The Influence of Fuel Spray Characteristics on the Engine Performance and Emission in the Direct Injection Type Diesel Engine

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ABSTRACT

The purpose of this investigation is to carry out, the influence factor on the fuel spray characteristics for improve the engine combustion performance and exhaust emission in direct injection type diesel engine. The fuel properties, fuel spray structure and the shape of the piston surface of diesel engine play an important role of engine combustion process and exhaust emission.

In order to obtain the effect of using auxiliary chamber and emulsified fuel on the fuel spray characteristics the experiment was conduct with single cylinder direct injection type diesel engine to examine the engine performance and gas emission. The results of this investigation showed that the increase auxiliary chamber volume and emulsified fuel give an effect on the fuel spray characteristics by reduced the concentration of nitric oxide emission in the combustion chamber. Also it can improve the combustion characteristics such as cylinder pressure, rate of pressure rise and rate of heat release.

Keywords: Emulsified fuel, Auxiliary Chamber, Direct Injection type Diesel Engine, Combustion Performance, Exhaust Emission

1. Introduction

Direct injection type diesel engines are extensively used in automotive systems particularly in road vehicles and marine transportation due to their superior fuel economy and power. However exhaust emission produce from direct injection type diesel engine has a serious environment problem and a method of reduction is urgently needed. The combustion of fuel in a diesel engine is a very complicated and interesting phenomenon. The fuel spray characteristics are the most influence factors on the emission and engine performance in the combustion process [1~4]. The method introduces of fuel in the cylinder results in heterogeneous mixture whose combustion starts at one or more point when the right conditions for the proper formation of air-fuel ratio and ignition are obtained in the combustion chamber.

To reduce the exhaust emission in diesel engine, the knowledge in combustion products for clean emission is need to understanding the chemical reaction of low emission factors on the combustion phenomena, fuel properties formation, mechanism of nitric oxide, and the other factors on the products in cylinder. Figure 1 shows the concept of controlling the exhaust emission in the combustion chamber of diesel engine.

In this point of a view, many studies have been investigated to obtain the reduction of diesel engine emission such as nitric oxide, carbon monoxide and hydrocarbon and increase engine performance [5~10].

The formation of nitric oxide is promoted by large oxygen concentration in burned gas. This because at the beginning of combustion process the gas combustion temperature are higher and have rich of oxygen. In any conditions that results in sufficiently higher the cylinder pressure and temperature will produce higher nitric oxide emission. In the fuel spray, the liquid core penetration is longer than the physical dimension of the piston bowl; liquid fuel will impinges on the wall or surface. These impinge on the wall cannot ignite or burn while remaining on the cylinder and piston bowl surface or one of the major cause in the concentration of hydrocarbon emission.

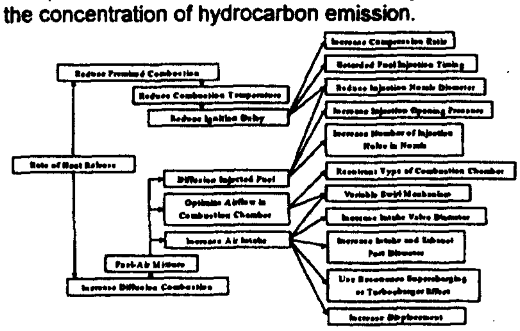

Fig. 1 Concept of combustion in diesel engine for reducing emission

The aims of this investigation focus on the effect of the auxiliary chamber and emulsified fuel to reduced the cylinder pressure, cylinder temperatures and the penetration of fuel sprays by experimental in the direct injection type diesel engine.

2. The method of Investigation

2.1 Experimental Apparatus

The experiment data used in this study were obtained from the experiment on four-stroke diesel

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engine. This involved the installation of a single cylinder diesel engine including fuel, air and instrumentation system. The cross sectional view of the combustion chamber and cylinder head of the test engine is shown in Fig. 2. The injector was inclined at an angle 30^0 to vertical axis, and the nozzle tip was located 8.75mm from the center of the piston.

