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PERFORMANCE AND EMISSION CHARACTERISTICS OF A VARIABLE COMPRESSION SI ENGINE USING ETHANOL-GASOLINE BLENDS AS FUEL

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ABSTRACT
For several decades gasoline has been used as one of the main source of energy in transportation sector and other SI engine applications. But now the fossil fuels are becoming scarcer due to rapid depletion of the sources and the increased demand of the growing population. Also the use of fossil fuels has raised the severe problem of global warming and pollution to the mankind as well as to the environment. Ethanol is seemed to be the most promising alternative fuel to gasoline to overcome these problems. Ethanol is clean, renewable and biodegradable having higher octane number. Ethanol can be produced from sugarcane, crop residues, agricultural biomass, municipal waste etc. The performance and emission characteristics of a single cylinder, air-cooled variable compression spark ignition (SI) engine have been experimentally investigated in the present work. The engine performance and emission characteristics at different compression ratios have been investigated and compared in this paper.

Keywords: Ethanol, SI Engine, Variable Compression Ratio, Brake Thermal Efficiency, Emissions

1. INTRODUCTION

The demand of energy increases rapidly with the growth in civilization. The majority of this demand is fulfilled from the combustion of fossil fuels. As a result, the reserve of the fossil fuel is rapidly exhausting. And the combustion of huge amount of fossil fuel creates enormous pollution to the atmosphere by emitting various pollutants. Researchers are trying to find out an alternative to petrol fuel. Ethanol is found to be one of the promising alternative fuel for SI engine. The most attractive properties of ethanol as a SI engine fuel are that it can be produced from renewable energy sources such as agricultural feedstock and it has high octane number and flame speed. Ethanol can be used in SI engines as pure or by blending with gasoline [1, 2, 5, 7]. Use of pure ethanol requires some modification on engine design and fuel system whereas it can be used in SI engines by blending with gasoline at low concentrations without any modification. If the ethanol-gasoline blends with ethanol at low concentrations are used, engine The burning of gasoline alone causes harmful emissions like CO, HC (hydrocarbon), NO_x etc which are the major pollutants and leads to global warming [4, 6, 8, 9]. By using ethanol-gasoline blends the emission levels of CO, HC and NO_x can be reduced.

2. PROPERTIES OF ETHANOL

Performance and emission characteristics of the engine depend on chemical characteristics of a fuel. As ethanol contains 35% oxygen, the combustion of the fuel is improved due to leaning effect [10]. Ethanol has higher octane number than gasoline thus it can lead in operation at higher compression ratios. Also due to low calorific value and high latent heat of vaporization of ethanol, engine volumetric efficiency may increase. Different relevant properties of ethanol are compiled from the previous works [3, 11] and presented in the tabular form for ready reference in Table 1.

Table 1: Properties of ethanol compared with gasoline

Fuel Property	Ethanol	Gasoline
Formula	C_2H_5OH	C_4 to C_{12}
Molecular weight	46.07	100-105
Density, kg/l, 15/15 °C	0.79	0.69-0.79
Specific gravity (Relative density), 15/15 °C	106 – 110	91
Freezing point, °C	–114	–40
Boiling point, °C	78	27-225
Vapor pressure, kPa at 38 °C	15.9	48-103
Specific heat, kJ/kg K	2.4	2
Viscosity, mPa s at 20 °C	1.19	0.37-0.44
Flash point, °C	13	–43
Auto-ignition temperature, °C	423	257
Latent heat of vaporization, (kJ/kg)	923	380–500
Lower heating value, (MJ/kg)	26.8	42.7
Flammability limits, Vol%		
Lower	4.3	1.4
Higher	19	7.6
Stoichiometric air-fuel ratio,	9	14.7
Octane number		
Research (R)	108.6	88–100
Motor (M)	89.7	80–90
Antiknock Index (R+M)/2	99.1	84–95

3. EXPERIMENTAL SETUP

The experiment is carried out in a single cylinder (MK-25) variable compression ratio spark ignition engine. Typical views of test engine have shown in Fig. 1. The specifications of test engine are shown in Table 2. The tests were performed keeping the speed constant at 2800 rpm at all loads. The test fuels used are gasoline; gasoline and ethanol blends (maximum 20% ethanol with gasoline by volume). The experiment was performed at compression ratios of 6:1. 8:1 and 10:1. The engine coupled with an eddy current dynamometer, whose load can be adjusted by torque controller by varies current (amp). A digital gas analyzer is used to measure the CO_2, CO, HC, NO_x and O_2 emissions in the exhaust gas from the engine

