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# Influence of 1-pentanol additive on the performance of a diesel engine fueled with waste oil methyl ester and diesel fuel

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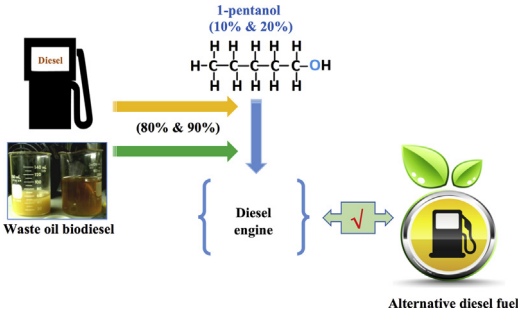
## HIGHLIGHTS

- Pentanol, made of biomass, is an important alternative fuel for diesel engines.
- Effect of using 1-pentanol in waste oil methyl ester (B) and diesel fuel (D) on engine performance and emissions was investigated.
- 1-pentanol addition did not reduce cetane number significantly.
- Engine characteristics were reported based on binary blends.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Biodiesel cannot directly be used in diesel engines because some of its fuel properties which poorly affect engine operation but it can be blended with diesel fuel or alcohols. It is important to research fuels with high biodiesel concentration which can be alternatives to diesel and B20. 1-Pentanol, a higher alcohol, shows promise as an alternative fuel used as a fuel additive in diesel and/or biodiesel in compression ignition engines. The purpose of this study is to investigate the effect of the use of 1-pentanol in waste oil methyl ester (B) and diesel fuel (D) on the exhaust emissions and performance of a diesel engine operating at various loads, 0, 3, 6, and 9 kW, with a constant engine speed (1800 rpm). 1-Pentanol (10% and 20% by volume) was added to diesel fuel and waste oil methyl ester to create the following fuel blends: D90P10, D80P20, B90P10, and B80P20. Basic fuel properties were investigated and determined to be within the limit of standards. According to the engine test results, the brake specific fuel consumption (BSFC) and exhaust gas temperatures (EGT) increased with the addition of 1-pentanol to diesel and biodiesel. Testing shows that the brake thermal efficiency (BTE) decreased for the diesel fuel blends D90P10 and D80P20. In contrast, biodiesel blends B90P10 and B80P20 exhibited an increase in BTE. Diesel blends D90P10 and D80P20 increased carbon monoxide (CO) and unburned hydrocarbon (HC) emissions while reducing the production of the oxides of nitrogen ($NO_x$). Compared to other biodiesel blends, B80P20 reduced the production of CO, HC, and $NO_x$ emissions at 0 and 3 kW loads while increasing the production of these emissions at 6 and 9 kW loads.

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## 1. Introduction

Global demand for the world's fossil fuel reserves has increased due to industrialization and an ever increasing number of

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petroleum dependent road vehicles. Fossil fuels are vital in the global transportation sector; of the fossil fuels used, diesel is the most prevalent. Stringent regulations on emissions worldwide, in combination with a decrease in the supply of petroleum resources, have spurred a global push towards establishing alternative energy sources that are renewable, clean, and cost-effective [1]. Biodiesel and bioalcohols are leading prospects among renewable energy sources that can be used in diesel engines, in large part, due to their economic and environmental impact [2].

Biodiesel is a renewable and environmentally friendly fuel that has gained widespread use in the world [3–5]. One caveat that has limited the proliferation of biodiesel is that it is sourced from constituents that serve as food and a source of nutrition. Waste oil is used to produce some forms of biodiesel in order to reduce negative effects on food production [4,6]. Sourcing waste vegetable oil from the food industry solves some of the issues faced in the widespread production of biodiesel [7]. A very important disadvantage of neat biodiesel (B100) when used in diesel engines is its high viscosity. Biodiesel is blended with diesel to compensate for biodiesel's high viscosity. However, this method of addressing the viscosity issue maintains a reliance on fossil fuels [8]. These biodiesel fuel blends that utilize diesel are shown to have increased $NO_x$ emissions compared to those of neat biodiesel [9,10]. Because the properties of alcohols are such that they may have positive effects on engine emissions, they have been added to biodiesel-diesel blends [11].

The amount of oxygen in the chemical structures of biodiesel and bioalcohols reduces their exhaust emissions. Additionally, biomass can be continuously supplied for the production of biodiesel and bioalcohols. For these reasons, and many others, the use of biodiesel and bioalcohols as renewable alternative fuels is advantageous to other energy sources [11,12].

Alcohols, a family of organic molecules, can be used in internal combustion engines. The ability to produce alcohols from biomass makes them very promising for use in diesel engines. Recently, studies investigating the use of alcohols in diesel engines have focused on methanol ($CH_3OH$), ethanol ($C_2H_5OH$) and butanol ($C_4H_9OH$) [11–14]. Methanol can be produced from both petroleum based materials and coal, while ethanol is produced from the fermentation of renewable biomass. Although it should be noted that phase separation occurs in diesel-ethanol fuel blends at temperatures below 10 °C [14–16]. Amongst the higher alcohols, butanol has a negative effect on diesel engine performance due to its lower cetane number than diesel [17–20].

