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Performance and emission characteristics of a VCR SI engine fueled with ethanol/gasoline blends

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ABSTRACT

Alternative fuels have become a centre of attraction these days due to its capability of reducing the dependency on fossil fuels and harm to the environment. Alcohol such as ethanol is considered as a clean and alternative fuel for SI engines when it is used in blends with gasoline in different fractions to increase oxygen content. In this experimental investigation, ethanol obtained from sugarcane waste was used in fuels prepared by blending it in increasing ratios (5, 10, 15 and 20 vol.%) with oxygen free gasoline. These ethanol/gasoline blended fuels were used to assess the combustion and emission characteristics of a VCR SI engine. Constant speed of 1300 rpm was maintained during the whole experimentation and the compression ratios were varied as 6, 7 and 9 respectively. Results showed that the ethanol - gasoline blends with 20 vol.% presented the highest volumetric efficiency, torque and brake power, whereas, the ethanol - gasoline blends of 5 vol.% presented the lowest volumetric efficiency, torque and brake power among other blends. Gasoline on the other hand showed the lowest volumetric efficiency, torque and brake power among all the test fuels. Also, the CO and UHC emissions were significantly reduced with the increase of ethanol content in the fuel blends, which indicates an efficient combustion. The impacts of compression ratios on the engine were also observed. The lowest values of CO and UHC emissions were observed at the compression ratio of 6 and with E20 blends. Ethanol – gasoline blends comprising 20 vol.% ethanol and 80 vol.% gasoline provided a better performance among all the blends used for the experimentation.

Keywords— *Alternative Fuels, Blends, Ethanol, Gasoline, VCR Engine*

1. INTRODUCTION

Environmental issues have always been a matter of significant concern over the past decades. Growing population and rise in economy are accompanied by increased materials and energy demands. Excessive usage of fossil fuels such as gasoline, diesel, etc. as an energy resource has led to several environmental consequences. If emissions of carbon monoxide (CO), unburnt hydrocarbons (UHC) and nitrogen oxides (NO_x) from an engine are to be reduced without much affecting the engine performance then ethanol proves to be an effective alternative fuel for serving the purpose [1, 2]. Since alcohol does not have any sulfur content or complex compounds, it proves to be a suitable alternative fuel for the internal combustion engines. Combustion due to the usage of alcohol fuels gives organic emissions which have lower reactivity eventually promoting the ozone formation substantially [3, 4]. Presence of excessive alcohol content in fuel corrodes the metallic components of the fuel system. Therefore, the engines systems should be redesigned or low blend rates should be used to diminish the corrosion problems [5].

Effects of Brazilian commercial gasoline (E27) and hydrous ethanol (E96) in a flex – fuel engine when operating in lean combustion modes of more than 5% and 12% shows reduction in indicated specific fuel consumption (ISFC) and emissions [6]. J. W. G. Turner et al. [7] studied the effect of ethanol-methanol-gasoline blends at different blend ratios on NO_x and CO_2 emissions. Results showed that dual fuel blends can reduce the CO_2 and NO_x emission more effectively than the neat gasoline. L. Sileghem et al. [8] investigated two different rates of ethanol – methanol – gasoline blends (G29.5 + E42.5 + M28 and G37 + E21 + M42) on CO and NO_x emissions. Results showed that the duel fuel blends can produce less CO and NO_x emission than the neat gasoline but higher than the neat methanol. Battal Dogan et al. [9] investigated the effects of ethanol – gasoline blends on the performance and exhaust emission of a four cylinder – four strokes - spark ignition engine using ethanol - gasoline blends of different blend ratios (E0, E10, E20, and E30) through exergy analysis. By addition of ethanol to gasoline, reduction in CO, CO_2, and NO_x without

