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Comparison of the Properties of Biodiesel-Bioethanol-Diesel Blended Fuel

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Energy production relies on finite fossil fuels and is usually regarded as the primary source of hazardous emissions and global warming. As a result, much attention has been dedicated to biofuel as a fuel for engine alternatives. Biofuel is now primarily utilized in blends with fossil diesel. As a result, this study was focused on adding bioethanol and biodiesel to fossil diesel. Biodiesel was manufactured by transesterification from waste cooking oil, while bioethanol was made through banana fermentation. The physical properties such as density, kinematic viscosity, flashpoint, and cetane index of fossil diesel-biodiesel-bioethanol blends were compared with fossil diesel fuel in laboratory experiments. When added, bioethanol was found to degrade the physical properties of blended fuels substantially. The substitution of bioethanol for fossil diesel resulted in a significant reduction of hazardous emissions. The assessment of flue gas emissions indicated a considerable reduction in CO_2, CO, hydrocarbon (HC) and NOx emissions.

Keywords: Biodiesel, Bioethanol, Blended fuel, Transesterification, Flue gas emission.

INTRODUCTION

Environmental pollution has increased dramatically since the industrial revolution, as greater energy use is necessary and desired for economic growth and living standards [1]. Fossil fuel combustion for the power generation and transportation sector occupies a more significant portion of the air pollution [2,3]. For decades, renewable energy sources such as biomass, biofuel and solar energy have generated electricity. However, the expense of solar photovoltaic systems is a factor in reducing solar photovoltaic applications [4]. At the moment, many countries are replacing fossil fuel-based power generation with solar power generation to achieve sustainable goals [5,6]. There are multiple advantages and disadvantages associated with solar energy, and many of them try to implement those by improving efficiency [7]. Biodiesel and bioethanol are the popular energy generation methods to replace fossil fuel combustion. Over decades, it has been practised with success stories to minimize fossil fuel combustion. However, the raw material cost mainly leads to the higher price of biodiesel and bioethanol, which decline the motivation to change to biofuels [8,9].

The biologically produced ethanol is called fermentative ethanol or bioethanol. Ethanol has obtained a significant role in the fuel market as a replacement again to the conventional fuels or a fuel additive by acting as the oxygenating compound for gasoline. The main goals of utilizing bioethanol as an alternative fuel are a solution for the incremental cost of fossil fuels, the emission of greenhouse gasses by vehicles and the impairing of the environment's air quality [10]. Bioethanol vests several physical and chemical qualities that help build up a renewable biofuel in the transportation sector.

Generally, bioethanol can be combined with fossil diesel without requiring engine modification. However, due to their chemical structure and features, bioethanol is immiscible in fossil diesel over a wide range of temperatures and water content, a significant disadvantage in bioethanol-fossil diesel fuel blends [11,12]. The presence of water in bioethanol or fossil diesel fuel can significantly reduce the solubility of the two components [13]. Anhydrous bioethanol readily mixes with fossil diesel fuel at normal ambient temperatures. Nevertheless, below 10 ± 1 ºC, the two fuels separate. The phase separation causes fuel instability. Phase separation can be avoided in two ways: adding an emulsifier that suspends tiny droplets of bioethanol inside the fossil diesel fuel or adding a co-solvent that serves as a bridging agent *via* molecular compatibility and bonding to create a homogeneous blend process [14]. Emulsification typically requires heating and mixing to produce the final blend, but co-solvents allow fuels to be 'splash-blended', which simplifies the blending process [15]. Furthermore, the bioethanol fossil diesel blend has a low cetane number, making it challenging to burn using diesel engines' compression ignition technology.

When used with fossil diesel, dimethyl ether is an excellent cetane number booster because its cetane number value is greater than 5516. However, this molecule cannot be employed efficiently in diesel engines due to its lower molecular weight, boiling temperature, and density characteristics, which cause it to evaporate considerably more quickly than diesel fuel molecules. Among other benefits, biodiesel is a chemically suitable additive to blend with bioethanol-fossil diesel fuel [12,16,17].

