Effect of inlet air temperature on SI engine fueled with diethyl ether-gasoline blends

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ABSTRACT

In this study the performance and emission characteristics of spark ignition genset engine fueled with gasoline and diethyl ether (DEE) blends are carried out. The DEE blends are varied from 3%, 6% and 9% by volume in gasoline. A four-stroke single cylinder constant speed spark ignition engine is used for the experiments. The variation in fuel consumption and exhaust emission with respect to two different inlet air temperatures are studied. The concentration of exhaust emissions such as HC, CO, NO_x is observed. The parameters such as inlet air temperature, brake specific fuel consumption, relative air to fuel ratio are also measured. It is noticed that 6% DEE blend in gasoline reduced almost reduced HC emission about 57% and also considerable reduction in CO emission at lower air intake temperature. The addition of diethyl ether has an improvement in performance and significant reduction in HC, CO and NO_x emissions.

Keywords: Fuel; diethyl ether; emissions; temperature; additives.

INTRODUCTION

The domestic and commercial power requirement is on the increase day by day. The normal grid power supply is insufficient and unreliable. The genset plays a major role in overcoming this issue catering to low power domestic applications [1]. A genset is a combination of an alternator and a prime mover. The prime mover can be a petrol engine or diesel engine. The petrol genset is often used for lower power applications where as diesel genset is mainly used for high power requirements [2]. One area where gasoline genset scores over diesel genset is during the cold weather starts. The heat necessary for combustion is achieved by a spark plug in gasoline genset hence cold start issues can be avoided [3]. The inlet air temperature plays a major role in combustion of fuel as well in exhaust emissions [4]. In order to study the variations with temperature change, the average temperature in summer and winter seasons in central and southern part of India are taken into account for this study. So the tests are conducted at 32ºC for summer and 22ºC for winter seasons.

The increase in price of gasoline and increase in environmental pollution due to internal combustion engines have forced the engineers all over the world to work on alternate fuels and fuel additives for improvement in efficiency with reduction in emissions. The exhaust emissions such as hydrocarbon (HC), carbon monoxide (CO),

oxides of nitrogen (NO_x) undergo series of reactions in the atmosphere and which are hazardous to health [5]. They lead to global warming, acid rain and respiratory track problems. The ultimate aim is to develop a fuel which reduces harmful exhaust emissions [6].The organic compounds which contain oxygen are known as oxygenates. It could be alcohols, ethers, esters, ketones and carbonates.

Jaat et al [7] experimentally established a reduction in ignition delay with increase in ambient temperature of biodiesel blends and its oxygen content did play a significant role. It was established that leaning effect in oxygenated blends such as with ethanol decreases CO and HC emissions in gasoline engines [8,9]. The organic compounds which contain oxygen are known as oxygenates. It could be alcohols, ethers, esters, ketones and carbonates [10]. Oxygenates are used as substitutes for lead additives in gasoline to enhance octane rating [11]. The amount of oxygenates added to gasoline can vary from 3% to 22% by volume. There is a decrease in energy content of the blended fuel and increase in fuel consumption depending on the amount and type of oxygenates added to the gasoline. This resulted in change of the air to fuel ratio and ensures complete combustion of fuel into CO_2 and H_2O [12, 13]. Ethanol addition to unleaded gasoline increase the engine torque, power and fuel consumption and reduce CO, NO_x and HC emissions. It was also found that ethanol-gasoline blends allow increase of compression ratio (CR) without the occurrence of knock [14]. It was observed that gasoline with a 35% butanol blend and ignition optimization, torque, power, brake specific fuel consumption (BSFC), HC, CO and O_2 emissions reduced and NO_x and CO_2emissions indicated an increase [15]. It was also reported that with small percentage of hydrogen-ethanol blends, the power produced by a SI engine was substantially higher [16]. Addition of methane in gasoline, acceleration in combustion was observed at low compression ratio with lean burning and fuel stratification conditions. A slight increase in in-cylinder pressure was observed leading to improvement in initial combustion [17,18].