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any major loss of power when compared with neat gasoline was achieved. Also, it was noticed that the reduction of the temperature inside the cylinder increases the HC emissions. Paolo Iodice et al. [10] studied the effects of ethanol in gasoline fuel blends in order to determine the effect on fuel consumption and engine out emissions of SI engines in cold operating conditions. Ethanol was extracted from grape pomace and was blended in increasing ratios of 10, 20, and 30 vol% with gasoline. Ethanol – gasoline blends were used as test fuels to evaluate the emissions and energy consumption of a motorbike equipped with a four stroke SI engine. The study reveled that the ethanol added into oxygen free gasoline reduced cold emissions. J. L. S Fagundez et al. [11] investigated the composition of optimal wet ethanol as a fuel in spark ignition engine using net energy factor (NEF) to calculate the energy efficiency of wet ethanol and hydrous ethanol fuel (HEF). The results of net energy factors showed a clear advantage of wet ethanol fuels over HEF; the optimal efficiency was wet ethanol fuel with 70% v/v of ethanol. P. Sakthivel et al. [12] carried out a comparative study on combustion, performance and emission characteristics of a two – wheeler under steady state (wide open throttle – WOT) and transient operating conditions with neat gasoline and 30% ethanol – gasoline blend using chassis dynamometer. In WOT test, CO and HC emissions decreased, however oxides of nitrogen (NO_x) increased with E30 compared to E0. E30 blend provided higher specific fuel consumption but resulted in decreased vehicle power. Delay in heat release rate and increase in combustion duration was also observed with E30. Mass emission studies over IDC test showed a decrease in CO and HC emissions with E30 while HC emission increased marginally. In this study, we aim to investigate the performance and emission characteristics of a VCR SI engine at a constant engine speed of 1300 rpm using the ethanol – gasoline blends at different blend rates (5%, 10%, 15% and 20 vol. %) by varying the compression ratios of a VCR SI engine, which is not presented in the early studies. The influence of the ethanol – gasoline blends on engine performance including the volumetric efficiency, torque, brake power and emissions at different engine compression ratios is examined and compared with that of the neat gasoline, which is also not presented in the earlier studies.

2. EXPERIMENTAL SETUP

2.1 Test engine and fuel preparation

The experiments were conducted on a single cylinder, dual fuel (petrol), variable compression ratio (VCR) engine at open ECU mode. The setup comprises of eddy current dynamometer for loading variations and set up of engine testing software IC Engine soft was compiled for the data collection and analysis purpose. The significant technical information of setup is listed in Table 1.

The ethanol was extracted from sugarcane waste by fermentation using dry yeast. Sugar content of the sugarcane sap is converted to acids, gases or alcohol due to the metabolic reactions during fermentation. A certain amount of sugarcane sap is boiled and poured into a bucket and a required amount of sugar is then added. The dry yeast is then diluted in hot water and added to the boiled sugarcane sap and mixed properly. The bucket opening is then sealed with an aluminum foil sheet. The mixture is then kept sealed inside the bucket for 20 days for the fermentation process to take place. Then the process is carried out by using further distillation. Distillation is a separation process of mixtures such as chemical compounds into its component parts, or fractions, by heating them to a temperature at which vaporization of one or more fractions of the compound will take place. For distillation, a simple pressure cooker with its nozzle connected to one end of a cooling coil is used. The other end of the cooling coil is kept open to provide a way out for ethanol. The ethanol extract is checked for its purity by introducing it to a periodic flame. The properties of ethanol and gasoline are determined. The prepared ethanol is then blended with gasoline in increasing ratios as 5, 10, 15 and 40 vol.%. Then the blends are supplied to engines to evaluate performance of the engine. The fuel properties are given in Table 2.2.

2.2. Performance and exhaust emission measurements

Infralyt CL gas analyzer is used for exhaust emissions and excess air ratio measurements. The gas analyzer is connected to the to the engine via engine exhaust stainless steel tail pipe, which discharged emissions from engine without any dilution into the analyzer at temperature range of 40 – 50 ºC. The gas analyzer measures CO, CO2 and UHC in a range of 0 – 10 vol.% for CO2, for CO 0 – 20 vol.% and 0 – 2000 ppm for UHC as shown in Table 2.3. The measurement technique of the gas analyzer is based on an infrared rays energy transmitted through the flow of exhaust gas to a detector. The rays are interrupted by a rotating wheel producing a sequence of signals. These signals are analyzed by a microprocessor which in turn presents the measurements. However, the engine performance measurements, which include volumetric efficiency, torque and brake power at a constant speed of 1300 rpm are carried out via different sensors and dynamometer connected with the engine, as discussed above.

