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The effect of the alcohol content in the fuel mixture on the performance and emissions of a direct injection diesel engine fueled with diesel-methanol and diesel-ethanol blends

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ABSTRACT

The study presents experimental examinations of a single-cylinder stationary diesel engine fueled with diesel-methanol and diesel-ethanol blends. Volume percent of alcohol in the blends ranged from 0 to 40%. The addition and the increase in the methanol content of up to 30% in diesel-methanol blends had a positive effect on thermal efficiency of the engine whereas no significant changes were found in the values of indicated mean effective pressure. Moreover this increase led to a substantial reduction in carbon monoxide emissions and did show a significant effect on emissions of hydrocarbons and carbon dioxide. Further increase in volume percent of methanol of over 30% caused disturbances in the combustion process, a substantial decline in in-cylinder pressure and unsteady engine work. In the case of the diesel-ethanol blends, the improved work of the test engine was observed for all alcohol content values. Engine efficiency increased while maintaining the constant level of indicated mean effective pressure. CO emissions were reduced, whereas THC and CO_2 emissions remained virtually unchanged. Addition of alcohol had a negative effect on nitrogen oxides emissions from the engine fueled with both diesel-methanol and diesel-ethanol blends. After exceeding the 30% content of alcohol, the work non-repeatability reflected by the COV_{IMEP} coefficient increased to over 10%, which can be considered as a limit of steady work of the combustion engine.

1. Introduction

The development of modern combustion engines is oriented mainly towards searching for replacement fuels which offer the alternative to fossil fuels, such as petroleum or natural gas used commonly to fuel engines [1–3]. This problem has been explored in many research centers all over the world. The studies have focused on both automotive engines and stationary engines used to drive electric generators. The latter are more and more often construed as cogeneration systems to generate electricity and useful heat at the same time [4–6]. Combined with modern systems for control of the combustion process, the use of new alternative fuels should lead to lower emissions of harmful exhaust components while maintaining improved functional parameters of the engine [7–10]. Among the alternative fuels, more and more attention has been attached to biofuels, which can be obtained from renewable sources of energy, such as biomass, derived from both plants and animal matter. Many studies have shown that combustion of biofuels is likely to reduce concentration of toxic compounds in engine exhaust, particularly nitrogen oxide, and carbon dioxide that leads to the greenhouse effect [11,12]. Another liquid biofuels that are gaining in importance as engine fuels are alcohols, such as methanol, ethanol, propanol and butanol [13]. Although alcohols do not seem to be ideal fuels due to the substantial oxygen content (for example, oxygen contributes to half of the molecular mass of methanol CH_3OH) and low heating value, the interest in alcohols as replacement engine fuels has been observed compared to conventional fuels [14]. Alcohol-based fuels are increasingly popular in spark-ignition engines, whereas their use in diesel engines is nearly not observed, mainly due to low value of cetane number and problems with compression ignition [15]. The explorations concerning the use of alcohol-based fuels in diesel engines are justifiable since these engines, compared to spark-ignition engines, offer an array of benefits. The most important advantages include greater reliability, fuel savings, greater power range, longer life, faster response to power demand, greater torque, enhanced power profiles and lower prices of diesel fuel [16]. The alcohols that have been most frequently used to fuel engines include methyl alcohol (methanol) and ethyl alcohol (ethanol), mainly due to relatively low costs of manufacturing and easy

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Nomenclature

NO_x	nitrogen oxides
HC	hydrocarbons
CO	carbon monoxide
CO_2	carbon dioxide
TDC	top dead centre
IMEP	indicated mean effective pressure, bar
HRR	heat release rate, J/deg
ITE	indicated thermal efficiency, %
COV_{IMEP}	coefficient of variation in indicated mean effective pressure, %
STD_{IMEP}	standard deviation of the IMEP, bar
LHV	lower heating value, MJ/kg
ID	ignition delay, deg
BD	burn duration, deg
V_d	displaced cylinder volume, cm^3
T	temperature, K
p	pressure, bar
n	engine speed, rpm

