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Performance and emission analysis of single cylinder SI engine using bioethanol-gasoline blend produced from Salvinia Molesta

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Abstract. Rapid depletion of world's crude oil reserve, rising global energy demand and concerns about greenhouse gases emission have led to the high-level interest in biofuels. The biofuel, bioethanol is found as an alternative fuel for SI engines as it has similar properties those of gasoline. Higher areal productivity with fast growth rate of microalgae and aquatic weeds makes them promising alternative feedstocks for bioethanol production. In this study, bioethanol produced from S.molesta (aquatic weed) using combined pre-treatment and hydrolysis followed by fermentation with yeast was used to make bioethanol- gasoline blend. The quantity of bioethanol produced from S.molesta was 99.12% pure. The physical properties such as density and heating value of bioethanol were 792.2 kg/m^3 and 26.12 MJ/kg, respectively. In this work, the effects of bioethanol–gasoline (E5) fuel blends on the performance and combustion characteristics of a spark ignition (SI) engine were investigated. In the experiments, a single-cylinder, four-stroke SI engine was used. The tests were performed using electric dynamometer while running the engine at the speed (3200 rpm), and seven different load (0, 0.5, 1, 1.5, 2, 2.5 and 3 kW). The results obtained from the use of bioethanol–gasoline fuel blends were compared to those of gasoline fuel. The test results showed an increase of 0.3% in brake thermal efficiency for E5. From the emission analysis, reduced emissions of 39 ppm unburned hydrocarbon, 1.55% carbon monoxide and 2% smoke opacity, respectively was observed with E5 at full load. An increase in CO2 by 0.17% and NOx by 86.7 ppm was observed for E5 at full load.

1. Introduction

The depletion of fossil energy resources, escalating prices of petroleum reserves with increased greenhouse gas emissions have forced researchers to use alternative fuels for energy needs[1]. Bioethanol is considered as a promising alternative fuel for SI engines due to its higher octane number and lower emissions of carbon monoxide, particulates, unburned hydrocarbon and carbon dioxide [2, 3]. The bioethanol can be produced from sugar bearing feedstocks like sugar cane, sweet potato, potato and lignocellulosic feedstocks like wood, grass, microalgae and aquatic weeds (freshwater and sea weed) [4]. The production of bioethanol from microalgae and aquatic weeds like S.molesta are quite promising due to its higher biomass productivity and lesser land requirement for its cultivation [5]. S.molesta (Kariba weed) is an aquatic weed found abundantly as a free floating plant on the fresh water bodies like ponds, lakes, dams causing the problems like clogging of hydroelectric dams, restricts irrigation and makes the water unsuitable for drinking purposes [6].

Characteristics of bioethanol such as octane number and specific gravity make it significant substitute of gasoline for modern spark-ignition (SI) engines. Bioethanol have cetane number lesser than diesel which does not provide sufficient self-ignition quality to use it in the compression-ignition engines. However, it can also be added with diesel to form bioethanol-diesel blends to reduce exhaust emissions for compression-ignition engines [7, 8]. Ethanol–gasoline blends are represented by an 'EX', where E stand for type of blend (bioethanol-gasoline) and X stands for percentage of bioethanol in the blends such as E5, E15, or E90. Bioethanol also have some disadvantages like less energy density as compared of gasoline. However, it is considered as high energy efficient fuel. One of the differentiable characteristics of bioethanol from other fuels is that it contains high oxygen content, so that called as oxygenated fuel. The existence of high oxygen content in bioethanol leads the better combustion of the blends with improved performance characteristics in SI engines [9, 10].

Numerous studies have been done over past recent years on the effect of the bioethanol-gasoline blends on performance analysis from spark-ignition engines. It has been seen that some emissions such as CO, UBHC and smoke can be decreased by using bioethanol-gasoline blends but not others such as CO_2, NOx. A/F ratio is one of the most emissions affecting property and emissions of CO, UBHC are strongly depending on A/F ratio [11]. As A/F ratio increases, CO and UBHC emissions decrease. Regarding decreased emissions, HC and CO emissions were observed to reduce with increased bioethanol quantity in bioethanol-gasoline blends [12]. This happens because of the presence of high oxygen content which acts as an oxidizing agent. HC emissions is also lead by the flame quenching which happens at the combustion chamber wall and the absorption of fuel vapor into oil layers on the cylinder wall during intake and compression, followed by desorption of fuel vapor into the cylinder during expansion and exhaust [13]. Uncontrolled increased emission of NOx has been reported while increasing bioethanol in blends, but these are not significant and consistent in many of the cases [8]. It may be because of higher oxygen availability in blends at the higher temperature but NOx emissions should be decreased theoretically with increased bioethanol content in blends because of the reasons discussed.

