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Macroscopic Spray Parameters of Karanja Oil and Blends: A Comparative Study

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ABSTRACT

Diesel engines are very efficient prime movers in their power range. Fuel is directly injected into the combustion chamber. Performance and emission characteristics of diesel engines are highly influenced by the fuel spray parameters and atomization of the injected fuel. As the emission regulations become stringent, it is very important to optimize the combustion in internal combustion engines for different fuels including alternative fuels. Spray visualization using optical techniques play a very important role to analyze macroscopic spray parameters and fuel atomization behavior. In the present experimental study, an important alternative CI engine fuel, Karanja oil and its blends with diesel have been investigated for their spray parameters and fuel atomization relative to mineral diesel. These parameters are different for the two fuels because of difference in the viscosity and density of the fuels. Combustion chamber pressure is a dominant factor, which strongly influences the spray characteristics. This research is a comparative study of the effect of ambient pressure on macroscopic spray parameters such as spray tip penetration, spray cone angle and spray area, of mineral diesel, Karanja oil (K100) and blends (K5, K20). Experiments were carried out in a constant volume spray visualization chamber under different chamber filling pressure (1, 4, 7 and 9 bars) at a fuel injection pressure of 200 bars. The light intensity on the illuminated spray was analyzed to find the atomization level of different fuels. Spray parameter like spray tip penetration, cone angle and the spray area were found to be higher for Karanja oil (K100) as compared to blends (K20 and K5) and mineral diesel. It was observed that as the concentration of Karanja oil in the blend decreases, atomization actually improves. It was also found that with increasing chamber pressure, atomization of fuel becomes relatively superior.

INTRODUCTION

Diesel engines are one of the most important power plants now-a-days. These engines are widely used because of their high efficiency and durability. Major problem with diesel engines is that they produce high NOx and soot emission compared to their gasoline counterparts. Diesel, a fossil fuel is depleting continuously because of limited reserves. In the recent past, there are many advances in the field of alternative fuels like straight vegetable oils (SVO), biodiesel etc. to replace the conventional mineral diesel. Researchers are attracted towards these alternative diesel engine fuels, which have emerged as efficient and sustainable fuel for limiting the emissions of greenhouse gases and improving the air quality [1]. Biofuels have different properties, which lead to variation in injection and atomization parameter as compared to conventional diesel [2]. Straight vegetable oils (SVO’s) are the oils derived from the plants like Karanja, Neem, Jatropha, Sunflower etc. and biodiesel is a product of transesterification of these oils with primary alcohols. Direct use of SVO’s to run the diesel engines is quite difficult because of their high viscosity and density. On the other hand biodiesel has similar properties as that of mineral diesel and is easier to use as fuel in diesel engines. The preparation of biodiesel requires lot of efforts and therefore its preparation becomes costly. However, vegetable oils can be fed directly into the engines by blending them with mineral diesel. The blending of vegetable oils with mineral diesel makes their properties closer to diesel. Karanja vegetable oil is an important alternative fuel, because it has comparable energy content, cetane number, heat of vaporization and stoichiometric air-fuel ratio to that of mineral diesel. In addition, Karanja oil is biodegradable and non-toxic. Its plant is abundantly available in Indian and South Asia and this species can survive in variety of environmental conditions. It has potential to grow on degraded soils, and low and high rainfall areas. Its seeds have high yield and can be harvested in non-rainy areas. Due to its numerous advantages, Karanja oils and their blends with diesel have been considered potential alternative fuels for CI engines in South Asia [3]. However, the biggest problem associated with the vegetable oils is their high viscosity (10-20 times higher than diesel). Therefore the fuel spray coming out of the injector has high penetration length, high spray area and cone angle compared to diesel [4] and they also have poor atomization characteristics which contribute to incomplete combustion due to inadequate fuel-air mixing. So, the Karanja oil needs to be modified to bring its combustion related properties closer to diesel. Several studies have been undertaken on the use of vegetable oils and its derivatives as fuel in diesel engines. Their spray characterization and atomization behaviour also have been studied widely. Kim et al. investigated the spray behaviour of DME (Dimethyl ether) and biodiesel [5]. They used image processing for atomization performance analysis of the two fuels. They observed that the ambient pressure has a significant effect on the spray characteristics. Both spray tip penetration and spray area decreases as the ambient pressure increases. They also found that the biodiesel spray characteristics are inferior to the DME. Park et al. investigated the combustion and exhaust emission characteristics of biodiesel with multiple injections [6]. Bang et al. studied the fuel spray injection characteristics and macroscopic behaviours of DME blended methyl ester derived from soya oil in different blends [7]. They found that the spray penetration length was same for biodiesel and blended fuel except pure DME. Lee et al. defined the spray characteristics of diesel fuel as macroscopic spray structure and atomization characteristics into microscopic spray structure. Macroscopic spray structure consists of spray tip penetration and the cone angle [8]. A common rail direct injection system with injection pressures 60, 70, 80 MPa with injection duration of 1.4 ms were used in their study. They reported that with increasing injection pressure, the spray tip penetration increases while the cone angle decreases, because the injection velocity increases. Misra et al. carried out a review of literature on the use of SVO's in compression ignition engines. They explained that small percentage of SVO's blended with mineral diesel enhance the engine exhaust emission of the engines [9]. It is already known that better fuel-air mixture preparation is very important to reduce emissions from diesel engines; therefore it is important to understand the fuel atomization and spray formation process of SVOs. Park et al. investigated the injection and atomization characteristics of biodiesel–ethanol blends. Solubility of ethanol in diesel fuel increases by adding 1-2% of additive package and the flammability of ethanol–diesel blends with the additive reaching the diesel level under cold-start conditions [10]. Additionally, the increase in the ethanol blend content resulted in increasing specific fuel consumption and brake thermal efficiency. The soot concentration was significantly lower than that of diesel. Smoke and PM reduced simultaneously. It was reported that the increased NOx observed with the use of biodiesel is due to increased local temperatures as a result of enhanced fuel-air mixing and increased spray penetration.