It is seen that alcohols and ethers are the commonly used additives. Alcohols has drawbacks such as high volatility, solubility in water, phase separation problem, high Reid vapor pressure which can cause clogging of the blended fuel due to increase in vapor pressure. It has high latent heat of vaporization which leads to cold start up and drivability issues. On the other hand, ethers are capable to overcome all the drawbacks and enhance gasoline combustion with high octane numbers and reduced HC, CO, and NO_x emissions [19]. Being toxic the usage of organic compounds with methyl group are shown less interest in many countries such as USA, GBR, France, etc. Since diethyl ether (DEE) is non-toxic and readily available with affordable cost is used as additive [20]. The DEE is synthesized by the reaction of ethanol with sulphuric acid in an aqueous medium at a temperature below 150ºC through dehydration process. It is an excellent CI engine fuel with high energy density than ethanol and aids cold start for engines [21]. The use of DEE blends under various load conditions in a CI engine. It was found that specific fuel consumption reduced at full load and injection timing needs to be advanced for reduction in smoke and HC emissions [22]. Studies on addition of DEE with LPG and CI in HCCI combustion mode indicate a reduction in thermal efficiency along with a reduction in NO_x and soot. However, an increase in CO and HC was observed with addition of 15% diethyl ether in diesel, injection timing was varied to find an optimized one. At full load conditions, advancement in injection timing reduced smoke and HC emissions and retardation improved the brake thermal efficiency and NO_x [23]. It was observed that the effect of variation in inlet air temperature on engine performance and emission characteristics on petrol engine is not yet discussed. In pursuit of a renewable high cetane number fuel comparable to conventional fuels for engines DEE was chosen. DEE is a

liquid fuel at ambient temperature and can be used as a fuel additive in engines without modifications. There are some concerns on the impact of DEE on air pollution during storage due to its high volatility and its tendency to oxidize and form peroxide [24]. Limited research has been observed on DEE-gasoline blends in spark ignition engines. In this study the effect on performance and emission characteristics of the gasoline and gasoline-DEE blends are used in gasoline engine. The effect on inlet air temperature at 22°C and 32°C are also analyzed and presented.

METHODS AND MATERIALS

The experiments are conducted on an air cooled, single cylinder, 4-stroke, gasoline constant speed engine. The engine is coupled with transient dynamometer. A load cell is attached with the dynamometer is used to measure load acting on the engine. The load cell has the rage of 0-100 Nm and has accuracy of 0.1Nm with the error of ±0.87Nm to its full scale. The schematic layout of the experimental set up is shown in Figure 1. The specification of the engine is detailed in Table 1. The fuel blends used in the experiment and its properties are presented in Table 2. Fuel properties such as density, viscosity, and calorific values are measured by using hydrometer, redwood viscometer and bomb calorimeter respectively. The latent heat of vaporization and auto ignition temperature are calculated based on the mass fraction used in the gasoline and is presented.
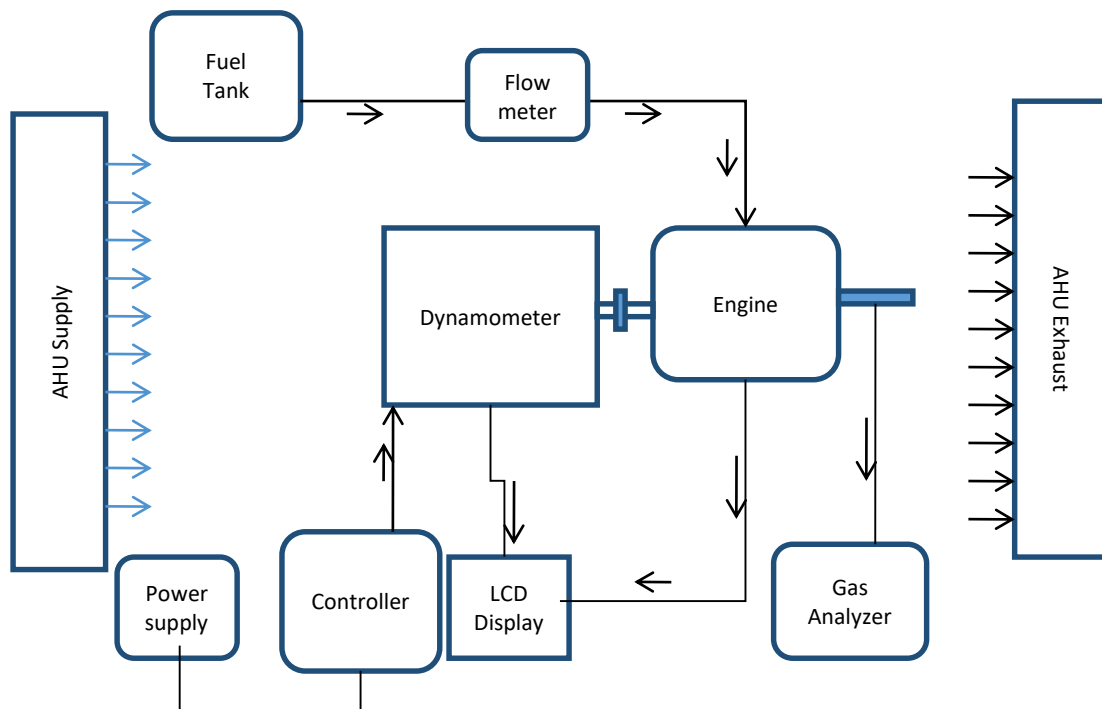
Figure 1. Schematic layout of the experimental setup.

