A Review on Fuel Injector Performance and Emission Characteristics of a Diesel Engine

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Abstract--- Diesel engines are primary source of power for the heavy duty vehicles. The advantages of diesel engines are high fuel efficiency, reliability and durability. The performance and emission characteristics of diesel engine depend on many parameters. The parameter like fuel injection pressure plays an important role. Other parameters include compression ratio, atomization of fuel, injection timing, air fuel ratio, intake temperature and pressure and also based on piston design. Fuel injection pressure plays an important role in better and a complex burn to reduce the emission. The injection timing and due to which the formation of cavity and fuel dribble also studied and a brief analysis were given.

I. INTRODUCTION

Diesel engine plays an important role in the transportation sector. It plays a dominant role in the field of power, propulsion and energy. They have high torque output so that they are used as commercial vehicles for the past years. But now due to continuous development of diesel engine coupled with advances made in high pressure fuel injection makes the improvement in performance and consumption. The diesel engine is a type of internal combustion engine more specifically it is a compression ignition engine in which the fuel ignited at high temperature and pressure created by the compression of air fuel mixture. The diesel engine is more efficient than petrol engine this is because in petrol engine the spark ignition is present which consumes more fuel than compression ignition engine. The fuel injection is the most vital part of the compression ignition engine. A diesel fuel injector sprays a timed and metered quantity of fuel into the cylinder. Metering of fuel charge may be performed mechanically or electrically. The engine performance greatly depends on the fuel effectiveness and their combustion process. When the fuel is injected into the combustion chamber towards the end of compression stroke, it is atomized to very fine droplets. These droplets vaporize due to heat transfer between the compressed air and from an air fuel mixture. Due to this continuous process the temperature reaches a higher value than the normal temperature in which self ignition temperature occurs. This causes the fuel to ignite spontaneously initiating the combustion process. The benefit of fuel injection is to deliver an accurate an equal mass of fuel to each cylinder of engine. The fuel injection is done in many ways and their types are given below.

- Single point injection.
- Continuous injection.
- Central point injection.
- Multi point fuel injection.
- Direct injection.

Single-point injection (SPI) uses a single injector at the throttle body. The single point injection was at low cost when compared to others. The carburetor supporting components such as the air cleaner, intake manifold and fuel line routing can be reused. This single point injection system was used a long ago. In a continuous injection system, fuel flows at all times from the fuel injectors, but at a variable flow rate. Continuous injection system can be a multi point or single point. In piston aircraft engines,

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continuous-flow fuel injection is the most common type. In contrast to automotive fuel injection systems, aircraft continuous flow fuel injection is all mechanical, requiring no electricity to operate. The control unit is fed by a constant-pressure fuel pump. The control unit simply uses a butterfly valve for the air, which is linked by a mechanical linkage to a rotary valve for the fuel. Inside the control unit is another restriction, which controls the fuel mixture. The pressure drop across the restrictions in the control unit controls the amount of fuel flow, so that fuel flow is directly proportional to the pressure at the flow divider. General Motors developed a technique called a central port fuel injection. It uses the tubes from the central injector to spray fuel at each intake port rather than the central throttle body. However fuel is continuously injected to all ports simultaneously, which is less than optimal. However the name is called as the central port fuel injection (CPFI).

II. FUEL INJECTION PRESSURE

The fuel injection pressure plays a key role in the atomization of the fuel. The fuel injection system in a direct injection diesel engine is to achieve a higher degree of atomization for better penetration of fuel in order to utilize the full air charge and to promote the evaporation in a very short time and to achieve higher combustion efficiency. The fuel injection pressure in diesel engine varies depending on the engine size and the type of combustion system employed in it. When fuel injection pressure is low, fuel particle will be large and hence ignition delay happens which causes the combustion increase. This also causes incomplete combustion leads to increase in NOx and CO emissions. If the injection pressure is too high ignition delay becomes shorter. An experiment is being conducted by varying the manifold inclination and also variation of the injection pressure [1] in which after thorough analysis at various inclinations of 30, 60 and 90 degree and pressure of 160,180 and 200 bar in which 60 degree and pressure of 200 bar was found the best as because the mechanical efficiency, volumetric efficiency were at best. We also had very less emission of carbon dioxide and NOx at inclination of 60 degree. Another experiment also conducted which also involves in analysis of fuel injection pressure. The experiment was done in a single cylinder four stroke diesel engine in which an exhaust gas analyzer also used to measure the gases. At constant speed of 1500 rpm it was done and various injection pressures were given in which higher injection pressure was given in which high quantity of fuel is used which leads to decreasing in brake thermal efficiency [2] and brake specific fuel consumption also increases with increasing the injection pressure. It was also found that when injection pressure is higher the carbon dioxide emission is also decreases. NOx also found to be very low emission when increasing the fuel injection pressure. HC emission also found increasing with decreasing injection pressure. Another experiment also conducted in regard to this which involves at two injection pressures of $140N/m^2$ and $160N/m^2$ in which minimum brake thermal efficiency was obtained at maximum injection pressure [3]. A study also conducted in which diesel is compared with gasoline in which fuel injection pressure is increased then the ignition delay is reduced for diesel while the gasoline is in which fuel injection pressure increased then ignition delay also increased [4]. The combustion duration decreases as the cylinder air pressure increases as it is because of the end of compression temperature and pressure. In another study the NOx emission are increased when the fuel injection pressure are increased [5] in which the fuel mixture will be lean and tends to complete combustion so which indicates that NOx emission increases with increase in fuel injection pressure. CO mixture occurs due to rich mixture and if injection pressure increases the mixture gets leaner and easily mixes with air. When compared with two injection pressures it was found that emission was decreased at high injection pressures.