In present investigation, experimental set up was developed to capture the images of different fuel sprays. Mineral diesel, Karanja oil and its blends with mineral diesel (K5, K20) are investigated for different chamber pressures. Microscopic spray parameters like spray penetration, spray cone angle, spray area and fuel atomization behaviour are analysed using image processing technique. Comparative studies have also been carried out to improve combustion and spray behaviour of Karanja oil and their blends.

EXPERIMENTAL SETUP

The experimental setup includes a constant volume spray chamber, air compressor, fuel supply system, high speed camera and data acquisition computer. Schematic diagram of the experimental setup is shown in figure 1, which is used to investigate the macroscopic spray parameters and fuel atomization. Constant volume spray chamber is capable to withstand an ambient air pressure upto 10 bar. Chamber has four optical windows (16 cm diameter each) and its lower portion is conical in shape with a drain valve. The drain valve is installed to be able to remove the fuel collected during the experiment, when the experiment is completed. Fuel injector and a pressure gauge is installed at the top of the chamber. Air connections are done to the chamber for maintaining the required ambient/ chamber pressure. Optical windows are made up of four circular pieces of glass, 19 mm thick. Windows are tested and found to withstand 10 bar chamber pressure safely, without any sign of failure. An air compressor (Make: Vayu air compressor, India; Model: SA10081R) is used for maintaining the required chamber pressure.