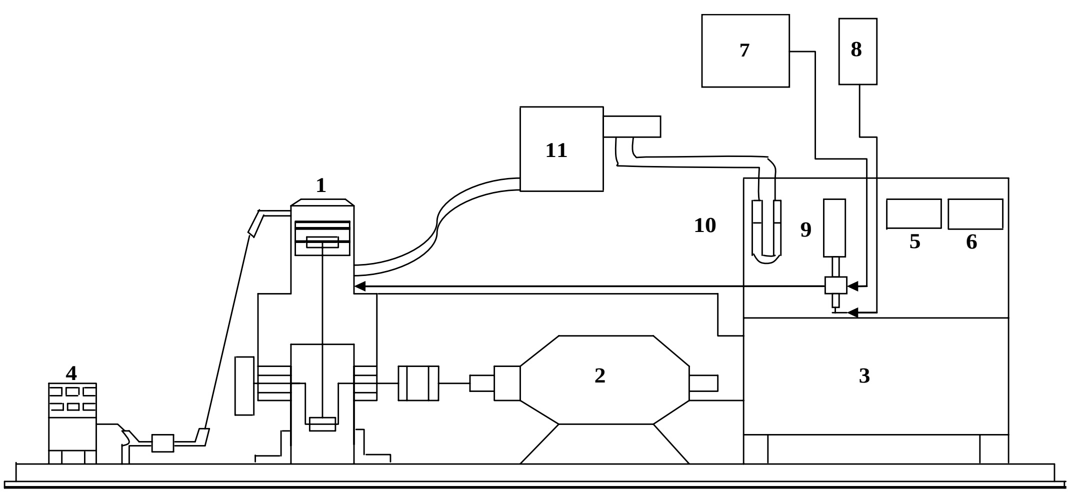
Table 2: Test Engine Specification

Sl. No.	Item	Specification
1	BP (MK-25)	2.5 kW
2	Rated speed	3000 rpm
3	Number of cylinders	1
4	Compression ratio	2.5:1 to 10:1
5	Bore	70 mm
6	Stroke length	66.7 mm
7	Type of ignition	Spark ignition
8	Method of loading	Eddy current dynamometer
9	Method of starting	Crank start
10	Method of cooling	Air cooled

4. RESULTS AND DISCUSSIONS

4.1 Effect of Ethanol on Brake Thermal Efficiency

The ratio of the brake power of the engine and the energy that should be released per unit time due to complete combustion of fuel is called the brake thermal efficiency of the engine. Figures 2a–2c indicate the variation of brake thermal efficiency of the engine with brake power (range 0.8473 to 1.964 kW) for pure gasoline (E0) and gasoline-ethanol blends having varying percentages of ethanol (denoted as E10, E20 and E30) at compression ratios of 6:1, 8:1 and 10:1.



1. Test engine. 2. Dynamometer. 3. Control panel. 4. Exhaust gas analyzer. 5. Speed indicator. 6. Torque controller. 7. Petrol tank 8.Ethanol tank. 9. Fuel flowmeter. 10. Manometer. 11. Air drum.

Fig. 1: Test set-up.

From the figures below, it is observed that the brake thermal efficiency increases gradually with the increase in the percentage of ethanol in the blends as well as the compression ratio.

The highest brake thermal efficiency was observed for E20 blend at the compression ratio of 10:1 and brake power of 1.923 kW and its value is around 20.85% as shown in figure 3c. But the values of brake thermal efficiency of the same blended fuel (E20) were found to 16.97% and 19.16% at compression ratios of 6:1 and 8:1 as shown in figures 3a and 3b respectively.

The brake thermal efficiency is relatively less for all the fuels due to practical limitations of the research engine used in these experiments. The limitation is that the engine is small and it operates on low loads.

The possible reason of the increase of the brake thermal efficiency due to increase compression ratio is the increase in the volumetric efficiency of the engine. The engine was running smoothly with E10 blend for all compression ratios considered here. But for higher blends (i.e. ethanol percentage>10%) the experiment was facing some problems at different compression ratios. This problem arises due to the occurrence of phase separation in the blend and phase separation occurs due to the presence of water in ethanol. The phase separation problem can be solved by adding additives like tertiary butyl alcohol, benzyl alcohol, cyclohexanol or toluene etc.