In this study, bioethanol produced from S.molesta (aquatic weed) using combined pre-treatment and hydrolysis followed by fermentation with yeast was used to make bioethanol-gasoline blend (E5). The effects of bioethanol–gasoline (E5) fuel blends on the performance and combustion characteristics of a spark ignition (SI) engine were investigated. In the experiments, a single-cylinder, four-stroke SI engine was used. The tests were performed using electrical dynamometer while running the engine at the speed (3200 rpm), and seven different load (0, 0.5, 1, 1.5, 2, 2.5 and 3 kW). The results obtained from the use of bioethanol–gasoline fuel blends were compared to those of gasoline fuel.

2. Fuel Specification

Fuel properties such as, calorific value and density of bioethanol, E5 fuels were measured and compared with gasoline and are depicted in table 1. Calorific value of bioethanol, 26.12 MJ/kg, measured by using Bomb calorimeter was found a little less than that of ASTM standard, which is 27 MJ/kg. This is because of its impurity mainly contains water.

Table 1. Characteristics of test fuels

Properties	Bioethanol (99.12% pure)	E5	Gasoline
Chemical formula	C_2H_5OH	-	C_4-C_{12}
Calorific value (MJ/kg)	26.12	43.20	44.45
Density (kg/m^3)	792.23	742.38	740.12

3. Performance evaluation of SRIRAM HONDA GK 200 engine

A petrol engine selected for the constant speed load testing of E5 fuel was a single cylinder, constant speed, four stroke SRIRAM HONDA engine, the specifications of which are shown in table 2. A constant speed of 3200 rpm was selected, which is little higher than the rated speed in order to check the performance characteristics at higher loads as compared to rated power. All the readings were taken from zero to full load using electrical dynamometer. Three readings were taken for all parameters at each load and average values were considered for reducing the error. Alternator efficiency was assumed as 80% for the calculation of brake power. The schematic view of the experimental test rig is shown in figure 1.

Table 2. Technical details of testing rig

Model	SRIRAM HONDA GK 200
BHP	2 HP @ 3000 rpm
SFC at rated power	600 g/kWh
Bore	67 mm
Stroke length	56 mm
No. of stroke	4
No. of Cylinder	1
Cooling system	Air cooled
Dynamometer type	Electrical

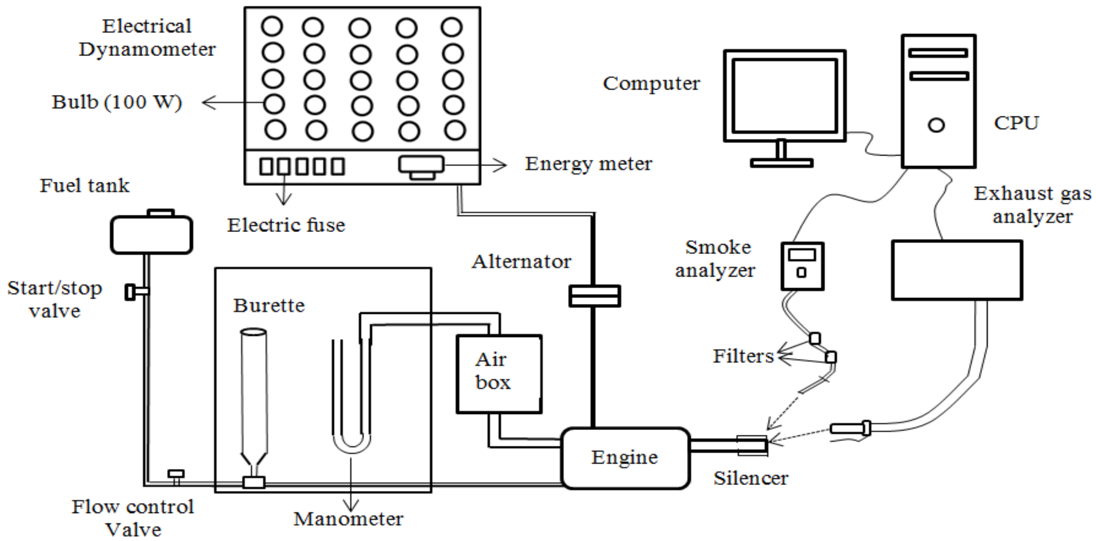

Figure 1. Engine test rig with performance and emission analysis unit

3.1 Performance analysis

The total fuel consumption, brake specific fuel consumption, brake thermal efficiency and A/F ratio were calculated and plotted against BP. The schematic view of test rig is shown in figure 1. Engine performance characteristics were observed with Gasoline alone, and E5.

