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Production of Bio-ethanol from an Underexploited Fruit of *Muntingia calabura* and Studying Performance and Emission Characteristics of Single Cylinder CI Engine

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Abstract: The need of bio-ethanol is being increased now a days, hence the production of bio-ethanol must be increased using cheaper and eco-friendly raw materials. Based on these criteria, underexploited fruits were considered as cheaper and eco-friendly source for bio-ethanol production. In the present study fruits from Singapore cherry (*Muntingia calabura*) was used as raw material to produce bio-ethanol by using *Saccharomyces cerevisiae* (yeast). The results obtained from this work shows that the higher rate of ethanol production through fermentation at the operating conditions (pH 5.5, temperature 30±2°C, speed 80 rpm, fermentation period 15 days) were feasible. The extracted bio-ethanol tested as a fuel in CI engine. Experimental work on performance and emission characteristics of ethanol blended diesel fuel was conducted on single cylinder four stroke CI engines at operating pressure 210 bar with rated speed of 1500 rpm. The different blends of Singapore cherry fruit fuel with diesel were also conducted. The results of this study suggests that fruits from Singapore cherry contain rich fermentable sugars and those can be converted into useful products like bio-ethanol, that serves as an alternative energy source.

Keywords: Bio-ethanol, Singapore Cherry, CI engine, Brake Power

1. Introduction

In the last few decades, the increasing energy requirements along with the need to face the consequences of climate change have driven the search for renewable energy sources, in order to replace as much as possible the use of fossil fuels. The main natural energy resources for example fossil fuel petroleum and coal are being utilized at a rapid rate and these resources have been estimated to last only a few years. Therefore, alternative energy sources such as ethanol, methane and hydrogen are being considered to meet the requirements of the country [1-6]. Some biological processes have rendered possible routes for producing ethanol and methane in large quantities. A world-wide interest in the utilization of bio-ethanol as an energy source has stimulated studies on the cost and efficiency of industrial processes for ethanol production mainly to facilitate automobile industries apart from other utility sectors [7].

Biomass including forest residues, agricultural wastes together with wood, herbaceous plants, crops as well as fruit resources is potentially emerged as huge establishment for Bio-energy. Besides, Ethanol fermented from renewable sources for fuel or fuel additives is known as bio-ethanol. The biofuel like, bio-ethanol, unlike petroleum, is a form of renewable energy source that can be produced from agricultural feed-stocks. The first generation of ethanol production used corn as a substrate, later corn was considered as a feedstock lead to the second generation of production of ethanol which used microorganisms and different wastes as substrates [8-14]. Apart from all these sources, the diversity of non-edible and less edible fruits in India is available at large quantities in different biodiversity locations. Since bio-ethanol is being generated by ethyl alcohol fermentation of agricultural crops, most frequently corn, potatoes, sugar beet, sugar cane etc., the edible and non edible categories of fruit cultivars are of great concern [15-16]. Amongst a fruit source, Singapore Cherry (*Muntingia calabura*) is produced in large scale quantity in most of the regions in India is vastly underutilized. In addition Singapore cherry is also an excellent source of carbohydrates which can be used for the production of ethanol by fermentation.

2. Material and Methods

The pure culture of *Saccharomyces cerevisiae* was obtained from MTCC (Microbial Type Culture Collection Centre, Chandigarh) and cultured on Sabouraud Dextrose Agar (SDA). The cultures were stored at 4°C and sub-cultured every 30 days.

Stirrer type fermenter unit used for fermentation process, the bio-ethanol produced was determined by LC-MS test. After distillation the properties of *Muntingia calabura* bio-ethanol and its blends with diesel were studied. Evaluation of fuel properties for bio-ethanol was done by detecting flash point, fire point, density, kinematic viscosity and calorific value.

Open cup apparatus consists of cup in which the fuel which is to be tested is collected and heated. A fire is bought near the cup and we observed sudden flash which is called flash point and then it catches fire it is called fire point. Electrical thermometer is used to which shows the temperature. As the percentage of blend in Diesel increases flash and fire point decreases.

Redwood viscometer used for the viscosity and density studies. As the percentage of ethanol in Diesel increases, both kinematic viscosity and density was studied. Bomb calorimeter used for the calorific values studies.

