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# Experimental investigation of the effect of diesel–cotton oil–*n*-butanol ternary blends on phase stability, engine performance and exhaust emission parameters in a diesel engine

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## HIGHLIGHTS

- *n*-Butanol is a very competitive renewable biofuel for use in diesel engines given its many advantages.
- Using *n*-butanol as a cosolvent gave better miscibility in the ternary blends of diesel–cotton oil–*n*-butanol.
- Experimental results showed that brake torque and power decreased and BSFC increased compared to those of diesel fuel.
- Exhaust emissions of $NO_x$ and HC increased, while $CO_2$ and CO decreased for DCtOnB as a fuel in diesel engine.
- DCtOnB is a promising candidate for renewable fuels at the expense of increasing BSFC, $NO_x$ and HC emissions.

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## ABSTRACT

This study focused on the effect of temperature and component concentration on phase stability of diesel–cotton oil–*n*-butanol ternary blends. Titration method was performed for plotting phase diagrams at different temperatures (−10, −5, 0, 5 and room temperature). Ternary blend of 70% diesel fuel, 20% cotton oil, 10% *n*-butanol by volume (DCtOnB), which was prepared by the splash-blending method, obtained from titration values at −10 °C temperature was selected for the engine performance and exhaust emission tests. Engine performance test results of DCtOnB showed that average values of brake torque (2.6%), brake power (1.6%), brake thermal efficiency (BTE) (31.2%), brake mean effective pressure (BMEP) (2.3%) and exhaust gas temperature (3.6%) are lower, while brake specific fuel consumption (BSFC) (34.1%) is higher than those of diesel fuel. As for the emissions of the DCtOnB, it was found that carbon monoxide (CO) and carbon dioxide ($CO_2$) emissions reduced significantly at low engine speeds, whereas oxides of nitrogen ($NO_x$) and hydrocarbon (HC) emissions increased, when compared to those of diesel fuel. Taking these facts into account, a blend of 70% diesel fuel, 20% cotton oil and 10% *n*-butanol was found the most suitable ratio for low temperature behavior due to the satisfactory fuel properties and reduced exhaust emissions.



## 1. Introduction

Investigation for sustainable and renewable alternative fuel for diesel engines has recently become important due to the growing concerns with regards to the future availability of fossil fuel reserves and environmental problems [1–3]. Diesel engines have been widely used for engineering machinery, automobiles and shipping equipment because of their excellent drivability and thermal efficiency [4]. With the great increase in the usage of diesel engine vehicles in daily-life, the consume of fossil fuels are also greatly increasing. Known petroleum reserves are predicted to become depleted in the near future [1,3].

Biofuels are known as a potential renewable and sustainable energy source in satisfying environmental and economical concerns [2]. Therefore, the fuels of bio-origin can provide a feasible solution to world's dependence on fossil fuel. Their requirement for engine modification or fuel modification is limited [5].

Some oxygenated fuels, which can be produced from resources available locally within the country, are known to have the potential for use as the alternative diesel fuel in biofuels [1]. Those oxygenates can be classified as alcohols and vegetable oils [1,6].

Vegetable oil's viscosity problem is regularly described in literature [7–9]. Because this problem prevent the use of vegetable oil as a direct substitute for diesel fuel, it has to be modified to a more

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suitable and compatible engine-friendly fuel for diesel engines. Various techniques and methods are used to solve the problems resulting from high viscosity [9,10].

In order to overcome the problem of high viscosity, four solutions have been proposed on fuel modifications: (1) vegetable oil/diesel blends, (2) pyrolysis, (3) vegetable oil transesterification to fatty alkyl esters or biodiesel, and (4) vegetable oil-based microemulsifications [1,2,6,11,12].

Transesterification of vegetable oils to biodiesel is by far the most widely studied technique to reduce viscosity. However, biodiesel has many drawbacks. The major drawback of transesterification process is a relatively expensive chemical process since it involves use of chemicals, catalysts and process heat [13]. Hence, there is still need for much research to be done for an effective, economical and efficient conversion process [2].

In this point, microemulsification is another way to reduce vegetable oil viscosity [12]. Due to the disadvantages of the transesterification process, microemulsification of vegetable oils can be considered as an alternative method to avoid the production of unpurified glycerol. While this method offers many advantages, it has received only limited research. The microemulsification method involves mixing two immiscible fluids, a vegetable oil–diesel, using alcohol to stabilize the mixture [11].

Some of the advantages of the microemulsification method are low production costs, simple and easy implementation, and minimal fuel processing. It can be used in diesel engines without any need for engine modification, and chemical reactions [11]. Therefore, microemulsification is one of the techniques by which high viscous vegetable oil is mixed with diesel fuel and alcohol to use in diesel engines [14].