3.2 Emission analysis

Relative volumes of CO, HC, O_2, NOx and CO_2 in exhaust gases from the single cylinder, four stroke SI engine were measured using AVL DiGas 444 exhaust gas analyzer with RS232 cable. The temperature of the catalyst has been measured with K type thermocouple and data are stored using data logger. Continuous observations were taken at every load and final measurements were calculated by taking averages of minimum 4 observations. The AVL 437C smoke meter was used to measure the opacity of exhausted gases. The opacity is the extinction of light between light source and receiver. Measurements have been taken according to the same test procedure, explained above. Exhaust gas analyzer and smoke meter range, accuracy and uncertainties details are shown in table 3.

Table 3. Details of Exhaust gas analyzer and smoke meter range, accuracy and uncertainties

Model of gas analyzer measured quantity	AVL DiGas 444 Exhaust Gas Analyzer		
	Range	Accuracy	Uncertainties (%)
CO	0-10%	±0.02%	±0.2
CO2	0-20%	±0.3%	±0.15
HC	0-10000 ppm	±20 ppm	±0.2
NOx	0-5000 ppm	±10 ppm	±0.2
	AVL 437 Smoke meter		
Smoke	NA	0.01%	±1.0

4. Results and discussion

4.1 Performance analysis of the engine using gasoline and E5

4.1.1 Brake thermal efficiency (η_{bth}). Brake thermal efficiency is defined as brake power of a heat engine as a function of thermal input from the fuel. It was calculated by using equation (1).

$$\eta_{bth} = \frac{B.P}{m_f \times C.V} \quad (1)$$

where, *B.P* is brake power, m_f is mass flow rate of fuel, and *C.V* is calorific value of fuel used. It was noticed that the brake thermal efficiency of the engine higher using E5 as compared to that using gasoline as shown in figure 2. This may be because of higher effect of the low calorific value of E5 than its TFC. There is not any significant improvement of brake thermal efficiency for gasoline and E5 has been seen at low BP till 0.6 kW. The maximum brake thermal efficiencies, 14.04 and 14.18% were observed for gasoline and E5 at the BP of 2.3925 and 2.4023 kW respectively. The maximum improvement of 2.44% of brake thermal efficiency was observed at the BP of 1.978 and 1.974 kW for gasoline and E5.

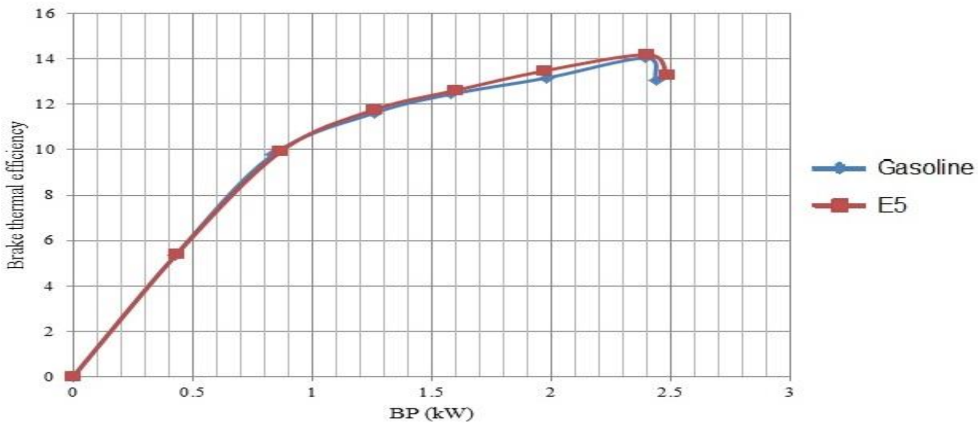

Figure 2. Variation of brake thermal efficiency with brake power

4.1.2 Brake specific fuel consumption (BSFC). It is the fuel flow rate per unit brake power output. It measures how efficiently an engine is using fuel supplied to produce work. It was calculated using equation (2).

$$BSFC = \frac{m_f}{B.P} \quad (2)$$

where, m_f is mass flow rate of fuel used and *B.P* is brake power.

