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Full Length Article

Experimental assessment of a diesel engine fueled with diesel-biodiesel-1-pentanol blends

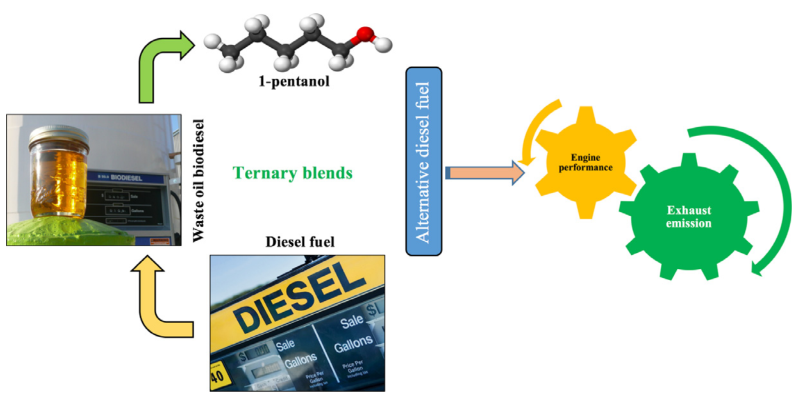
Nadir Yilmaz [a,*], Alpaslan Atmanli [b]

[a] Department of Mechanical Engineering, New Mexico Institute of Mining and Technology, Socorro, NM, USA
[b] Turkish Land Forces NCO Vocational College, Automotive Sciences Department, 10110 Balikesir, Turkey

HIGHLIGHTS

- 1-Pentanol is a very competitive renewable biofuel for use in diesel engines given its many advantages.
- Diesel-biodiesel and diesel-biodiesel-1-pentanol blends were tested in a diesel engine.
- Comparisons were made against diesel-biodiesel blend.
- Engine performance characteristics and exhaust gas emissions were reported.

GRAPHICAL ABSTRACT



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ABSTRACT

Higher alcohols made of renewable resources have better fuel properties and can potentially serve as better alternatives than lower alcohols in fuel blends. 1-Pentanol, which has a chain of five carbons and can easily be blended with both diesel and biodiesel, is a promising type of alcohol for the future. The purpose of this work is to investigate the fuel properties of ternary blends of diesel (D), waste oil methyl ester (B) and the higher alcohol of 1-pentanol (Pen), the effects of such blends on engine performance and emissions of a diesel engine. By splash blending, several ternary blends were prepared: DB (80% diesel and 20% biodiesel by volume), D75B20Pen5 (75% diesel, 20% biodiesel, 5% 1-Pentanol), D70B20Pen10 (70% diesel, 20% biodiesel, 10% 1-Pentanol) and D60B20Pen20 (60% diesel, 20% biodiesel, 20% 1-pentanol). In order to determine engine performance and exhaust emissions, tests were performed at 3 engine loads (0, 1.5, 3 kW) with a constant engine speed (2000 rpm). Ternary blends increased brake specific fuel consumption (BSFC) while decreased brake thermal efficiency (BTE) as compared to diesel fuel. Also, an increase of pentanol concentration had an increasing effect on exhaust gas temperature (EGT). The higher latent heat of evaporation caused a cooling effect, reduction in combustion efficiency and an increase in CO emissions. Similar to CO emissions, HC emissions of pentanol blends increased significantly. Also, the addition of pentanol to diesel-biodiesel blends has a significant impact on the increase of NO_x emissions.

1. Introduction

Oil reserves are being depleting world-wide due to the demand on petroleum fuels, which are the current primary energy

* Corresponding author.
E-mail address: yilmaznadir@yahoo.com (N. Yilmaz).

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resources used worldwide. With that, diesel fuel has become more advantageous over gasoline because of the lower price of making it [1,2]. Diesel is widely used not only in transportation sector but also in the power generation industry and other industrial sectors. More pollutants are still being released to the atmosphere due to either industrial applications or daily use of an increasing number of diesel-based motor vehicles [3]. As a result, human health and environment are being negatively affected with harmful emissions.

World environmental organizations and developed countries have come up with protocols which aim to reduce CO_2 emissions in the long term. In this regard, developed countries have focused on using new alternative energy resources which are economical and environment-friendly. Finding new alternatives also allows nations to reduce their dependency on petroleum-based fuels and the possibility of economic crises due to oil is lessened. Developing countries are also currently spending greater efforts to increase the use of biofuels [4,5].

Renewable fuels could be part of the solution as long as they are easily accessible and widely used with large production. Biodiesel and bioalcohols are such promising renewable fuels, which satisfy the criteria for use in diesel engines. Production of such fuels is proving to be economical and environmentally friendly, as well [6–8].

After extensive studies, it has been seen that biodiesel, due to its biodegradability and renewability can be used as an alternative to diesel [9]. However, the use of 100% biodiesel has potential downsides such as fuel-related phase separation and higher emissions as compared to diesel [9,10]. Bioalcohols which can be produced from renewable feedstocks cannot directly be used in diesel engines because of low cetane number and high latent heat of evaporation as well as high water content in low temperatures [10–12].

In spite of such disadvantages, biodiesel and bioalcohols are still two of the most important alternative types of fuels for use in diesel engines. Most of the research in that regard has focused on blends with diesel and in order to reduce the disadvantages of vegetable oils used in biodiesel production and other fuel-related problems, with research showing particular focus on alcohols such as methanol (CH_3OH) and ethanol (C_2H_5OH) [13,14].

