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The Experimental Investigation of the Effect of Methanol and Dodecanol Additives to Diesel Fuel on Engine Performance and Smoke Emissions in a CI Engine

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Abstract

In the experimental study, the effects of diesel-methanol-dodecanol blends on engine performance and smoke emission in a single-cylinder, four-stroke, water-cooled, normally aspirated compression ignition engine were investigated. Fuel blend ratios in the study; Diesel (D100), diesel-methanol (D90M10) and diesel-methanol-dodecanol (D89M10D1) were used. In order to solve the phase separation problem in the diesel-methanol blend, 1% by volume of dodecanol was added. The test engine was operated at four different loads (6, 12, 18 and 24 Nm) and constant engine speed (1800 rpm). The performance parameters such as brake specific fuel consumption, brake specific energy consumption and brake effective efficiency for each blend at various engine loads are calculated based on the experimental data. The results indicated that in low load conditions, the specific fuel consumption increased by maximum 8.4% with the addition of methanol to the diesel fuel, while this rate decreased to 3.7% with the addition of dodecanol. By adding dodecanol to the methanol-diesel mixture, minimum smoke opacity was obtained at low and high loads, respectively, at 32.72% and 53.75%.

Keywords: Dodecanol; Methanol; Performance; Smoke

Research Article

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1. Introduction

CI engines are greatly used in heavy vehicles, marine transportation vehicles, thermoelectric power plants and carriage due to their high efficiency, usability, and endurance (1, 2). As a consequence of this widespread use, the harmful exhaust emissions produced by compression ignition engines increase their impact on the environment and human healthiness, and this situation is of great concern (3, 4). Reducing harmful exhaust emissions, increasing thermal efficiency, and improving fuel consumption in compression ignition engines are among the hot research topics of today (5, 6). The heavy exhaust emission standards applied worldwide, and the limited reserves of fossil fuels also force these issues to research (7, 8).

One of the most important problems of compression ignition engines is NO_x and particulate matter emissions resulting from combustion. It is known that there is an equilibrium relationship between these two emissions (9, 10). The most important proof of this balance relationship can be shown that it is tough to improve NO_x and smoke emissions synchronically (11, 12). However, low temperature combustion (13-15), dual fuel mode trials with alcohols such as methanol (16), ethanol (17), n-butanol (18) are of great interest in an effort to improve NO_x and smoke emissions synchronous.

Methanol is a simple hydrocarbon that contains high amounts of oxygen in its structure, and can be obtained from resources such as coal, lignite, and from sustainable, unlimited reserves of biomass resources (19-23). Recently, tons of methanol have been used directly or as a blend in both the energy field and automotive R&D centers (24, 25). The use of methanol is increasing day by day. Methanol, which has a high octane number, allows it to work more efficiently in CI engines. Thanks to its low boiling temperature feature, it provides a better fuel evaporation in cold operating conditions. Another feature of methanol is its high evaporation temperature. This feature causes the combustion pressure and temperature to decrease. However, the high evaporation temperature brings with it low emission characteristics. Methanol has been the subject of many research and development studies due to both its chemical and physical properties and its easy production (24).