The use of alcohols in diesel engines is important due to the fact that they reduce the production of harmful emissions and they reduce the demand for fossil fuels [21]. Due to the low cetane number, and other properties of alcohols, pentanol or butanol may not be suited for use in diesel engines directly. Alcohol molecules contain alkyl and hydroxyl which allow alcohols to mix with diesel regardless of the number of carbon molecules [22]. Fuel properties of alcohols improve with respect to higher carbon numbers and show similarities with diesel fuel properties. Pentanol ($C_5H_{11}OH$), which has 5 carbon atoms and can be produced from renewable resources, is a promising alternative fuel for use in diesel engines. Pentanol is a straight-chain alcohol which is recently getting attention because of its advantages over other butanol isomers. While being a longer-chain alcohol, pentanol requires less energy for its production when compared to other lower alcohols [12]. In recent years, pentanol addition to diesel-biodiesel has been investigated and it was concluded that pentanol could be a promising future generation bioalcohol for diesel engines [23–29,30]. However, there is a limited number of studies in literature with regards to the use of pentanol blends with diesel and biodiesel in diesel engines [12,31,32].

Summary of the studies involving diesel and pentanol blends indicates a few investigations as follows. Four different 1-pentanol/diesel and n-butanol/diesel blends were examined by Campos-Fernandez et al. [33] in a direct injection diesel engine. Their study showed that BSFC slightly decreased for 1-butanol/diesel blends when compared to 1-pentanol/diesel blends and neat diesel. Additionally, Campos-Fernandez et al. proposed two alternative diesel fuel blend formulations that will not reduce performance, 30% butanol/diesel and 25% 1-pentanol/diesel. Wei et al. [34] tested DP10, DP20 and DP30 (10, 20 and 30 vol% pentanol fraction in diesel fuel) blends, which showed higher BSFC, HC, CO, and $NO_x$ emissions and produced lower particulate mass concentrations than diesel fuel. Campos-Fernandez et al. [35] studied pentanol-diesel blends in a diesel engine with the pentanol concentrations of 10%-15%-20% and 25% and found out that pentanol-diesel blends show similar characteristics as diesel fuel. It was emphasized that 25% of pentanol can be used in diesel engines without any engine modification. Zhang et al. [36] examined engine performance, particulate matter (PM) and elemental carbon (EC) emissions of a diesel engine running on diesel blends with 10% and 20% of n-butanol and pentanol. Pentanol showed better BSFC than butanol while PM and EC emissions decreased with both fuel additions. Kumar et al. [37] tested a diesel engine in premixed low temperature combustion (LTC) mode with 40% iso-butanol or n-pentanol in diesel fuel under exhaust gas circulation (EGR) conditions and two injection timings. Although alcohols additions caused engine performance loss, higher alcohols reduced $NO_x$ and PM emissions significantly. In another study, Kumar et al. [38] mixed 15%, 38% and 45% *iso*-butanol or n-pentanol with diesel fuel which were tested in single cylinder diesel engine under different EGR modes. Although the alcohol additions increased HC and CO emissions, $NO_x$ emissions decreased for all alcohol blends. Kumar et al. [39] tested 10%, 20%, 30% and 45% of pentanol with diesel fuel in a diesel engine under 3 different EGR modes and the results showed engine performance loss, higher HC and CO emissions and lower $NO_x$ emissions. Ma et al. [40] investigated 20%, 40% pentanol and diesel blends in a constant volume chamber for ignition and combustion characteristics. It was noted that there was a slight increase in the natural flame luminosity and a slight decrease in soot because of the oxygen content of pentanol. Other studies also indicate that pentanol can be used in diesel engine if it is mixed with diesel fuel or other fuels [41,42].

Pentanol can be used to decrease the high viscosity of biodiesel which is a major alternative fuel but there is a limited number of studies as well. Zhang et al. [43] studied 10% and 20% n-butanol and n-pentanol blended with biodiesel and tested the blends in a diesel engine at 3 different engine loads. All blends showed higher BSFC. Also, all alcohol blends showed reductions in PM, EC and polycylic aromatic hydrocarbons (PAHs). Yilmaz et al. [44] blended 90% biodiesel and 10% propanol, n-butanol or 1-pentanol. When compared to B100, propanol and n-butanol blends decreased BTE while pentanol improved BTE. All alcohol blends decreased $NO_x$ emissions. The best reduction of HC was observed with pentanol blends. Zhu et al. [45] added 10%, 20% and 30% n-pentanol to waste cooking oil bio- diesel and investigated the effect of the fuel blends and engine load on PM, showing reduction in PM emissions. All alcohol blends increased HC and CO emissions. The blend with 30% pentanol indicated an increase in $NO_x$ emission. It was concluded that 10% pentanol is an ideal blend with biodiesel.

When the conclusions of all studies are examined, several points can be made. Unlike the lower alcohols, pentanol can easily be blended with biodiesel and diesel. Some of the contributing factors to its practical use in fuel blends in diesel engines include its chemical structure (the number of carbon atoms), higher cetane number, calorific value, viscosity, flame speed, lower latent hear of evaporation, ignition temperature, lower risk for corrosion, lower polarity, the ability to create miscible solutions with it [33–40]. Although very little research has been conducted

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