Alcohol fuels can be successfully used directly in a spark engine or they can be blended with diesel fuels [6,15,16]. Butanol is one of the primary alcohol types, which has more advantages than ethanol and methanol as an alternative fuel for diesel engines [17,18]. Butanol as a higher alcohol can also be used as a blend component, owing to its properties, such as viscosity and cetane number, which are closer to that of diesel than that of lower alcohols [15]. Butanol as a potential second generation biofuel is a very competitive alcohol to be applied in diesel engines and is becoming popular recently [2,3,15,17–20]. Butanol have different isomers, based on the location of the –OH and carbon chain structure. 1-Butanol, also better known as *n*-butanol, has a straight-chain structure with the –OH at the terminal carbon. This is the isomer used in the present study.

The solubility of vegetable oil in diesel depends on the composition of diesel and the temperature. Phase separation occurs at relatively low temperatures, which are still used in the blending of vegetable oil. The microemulsification technique helps to overcome the immiscibility of vegetable oil and diesel [12]. The phase stability of the vegetable oil and diesel blends can also be prevented by using *n*-butanol [3,18]. Blending vegetable oil, diesel fuel and butanol improves the vegetable oil fuel properties [21]. *n*-Butanol is a less polar molecule than ethanol, and thus it presents more miscibility with diesel in contrast to ethanol, which is a lower alcohol, the miscibility of *n*-butanol with vegetable oils at a wide range of operating conditions is excellent [3,4,22]. In fact, *n*-butanol has been used as a co-solvent in ethanol–diesel and methanol–diesel blends [23]. Among the applicable co-solvents, *n*-butanol is used primarily because of their similarity to diesel oil, which allows the use of *n*-butanol/diesel blends in any proportion. *n*-Butanol as a co-solvent allows the addition of more vegetable oil–blended fuel [24].

The current literature concerning the use of *n*-butanol/vegetable oil/diesel fuel blends in diesel engines and its effects on their performance and exhaust emissions is nearly absent.

The effects of blends containing croton mogalocarpus oil/*n*-butanol/diesel on engine performance, combustion, and emission characteristics are reported in the study by Lujaji et al. In this study it was observed that brake specific energy consumption of blends was found to be higher when compared with that of diesel fuel. Butanol containing blends show higher cylinder pressure and heat release rate compared to that of diesel fuel on higher engine loads. Carbon dioxide and smoke emissions of the *n*-butanol blends were lower in comparison to diesel fuel [3,25].

Study by Weerachanchai et al. reports that the blending of the palm kernel bio-oil with diesel by using *n*-butanol as a cosolvent is a promising alternative to avoid the problems associated with the direct use of palm kernel bio-oil as fuel. This study indicates that the use of butanol as a cosolvent showed better characteristics of phase behavior and fuel properties than the use ethanol [26].

In other limited number of studies, the effects of *n*-butanol/diesel fuel blends on engine performance and emission were investigated.

Common conclusion of these experimental studies is that next generation promising fuel, *n*-butanol, can be used safely and advantageously, both from the viewpoints of thermal efficiency and exhaust emissions, in the diesel engines using high blending ratios with the diesel fuel. In comparison to ethanol–diesel blends, *n*-butanol requires no cetane enhancing additive or solubilizer due to its relatively high cetane number, high solubility, no phase separation in the diesel fuel [17,19,20,27–32].

Filling this gap, this research is focused on the use of *n*-butanol as an additive in stabilizing neat cotton oil, which is grown widely in Turkey, diesel blends. The main objective is to investigate the phase stability of diesel–cotton oil–*n*-butanol ternary blend system in order to determine soluble areas within the phase diagrams. The phase diagrams are plotted at different blending component concentrations, and different temperatures. Finally, engine performance and exhaust emission of the chosen blend concentration, which composed 70% diesel fuel (D), 20% cotton oil (CtO), 10% *n*-butanol (nB), is evaluated in a turbocharged direct injection diesel engine.

## 2. Materials and methods

### 2.1. Experimental set-up

Schematic layout of the testing apparatus is shown in Fig. 1. As shown in Fig. 1, a Land Rover turbocharged direct injection 110 type diesel engine coupled with BT-190 hydraulic dynamometer, has a maximum speed of 7500 rpm, a maximum torque of 745 N m, a maximum brake power of 119 kW, and a load cell capacity of 2500 N. Table 1 shows the technical specifications of the test engine.

The engine fuel system was modified by adding a tank fueled with DCtOnB and a two-way, hand controlled valve, which allowed rapid switching between diesel fuel and DCtOnB. Also, a cooling water tank with PT-100 temperature sensors, located in inlet and outlet water pipe, were added to test bench for controlling of cooling water of the engine. Exhaust emissions were measured with Testo 350 analyzer box equipped with control unit. The analyzer box provided a $O_2$ measurement range of 0–25 vol.% with a resolution of 0.2 vol.%, CO range of 0–10,000 ppm with a resolution of 5 vol.% (200–2000 ppm), NO range of 0–4000 ppm with a resolution of 5 vol.% (100–1999 ppm), $NO_2$ range of 0–500 ppm with a resolution of 5 ppm (0–99.9 ppm), $CO_2$ range of 0–50 vol.% with a resolution of 0.3 vol.% (0–25 vol.%) and HC range of 100–40,000 ppm with a resolution of 10 vol.%.

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