Methanol as an engine fuel is used in various methods such as addition, blends, dual fuel mode, fumigation, and emulsification in compression ignition engines (26, 27). Its use as a blend or as an additive makes it challenge to use in CI engines owing to the lean solubility of methanol in diesel. The low dissolvability is because the hydroxyl in methanol makes the dipole moment more polar. This reduces the top limit of petroleum-alcohol mixtures without the utilise of a co-diluent (28). Sayin et al. (29) investigated the impression of methanol-diesel mixtures on engine performance and emissions. They reported a derogation in engine performance and an improvement in CO, HC and smoke emissions with the adjunct of methanol to diesel fuel. Bayraktar (22) studied on a methanol-dodecanol-diesel ternany blends in a single-cylinder CI engine. The study was carried out at particular CR (19:1, 21:1, 23:1, and 25:1) and methanol ratios varying from 2.5% to 15%. He reported that 10% methanol-diesel blend improved engine performance by about 7%. Yilmaz and Donaldson (30) reported that the usage of methanol as fuel in a CI engine causes high emissions and poor performance characteristic by virtue of engine oil subtilization with fuel. Çanakçı et al. (31) investigated the effect of methanol-diesel mixtures varying from 0% to 15% by volume on the performance and emission characteristics in their experimental study. They reported that the performance characteristics deteriorated by means of the increase of methanol addition in the blend. They also reported that CO and HC emissions improved, but NO_x emissions tend to increase. The reason for this was reported the oxygen content of methanol. Jamkorzik (32) reported that the methanol-diesel mixture gave a better CO emission but increased NO_x emission. Additionally, he noted that there were no substantial changes in CO_2 and HC emissions. Huang et al. (33) observed that the methanol-diesel blends shortened the combustion duration and increased the heat release rate. Agarwal et al (34) studied the effect of a low proportion of methanol-diesel blend (MD5) on irregular emissions. They observed that the addition of 5% methanol to diesel did not have a significant effect on irregular emissions. Li et al. (35) conducted an experimental study on different alcohol mixtures in a spark ignition engine. In the study, methanol, ethanol and butanol fuels were used at different load and equivalence ratios. The effects of mixtures on engine emissions and performance characteristics were investigated. It has been stated that an improvement in emissions with alcohol use has been observed. Chao et al. (36) studied methanol - diesel blends (0, 5, 8, 10 and 15% v/v) in a heavy-duty CI engine. They observed that the adjunct of methanol sparked off higher carbonyl emissions, irregular emissions such as benzaldehyde and acrolein. Wei et al. (37) studied the effect of methanol-mineral diesel blends on unregulated and regulated emissions. They reported that increasing the methanol addition by up to 30% (v/v) improved HC, CO, and NO_x emissions, but there was no change on unregulated emissions. The methanol-mineral diesel blends shorten the combustion duration and increases the HRR. Exhaust gas recirculation (EGR) and compression ratio (CR) affected engine performance as well as NO_x, HC and CO emissions (38). When the literature is examined, it has been observed that the in-cylinder temperature can be reduced by adding methanol to diesel. The main reason for this has been shown to be the low calorific value of methanol (39).

In compression ignition engines, the extremely unstable combustion and the formation of rich mixing zones are the biggest reasons for smoke emission formation (40). According to the researches, smoke emissions affect both the environment and human health negatively. It is stated that it has effects on humans such as headache, chronic respiratory, allergic diseases, cancer, growth retardation in infants (41). In this study, ways to improve the smoke emission from compression ignition engines with the addition of methanol and dodecanol were investigated. In addition, the effects of diesel, diesel-methanol and diesel-methanol-dodecanol blends (two-fuel mixture methanol (10% v/v)) on engine performance were also investigated. Studies with each fuel were compared with each other. The experiments were carried out at part loads and constant speed.

2. Experimental setup and procedure

2.1 Experimental setup

All studies were carried out on a single cylinder, water-cooled, normally aspirated, direct injection CI engine that was made by Anadolu Motor. The technical characteristics of the test engine are presented in Table 1.

Table 1. Technical characteristics of the test engine.

Model		**3LD510**
Cylinder volume		510 cm^3
Bore x Stroke x Compression ratio		85 mm x 90 mm x 17,5:1
Max engine speed (rpm)		3000
Max power-BG (kW)	N (DIN 70020)	NA (DIN 6271)
	NB (DIN 6271)	10,0 (7,3) @ 3000
	NA (DIN 6271)	9,0 (6,6) @ 3000
Max. torque - N-m @ rpm		32,8 @ 1800

Engine performance and smoke emission tests were carried through at the thesis center of Karamanoğlu Mehmetbey University, Vocational School of Technical Sciences. In Figure 1, the test center used during the experiments is presented. The experimental setup schematic view is submitted in figure 2.