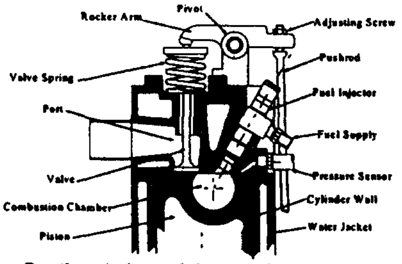

Fig. 2 Sectional view of the combustion chamber of the diesel engine

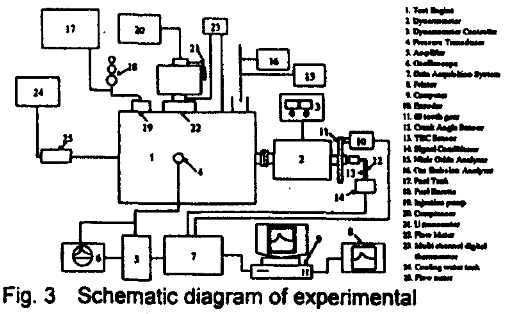

Fig. 3 Schematic diagram of experimental apparatus

The engine configuration used in this work consisted of direct injection, four strokes, naturally aspirated with displacement of 1425cc. The engine has 17.4 compression ratio and a rated power output of 7.36kW at 1200 rpm. An arrangement of apparatus is shown schematically in Fig. 3. The engine was control by using an eddy current dynamometer directly coupled to the crankshaft and a DC motor for power absorption.

2.2 Experimental Procedure

The load applied to the engine is a strain gage load cell measured a function of a current level in the dynamometer. The dynamometer controller is maintaining the speed with ± 20 rpm at any of the test conditions. The experiment performed in this work were done at 900, 1000, and 1100 rpm. The fuel opening injector pressure used in these works are 140, 180 and 220 bar.

The quartz piezoelectric water-cooled pressure transducer was used to measurements the cylinder pressure in the combustion chamber. The pressure detector located pass through the cylinder head and water jacket on the cylinder head. To fixed that the sensing face of the transducer was almost, flush with the inner surface of the cylinder head. This is because, to avoid high frequency pressure pulsation be picked up the transducer. The measuring range of the pressure transducer was 0-250 bar with a gas temperature range of up to 2500°C. The oscilloscope was used to monitor the cylinder pressure, which was useful for selecting an appropriate time for record data.

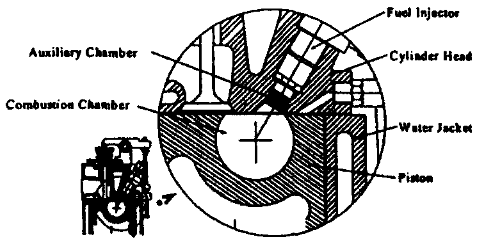

Fig. 4 Configuration of direct injection with auxiliary chamber

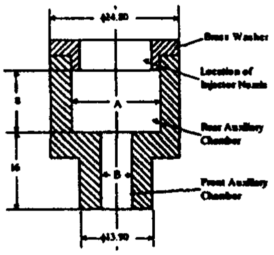

Fig. 5 Auxiliary chamber basic design

Table 2 The diameter of the auxiliary chamber

	A	B	Symbol
Modification 2	17.00	4.00	A2
Modification 3	17.00	5.00	A3
Modification 4	17.00	6.00	A4

The exhaust emission gas was analysed using the gas analyzer meter and the engine was operated with 60 ± 5^0 cooling water temperature at the different speed and load. The injection nozzle is mounted with auxiliary combustion chamber incorporated in the cylinder head as shown in Fig. 4. For this purpose they are several sets of auxiliary chamber with different volume are used respectfully in Fig. 5. The details of the auxiliary chamber are described in Table 2. The auxiliary chamber is expressed as the percentage of the total volume of combustion chamber at top dead center. There are three kind of emulsified fuel used with 5%, 10% and 15% of water for this investigation.

2.3 Experimental Data Analysis

The mean pressure for cylinder history was computed by using pressure-crank angle data. The mean pressure for the cylinder chamber at crank angle θ is given by,

$$P(\theta)=\sum_{i=1}^{m}\frac{P_i(\theta)}{m} \quad (1)$$

where m is a total number of samples

The cylinder pressure data are used to calculate the rate of pressure rise, rate of heat release and burning fraction. The rate of pressure rise can be obtained by using the numerical differentiation of pressure from the equation (1).

