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Experimental Research with Diethyl Ether on Engine Performance and Emissions in a Spark Ignition Engine

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Abstract

In this study, the influences of the diethyl ether addition into pure gasoline were researched experimentally in a single cylinder, four stroke, air-cooled spark ignition engine. Experiments were conducted at wide-open throttle and different engine speeds of 2400, 2800, 3200, 3600 and 4000 rpm. The effects of diethyl ether as an additive on engine torque, specific fuel consumption (SFC), thermal efficiency, CO, CO_2 and HC emissions were observed. Test results presented that engine torque and power first increased and then decreased with the addition of diethyl ether. SFC increased by about 4.18%, 7.44%, 11.39% and 14.41% with DEE10, DEE20, DEE30 and DEE40 compared to pure gasoline at 2800 rpm respectively. Remarkable reduction were observed on CO and HC emissions with the addition of diethyl ether into gasoline. CO was reduced by 0.67%, 3.39%, 10.61% and 11.11% with DEE10, DEE20, DEE30 and DEE40 compared to gasoline at 4000 rpm respectively. Similarly, HC decreased by 3.70%, 8.82% and 10.58% with DEE20, DEE30 and DEE40 compared to gasoline at 4000 rpm respectively. Diethyl ether presented positive and satisfying results in view of exhaust emission compared to pure gasoline. However, it was found that thermal efficiency decreased and specific fuel consumption increased with diethyl ether addition. In addition, it was seen that diethyl ether can be used as an additive without modification in spark ignition engines.