Fig. 1. The test center used during the experiments

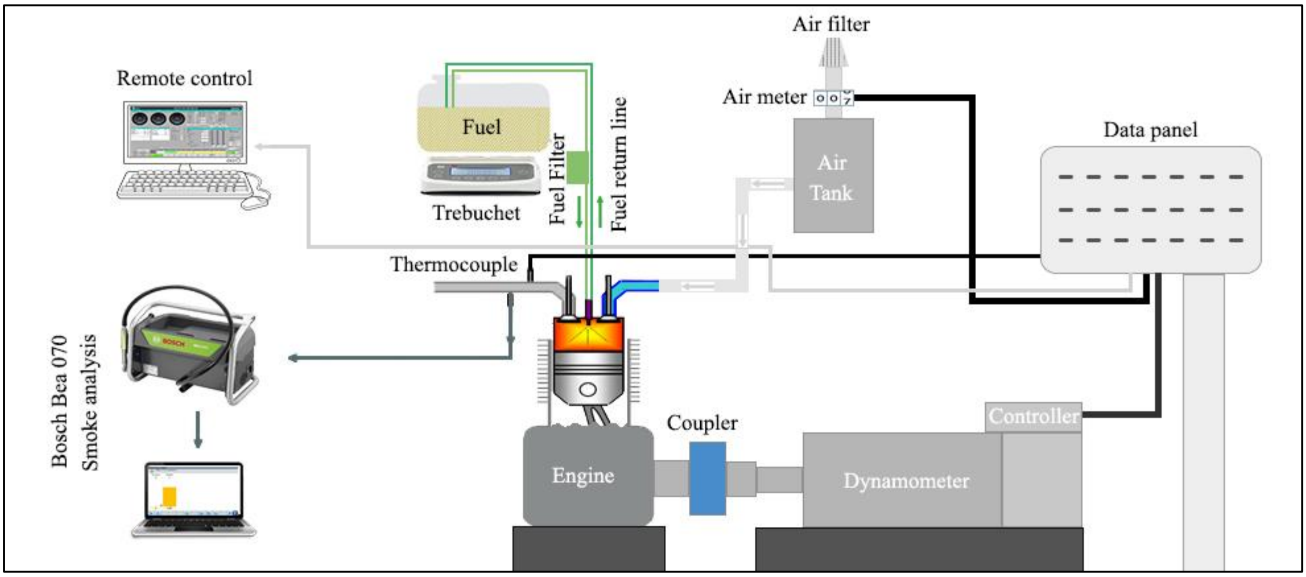

Fig. 2. Experimental setup

2.2 Procedure

In the experiments, commercial diesel was procured from a liquid fuel station as the main fuel. The methanol and dodecanol was supplied from a local company that sells chemical substances. Diesel, methanol-diesel, and methanol-dodecanol-diesel blends were adjusted in graduated measuring cups under normal conditions. The Physical and chemical characteristics of diesel, methanol, and dodecanol used in the experiments are presented in Table 2.

Table 2. Properties of diesel (42), methanol (43) and dodecanol (22)

Fuel Properties	Diesel	Methanol	Dodecanol
Chemical structure	$C_{12.19}H_{23.39}$	CH_3OH	$C_{12}H_{26}O$
Density (kg/m^3)	820-840	795	830
Low heat value (MJ/kg)	42-43	20.26	39.86
Heat vaporization (kJ/kg)	270-375	1160	-
Cetane number	50-53	3	-
Stoichiometric air–fuel ratio	14.58	6.5	13.4
Oxygen content (%) by weight	0%	50%	8.6%

The volumetric ratios of the fuel blends used in the experimental study are presented in Table 3. Diesel-methanol and Diesel–methanol–dodecanol blends have been equipped by mixing methanol having a naivete of 99.5% in proportion of 10% (by volume) and have been directly injected into the combustion chamber. Dodecanol of 1% (by volume) was put in diesel-methanol blend to obtain more stabilized mixture.

