Experimental Investigation on Spray Characteristics of Waste-Cooking-Oil Biodiesel/Diesel Blends at Different Injection Parameters

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Abstract- **Biodiesel is a promising alternative solution for the energy crisis, as it is renewable, biodegradable, non - toxic and it has a fully competitive edge with petrol diesel in most technical aspects. Because of the increasing global request for diesel fuel consumption, consumption of non-renewable fossil fuels, exhaust emissions, all these led to search about alternative fuels. Biodiesel is one of the potential alternatives for depleting fossil fuels. Biodiesel fuel is an eco-friendly and renewable source of energy. Biodiesel fuel is an eco-friendly and renewable source of energy. Biodiesel is one of the best solutions and alternatives available to all countries of the world. Inedible plants and vegetable oils such as Jatropha oil, Karanji Pongamia oil, Neem oil, Jojoba oil, Cottonseed oil, Linseed oil, Mahua oil, Deccan hemp oil, Kusum oil, Orange oil, and Rubber seed oil were used as biodiesel in diesel engine. Biodiesel is produced by chemical methods from vegetable oils, but the use of vegetable oils is a high cost.**

Scientists searched for other sources and at the same time has a low cost. They found that waste cooking oil is the ideal solution to that problem. Four methods to minimize the high viscosity of vegetable oils to enable their use in common diesel engines without operational problems such as engine charges have been investigated: blending with petro diesel, pyrolysis, microemulsification (solvent blending), and transesterification. Transesterification is by far the most common method. Only the transesterification reaction leads to the products commonly known as biodiesel, i.e., alkyl esters of oils and fats. Biodiesel was produced from waste Cooking-oil by transesterification process have been applied for most countries to improve and raise the national energy return. Blends of WCOB and diesel were used instead of pure diesel fuel in diesel engine. However, the spray characteristic of the injected fuel depends on different parameters such as fuel injection pressure, the temperature of the injected fuel, ambient pressure, fuel viscosity, and fuel density.

In internal combustion engines, such as the diesel engine used to conduct the experiment, a 20 mm window and a transparent glass box are used to facilitate the visualization of spray characteristics. The spray characteristics of the diesel/ waste cooking oil biodiesel blends fuel were studied experimentally at different injection pressure and temperature. Spray characteristics of biodiesel WCOB / diesel under various injection pressures of 150 to 300 bar and injection temperature of 25 to 275 °C have been measured and illustrated by sparing the fuel blends in a surrounding area using a high-speed Digital camera. In this work, the biodiesel/diesel blend of B40D60 has been tested. The experimental data shows the WCOB biodiesel of B40D60 gives longer spray tip penetration and spray angle are smaller than those of diesel fuels at different pressure and temperature.

Nomenclature

WCOB	Waste cooking oil
B0D100	Diesel 100%,Biodiesel 00%
B40D60	Diesel 60%,Biodiesel 40%

Index Terms— **Spray Characteristics, transesterification, Waste-Cooking-Oil, tip penetration and spray angle**

1. Introduction

Due to the continuous increase of the population, the rate of the energy consumption used in industry, transportation and others are increasing. Fossil fuels are the dominant fuel for these uses and result in environmental pollution [1-3] which resulted in the industry to turn to the development of alternative fuels such as biodiesel. Biodiesel fuel is an eco-friendly and renewable source of energy. Biodiesel have also shown promising results in substantial reduction of unburned hydrocarbon (HC), particulate matter (PM), smoke emission and carbon monoxide (CO)[4-8].

Biodiesel an eco-friendly fuel is extracted from vegetable oil, animal fats and waste cooking oil by transesterification process [8-10]. The use of biodiesel instead of fossil fuel would reduce Environmental pollution and global warming resulting from emissions such as sulfur and, carbon oxides and hydrocarbon emissions[10] . The biodiesel is a fuel that produced through processes such as transesterification, micro emulsion, thermal cracking process and direct use and blending. The most common method is the transesterification process and get biodiesel. Biodiesel from vegetable oils, waste cooking oil, and other renewable sources is an alternative to non-renewable fuels such as diesel, coal, etc. This because that method is easy to apply, It does not need special circumstances.

On the other side, biodiesel produced from waste cooking oils (WCO) is cheap in terms of cost which is estimated to be 80% of the total biodiesel cost [11, 12]. The use of WCO biodiesel has shown of increase or decrease performance and emission. The performance and emission characteristics of WCO biodiesel can be improved by varying injection parameters like injection timing, injection pressure and injection temperature [13-16].

