Effect of temperature and pressure on characteristics of high speed diesel jets

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Abstract

This study investigates on effects of temperature and pressure in the test chamber on dynamic characteristics of high speed diesel fuel jets. The horizontal single stage powder gun was used to generate the high speed diesel jet by the method called “projectile impact driven method”. In the experiment, the projectile velocities of around 700 m/s and a conical nozzle with 30° cone angle and orifice diameter of 0.7 mm are used, and high speed video camera and optical system with shadowgraph technique were also used to capture the dynamics characteristics of the jets. The high speed diesel fuel jets are injected into the test chamber in which temperature and pressure were varied to the conditions that are standard condition (30°C, 1 bar), high temperature condition (150°C, 1 bar), and high pressure condition (30°C, 8.2 bar).

From experimental results, it is found that at the standard condition the maximum average jet velocity is around 1,400 m/s, and this is much higher than which at the high temperature and high pressure condition (1,200 m/s and 1,000 m/s respectively). However, at the later stage the jet emerged into high temperature air has the highest velocity value because of high rate of evaporation and atomization around a thin jet core which can be observed from the visualized images.

Key words: high speed diesel fuel jet, shadowgraph technique, projectile impact driven method

1. Introduction

In diesel engine, the combustion and pollutant emissions are influenced by fuel atomization, injection pressure, shape of inlet port and other factors. Recently, the high speed direct injection engines (HSDI) have become very influential the passenger car. The injection pressure have been increased up to 2000 bar [1-2]. The higher injection pressure results enhancement of atomization and better mixing of fuel to air during ignition period. Emission will be less and the engine performance will be increased [3-11]. This finally improves engine efficiency.

Previously, the diesel engine cannot operate at high rotational speed, because of fuel atomization and mixing problem causing long ignition delay period. However, the formation of fuel-air mixture is enhanced and the ignition delay can be reduced by using high pressure injection system. The high pressure injection characterize the high speed fuel jets (HSFJ) which may be beneficial for the engine such as in the common rail high speed diesel engine, supersonic combustion ram (SCRAM) jet engine. Besides, when the diesel spray travelling faster than the sound speed in medium at which shock waves occur, the fuel droplets become small. The shock wave heating may be useful for enhancing the combustion [12].

Many experimental and theoretical studies on characteristics of high speed liquid jets are injected into quiescent media. But, the characteristics of high speed diesel jets have attracted especially under high temperature and pressure condition like to the diesel engine combustor.

The objective of this work is to investigate the effect of test chamber temperature and pressure on characteristics of high speed diesel fuel jets. In this work, the supersonic diesel fuel jets are impulsed jet. The test section was varied air temperature and pressure, three conditions: 30°C and 1 atm, 150°C and 1 atm, and 30°C and 8.2 bar, respectively. The high speed video camera and optical system with shadowgraph technique were used to capture the dynamics characteristics of the diesel fuel jets.

2. Experimental apparatus and methodology

2.1 Test rig

In this study, the supersonic diesel fuel jets were generated by using the “projectile impact driven method”. With this method, the diesel fuel retained in the nozzle sac is impacted by a high velocity projectile. On the impact, the momentum transfer from the projectile to retained diesel liquid and a high speed diesel spray is injected into a test chamber as shown in the Fig. 1.

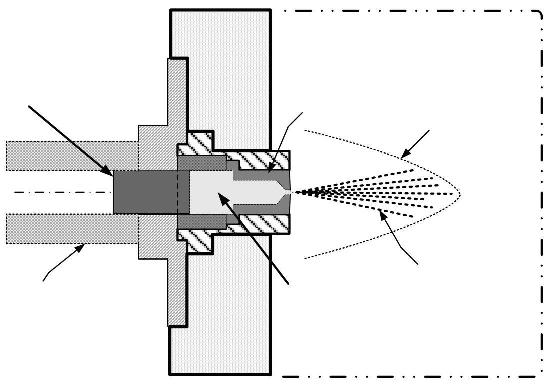

Fig. 1 Projectile impact driven method

The high velocity projectile is produced by using a powder gun. It is called “Horizontal Single Stag Powder Gun (HSSPG)”. The

HSSPG compose of launcher (powder gun), launch tube (gun barrel), pressure relief section, nozzle assembly and a test chamber. The whole view of apparatus is shown in Fig. 2.