The energy equation for a thermodynamics system of engine is written as

$$\frac{dmu}{d\theta}=-P\frac{dV}{d\theta}+\frac{dQ_{hr}}{d\theta}-\frac{dQ_{ht}}{d\theta} \quad (2)$$

where,

$\frac{dmu}{d\theta}$; rate of change of total internal energy in the system with mass m

$P\frac{dV}{d\theta}$; rate of mechanical work done by the system on its boundary

$\frac{dQ_{hr}}{d\theta}$; rate of heat release by combustion process

$\frac{dQ_{ht}}{d\theta}$; heat transfer with the combustion wall

By substituting the equation of state for ideal gas and specific heat relation in equation (2), the energy equation for the engine system is given by

$$\frac{dQ_{hr}}{d\theta}-\frac{dQ_{ht}}{d\theta}=\frac{1}{\gamma-1}\left(P\frac{dV}{d\theta}+V\frac{dP}{d\theta}\right)+P\frac{dV}{d\theta}$$

$$\frac{dQ_n}{d\theta}=\frac{\gamma}{\gamma-1}P(\theta)\frac{dV(\theta)}{d\theta}+\frac{1}{\gamma-1}V(\theta)\frac{dP(\theta)}{d\theta} \quad (3)$$

where

γ ; ratio of specific heat, $\frac{dQ_n}{d\theta}$; net heat release

The mass burning fraction of fuel-air mixture for the combustion region can be expressed as,

$$BR=\int_1^{\theta}\frac{dQ}{d\theta}\Big/\int_1^{2}\frac{dQ}{d\theta} \quad (4)$$

where 1 and 2 are initial and final point for the burning time.

3. Results and Discussion

3.1 Effect of auxiliary chamber

Figure 6 shows the comparison of cylinder pressure between auxiliary chamber and normal combustion chamber at case A4 and 1100 rpm engine speed. The cylinder pressure of the engine with the auxiliary chamber was reducing compare with the normal combustion chamber.

As shown in Fig. 7 the peak pressure of cylinder combustion decrease with the increase of the auxiliary chamber volume and engine speed. These trends indicate that the combustion characteristics have an effect on the design of the auxiliary chamber volume. The modification of auxiliary chamber volume has the effect of reducing the spray penetration, thus increasing the total area available for fuel-air mixing by the volume of auxiliary chamber. Therefore, injection velocities from each volume auxiliary chamber and fuel spray atomization have changed significantly.

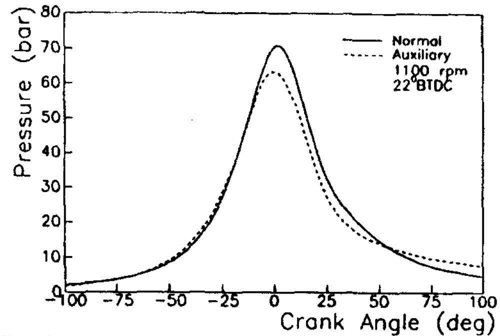

Fig. 6 Comparison between auxiliary chamber and normal combustion chamber on the cylinder pressure

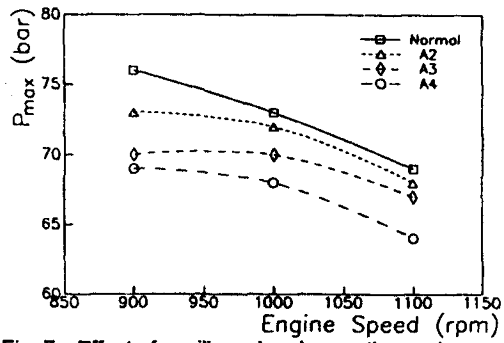

Fig. 7 Effect of auxiliary chamber on the peak pressure of combustion process

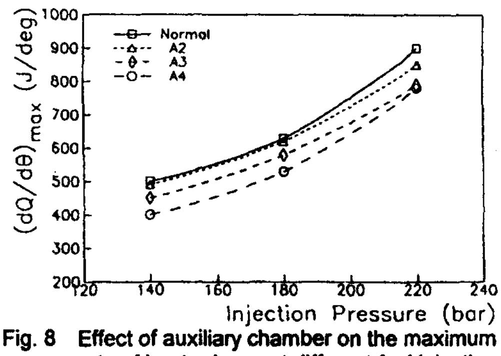

Fig. 8 Effect of auxiliary chamber on the maximum rate of heat release at different fuel injection pressure

Figure 8 shows the influence of auxiliary chamber volume on the maximum value of heat release rate at different fuel injection pressure. The increases of fuel injection pressure in the auxiliary chamber bring about the maximum rate of heat release. As expected increase the fuel injection pressures changes in the fuel viscosity and increase the injection velocity and spray penetration. In other hand, the rates of heat release decrease as the auxiliary chamber volume increased. These trends related to the improvement of the injection rate such as fuel atomization and fuel-air mixing in the combustion chamber.