The WCOB also differs from diesel in its chemical and thermo-physical properties such as viscosity, higher density, cetane number and oxygen concentration. Biodiesel are better than fossil diesel in terms of flash point, aromatic content, sulphur content and cetane number[17, 18]. These differences in properties and injection strategies will influence the spray characteristics, fuel evaporation and atomization process of WCO biodiesel compared to diesel which eventually causes differences in performance, combustion and emission characteristics. All of these possible paths demand economic analysis to be done among various alternative production technologies, catalysts, feedstock types as well as various biodiesel and glycerol purification technologies to pinpoint economically better ones.

There are a number of worth mentioning investigations performed to test economics of biodiesel production processes [19-23] as shown in Fig. 1 [24]. They investigated the spray characteristics of RME biodiesel and showed longer penetration, narrow spray angle and smaller spray volume due to its high viscous nature [25, 26]. They also studied the spray and combustion development process of soybean biodiesel blends and reported that fuel impingement and spray tip penetration increased by increasing biodiesel blend ratio. The advance of the spray characteristics leads to improvement atomization in the DI diesel engine. The spray characteristics can be obtained of fuel evaporation and mixture formation in dense atomized spray using photographic imaging method, to obtain spray data suitable for tuning direct injection systems to different fuels. It studied the spray characteristics of waste cooking oil biodiesel under atmospheric conditions and reported That B100 had longer spray tip penetration and larger droplet diameter but B20 showed similar characteristics to diesel with slightly larger droplet sizes and shorter tip penetration. Therefore, the study of spray characteristics of WCO biodiesel makes significance to better understand its spray development process compared to fossil diesel under engine like conditions [27].

The composition of biodiesel mainly depends on its feedstock; however, in the case of waste cooking oil biodiesel, it is not bearding to identify the feedstock as there are a wide variety of cooking oils available [28]. It studied the effect of varying fuel injection pressures and injection timings on particulate size number distribution. Spray characteristics were investigated in a single-cylinder common rail direct injection, compression ignition engine fuelled with biodiesel blends and diesel. The realization results showed that spray tip penetration and spray area of biodiesel blends and diesel are longer for higher injection pressure than at lower injection pressure at the same elapsed time after the start of injection [14, 24, 29].

In this study, using the test apparatus shown in Figure 2, we investigated spray penetration, spray cone angle and spray tip speed of three biodiesels of different blends sourced from inedible oils and analyzed the changes in spray penetration and spray cone angle throughout the entire spray process. We studied the effects of parameters such as injection pressure, injection temperature on spray tip penetration and cone angle in B40 biodiesel and diesel pure. The test rig was composed of a constant-volume. In figure1 shows the spray tip penetration and cone angle. In this study, only one type of fuel injector is used with orifice 20 mm and cone angle of 30°. The injection temperatures and injection pressures that were used are 25 ºC, 60 ºC, 80 ºC and 100 ºC and 150bar, 225bar, 250bar, 275bar and 300bar respectively. The paper aims to study the atomization of WCOB and their blends with diesel and to compare these results with those obtained from diesel pure.

The aim of the study is to find an alternative to diesel using biodiesel under different pressures and temperatures and get the best ratio of biodiesel to run diesel engines and compare the results obtained with pure diesel.

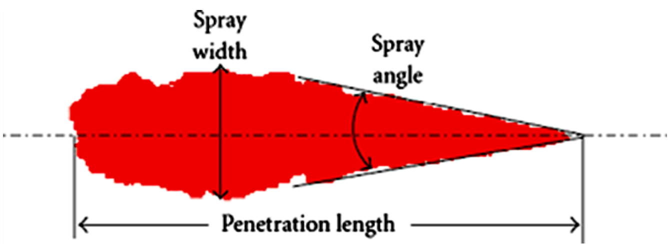

Figure 1: [24] Spray structure

2. EXPERIMENTAL SETUP

I. Bio-oil preparation

The biodiesel derived from the Non-edible waste cooking oil was got from great restaurants to prepare biodiesel. Transesterification process was used to produce biodiesel from waste cooking oil in the chemistry lab. In figure 2 Chemicals like methanol (purity98%), cyclohexane, and sodium hydroxide (purity 99%).cyclohexane were added as higher alcohol while methanol and sodium hydroxide was used as alcohol and catalyst respectively for getting biodiesel. In the current experience, diesel and biodiesel blends were produced. The blended fuel comprises 60% of biodiesel by volume named as B60.The blend of diesel, waste cooking oil biodiesel is B60D40.

Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol. Single stage alkaline transesterification process was used for producing biodiesel from waste cooking oil as shown figure 2. A solution mixing of 220 mL of methanol and 6g sodium hydroxide was blended with 500 ml waste cooking oil at a molar ratio of 10:1 and heated for a period of 60 min at a temperature of 60 ◦C. different properties of diesel and waste cooking oil biodiesel are shown in Table 1.

TABLE 1.

PHYSICAL AND CHEMICAL PROPERTIES OF DIESEL AND WCOB

Properties	Diesel	WCO	WCOB	ASTM standards
Density [kg /m3]	0.835	0.924	0.88	ASTM D975
Kinematic viscosity [mm2 s–1]	2.38	36.4	3.54	ASTM D445
Specific gravity	0.820	-	0.870	ASTM D1298
Lower caloric value [kJ kg–1]	42100	-	39510	ASTM D240
Flash point ºC	45	212	158	ASTM D93
Fire Point ºC	56	-	165	ASTM D93
Cetane index	55	49	68	ASTM D976
Boiling Point ºC	180-340	-	315-350	ASTM D86
Cloud point º C	0		6	ASTM D2500
Carbon wt.%	85.16	46	76.78	ASTM D5291
Hydrogen wt.%	14.26	-	13.17	ASTM D5291
Oxygen wt.%	0	-	9.414	ASTM D5291
Nitrogen wt.%	0.430	-	0.636	ASTM D5291
Sulfur content wt.%	0.152	-	0	ASTM D5291
Copper strip corrosion	1a	-	1a	ASTM D130
Ash content % by mass	0.011	0.006	0.015	ASTM D129

3. Engine Setup

A figure of the biodiesel spray test rig used for analysis spray characteristics is shown in Fig. 3. This experiment done in the modified single cylinder air cooled DI diesel engine. The following types of fuels were used in the experimental studies:

WCOB (B40), Diesel fuel (DF). Properties of the tested fuels are presented in Table 1. Only the most important properties of the fuels were analyzed and compared in this study. The fuel is provided from the fuel tank to the pressure pump to investigate the spray characteristics using high-speed direct photography technique, with fuel injection pressure set from 150 to 300 bars and injection temperature set from 25 to 275 ºC. The injected fuel was filmed by the optical window.