Figure 1. *Four stroke Single Cylinder CI engine with electrical loading.*

During Engine Studies, The experiments were conducted on 4 Stroke; Single Cylinder Diesel engine with electrical loading is as shown in figure 1. Engine Specification shown in table-1. Experimental work on performance and emission characteristics of ethanol blended diesel fuel was conducted on single cylinder four stroke CI engines at operating pressure 210 bar with rated speed of 1500 rpm. The various blends of the *Muntingia calabura* fruit produced bio-ethanol with diesel were tested.

Table 1. *Engine specifications.*

Company	Kirloskar
Engine type	Four Stroke Single Cylinder
Power	5.2kW
Stroke	110mm
Speed	1500rpm
Compression Ratio	17.5:1
Cooling	Water Cooled
Fuel injection	Mechanical injection with injection timing 23°bTDC
Injection pressure	210bar

AVL DIGAS 444D gas analyser is used to measure exhaust gas emissions. The below given figure 2. Show the exhaust gas analyser.

Figure 2. *Exhaust gas analyser.*

3. Results and Discussions

The tests mentioned as above were conducted as per the specified procedures and had a satisfactory results and we found that the Singapore cherry produced a good yield, which is 9.7% [17].

The results obtained by performing experiments under pure diesel mode and ethanol blended diesel fuel mode and results are shown in figures 3-10**.**

The properties of bio-ethanol from *Muntingia calabura*and its blends with diesel as shown in table 2.

Table 2. *Properties of fuels.*

Sl.No	Properties	*Percentage of ethanol blends with diesel*				
		0	5	10	15	100
1	Flash point °C	54	52	44	38	18
2	Fire Point °C	60	55	49	41	19
3	Density kg/m^3	839	839.41	839.11	838.92	836.5
4	Kinematic Viscosity mm^2/sec	3.11	2.81	2.73	2.48	1.32
5	Calorific value kJ/kg	43000	42630	42380	42010	19000

Table 3. *Data showing Resolution measurement of Emissions.*

Emissions	Resolutions
HC	1ppm
CO_2	0.01%
CO	0.01%
O_2	0.01%
NO_x	1ppm

Performance and Emission Characteristics were studied as given below.

3.1. Brake Specific Fuel Consumption (BSFC)

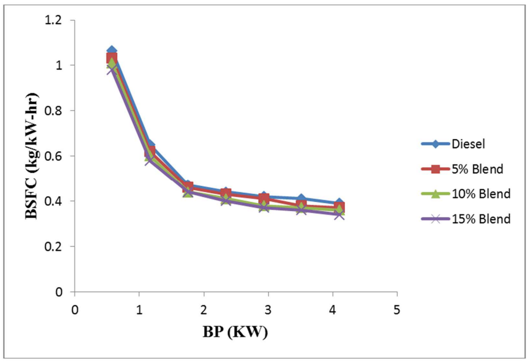

Figure 3. *Variation of BSFC with Brake power (BP) for Diesel and various blend of ethanol.*

The figure 3 illustrates the variation of BSFC with BP for Diesel, 5%, 10% and 15% Ethanol blends. The BSFC decreases with increase in BP for Diesel and for different blends. As compared to Diesel the BSFC are decreased for Ethanol fuel blends due to decrease in Calorific value. Due to the complete combustions of fuels because of more oxygen molecules presence in ethanol blends hence brake specific fuel consumption decreases. At 0.58kW BP the difference between Diesel point and 15% ethanol blend point the BSFC is decreased by 11% compared to Diesel. At 4.11kW BP we observed that there is 5% decrease in BSFC for 15% ethanol blend point than Diesel. So as the percentage of ethanol blend increases the BSFC value decreases respectively. Thus 15% ethanol blend has lower BSFC compared to other blends and Diesel for various loads.

3.2. Brake Thermal Efficiency (BTE)

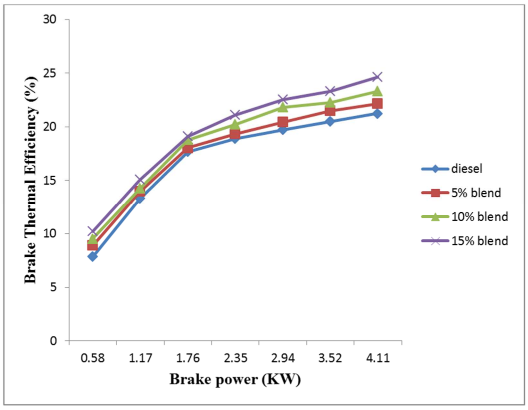

Figure 4. *Variation of Brake thermal efficiency (BTE) with Brake power (BP) for Diesel and various blend of ethanol.*