4.2 Effect of Ethanol on Brake Specific Fuel Consumption

Brake specific fuel consumption (BSFC) is defined as the fuel consumption rate to produce unit brake power, i.e. it is the ratio of the fuel consumption rate and the brake power. As the heating value of ethanol is lower than the gasoline, fuel consumption (kg/s) for blended fuel is expected to be more than that of pure gasoline. Figures 3a-3c shows the variation of BSFC with brake power of the engine running on gasoline and various blends of ethanol and gasoline at different compression ratios. It is observed that the BSFC of the engine with pure gasoline as well as different blends of gasoline and ethanol decreases with the increasing loads from 0.8473 to 1.964 kW at all compression ratios.

It is also found that with the increasing compression ratios, BSFC decreases gradually. The maximum decrement was found for E20 blend at compression ratio of 6:1 as observed in Fig. 4a and it was about 37.28%. Above this compression ratio, BSFC slightly increases with respect to compression ratio of 6:1. At all brake power and compression ratios, BSFC is higher for pure gasoline with respect to other blended fuel.

4.3 The Effect of Ethanol on Volumetric Efficiency

The volumetric efficiency is defined as the ratio of actual volume of air-fuel mixture flow into the cylinder at atmospheric pressure and temperature to the volume displaced by piston. Figures 4a-4c shows the variation of volumetric efficiency with the brake power for different percentages of ethanol-gasoline blends (E10, E15 and E20) and pure gasoline (E0) at compression ratios of 6:1, 8:1 and 10:1 respectively. The results obtained by the experiment indicate that the volumetric efficiency increases with the increase of ethanol percentage in the blend compared to pure gasoline for a particular compression ratio. Figure 4b indicates the maximum increase of volumetric efficiency for E20 blend is 21.72% at a compression ratio of 8:1 in comparison to E0 at loads ranges from 0.8473 to 1.964 kW.

4.4 Effect of Ethanol on CO_2 Emission

It is known that if the complete combustion takes place inside the combustion chamber then CO_2 emission increases rapidly. Although there is no possibility to occur complete combustion but it may be nearly complete combustion is depending upon the engine operating condition and fuel being used for engine. Figures 5a-5c shows the variation of CO_2 emission with the variation of brake power for different ethanol-gasoline blends (E10, E15 and E20) and pure gasoline at different compression ratios of 6:1, 8:1 and 10:1 respectively. It is observed from the figures that CO_2 emission increases gradually with increasing loads, compression ratios and ethanol percentages in the blend. It is also observed that maximum and minimum increase of CO_2 has occurred for E20 and E0 fuel respectively at all compression ratios. The maximum increment of CO_2 emission for E10, E15, and E20 with respect to E0, are 11.22%, 18.29% and 33.19% respectively at the compression ratio of 8:1 as shown in Fig. 5b. The most possible reason for that is the oxygen enrichment of fuel ethanol in the ethanol-gasoline blend. So during combustion, when the ethanol is supplied, the excess amount of oxygen causes leaning effect lead to better combustion and reduces the phenomena of dissociation due to decrease in temperature and whole incident compels for the increase in CO_2 emission.

4.5 Effect of Ethanol on CO emission

It is obvious that the emission of CO_2 and CO is interrelated i.e. if CO_2 emission increases then CO emission decreases naturally. So it is expected that CO emission decreases with the increasing ethanol percentages in the blend. Figures 6a-6c show the variation in CO emission with the variation of brake power with pure gasoline (E0) and different percentages of ethanol-gasoline blends (E10, E15 and E20) at different compression ratios. From the figure it is clear that with the increase of brake power and compression ratios, CO emission decreases gradually. The highest decrement of CO emission for E10, E15 and E20 blends with respect to E0 were observed to be 18.19%, 31.35% and 47.35% respectively at compression ratio of 10:1 as shown in Fig. 6c.