Table 3. The volumetric ratios of the fuel blends

Test Fuels	Volumetric ratio (%, v/v)		
	Diesel	Methanol	1-dodecanol
D100	100	-	-
D90M10	90	10	-
D89M10D1	89	10	1

In an effort to load the engine, the engine output shaft is coupled to the rotor of the electric dynamometer. The technical characteristics of the electric dynamometer are submitted in table 4.

Table 4. The technical characteristics of the electric dynamometer

Model	ABB
Nominal Power (kW)	49.3
Nominal Torque (Nm)	157
Max. Speed (rpm)	7500
Efficiency (%)	93.6

A stopwatch and assay balance were used to measure fuel consumption. BOSCH BEA 070 model exhaust emission device was used to determine the smoke emission in the experiments. The measuring range of the emission device is (0-100%) and the sensitivity is 0.1% by volume. Engine performance and smoke emission parameters have been comparatively determined when using diesel, diesel-methanol and diesel-methanol-dodecanol blends.

3. Results

This experimental study was carried through at maximum engine torque speed (1800 rpm) and part loads (6, 12, 18 and 24 Nm). Before obtaining data for each experiment, the engine was operated for a while till the coolant temperature, lubricating oil temperature, and exhaust gas temperature stabilized.

3.1. Brake specific fuel consumption (BSFC)

Figure 3 depicts the variation in BSFC for various engine loads in all test fuels. When figure 3 is examined, it is seen that BSFC for three different fuels decreases as the engine load increases. Maximum BSFC for D100, D90M10 and D89M10D1 fuels was 345,133 g/kWh, 352.179 g/kWh and 349.55 g/kWh, respectively, at 6 Nm load. The minimum BSFC for D100, D90M10 and D89M10D1 fuels was obtained as 224.1 g/kWh, 242.945 g/kWh and 232.372 g/kWh, respectively, at 24 Nm load. The lower calorific value of methanol compared to diesel can be shown as one of the causes for higher fuel consumption. Because more fuel input must be given in order to maintain the energy procured by diesel fuel. Augment of 1% dodecanol to the methanol-diesel blend provided some improvement in BSFC.

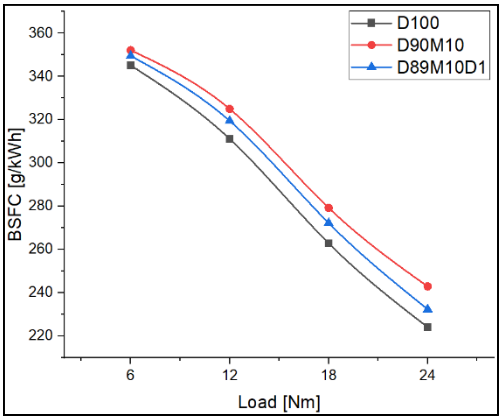

Fig. 3. BSFC of D100, D90M10 and D89M10D1 fueled engine at different engine loads

3.2. Brake thermal efficiency (BTE)

BTE could be calculated based upon the braking power and consumption rate of the fuel sent into the cylinder. BTEs according to variable loads for each fuel blend are presented in figure 4.