The figure 4 illustrates the variation of BTE with BP for Diesel and different ethanol fuels blend. The BTE increases with increase in BP for both Diesel and ethanol fuel blends. Due to lower calorific value and higher latent heat of vaporization as the percentage of ethanol fuel blends increases in Diesel the BTE increases as compared to diesel fuels. At 0.58kW BP we observed that there is 18% increase in BTE for 15% ethanol blend compared to Diesel. At 4.11kW BP we observed that there is 11% increment in BTE for 15% ethanol fuel blend compared to Diesel. Thus for 15% ethanol blend has higher BTE compared to other ethanol blends and Diesel for different loads.

3.3. Exhaust Gas Temperature (EGT)

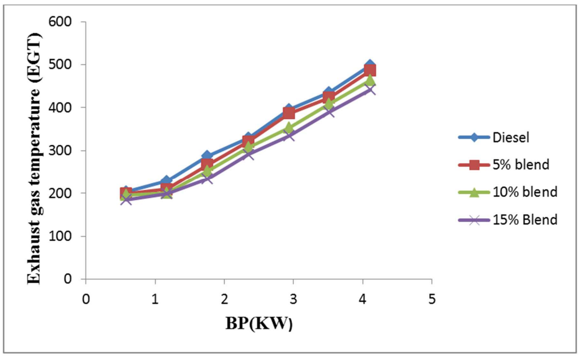

Figure 5. *Variation of EGT with BP for Diesel and various blend of ethanol.*

The figure 5 shows the variation of EGT with BP for Diesel and various percentage ethanol fuel blends. Exhaust gas temperature for ethanol fuel blends decreases as compared to Diesel because as the percentage of ethanol blend increases which increases the oxygen in the fuel blends which gives cooling effect to the engine hence reduces the exhaust gas temperature. Lower calorific value of ethanol fuel blends also decreases the exhaust gas temperature. For 0.58kW BP there is 9% decrease in exhaust gas temperature for 15% ethanol fuel blend as compared to Diesel. At 4.11kW 6% decrease in exhaust gas temperature for 15% ethanol fuel blends compared to Diesel.

Thus for 15% ethanol fuel blend has lower exhaust gas temperature compared to other blends and Diesel for various loads.

3.4. Peak Pressure Rise

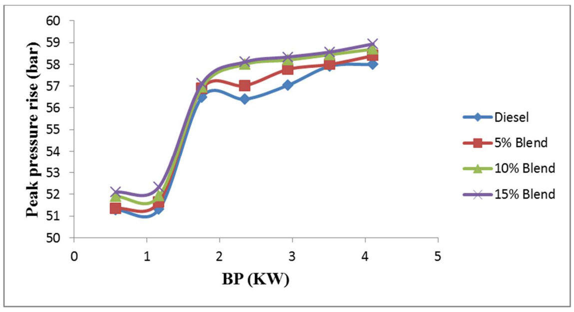

Figure 6. *Variation of Peak pressure rise with BP for Diesel and various blend of ethanol.*

The figure 6 illustrates the variation of Peak pressure rise with BP for Diesel and various percentages of ethanol blends. Ethanol has more content of oxygen and rapid combustion will occur hence sudden peak pressure rise was achieved. As the BP increases the peak pressure rise is higher in ethanol fuel blends and lower pressure rise in diesel for various loads. Thus 15% ethanol fuel blends is having higher peak pressure rise as compared to other fuel blend and diesel for various loads.

3.5. Carbon Monoxide (CO) Emissions

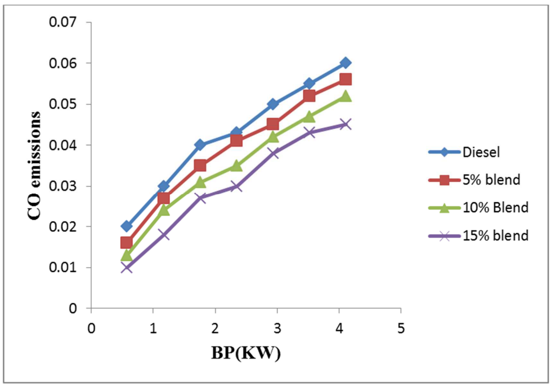

Figure 7. *Variation of CO emissions with BP for Diesel and various blend of ethanol.*