Keywords: Engine performance, Emission, Diethyl ether, Spark ignition engine

Research Article

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1. Introduction

Researchers have focused on alternative fuels owing to depletion of oil reserves and harmful exhaust emission produced by motored vehicles. Diesel engines that are commonly used in transportation on heavy-duty trucks present higher thermal efficiency according to spark ignition (SI) engines with better fuel economy. However, they emit higher amount of exhaust emissions according to spark ignition engines. In addition, NO_x and soot emissions could not be decreased together in diesel engines. On the other side, spark ignition engines have advantages due to lower exhaust emissions and better operating in cold start conditions compared to diesel engines in spite of lower thermal efficiency due to lower compression ratio. These phenomena can be improved by using fuel additives in spark ignition engines [1-6]. Diethyl ether (DEE) has good attraction to overcome these difficulties in spark ignition engines. DEE is referred as renewable biomass, which produced from ethanol [5-11]. It is also oxygenated fuel that has capability of improving oxidation reactions during combustion [1-5]. Easy vaporization characteristic and lower auto ignition temperature properties of DEE present advantages in view of usage as fuel additive [1-3]. DEE is non-corrosive and can be easily used with conventional fuels since it is in liquid form [2,3]. DEE can take a role as an ignition improver resulting in higher thermal efficiency [12,13]. Balaji et al. [14] analyzed the combustion of DEE-ethanol-gasoline fuel mixtures. They have found that CO, HC and NO_x decreased whereas CO_2 increased. Kumar et al. [15] discussed the influences of inlet air temperature in a gasoline engine fueled with DEE/gasoline mixtures (3%, 6% and 9% DEE). They stated that HC reduced by about 57% with 6% DEE test fuel. It was also found that CO decreased at lower inlet air temperature. Tilaki et al., [16] prepared gasoline/methanol and gasoline/ethanol fuel blends in order to test in a spark ignition engine. Less pollutant were realized with gasoline/methanol compared to gasoline/ethanol fuel mixtures at low engine speed. It was proved that methanol was more convenient fuel in view of lower exhaust emissions. Sezer [1] mixed DEE at the ratio of 2.5%, 5%, 7.5% and 10% with pure diesel and experimented in a diesel engine. Indicated mean effective pressure (imep), engine torque and effective power declined when DEE/diesel fuel blends were used. He found maximum increase by 10.9% on effective efficiency with DEE7,5 test fuel. In another study [7], Sezer researched the influences of ethanol and DEE into pure diesel on performance and emissions. Experiments showed that fuel blends caused to decrease injection pressure. DEE fuel blends caused to retard on injection timing. Besides, he noticed that in cylinder pressure and temperature declined with fuel blends. Polat et al,. [11] aimed to control the HCCI combustion phasing via using fusel oil and DEE. They realized that in cylinder pressure and heat release were advanced with the rise of DEE rate in the fuel mixtures. In addition, operating range was expanded with the rise of DEE rate. It was also determined that DEE40 presented lower HC and CO by about 41.6% and 56.2% respectively. They have also implied that DEE60 delivered the highest thermal efficiency as 42.5%. Ibrahim [17] evaluated the effects diesel-DEE fuel mixtures (D85, D90, D95) in a diesel engine at 1500 rpm. He found that engine performance improved when DEE was used as an additive. When D85 test fuel was utilized, maximum BTE increased by about 7.2% and the lowest BSFC (brake specific fuel consumption) decreased by 6.7% according to diesel. Polat [18] studied the influences of DEE/ethanol fuel mixtures (E30/D70, E40/D60, E50/D50) and 100% DEE in an HCCI engine. Results demonstrated that HCCI combustion did not occur with the higher ratio of ethanol and leaner mixtures owing to higher octane number and auto ignition temperature. He showed that imep increased by 23% with E40/D60 according to E30/D70 at lambda 2 and 353 K intake air temperature. He also found that E40/670 and E30/D70 presented almost zero NO_x. Kumar and Murugesan [19] observed the effects of DEE with diesel/ nut shell biodiesel mixtures. It was seen that combustion temperature reduced owing to higher latent heat of additives. Hence, NO_x were reduced. They revealed that BTE improved with fuel additives because of better combustion characteristics. Yılmaz and Solmaz [20] researched the influences of ethanol/DEE fuel blends in view of HCCI combustion. They found that the usage of pure DEE combustion was taken to advance. On the contrary, ethanol caused to retard of SOC due to lower reactivity of the mixture. Maximum indicated thermal efficiency (ITE) was determined as 35% with the usage of 100% DEE. Ayhan and Tunca [21] researched the influences of DEE/diesel fuel blends. It was seen that torque and effective power decreased and SFC (specific fuel consumption) and effective efficiency improved with the usage of fuel mixtures. Gorski et al., [22] tested the physico-chemical characteristics of DEE/linseed oil fuel mixtures empirically. They have found that DEE provided a decrease of plant oil viscosity and density and improved the low temperature characteristics of tested oils. Fabis [23] studied the analysis of in-cylinder pressure variations in case of LPG/DME fuel combustion in internal combustion engines (ICE). He presented a method for consideration of DME (dimethyl ether) usage as a combustion activator. It was found that later combustion was seen with the increase of DME proportion independently of the engine speed. Diethyl ether is also good alternative fuel for advanced combustion modes. Chemical kinetics play significant role on low temperature combustion. Chemical properties of fuel affects the combustion phasing. As it is known, HCCI combustion suffers from misfiring at low engine loads. High reactivity and higher oxygen content of diethyl ether improve the oxidation [24-28]. Jena et al., [24] researched the influences of DEE-diesel fuel mixtures in partially premixed combustion (PPC) mode. It was found that DEE-diesel blends showed higher brake thermal efficiency than diesel in PPC mode. They have also implied that lower BSFC was found with DEE-diesel fuel blends on PPC mode compared to diesel combustion at lower brake mean effective pressure. Mohebbi et al., [25] evaluated the effects of diethyl ether addition in a reactivity controlled compression ignition (RCCI) engine fueled with ethanol and diesel. It was found that imep increased by 14% and maximum pressure rise rate (MPRR) decreased 33% with 40% diethyl ether addition into ethanol. They have also noticed that diethyl ether improved the oxidation reactions of hydrocarbons. Mack et al., [26] analyzed the influences of diethyl ether and ethanol mixtures on HCCI (Homogeneous charged compression ignition) combustion. It was presented that some fuel blends of HCCI combustion can have preferred combustion. Zapata-Mina et al., [27] investigated the HCCI engine performance fueled with diethyl ether-fusel oil fuel mixtures (D40F60, D60F40, D80F20) from exergy indicators. Results showed that the variation of lambda presented the best performance with the operation of fuel blends. It was also implied that the increase of diethyl ether addition in the fuel mixtures caused to decrease HCCI engine performance. They found the highest and lowest exergy efficiency with D40F60 and D80F20 respectively. Gurusamy and Subramanian [28] studied the influences of premixing of DEE and benzyl alcohol in a compression ignition (CI) engine fueled with pine oil diesel fuel mixture. Fuel (P50) was obtained by mixing 50% pine oil and 50% diesel volumetrically. The tests were conducted in a four stroke CI engine at different engine torque values on PCCI (premixed charge compression ignition) mode. They observed that BTE increased by about 4.5% and 8.75 % with benzyl alcohol and DEE respectively compared to P50. In addition, CO and HC increased with premixing of DEE and benzyl alcohol. However, smoke and NO_x emissions decreased with premixing of DEE and benzyl alcohol. DME (dimethyl ether) can be also utilized with diesel in CI engines. It has higher cetane number and lower auto-ignition temperature. It was tested in a CI engine on HCCI combustion mode. DME presented zero smoke and very low NO_x emissions with higher equivalence ratio on HCCI mode [29]. HCCI engine performance, emissions and combustion were modeled with diethyl ether-fusel oil blends. Optimum response variables were determined as 11.80 Nm engine torque, 268 g/kWh BSFC, 1.365 COV_{imep} [30]. Shere and Subramanian [31] investigated the effects of fuel injection timings with diesel/DME. Diesel injected into the cylinder where as DME was injected into the inlet line. It was noticed that delayed injection timing hopeful method to enhance DME energy share. Sinha et al., [32] investigated the influences of DME energy share in CI engine. They concluded that DME energy share increased from 44% to 53% with reduced compression ratio. Polat et al., [11] intended to control HCCI combustion process to extend operating range with fusel oil-diethyl ether mixtures. They have seen that the increase diethyl ether addition in the fuel blends caused to expand operating range. It was also found that imep increased by 67.5%