The column tube manometer is used for measuring the fuel consumed by the engine. The inlet and exhaust gas temperatures are measured by using the thermocouples fixed at inlet and exhaust manifold respectively. The Horiba Mexa 584L gas analyzer is used to measure the concentrations of exhaust gas emissions. The specification of the gas

analyzer is given in Table 3. The required inlet air temperature is maintained constant by air handling unit (AHU) in the test bed as shown in Figure 1.

Table 1. Engine specifications

Engine type	Single cylinder, 4- stroke, air cooled
Engine make	Briggs and Stratton
Fuel	Gasoline
Bore(mm)	89
Stroke(mm)	63
Peak torque (Nm)	25.9
Rated power(kW)	9.7
Rated speed(rpm)	3600

Table 2. Properties of the fuel [12,13][a] [7,21,28][b]

Properties	Gasoline[a]	Diethyl ether[b]	97% G + 3% DEE	94% G + 6% DEE	91% G + 9% DEE
Calorific value (kJ/kg)	44500	33892	44420	43865	43545
Latent heat of vaporization(kJ/kg)	331.6	376	332.9	334.2	335.6
Kinematic viscosity at T=32°C (cSt)	0.41	0.22	0.40	0.398	0.392
Kinematic viscosity at T= 22°C (cSt)	0.44	0.32	0.44	0.43	0.43
Density (kg/m^3) ASTM D4052	719.7	713	718	716	715
Flash point (°C)	-43	-40	-	-	-
Auto ignition temperature(°C)	257.2	160	254	251	248
Octane number	91	14	-	-	-

A thermocouple is fitted in the AHU exhaust to control the temperature inside the bed. The miscibility of DEE blends with gasoline is ensured properly by stirring the fuel with a magnetic stirrer.

Table 3. Specifications of gas analyzer

Pollutant	Range	Resolution	Principles
NO$_x$	0-5000 ppm	1 ppm vol	Chemiluminescence
HC	0-20000 ppm	1 ppm vol	Non-dispersive infrared
CO	0-20 % volume	0.01% vol	Non-dispersive infrared
CO$_2$	0-20% volume	0.01% vol	Non-dispersive infrared
O$_2$	0-25% volume	0.01% vol	Carbon balance method

Experimental Procedure
The engine is tested based on the procedure recommended by Central Pollution Control Board (CPCB) of India for gasoline genset engine. The engine is started and allowed to

warm up until it attains thermal stability which can be ensured by attaining the constant exhaust gas temperature and surface temperature of cylinder head. The residual fuel in the fuel line is flushed out before each test with the new blend. The experiments are carried out by blending 3%, 6% & 9% diethyl ether with gasoline at the inlet air temperature of 32°C and 22°C.DEE can increase wear rate in the engines, it restricts the usage in large quantities [25]. Hence the percentage of DEE is used less than 10% by volume in this study. The data are observed by taking two runs and the average value of the required parameters. According to the CPCB test procedure [26], the engine is subjected run at three modes such as 50%, 75%, 100% of rated load at a constant speed. The speed of the engine is fixed at 3000 rpm. The alternator which is coupled to the engine has to produce the alternate current (AC)of 50 Hz power supply. The speed of the engine is calculated and is fixed based on the frequency required. In order to calculate the speed, the required frequency is multiplied by 120 over number of poles in the generator stator. The maximum torque at 3000 rpm is found by conducting full throttle performance test on the engine and is 25 Nm. Table 4 shows the weightage factor, torque and speed for different modes of operation used in the experiment.