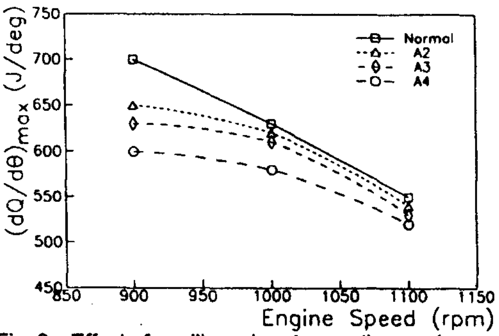

Fig. 9 Effect of auxiliary chamber on the maximum rate of heat release at different engine speed

As shown in Fig. 9 the increase of auxiliary chamber volume and engine speed result in the decrease in the maximum rate of heat release. At the higher speed, the time available for fuel-air mixing and chemical reactions in the combustion chamber are been reduced and at the same time the wet walls of the combustion chamber are reduced. The evaporation of fuel and turbulence flow of the air in the combustion chamber increases with the increases engine speed and also heat transfer from the fuel to the wall is isolate by the main chamber and auxiliary chamber. These suggest that the engine speed influence on the heat transfer characteristics in the combustion process.

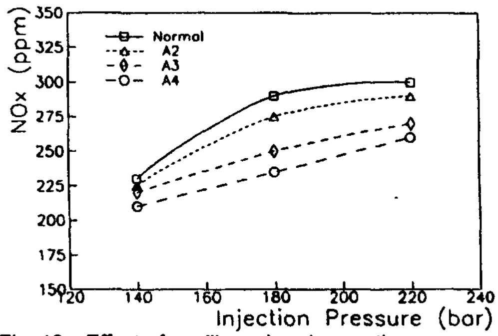

Fig. 10 Effect of auxiliary chamber on the concentration nitric oxide emission at different fuel injection pressure

Figure 10 shows the effect of auxiliary chamber on the concentration of nitric oxide emission. At higher fuel injection pressure, the amounts of fuel injected increase and improve the fuel spray atomization. However, the increase of fuel injection pressure acts on the increase of concentration of nitric oxide in the engine. The purpose increase auxiliary chamber volume is to reduce the formation of nitric oxide by lowering the combustion gas temperature and cylinder pressure in the combustion chamber. The combustion process with the auxiliary chamber volume not only reduces the nitric oxide emission concentration but also lowering the noise level, and the rate of heat release in the combustion chamber.

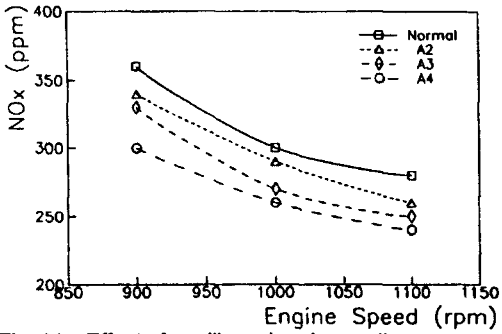

Fig. 11 Effect of auxiliary chamber on the concentration nitric oxide emission at different engine speed

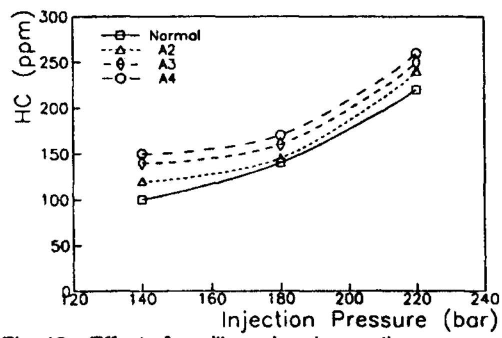

Fig. 12 Effect of auxiliary chamber on the concentration hydrocarbon emission at different fuel injection pressure

The influence of engine speed on the formation of nitric oxide at different auxiliary chamber volume is shown in Fig. 11. As shown in the figure the concentration nitric oxide emission decrease with increase the engine speed. These suggest that more energy have been released at the higher engine speed and cause the decreasing in the rate of heat release at the combustion chamber. The energy changes involved the combustion and cooling process have an influence in the increase of the engine speed.

