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Production of Bioethanol from *Salvinia Molesta* and its Utilization in Single Cylinder SI Engine

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ABSTRACT

Higher areal productivity with fast growth rate of microalgae and aquatic weeds makes them as a promising alternative feedstocks for bioethanol production. In this study, *S.molesta* (aquatic weed) was used for the production of bioethanol using combined pre-treatment and hydrolysis followed by fermentation with yeast. The quantity of bioethanol produced from *S.molesta* was measured using Potassium dichromate test, distilled under vacuum and ordinary condition, and dehydrated using CaO and found to be 99.12% pure. The physical properties such as density and calorific value of *S.molesta* bioethanol were 792.2 kg/m^3 and 26.12 MJ/kg, respectively. The performance and emission analysis of a single cylinder SI engine was analyzed using E5 (5% vol. *S.molesta* bioethanol with 95% vol. gasoline) and compared with that of 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 was observed with E5 at full load. An increase in CO_2 of 0.17% by volume and increase in NOx of 86.7 ppm was observed for E5 at full load.

Keywords- Bioethanol, Fermentation, Density, Calorific value

1. INTRODUCTION

The depletion of world's crude oil reserve and increase in energy demand and greenhouse gases emissions led to the interest in biofuels [1, 2]. The biofuels are solid, liquid and gaseous fuels predominantly derived from organic matter [3]. Biodiesel, bioethanol and biohydrogen, biomethanol, methane, bio-oil, bio-char, biosynthetic gas (bio-syngas), Fischer-tropsch are some of the biofuels [4]. These can be divided in to two major categories: primary and secondary. The primary biofuels consists of firewood, animal waste, forest and crop residue which are used for heating, cooking or electricity production by direct combustion. The secondary biofuels consists of biofuels produced from edible (first generation), non-edible (second generation) and microalgae and aquatic weeds (third generation) [5].

The production of first generation biofuel is limited due to the competition of food versus energy. The second generation biofuels are produced from land based lignocellulosic feedstocks such as Jatropha, cassava, grass which requires large area of land for the cultivation. The lignocellulosic feedstock consists of cellulose, hemicellulose and lignin. Cellulose and hemicellulose content of lignocellulosic materials are converted into simple sugars such as hexose and pentose using saccharification (saccharides hydrolysis) which are further converted into bioethanol through fermentation. The third generation biofuels which uses macroalgae, microalgae and aquatic weeds with less land or no land to grow. One of the most common aquatic weed is *Salvinia molesta* or Kariba weed is a free-floating plant found in most of the freshwater bodies like ponds, lakes, dams. The major problems with *S. molesta* are clogging of hydro-electric dams, restrict irrigation, cause flooding and erosion, reduce suitable habitat for native fish, such as eel and whitebait and it makes the water unsuitable for drinking purposes [6].

In this work, an attempt was made to produce bioethanol from *S.molesta* using combined pre-treatment and hydrolysis followed by fermentation. The physical properties such as density and calorific value of bioethanol were measured and compared with that of gasoline. Then, performance and emission analysis of single cylinder SI engine fuelled with E5 (5% vol.

bioethanol with 95% vol. gasoline) was compared with gasoline.

2. MATERIALS AND METHODS

2.1 Production of bioethanol from S.molesta

S. molesta was collected from the water bodies near Mavoor, Kerala and washed with water to remove dirt and mud and sun dried for 2 weeks and then powdered to the particle size less than 1mm using a mechanical pulverizer. 250 g of powdered *S. molesta* was mixed with 2.5 l H_2SO_4 (1M), and kept for combined pre-treatment and hydrolysis for 30 min using autoclaving at 121^{o}C. The solutions with dissolved sugars (hydrolysates) from the mixture after combined pre-treatment and hydrolysis were filtered using Whatman No.1 filter paper. Then the pH of the solution was adjusted using $Ca(OH)_2$ and 6 g of yeast (*Saccharomyces cerevisiae)* was mixed with 2.5 l of hydrolysate for fermentation. The fermentation was allowed for 5 days at a pH of 5.6 and at room temperature. Bioethanol yields were measured using Potassium dichromate test [5]. The fermented solution was distilled with ordinary distillation apparatus.