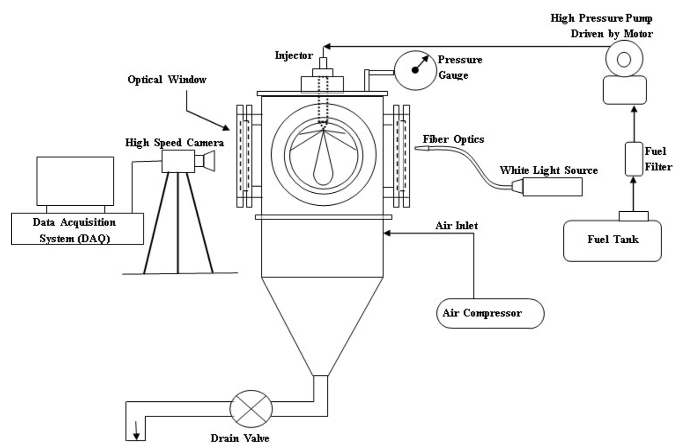

Figure 1: Schematic of experimental setup for fuel spray characterization

The fuel injection system used in the spray experiments is similar to the one used in constant speed single cylinder engine (Make: Kirloskar oil engines limited, Pune, India; Model: DM-10). The injector is a mechanical fuel injector with delivery valve opening pressure of 200 bars. It has three nozzles (Nozzle diameter = 0.29 mm), which are placed at 120° angle from each other. The fuel pump is a mechanical jerk pump which it delivers the fuel at pressure more than 200 bars. Fuel injector is connected to the fuel pump with a high pressure line and fuel pump is operated by an electric motor of 0.5 hp. A white light source (Make: Thorlabs, USA) is use to illuminate the fuel droplets in the constant volume spray chamber. Light entering from one window of the chamber illuminate the fuel droplets. Spray visualization can be done from an orthogonally placed window. A high speed camera is used to take images of the droplets (Make: Basler model: A601fc). High speed camera is connected with the data acquisition computer and the images are taken by using image grabbing and analysis software. The images analysed for the macro analysis of spray characteristics using National Instrument's Vision Assistance 2009 software, which has a graphical tool to process the images effectively. This software analyzes the image according to the number of pixels and pixel values (Pixel intensity). The brightness level and the threshold values were fixed for image analysis for all the experiments.

Viscosity and density of fuels are critical parameters in spray characterization, therefore these properties were measured for each fuel. A kinematic viscometer (Make: Stanhope Seta, UK; Model: Seta11300) is used for measuring the viscosity of Karanja oil blends vis-à-vis mineral diesel. A portable density meter (Make: Kyoto Instruments, Japan; Model: DA-130N) was used for measuring the density of the test fuels.

The experiments were carried out at 200 bar injection pressure for mineral diesel and Karanja oil blends. Leak test was performed before starting the experiment. Experiments were performed for 4 different chamber pressures (9, 7, 4 and 1 bar). Fuel used was mineral diesel and Karanja oil blends (K5, K20 and K100).

RESULTS AND DISCUSSION

A detail test matrix was prepared for conducting the experiments. Karanja oil, mineral diesel and their blends (K5 and K20) are characterized for their important properties like density and kinematic viscosity. Fuel spray characterization includes (1) Spray tip penetration (2) Spray cone angle and (3) Spray area. These parameters have individual importance for spray development in the combustion chamber especially for NOx and PM emissions. Properties of fuels like density and kinematic viscosity are measured for all fuel sample (Table 1). These properties have significant influence on the spray parameters. The results show that the kinematic viscosity of Karanja oil is 41.04 cSt at 40°C and density is 925 kg/m^3 at 15°C, which are higher than mineral diesel.

Table 1: Kinematics viscosity and density of test fuels

Fuels	Density (kg/m^3) at 15°C	Kinematic viscosity (cSt) at 40°C
Diesel	817	2.55
K5	825	3.88
K20	839	4.97
K100	925	41.04

However due to higher density and viscosity of Karanja oil, larger droplets are formed, which have higher initial injection velocity thus the momentum of droplets is relatively very high leading to higher jet penetration. Few milliseconds after start of injection, droplets transfer their momentum to other subsequent droplets therefore conveying the momentum of droplets results in higher penetration of spray tip and poor fuel atomization leading to inefficient mixing of fuel and air.

Spray Tip Penetration

Spray tip penetration is the maximum penetration length gained by the spray tip after the start of injection. The chamber pressure rise (from 1 bar to 9 bars) increases the density of air inside the spray chamber. At the spray tip, droplets face higher resistance against the dense air of the chamber. Due to this, the droplet velocity becomes high near the injector nozzle and it decreases as it moves forward thus decreasing spray tip penetration. The spray penetration of diesel is lowest under all chamber pressure conditions because the density of diesel is lowest hence it atomizes more rapidly as compared to other test fuels. Karanja oil (K100) has highest spray tip penetration (at 1, 4, 7 and 9 bars chamber pressure) followed by K20, K5 and diesel (Figure 2) at same chamber pressure.