Direct use of consumable vegetable oils in biodiesel production can have adverse effects on their availability for human use and thus, biodiesel made of waste vegetable oils and non-edible oils is a preferred source of fuel. With the fact that methanol and ethanol have phase separation at low temperatures and that diesel engines have high cost of repairs, there are hurdles to use both alcohols. In addition, methanol and ethanol have shown low engine performance and high emissions as well [15–19]. In order to solve such problems, it has been proposed to use alcohols with higher carbon chains, which eventually have better fuel properties such as higher cetane number, higher calorific value and lower latent heat of evaporation [20,21]. Propanol (C_3H_7OH), *n*-butanol (C_4H_9OH) and pentanol ($C_5H_{11}OH$) are at the forefront of high carbon alcohols. These alcohols can be easily blended with both diesel and biodiesel at any ratios with no phase separation [20–23]. Especially 1-pentanol has a low polarity with a high hydrophobic capacity and a polar interaction parameter of δ_{pnP}: 2.2. In addition, high capacity production technologies in recent years have allowed for a reduction in the cost of making pentanol as compared to butanol [12].

Although there are a limited number of studies with propanol, *n*-butanol has been blended with vegetable oil, biodiesel, diesel, and used in diesel engines. It has been noted that as the number of carbons in the fuel structure increases, fuel properties show improvement [15–20,23–27]. With that, 1-pentanol, another high-carbon chain alcohol, is investigated for use in diesel engines [20–22,28,29]. However, there are a few investigations with regards to pentanol in diesel engines. In several studies, diesel-pentanol blends have been used, and studies noted that pentanol is advantageous over lower carbon alcohols [30–35]. In biodiesel-pentanol studies, Yilmaz et al. [36] blended 80% biodiesel and 20% propanol, *n*-butanol or 1-pentanol. Those blends showed improvements as compared to neat biodiesel (B100). Zhua et al. [37] added 10%, 20% and 30% *n*-pentanol to waste cooking oil biodiesel and investigated the effect of the fuel blends and engine load on particulate emission (PM), showing reduction in PM emissions. Zhang et al. [38] 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. Both alcohol blends showed reductions in polycylic aromatic hydrocarbons (PAHs).

Nowadays, biodiesel is blended with diesel such as B20 and used in diesel engines. In order to improve fuel properties of such blends, special additives are used [11,12,16]. At this stage, it is important to research pentanol in biodiesel-diesel blends.

Atmanli [39] tested a 4-cylinder diesel engine at various loads using diesel-biodiesel blends mixed with 20% propanol, *n*-butanol or 1-pentanol. Adding pentanol to diesel-biodiesel showed a reduction in BSFC and an increase in exhaust gas temperatures (EGT). In addition, NOx and HC emissions decreased while CO increased. In a different study, Li et al. [40] mixed 30% pentanol, 40% diesel and 30% biodiesel which was compared to diesel-biodiesel and neat diesel. The ternary blends of pentanol, diesel and biodiesel showed very good results in terms of engine characteristics and emissions. Imdadul et al. [41] mixed 10%, 15% and 20% of pentanol with 80–10% diesel-biodiesel, 70–15% diesel-biodiesel and 60–20% diesel-biodiesel, and tested the blends in a single-cylinder diesel engine at full load. Higher pentanol blends improved fuel properties but higher NO_x and CO emissions were detected. On the other hand, smoke and CO_2 emissions were reduced. It was noted that pentanol could be an additive for biodiesel-diesel blends. In another study by Imdadul et al. [42], 15% biodiesel-70% diesel and 20% biodiesel-60% diesel were mixed with 15% and 20% *n*-butanol or pentanol. Tests were performed in a single-cylinder diesel engine at full-throttle with varying speed conditions. Results indicated that pentanol was a better alternative than butanol. In addition, Imdadul et al. [43] used a cetane improver in order to increase the cetane number of diesel-biodiesel-alcohol due to the low cetane number of alcohols. Blends consisted of 20% palm biodiesel-75% diesel and 10% palm biodiesel-80% diesel with 5% and 10% pentanol and 1000–2000 ppm ethyl hexyl nitrate as a cetane improver. As the blends had higher cetane numbers, engine performance tests indicated lower BSFC and NO_x, and higher CO and HC.

In this work, 1-pentanol was added to diesel-biodiesel blends and characteristics of engine performance and emissions were investigated. 5%, 10% and 20% (by volume) 1-pentanol was blended with diesel-biodiesel (20% waste oil methyl ester) to create D75B20Pen5, D70B20Pen10 and D60B20Pen20 test fuels. The blends were tested in a single-cylinder diesel engine at constant speed but varying engine loads. Results were compared to the baseline fuels, diesel and D80B20.

2. Experimental procedure and specifications

Engine performance and exhaust emission tests were performed on a direct injected, single-cylinder diesel engine generator with a Subaru RGD 3300H engine (Fig. 1). The main technical characteristics of the test engine are tabulated in Table 1. The exhaust emissions were measured with an EMS 5002 exhaust gas analyzer. The analyzer provided a HC measurement range of 0–2000 ppm with a resolution of 1 ppm, CO range of 0–10 vol.% with a resolution of 0.01 vol.%, CO_2 range of 0–20 vol.% with a resolution of 0.1 vol.%, O_2 range of 0–25 vol.% with a resolution of 0.01 vol.%