2.2 Preparation and characterization of E5 and E10

40 ml (5% v/v) of dehydrated bioethanol was mixed with 760 ml of gasoline to make 800 ml of E5. 1 ml (10% v/v) of dehydrated bioethanol was mixed with 9 ml (90%v/v) to make 10 ml of E10 because only characterization of E10 was done due to insufficient quantity. Calorific value of bioethanol, E5 and E10 were measured by using bomb calorimeter. Density of these fuels was measured by gravimetric method with electronic weighing balance.

2.3 Engine set up details

The schematic diagram of the engine testing setup is shown in Fig.1. The petrol engine selected for the constant speed load testing of E5 fuel was a single cylinder, constant speed, 4-stroke SRIRAM HONDA engine, the specifications of which are shown in Table 1. The engine is coupled to an electrical dynamometer for conducting constant speed load test at 3200 rpm. The time taken for 10 cc of fuel to flow through burette was used for measuring fuel consumption at each load. An exhaust gas analyzer, AVL Digas was used for measuring the emissions such as CO, CO_2, NOx, unburned hydrocarbon. A smoke meter, AVL 437C was used for measuring smoke opacity. Three readings were taken for all parameters at each load and average values were considered for reducing the error.

Table 1 Specifications of the engine

Engine type	Four stroke, SI engine
Number of cylinder	1
Bore and stroke	67 mm x 56 mm
Rated power output	1.49 kW @ 3000 rpm
Compression ratio	9:1
Type of cooling	Air cooled
Dynamometer type	Electrical

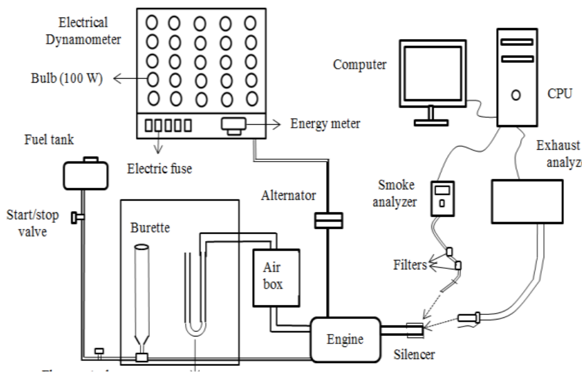

Fig. 1 Schematic diagram of engine set up

3. RESULTS AND DISCUSSION

3.1 Production of bioethanol from S.molesta

62 ml of hydrous bioethanol was produced from 12.21 l of fermented solution (having bioethanol yield of 3.9 g/l) which was produced from *S. molest* using combined pre-treatment and hydrolysis with H_2SO_4 (1M) solution and fermentation using dry *S. cerevisiae* and distillation by using 5 l capacity fabricated ordinary distillation apparatus. Finally, 97.62% v/v bioethanol-water mixture was extracted from 3 cycles of vacuum distillation using rotary vacuum evaporator. 6.2 g (10% w/v) of CaO was mixed with 62 ml bioethanol-water mixture. Process was repeated three times to get maximum possible bioethanol concentration and 54 ml of 99.12% pure bioethanol was measured by Potassium dichromate test.

3.2 Comparison of properties of gasoline, bioethanol, E5 and E10

The physical properties such as, calorific value and density of bioethanol, E5 and E10 fuel were measured and compared with gasoline. As shown in Table 2, the calorific value of bioethanol, 26.12 MJ/kg, measured by using Bomb calorimeter was found a little less than that of ASTM bioethanol standard, which is 27 MJ/kg. This is because of its impurity mainly contains water. The measured properties of all the test fuels are shown in Table 2.