using DEE40 according to DEE80.

Thermal efficiency of SI engines is lower than CI engines because of the lower compression ratio. DEE is an oxygenated fuel and it has lower auto-ignition and easy vaporization characteristics. It was aimed to improve the chemical oxidation reactions with DEE addition into pure gasoline and increase engine performance. It was intended to discuss the influences of DEE in a detail in view of engine performance and exhaust emissions. So, the scope of the current research is to investigate the influences of DEE addition into gasoline on performance and exhaust emissions in a SI engine at wide-open throttle (WOT) condition with different engine speeds.

2. Material and Method

Experimental investigation was performed at Burdur Mehmet Akif Ersoy University, High Vocational School of Technical Sciences Automotive Laboratory. Fig.1. depicts the schematic view of the engine test setup. To evaluate the influences of diethyl ether addition into pure gasoline on engine performance and exhaust emissions, five engine speeds were selected. Experiments were performed at WOT condition and different engine speeds including 2400, 2800, 3200, 3600 and 4000 rpm. Torque sensor was mounted between test engine and dynamometer to measure the engine torque as seen in Fig.1. A single cylinder, SI engine was utilized to see the influences of DEE on performance and emissions. The specifications of the test engine are presented in Table 1.

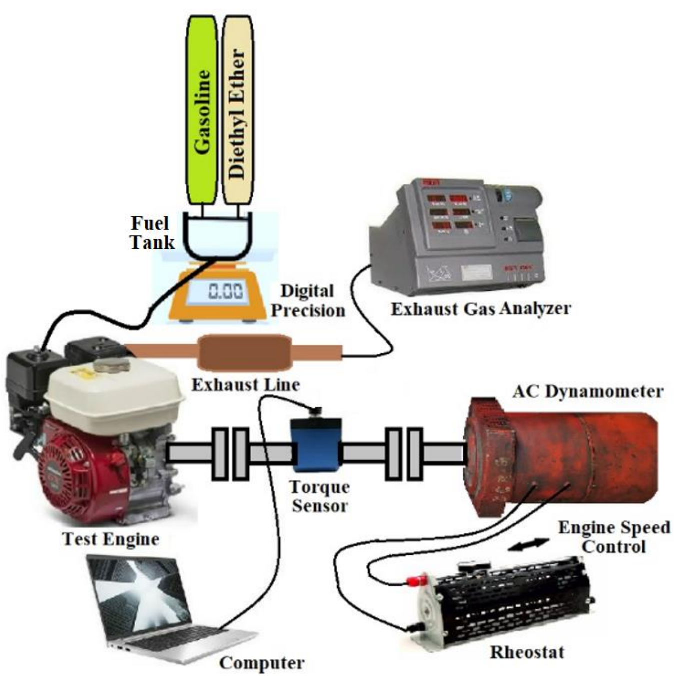

Fig. 1. Schematic view of the engine test setup

Engine oil temperature and engine block temperature were kept constant in order to enhance durability. Performance values were measured after the engine reached the operating temperature for each test stage. A single cylinder SI engine was coupled with AC dynamometer to load. When the test engine was run, dynamometer starts to generate electricity. At this point, test engine was loaded using rheostats and resistances that were connected to the circuit as seen in Fig.1. Engine load can be controlled via the changing of rheostat position. Ampere meters were also used in order to control the current flowing through the rheostat. Fuel consumption was determined with PLT Power brand digital precision that has 0.5 gr accuracy.