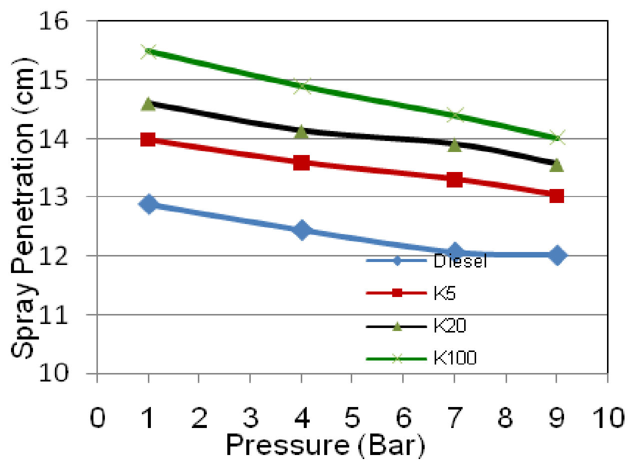

Figure 2: Spray tip penetration of Karanja oil blends at various chamber pressures

The spray tip penetration of K100 is 15.49 cm at 1 bar chamber pressure and 14.02 cm at 9 bars as compared to diesel, which has 12.89 cm spray penetration at 1 bar chamber pressure and 12.02 cm spray penetration at 9 bars. High ambient pressure causes higher resistance to the droplets. Therefore the momentum of the droplets also reduces at the tip of the spray. Diesel has lowest density therefore it shows good atomization characteristics compared to other fuels however lower spray tip penetration as compared to K100, K20 and K5. In case of K20, jet penetration is 14.61 cm at 1 bar chamber pressure which is lower than K100 but higher than diesel. This happens because of the reduced viscosity and density of the Karanja oil blends (Table 1). Therefore, the atomization at the tip is higher compared to K100. At 9 bars, K20 spray tip penetration is 13.57 cm, which is also lower than K100 because of the same reason.

Spray Cone Angle

The spray cone angles have been investigated by connecting the two points at half of the spray length where pixel intensity is slightly higher than the critical pixel intensity to the nozzle. The spray images are processed and cone angle data is plotted (Figure 3) for all the test fuels. It is found that the spray cone angle increases as the chamber pressure increases. At 1 bar spray chamber pressure (Figure 3), the ambient density of spray chamber is lower; therefore the spray cone angle is lower. The fuel droplets have higher initial velocity, which reduces because of resistance from ambient air subsequently. The fuel droplets travel faster along the axis rather than radial direction. Therefore the cone angle of the fuels is lower at 1 bar (Figure 3).

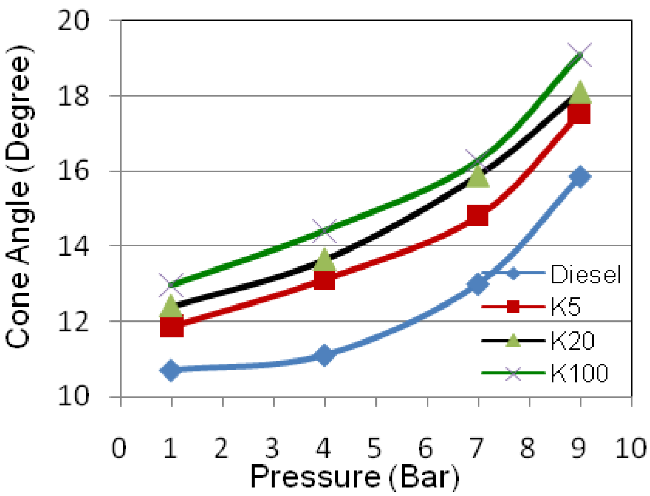

Figure 3: Spray cone angle of Karanja oil blends at various chamber pressures

Karanja oil has the higher fuel density than blends. Therefore oil droplets movement is lower in the radial direction as compared to its blends. However as the spray chamber pressure increases (from 1 to 9 bars), the fuel droplet concentration level increases at bottom part of the spray because of higher ambient resistance due to higher ambient density in the chamber. Thus spray spreads and the cone angle increases with increasing spray chamber pressure (Figure 4). K100, K20 and K5 have lower spray cone angle of 12.98°, 12.41° and 11.88° respectively.

Spray Area

From the images, the pixels are identified whose pixel value is more than the critical pixel value. The spray area is the area covered by line joining these pixels with critical value. Figure 4 shows the effect of increase in chamber pressure for different test fuels. With increasing chamber pressure, the spray area increases (Figure 5). The spray area of diesel is lowest as compared to other test fuels. The explanation is same as that of spray cone angle. Higher density and viscosity of vegetable oils lead to larger size droplets formation and leads to poor atomization. With increasing chamber pressure, the fuel droplet concentration increases near the tip of the spray. Droplets face higher resistance due to higher chamber pressure and the momentum of the droplets force them to move outward in the radial direction. But as the chamber pressure increases from 1 bar to 9 bars, the spray droplets experience higher air resistance exerted on them.