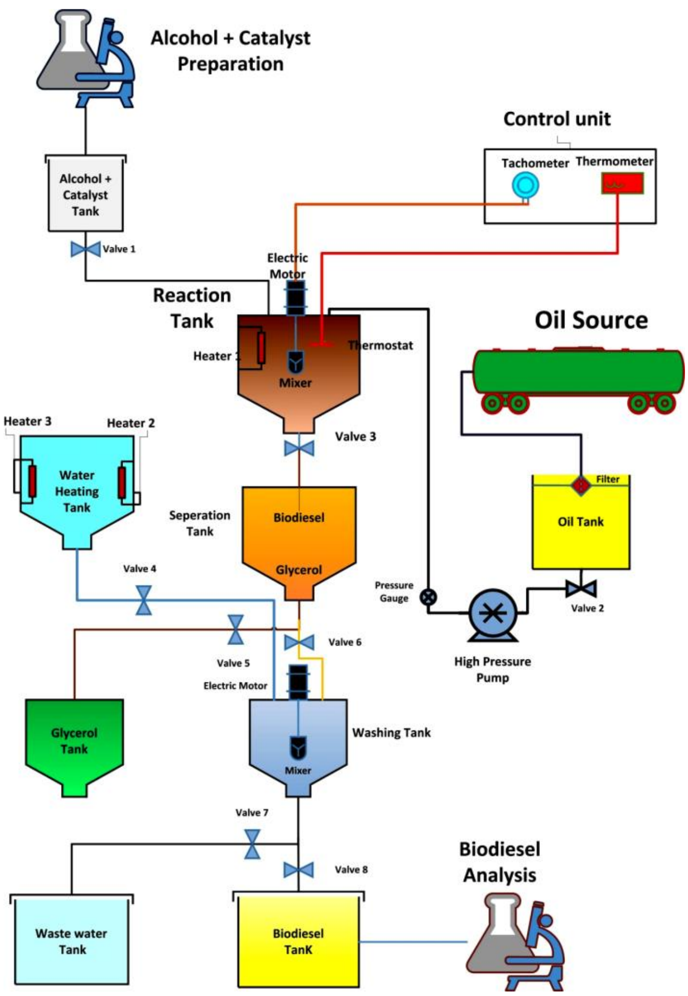

Figure 2: Schematic diagram for production process from WCO biodiesel

Photography and access to the combustion chamber is from the side through a hole just down the cylinder head. The LED white light source is used as a purpose for spray visualization more clearly. Sprinkler hole used 20 mm in right angle triangle direction; the spray contour can be controlled by quartz glass. The high-speed digital camera was situated at angle 30 ° and placed one side of the optical window to visualization for capture the spray structure and the LED light source is passed through the other side of the optical window at exactly 90 to see it better. The camera is connected to the computer via a wired connector. Images are filmed by using the high-speed camera and the images are taken in a multiple shot mode. The images taken are further processed, and the characteristics of spray are measured such as spray tip penetration and spray cone angle. All experiments were conducted at constant fuel injection timing at the non-evaporating condition.

The specifications of the produced biodiesel are measured by the laboratories of biodiesel Alrafeek Company.

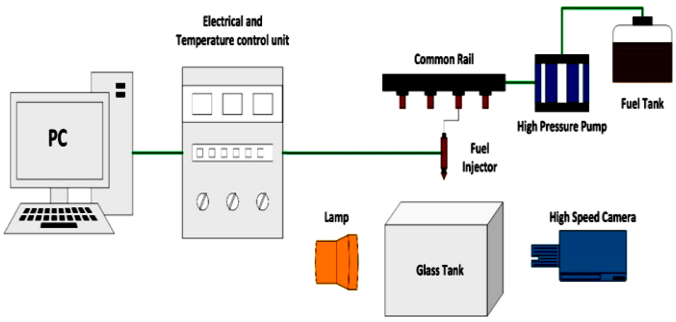

Figure 3: Experimental setup for study spray characteristics

4. RESULT AND DISCUSSION

Blends of waste cooking-oil biodiesel and diesel oil were mixed in volume percentages of 40% as B40. The present study aspires to investigate the spray characteristics and fuel droplet atomization behavior of the test fuels (diesel B0, B40) by varying the injection pressures and injection temperature. The type of fuel used for injection greatly affects spray properties due to different viscosity and density. Images are registered for every injection pressure and injection temperature for diesel and biodiesel by using the high-speed digital camera. The macroscopic diesel spray structure is characterized mainly by spray tip penetration, cone angle.

4.1 Macroscopic structure of diesel and biodiesel spray at varying injection pressure and injection temperature

The spray development diesel and biodiesel blend B40 under fuel injection pressure of 150bar, 200bar, 225bar, 250bar, 275 and 300bar and ambient temperature 25ºC is shown in figs. 4, 5. 250 bars were simulated with each injection temperatures 25 ºC, 60 ºC, 80 ºC, 10 ºC 0, 150 ºC, 200 ºC, 250 ºC and 275ºC as shown in figs. 4 and 5. The varying images were taken to find out the macroscopic spray characteristics. The background of the images of the study was clearly changed the shape of the spray.

4.2 Spray Tip Penetration and spray cone angle under varying injection pressure

The spray tip penetration for WCOB and diesel spray under various injection pressures is shown in Fig. 6. The spray tip penetration for WCOB and diesel spray under various injection pressures is shown in Fig. 6 It can be observed that WCOB spray forms a longer tip penetration in comparison with diesel at non-evaporating condition, the reason for that is high injection pressure and less atomization of WCOB. The less atomization of WCOB has high viscosity and surface tension. This leads to higher spray tip penetration. The spray cone angle for diesel and WCOB (B40) spray under various injections pressure is shown in Fig. 7. The higher injection pressure provides the high spray velocities and high injection flow rates of WCOB. This resulted in a narrow spray cone angle. The high injection pressure cancels the effect of friction between WCOB and nozzle surface due to the high viscosity of WCOB[30, 31]