Table 1. Specifications of the test engine

Model	Honda GX160
Engine	Four stroke-Single cylinder
Bore x stroke [mm]	68x45
Cylinder volume [cm³]	163
Compression ratio	8.5:1
Maximum power output HP@3600rpm	5.5
Maximum Torque[Nm]@2500 rpm	10.78
Cooling system	Air-cooled

Diethyl ether was utilized as fuel additive into pure gasoline in this study. Properties of the diethyl ether and gasoline are presented in Table 2. During experiments, diethyl ether was volumetrically blended at the rate of 10, 20, 30 and 40 % with pure gasoline and test fuels have been obtained. Test fuels have been called as DEE10 (10 % diethyl ether + 90 % gasoline), DEE20 (20 %diethyl ether+ 80 % gasoline), DEE30 (30 % diethyl ether+70 % gasoline) and DEE40 (40 %diethyl ether+60 % gasoline). Pure gasoline was used as main reference fuel in the tests.

Table 2. Properties of the test fuels [1,2,11,14,17,18,21,33-37]

	Gasoline	Diethyl ether
Density [kg/m^3]	746	713.4
Calorific value [kJ/kg]	43594	33900
Latent heat of vaporization [kJ/kg]	331.6	376
Flash point [°C]	-43	-40
Octane number	96.47	14
Auto ignition temperature [°C]	257.2	160
Boiling point [°C]	30-225	34.6

Engine torque was measured instantaneously depending on the engine speed. Torque sensor was mounted between the test engine and AC dynamometer as seen in Fig.1. Torque sensor has capability to measure engine torque and engine speed. Constant torque values versus engine speed were transferred to the computer. Technical properties of the torque sensor are shown in Table 3.

Table 3. Technical properties of the torque sensor

Model	Burster 8661
Nominal supply voltage range [V DC]	10-30
Rated torque output voltage [V]	+10
Insulation resistance [MΩ]	> 5
-3 dB cutoff frequency [Hz]	200
Fluctuation [mV]	<50
Driver signal (K pin) [V DC]	10…30

Evaluation of the released emissions is also essential. CO, CO2 and HC emissions have been measured by using exhaust gas analyzer. Technical properties of the exhaust gas analyzer are presented in Table 4.

Table 4. Technical properties of the exhaust gas analyzer

	Operating range	Accuracy
CO	0- 14 %	0.001 %
HC	0- 9999 ppm	1 ppm
NO_x	0- 5000 ppm	1 ppm
CO_2	0-18 %	0.1 %
O_2	0-25 %	0.01 %
λ	0-4	0.001

2.1 Data Reduction

Engine torque was measured depending on the engine speed. Effective power can be also determined. SFC defines the fuel economy. SFC was calculated using Eq. (1).

$$SFC = \frac{m_f}{N_e} \quad (1)$$

m_f denotes the fuel consumption and N_e refers to effective power. Thermal efficiency is an indication parameter how heat energy produced by fuel is converted to net work. Thermal efficiency was determined using Eq. (2) [6].

$$\eta_T = \frac{N_e}{m_f Q_{LHV}} \quad (2)$$

Where η_T shows the thermal efficiency and Q_{LHV} defines the calorific value of the fuel [6].

3. Results and Discussion

The experiments were carried out under stable operating conditions. Uncertainty analysis was presented using Eq. (3) [19,22,38,39].

$$\Delta f = \left[\left(\frac{\partial f}{\partial x_1} \Delta x_1 \right)^2 + \left(\frac{\partial f}{\partial x_2} \Delta x_2 \right)^2 + ... + \left(\frac{\partial f}{\partial x_n} \Delta x_n \right)^2 + \right]^{1/2} \quad (3)$$

Table 5 presents the uncertainties of various measurements.