Table 1: Engine specifications

Characteristics of engine	Technical specifications
Model name	VCR dual fuel research engine
No. of cylinders	1
Number of strokes	4
Diameter of cylinder	87.5 mm
Length of stroke	110 mm
Length of connecting rod	234 mm
Diameter of orifice	20 mm
Length of dynamometer arm	185 mm
Power	3.5 Kw
Speed range	1200 to 1800 rpm
CR range	6:1 to 10:1

Table 2: Fuel properties

Characteristics	Ethanol	Gasoline
Molecular formula	C_2H_5OH	$C_4 – C_{12}$
Molecular weight	46	94 – 120
O_2 content (%)	34.8	0
Density (kg/m^3)	785	740
LHV (MJ/kg)	26.9	44.3
Octane number	108	> 90
Auto – ignition temp. (ºC)	425	228 – 470
Stoichiometric A/F ratio	9.00	14.8
Latent heat of vapor. (kj/kg)	840	305
Boiling point (ºC)	78	38 – 204

Table 3: Gas analyzer technical details

Characteristics of gas analyzer	Technical specification
Model	Infralyt CL
Measuring principle	NDIR
Measuring range	
CO	0 – 10 vol.%
CO_2	0 – 20 vol.%
UHC	0 – 2000 ppm vol.

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O_2	0 – 20 vol.%
Lambda	0 – 9999
r/min	400 – 9999
Temperature	0 – 130 ºC
Exhaust gas temperature range	0 – 600 ºC
Environment operating temperature	5 – 45 ºC
Humidity (rel.) not condensing	< 90%
Warm – up time	< 10 min
Accuracy	OIML class 1 and 0
Power supply	240 V/1 Ph/50 Hz alternative
Weight	Ca. 9 kg
Dimensions (W×H×D)	294 mm × 203 mm × 430 mm
Connectable transducers	Trigger clamp Ignition pulse antenna Dwell angle probe Optical sensor Diagnostic connector Slack point sensor

2.3 Experimental Procedure
The experiment procedure comprises of blend testing and comparison with neat gasoline. VCR SI engine was used for the performance and emission analysis. Four different set of blends namely E5, E10, E15 and E20 and finally gasoline as baseline fuel was imparted in the engine for combustion. The data of the performance of ethanol – gasoline fuel blends was recorded via IC engine soft ware. These experiments were conducted on varying loading condition and at the fixed speed of 1300 rpm. Same cycles of experiments were repeated by changing the compression ratios to 6, 7 and 9 respectively. The fuel used for a period of time was measured in order to determine the fuel consumption. The air properties were almost maintained at all experiments where the tests were conducted at the same ambient conditions, such as surrounding environmental temperature, humidity, etc. All the tests were conducted at the steady state operating temperature of the engine. The data of blended fuel performance was compared with the data of neat gasoline for the purpose of analysis by considering the effect of continuous cycle variations in the outcomes of performance and emissions.

3. RESULTS AND DISCUSSIONS
Every performance and emission data were recorded at the constant speed of 1300 rpm and at varying load conditions

3.1 Performance characteristics
The performance analysis of any fuel in the VCR SI engine can be done on the basis of some basic parameters like Brake power (BP), Torque (Tq), and Volumetric efficiency (VE).

3.1.1 Brake power (BP): Brake power is the power available at the engine crankshaft. It may be input power or output. It is considered output for IC engines whereas for compressor it is considered as input power. From the values in table 4, it is observed that E20 blend has the highest brake power at the compression ratio of 9. The blend E5 provides the lowest brake power at compression ratio of 6. Also, the brake power of the engine increases when the ethanol content and the compression ratio values are increased.

3.1.2 Torque (Tq): Torque, in simple terms is the tendency of a force to rotate an object about an axis. For automobiles the measure of rotational endeavor applied on the engine crankshaft by the piston is termed as torque. The amount of torque that an engine can exert depends upon the engine RPM. The values in table 3.1 show that the torque is max at the compression ratio of 9 for E20 blends. Among the other blends minimum torque is observed for the E5 blends at the compression ratio of 6. It was also observed that the increase in the compression ratio impacts the torque.

3.1.3 Volumetric efficiency (VE): Volumetric efficiency in IC engine is the ratio of the mass density of the air – fuel fusion drawn into the cylinder at atmospheric pressure (during the intake stroke) to the mass density of the same volume of air in the intake manifold. The values from table 3.1 shows rise of the volumetric efficiency when the value of compression ratio and ethanol content increases. The volumetric ratio is at its maximum for E20 blends and at compression ratio of 9. E5 blends at compression ratio of 6 gives the lowest volumetric efficiency among other blends. According to the tabulated values neat gasoline has the lowest volumetric efficiency.