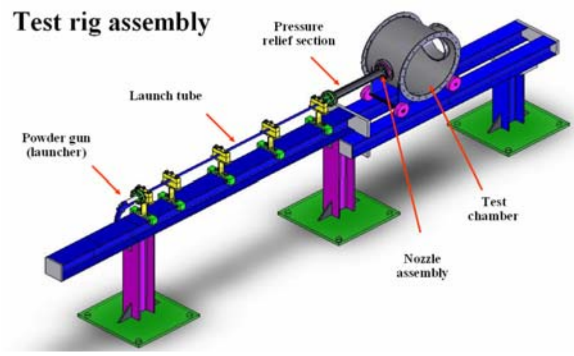

Fig. 2 The horizontal single stage powder gun

The launcher was designed and manufactured to fire the projectile. This launcher can achieve a maximum projectile velocity of about 1400 m/s, at maximum cartridge case containing propelling charge of 7 g. The projectile, is made from polymethyl methacrylate (PMMA), is cylindrical shape with diameter 8 mm, length of 15 mm, and mass of 9.2 g. The launch tube (gun barrel) has an in-bore diameter of 8 mm and length of 1.5 m. It has also acts as a gun barrel. At the end of the launch tube, the pressure relief section is attached. It has a length of 40 cm and it has vent slot of 4 places, each having a width of 3 mm and a length of 36 cm. This is to release the intensely compressed air (or the blast wave) in front of moving projectile from launch tube. If the blast wave is not released, it will prematurely hit the liquid packet and push it through nozzle as a slow jet. The test chamber has a diameter of 48 cm. It is enclosed by PMMA and windows on two sides for visualization. In addition, the test chamber condition is varied by controlling the operation of heater and air compressor. The heater of 1,000 watt, air circulating fan and thermometer probe were placed inside the test chamber as shown in Fig. 3.

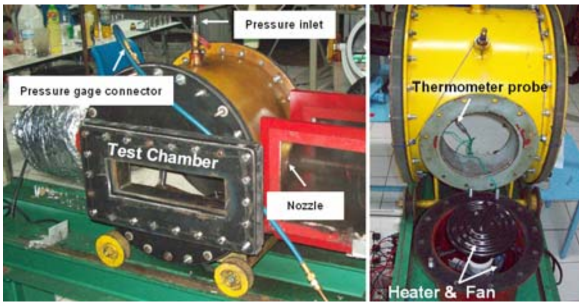

Fig. 3 Test chamber and assembly

The nozzle geometries are important factor that affect to liquid jet characteristic. In this study, a single-hole conical nozzle was used. The schematics and the dimensions of the nozzle used in this study are given in Table 1 and Fig. 4.

2.2 Visualization setup

In this study, the main purpose is to capture the appearance of supersonic diesel fuel jets and structure of shock wave attached to leading edges of the jet. The shadowgraph technique and high speed video camera were used to capture the dynamics shape and behavior of supersonic diesel jets. The schematic arrangement of the shadowgraph system is shown in Fig. 5.

Table.1 Specification of nozzle used in the Experiment

Nozzle	α (Degree)	D (mm)	d (mm)	l (mm)	l/d -	Vol. (cc.)
Conical	60	8	0.7	3	4.2	1.5