Figure 12 shows the results of hydrocarbon concentration at different of auxiliary chamber volume and fuel injection pressure. An increase of the fuel injection pressure increases the concentration of hydrocarbon emission in the combustion chamber. These suggest that the auxiliary chamber volume have influenced in the quantity of the fuel injected in the combustion chamber. Increasing the auxiliary chamber volume gives benefit to the flame area and causes the increase of burning fraction in the combustion chamber.

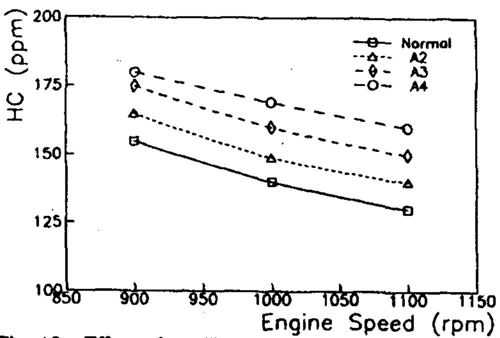

Fig. 13 Effect of auxiliary chamber on the concentration hydrocarbon emission at different engine speed

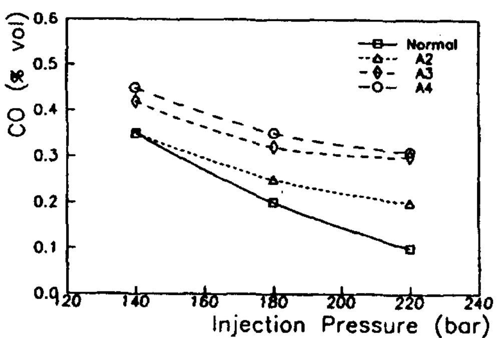

Fig. 14 Effect of auxiliary chamber on the concentration carbon monoxide emission at different fuel injection pressure

Figure 13 shows the effect of auxiliary chamber volume on the concentration of hydrocarbon emission at different engine speed. The concentration of hydrocarbon emission decreases as the engine speed increases. At higher engine speed a higher mixing rate of fuel-air ratio are achieved and resulting higher flow velocities of fuel-air mixing in the combustion chamber, which effected on the combustion process in the chamber. This suggests that the mixing rate of fuel-air ratio be increased in the proportional of the engine speed.

The effect of auxiliary chamber volume on the concentration of carbon monoxide emission as shown in Fig. 14. An increase of the fuel injection pressure decreases the concentration of carbon monoxide emission but increase of the concentration of carbon monoxide emission when the volume of auxiliary chambers increase.