Table 4. Details of test modes

Mode no.	1	2	3
Load %	100	75	50
Weightage factor	0.3	0.5	0.2
Speed (rpm)	3000	3000	3000
Torque (Nm)	25	18.75	12.5

Table 5. Uncertainties of measured and calculated parameters

S. No	Parameter	Uncertainty %
1.	CO	±1.7
2.	HC	±1
3.	NO_x	±1.2
4.	BP	±1.05%
5.	BSFC	±1.12%

The engine is loaded from10% to 100% of maximum load. The weightage factor is applied only to 100%, 75% and 50% load conditions. The inlet air conditions are monitored and maintained at the set temperature. The performance parameters such as Specific fuel consumption and exhaust gas temperature are observed. The emission parameters such as HC, CO and NO_x are observed using gas analyzer at each load conditions. The instruments used in the experiments are calibrated before and after the test and the readings are repeatable within the limit prescribed by CPCB. The errors involved in the experiments are calculated using uncertainty analysis which is widely followed among the researchers. Uncertainties of the measured and calculated parameters are found by using Root-sum-square method and are presented in Table 5.

RESULTS AND DISCUSSION

The experiments are conducted at a controlled intake temperature of 32/22 ±1°C. The various blend percentages of DEE with gasoline used in the experiment are 3%, 6% and 9% by volume. The performance and emission characteristics are observed and presented. The parameters analyzed in the engine are CO, HC, NO_x and BSFC. Figure 2(a) shows the variations of the CO emissions at inlet air temperature of 32°C with respect to load. The CO emission of base fuel and 9% DEE blends are gradually decreased when the load is increased from 10% to 50%. Further, the increase in CO is observed at maximum load condition. This is due to decrease in combustion temperature which leads to partial oxidation of CO to CO_2 conversion process [27, 29]. It is observed that when the load increased from 10% to 75 % the CO emissions are decreased for 3% DEE and 6% DEE blends respectively. At maximum load it is seen that the CO emissions are increased. This could be due to lack of oxygen for complete combustion. The density of the air is decreased due to increase in inlet temperature which reduced the oxygen for combustion [30].
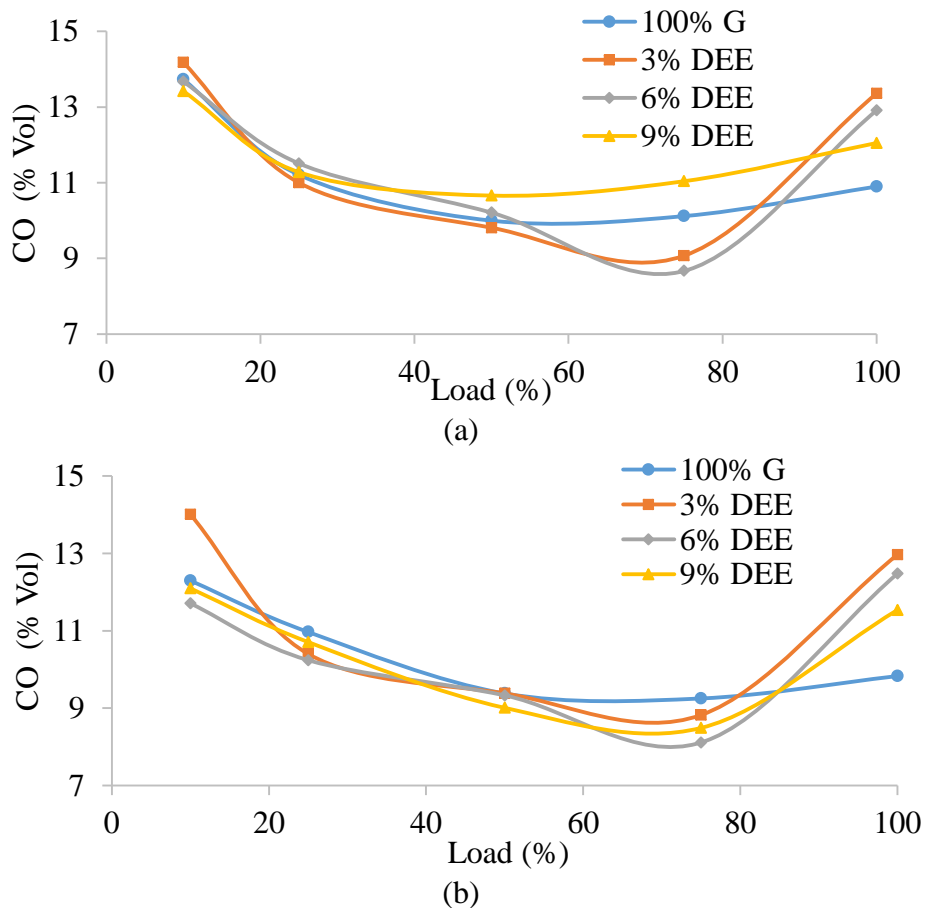