Engine performance was superior at low fuel injection pressure [6] at all loads.

III. Fuel Injection Timing

The injection timing in diesel engine also plays an important role in performance and emission characteristics of diesel engine. Advancing and retarding the injection timing changes the position of piston and cylinder pressure and temperature inside the combustion chamber. An experiment is been conducted for analyzing the performance at various ignition timings. Different injectors with number of holes were used .the smoke emission with diesel generally increases as the injection timing is retarded. When the injection is advanced the injection occurs at lower temperature and pressure in the cylinder. Due to this there occurs an increase in ignition delay so that a little portion of the injected fuel burns in the premixed mode which results in lower smoke level but when a greater advancement of injection timing leads to increase in smoke level but fall of brake thermal efficiency is observed [7]. It was also observed that HC and CO emissions were also decreased at slight advancement of injection timings. High heat release was observed at lower nozzle size and when there is a low release heat resulted in low pressure rise rate which benefits the noise reduction level.

IV. Cavitation and Fuel Dribble

Cavitation is formed inside diesel injector nozzles affects the atomization behaviors and also spray characteristics which affects the performance and adversely affects the environment by pollution. An experimental study was conducted in which varying injection pressures were given and analysis of cavitations is observed. It can be seen that the cavitation inception and distribution are influenced by the injection pressure in which higher the injection pressure corresponds to earlier cavitation inception [8]. In this study there are two types of string cavitation are formed and one is observed as same as cavitation in single hole nozzle which starts from the needle tip and the other forms between the sac and the holes. During the period of opening of the needle the cavitation region would change with respect to needle motion which was similar to study results obtained by another author [9].

The injector needle shutdown of the fuel injector leads to the formation of unburned fuel and hydrocarbons which leads to decrease in engine thermal efficiency [10]. To minimize these dribbling an experiment study was conducted which gives a clear cut idea on the fuel dribbling process. There was a brief analysis on three hole injector nozzle in which a two mode injection pressure was given.

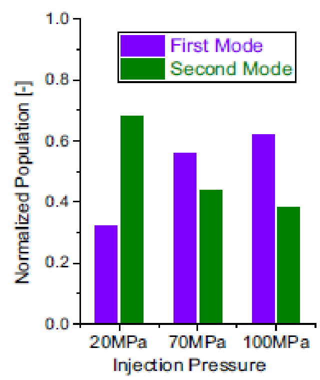

Fig 1

The figure 1 gives a graphical representation on the injection pressure and the normalized population of the fuel. The graph shows of two modes in which one is Case A and the other is Case B. In Case A, a ‘spray like’ highly disturbed fuel flow was observed and in Case B an undisturbed fuel flow like ‘fuel dribbling’ was observed. The highly disturbed fuel flow and high degree of sac pressure drop in Case A which seem to open the passage of air ingestion with more ease. After these process a membrane like fuel flow is formed that makes the droplets into a very fine droplet. These droplets were smaller than the hole diameter. In Case B it has a weak air ingestion force which made the outer air to be ingested. This leads to breakup of liquid in longer distance and droplet size are formed equal to the hole diameter size. These results were clarified that at the end of injection the velocity and presence of air ingestion are primary factors to determine the breakup of fuel dribble. By increasing the needle closing speed it would reduce the droplet size of the fuel dribble [11]. Increasing the injection pressure would have some effects on fuel dribble unless there is an increase in needle closing speed.

