EXPERIMENTAL STUDY OF SPRAY CHARACTERISTICS USING DIMENSIONLESS ANALYSIS

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ABSTRACT

In recent days, current research is going in alternative fuels due to increase in global warming and pollution in all over the world and also very stringent emission norms. In this way, the study on spray progress plays an important role in improving complete combustion and emission of fuel, because it is directly affects the air-fuel mixture formation. The macroscopic spray characteristics of fuel primarily depends on the fuel injection process, fuel density, viscosity, ambient pressure and temperature and some other parameter too. The main aim of this work is to study the injection pressure of the spray characteristics at ambient condition of diesel and Jatropha Oil Methyl Ester (JOME) fuelled in spray chamber under non evaporating condition. The spray characteristics such as spray tip penetration and spray cone angle were measured by using image processing technique (Mie scattering). Moreover, spray development were identified using dimensionless analysis by evaluating the role of the leading forces assisting the liquid jet breakup. The primary forces such as surface tension, aerodynamic drag and inertia force, which indirectly influence the Reynolds number and Weber number. The effect of the spray tip penetration and spray cone angle were more perceptive for Weber number compared with Reynolds number. This analysis bring forth dimensionless correlation for spray tip penetration and spray cone angle that initiate in higher spray break up and atomization process.

Key words: Spray tip penetration, spray cone angle, Reynolds number, Weber Number and JOME.

INTRODUCTION

The environmental issue and global problem as well as energy resources has fortified Internal combustion engineer to study the alternative fuel such as biodiesel, ethanol, hydrogen and other fuel, particularly vegetable oil and animal fat oil plays important role in many countries to replace the petroleum based product in internal combustion engines. Alternative duels produce the less Carbon Monoxide (CO), Hydrocarbon (HC) and Particulate Matter (PM) compare to oxygenate fuel and to reduce to Carbon dioxide to obtain the neat emission. Even though, it having some cons in practical uses for example lower fuel economy due to lower heating value (Demirbes & Phan, 2008). Biodiesel getting from transesterification process, it is nontoxic, eco-friendly and degradable derived from bio-origin family (Ramdhas, 2010). Especially in India, numerous trials has been made in engine by using Jatropa curcas and karanja oil, which attained from animal feed-stocks and besides it is two phase flow process in injection (Badrelin, 1987). European countries insisting the people to mix the biodiesel fuel with conventional fuel to blend up to 12% in last decade (Choi, 2012).

The injection spray is the process that fuel is injected from nozzle and it is associated with the following parameters such as fuel atomization, interaction with surrounding air, mixture formation and combustion. Regarding a new fuel applied into the diesel engine the spray process is different due to the different properties from diesel and control strategy should be changed accordingly in order to achieve the optimum performance. Viscosity, surface tension and density are the three main parameters which influence fuel spray characteristics. Higher viscosity and surface tension will prohibit the atomization and instability of fuel droplets due to the different biodiesels properties from diesel studies on the spray characteristics are necessary (Yanfei, 2013). The spray characteristics of non-edible oil using experimental simulation methods. Parameters such us as spray tip penetration, spray cone angle and spray tip speed were measures at different blend ratios in constant glass chamber with visualization technique using high speed camera. The experimental consequences showed, increasing in blend ration is increase the spray tip penetration and spray speed at the same time spray cone were drastically reduced. Moreover, SMD for biodiesel compared with diesel shows high value and the spray obtain was dense because of biodiesel having higher viscosity and surface tension compared to diesel fuel (Gao, 2009). Some other researcher perform an experiment to study the effect of blending ratio and injection pressure in the spray morphology of blended fuel containing conventional diesel fuel and unrefined fuel. The progress of spray injection were performed by using Laser diffraction particle analyser (LDPA) and spray penetration as well as fine atomization also have...
been studied using Sauter Mean Diameter (SMD) as well as droplet concentration under various injection condition. The fuel containing unrefined biodiesel fuel exhibited different spray patterns in comparison to conventional fuel due to the fuels high viscosity and large surface tension. The main work of the experimental investigation of fuel spray characteristics of diesel and biodiesel fuels at various injection duration at constant pressure and ambient temperature at non evaporating condition.

EXPERIMENTAL SETUP

A schematic diagram of experimental setup shown if fig 1. The setup consists of a spray chamber, fuel injection system, high speed video camera and data acquisition system. In this experiment, the diesel spray was observed from a constant volume chamber along with fuel injection system. The spray chamber made up of quartz crystal. The fuel injection system having electric motor (0.25hp), fuel pump (Jerk type) and fuel injector. A high speed video camera name viz, Fastec Motion to capture the image and it will be further processed and analyzed by using (ProAnalyst software). In this work, the starting of injection pressure were studied at 3 different condition at 180 and 220 bar. The image acquiring time from camera is 2.3ms to 2.7ms. The total image capturing time is 3.5 sec and frame rate of1250 fps with resolution of 800×600. The Mie scattering technique is applied, one end came ra and other end is light source. A 1000 W halogen lamp is used to illumine for clear and visible images.

**Figure. 1. Schematic diagram**

Reynolds and Weber numbers necessity

The spray breakup regime and spray morphology can be investigated using Weber number signifies the ratio of inertia force to surface tension force \((We = \frac{\rho du^2}{\sigma})\), Reynolds number signifies the ratio of inertia force to viscous force \((Re = \frac{\rho du}{\mu})\). \(d\) is the nozzle diameter mm, \(u\) is the jet velocity through the nozzle m/sec, \(\sigma\) is the surface tension N/m, \(\mu\) is the viscosity of liquid Nm/sec². These dimensionless parameters are used to find the effects of ambient pressure, fuel pressure, nozzle diameter, fuel temperature, fluid properties.