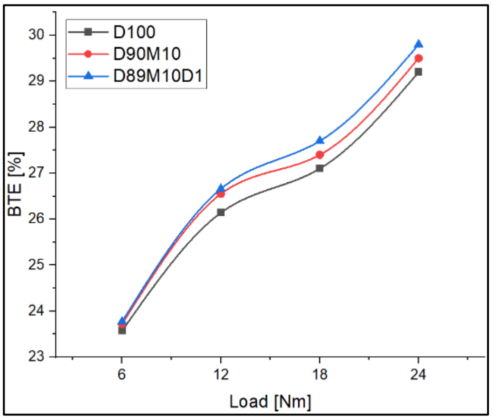

Fig. 4. BTE of D100, D90M10 and D89M10D1 fueled engine at different engine load

It was determined that BTE values depicted an increasing trend with increasing engine load for three fuels. On the other hand, at all loads, BTE increased mildly with the addition of 1% dodecanol to methanol. Jamrozik (32), Huang et al. (33), Bayraktar (22) and Agarwal et al. (44) obtained similar results for BTE. The high latent heat of evaporation of methanol and dodecanol additives is very effective in reducing the in-cylinder temperature. This causes ignition delay, sudden combustion of unburned air/fuel mixture, high flame velocity and short combustion phase. Therefore, it can be said that they are effective on the increase in BTE. In addition, it can be said that the oxygen presence of methanol and dodecanol additives is also effective on BTE(44).

3.3. Brake specific energy consumption (BSEC)

BSEC is an indication of efficiency of attaining energy from the fuel to generate unit power. BSEC is obtained by multiplying the BSFC with the calorific value. BSEC is a more certain measure than BSFC for comparing fuels which have different calorific values (45). Figure 5 depicts the variation in BSEC for various engine loads in all test fuels. The BSEC values of methanol-diesel and methanol-dodecanol-diesel blends are lower than diesel. It is obtained that BSEC of both the methanol and methanol-dodecanol test fuels were nearly similar.

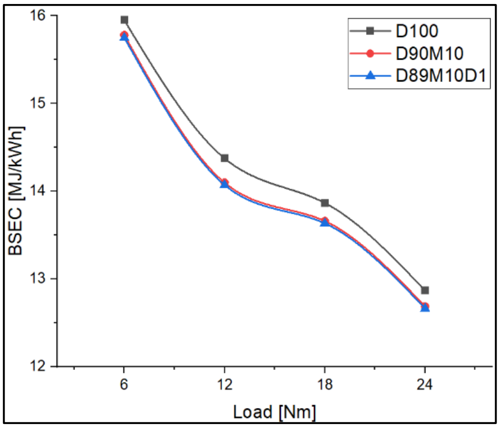

Fig. 5. BSEC of D100, D90M10 and D89M10D1 fueled engine at different engine loads

3.4. Exhaust gas temperature (EGT)

Figure 6 presents the variations in EGT for D100, D90M10 and D89M10D1 fuel blends according to the various engine loads. It was determined that EGT worths indicated an increasing trend with increasing engine load for all blends. Maximum EGT was obtained as 397.3 ºC, 390.9 ºC and 395.9 ºC for D100, D90M10 and D89M10D1, respectively at 24 Nm. Among all fuel blends at variable loads, commercial diesel fueled engine ended up higher EGT as regards D90M10 and D89M10D1. It can be said that the reason for this is that diesel has a lower latent heat of evaporation compared to methanol and dodecanol. Similar results are acquired in Agarwal et al (44).

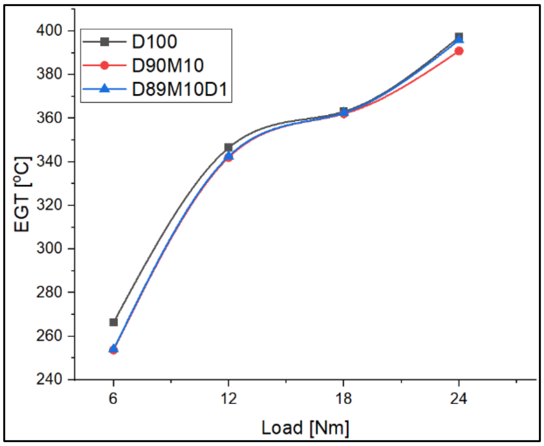

Fig. 6. EGT of D100, D90M10 and D89M10D1 fueled engine at different engine loads

3.5. Smoke Opacity

Figure 7 depicts the variation in smoke opacity for various engine loads in all test fuels. Smoke opacity tended to increase for all test fuels as engine load increased. Maximum smoke opacity was achieved at 24 Nm for all fuels. Smoke opacity of D100, D90M10 and D89M10D1 fuels at 24 Nm are respectively 54.7%, 38.6% and 25.3%. Minimum smoke opacity at 6 Nm and 24 Nm was achieved with D89M10D1 fuel. D89M10D1 blend, compared to diesel, an improvement of 33.72% and 53.75%, respectively, was observed. It can be said that the addition of methanol and dodecanol to diesel significantly reduces smoke opacity.