Biodiesel is chemically and thermally identical to diesel fuel. Due to the greater cetane number, it is more suited for combustion in a diesel engine. Biodiesel is an excellent lubricant and can compensate for the lubricant loss caused by replacing sulphur-containing diesel fuel with low-sulphur diesel fuel [18]. Biodiesel can be produced from any fat or oil by a process known as transesterification as illustrated in Fig. 1.

However, it is crucial to reduce raw material and biodiesel production costs. Biodiesel production cost has been reduced by implementing operating conditions [19]. It has been reported that raw material costs account for between 60% and 95% of total manufacturing costs. The raw material cost can be reduced by using waste cooking oil (WCO) as raw material, effectively lowering feedstock costs by 60-70% [3]. Biodiesel blending with fossil diesel, bioethanol blending with fossil diesel and biodiesel, bioethanol blending with fossil diesel have been performed by several researchers [11,20-23]. However, the properties comparison with blending and the optimizing blending ratio and the quality of the flue gas emission have not been appropriately addressed. In order to fill the gap, the present study focuses on the blending of biodiesel and bioethanol with fossil diesel and optimizing the blending ratio to achieve the highest yield. At the same time, parameters of the optimized blend were analyzed to verify the quality of the blend for proper combustion. The flue gas emission was also analyzed to check the greenhouse gas emission with the optimum blending of biodiesel and bioethanol with fossil diesel.

EXPERIMENTAL

Biodiesel production from transesterification: Initially, waste cooking oil had an acid value of 1.67 mg KOH/g. As a result, waste cooking oil was transesterified directly, according to Arachchige *et al.* [19]. The potassium methoxide solution was made by dissolving the 1 wt.% KOH in methanol at a concentration of 20% (v/v). The molar ratio of oil-to-methanol was 1:6. Experiments were conducted in a 250 mL batch reactor equipped with a magnetic stirrer. A waste cooking oil (100 mL) was added into the batch reactor, followed by the potassium methoxide. The reaction temperature was maintained at an average of 60 ± 1 ºC throughout the tests at 600 rpm for 30 min. After the reaction, the mixture was transferred to a separatory funnel and allowed to stand overnight. Following the lower glycerol phase separation, the crude FAMEs (upper layer) was collected and washed with warm water for 20 min at 600 rpm before being transferred to a separatory funnel. After 4 h, complete phase separation occurred, and the pH of the obtained biodiesel was tested. The washing operation was repeated until the pH of the biodiesel reached around 7.

Bioethanol production from fermentation: A fully ripened and damaged banana sample was collected from a local market, ready to send to the municipal garbage. The samples were taken to the sterilization step that washing the sample with 5% $KMnO_4$ solution and after that rinsed twice with distilled water. Then a home use blender was used to ground 8.0 kg of banana sample to reduce the particle size and increase the rate of downstream reactions. The whole sample was transferred into the tank, which has excess air space after adding water to dissolve the banana sample in solid:liquid ratio is 1: 4. The specific gravity of the medium was measured. After that the pH of the medium was measured and pH was adjusted to 5. Then, the sample was brought to the fermentation process. Alcoholic fermentation of reducing sugars is the biological process by a microorganism that converts simple sugar into ethanol, releasing CO_2 and other byproducts. Baker's yeast (*Saccharomyces cerevisiae*) inoculum was prepared by dissolving them in 500 mL of warm water with 100 g of sugar dissolved. The yeast was added in ratio 25: 1 of sample weight to yeast weight. Then inoculum was introduced into the prepared banana sample. The fermentation tank was sealed with a lid, and an air trap was set up to release CO_2 by making an anaerobic environment in the medium. The fermentation process was done at room temperature (average at 30 ºC). In fermentation, temperature plays a significant role because the fermentation rate goes up when the temperature rises in the medium. When the temperature exceeds 40 ºC, most enzymes in micro-