4.6 Effect of Ethanol on HC Emission

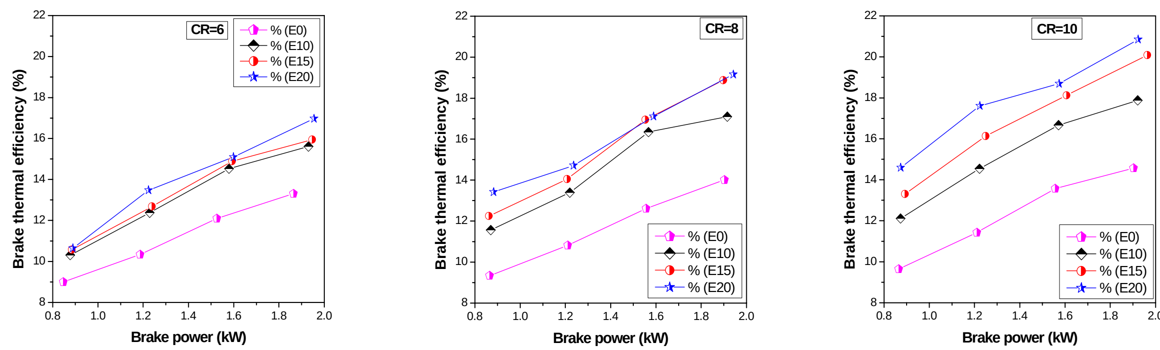
HC emission from any hydrocarbon fuel depends fully on its combustion characteristics inside the combustion chamber i.e. if combustion is better, then HC emission decreases and vice versa. Since ethanol

contains excess amount of oxygen, it is expected that HC emission will decrease by the use of ethanol-gasoline blend as a fuel. Figure 7a-7c shows the variation of HC emission with brake power for different ethanol-gasoline blends (E10, E15 and E20) and pure gasoline (E0) at different compression ratios. From the figure it can be seen that with increase in brake power HC emission for E0, E10,
E15 and E20 decreases drastically. The maximum decrement in HC emission for E10, E15 and E20 with respect to E0 at different compression ratios are given below and shown in figures 7a, 7b and 7c respectively. From the figure and the experimental data, it is clear that HC emission significantly reduces with the increase of ethanol percentage in the blend and slightly increases with the increase of compression ratios.

4.7 Effect of Ethanol on NO_x Emission

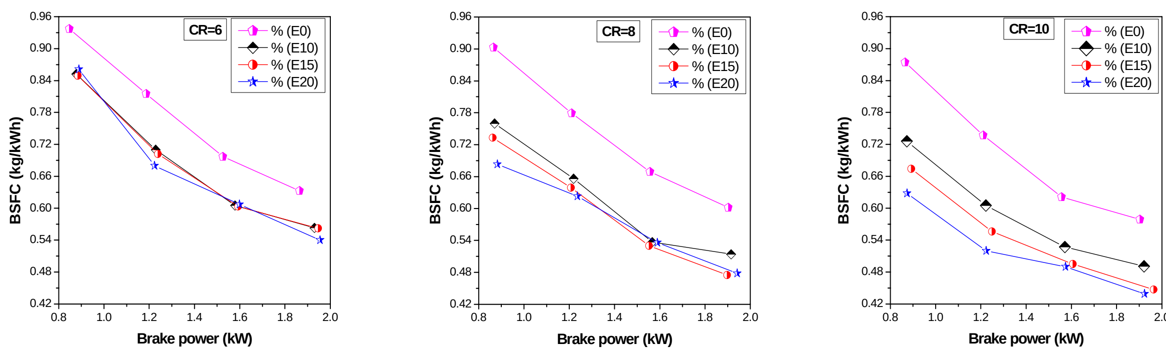
It is known that with the increase in brake power the combustion temperature increases rapidly. If the maximum actual combustion temperature reaches above 1200°C, nitrogen readily reacts with oxygen in a complex manner to form oxides of nitrogen (NO_x) and the presence of NO_x is detected in the exhaust gas. The variation of NO_x emission with the brake power for different ethanol-gasoline blends and pure gasoline at different compression ratios are plotted in figures 8a-8c corresponding to compression ratios of 6:1, 8:1 and 10:1 respectively. It is observed from the figures that NO_x emission increases with the increase in load and percentage of ethanol in the blend.

It is true for pure gasoline. But variation with compression ratios for a particular load and blend is quite small. Figures clearly indicate that NO_x emission is higher for E20 blend and lesser for E0 fuel at all compression ratios and the emission level of NO_x with gasoline is very close to that with E10. Figures also indicate that NO_x emissions depend on certain operating condition such as load, at lower load i.e. 0 to 1.2 kW, emission is lower enough and at higher load i.e. 1.2 to



