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ETHANOL BLEND EFFECTS ON THE SPRAY PROPERTIES OF A BIODIESEL FUEL BY AMBIENT PRESSURE VARIATION

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ABSTRACT

Diesel engine spray nozzles are crucial to pollutant generation and engine efficiency. Nozzle performance can be enhanced by adjusting the nozzle's internals. A successful demonstration of the nozzle would be one in which the spray's outcome was uniformly dispersed throughout a wide area, with the grains scattered similarly. The purpose of this research was to examine how a diesel-ethanol characteristic under normal atmospheric pressure (spray tip penetration, the velocity of spray, and spray angle) and, in general, to assess the performance of biodiesel fuel on diesel engines, a substantial amount of biodiesel and operational expenses for the engine are necessary. It was an experimental approach to the study. The research involved recording spray fuel at the nozzle. Using a 480 fps high-speed camera, we tested BD20, BD20E5, and BD20E10 fuel at three different ambient pressures (1 bar, 2 bar, and 3 bar). The injection pressure was 15 MPa, and the fuel temperature was 28.2 degrees Celsius. Spray tip penetration and spray velocity decreased and spray angle increased after ethanol was added to the mixture, consistent with the studies' findings. Lowered spray tip penetration, slower spray speeds, and a complete spray angle result from the increased ambient pressure.

1. INTRODUCTION

Fuel injection technology is crucial in combustion engines, especially diesel engines. Spray determines the quality of the fuel mixture in the air in high-pressure heat. A good mixture will determine the combustion results that affect the increased engine power, low engine noise levels, low fuel consumption, and low emissions from the engine (LeBlanc, 2019). Viscosity affects the characteristics of the fuel spray. High-viscosity fuel will produce larger granules in the combustion chamber, making combustion imperfect (Hou et al., 2021). Researchers have experimented with blending ethanol into fuel to measure the effect on viscosity. A diesel fuel's dynamic viscosity, kinematic viscosity, boiling point density, and flash point can be lowered by adding ethanol as an additive (Anhar et al., 2016). If ethanol is mixed with B20, you can make it less thick and dense (Zaharin et al., 2017). The effects of ethanol on fuel spray characteristics were the subject of further studies by mixing biodiesel and ethanol with a comparison of BD20E5 and BD20E10 (Alifuddin et al., 2020). Several studies have been conducted to analyze how outside pressure influences diesel engine spray characteristics. Using the exact 0.1, 1, and 2 MPa changes in ambient pressure (LeBlanc, 2019) tested several biodiesel fuels. Spray tip penetration, cone angle, and spray area were measured to see how diesel and biodiesel mixes were affected by 0.1, 0.4, 0.7, and 0.9 MPa differences in ambient pressure, according to (Jaat et al., 2015). Still, according to Jaat et al. (2015), at 0.2, 0.3, 0.4, 0.5, and 0.6 MPa, at almost the same pressure for Karanja biodiesel fuel (Lee et al., 2017). Similarly, Pang et al. (2019) and Zhang and Wang (2017) with varying ambient pressure variations for the same purpose.

Relevant research by Kandasamy et al. (2019) shows that a single-cylinder high-speed automotive diesel engine underwent rigorous 500-hour testing for durability, emission, and performance, fuelled with ethanol-blended biodiesel. The base biodiesel fuel (B5) was created by mixing 5% esterified cotton seed methyl ester with 95% neat diesel. To create the ethanol blended biodiesel fuel (B5E20), 20% pure ethanol was added to the B5 fuel. During the test, parameters such as blow-by, crankcase pressure, lubricating oil consumption, performance, and emission characteristics were measured for both fuelled engines. Results showed a significant decrease in maximum brake power and torque for the B5E20-fuelled engine at the end of the 500-hour durability run.