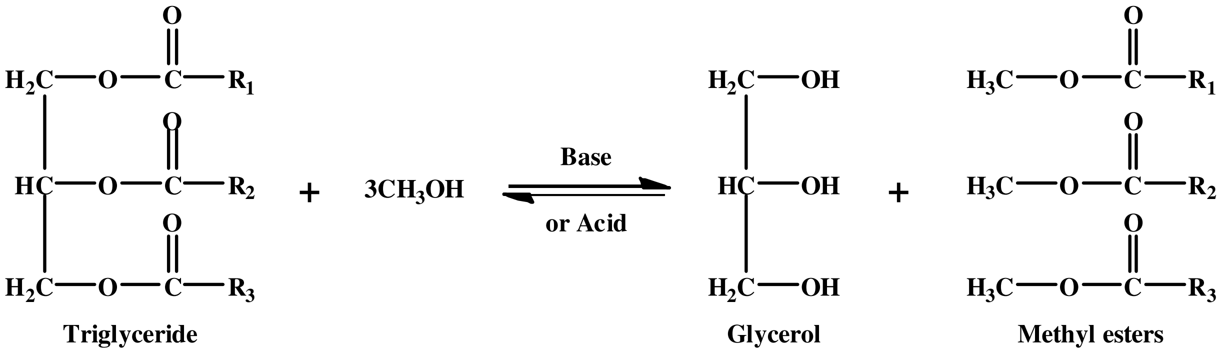

Fig. 1. Schematic representation of the transesterification reaction

organisms can denature or unfold, resulting in the rate of fermentation decrease. After 7 days of the fermentation period, the fermented medium was filtered to remove solid particles. The specific gravity was measured. Reduction of specific gravity revealed that ethanol has produced in the medium, and a specific gravity method was used to determine ethanol yield approximately. To separate the bioethanol series of distillation was done. After bioethanol reached 95% purity terminated the distillation process and bioethanol was dehydrated to water content less than 1% by volume.

Preparation of blended fuels: Biofuels containing up to 20% with fossil diesel fuel can be used with little or no modification in engines designed for pure diesel [17]. As a result, various volume fractions of biodiesel and bioethanol were employed to create volumetrically equivalent 20% biofuels, as indicated in Table-1. According to Table-1, fossil diesel, biodiesel and bioethanol were mixed volumetrically, then blended fuel samples were prepared in a precision beaker glass and swirled at 2000 rpm for 15 min at 25 ºC. Physical qualities such as density, kinematic viscosity, flashpoint and cetane index were determined. A diesel three-wheeler was used to assess flue gas analyses. The vehicle's specifications are given in Table-2.

TABLE-1
VOLUMETRIC RATIOS OF FOSSIL DIESEL, BIODIESEL AND BIOETHANOL (D-B-E) SYSTEM

Blended fuel	Volume ratio (%)		
	Fossil diesel	Biodiesel	Bioethanol
D100	100	0	0
B100	0	100	0
E100	0	0	100
D80B20	80	20	0
D80B15E5	80	15	5
D80B10E10	80	10	10
D80B5E15	80	5	15
D80E20	80	0	20

TABLE-2
TECHNICAL SPECIFICATIONS OF THE VEHICLE OF DIESEL THREE-WHEELER

Particulars	Specification
Fuel type	Diesel
Engine type	Single cylinder -Naturally aspirated, Air-cooled, DI
Wheel base	1920 MM
Displacement	436 cc
Kerb weight	420 Kg
Fuel tank capacity	10.5 ltr
Gear type	Constant mesh (4 Forward, 1 Reverse)
Max. power	5.52 kW @ 3600 + 50 rpm
Max. torque	18 Nm @ 2400 - 2200 rpm

