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Performance tests of a diesel engine fueled with pentanol/diesel fuel blends

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HIGHLIGHTS

- ▶ We have fueled a diesel engine with pentanol/diesel fuel blends.
- ▶ Performance results are similar for both pentanol blends and straight diesel fuel.
- ▶ Performance results are better for pentanol blends than ethanol blends.
- ▶ Pentanol *LHV*, *ST*, *VLH*, ρ and *CN* values are closer to diesel fuel than lower alcohols.
- ▶ The presence of oxygen offsets pentanol reduced *LHV* and provides better combustion.

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ABSTRACT

The use of straight (in modified engines) or blended alcohols with fossil fuel provides an attractive alternative fuel for internal combustion engines. Moreover, alcohol can be produced by biorefineries, thus reducing the use of fossil resources. However, main achievements in this field correspond to the use of short-chain alcohols, like ethanol, while there is little experience with higher alcohols. In this work, the performance of a direct-injection diesel engine, without any modifications, fueled with 1-pentanol/diesel fuel blends has been evaluated. Blends with 10% pentanol/90% diesel fuel, 15% pentanol/85% diesel fuel, 20% pentanol/80% diesel fuel and 25% pentanol/75% diesel fuel (v/v) were tested and engine performance results were compared with those provided by neat diesel fuel. Experimental results showed insignificant engine power, brake thermal efficiency and brake-specific fuel consumption variations when the engine was fueled with the majority of the blends instead of straight diesel fuel. Moreover, statistical analysis showed no significant differences between the blends and diesel fuel (EN 590) tests. During engine starting, no difficulties were experienced and the engine performed satisfactorily on the blends throughout the entire test. On the basis of this study, pentanol/diesel fuel blends can be considered acceptable diesel fuel alternatives if exhaust emissions and long-term engine tests show acceptable results.

1. Introduction

Nowadays countries are researching alternatives to fossil fuels, mainly due to the increase and fluctuation in prices of diesel fuel and petrol, a growing environmental conscience and the shortage of petroleum. In fact, "Directive 2009/28/ CE of the European Parliament and the Council on the promotion of the use of energy from renewable sources" specifies that each EU Member State shall ensure that, in 2020, the share of energy from renewable sources in all forms of transport is at least 10% of the final consumption of energy in transport in the Member States.

There is a growing interest on using alcohols as an option to substitute petrol in spark ignition engines and extensive research has been carried out [1–8]. The use of oxygenated fuels involve oxygen enrichment, enhancement of premixed combustion phase of blends and improvement of the diffusive combustion phase [9–11]. However, some difficulties prevent their use as fuel for diesel engines, among them are: (a) the lower heating value (*LHV*) of alcohols are below that of diesel fuel, thus to provide the same engine power, more alcohol by mass and volume than diesel fuel is needed [12]; (b) high percentage of alcohol presents miscibility and stability problems when blended with diesel fuel [13] and phases separate on the presence of water traces [14]; (c) alcohols have low cetane numbers, but diesel engines need high cetane number to facilitate autoignition and provide little ignition delay [15]; (d) the poor autoignition capacity of alcohols is responsible

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of severe knock due to the rapid burning of vaporized alcohol [14]; (e) alcohols depict inappropriate lubricating properties compared to diesel fuel [12,14] and may even dilute the lubricant film on the piston wall, thus affecting engine durability.

To solve the aforementioned disadvantages, different technologies comprising modified and unmodified engines running on alcohol blends have been proposed. Pulverization of alcohol, double injection of diesel fuel and alcohol, direct alcohol/diesel fuel blends and emulsions are among the most used alternatives [16]. Direct use of alcohol/diesel fuel blends is one of the most interesting possibilities because of their lower cost and, most important, modifications on diesel engine are not necessary using low alcohol concentrations. Due of these reasons, finding both the most appropriate type of alcohol and the optimum alcohol/diesel fuel blend to substitute diesel fuel on diesel engines is needed.

Ethanol and methanol are the most researched alcohols to be used as alternate fuels, although as methanol has very limited solubility in diesel fuel [13], the most common alternative is ethanol. Can et al. [17] found reductions on engine power of 20% and 12.5%, when diesel fuel was blended with 15% and 10% ethanol, respectively. Ajav et al. [18] found a power reduction of 5% and a brake-specific fuel consumption increase above 20% for 20% ethanol blended with diesel fuel. Hansen et al. [19] found a 7–10% decrease in an engine power at rated speed with 15% dry ethanol, 2.35% Pure Energy Corporation (PEC) additive and 82.65% diesel fuel blend. Li et al. [20] studied ethanol/diesel fuel blends, from 5% to 20% of ethanol, to find out that brake-specific fuel consumption increased using all tested blends. Lu et al. [10] tested an ethanol addition (from 10% to 20%) to diesel fuel on a diesel engine. Results showed that brake-specific fuel consumption increased at overall engine operating conditions. Bilgin et al. [21] found that the addition of 4% ethanol to diesel fuel increased brake power by 1.5%, while brake-specific fuel consumption decreased by 2.5%. Kass et al. [22] tested two diesel fuel blends containing 10% and 15% dry ethanol and 2% GE Betz additive, respectively and reported around 8% torque reduction for both fuel blends. Therefore, usually using ethanol/diesel fuel blends, percentages of alcohol higher than 10% means power reduction while brake-specific fuel consumption increases.