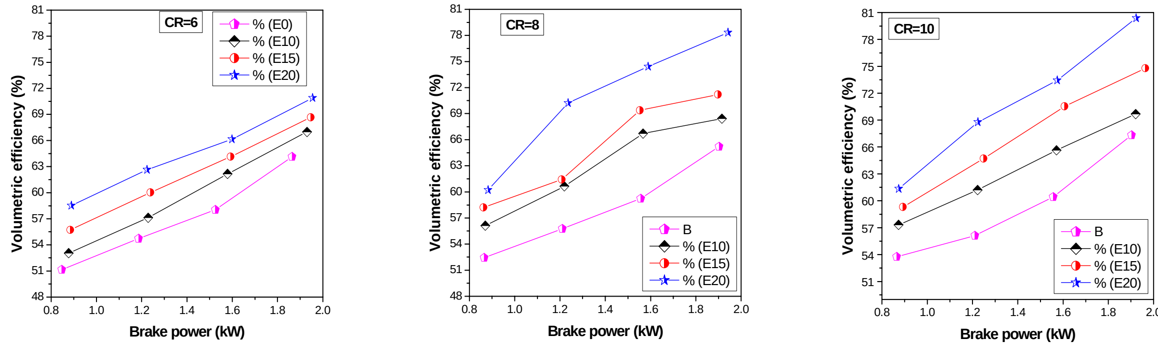
(a) (b) (c)

Fig. 2: Variation of brake thermal efficiency with brake power for different gasoline-ethanol blends at different compression ratios (a) 6:1, (b) 8:1, (c) 10:1.



(a) (b (c)

Fig. 3: Variation of brake specific fuel consumption with brake power for different gasoline-ethanol blends at different compression ratios (a) 6:1, (b) 8:1, (c) 10:1.



(a) (b) (c)

Fig. 4: Variation of volumetric efficiency with brake power for different gasoline-ethanol blends at different compression ratios (a) 6:1, (b) 8:1, (c) 10:1.

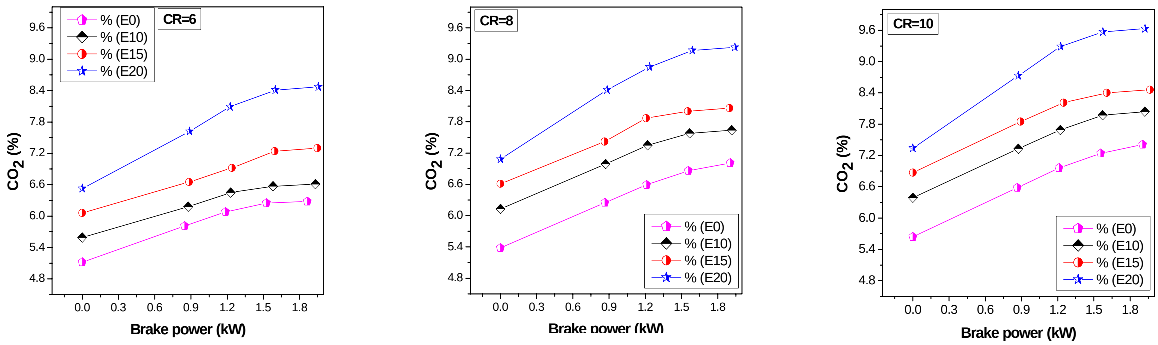
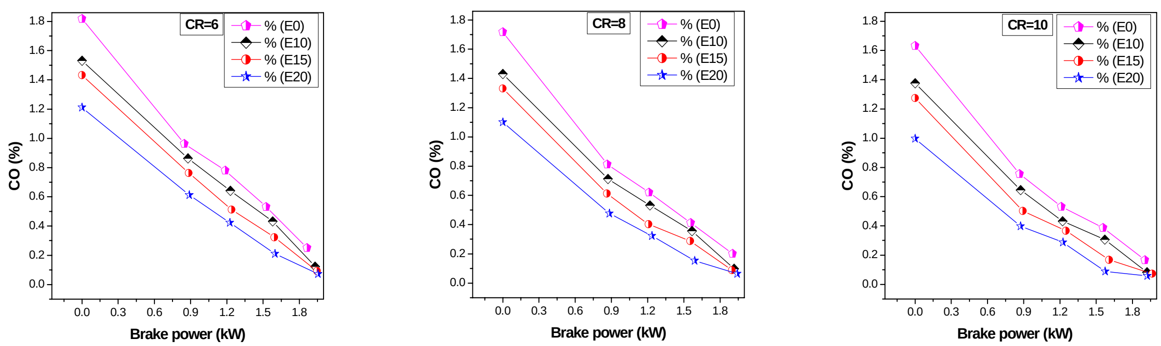
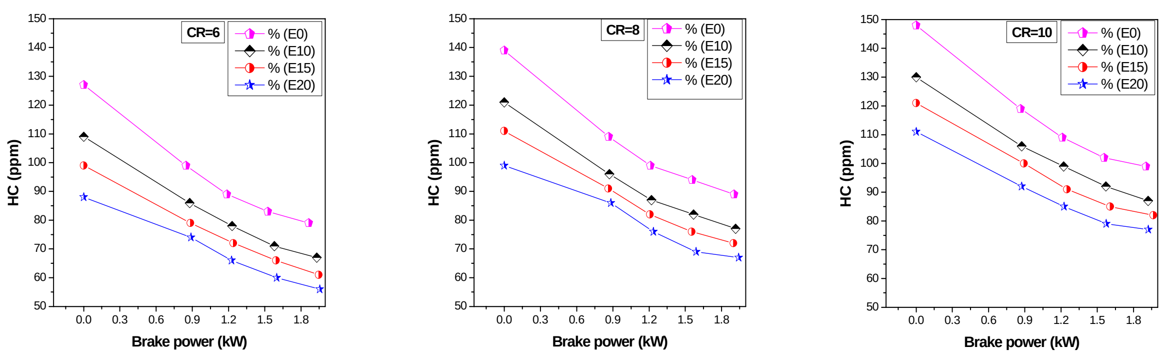