Figure 3 shows the comparison for BSFC of gasoline and E5 for different loading. BSFC first decreased, reach at lowest point and then increased with increasing load for both gasoline and bioethanol. This is because of reduction of heat loss due to higher opening of throttle at higher loadings. The theoretical A/F ratio of gasoline is 1.6 times higher than bioethanol [52]. It has been seen that BSFC for E5 is little higher than gasoline. This is because of higher TFC of E5 for producing same output power as compared to gasoline. It was seen that after BP of 1.8 kW, there is not any significant difference in BSFC for gasoline and E5. The lowest BSFC, 0.576 and 0.587 kg/kWh for gasoline and E5 were observed at the BP of 2.3925 and 2.4023 kW, respectively.

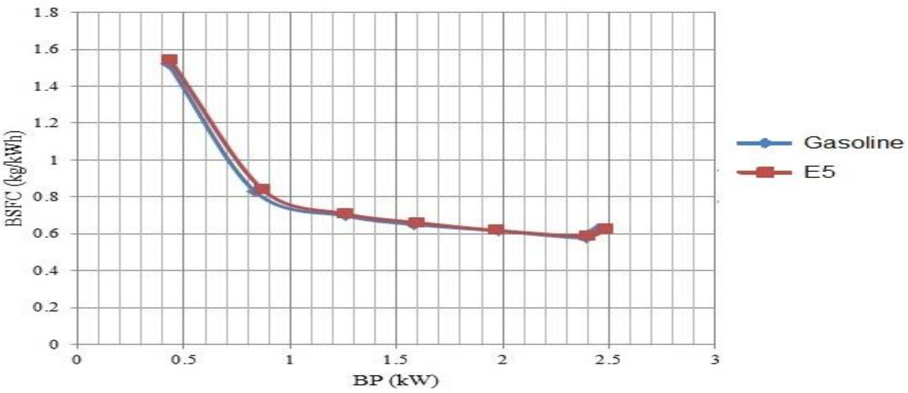

Figure 3. Variation of brake specific fuel consumption with brake power

4.1.3 A/F ratio. A/F ratio is useful to know the engine operating conditions. As load increases, A/F ratio decreases because of higher fuel consumption to produce required power output. It was calculated using equation (3).

$$A/_F = \frac{m_a}{m_f} \tag{3}$$

where, m_a is mass flow rate of air and m_f is mass flow rate of fuel used.

Engines runs with slightly lean A/F mixture at no load and rich A/F mixtures at higher loads. A/F ratios of 14.989 and 15.556 were noted for gasoline and E5, respectively at no load conditions. Theoretically, stoichiometric A/F ratio of gasoline (14.7) is 1.6 times higher than bioethanol [8]. Hence by adding bioethanol with gasoline reduces stoichiometric A/F ratio of blends and provide actual lean A/F ratio. The variation of A/F for gasoline and E5 is shown in figure 4. The A/F ratio for E5 was higher than that of gasoline for all loads. This is because of the presence of high oxygen content in E5, which leads to more efficient and complete combustion as compared to gasoline.

