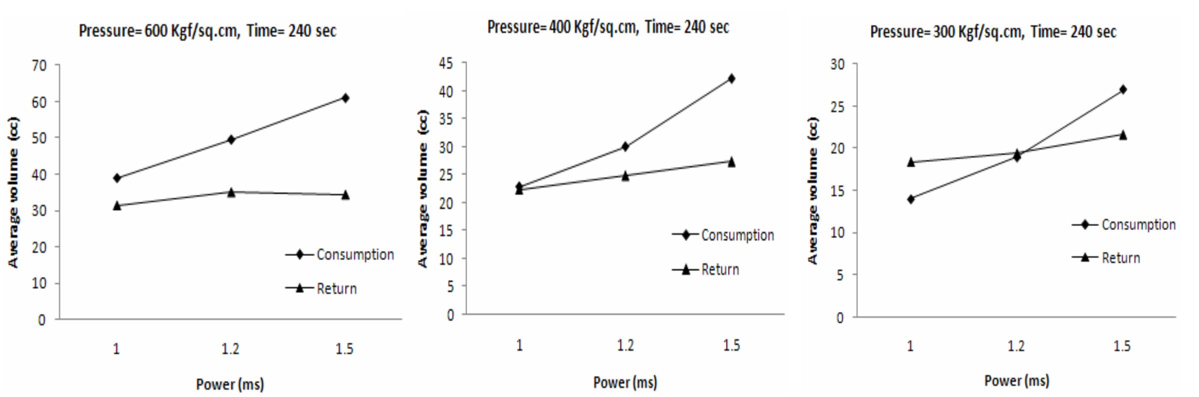


Fig 10. Fuel consumption, fuel return analysis at different pressure and power set up

CONCLUSION

Common rail injection technology accumulates high-pressure fuel in the rail and injects the fuel into the engine cylinder at timing that is duly controlled by the engine control unit (ECU). Fuel consumption and fuel return rate at different pressure set up and power is a vital issue. Common rail system allows high pressure injection independent from the engine speed. On the other hand, swirl spray from 14-holes ensures fine particle drops that maintain suitable SMD. That's why the system can reduce the harmful emission such as nitrogen oxides (NOx), particulate matter (PM) and improve the engine efficiency.

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