Fig. 5: Variation of CO_2 with brake power for different gasoline-ethanol blends at different compression ratios (a) 6:1, (b) 8:1, (c) 10:1.



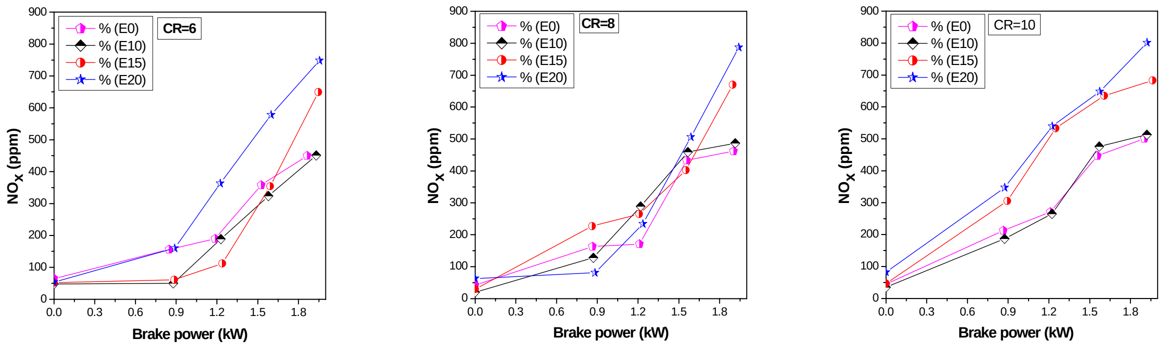
(a) (b) (c)

Fig. 6: Variation of CO with brake power for different gasoline-ethanol blends at different compression ratios (a) 6:1, (b) 8:1, (c) 10:1.



(a) (b) (c)

Fig. 7: Variation of CO_2 with brake power for different gasoline-ethanol blends at different compression ratios (a) 6:1, (b) 8:1, (c) 10:1.



(a) (b) (c)

Fig. 8: Variation of NO_X with brake power for different gasoline-ethanol blends at different compression ratios (a) 6:1, (b) 8:1, (c) 10:1.

5. CONCLUSIONS

The following conclusion can be drawn from this experimental investigation on ethanol-gasoline blends. The brake thermal efficiency increased but the BSFC decreased with the increase in compression ratio and ethanol percentage in the blend, the volumetric efficiency was maximum for E20 blend and compression ratio 10:1. CO_2 emission increases and emission of CO decreases with the ethanol percentage in the blend and also decreases due to increasing compression ratios and brake power. HC emission was slightly increases with the increase of compression ratios. HC emissions decrease with increase of ethanol in the blends. In general, No_x emissions decrease with ethanol percentage in the fuel. But, NO_x emission depends upon the operating conditions also. At low loads, No_x emission is less and at higher loads, it is more. The addition of 20% ethanol to the gasoline gave the best results of the engine performance and exhaust emissions and it was achieved in our experiments without any problems during engine operation.

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