Analysis of Straight Vegetable Oil (SVO) Spray Characteristics and Droplets Distribution By Using Nano-Spark Shadowgraph Photography Technique

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Abstract *- Biofuel is an alternative fuel to reduce the dependent on fossil fuel due to the limited oil stock and increment of oil prices. Straight vegetable oil (SVO) has several superior combustion characteristics such as less hydrocarbons, carbon monoxide and particulate matter compared to diesel fuel. More advantages are high biodegradability, excellent lubricity and no sulfur content. During combustion, approximately 10wt% of its oxygen content promote more complete combustion process and effectively reduce unburned hydrocarbons (UHC), carbon monoxide (CO) as well as suspended aerosol carbon granules. However, high kinematic viscosity of SVO affects the spray characteristics thus effect the engine efficiency. In this study, the effect of kinematic viscosity of SVO on fuel injection spray characteristic are investigated using constant volume high pressure spray chamber and nano-spark shadowgraph photography technique.*

Keywords - diesel spray, solid vegetable oil (SVO), droplets, penetration, cone angle.

1. Introduction

Biofuel refers to fuel that are mainly derived from biomass or bio waste such as a vegetable oil or animal fat-based diesel fuel. Unlike petroleum diesel, biofuel is a renewable resource meaning that it can be continually replenished. The use of biofuel could reduce the dependent on fossil oil and might be the solution to the increasing energy crisis. Major advantage of using biofuel is that it can be used with diesel engine with less modification needed. With the continued rise of fuel prices, biofuel is set to become more popular as one of a fuel replacement option in the transportation industries.

Among advantages are biofuel produce less emission compared to fossil fuel[1,2]. The ozone forming potential of biofuel hydrocarbons (HC) is 50 percent less than diesel. The exhaust emissions of sulfur oxides and sulfates (major components of acid rain) from biofuel are essentially eliminated compared to diesel. It has the advantages of high biodegradability, excellent lubricity and no sulfur content[3,4]. Traditional diesel engines have a much higher rate of engine wear due to oil lubricant problem. Using biofuel could improve lubricity inside the engine thus lengthen engine durability. With the stringent emission regulation endorsed by many countries, biofuel becomes much more attractive as a practical fuel to use.

On the other hand, some disadvantages of biofuel application are biofuel production is currently more expansive than diesel. Biofuel contains energy value at approximately 10% less than diesel fuel, leading to reduction of engine power output. Therefore, vehicles running on biofuel records about 10% fewer miles per gallon of fuel than diesel[5,6]. Moreover, biofuel exhaust emission shows no reduction in nitrogen oxides (NOx) emission[7,8]. Most significantly, the issue of biofuel application is on its high kinematic viscosity compared to diesel fuel.

High kinematic viscosity of biofuel leads to operational problem on fuel injector and engine chamber due to the production of deposits inside engine and fuel injector nozzle.
In this research, experiment on spray characteristics of biofuel was done in order to analyze the affect of biofuel kinematic viscosity on fuel spray. The high level of kinematic viscosity could cause some sort of resistance of fuel flow during fuel injection, effecting the spray geometry thus the atomization process[9].

2. Experimental Setup

Figure 1 shows optical setting for biofuel experiment with single spark shadowgraph technique. In this setting, Nikon D60 DSLR, prime lens: Nikkor 50mm f/1.4 was used for wide angle photography. ND filter was used in order to reduce by 30% the brightness of light spark emitted by spark head.

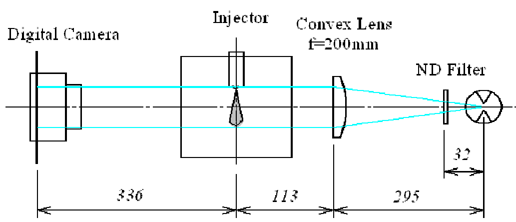

Figure 1. Single spark optical setting for biofuel spray experiment.

2.1. Test Fuels Properties

Properties of straight vegetable oil (SVO) used in this experiment are shown in Table 1. Referring to Table 1, kinematic viscosity value measured for SVO fuel at 303K is 47.78mm^2/s compared to 3.30mm^2/s for diesel (GO) fuel. Kinematic viscosity for SVO is almost 14.5 times higher than GO fuel.

Table 1. Properties of diesel fuel (GO) and straight vegetable oil (SVO).