Table 2 Characteristics of test fuels

Properties	Bioethanol (99.12% pure)	E5	E10	Gasoline
Chemical formula	C_2H_5OH	-	-	C_4-C_{12}
Calorific value (MJ/kg)	26.12	43.20	39.45	44.45
Density (kg/m^3)	792.23	742.38	743.58	740.12

3.3 Performance analysis of the SI engine

The performance analysis of the stationary SI engine was evaluated using E5 and compared with that of pure gasoline operation.

3.3.1 Brake thermal efficiency

Brake thermal efficiency is the ratio of brake power output to the chemical energy input. It was noticed that the brake thermal efficiency of the engine was higher with E5 as compared to that using gasoline as shown in Fig. 2. This is because of the lean A/F ratio for E5 which provide more complete combustion. There is not any significant improvement of brake thermal efficiency for gasoline and E5 has been seen at low brake power till 0.6 kW. The maximum brake thermal efficiencies, 14.04 and 14.18% were observed for gasoline and E5, respectively at 2.39 kW. The maximum improvement of 2.44% of brake thermal efficiency was observed at 1.97 kW for gasoline and E5.

3.3.2 Brake specific fuel consumption (BSFC)

BSFC is the fuel flow rate per unit brake power output. It measures how efficiently an engine is using fuel supplied to produce work. As shown in Fig.3, BSFC first decreased, reach at lowest point and then increased with increasing load for both gasoline and E5. This is because of reduction of heat loss due to higher opening of throttle at higher engine loadings. It has been seen that BSFC for E5 is little higher than gasoline. This is because of higher total fuel consumption of E5 for producing same output power as compared to gasoline. It was seen that after brake power 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, respectively were observed at the brake power of 2.39 kW

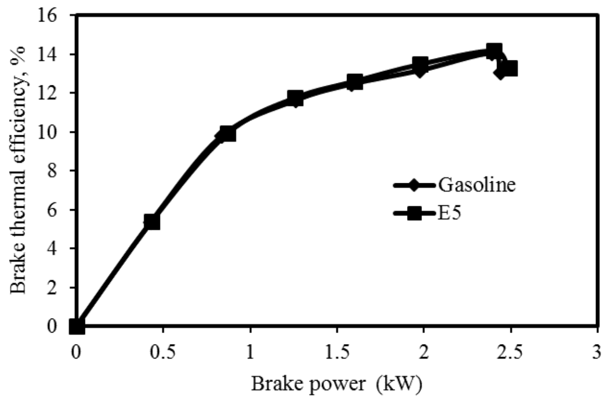

Fig. 2 Variation of brake thermal efficiency with brake power

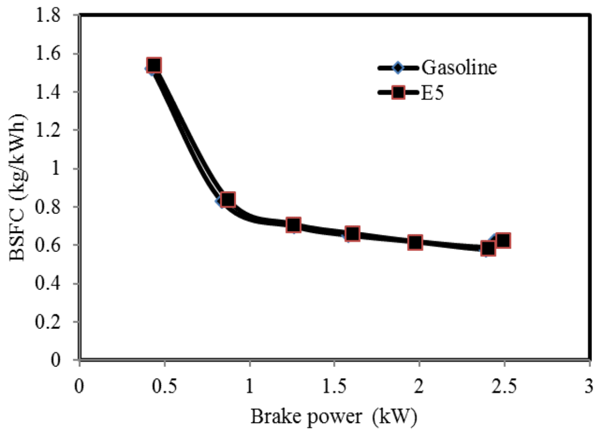

Fig. 3 Variation of brake specific fuel consumption with brake power

3.3.3 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. 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. Hence by adding bioethanol with gasoline reduces stoichiometric A/F ratio of blends and provide actual lean A/F ratio. As shown in Fig.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.