Additionally, during the durability trials, comparing the B5E20 fuelled engine to the B5 fuelled engine showed higher lubricating oil consumption and positive crank pressure. Using B5E20 fuel leads to a reduction in smoke and CO emissions across all speed ranges. However, NOX and unburned hydrocarbon emissions decrease only in the lower to medium speed range, after which they increase. After 500 hours of durability run, both fuels experience increased engine emissions, as anticipated. Another previous research yield by Aydın and Öğüt (2017) said that safflower seeds were utilized to create biodiesel using a multi-step process. The seeds were dampened, rolled, roasted at 90°C, and pressed to produce Safflower Oil Methyl Esther (Safflower Biodiesel) through trans-esterification. Mixing safflower biodiesel, diesel fuel, and bio-ethanol in varying ratios of 2.5% and 5% created five different experimental fuel blends. The fuels were analyzed through various tests, including kinematic viscosity, density, water content, pH level, caloric value, flash point, clouding, pour and freezing points, copper bar corrosion test, iodine number, CFPP (Cold Filter Plugging Point) test, and cetane number.

The following research background results from Geng et al. (2021) indicate that the introduction of ethanol into biodiesel results in a broader spray cone angle (SCA) and a shorter spray tip penetration (STP). Furthermore, the size-volume distribution (SVD) curves for atomized fuel droplets shift to smaller diameters, and the Sauter mean diameter (SMD) of biodiesel-ethanol (BE) blends gradually decreases as the ethanol proportion increases. The fuel injection method involves multi-injection at lower loads, and the peak cylinder pressures (PCPs) for BE blends surpass diesel by 0.77-1.96% at varying ethanol blending ratios. However, the peak heat release rates (PHRRs) of BE blends exceed diesel by 9.3-11.5% due to a faster combustion rate, longer main injection duration, and more hydroxyl radicals created in the pilot-injection stage. Under medium-high workloads, the injection strategy shifts to a single injection, and the PCPs of BE blends nearly match those of diesel. The PHRRs of BE blends for various ethanol blending ratios are 9.76% to 11.91% lower than diesel due to differences in fuel properties, including lower diffusion combustion ratio and heat value and modified injection duration. However, peak pressure rise rate and cyclic variation results indicate that higher ethanol levels increase combustion noise and decrease combustion stability.

In terms of emissions, soot emissions for different BE blends decrease by 11.28% to 47.23% compared to biodiesel, while NOx emissions increase by 2.68% to 7.04% and HC emissions increase by 9.99% to 21.47% with an increasing ethanol blending ratio. In order to optimize engine performance, a 20% ethanol blending ratio in biodiesel is recommended. Based on the study's results, more research is needed on fuel additives like ethanol and atmospheric pressure changes. Therefore, the purpose of this research is to determine how changes in ambient pressure and the biosolar fuel mixture (diesel oil and biodiesel) and ethanol affect the spray and the urgency of spray in this research is willing to find an effective mixture for gaining the best characteristics tip penetration, spray angle, and velocity which those are effected to combustion engine performance.

2. METHODS

In the study characteristics of this spray used a mixture of diesel fuel, biodiesel, and ethanol with the composition of BD20 produced by Pertamina Indonesia, BD20E5 (BD20 95% and ethanol 5%), and BD20E10 (BD20 90% and ethanol 10%). BD20 combines 80% diesel oil and 20% biodiesel, expertly produced by PT Pertamina Indonesia. Mixing of biodiesel and ethanol is done manually by dissolving (Paendong et al., 2019). The dissolving process is carried out at room temperature and stirred for 10 minutes at a constant speed to perfectly mix the fuel. In research, fuel mixing processes are still conducted manually, as was done in previous studies (Waluyo et al., 2020). To better understand the fuel blend ratio, refer to Table 1.

Table 1 Blended fuels

Mixture	Diesel Oil	Biodiesel	Ethanol
B20	80%	20%	-
B20E5	95%		5%
B20E10	90%		10%

The fuel that has been tested is characteristically inserted into the tester nozzle. Then the fuel is injected into the spray chamber with an injection pressure of 15 MPa. Verification of injection pressure can be observed on the pressure guage nozzle tester. In the R175 type injector, the injection pressure setting is performed by adjusting the screw round on the injector. The chamber is conditioned at pressures of 1 bar, 2 bar, and 3 bar. Chamber/ambient pressure conditioning is performed by inserting compressed air from the compressor into the chamber. The chamber has two transparent sides made of acrylic glass. One side is used for shooting, and the other side for lighting, as shown in Figure 1. The experimental conditions of this study can be shown in Table 2.