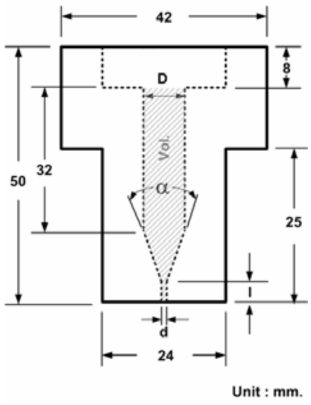

Fig. 4 Nozzle geometries used in the Experiment

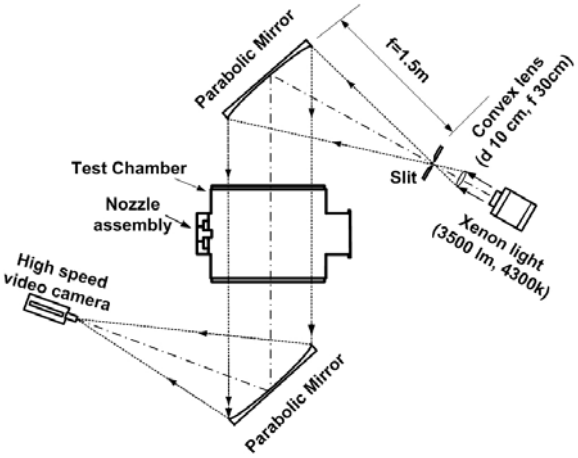

Fig. 5 Z-type shadowgraph arrangement

The xenon lamp (3500 lumens) was used as the light source which has a 3 ms rising time. A convex lens used to focus on the pin-hole (slit). Two parabolic mirrors having a diameter of 30 cm and focus length of 1500 cm were used. The supersonic diesel jets and its shock wave were recorded by a Photron High Speed Video Camera (HSVC) model SA5 which can record the pictures at the frame rate of 30000 frames per second (fps) with picture resolution of 1024x240 pixel and shutter speed of 1/1,000,000 s.

2.3 Methodology

In this study, the high speed diesel fuel jets generated from HSSPG is impulsive jet. By projectile impact driven method, the diesel fuel retained in the nozzle sac is impacted by a high velocity projectile. The diesel fuel obtains the momentum transfer from the projectile and is injected from the conical nozzle into the test chamber. The projectile velocity is measured by using the image from high speed video camera. Fig. 6 the projectile velocity is 780 m/s, can be calculated by

$$V_P = \frac{S}{t} \tag{1}$$

When S is distance between projectile and muzzle (104.13 mm, in this case) and t is time of flight of projectile (133.32 μs, measured by HSVC at fps)

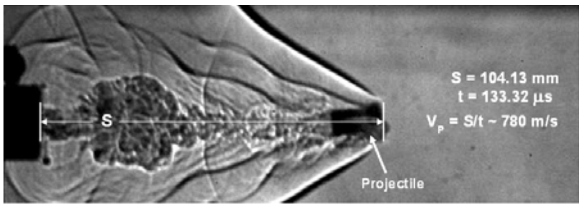

Fig. 6 High speed projectile (Mach ~ 2)

In this experiment, the projectile average velocity is around 700 m/s which is achieved by using propellant mass of 3 g. Diesel fuel was used as the retained liquid to generate the high speed jet. The properties of common commercial diesel fuel are listed in the Table 2.

Table 2 Diesel fuel properties

Property	Diesel Fuel
Density (g/ml), at 20^{o}C	0.84
Viscosity (cSt), at 20^{o}C	1.8-5.0
Specific gravity, at 20^{o}C	0.82-0.90
Flash point (^{o}C)	>52
Surface Tension (N/m), at 20^{o}C	0.025
Boiling Point, at 1 atm	288-338 ^{o}C

3. Result and discussions

The following conditions for temperature and pressure in a test chamber are used in this study:

- standard or atmospheric condition (air temperature of 30°C and pressure of 1 bar)
- high temperature condition (air temperature of 150°C with the atmospheric pressure)
- high pressure condition (atmospheric temperature with pressure of 8.2 bar)

3.1 Effect of test chamber temperature

In experiment, by using the shadowgraph technique and an optical system with the HSVC, which the frame rate is set up to be 30,000 fps, the dynamic characteristics of the jet can be captured; in addition, the regimes of the fine droplet formation, around jet core, under influence of aerodynamic drag and surface tension can be also observed.

In this section, the effects of temperature on characteristics of high speed diesel jet are explored where the air in a test chamber is specifically conditioned to be at 30°C (standard condition) and 150°C (high temperature condition), and the nozzle with orifice diameter of 0.1 and sac volume of 1.5 ml is used. The results as visualized on the jet flow on both conditions are shown in Fig. 7.

In the Fig. 7, supersonic diesel jets and shock wave attached to leading edges of the jet can be obviously observed in both cases. At the initial stage of the jet growth on a standard condition at first 66 μsec, as shown in Fig. (a1), it is found that average jet velocity and the penetration of jet tip are around 1,400 m/s (Mach = 4) and 46 mm, These are higher than that on a high temperature condition where the velocity and the penetration are 570 m/s and 33.3 mm respectively, as shown in Fig. (b1). Moreover, shape of jet core in high temperature air is very thin and the diesel droplet shroud can not be clearly seen. This is because high evaporation rate of liquid droplet into gas phase around the core is increased with high temperature air. At the later stage (133 μsec to 199 μsec) secondary and third jet can be found in both cases; however, a changed angle of shock wave structure can not be observed in the high temperature condition as shown in Fig. 7 a(4). Because of decreasing aerodynamics drag due to high evaporation rate and low air density, the jet core being very thin shape can be more accelerated at high velocity. In addition, at high temperature, increasing the cavitation rate during the nozzle flow may also results in the high rate of fuel liquid evaporation into its gas phase; thus, amount of the liquid emerged into a test chamber is very small and the core is to be thin shape at high velocity. Therefore, it overtakes the jet at standard condition as shown in Fig. 7 (a4) and (b4).