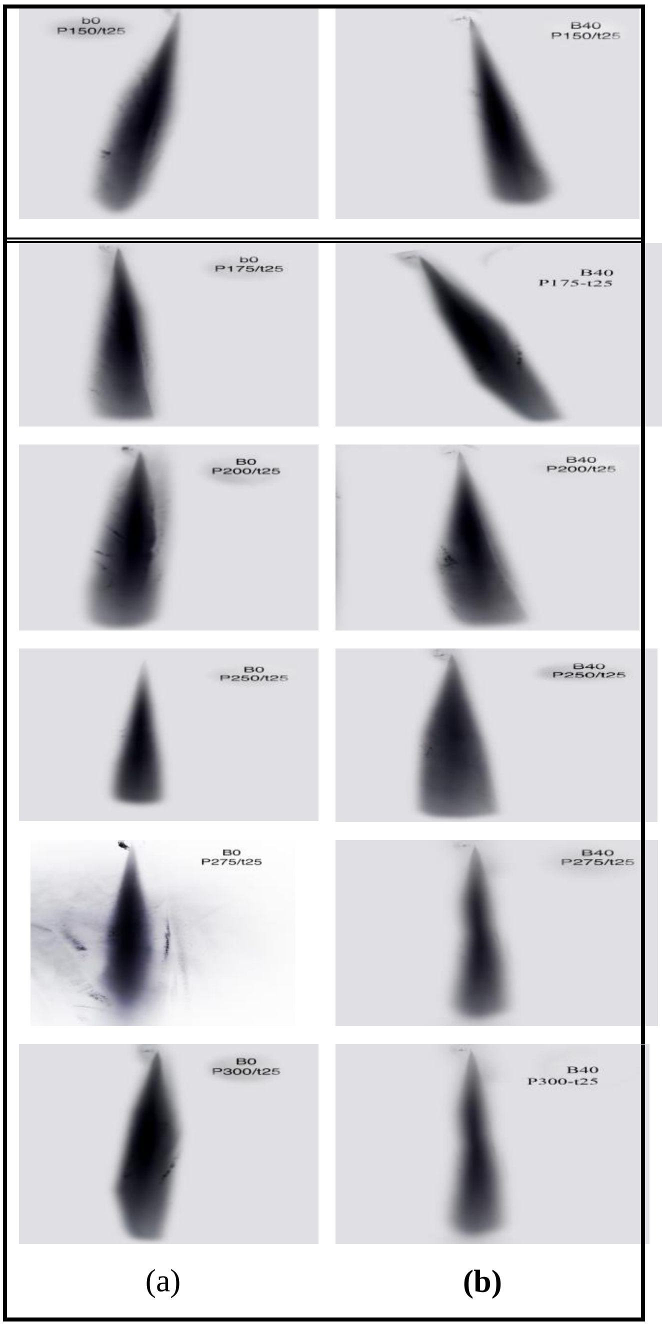

Figure 4: (a) Spray characteristics for B0
(b) B40 under injection pressure (150 bar to 300 bar) and ambient temperature 25 ºC

4.3 Spray Tip Penetration and spray cone angle under varying injection temperature

Figure 7 shows the relationship of both and injection temperature and spray angle, tip penetration. Increase injection temperature the longest penetration is achieved by B40 at injection pressure 250 bar and temperature 275 ºC. On the other hand, the shortest penetration length can be seen in pure diesel at injection pressure 250 bar and ambient temperature 25 ºC. For spray angle, the changes in spray characteristics. Unlike spray penetration, pure diesel has the highest spray angle compared to both B40 at injection pressure 250 bar and ambient temperature 275 ºC.