Table 2 Experimental conditions

Fuel	BD20, BD20E5, BD20E10
Chamber/Ambient Pressure (Pa)	1 bar, 2 bar, and 3 bar
Injectors and injection conditions	
Injector type	R175 type
Number of nozzle holes	1
Nozzles diameter	0.8 mm
Injection Pressure	15 Mpa
Chamber	
Dimension	Length x width x height = 30 x 30 x 30 (cm)
Thick iron plate	10 mm
Thick acrylic glass	10 mm

Spray characteristic recording using a high-speed camera of 480 fps and a resolution of 224×168. The background of the spray (screen) uses black to make the result of the fuel spray more clearly visible. The lighting position is facing the direction of the fuel spray because, from the results of some tests, the position produces the best visualization of spray characteristics. Lighting uses a 1000-watt halogen lamp. This test setup can be seen in Figure 1.

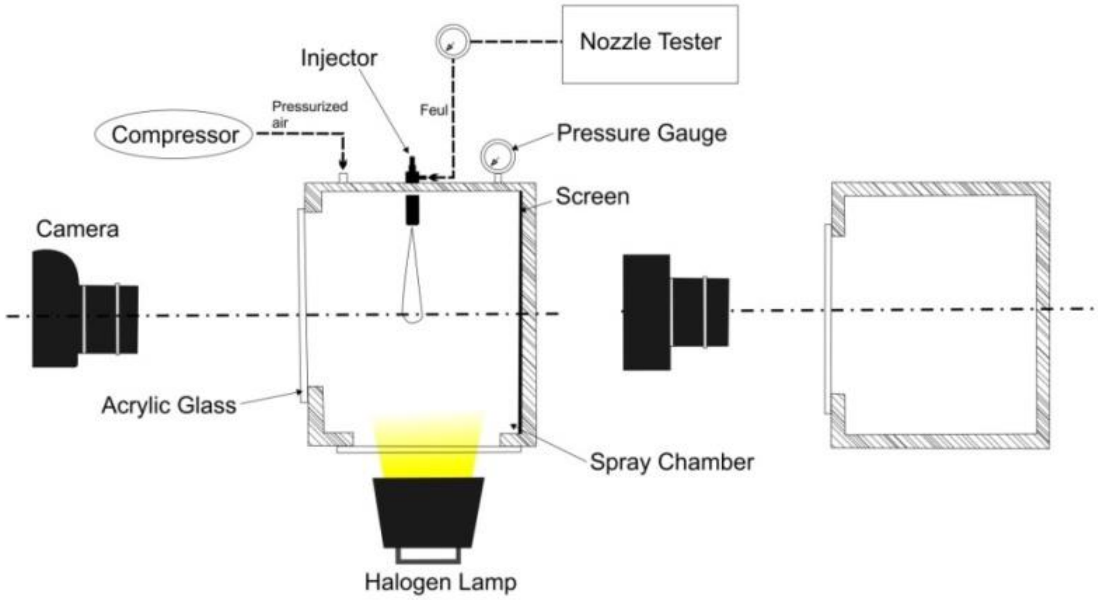

Figure 1 The Test Set up

The result is converting a video recording of the fuel spray process into an image to make measuring spray characteristics easier and more accurate. Visualization of spray characteristics is taken at 4.16 ms, the second image of the initial image of the spray process. Then the image is measured as the length of the penetration spray tip and spray angle using the ImageJ application.

3. RESULTS AND DISCUSS

3.1. Result

3.1.1. *Fuel Characteristics*

The blended fuel is characteristically tested; the results are shown in Table 3. From Table 1, the mixture of fuel and ethanol results meet the criteria for use as fuel in diesel engines because the results are close to PT Pertamina Indonesia's standards, namely BD20.

Table 3 Fuel characteristics

Fuel	Calorific value (Kcal/Kg)	Flash Point (C°)	Density 40° (gr/mL)	Viscosity 40° (Cst)
BD20	-	52	0,87	4,5
BD20E5	10191,8	85	0,83	4
BD20E10	9423,74	80	0,834	3,5

Table 3 indicates that each fuel variation yields distinct outcomes. BD20E5 records the highest calorific value and flash point at 10191.8 Kcal/Kg and 85°C, respectively, followed by BD20E10 at 9423.74 Kcal/Kg and 80°C. Conversely, BD20 has the lowest outcome, with the first experiment only showing 53°C. However, its density and viscosity at 40°C outperform the others, measuring 0.87 gr/mL and 4.5 Cst, respectively. Despite BD20E5 trailing BD20 in two areas, it has the best overall characteristics. While the difference is not significant, it still performs better than BD20.