Figure 2. Comparison of CO emission with load at (a) 32°C inlet air temperature (b) 22°C inlet air temperature.

Figure 2(b) shows the variations of the CO emissions at inlet air temperature of 22°C with the load. The CO emissions of base fuel and 3%, 6% and 9% DEE blends are gradually decreased respectively when the load is increased from 10% to 75%. It is due to increase in density of air which provided more oxygen for complete combustion of

fuel. The CO emission is increased about 33% at maximum load condition for 3% DEE blend. This could be due to fuel rich mixture conditions which alters the combustion characteristics and increased CO emission. As the blend percentage increased, the CO emission is decreased which could be due to fuel bound oxygen supports for combustion process [13, 31]. The average CO emissions are calculated using weightage factor at 3%, 6% and 9% DEE blend has the reduction of about 10%, 10.5% and 0.05% respectively at the inlet air temperature of 32°C. This could be due to fuel bound oxygen supports for combustion and oxidation of CO. It is observed that CO emission for 3%, 6% and 9% DEE blends are increased by 6.5%, 0.02% and 0.05% respectively at 22°C. The decrease in temperature at the inlet reduces the combustion gas temperature and increases the CO emission [8].
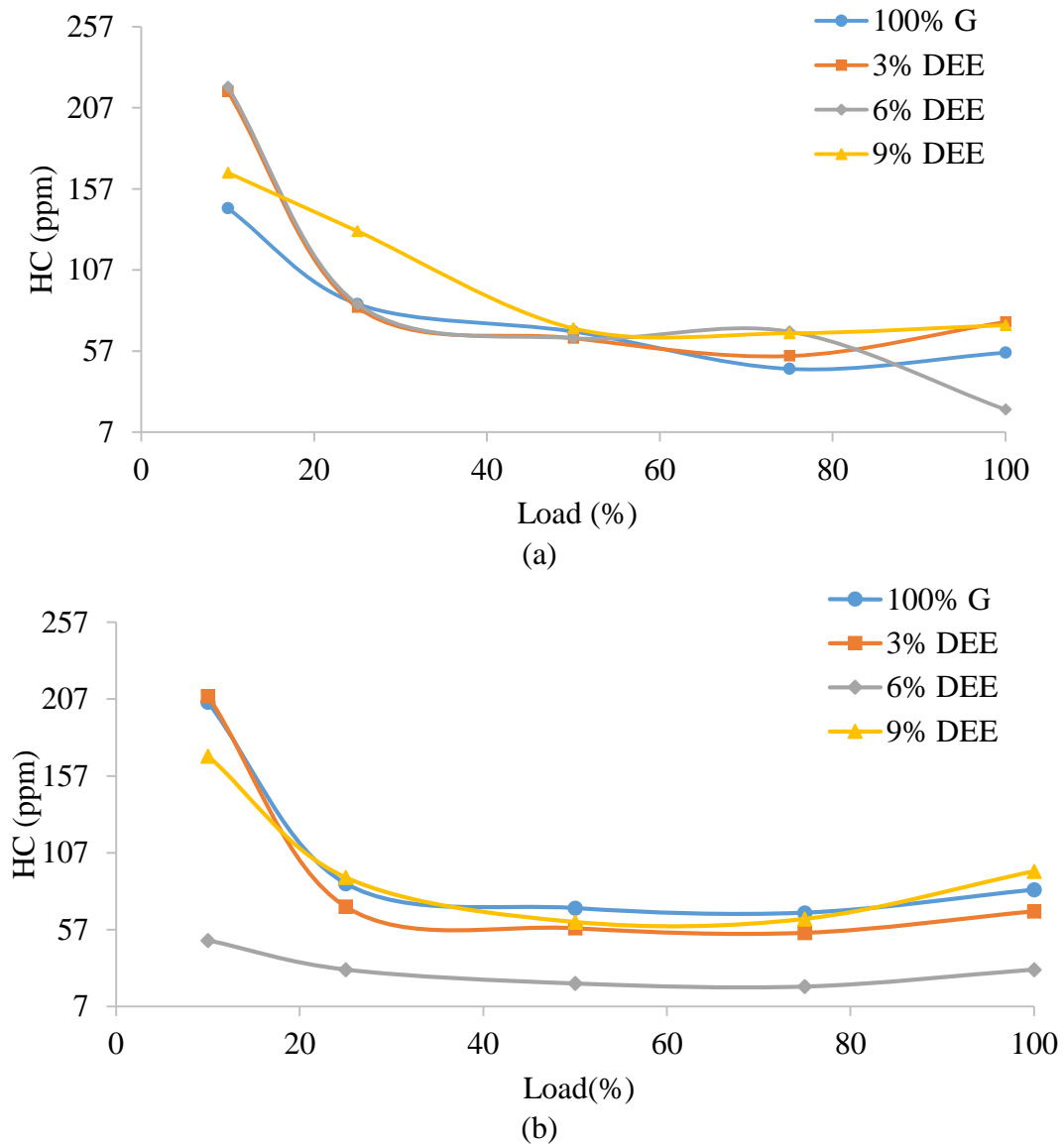