3.2 Effect of emulsified fuel

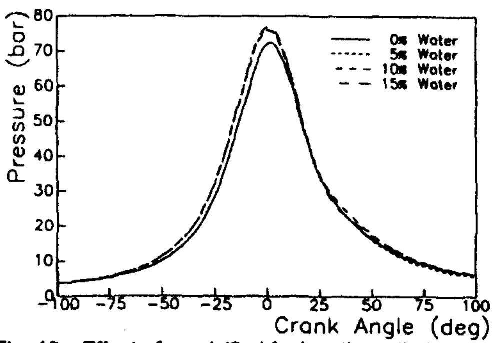

Fig. 15 Effect of emulsified fuel on the cylinder pressure

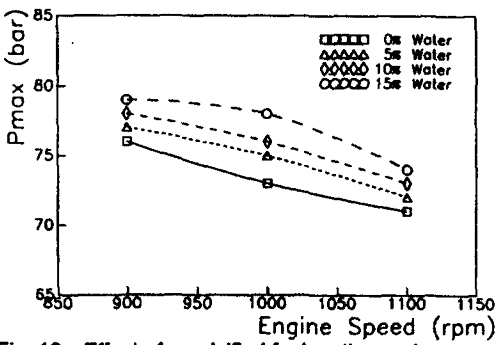

Fig. 16 Effect of emulsified fuel on the peak pressure at different engine speed

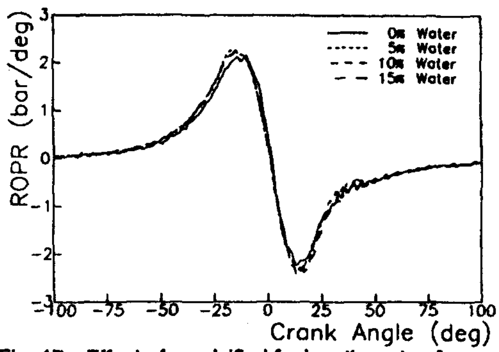

Fig. 17 Effect of emulsified fuel on the rate of pressure rise

The emulsified fuel give a great effect on the cylinder pressure in the combustion chamber as shown in Fig. 15 and Fig. 16. Figure 15 shows that the early peak and higher value of the cylinder pressure occur with the emulsified fuel is used. As expected emulsified fuel given a changed in the fuel properties such as fuel density, lower heating value and the specific volume of the fuel in the combustion chamber. The implication of changed the fuel properties given an early rapid combustion process in the combustion chamber. Therefore the results from these events give the increase in the cylinder pressure and shifted the maximum curve of the cylinder pressure to the left side of the top dead center in the combustion process.

Figure 16 shows the relation between peak pressure and engine speed. When increase the engine speed increase, the peak pressure decreases but the maximum cylinder pressure still higher in the combustion chamber. It can be seen that the decrease emulsified fuel attributed to improve the maximum cylinder pressure of the combustion process in the combustion chamber.

The effects of emulsified fuel on the rate of pressure rise are shown in Fig. 17. In this figure, the rate of pressure rise was higher with the conventional fuel. The rate of pressure rise shows the decrease of peak value of emulsified fuel compare with the peak value of the conventional fuel because of the late start of combustion process in the chamber.

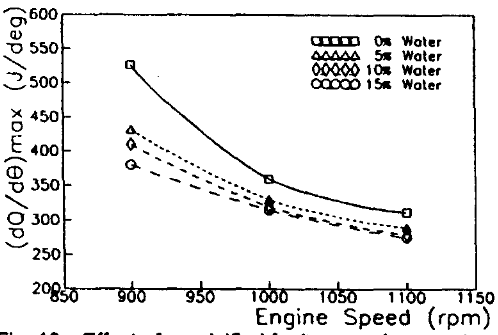

Fig. 18 Effect of emulsified fuel on maximum rate of heat release at different engine speed

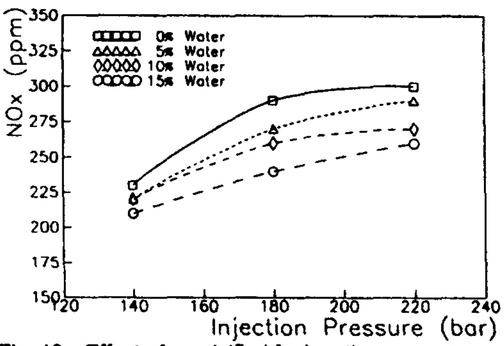

Fig. 19 Effect of emulsified fuel on the concentration nitric oxide emission at different injection pressure

The fuel was sprayed by a pintle nozzle with the direction of swirl motion of the piston bowl wall. The mixture formed in the combustion chamber burns up quickly as engine speed increase and producing a lower rate of heat release as shown in Fig. 18. As shown in the figure increase the engine speed and emulsified fuel result in decrease in the maximum rate of heat release.

When the emulsified fuel is used the concentration of nitric oxide emission lower compare with the conventional fuel as shown in Fig. 19. However the concentration of nitric oxide emission in the engine cylinder are increase as the increase of the fuel injection pressure. The higher fuel injection pressure related to the improvement in the fuel atomization and mixing in the combustion chamber.

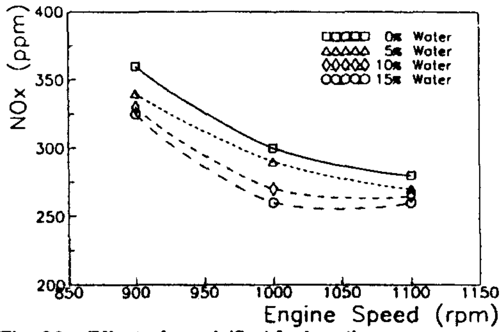

Fig. 20 Effect of emulsified fuel on the concentration nitric oxide emission at different engine speed

