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Effects of a cetane improver on fuel properties and engine characteristics of a diesel engine fueled with the blends of diesel, hazelnut oil and higher carbon alcohol

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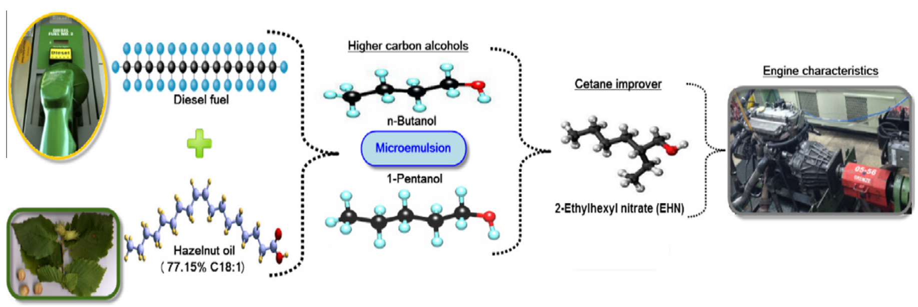
HIGHLIGHTS

- n-Butanol and 1-pentanol have a promising future as biofuels for diesel engines.
- Microemulsion was used to blend hazelnut oil and diesel with n-butanol and 1-pentanol.
- Basic fuel properties of the microemulsion blends were reported in detail.
- Cetane numbers of the microemulsion blends were improved by adding EHN additive.
- EHN was an effective additive to reduce NO_x at the expense of increasing CO.

GRAPHICAL ABSTRACT



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ABSTRACT

Among vegetable oils, hazelnut oil (H), because of its high oleic acid content, is an important biofuel resource for use in diesel engines. Microemulsion, which is a viscosity reduction method, is a more practical and less time-consuming method as compared to transesterification, and can be used to blend diesel (D), vegetable oils and higher alcohols such as n-butanol (nB) and 1-pentanol (Pn), which have a promising future as biofuels for diesel engines, which, in return, can increase the biofuel utilization rate in diesel engines. While alcohols are known to have low cetane numbers, it is necessary to keep the cetane number of microemulsion based fuels high enough. Thus, in this work, 2-ethylhexyl nitrate (EHN) cetane improver was added at 500, 1000 and 2000 ppm concentration to the microemulsions of D (70 vol.%)–H (20 vol.%)–nB (10 vol.%) (DnBH) or Pn (10 vol.%) (DPnH) and the effects of the cetane improver on fuel properties and engine characteristics were investigated in detail. Addition of EHN to DnBH and DPnH microemulsions increased the cetane number by about 13.12% and 12.26%, respectively while it did not have any significant effect on density, kinematic viscosity, cloud point, cold filter plugging point (CFPP) or flash point. The engine tests were performed on a direct-injection, turbocharged diesel engine (TDI) at five engine loads (0%, 30%, 60%, 90% and 100%) at 2200 rpm constant engine speed. As compared to DnBH and DPnH microemulsions, the addition of EHN cetane improver notably decreased brake specific fuel consumption (BSFC) and oxides of nitrogen (NO_x) and increased carbon monoxide (CO) emissions, but had the opposite effects on hydrocarbon (HC) emissions for both microemulsions.

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1. Introduction

The rapid increase of industrial production and transportation has had a great effect on climate change and global warming. As oil prices increase, developing countries show more demands on the use of diesel, which is cheaper than gasoline. Pollutants that are formed as a result of diesel are harmful to humans and the environment, and must be under better control [1,2]. Countries including the USA and the EU recognize that harmful emissions that are released from diesel engines in transportation need to be reduced.

Based on the Environmental Protection Agency (EPA) directive in the USA and the Euro VI norms in Europe, it is anticipated that new emission regulations will be accepted by 2017 and NO_x, CO and PM emissions should be reduced by 25%, 24% and 10%, respectively by 2030 [3]. In order to achieve these goals, alternative fuels have been recognized as a necessity compared to petroleum derived fuels. Vegetable oils containing C_{10}–C_{40} fatty acids and alcohols with high oxygen content are among some of the most important alternative fuels [4,5].

In order to use vegetable oils as alternatives in diesel engines, their high viscosities must be reduced. Among various methods to reduce viscosities, microemulsion is a cheaper, more practical and easier method than transesterification [6,7]. In addition, microemulsion can be used to easily blend two alternative fuels, such as vegetable oils and alcohols, and increase the biofuel utilization rate in diesel engines [8,9].

Vegetable oils can be mixed with diesel at certain ratios and used in diesel engines. Alcohols can also be mixed with diesel and vegetable oils in any ratios and used in diesel engines without any modification [10,11]. However, lower carbon alcohols such as methanol and ethanol have disadvantages with microemulsion at low temperatures due to separation [12–15]. In addition, poor lubricity, low cetane numbers and heating values of lower carbon alcohols prohibit them from being directly used in diesel engines [13]. Among higher carbon alcohols with promising future alternatives, n-butanol and 1-pentanol have more similar properties to diesel than lower carbon alcohols. Especially due to the advantage of n-butanol and 1-pentanol having low polarity and being hydrophobic, phase separation does not occur. Additionally, they have lower polar interaction parameters (δ_p: polar solubility) as δ_{pnB}: 2.8 and δ_{pnP}: 2.2, respectively, and thus they present more miscibility with diesel and vegetable oils, which are apolar [2,8,15]. Use of n-butanol in diesel engines has gained a lot of attention in recent years and most of the studies note that the fuel properties of blends with n-butanol need to be improved in order to increase the overall cetane number [2,8,10,11,14,16–20].