Selection of biodiesel and its physical chemical properties

The use of edible vegetable oils such as sunflower, rapeseed oil and soybean oil for fuel purposes may directly affect the economy i.e. it may cause and increase in the prices of cooking oils. In order to avoid the consequence, it is essential to use non-edible oils for biodiesel production. Rubber seed oil, Jatropha oil and Linseed oil are examples of non-edible oils. Transesterification (also known as alcoholysis) is the chemical process in which vegetable oil reacts with an alcohol (e.g. methanol and ethanol) in the presence of a catalyst such as sodium hydroxide or potassium hydroxide, to form alkyl esters with glycerol as a byproduct. In the present study, Jatropha oil is used as a feed stock to produce biodiesel by transesterification processes. Jatropha oil reacts with methanol in the presence of potassium hydroxide catalyst to produce JOME (Jatropha oil methyl ester). To complete the transesterification process, 3:1 molar ratio of alcohol is needed. A mixture of Jatropha oil and sodium hydroxide (used as catalyst) are heated and maintained at 650C for one hour, while the solution is constantly stirred. Two distinct layers are formed, the lower layer is glycerin and upper layer is ester. The upper layer (ester) is separated and moisture is removed from the ester by using calcium chloride. It is observed that 90% ester can be obtained from vegetable oil. One litre of Jatropha oil requires 6.9 grams of sodium hydroxide and 200ml of methanol for its conversion to biodiesel. The comparison of physical properties of Jatropha oil, JOME and diesel oil are shown in Table 1
RESULTS AND DISCUSSION

The aim of the present investigates the constant injection duration with varying injection pressure. Fuels used for this experiment JOME and diesel and images are obtained by using Fastec Motion camera as shown in figure 4. Fuel having higher spray tip penetration and lower spray cone angle.

Weber number and Reynolds number effect on macroscopic spray structure

For injection pressure (180-240 bar), weber number varies from 10,000 to 30000 and Reynolds number varies from 30,00000 and 60,00000. In order to examine the relative importance of inertia force, surface tension force and viscous force. Inertia force is an important parameter, which is concentrated by injection pressure to ambient pressure with secondary jet break up with fluid viscosity. Surface tension and viscous force accordingly compare to inertia force. The main aim to focus the inertia force and viscous force on the spray characteristics. At initial condition low weber number and Reynolds number due to small inertia force to large viscous force at ambient temperature, although in this condition small spray momentum because low interaction between liquid and surrounding air. The spray cone angle increases due to Rayleigh break up theory. At higher condition larger weber number and larger Reynolds number, especially this region higher Reynolds number and resulting higher weber number, due to higher Reynolds number and acceleration breakup process increase in the spray tip penetration.
Correlations between spray characteristics and dimensionless number

Fig. 2 and 3 illustrates the spray angle and spray tip penetration versus Reynolds number and Weber number. The data were compared for 2.5 ms. Correlations are obtained for together spray cone angle and spray tip penetration as described by the following equations.

\[ S \propto W e^{0.3748} \]  
\[ S \propto R e^{0.70225} \]  
\[ \theta \propto W e^{0.4146} \]  
\[ \theta \propto R e^{0.8798} \]

Where \( \theta \) is the spray cone angle and \( S \) is spray tip penetration.

The expressions (1), (2), (3) and (4) provide a quantification of the inertia effect on spray cone angle and spray tip penetration. Correlations were developed to understand the outcome of all three dimensionless numbers on spray cone angle and spray tip penetration and shown in equation (3)-(4). For all spray parameter, two equations are provided to distinguish between Reynolds number regimes.

\[ S \propto R e^{0.70225} W e^{0.3748} \]  
\[ \theta \propto R e^{0.8798} W e^{0.4146} \]

The dimensionless analysis reported in this study comprehend the effect of fuel injection pressure, ambient pressure, fuel properties on spray for a single hole nozzle. For the test fuels and fuel temperature conditions, Weber number varies from 313000 to 428000, Reynolds number varies from 9900 to 21500. The analysis yielded dimensionless correlation for spray penetration and spray cone angle characteristics at 2.5 ms based on the regions of these three dimensionless numbers.

These correlation enumerate the effects of primary forces on spray tip penetration and spray cone angle for direct injection single hole nozzle. A well-built correlation is observed between these two spray parameters and Weber number which was credited to more amount of inertia effect compared to surface tension effect. The Weber number has more effect on the spray tip penetration and spray cone angle, compared to the Reynolds number. The inertia force and air drag force are more important factor compared to the viscous force and surface tension forces. The formulations could be used to generate general spray models which express the physical mechanism explicitly, independent of the test conditions and fuel used.

CONCLUSION

Dimensionless analysis were useful for fuel spray in a spray chamber to investigate the macroscopic characteristics of single hole nozzle. Weber number, Reynolds number were used to represent primary effect on spray atomization of JOME and diesel. Spray characteristics are mainly dependent on the competition among the four key forces acting on a liquid jet such as inertia force, surface tension force, air drag force and viscous force, which can be represented by a three-dimensionless numbers, Weber number, Reynolds number. The excellent correlations between these three dimensionless numbers and spray macroscopic characteristics have yielded a set of common formulations. These formulations provide important insight into the spray breakup and atomization processes and could be used to generate general spray models which express the physical mechanism noticeably, independent of the test conditions and fuel used.

REFERENCES

Demirsbas A. Relationships derived from physical properties of vegetable oil and biodiesel fuel, Fuel 2008; 87:1743-8
Phan AN Phan TM Biodiesel production from waste cooking oils, Fuela 2008; 87; 3490-6
Yanfei Li, Guohang Tian and Hongming Xu, Application of biodiesel in automotive diesel engine INTECH,.2013, pp.387-405.