V. FUEL INJECTION DEPOSITS

The control of fuel injector deposits is a great challenge for the diesel engine. Some of the worst character of injector deposits are pre ignition and engine misfiring and malfunctions. Emission are greatly involved in the fuel injector deposits where the emission are controlled as discussed in earlier review papers and when there is a good control of emission and other particulates the deposit formation are lesser in which the efficiency of the engine are drastically increased. These deposits are formed due to the oxidation, condensation and precipitation of the unstable and unburned hydrocarbons [12]. The injector temperature are made to lower down as to reduce the deposits formation and also some method were adopted like cooling of cylinder head [13] , adding injector surface with an insulating material. The analysis were done in which a very low temperature may have a negative effect on the spray pattern [14] and in higher injector pressure the fuel droplets are formed smaller in which they are compact. It also suggest that the anti oxidants formed or sprayed at the end of injector does not considerably good because they act only for few days and later when small deposition occur it starts continuing till it attains bigger.

VI. RESULT AND CONCLUSION

The fuel injector pressure and the intake manifolds play an important role in the performance of an engine. The fuel injection pressure increases as fuel particle size becomes small and the mixing of fuel and air becomes better for the complete combustion process to take place. Increasing the pressure decreases the NOx while decreasing the pressure the HC was found to be higher. Due to this drastically the fuel injector deposits are made hence the efficiency falls down. These deposition particles were also discussed and the smoke emission increases as the time is retarded for the injection to be done. Cavitation and fuel dribble also formed when varying the fuel injection parameters and their brief analysis were studied and hence the fuel injection pressure plays a predominant role in all aspects that determines the efficiency of the engine.

REFERENCES

[1] M.L.S. Deva Kumar, S. Drakshayani and K.Vijaya Kumar Reddy, “ Effect of Fuel Injection Pressure on Performance of Single Cylinder Diesel Engine at Different Intake Manifold Inclinations”, International Journal of Engineering and Innovative Technology (IJEIT), Vol. 2, No. 4, 2012.

[2] K. Kannan and M. Udayakumar, “Experimental Study on the Effect of fuel Injection pressure on Diesel Engine Performance and Emission”, ARPN Journal of Engineering and Applied Sciences , Vol. 5, No. 5, 2010.

[3] P. Bridjesh and G. Arun Kumar, “Study on the Effects of Variation of Fuel Injection Pressure on Single Cylinder Diesel Engine”, ARPN Journal of Engineering and Applied Sciences, Vol. 10, No.1, 2015.

[4] M.A. Ghadikolaei, “Effect of Cylinder Air Pressure and fuel Injection Pressure on Combustion Characteristics of Direct Injection (DI) Diesel Engine Fueled with Diesel and Gasoline”, International Journal of Application or Innovation in Engineering and Management, Vol. 3, No. 1, 2014.

[5] C. Syed Aalam and C.G. Saravanan, “Effects of Fuel Injection Pressure on CRDI Diesel Engine Performance and Emission using CCD”, International Research Journal of Engineering and Technology, Vol. 2 , No. 5, Pp.1411-1416, 2015.

[6] H. Mustaffa, Mechanical System Design Development of Fuel Injection System on Single Cylinder Internal Combustion, 2016.

[7] L. Ranganatha Swamy, T.K. Chandrashekar, N.R. Banapurmath and P.Nashipudi, “ Effect of Injection Timing, Combustion Chamber Shapes and Nozzle Geometry on the Diesel Engine Performance”, Universal Journal of Petroleum Sciences, Vol.2, Pp.74-95, 2014.

[8] Z. He, Z. Zhang, G. Guo, Q. Wang, X. Leng and S. Sun, “Visual experiment of transient cavitating flow characteristics in the real-size diesel

injector nozzle", International Communications in Heat and Mass Transfer 78, Pp.13-20, 2016.

[9] R. Payri, X. Margot and F.J. Salvador, "A numerical study of the influence of diesel nozzle geometry on the inner cavitating flow", SAE Technical Paper 2002-01-0215.

[10] S. Moon, W. Huang, Z. Li and J. Wang, " End-of-injection fuel dribble of multi-hole diesel injector: Comprehensive investigation of phenomenon and discussion on control strategy", Applied Energy, 179, Pp.7-16, 2016.

[11] W.E. Eagle and M.P.B. Musculus, Cinema-Stereo imaging of fuel dribbles after the end of injection in an optical heavy duty diesel engine (2014).

[12] S. Moon, J. Choi, E. Abo-Serie and C. Bae, " The effects of injector temperature on spray and combustion characteristics in a single cylinder DISI engine", SAE Technical Paper, No.2005-01-0101, 2005.

[13] K. Noma, T. Noda and T. Ashida, " A study of injector deposits, combustion chamber deposits (CCD) and intake valve deposits (IVD) in direct injection spark ignition (DISI) engines", SAE Technical Paper, No. 2003-01-3162, 2002.

[14] H. Xu, C. Wang, X. Ma, A.K. Sarangi, A. Weall and J. Krueger-Venus, " Fuel injector deposits in direct-injection spark-ignition engines", Progress in Energy and Combustion Science, Pp.63-80, 2015.