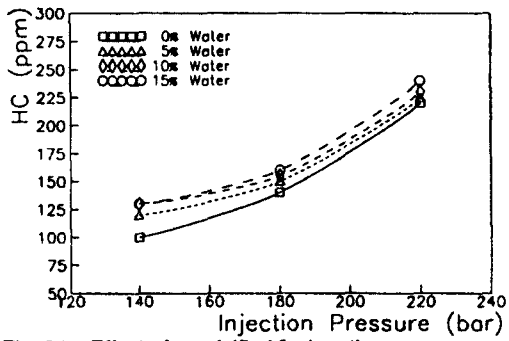

Fig. 21 Effect of emulsified fuel on the concentration hydrocarbon emission at different fuel injection pressure

The influence of engine speed on the formation of nitric oxide in the engine cylinder is shown in Fig. 20. As shown in figure the concentration of nitric oxide emission decreases with the increase of engine speed. These can be explaining that the increase engine speed has an effect on the degree of turbulence flow in the combustion process in the combustion chamber. At the higher engine speed, the time available for fuel-air mixing and chemical reactions in the combustion chamber are been reduced. Therefore the evaporation of fuel and turbulence of the air in the cylinder chamber increases with rising engine speed.

On the other hand, with increase of emulsified fuel decrease the concentration of nitric oxide emission in the combustion chamber. These suggest that when the emulsified fuel was inject into the combustion chamber, results in the break-up of fuel into the fine droplet and the spray penetration become shorter compare with the conventional fuel.

The influence of emulsified fuel on the concentration of hydrocarbon emission at different fuel injection fuel shown in Fig. 21. Increase the emulsified fuel increase the concentration of hydrocarbon emission in the combustion chamber.

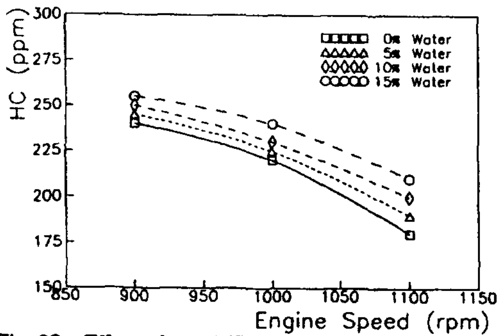

Fig. 22 Effect of emulsified fuel on the concentration hydrocarbon emission at different engine speed

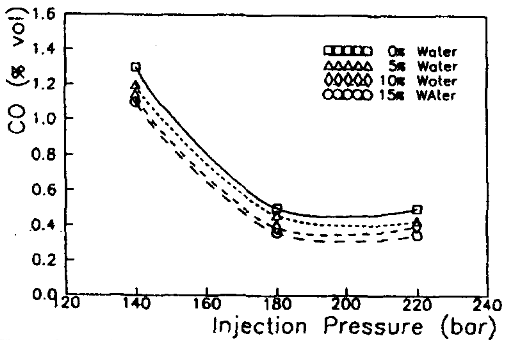

Fig. 23 Effect of emulsified fuel on the concentration carbon monoxide emission at different fuel injection pressure

Figure 22 shows the effect of emulsified fuel on the concentration hydrocarbon emission at different engine speed. Experimental data shown that the increase engine speed decrease the concentration hydrocarbon emission in the combustion chamber. According to these results, the concentration hydrocarbon emission strong influences on the engine speed but not to the emulsified fuel.

Figure 23 shows the effect of emulsified fuel on the concentration of carbon monoxide emission at different fuel injection pressure. An increase of fuel injection pressure decreases the concentration of carbon monoxide emission. From this results increase the fuel injection pressure, increase the fuel injection velocity and spray penetration in the chamber. The increases probably improve the misfire in the combustion process with the fuel injection pressure and emulsified fuel.

4. Conclusion

The effects of auxiliary chamber and emulsified fuel on the engine and emission performance in direct injection diesel engine have been investigated. The following conclusion can be drawn from this work.

(1) The increase of the auxiliary chamber volume decrease the cylinder pressure, rate of pressure rise and the rate of heat release of the engine.
(2) The increase of the fuel injection pressure increase the cylinder pressure, rate of pressure rise and rate of heat release of the combustion process.
(3) Increases the auxiliary chamber volume decreases nitric oxide and increases carbon monoxide and hydrocarbon emissions.
(4) Increases the emulsified fuel increase the cylinder pressure, rate of pressure rise and the rate of heat release in the combustion chamber.
(5) The concentrations of nitric oxide and carbon monoxide emission decrease as the increases in the emulsified fuel.
(6) Increases the emulsified fuel increase the concentration of hydrocarbon emission in the combustion process.

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