3.2 Emission characteristics
The pollutant emissions of CO, CO_2 and UHC using neat gasoline and ethanol – gasoline blends are summarized in table 3.2. In the table, ethanol – gasoline blends with 5, 10, 15 and 20 vol.% ethanol in gasoline are denoted as E5, E10, E15 and E20. As shown in the table 5, the neat gasoline presents the highest emissions of CO and UHC and the lowest emissions of CO_2 at all the compression ratios. Using blended fuels containing ethanol with gasoline results a significant reduction in CO and UHC emissions, compared to neat gasoline fuel. This is because of the oxygen content in the blended fuels, which enhances the combustion process significantly.

The changes in CO_2 emissions have an opposite manner when compared to the CO and UHC emissions concentration; CO_2 emissions increase while the CO and UHC emissions decrease as shown in table 2. The reason of emissions trends could be explained in details as follows. Ethanol contains oxygen atoms in their basic forms, see table 1.

When ethanol is added to gasoline fuel, it can provide more oxygen for the combustion process and that leads to the so – called ethanol leaning effect. Blended fuels, therefore, can be treated as partially oxidized hydrocarbons. Owing to the partially oxidized and the leaning effects of blended fuels, CO and UHC emissions decrease tremendously and CO_2 emissions increase. The compression ratio also plays a significant role in the emissions from an engine. Furthermore, as the compression ratio is increases CO and UHC emission decreases. However, CO_2 emission increases with the increase of compression ratios. The lowest values of CO and UHC emissions can be observed at the compression ratio of 6 with E20 blends.

Table 4: Performance of gasoline and blended fuels

Compression Ratio	Gasoline			E5			E10			E15			E20		
	BP (kW)	Tq (Nm)	VE (%)	BP (kW)	Tq (Nm)	VE (%)	BP (kW)	Tq (Nm)	VE (%)	BP (kW)	Tq (Nm)	VE (%)	BP (kW)	Tq (Nm)	VE (%)
6	1.06	2.23	0.14	1.12	2.25	0.18	1.20	2.29	0.23	1.21	2.31	0.25	1.25	2.37	0.30
7	1.10	2.38	0.19	1.16	2.27	0.22	1.23	2.32	0.26	1.24	2.34	0.28	1.27	2.39	0.32
9	1.16	2.44	0.25	1.22	2.30	0.26	1.28	2.36	0.30	1.30	2.40	0.33	1.34	2.42	0.37

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Table 5: Pollutants emitted from gasoline and blended fuels

Compression Ratio	Gasoline			E5			E10			E15			E20		
	CO (%)	CO_2 (%)	UHC (ppm)	CO (%)	CO_2 (%)	UHC (ppm)	CO (%)	CO_2 (%)	UHC (ppm)	CO (%)	CO_2 (%)	UHC (ppm)	CO (%)	CO_2 (%)	UHC (ppm)
6	4.6	4.30	190	3.80	4.71	185	3.75	4.65	164	3.69	4.82	157	3.34	5.12	152
7	4.55	4.66	186	3.72	4.68	179	3.60	4.54	162	3.50	4.74	155	3.20	5.04	146
9	4.49	4.50	180	3.64	4.42	176	3.58	4.32	158	3.36	4.62	150	2.98	4.92	142

4. CONCLUSION

The above analysis of ethanol – gasoline blends on VCR SI engine leads to the outcomes that at every operating parameter the brake power, torque and the volumetric efficiency of the E20 blends will be higher than all the other blends and also than the neat gasoline. Also, CO and UHC emissions decreases with the increase of ethanol contents in the blends. However, the CO_2 emissions increases with the increase of ethanol content in the blends. This happens due to the efficient combustion of blended fuels; more efficient is the combustion, more will be CO_2 emissions. As the ethanol content increases so does the engine performance and emissions except CO_2 is reduced to an effective exent. The compression ratio of the engine also makes a significant impact on its performance and emissions. The ethanol gasoline blends provides a better performance than the neat gasoline. Overall, it can be stated that the ethanol – gasoline blends on the basis of complete analysis by keeping loads and compression ratios as the variable function has the potential to be utilized as an alternative fuel in SI engines.

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