RESULTS AND DISCUSSION

Physico-chemical properties of fossil diesel, biodiesel, bioethanol and blended fuels: The physico-chemical properties of fossil diesel, biodiesel, bioethanol and fossil diesel-biodiesel-bioethanol blends fuels are summarized in Table-3. The density of any fuel is crucial since it directly affects the engine's performance characteristics. Additionally, density is related to other variables, such as the viscosity, cetane number and heating value [11]. Density impacts atomization and the combustion efficiency [24]. Because the diesel fuel injection system measures fuel by volume, fluctuations in fuel density will alter the engine's output power. Bioethanol (E100) had a lower density (0.7901) than fossil diesel (D100) fuel, as shown in Table-3, whereas biodiesel (B100) has a higher density (0.8592). Bioethanol into fossil diesel creates a slight layer separation due to the less solubility. However, adding biodiesel with bioethanol into the fossil diesel acts as an emulsifier for bioethanol and diesel mixture, increasing solubility by reducing the interfacial tension forces and increasing the affinity of two liquids. At the same time, biodiesel allowed the addition of a higher percentage of bioethanol into fossil diesel by improving the tolerance of the blend to water and keeping the mixture stable. The density of the blends dropped as the proportion of bioethanol rose. However, increasing the quantity of biodiesel increased density, as biodiesel had a higher density than the other two components. It is generally understood that increasing the density of fuel oil results in more excellent flow resistance, which results in increased viscosity, resulting in poor fuel injection [11].

Viscosity is another critical feature of a fuel. It affects the size of the fuel droplets, jet penetration, atomization quality, spray characteristics, and combustion quality [24]. According to Table-3, the kinematic viscosities of the blends were exceptionally close to that of fossil diesel fuel; however, when biodiesel fuel was added to the fossil diesel-bioethanol blend, the kinematic viscosity increased dramatically. The biodiesel component of blended fuels, declined, the kinematic viscosity also fell. The viscosity of a fatty ester is mainly determined by the chain length of the fatty acid, and biodiesel fuel is composed of both fatty ester and fatty acid [25]. Additionally, the data indicated that when bioethanol and biodiesel were combined with fossil diesel fuel, the final kinematic viscosity of the blended fuel approached that of fossil diesel fuel.

The flashpoint of a fuel reveals its flammability; it is the lowest temperature at which the vapour above the sample spontaneously ignites, when an ignition source is applied under specific test conditions. While the flashpoint has no direct effect on combustion, it is critical for gasoline transportation, storage,

TABLE-3
PROPERTIES OF FOSSIL DIESEL, BIODIESEL, BIOETHANOL AND BLENDED FUELS

Properties	Test method	D100	B100	E100	D80B20	D80B15E5	D80B10E10	D80B5E15	D80E20
Density at 15 °C (g/cm^3)	ASTM D4052	0.8080	0.8592	0.7901	0.8200	0.8177	0.8128	0.8090	0.8011
Kinematic viscosity at 40 °C/ mm^2/S	ASTM D445-19a	3.0062	4.2336	1.1325	3.1294	2.4708	1.9823	1.4970	1.2101
Flash point (°C)	ASTM D93-20	66	124	13	82	16	15	13	13
Cetane index	ASTM D613	47.64	58.4	5-8	52.42	48.66	46.85	45.85	44.23

and handling. Numerous variables, including the residual alcohol content, influence the flashpoint of biodiesel. Fossil diesel fuel produces insufficient vapour at room temperature to reach its lower flashpoint [12]. The flashpoints of fossil diesel, biodiesel, bioethanol, and blends were determined, and it was revealed that the flashpoints of blended fuels increased as the percentage of biodiesel increased. Thus, this is a matter of fire safety. It also observed that the bioethanol had a lower flashpoint than the ambient temperature that instituted an important disadvantage regarding their transportation, distribution and storage. Although biodiesel had a more significant flashpoint, as indicated in Table-3, adding a modest amount of bioethanol into the fossil diesel-biodiesel blended fuel instantly reduced the overall flashpoint. The flashpoints of blended fuels were found to be in between 16 ºC and 13 ºC. The lowest flashpoint of 13 ºC was attained in 15% of the bioethanol in blend, which is identical to the figure for E100. Thus, regardless of the biodiesel portion utilized, the flashpoint of fossil diesel-biodiesel-bioethanol blends were dominated by the bioethanol component. As a result, precautions must be taken when handling and transporting the fuel. Thus, specific and proper management of these diesel-biodiesel-ethanol blends are essential to avoid explosions during storage, handling, and transportation.