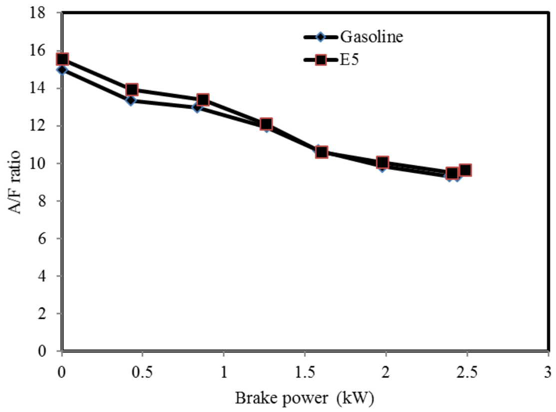

Fig. 4 Variation of A/F ratio with brake power

3.4 Emission analysis of the SI engine

The emissions such as unburned hydrocarbon, CO_2, CO, NOx, smoke opacity of the stationary SI engine were analyzed using E5 and compared with that of pure gasoline operation.

3.4.1 Unburned hydrocarbon (UHBC)

As shown in Fig.5, the unburned hydrocarbon emission increases with increase in brake power for both fuels. This is due to the reduction in A/F ratio with increase in brake power as discussed earlier. With gasoline, the unburned hydrocarbon emission was higher for all loads compared to E5. This can be attributed due to the flame quenching or incomplete combustion (partial burning or complete misfire). A little reduction in UBHC emission using E5 as fuel was observed as 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.

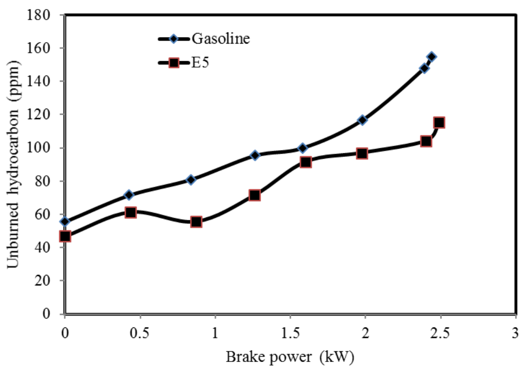

Fig. 5 Variation of unburned hydrocarbon emission with brake power

3.4.2 Carbon dioxide (CO_2)

As shown in Fig.6, the CO_2 emission was decreased with increase in load for both fuels. This might be due to relatively incomplete combustion of E5 and gasoline and lower A/F ratios achieved at higher loads. Higher emissions of CO_2 for E5 were observed as compared of gasoline. 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.

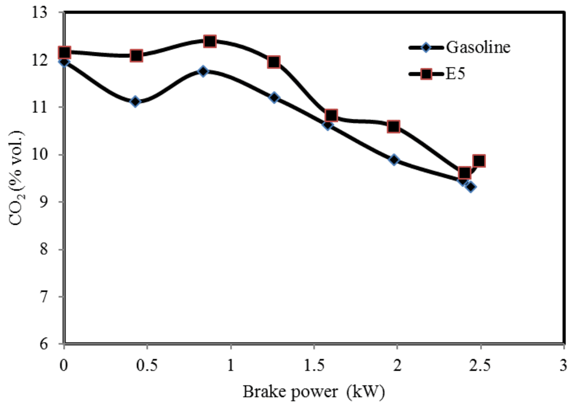

Fig. 6 Variation of carbon dioxide emission with brake power

3.4.3 Carbon monoxide (CO)

CO is the main constituent formed due to incomplete combustion of fuels in engines. It strongly depends on A/F ratio. As A/F ratio decreases, CO emission increases because of incomplete combustion. As shown in Fig.7, a significant reduction in the percentage by volume of CO emissions using E5 as compared to gasoline. 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.

3.4.4 Oxides of nitrogen (NOx)

NO_x in the exhaust are due to high oxygen content in the fuel or high temperatures in the combustion chamber. As shown in Fig.8, NOx emission increased with increase in load for both fuels. This is due to higher temperature at higher loads. A significant increment in NOx emission for E5 was observed which increased with load. This might be because of the presence of high oxygen content in E5 as compared to gasoline.