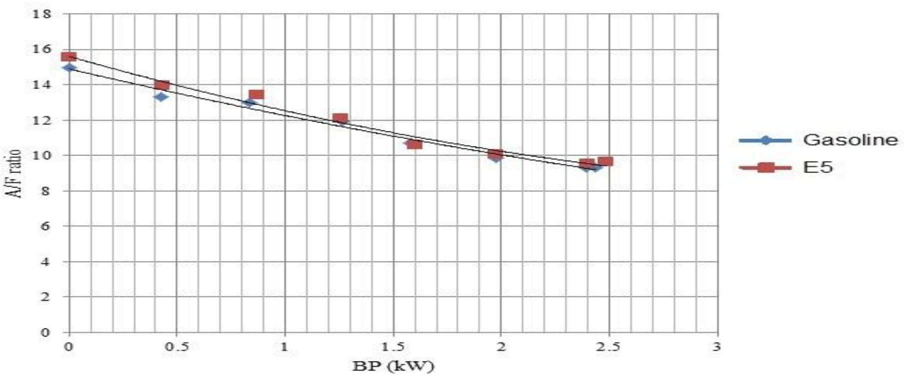

Figure 4. Variation of A/F ratio with brake power

4.2 Emission analysis of the engine with Gasoline and E5

4.2.1 Unburnt hydrocarbon. (UHBC). UBHC emissions in SI engine may happen due to flame quenching or incomplete combustion (partial burning or complete misfire). It strongly depends on A/F ratio. As A/F ratio decreases, UBHC emission increases as shown in figure 5. A little reduction in UBHC emission using E5 as fuel was observed compared to gasoline. This may be because of more efficient combustion of E5 due to presence of high oxygen content and higher A/F ratio as compared to gasoline. Significant reductions of UBHC for E5 by 8.80, 10.17, 25.25, 23.83, 8.34, 19.66, 43.67, 39.54 ppm as compared to gasoline were recorded.

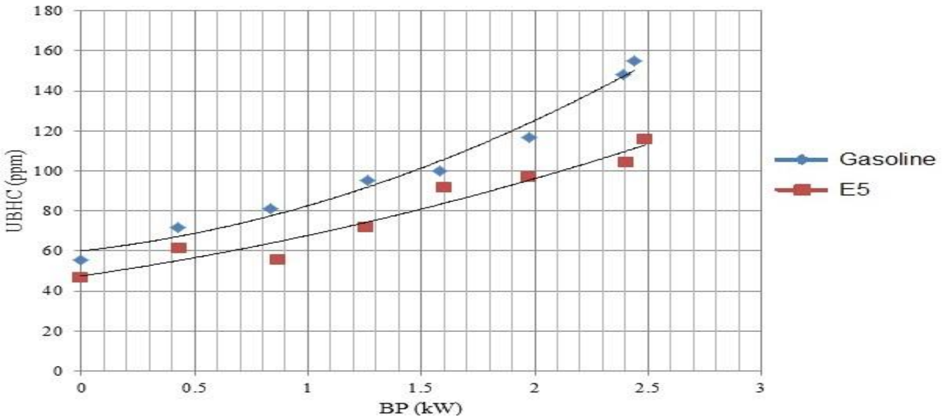

Figure 5. UBHC vs BP

4.2.2 Carbon dioxide (CO_2). CO_2 is the product of complete combustion of fuel in the combustion chamber of the engine. The basic trend of CO_2 emissions is that it decreased with increased load on the engine. This might be due to relatively incomplete combustion of fuels and lower A/F ratios achieved at higher loads. Higher emissions of CO_2 for E5 were observed as compared of gasoline as shown in figure 6. This is because of the more efficient combustion of E5 due to high oxygen content and higher A/F ratio achieved at every load as compared to gasoline. Little increment of CO_2 emissions by 0.215, 0.97, 0.64, 0.76, 0.20, 0.70, 0.175, 0.55% as compared to gasoline were recorded.

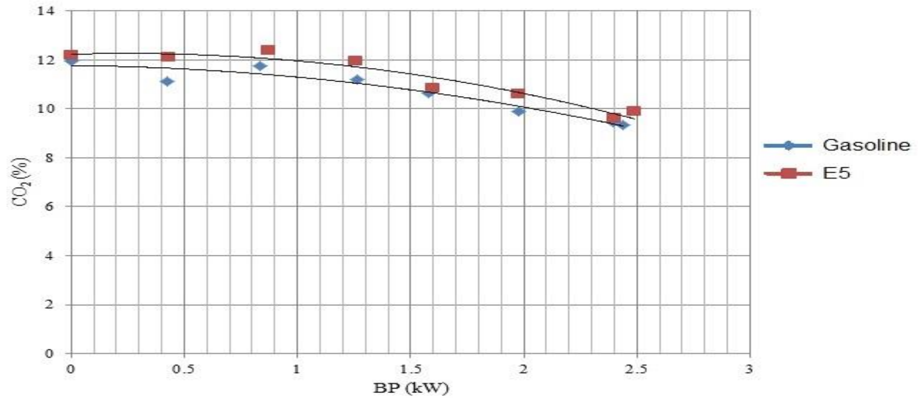

Figure 6. Variation in carbon dioxide emission with brake power

4.2.3 Carbon monoxide (CO). CO is the main constituent as a result of incomplete combustion of fuels in engines and strongly depends on A/F ratio. As A/F ratio decreases, CO emission increases because of incomplete combustion. A significant reduction in the percentage of CO emissions using E5 as compared to gasoline is shown in figure 7. This is because of the higher A/F ratio achieved and efficient combustion of E5 due to high oxygen presence as compared to gasoline. At no load condition, 4.23%