Large values of both lower heating value (*LHV*) and cetane number (*CN*) are desirable fuel characteristics on diesel engines, while self-ignition temperature (*ST*) and vaporization latent heat (*VLH*) should exhibit moderate values. The value of fuel properties, including *LHV*, *CN*, *ST*, *VLH* are established by the different molecular structure of alcohols. Normal paraffins (straight chains) have higher *LHV* but lower *VLH* and *ST* when the number of carbon increases. Moreover, normal paraffins have higher *self-ignition* tendency (lower *ST*) than isoparaffins (branched chains), n-oleofins, cycloalkanes and aromatic hydrocarbons considering the same number of carbons [23].

In regard to cetane number, normal paraffins exhibit a higher value than isoparaffins, monocycloparaffins, alkylbenzenes, polycycloparaffins and polyaromatics, even showing the same number of carbons [24]. Moreover, considering normal paraffins, the higher the molecular weigh the higher the *CN* value [24]. *CN* decreases with the decrease of the chain length [25,26] or the branches increase [25]. Also, the longer the chain of carbon the smaller the knock [27]. Moreover, in structures with isomers, when the number of branches increases, knock tendency increases [27]. In regard to density, it increases with the number of carbons [24], being smaller for paraffins, followed by cycloparaffins and finally, aromatics [24].

Therefore, it may be inferred that the increase of the chain length and the absence of branches in an alcohol show some advantages like higher *LHV*, density and *CN*, lower *ST*, *VLH* and knock tendency, although the percentage of oxygen decreases.

The use of higher-alcohols blended with diesel fuel may provide additional advantages compared to short-chain alcohols (up to a limit), i.e. longer molecular unbranched structure of alcohols that means higher *LHV and CN*, lower *ST* and knock reduction, etc. However, very little work has been reported on higher-alcohols being used as alternative fuel or fuel additives. To the best of our knowledge, references of the use of pentanol as fuel are almost inexistent. In fact, Gautam and Martin II [3] studied the effects of 10% of different alcohols blended with petrol on spark ignition engines. The maximum amount of pentanol used was less than 3%, while power, torque and specific fuel consumption were not evaluated.

Moreover, the concept of a biorefinery for higher-alcohol production is to integrate ethanol formation via fermentation with conversion of this simple alcohol intermediate into higher alcohols [28], i.e. pentanol. Biorefineries use renewable raw materials to produce energy together with a wide range of commodities, decreasing the dependency on fossil fuels reserves. Thus, pentanol may be produced through this promising route for sustained growth and preserving the environment.

The purpose of this study is to test and analyze the influence of 1-pentanol/diesel fuel blends on diesel engine performance. This target includes testing a diesel engine fueled with different 1-pentanol/diesel fuel blends and analyzing brake engine power, torque, fuel consumption, brake-specific fuel consumption, brake thermal efficiency and to find out the optimum alcohol/fuel blend to run on direct-injection diesel engines.

2. Materials and methods

2.1. Fuel blends

1-Pentanol PRS was purchased from Panreac S.A.U. (Barcelona, Spain). Some properties of diesel fuel, methanol, ethanol and pentanol are given in Table 1. The tested fuels were straight diesel fuel (D100), 10% pentanol/90% diesel fuel blend (v/v) (P10), 15% pentanol/85% diesel fuel blend (v/v) (P15), 20% pentanol/80% diesel fuel blend (v/v) (P20) and 25% pentanol/75% diesel fuel blend (v/v) (P25). Some blends properties are shown in Table 2. Kinematic viscosity (ν) was measured with a Cannon-Fenske viscometer, flash point (*FP*) was measured with a closed cup Penski–Martens tester, cold filter plugging point (*CFPP*) was measured with an ISL device, density (ρ) was measured with a Proton hydrometer and higher heating value (*HHV*) was evaluated with an IKA C-200 calorimeter.

2.2. Test equipment

The fuel tests were performed in a 2500-cm^3 capacity, three-cylinder, four-stroke, water-cooled, 18.5:1 compression ratio, direct-injection diesel engine (Perkins model AD 3-152). The maximum torque was 162.8 Nm at 1300 rpm and the maximum engine power was 34 kW at 2250 rpm (DIN 6270-A). The engine was not

Table 1
Fuel properties[a] of diesel fuel, methanol, ethanol and pentanol.

Properties	Diesel fuel	Methanol	Ethanol	Pentanol
Chemical formula	$C_{14.342}H_{24.75}$	CH_3OH	C_2H_5OH	$C_5H_{11}OH$
Molecular weight (g/mol)	197.21	32.04	46.07	88.15
Oxygen (wt%)	0	49.93	34.73	18.15
Density (kg/m^3)	837	791.3	789.4	814.8
Boiling point (°C)	210–235	65	79	138
ST (°C)	254	385	363	300
LHV (MJ/kg)	42.65	20.08	26.83	32.16
VLH (kJ/kg)	375	1162.64	918.42	308.05
CN	45–50	2	11	20

[a] Data have been taken from Refs. [3,21,26,29,30].