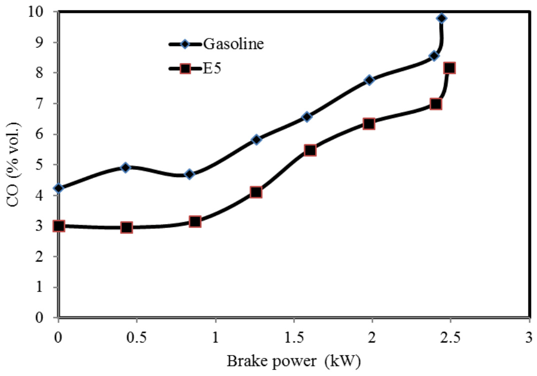

Fig. 7 Variation of carbon monoxide emission with brake power

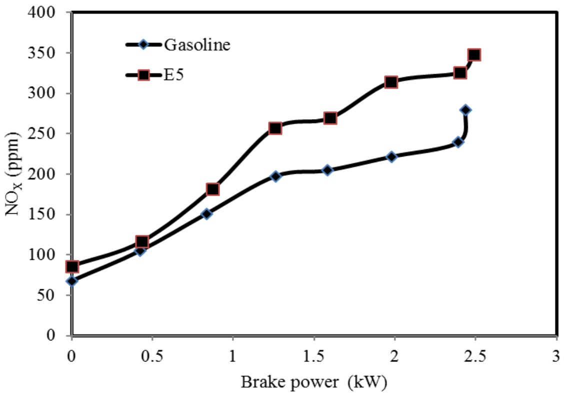

Fig. 8 Variation of nitrogen oxides emission with brake power

3.4.5 Smoke opacity

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. As shown in Fig. 9, the smoke opacity increased with load for both fuels. It was clear that the smoke opacity was lower with E5 as compared to gasoline.

4. CONCLUSIONS

Bioethanol was produced from *S.molesta* and dehydrated using CaO. The physical properties such as density and calorific value of bioethanol, E5 and E10 was measured and compared with gasoline. The performance and emission analysis of stationary SI engine using E5 of bioethanol produced from *S.molesta* was done and compared with that by using gasoline. The following conclusions are drawn:

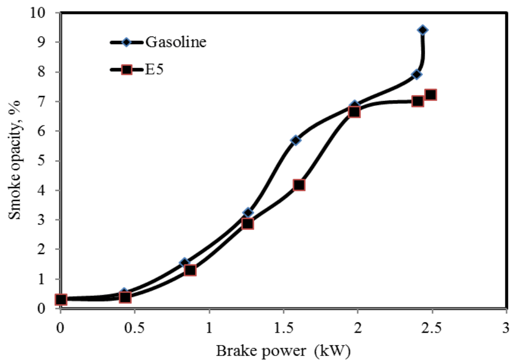

Fig. 9 Variation of smoke emission with brake power

- 54 ml of 99.12% pure bioethanol was produced from *S.molesta* after distillation and dehydration using CaO
- The physical properties such as density, calorific value of bioethanol, E5 and E10 are comparable to that of gasoline.
- The performance analysis of SI engine showed an improvement of 0.4% brake thermal efficiency with E5 as compared to gasoline at 1.97 kW.
- The emission analysis of SI engine, carbon monoxide, unburned hydrocarbon, and smoke were found to be decreased using E5 as compared to that of gasoline. Significant reduction of 43.67 ppm in unburned hydrocarbon and 1.55 and 0.11% in carbon monoxide and smoke, respectively were recorded at 2.40 kW for gasoline and E5.
- Emissions of oxides of nitrogen and carbon dioxide were observed slightly higher as compared to gasoline. The increments of 86.67 ppm and 0.175% in oxides of nitrogen and carbon dioxide, respectively were recorded at the brake power of 2.40 kW for gasoline and E5.

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