and 3.0% of CO emissions were recorded for gasoline and E5, respectively. Significant reductions of CO emissions by 1.23, 1.96, 1.54, 1.72, 1.10, 0.748, 1.55, and 1.54 % as compared to gasoline were recorded.

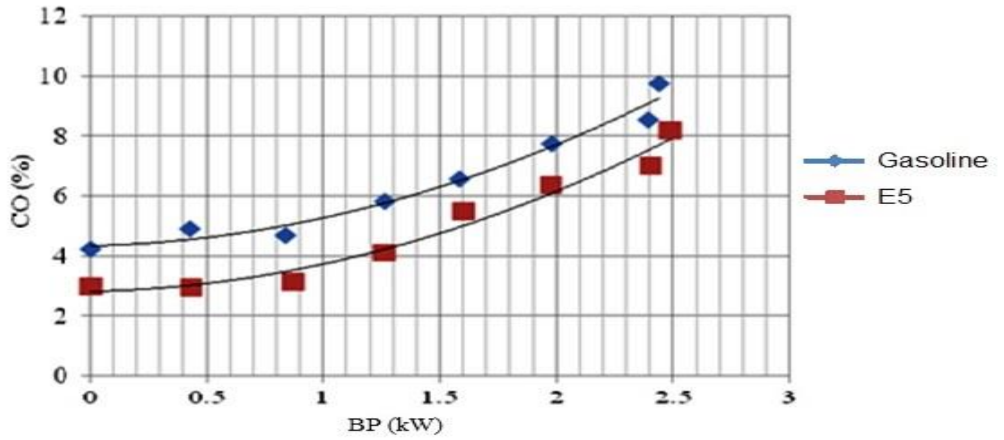

Figure 7. Variation of carbon monoxide emission with brake power

4.2.4 Oxides of nitrogen (NOx). NO_x in the exhaust are due to high oxygen content in the fuel or high temperatures inside the combustion chamber. As load increases, NOx emission increases because of higher temperature at higher loads. Figure 8 shows the comparison of NOx emissions for gasoline and E5. A significant increment in NOx emission for E5 was observed which increased with load. This might be because of the high oxygen content present in E5 as compared to gasoline. Increased NOx emissions for E5 by 18.34, 11.25, 30.25, 59.67, 65.67, 92.67, 86.67, 68.37 ppm as compared to gasoline were recorded.

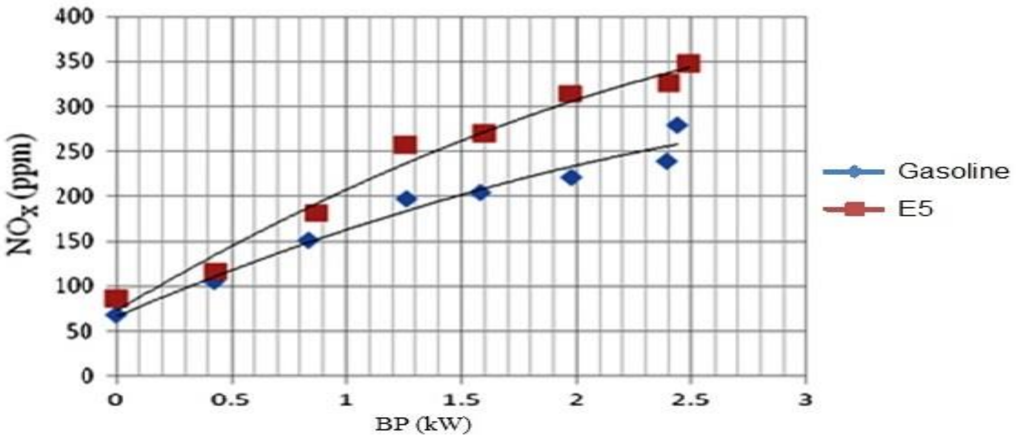

Figure 8. Variation of NOx emission with brake power

4.2.5 Smoke. Smoke is solid particles, usually formed by dehydrogenation, polymerisation and agglomeration reactions which occur inside the combustion chamber. In the combustion process of different hydrocarbons, acetylene (C_2H_2) is formed as intermediate product. These acetylene molecules after simultaneous polymerisation dehydration produce carbon particles. Figure 9 shows the difference in the smoke emission for E5 and gasoline at different loads. A little reduction in smoke emission was observed for E5 as compared to gasoline.