(a)

(b)

Figure 3. Comparison of HC emission with load at (a) 32°C inlet air temperature (b) 22°C inlet air temperature.

Figure 3(a) shows the variations of the HC emissions at inlet air temperature of 32°C with the load. The HC emissions of the base fuel and 3%, 6% and 9% DEE blends are gradually decreased when the load is increased from 10% to 75%. At maximum load

condition, the HC emissions are increased except for 6% DEE blends. It could be due to flame quenching and crevice volume effects significantly contributed to hydrocarbon emission [32, 34]. It is observed that 6% DEE blend shows decrease in HC emission at maximum load. It could be because of the addition of DEE reduced the ignition delay [12] and enhanced the combustion characteristics. Figure 3(b) shows the variations of HC emissions at inlet air temperature of 22°C with the load. It is found that 6% DEE blend shows the reduction in HC emission in all load conditions. A reduction in HC emission of about 62% is observed at maximum load condition. This could be due to better oxidation as the temperature of the inlet air reduced and the oxygen present in the fuel supports for combustion [33]. At maximum load condition, more HC molecules are trapped in the crevices which significantly contribute to HC emissions for 9% DEE blend. It is observed that HC for 3%, 6% and 9% DEE blends are increased by 9%, 0.02% and 18.3% respectively. HC emission for 3%, 6% and 9% DEE blends are decreased by 9%, 57% and 0.1% respectively at 22°C. A maximum decrease in HC emission is observed for 6% DEE blend.
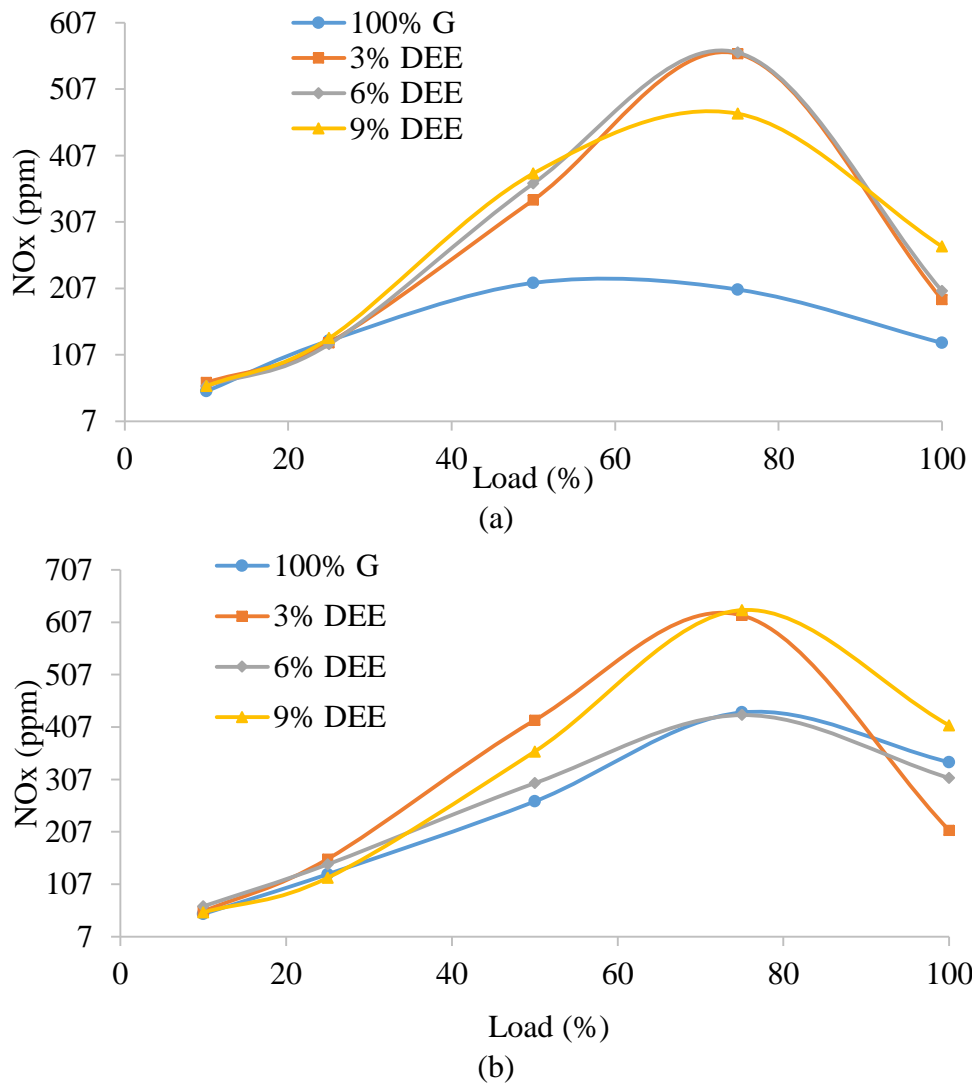