3.2 Effect of test chamber pressure

Figure 7 shows the resulting images from high-speed video camera. This jet is generated under the various pressures in test chamber (i.e. standard pressure of 1 bar and high pressure of 8.2 bar). There is noted that in the high pressure the image is not quite clear because the light beam of optical system passes though the compressed -turbulently air inside the test chamber. This causes the refraction of light which create the dark zone in images.

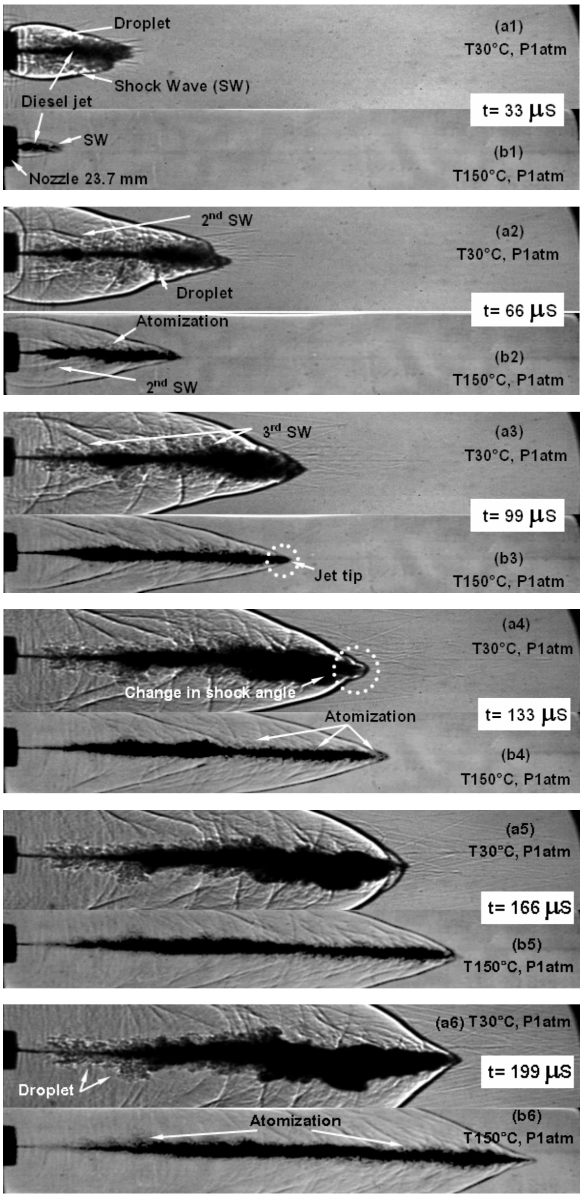

Fig. 7 Comparison various stag of high speed diesel jet between (a) at standard condition and (b) at high temperature condition

The maximum velocities of jets traveling in the test chamber in which the pressure is conditioned to those pressures are 1,400 m/s and 990 m/s respectively. This is because the large amount of aerodynamic drag is produced in the high pressure condition and it, moreover, results in the atomization and evaporation around the jet core reduced. Therefore, the change in shock wave angle can be observed at early stage, t = 66 µsec as shown in Fig. 8 (b2), and shock's distance ahead of the jet is more increased at later stage.