Table 5. Uncertainties of various measurements

	Accuracy	Uncertainty (%)
Fuel consumption [g]	± 0.5	± 0.16
Engine torque [Nm]	± 0.01	± 0.38
Engine power [kW]	± 0.01	± 0.13

The change of engine torque is seen in Fig.2. Maximum torque was observed at 2400 rpm for each test fuel. Engine torque decreased with the rise of engine speed. Gas leakages increases at high engine speeds resulting in lower engine torque. Engine torque increased with the addition of diethyl ether except for DEE40. DEE40 gave the lowest torque value among the test fuels. High amount of diethyl ether addition decreased the torque because of the lower calorific value and density of diethyl ether. Released heat energy declined with the higher ratio of diethyl ether in the fuel mixtures. Engine torque decreased by about 1.91% at 2400 rpm with DEE40 according to pure gasoline. It should be also said that more oxygen content of DEE supported to obtain higher engine torque due to improving of oxidation reactions. However, high rate of DEE addition resulted in lower engine torque owing to lower heating value. Polat et al., [11] found that imep decreased at high engine speeds at a specific lambda value with DEE40. It can be said that force exerted on the piston decreases with DEE40. It was mentioned that the increase of DEE addition in the fuel blends caused to disappear misfire problem with leaner mixtures in an HCCI engine. They have also implied that imep decreased with the increase of DEE addition in the fuel mixtures. Rate of pressure rise rate decreased from 5.08 bar/°CA to 3.1 bar/°CA with diesel and optimum 52% DME ES (energy share) respectively in a dual fuel CRDI CI engine [31]. In the work of Ardebili et al., [30], engine torque decreased with DEE addition from 40% to 70% ratio. However, it was seen that engine torque increased after 70% DEE ratio on HCCI combustion. In another work [29], imep increased with the increase of equivalence ratio with DME on HCCI combustion at 1400 rpm. In [28], the addition of DEE caused to slight increase on cylinder pressure. It was also found that ignition delay decreased with DEE compared to P50 on PCCI mode.

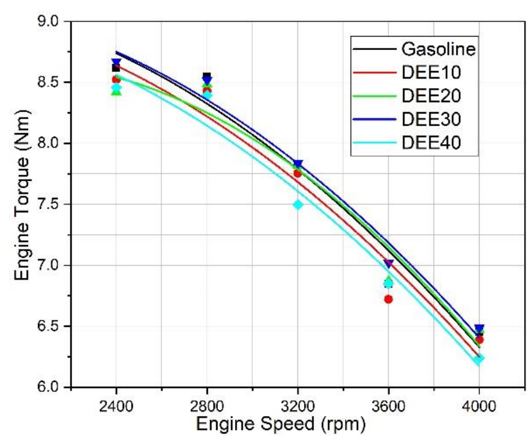

Fig. 2. The change of engine torque

Power output increases with the increase of engine speed. Fig. 3. shows the influences of DEE on engine power output. Maximum effective power was calculated at 4000 rpm for all test fuels. Power output first increased and then declined with DEE addition into pure gasoline. Calorific value of DEE is less than gasoline. So, the heating value of fuel mixtures decreases with the rise of DEE-addition. Maximum power output was computed at 4000 rpm for all test fuels. Minimum power output was calculated with DEE40. On the contrary, DEE30 delivered the highest power output between the test fuels. Power output decreased by 3.36% with DEE40 compared to gasoline at 4000 rpm. Zapata-Mina et al., [27] showed that power output increased with the increase of engine speed on HCCI combustion. They have also found that the increase of DEE in the fuel mixtures caused to decrease maximum power output. Ayhan and Tunca [21] observed the decrease of DEE-diesel fuel mixtures on effective power in a direct injection diesel engine. It was claimed that lower heating value of DEE caused to decrease effective power. Ibrahim [17] showed the variations of specific heat ratio versus engine indicated power with DEE-diesel fuel mixtures in a diesel engine. It was found that specific heat ratio decreased with the increase of engine indicated power. Polat et al., [11] observed the increase of MPRR with the increase of DEE in an HCCI engine. They explained that higher in-cylinder pressure was obtained in a shorter time with fuel blends. It can be said that higher cetane number and lower auto-ignition temperature of DEE caused to obtain higher MPRR.