The cetane index is proportional to the density value [26]. The cetane index is a measure of the ignition property. The lower the cetane index shows, the poorer the ignition quality. Additionally, the cetane index affects the engine's start-up, combustion management and performance. Therefore, improving the cetane index within a limit is beneficial. According to Table-3, the cetane index of the fossil diesel-biodiesel-bioethanol mixture declined as the amount of bioethanol was increased since bioethanol had a lower cetane index value of roughly 5-8. It was determined that biodiesel had improved this feature due to its high cetane index value compared to fossil diesel and blended fuels. It can reclaim the ignition quality feature poorer, allowing the fuel blend to meet the cetane index requirement. The sample comprised 80% fossil diesel, 15% biodiesel and 5% bioethanol (D80B15E5), had the most excellent cetane index than the fossil diesel.

Flue gas emission of fossil diesel, biodiesel, bioethanol and blended fuels: The effects of adding bioethanol and biodiesel to fossil fuel on flue gas emissions of a 436cc diesel three-wheeler were examined. Compared to fossil diesel combustion, the inclusion of biodiesel and bioethanol blends considerably reduced CO, CO_2, NOx and hydrocarbon (HC) emissions as shown in Table-4. Biodiesel and its blended fuels with bioethanol reduced CO and HC emissions primarily due to their increased oxygen content. Biodiesel contains 13% more oxygen than fossil diesel, whereas bioethanol contains 35% more oxygen, resulting in improved spray and atomization, better combustion and consequently lower HC and CO emission [27]. Adding bioethanol to fossil diesel-biodiesel-bioethanol blends were decreased CO_2 emissions because bioethanol has a lower carbon-to-hydrogen ratio, speeding up CO molecule oxidation to CO_2. As a result, more water was produced while producing less CO_2 gas [18,28]. NOx emissions were reduced in diesel-biodiesel-bioethanol fuel blends instead of fossil diesel. This observation was related to the lower cetane number of bioethanol. The cetane number of the entire blend drops as the bioethanol concentration increases [29]. As a result of the low heating point of the fuel, improved fuel-air mixing occurs during ignition. Increased fuel evaporation resulted in decreased combustion temperature, which reduced the NOx formation rate [28]. Additionally, for blended fuels, the cooling impact of bioethanol, which is a result of its reduced calorific value (27.6 MJ/kg) and high latent heat of vaporization (0.91 MJ/kg) as compared to fossil diesel, may result in a reduction in combustion temperature and hence NOx emissions [27,29].

Conclusion

The effect of adding bioethanol to a fossil diesel-biodiesel blend by varying the percentages of biodiesel and bioethanol on physical parameters such as density, kinematic viscosity, flashpoint and cetane index was examined in this study. When bioethanol was introduced, it was significantly reduced the physical qualities of blended fuels. Regardless of the biodiesel portion used, the bioethanol component dominated the flashpoint of fossil diesel-biodiesel-bioethanol blends. Compared to fossil diesel combustion, the inclusion of biodiesel and bioethanol blends considerably reduced CO, CO_2, NOx and hydrocarbon emissions.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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TABLE-4
FLUE GAS EMISSION COMPARISON FOR FOSSIL DIESEL, BIODIESEL AND BLENDED FUELS

Exhaust emission	D100	B100	D80B20	D80B15E5	D80B10E10	D80B5E15	D80E20
CO_2 (%)	1	0.8	0.9	0.9	0.8	0.8	0.7
CO (ppm)	278	146	205	190	177	168	162
NO (ppm)	9	7	8	8	8	8	7
NO_x (ppm)	28	20	25	25	24	23	21
HC (ppm)	15	4	12	11	10	9	8

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