(a)

(b)

Figure 4. Comparison of NO_x emission with load at (a) 32°C inlet air temperature (b) 22°C inlet air temperature.

The NO_x emissions at inlet air temperature of 32°C of base gasoline and DEE blends with different load conditions is shown in Figure 4(a). The air fuel mixture is nearly stoichiometric which enables complete combustion and higher heat release which resulted in higher combustion temperature leads to higher NO_x emission. At 100% load condition the NO_x emission is decreased due to fuel rich conditions resulted in incomplete combustion which reduces the combustion temperature [11, 35] and thereby NO_x. Figure 4(b) shows the variation of the NO_x emissions at inlet air temperature of 22°C at different load conditions. The NO_x emission of base fuel and 3%, 6% and 9% DEE blends are increasing when the load is increased from 10% to 75%. A reduction in NO_x about 38% and 8% at maximum load condition is observed for 3% and 6% DEE blends respectively. This is due to the decrease in air inlet temperature leads to reduction in combustion gas temperature [7] thereby NO_x emission. It is observed that an average increase in NO_x of about 112%, 116% and 101.2% for 3%, 6%, 9% DEE blends respectively at 32°C. It is observed that NO_x of 3% and 9% DEE blend is increased about 28% and 37% respectively at 22°C. The NO_x is decreased about 1.2% for 6% DEE blend 6% at the same inlet temperature.
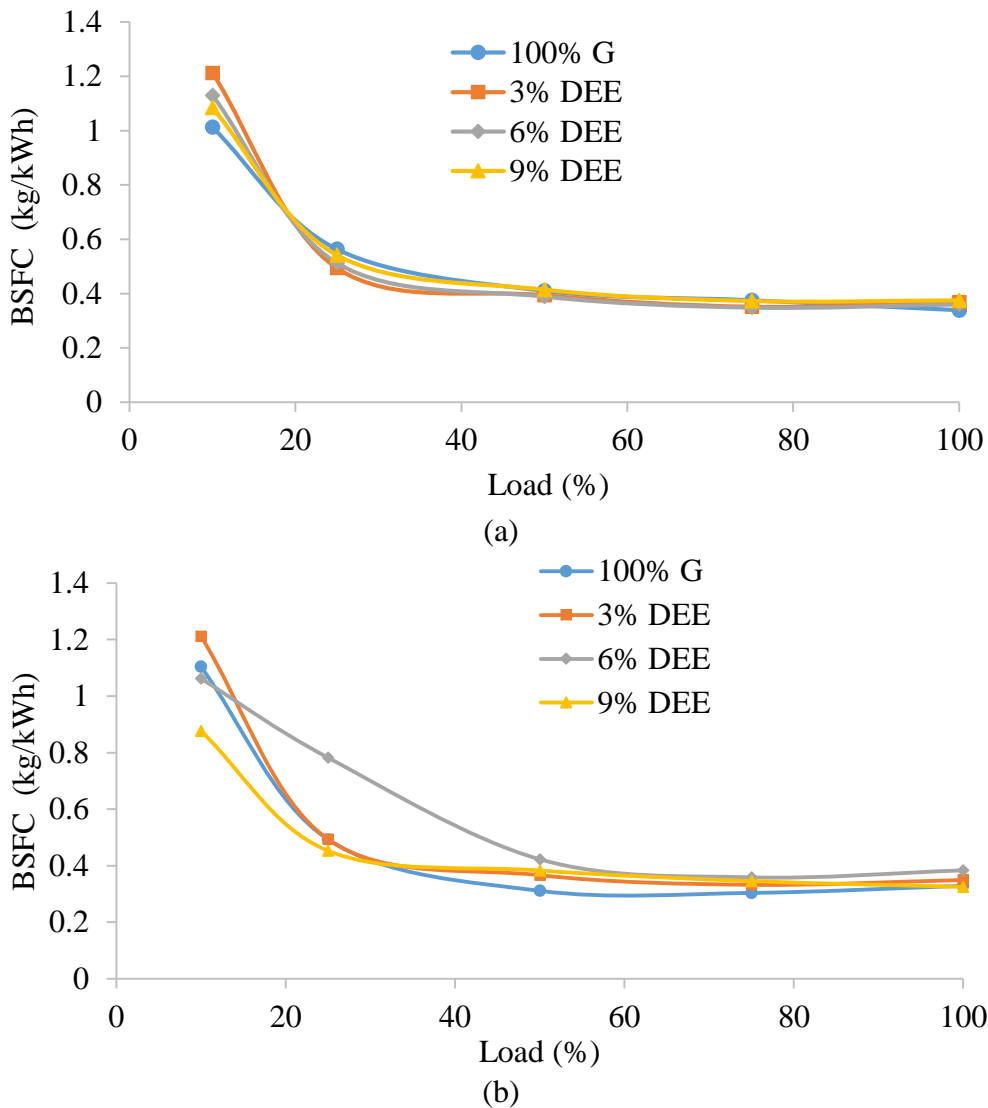

(a)

(b)

Figure 5. Comparison of BSFC with load at (a) 32°C inlet air temperature (b) 22°C inlet air temperature.