Fuel and Notation		GO	SVO
Density	g/cm^3	0.827	0.911
Kinematic viscosity	**mm^2/s@303K**	**3.30**	**47.78**
Carbon	wt-%	0.86	0.78
Hydrogen	wt-%	0.14	0.11
Oxygen	wt-%	0	0.11
Lower heating value	kJ/kg	42.70	38.14

Pre-experiment was done to analyze the affect of fuel temperature on kinematic viscosity. Referring to Figure 2, same pattern can be seen in all the test fuel samples of GO, biodiesel fuel (BDF) and SVO where its kinematic viscosity value are declining with the increasing of the fuel temperature. Figure 3 shows distillation characteristics of the test fuels. The measurement was strictly done following the JIS K2254 which is Japan Standard Measurement Method for fuel distillation test. The result shows that BDF has 95% high-end distillation component compared to GO. Meanwhile, SVO shows highest distillation measurement among others test fuels. Pre experiments results shows that SVO has highest kinematic viscosity and highest distillation among others test fuels which will affect spray characteristic when injected into engine. At the same time, Fig. 3 show that fuel properties change significantly with the temperature, which affects the spray development and spray penetration.

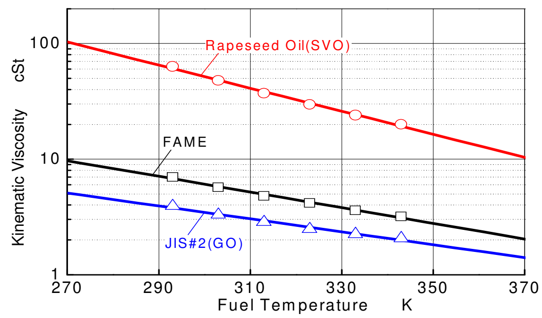

Figure 2. Affect of fuel temperature on kinematic viscosity.

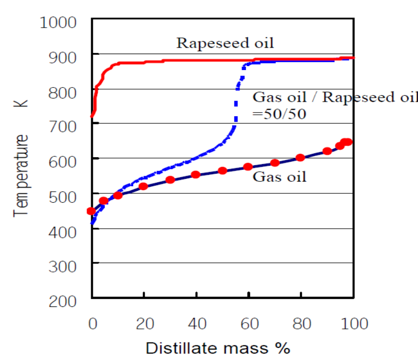

Figure 3. Distillation characteristic of test fuels.

3. Results and Discussion

3.1. Spray comparison of SVO, BDF and GO

Figure 4 shows spray images of SVO, BDF and GO fuel taken at ambient temperature T_i=298K, fuel injection pressure P_{inj}=40MPa and time after start of injection t=0.5ms. Referring to the images, SVO spray penetration was obviously shorter than BDF and GO spray. Moreover, narrow spray cone angle can be seen from SVO spray from nozzle tip until spray tip area. No structures like branches formed along SVO spray boundary as can be seen in BDF and GO spray. This is due to the high value of kinematic viscosity for SVO fuel as shown in Table 1. Meanwhile, BDF has similar value of kinematic viscosity compared with GO thus its spray behavior shows similar characteristics with GO spray.

3.2. Effect of Injection Pressure and Ambient Temperature on SVO Fuel Spray

Figure 5 shows the effect of ambient temperature T_i=298K and 700K on SVO spray penetration (left) and magnified images of droplets at spray boundary area (right). The images were taken using single spark photography method as shown in Fig. 1. Referring to Fig. 5, SVO spray at T_i=298K show narrow spray pattern while SVO spray at T_i=700K shows similar spray characteristic with GO fuel in terms of spray penetration and spray cone angle. Furthermore, at T_i=700K, structures like branches can be seen developed along spray boundary region. As shown in Fig. 2, kinematic viscosity value of SVO decreased with increased of fuel temperature. Therefore, SVO spray at high ambient temperature could form similar spray structures as GO spray. Magnified images of droplets shows smaller size droplets exist inside spray boundary region at higher ambient temperature of T_i=700K as compared to lower ambient temperature of T_i=298K . Generally, high injection pressure spray inside high ambient temperature produces relatively small-size droplets and as a result, small size droplets could lead to a better atomization process[10].

Figure 6 shows detail observation inside spray boundary region between GO and SVO. Magnified images of droplets shows no vapor phase can be visibly seen inside SVO spray boundary region. Contrary, GO fuel spray shows large vapor phase developed at spray boundary region. From the observation, it can be conclude that SVO spray at high ambient temperature and high injection pressure could promotes faster atomization process but slower vaporization compared to GO fuel. Slow vaporization process of the fuel will increase the exhaust emission when injected into engine that running at low load.

3.3. Effect Droplets Distribution of SVO and GO Spray

To investigate further the atomization process of SVO spray, droplets distribution in term of droplets diameter D and number of droplets exist inside spray boundary N has been done by analyzing images taken using single spark photography technique. Figure 7(a) and (b) shows droplets distribution of SVO spray at ambient temperature of T_i=298K and 700K, respectively. Moreover, each graph shows an effect of injection pressure P_{inj}=40MPa and 70MPa on droplets distribution. Figure 7(a) shows at spray tip area, higher injection pressure P_{inj}=70MPa records smaller size droplets than P_{inj}=40MPa. However, no significant effect of injection pressure can be observed at spray upstream area to midstream area. Meanwhile, Fig. 7(b) shows, overall droplets size become smaller when fuel injected inside T_i=700K. High injection pressure spray at high ambient temperature produce small droplets size which less than 20µm along spray boundary.