The figure 7 illustrates the variations of CO emissions with BP for Diesel and various ethanol blends. It is indicated that CO emissions are decreased with increase in percentage of ethanol blend compared to Diesel. Ethanol is oxygenated fuel so ethanol blends have more content of oxygen compared to diesel and gives complete combustion and also reduces the emissions of CO. At 0.58kW BP about 36% of CO emissions are reduced for 15% ethanol blend compared to diesel. At 4.11kW BP about 22% of CO emissions are reduced for 15% ethanol blend compared to diesel. Thus graph shows that 15% of ethanol blend has lower CO emissions compared to other ethanol fuel blends and diesel at various loads.

3.6. Carbon Dioxide (CO_2) Emissions

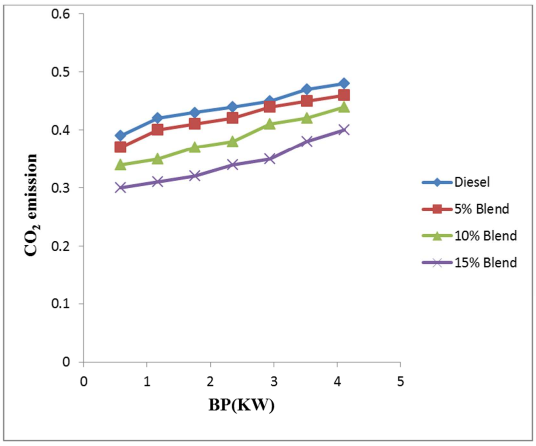

Figure 8. *Variation of CO_2 emissions with BP for Diesel and various blend of ethanol.*

The figure 8 illustrates the variation of Carbon Dioxide (CO_2) emissions with Brake power (BP) for various ethanol fuel blends and diesel. Due to more oxygen content in ethanol fuel blends complete combustion will occur. This result in decrease in CO_2 emissions for ethanol blend compared to diesel. So as BP increase CO_2 emissions will be reduced. At 0.58kW BP about 28% of CO_2 emissions will be reduced for 15% ethanol fuel blend compared to diesel. At 4.11kW BP about 12% of CO_2 emissions will be reduced for 15% ethanol fuel blends compared to diesel. Thus from above graph it is concluded that for 15% ethanol blend has lower CO_2 emissions compared to other ethanol fuel blends and diesel at various loads.

3.7. Hydrocarbon (HC) Emissions

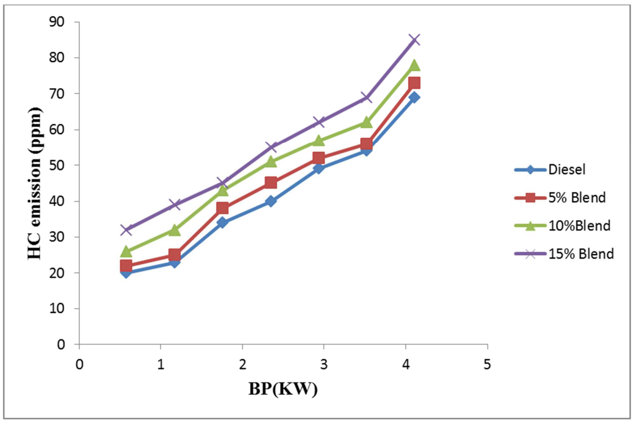

Figure 9. *Variation of HC emissions with BP for Diesel and various blend of ethanol.*

The Figure 9 illustrates the variation of HC emissions with BP for various Ethanol blends and diesel. Ethanol blends having high latent heat of vaporization and low Cetane number, which reduces the exhaust gas temperature and promote the rapid combustion hence with increase in percentage of ethanol blends increases the Hydrocarbon emission compared to diesel. As Brake power increases hydrocarbon emissions also increases with increase in percentage of ethanol blends. At 0.58 kW BP about 31% of hydrocarbon emissions were increased for 15% ethanol blends compared to diesel. Similarly at 4.11 kW BP about 12% of hydrocarbon emissions was increased for 15% ethanol blend than diesel. Thus the above graph shows that there will be increase in HC emissions for ethanol blends compared to diesel for various loads.