3.2 Discussion

3.2.1. *Spray Tip Penetration*

The spray of a mixture of biodiesel and ethanol with varying ambient pressure is shown in Figure 2, where in the picture shown, it is recorded at 4.16 milliseconds after the third spray. The effect of adding ethanol and variations in ambient pressure on the spray tip penetration length is more easily observed when the results of the spray length measurement are displayed graphically.

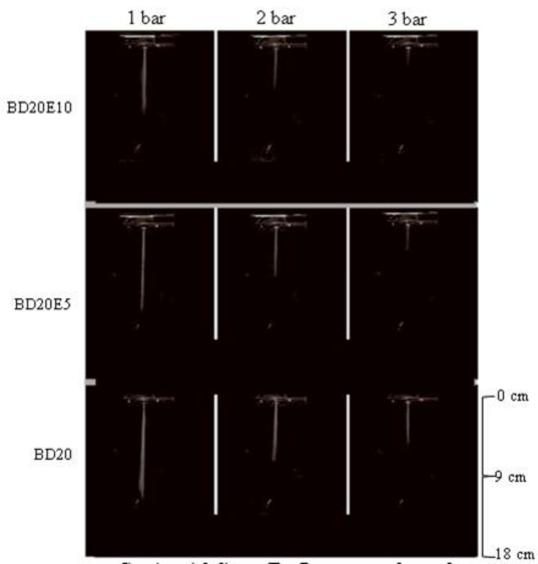

Figure 2 Result of spray tip penetration 4.16 ms

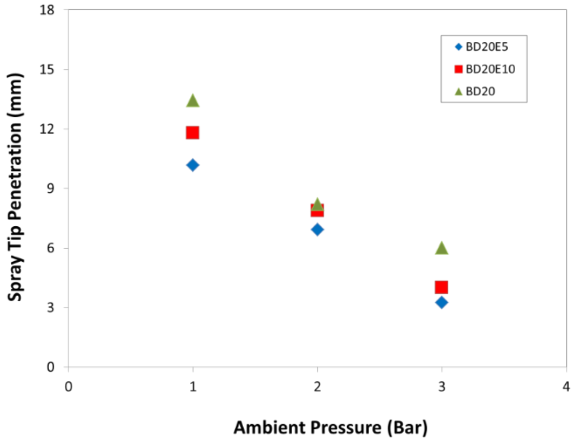

Figure 3 Effect of Ambient Pressure on Spray Tip Penetration (4.16 ms)

Diesel fuel blended with biodiesel and ethanol (compositions BD20, BD20E5, and BD20E10) at 4.16 ms spray time and varying ambient pressure is depicted in Figure 3. Figure 3 displays BD20 spray tip penetration measurements at different ambient pressures, showing that it consistently has the deepest penetration. An increase in ambient pressure shortens the spray tip penetration length because the fuel grains cannot penetrate as far into the chamber due to the increased air density. Spray tip penetration is reduced at constant ambient pressure when ethanol is added to BD20 because the fuel mixture becomes less viscous when added ethanol, making it harder for the fuel grains to mix with the air in the combustion chamber. Spray tip penetration is reduced as the ambient pressure rises because the fuel grains have more difficulty breaking through the dense air in the chamber (Addepalli et al., 2021). Spray tip penetration is said to be reduced by an increase in ambient pressure Jaat et al. (2015) due to a loss of initial momentum. A similar conclusion can be drawn from Tarom et al. (2018) study and in line with Alifuddin et al. (2020), Corral-Gómez et al. (2019), and Kim and Lim (2020).

3.2.2. *Spray Angle*

Figure 4 depicts a spray image taken at a spray time of 8.32 ms, demonstrating the impact of varying fuel mixtures (BD20, BD20E5, and BD20E10) with varying ambient pressure at the spray angle. The effect of adding ethanol and variations in ambient pressure on the spray angle was measured and graphically displayed (shown in Figure 5) for more straightforward observation.