1-Pentanol, an alcohol with five carbon atoms and a straight carbon chain, is a next generation alternative fuel with a promising future for use in diesel engines [21,22]. However, there are a limited number of studies in literature with regards to the use of pentanol in diesel engines with respect to performance and emissions. Among the limited studies, mostly blends of diesel and pentanol are investigated. Campos-Fernández et al. [22] evaluated 1-pentanol/diesel blends with various blending ratios (10–25%) in a diesel engine without any modification, while emphasizing the fact that pentanol had similar fuel properties to those of diesel and much better fuel properties than lower carbon alcohols. And, they concluded that 25% of pentanol and 75% of diesel can be directly used in diesel engines and thus can replace 100% diesel. Wei et al. blended *n*-pentanol and diesel with 10%, 20%, 30% of *n*-pentanol and investigated the effects of *n*-pentanol/diesel blends on combustion, performance, and gaseous and particulate emissions of a diesel engine [23]. It was noted that an increase of *n*-pentanol in the blends increased BSFC while not affecting BTE. In addition, HC, CO and NO_x emissions increased, but particulate emissions significantly decreased with the increase of *n*-pentanol in diesel. Li et al. [24] used 100% pentanol in a direct injection diesel engine and examined the combustion and emission characteristics of the engine with pilot-main and single-injection strategies. Simultaneous reduction of soot and NO_x was achieved without exhaust gas recirculation while the engine ran on only pentanol. Kumar and Saravanan blended diesel with 10%, 20%, 30% and 45% of pentanol and evaluated diesel/pentanol blends in a diesel engine with 10%, 20% and 30% of EGR [25]. An important conclusion was that diesel/pentanol blends with 45% of pentanol could directly be used in diesel engines without any engine modifications and with no harm to the engine. Moreover, NO_x was reduced with 45% of pentanol and 30% of EGR. In another study performed by Li et al. [26], performance and emission characteristics of a diesel engine were investigated with pentanol/diesel and pentanol/biodiesel/diesel blends. By using the pentanol blended fuels, soot and NO_x were simultaneously reduced at only low-partial loads and NO_x increased at high loads as compared to diesel fuel.

Literature indicates that lower cetane numbers of alcohols affect NO_x formation in diesel engines. NO_x formation occurs mostly during premixed combustion [27,28]. NO_x formation is proportional to an increase of in-cylinder temperature, which can be caused by premixed combustion and a high combustion rate. Cetane number is an important measure and indicator of premixed combustion and combustion rate [29]. Higher CN leads to lower ignition delay and premixed combustion phase which, in return, contribute to better engine operations and lower NO_x [30–33]. Due to the importance of cetane number and the fact that alcohols have lower cetane numbers than vegetable oils and diesel, it is necessary to add cetane improvers to diesel/vegetable oils/alcohols blends in order to achieve engine stability, better combustion efficiency and lower emission release [11,14,17,34].

Cetane improvers in diesel fuel are traditionally alkyl nitrates (amyl nitrate, hexyl nitrate and octyl nitrate) [33,35–38]. Li et al. [30] added 0.3% of three cetane improvers (EHN, cyclohexyl nitrate and 2-methoxyethyl ether) into 10% methanol and 90% biodiesel blends. Tests indicated that cyclohexyl nitrate, EHN and 2-methoxyethyl ether had the most to least impact on the improvement of the cetane number in the blends, respectively. With the additives, NO_x emissions decreased while CO and HC emissions increased. Suppes et al. studied the effectiveness of EHN on ignition properties and found out that increasing EHN concentrations in test fuels decreased ignition delay [37]. Hess et al. added 1000 ppm of EHN to B20 and noticed that the addition of EHN to B20 reduced NO_x by 4.5% because of a higher cetane number, which leads to lower ignition delay and less release of NO_x [39]. In another study, Zhang et al. added 2% EHN to DMF (2,5-dimethyl furan)–diesel blends which led to an 80% reduction of soot, significant decreases in THC emissions and slight increases in NO_x [40].

In all the previous studies, it was noted that the addition of EHN to biofuel blends increased cetane numbers and reduced NO_x emissions. However, literature studies do not show any work in which EHN is added to higher alcohols or microemulsion based fuels.

Basic criteria for choosing the most convenient raw biomass are the costs of the raw material, easy access to the resource, energy security and the economical impact on the local region [41]. Hazelnut oil is an appropriate alternative for diesel engines because of its content having 77.15% oleic acid (C18:1) [14,42]. Turkey is the world leader in terms of hazelnut and hazelnut oil production, as it supplies 82.86% of the total worldwide demand. In terms of hazelnut production, Turkey is followed by Italy (10.81%), Spain (3.55%), the USA (1.86%) and Greece (0.92%) [14,43]. Thus, it is important to note that making biofuels with hazelnut oil, by following the EU directives and standards, could be an alternative fuel solution for Turkey, which mostly imports oil from Middle Eastern