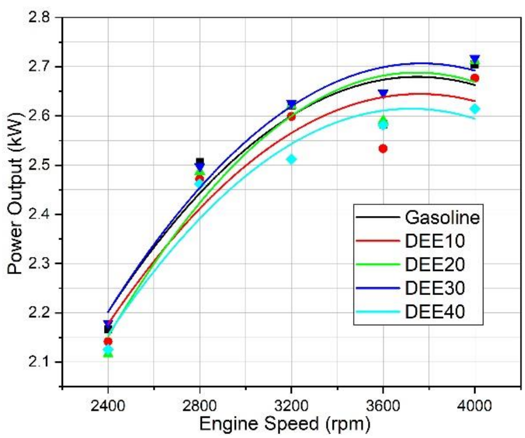

Fig. 3. The influences of DEE on power output

Fig.4. depicts the influences of SFC using test fuels. SFC is one of the most significant performance indication in the internal combustion engines. At low and high engine speeds, effective power decreases owing to mechanical losses and insufficient oxygen that is needed for complete combustion. So, SFC increases at low and high engine speeds as shown in Fig.4. Minimum SFC values were obtained at 2800 rpm for test fuels. It is obvious to mention that the increase of DEE addition caused to increase SFC as given in Fig.4. The highest SFC was computed with DEE40. SFC increased by about 4.18%, 7.44%, 11.39% and 14.41% with DEE10, DEE20, DEE30 and DEE40 compared to pure gasoline at 2800 rpm respectively. Lower calorific energy and higher density of diethyl ether causes to obtain higher SFC, because more fuel energy is needed to obtain same power output with diethyl ether/gasoline fuel blends.

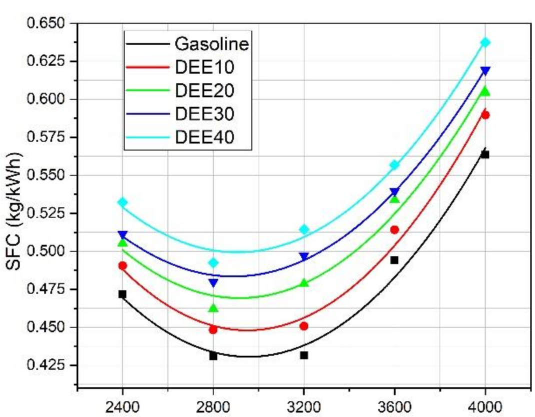

Fig. 4. The influences of DEE on SFC versus engine speed

Sezer [1] found that SFC decreased until DEE 7.5 test fuel. But, SFC increased with DEE10. Balaji et al., [14] concluded that fuel consumption increased with the increase of DEE addition at the same engine torque in a spark ignition engine. Kumar et al., [15] found that BSFC increased by 16% and 8.5% with 6% and 3% DEE fuel mixtures respectively at maximum engine load and 22°C inlet air temperature in a SI engine. They have stated that lower heating value of DEE resulted in higher BSFC.

Fig. 5. refers the changes of thermal efficiency using test fuels. At low engine speeds, sufficient time can be available and heat can be transferred to the cylinder wall [6]. Hence, lower efficiency is obtained. Similarly, volumetric efficiency decreases because of gas leakages and flow losses at high engine speeds. Combustion could not be completed well with the lack of oxygen and some unburned hydrocarbon remains in the combustion chamber and discharges from the cylinder. Insufficient oxygen slows down the oxidation reactions at high engine speeds [6]. Thus, thermal efficiency decreases. It can be implied that there is good agreement between SFC and thermal efficiency. Thermal efficiency was obtained maximum at 2800 rpm where SFC values are minimum. Thermal efficiency decreased by 1.05%, 1.57%, 2.97% and 3.15% with DEE10, DEE20, DEE30 and DEE40 according to pure gasoline at 2800 pm respectively. The addition of DEE decreased the calorific value of fuel mixture. It can be also mentioned that high latent heat of vaporization of DEE causes to obtain lower thermal efficiency. High latent heat of evaporation also presented cooling effect during combustion resulting in lower in cylinder gas temperature. So, released heat energy declined with the rise of DEE addition.

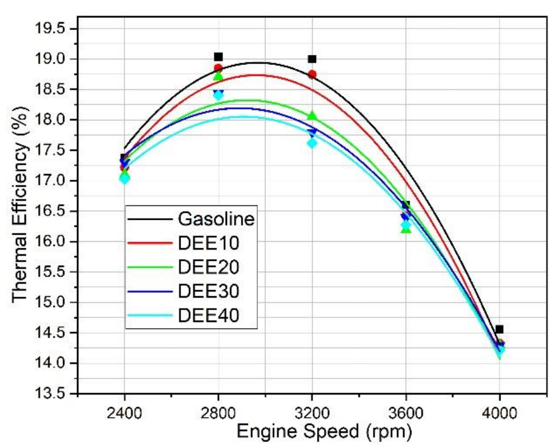

Fig. 5. Changes of thermal efficiency

Polat et al., [11] mentioned that the usage of DEE80 presented earlier CA50 in an HCCI engine. So, this situation caused to obtain lower indicated thermal efficiency (ITE) on HCCI combustion. Balaji et al., [14] found BTE by about 15%, 14.5% and 14.8 % with 10% ethanol-2.5% DEE, 10% ethanol-5% DEE and 10% ethanol-7.5% DEE test fuels respectively for the 50% engine load in a SI engine. It was found that the increase of DEE additive decreased effective efficiency for 25, 50 and 75% engine loads in a direct injection diesel engine [7].