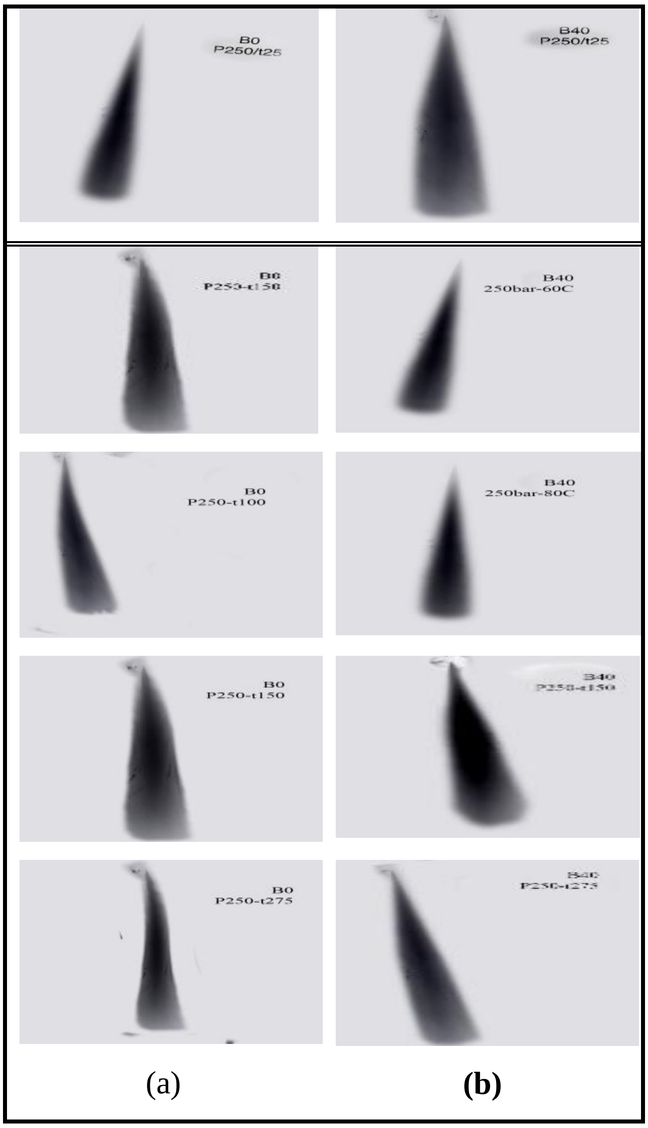

Figure 5: (a) Spray characteristics for B0
(b)B40 under injection temperature (25 ºC to 275 ºC) and injection pressure 250 bar.

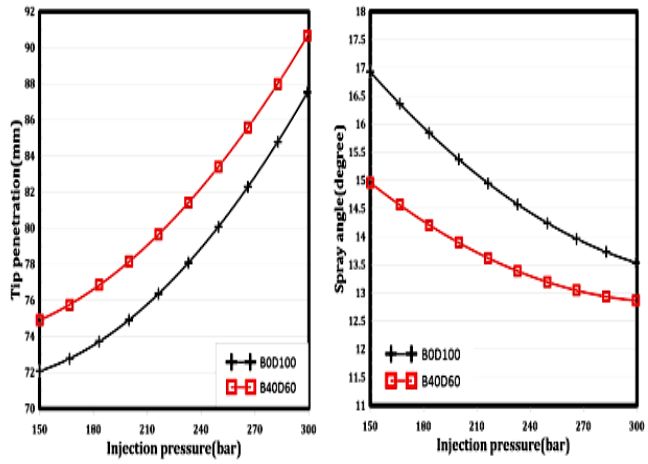

Figure 6: Effect of Injection Pressure on tip Penetration and spray angle

Lowest spray angle can be seen in blend B40 at injection pressure of 280 bar and injection temperature 25 ºC. As the temperature and pressure is increased, a great difference in the spray structure is noted. It raises mixture formation and distributes a larger amount of fuel between sprays thus creates good spray atomization and exhibits a greater amount of fuel-air premixing prepared for combustion.

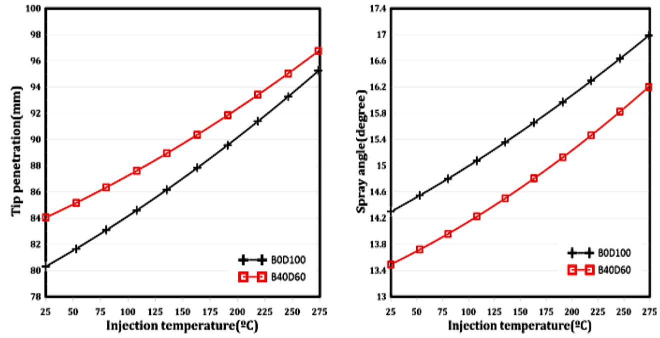

Figure 7: Effect of Injection temperature on tip Penetration and spray angle

CONCLUSION

Experiments have carried out with blend of B40D60 and compared to diesel under different injection pressures of 150,175,200,225,250,300 bars and different injection temperature. These results explain that increase in injection pressure and ambient temperature increases the spray penetration length and spray angle of biodiesel fuel (B40). This study was performed on single nozzle orifice diameter which is 20 mm. As the injection temperatures increases, the spray tend easily evaporate and disperse, which resulted in the following:

- Due to the high density and viscosity, the WCOB increases the tip penetration rate of the spray and the cone angle decreases at B40D60 compared to the pure diesel fuel.
- Increase the injection pressure until 300 bar of the B40D60 increases the spray penetration and the cone angle of WCOB.
- The spray tip penetration increases with the increase in the injection temperature for biodiesel, also cone angle decreases compared to the diesel.

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