3.8. Oxides of Nitrogen (NO_x) Emissions

The figure 10 illustrates the variation of NO_x emissions with BP for various ethanol blends and diesel. The NO_x formation is highly influenced by combustion temperature. From the graphs, it was observed that the NO_x emission increases with the increase in load for diesel and various blended fuels. Moreover at all load ranges, the NO_x emission is less for all blended fuels when compared with that of diesel. The high latent heat of vaporization and lower calorific value of ethanol reduces the cylinder temperature which in turn reduces the

NO_x emissions. At 0.58kW BP about 19% of NO_x emissions were decreased for 15% ethanol blend compared to diesel. Similarly at 4.11kW BP about 10% of NO_x emissions were decreased for 15% ethanol blend than diesel.

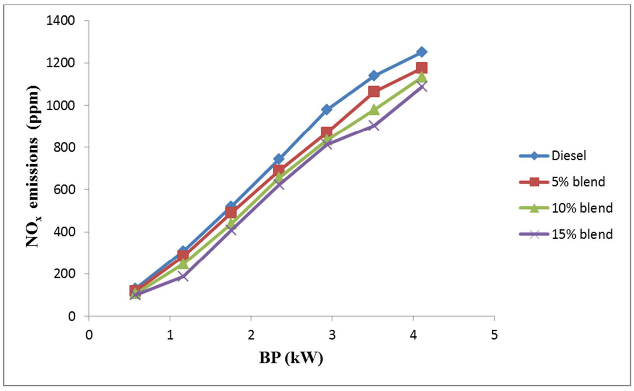

Figure 10. *Variations of NO_x emissions with BP for Diesel and various blends of ethanol.*

4. Conclusions

The produced bio-ethanol from *Muntingia calabura* fruit and analysis of fuel properties and performance and emission characteristics were carried out in single cylinder CI engine and compared. We observed that diesel ethanol blends reduces emissions [18-23].

The results of the experimental work are summarized about the engine study as follows:

(1). The Brake specific fuel consumption (BSFC) of ethanol blended diesel was decreased because ethanol blended diesel have lower calorific value and lower Cetane number compared to diesel. At 0.58kW BP about 8% BSFC was decreased for 15% ethanol blend compared to diesel. At 4.11kW BP about 13% decrease in BSFC for 15% ethanol blend compared to diesel.

(2). The Brake thermal efficiency (BTE) of ethanol blended fuel is increased with increase in Brake power (BP) as compared to diesel. This is because the ethanol blend diesel has more oxygen content and high latent heat of vaporization as compared to diesel which promotes the combustion. At 0.58kW BP about 11% BTE was increased and at 4.11kW BP about 5% BTE was increased compared to diesel.

(3). The ethanol blend diesel has more oxygenated fuel compared to diesel and results in complete combustion. Hence CO emissions were reduced for ethanol blend diesel compared to diesel. At 0.58kW BP about 36% of CO emissions were reduced and at 4.11kW BP about 22% of CO emissions are reduced compared to diesel.

(4). The ethanol blend fuel decreases the CO_2 emissions compared to diesel because of complete combustion. At 0.58kW BP about 28% of CO_2 emissions are reduced and at 4.11kW BP about 12% of CO_2 emissions are reduced compared to diesel.

(5). Due to rapid combustion the hydrocarbon emissions were more for ethanol blend diesel compared to diesel. At 0.58kW BP about 31% of HC emissions will be increased and at 4.11kW BP about 12% oh HC emissions are increased compared to diesel for *Muntingia calabura* fruit ethanol.

(6). NO_x emission increases with the increase in load for diesel and various blended fuels. Moreover at all load ranges, the NO_x emission is less for all blended fuels when compared with that of diesel. The high latent heat of vaporization and lower calorific value of ethanol reduces the cylinder temperature which in turn reduces the NO_x emissions. At 0.58kW BP about 19% of NO_x emissions were decreased for 15%ethanol blend compared to diesel. Similarly at 4.11kW BP about 10% of NO_x emissions were decreased for 15% ethanol blend [24-27].

5. Scope for Future Work

Ethanol has been produced from fruits for long period of time. The *Muntingia calabura* fruit contains more sugars therefore these can be used for the ethanol production to solve energy crisis problem by producing more ethanol in a stable way. The industrial production is not tested so far. The ethanol content can be increased by variety of optimization technique. Co-culturing of *Saccharomy cecerevisiae* with other microbes enhance its production from different perspectives. Therefore *Muntingia calabura* fruit and the yeast fermentation technology are still an area of research interest for the improved production of bio-fuels.

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