Fig.6. illustrates the influences of DEE on CO emissions. CO is

produced owing to lower in cylinder temperature and insufficient oxygen [6]. As seen in Fig. 6, CO was reduced with the rise of diethyl ether addition in the fuel mixtures. The lowest CO was produced with DEE40. The another reason of reduced CO is that DEE has higher amount of oxygen. This situation helps to react more fuel molecules with oxygen molecules. At 4000 rpm, CO measured lower by about 0.67%, 3.39%, 10.61% and 11.11% with DEE10, DEE20, DEE30 and DEE40 according to pure gasoline. Kumar et al., [15] mentioned that CO reduced for base fuel, 3% DEE, 6% DEE and 9% DEE test fuels at 22°C inlet air temperature from 10% to 75% engine load in a spark ignition engine. Sezer [7] found lower CO emissions with ethanol, DEE fuel blends at middle and high engine loads compared to diesel. Polat [18] explained that the lowest CO was formed with DEE according to ethanol-diethyl ether fuel blends with HCCI combustion. In [19], similar results were found that CO decreased with DEE additives in a diesel engine. It was implied that higher oxygen content improved the combustion and decreased the rich mixture region. So, CO formation decreased.

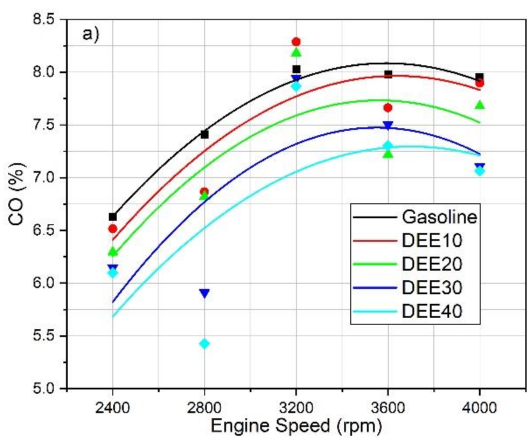

Fig. 6. Influences of DEE on CO emissions

Fig. 7. refers the variations of CO2 using test fuels versus engine speed. As expected, there is inverse relationship between CO and CO2. In contrast with CO, CO2 increased with the addition of diethyl ether. Lower CO is formed with fuel blends according to gasoline as given in Fig.7. But, CO raised with the rise of DEE proportion in the fuel mixtures. At high engine speeds, rise on average in-cylinder temperature was seen and allow to obtain more CO2. The highest CO2 were measured at 4000 rpm for all test fuels. The lowest CO2 was measured with DEE10 according to other test fuels. Higher oxygen content of DEE supports to occur oxidation reactions resulting CO2 formation. At 4000 rpm, CO2 increased by 10.85% with DEE40 compared to DEE10. Minimum CO2 values were measured with DEE10.

The existence of higher oxygen content helps to occur better combustion. Lower density and viscosity of DEE improved the mixing and rapid oxidation reactions caused to increase CO2 with the increase of DEE addition [19]. Tilaki et al., [16] determined minimum CO with methanol and ethanol in a spark ignition engine. Ardebili et al., [30] showed the increase by about 8.27% with 60% DEE ratio compared to 80% DEE ratio on CO2 with HCCI combustion.