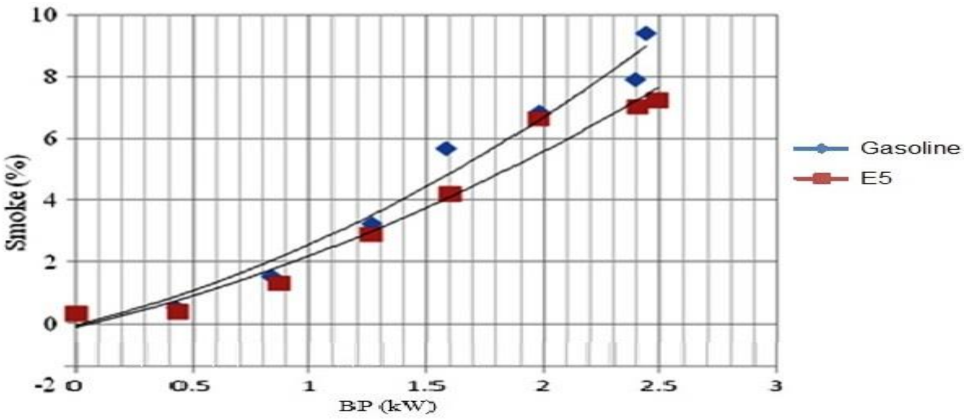

Figure 9. Variation of smoke emission with brake power

5. Conclusion

Salvinia molesta can be used as an alternative feedstock for the production of bioethanol which can be used to make bioethanol-gasoline blends as a fuel for SI engines. The performance and emission analysis of a single cylinder SI engine was analyzed using E5 and compared with that using gasoline. The test results showed an increase of 0.3% in brake thermal efficiency for E5. From the emission analysis, reduced emissions of 39 ppm unburned hydrocarbon, 1.55% carbon monoxide and 2% smoke opacity, respectively were observed with E5 at full load. An increase in CO_2 of 0.17% by volume and increase in NO_x of 86.7 ppm were observed for E5 at full load. It is observed that for E5 blend there is no significant improvement in performance analysis but shows a weighty improvement in emission analysis as compare to that of using gasoline.

References

[1] Balat M 2011 *Energy Convers. Manage.* **52** pp 858-875
[2] Hsieh W, Wu T and Lin T 2002 *Atmospheric Environment* **36** pp 403-410
[3] Al-Hasan M 2003 *Energy Conversion and Management* **44** pp 1547-1561
[4] Mubarak M, Shaija A, Suchithra T. V 2013 *23rd National Conf. on I. C. Engine and Combustion* (SVNIT, Surat, India, 13-16, December 2013)
[5] Singh J and Gu S 2010 *Renew and Sust En rev* **14** pp 1367-1378
[6] Brennan L and Owende P 2010 *Renew and Sust En rev* **14** pp 557-577
[7] Bielaczyc P, Woodburn J, Klimkiewicz D, Pajdowski P and Szczotka A 2013 *Fuel Proc. Tech.* **107** pp 50–63
[8] Schifter I, Diaz L, Rodriguez R, Gómez J P and Gonzalez U 2011 *Fuel* **90** pp 3586–3592
[9] Siddegowda K B and Venkatesh J 2013 *Inter. J. of Innov Res in Sci, Eng and Tech.* **2** (9) pp 2319-8753
[10] Pal A 2014 *Int. J. of Thermal Technologies* E-ISSN 2277 – 4114
[11] Kumar J, Ansari N A, Verma V and Kumar S 2013 *American Journal of Engineering Research* **02** (07) pp 191-201
[12] Canakci M, Ozsezen A N, Alptekin E and Eyidogan M 2013 *Renewable Energy* **52** pp 111-117
[13] Eyidogan M, Ozsezen A N, Canakci M and Turkcan A 2010 *Fuel* **89** pp 2713–2720