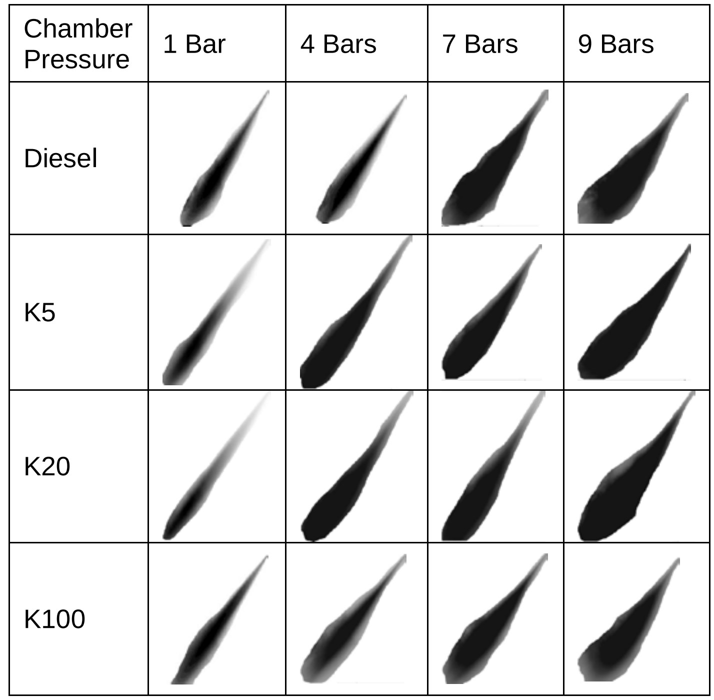

Figure 4: Effect of chamber pressure on fuel spray of test fuels

Therefore instead of moving forward, the droplets get concentrated at the center of spray and also start moving radially outward. Because of the shear resistance at the surface, droplets are prone to break up and get converted into finer droplets, which increases the number of droplets and also the area of the spray. Spray area at 1 bar for K100 is 22.25 cm^2 and for K20, it is 21.4 cm^2. Diesel has lowest spray area 17.5 cm^2. As the chamber pressure increase to 9 bars, the spray area increases for K100, K20 and K5 (38.10, 35.92 and 34.27 cm^2 respectively) (Figure 5).

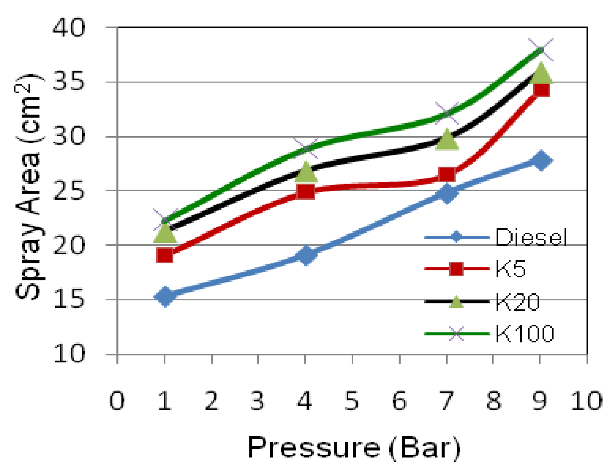

Figure 5: Spray area of Karanja oil blends at various chamber pressures

CONCLUSION

Spray characteristic is highly dependent on the fuel viscosity and density. These two properties restrict the use of vegetable oils in diesel engine. In this study, Karanja oil has been blended with mineral diesel to improve the fuel properties. K5, K20 and K100 were compared to mineral diesel. Experiments were carried out in a constant volume spray chamber at constant fuel injection pressure of 200 bars under different chamber pressures of 1, 4, 7 and 9 bar. Spray characteristics analysed are spray tip penetration, spray cone angle and spray area. It is found that the spray tip penetration length decreases with the increasing chamber pressure. It is maximum for K100, which is followed by K20, K5 and mineral diesel. Similarly cone angle and spray area also increases with increasing chamber pressures. At 9 bar chamber pressure, K100 has the highest cone angle followed by K20, K5 and mineral diesel. The spray area of K100 is highest for all chamber pressures which are followed by K20, K5 and mineral diesel.

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