Greek letters

φ	crank angle, deg
λ	excess air ratio
ρ	density, kg/m^3
δ	error of measurement
Δ	uncertainty of result

production processes. Methanol can be manufactured on the industrial scale from broadly available resources, including both non-renewable (natural gas, coal) and renewable (gas generated from biomass or municipal waste) sources. Ethanol is typically obtained during alcohol fermentation of sugars, with sugar sources being mainly cereals (wheat, maize, barley, sorghum) and potatoes or agave [17]. In recent years, alcoholic fuels have been widely used in compression ignition engines that use two-fuel systems for combined combustion of alcohol and diesel. Effective combustion of alcohol-based fuels in diesel engines is possible only for fuels with low autoignition temperature and high cetane number i.e. a blend that offers good conditions for compression ignition. This type of combustion is possible in the engines that use two-fuel systems for combined combustion of alcohol and diesel. Alcohol-based fuel for two-fuel engines operating in a Diesel cycle can be supplied in several ways. The most popular method is injection of liquid alcohol to the manifold near the inlet valve [18–20] and direct injection of the alcohol-diesel blend to the cylinder, prepared in the engine supply system [21–24]. Recent years have seen the research on opportunities to use alcohol-based fuels to fuel compression ignition engines. Oliveira et al. [25] investigated the effects of fuel blends containing 5, 10 and 15 wt.% of anhydrous ethanol in diesel oil with 7% of biodiesel on performance, emissions and combustion characteristics of a diesel power generator. The engine was tested with the fuel blends directly injected into the combustion chamber, and the applied load varied from 5 to 37.5 kW. The results were compared with standard biodiesel operation, and showed that in in-cylinder peak pressure and heat release rate were decreased at low loads and increased at high loads with the use of ethanol. Increasing ethanol concentration caused increased ignition delay, decreased combustion duration and reduced exhaust gas temperature. The use of ethanol led to the reduction in carbon dioxide (CO_2) emissions, up to 8.6% lower than for biodiesel. Carbon monoxide (CO), total hydrocarbons (THC) and oxides of nitrogen (NO_x) emissions showed different behavior, depending on load and ethanol concentration. In the study [26], standard diesel fuel, biodiesel (45%) – methanol (10%) – diesel (45%), biodiesel (40%) – methanol (20%) – diesel (40%), biodiesel (45%) – ethanol (10%) – diesel (45%) and biodiesel (40%) – ethanol (20%) – diesel (40%) blends were tested in a compression ignition engine under the same operating conditions. Performance and emission characteristics of the engine fueled with biodiesel-methanol-diesel (BMD) and biodiesel-ethanol-diesel (BED) were compared to standard diesel fuel as the baseline. Overall, biodiesel-alcohol-diesel blends show higher brake specific fuel consumption than diesel. As alcohol concentrations in blends increase, CO and HC emissions increase, while NO emissions were reduced. Also, methanol blends were more effective than ethanol blends for reducing CO and HC emissions, while NO reduction is achieved by ethanol blends. Al-Hassan et al. [27] performed an experimental investigation on the effects of using of diesel-ethanol (DE) and diesel-biodiesel-ethanol DBE blends including ethanol of various proportions on CI engine performance. The experimental results of the engine performance indicated that the equivalence air-fuel ratio and the brake specific fuel consumption for the fuel blends are higher than that of diesel fuel and increases with the increase of the ethanol concentration in the blends. The brake power for the fuel blend of 5% ethanol concentration is close to that of diesel fuel and decreases with higher concentrations. The brake thermal efficiency was increased with fuel blends of 5 and 10% ethanol concentration and decreases with a higher ethanol proportion in the blends. Ferreira et al. [28] used the fumigation method in which they carried out the injection of alcohol into the air intake. These researchers showed the performance and emissions profile of a diesel engine operating with ethanol injected into the air of the inlet manifold in time with the high-pressure injection of a diesel-biodiesel blend. The high-pressure injection fuel was always a binary blend of diesel and biodiesel, which was supplemented by injected ethanol, producing 5 different fuel compositions. The addition of ethanol led to a reduction in diesel fuel consumption, although the overall energy expenditure was increased. The emissions profile showed a consistent reduction in NO_x emissions and opacity with the addition of ethanol, but an increase was found for CO and THC emissions. The energy analysis showed a decrease in engine efficiency with addition of ethanol. A significant decline was observed in the air intake temperature for the use of ethanol, suggesting that part of the reduction in NO_x may be attributed to this temperature reduction. It was demonstrated that the ethanol addition can be an important method to reduce the amount of NO_x in the exhaust from diesel engines. The aim of the study [29] was to evaluate the performance and emissions of high proportion of methanol and propanol (20% by volume) in a B30 blend and conventional diesel when operating on a direct injection diesel engine. The experiments were conducted from 1200 rpm to 2600 rpm with the intervals of 200 rpm at full load conditions for seven types of blends. The results revealed lower brake power for B30M15P5 and B30M17P3 test fuels. However, an increase in brake specific fuel consumption (BSFC) of 31.12% and 34.01% was found when the engine was fueled with B30M15P5 and B30M17P3, respectively. It was concluded that NO_x emissions decreased up to 32.4% and 27.9% for B30M10P10 and B30M15P5, respectively at 2000 rpm in comparison with biodiesel. Balamurugan and Nalini [30] performed experimental investigations aimed to enhance the performance of a