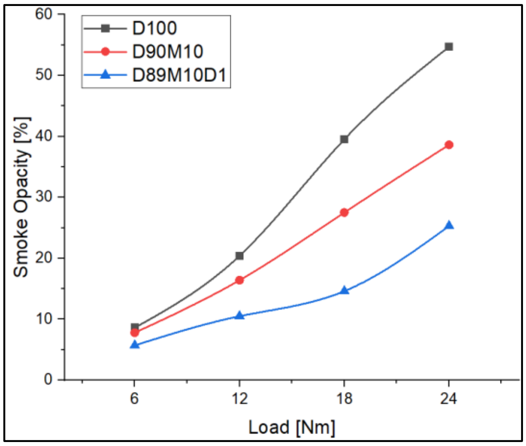

Fig. 7. Smoke emissions of D100, D90M10 and D89M10D1 fueled engine at different engine loads

4. Conclusions

In this experimental study, the effects of methanol and dodecanol addition on engine performance and smoke emission in a single cylinder, four stroke, water cooled, normally aspirated, diesel fueled CI engine were investigated. The study was conducted at constant maximum engine torque speed and part loads for all test fuels. Diesel, diesel-methanol and diesel-methanol-dodecanol mixtures were used as test fuel. Methanol was added at 10% by volume, while dodecanol was added at 1%.

Among all test fuels used in the study, the D89M10D1 showed a better BTE and a lower BSEC compared to other fuels. Compared to diesel, methanol-diesel and methanol-dodecanol-diesel blends exhibited lower smoke emission characteristics. The lowest smoke emission was obtained by adding 1% dodecanol to methanol. The fact that the addition of dodecanol reduces the phase problem in the methanol-diesel blends can be shown as one of the most important factors in this improvement. In addition, the high oxygen content and high specific heat capacity of methanol may have contributed to its lower smoke emission.

Additions of both methanol and methanol-dodecanol to diesel showed an increase in BSFC. The lower calorific value of methanol-diesel and methanol-dodecanol-diesel mixtures compared to diesel can be shown as one of the most important reasons for the increase in BSFC. The total energy provided by diesel fuel is desired to be conserved by blended fuels. This causes more fuel consumption.

In general, this experimental study showed that an acceptable engine performance and smoke opacity were obtained with the addition of additives (methanol and dodecanol). With the addition of 1% dodecanol by volume, it showed better smoke opacity characteristics compared to both diesel and methanol-diesel mixtures. Addition of 1% dodecanol to diesel-methanol mixtures in compression ignition engines was found to be a suitable mixture.

Abbreviations

BSEC	: Break specific energy consumption
BSFC	: Break specific fuel consumption
BTE	: Break thermal efficiency
CI	: Compression ignition
CO	: Carbon monoxide
CR	: Compression ratio
D100	: Diesel 100%
D90M10	: Diesel 90%+Methanol 10%
D90M10D1	: Diesel 89%+Methanol 10%+Dodecanol 1%
EGR	: Exhaust gas recirculation
EGT	: Exhaust gas temperature
HC	: Hydrocarbon
NO_x	: Nitrogen oxide
PM	: Particulate matter
R&D	: Research and development

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the present paper.

CRediT Author Statement

Halil Erdi Gülcan: Writing - Original draft, Investigation, Visualization, Methodology,
Nurullah Gültekin: Investigation, Methodology, Writing,
Murat Ciniviz: Investigation, Supervision.

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