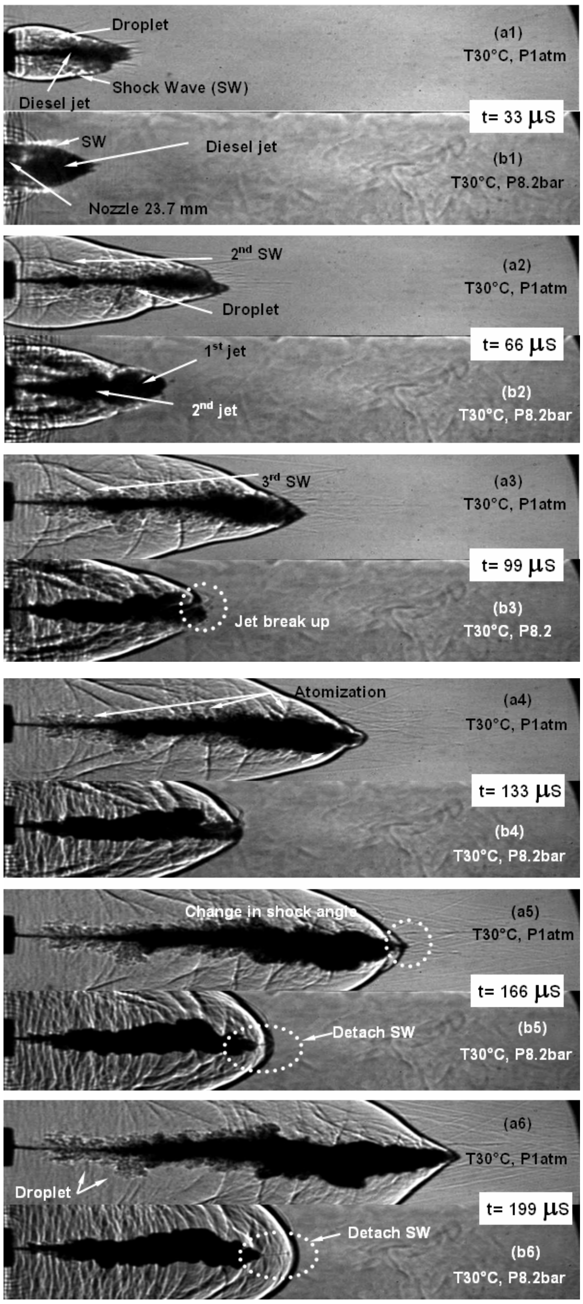

Fig. 8 Comparison various stag of high speed diesel jet between (a) at standard condition and (b) at high pressure condition

3.3 Diesel jets velocities and penetration distance

Fig. 9 shows the characteristics of a high speed diesel jet in terms of velocity and penetration distance emerging from a nozzle of geometry as shown in Fig. 4. The diesel liquid jet characteristics, expressed as jet tip penetration distance and average velocities defined as the jet penetration distance divided by jet emerging time, are shown in Fig.5. The results with the various conditions are compared and discussed. It is found that average jet velocity, around 1,400 m/s, created under standard condition is quite higher than that under another condition; however, at later stage, after 133 μsec, the jet emerged into high temperature air has the highest velocity value. This is because of low aerodynamic drag, high evaporation and cavitation rate as described in a previous section. It is conversely in the high pressure condition. Therefore, the amount of jet tip velocity and penetration distance is lower.

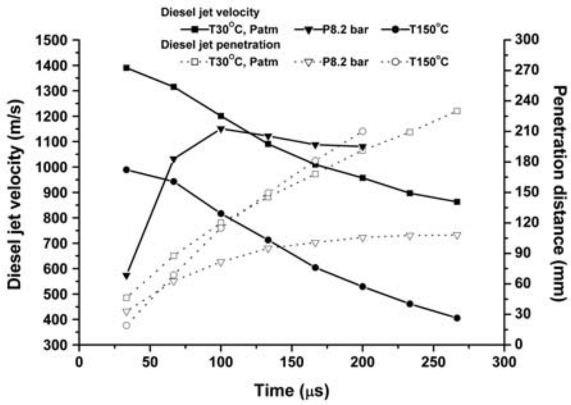

Fig. 9 The effect of test chamber condition on jet velocity and penetration distance

4. Concluding remarks

This paper has reported studies on the injection of high speed diesel jets into the air with various conditions. A high speed video camera and shadowgraph technique were used to visualize the high speed diesel jet and shock wave. The experimental analysis of dynamics jet at three conditions which are standard, high temperature and high pressure conditions is presented. It is found that a at the initial stage the average jet velocity, around 1,400 m/s, created under standard condition is quite higher than that under another conditions. At the later stage, however, the jet emerged into high temperature air has the highest velocity value; in addition, high rate of evaporation around thin a jet core can be observed.

5. Acknowledgement

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