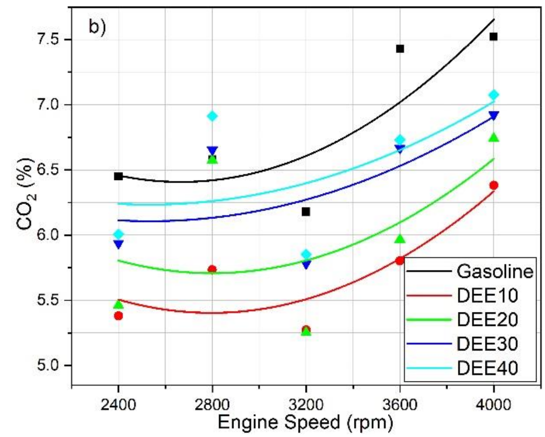

Fig. 7. The variations of CO2 emissions

The variations of measured HC are shown in Fig.8. HC is formed owing to incomplete combustion and weak ignition properties of the charge mixture especially at near the cylinder wall where flame goes down due to cooler surface of cylinder. Some fuel molecules could not be ignited in the cavities and edge areas in the combustion chamber where flame can not reach due to weak turbulence and homogeneity at low engine speeds [6]. Thus, HC formation is increased. Kumar et al., [15] stated that HC decreased gradually with base fuel and 3%, 6% and 9% DEE fuel mixtures from 10% to 75% engine load in a spark ignition engine. Balaji et al., [14] concluded that 26.5%, 24.3% and 18.2% reductions were seen on CO, HC and NOx emissions using diethyl ether-unleaded gasoline fuel mixtures for all engine torques in a SI engine. Kumar and Murugesan [19] clarified that HC reduced with DEE addition in a diesel engine. They implied that DEE shortened ID owing to higher cetane number. Besides, they emphasized that higher oxygen content of DEE improved the oxidation reactions and HC formation reduced. Polat [18] revealed that lower HC emission was obtained with DEE compared to ethanol-diethyl ether fuel blends in an HCCI engine.

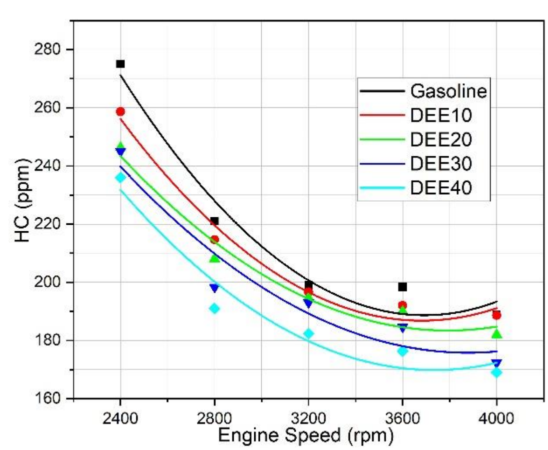

Fig. 8. The variations of HC emissions with test fuels

It can be clearly said that HC reduced with diethyl ether additive in the fuel mixtures. Higher oxygen content of DEE leads to improve oxidation. HC reduced by 10.58% with DEE40 compared that gasoline at 4000 rpm. It can be also implied that combustion becomes favorable due to lower octane number of DEE. Flame development is improved with the addition of DEE because of its volatile nature resulting in lower unburned hydrocarbon.

4. Conclusions

The purpose of the current work is to research the influences of DEE addition into gasoline in view of engine performance and exhaust emissions such as CO, CO2 and HC pollutants.

- Test results showed that DEE caused to increase engine torque and power output apart from DEE40.
- SFC increased with the increase of DEE addition owing to lower calorific value and higher density.
- Thermal efficiency declined by 1.05%, 1.57%, 2.97% and 3.15% with DEE10, DEE20, DEE30 and DEE40 according to pure gasoline at 2800 pm respectively.
- It was also seen that notable reduction was realized on CO and HC emissions with DEE additive. CO and HC decreased by 11.11% and 10.58% with DEE40 compared to gasoline at 4000 rpm.
- It was seen that engine performance decreased with high rate of DEE. However, test results demonstrated that DEE reduced CO and HC compared to gasoline.
- As a result, DEE can be utilized as an additive without modification in spark ignition engines.

Nomenclature

AC	Alternative current
BTE	Brake thermal efficiency
*CA*50	Location where the half of the mixture completed the combustion
CI	Compression ignition
CO	Carbon monoxide
CO_2	Carbon dioxide
COV_{imep}	Coefficient of cyclic variations of imep
CRDI	Common rail direct injection
DC	Direct current
DEE	Diethyl ether
DME	Dimethyl ether
ES	Energy share
I*CE*	Internal combustion engine
Im*ep*	Indicated mean effective pressure
ITE	Indicated thermal efficiency
HC	Hydrocarbon
HCCI	Homogeneous charged compression ignition
HP	Horse power
LPG	Liquefied petroleum gas
MPRR	Maximum pressure rise rate
NO_x	Nitrogen oxides
PPC	Partially premixed combustion
PCCI	Premixed charged compression ignition
SFC	Specific fuel consumption
SI	Spark ignition
SOC	Start of combustion
WOT	Wide open throttle
λ	Lambda

Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

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