Figure 5(a) and Figure 5(b) shows the variations of BSFC at inlet air temperature of 32°C and 22°C respectively. The BSFC of base fuel, 3%, 6% and 9% DEE blends are decreased when the load is increased from no load to maximum load conditions. The BSFC is at par with the base fuel at medium and maximum load conditions at 32°C. An increase in BSFC of 16% and 8.5% is observed for 6% and 3% DEE blends at maximum load condition respectively at 22°C. This is mainly due to decrease in calorific value of the fuel blends as the DEE blend percentage increased [36,21]. It is observed that the BSFC of 3% and 6% DEE blend is decreased to 1.9% and 3% respectively at 32°C. The BSFC is increased about 3% for 9% DEE blend. It is observed that the BSFC of 3%, 6%, 9% DEE blend is increased to 11%, 19% and 10.7% respectively at 22°C air inlet temperature.

CONCLUSION

In this study, three blends of gasoline-DEE were used in a SI engine and the performance and emission characteristics with two inlet air temperature representing the summer and winter average temperatures at the southern part of India was carried out. It was found that the CO emissions and brake specific fuel consumption reduced for the inlet temperature of 32°C and increase in HC and NO_x emission was observed. The result for 22°C was just the opposite where CO and BSFC increased and HC and NO_x indicated a decrease. An optimal blend was observed to be 6% DEE with gasoline which gave reduced emission with marginal reduction in brake specific fuel consumption. A strong correlation of effect of temperature on the emission and performance behavior with DEE and gasoline blends was observed in this study. There is a scope for further studying the SI engine performance by varying the inlet air temperatures and increasing the quantity of DEE in the blends.

ACKNOWLEDGEMENTS

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