4. Conclusions

Improvement of SVO spray by various control strategies have been done and reported in this paper. The conclusions of the results are shown as follows:

1. Kinematic viscosity value highly effect spray geometry such as penetration and cone angle. SVO spray penetration measured shortest and narrow cone angle compared with BDF and GO spray in T_i=298K. These are due to the high level of kinematic viscosity inside SVO compared to BDF and GO fuel.
2. SVO spray at high ambient temperature produce similar spray structures as GO spray due to kinematic viscosity level of SVO decreased with increased of fuel temperature. High ambient temperature spray produce smaller droplets size that could promote atomization but slower vaporization compared to GO fuel cause increase of emission when running in low load engine.
3. High injection pressure spray produces relatively small-size droplets. High injection pressure spray inside high ambient temperature produces small droplets size which less than 20µm along spray boundary from nozzle tip to spray tip area and this could improve atomization process for SVO spray.

5. References

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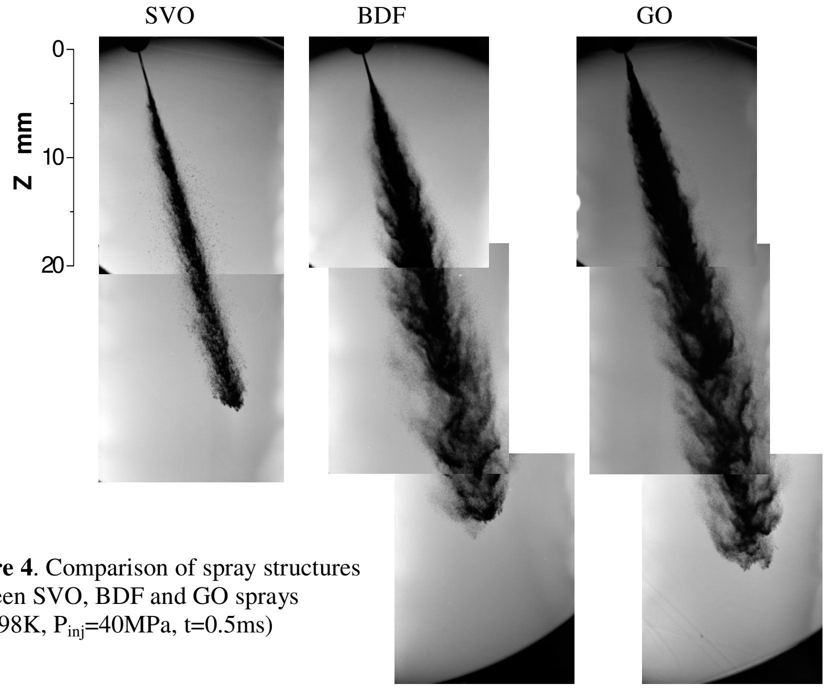


Figure 4. Comparison of spray structures between SVO, BDF and GO sprays (T_i=298K, P_{inj}=40MPa, t=0.5ms)