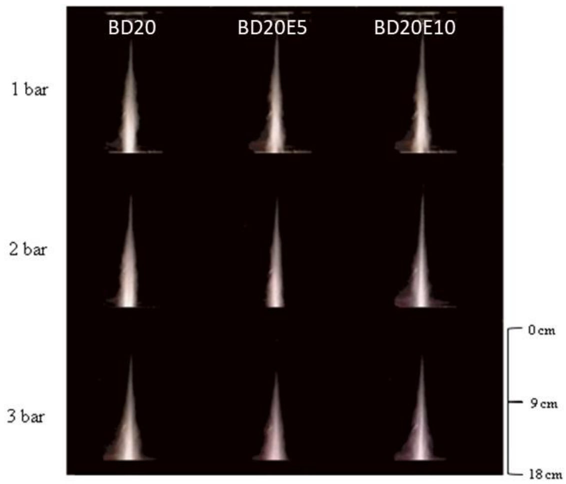

Figure 4 Effect of Ambient Pressure on Spray Angle (8.32 ms)

Increases in ambient pressure are depicted in Figure 5 as an expansion of the spray angle because as ambient pressure rises, the air within the chamber becomes denser, transforming the spray granules into droplets as the spray angle rises. Previous research has shown by Jaat et al. (2019) that an increase in ambient pressure results in a wider spray angle. As a result of the high pressure within the chamber, the spray expands.

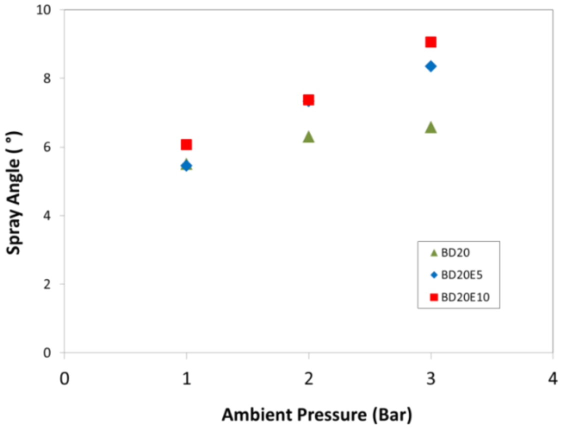

Figure 5 Effect of Ambient Pressure on Spray Angle (8.32 ms)

The addition of ethanol causes a steeper spray angle, leading to finer fuel atomization and smaller dopret granules due to reduced fuel viscosity and density when the liquid phase changes to droplets—in the research of Corral-Gómez et al. (2019) proved that a decrease in viscosity, density, and surface tension would cause an increase in spray angle. Research by Kim and Lim (2020) explains that adding ethanol fuel to biodiesel will cause a slight effect to increase the spray angle.

4.3 Velocity of Spray

Figure 6-8 depicts spray images of biodiesel and ethanol blend fuel at 1, 2, and 3 bar ambient pressures. Spray velocity as a function of biodiesel and ethanol fuel blend at 1 bar ambient pressure is depicted in Figure 6. This figure shows that all sprays have reached the end wall on the third spray or at 6.25 ms, meaning that at one ambient bar pressure, the spray speed is high so that it reaches the end wall quickly because, at low ambient pressure, the air density in the chamber is low so that the fuel grains easily diffuse into the air in the chamber.

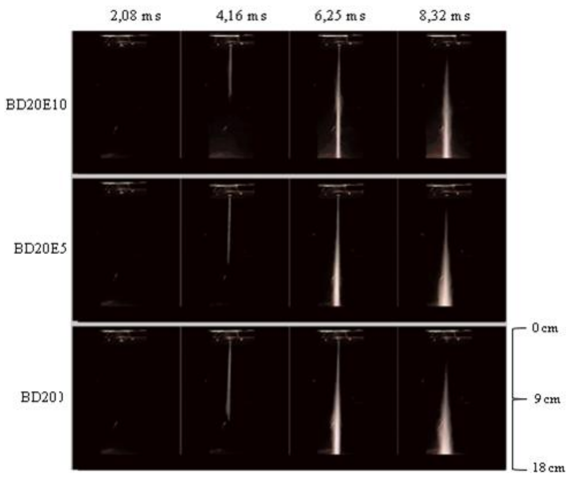

Figure 6 Effect of Mixture of Fuel on Velocity of Spray (Pa= 1 bar)