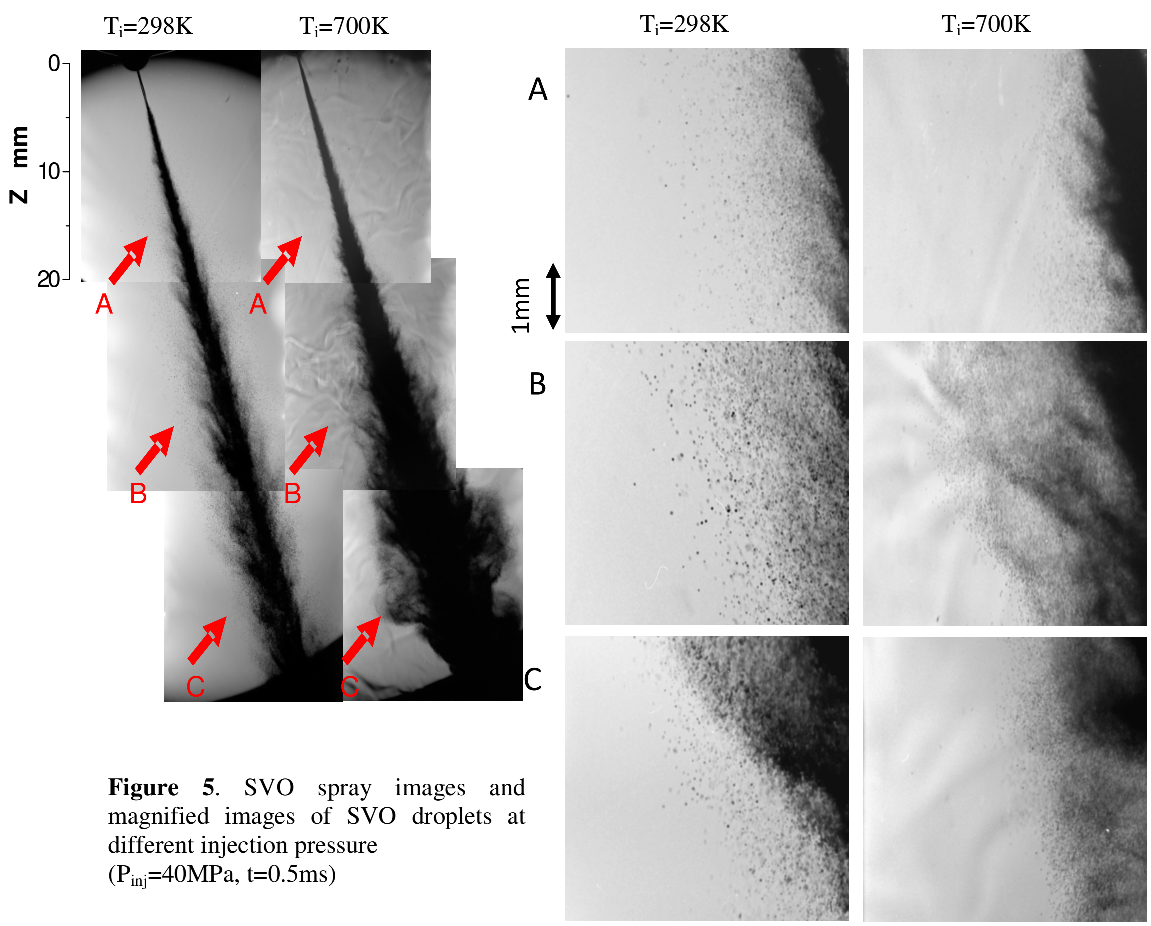


Figure 5. SVO spray images and magnified images of SVO droplets at different injection pressure (P_{inj}=40MPa, t=0.5ms)

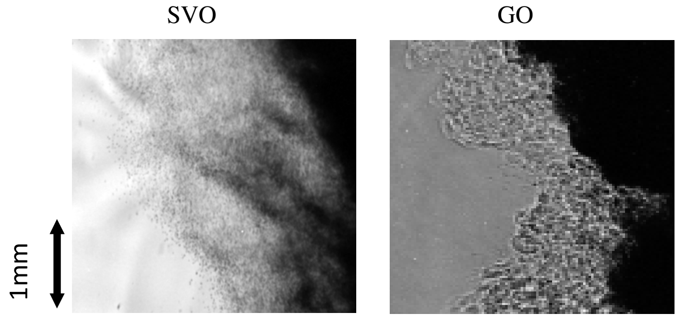
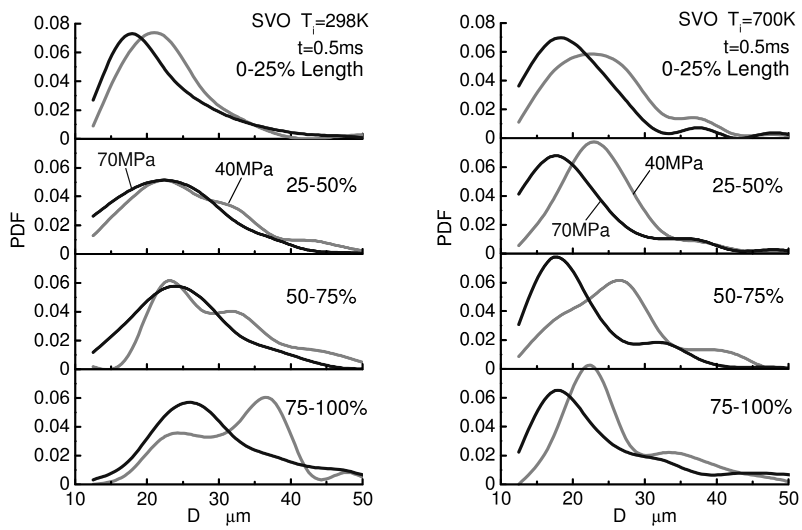


Figure 6. Spray characteristics at spray boundary region.
(T_i=700K, P_{inj}=70MPa)



(a) T_i=298K (b) T_i=700K

Figure 7. Effect of injection pressure on droplets distribution of SVO spray