Figure 7 shows the mixture effect of biodiesel and ethanol fuel at 2 bar ambient pressure on the spray speed. This figure shows that all sprays are just beginning to reach the end wall on the third spray or at 6.25 ms, meaning that at two ambient bar pressure, the spray speed is lower than that of a spray with Ta 1 because, at higher ambient pressure (2 bar), the air density in the chamber increases so that it is more difficult for fuel grains to diffuse into the air in the chamber so that the spray motion is blocked.

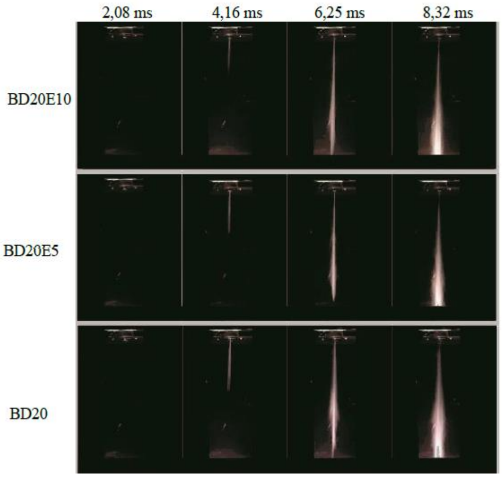

Figure 7 Effect of Mixture of Fuel on Velocity of Spray (Pa= 2 bar)

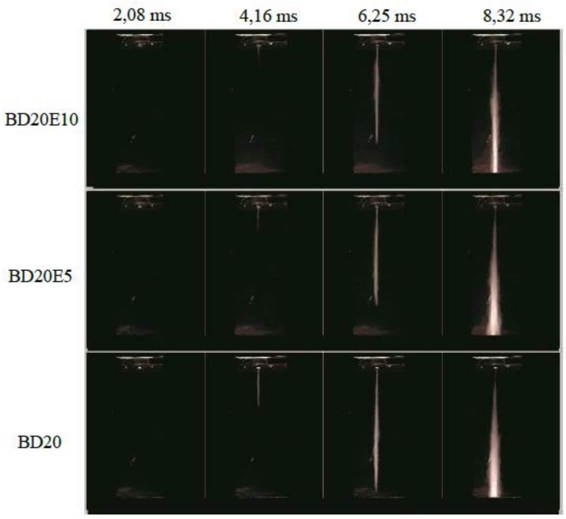

Figure 8 Effect of Mixture of Fuel on Velocity of Spray (Pa= 3 bar)

Spray velocity affected by a 3 bar ambient pressure and a biodiesel/ethanol fuel blend is depicted in Figure 8. This figure shows that all sprays have not reached the end wall on the third spray or at 6.25 ms, meaning that at three ambient bar pressure, the spray speed is also lower than that of the spray with Ta 1 bar and 2 bar. Due to the higher ambient pressure (3 bar), the more difficult it is for the fuel grains to diffuse into the air in the chamber, so the spray motion is also increasingly inhibited. Adding ethanol to biodiesel causes the spray speed to decrease because the viscosity of the fuel also decreases at all ambient pressures; adding ethanol changes the fuel mixture's properties. The purpose of the discussion section is to provide theoretical interpretations of the study's findings rather than a simple description of those findings. Studies conducted and reported in peer-reviewed journals should be cited to add depth to the discussion.

5. CONCLUSION

The research results on adding ethanol to biodiesel fuel with variations in ambient pressure show that blending ethanol with biodiesel fuel reduces spray tip penetration, raises the spray angle, and slows the spray speed. Spray tip penetration is reduced, spray angle is widened, and spray speed is slowed as ambient pressure rises because more air is packed into the chamber. For the best spray condition, it is recommended following research to have the correct variation between the ambient pressure, composition, or treatment of the fuel used and the injection pressure to obtain a spray condition that can increase the homogeneity of the air and fuel mixture.

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