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Production of biodiesel from high FFA rice bran oil and its utilization in a small capacity diesel engine

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Biodiesel is gaining momentum in India and rice bran oil (RBO) could be utilized as a possible source of biodiesel. Since industrial grade RBO has high FFA content, base catalyzed transesterification process is not an appropriate method for production of biodiesel. This study reports two-stage formulation process (esterfication followed by transesterification) to convert industrial grade RBO into biodiesel, physio-chemical characterization of biodiesel and run a small capacity, single cylinder, direct injection diesel engine on biodiesel .The performance and emission results of biodiesel are compared with diesel.

Keywords: Biodiesel, Rice bran oil, Transesterification

IPC Code: F02B; C10L 1/00

Introduction

The world has for sometime witnessed growing concern over the environmental impact and/or exhaust of conventional fossil fuel energy sources[1]. These concerns have highlighted the need for diversification and prompted research worldwide into potential alternative sources of fuel energy for internal combustion (IC) engines[2]. In India, diesel engines, being more efficient and sturdier than spark ignition (SI) engines, are frequently used on farms[3], in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipment, etc[4]. Diesel used in diesel engines contains higher amounts of aromatics and sulphur, which cause environmental pollution. Properties of biodiesel are similar to mineral diesel and can be used in conventional diesel engines without significant modifications[5]. Biodiesel is synthesized from direct transesterification of vegetable oils, where the corresponding triglycerides react with a short-chain alcohol, usually methanol in the presence of a catalyst[6].

Rice bran oil (RBO) offers significant potential as an alternative low-cost feedstock for biodiesel production. High viscosity of RBO may contribute to the formation of carbon deposits in the engines, incomplete fuel combustion and result in reducing the life of an engine if used in neat form. Therefore, main objective of present study is to decrease viscosity of RBO by converting it into methyl ester, and to evaluate engine performance using methyl ester of RBO as a fuel. RBO, extracted from rice bran (Fig. 1), is a by product of the pearling process of rice and comprises pericarp, aleurone layer, embryo and some endosperm[7,8]. Bran (8% of milled rice) contains: oil, 15-20; wax, 0.4-1.5; protein, 5-8; soluble carbohydrates, 40-50; and fibre, 5-8%. Typical composition[9] of crude RBO is: triglycerides, 81.3-84.3; diglycerides, 2-3; monoglycerides, 5-6%; free fatty acids (FFAs), 2-3; wax, 0.3; glycolipids, 0.8; and phospholipids and unsaponifiables, 1.6%. Rice bran is invariably high in FFAs. After milling, enzyme in the bran is activated and starts to hydrolyze the oil contained in the bran, which produces excessive FFA. RBO extracted from the bran immediately after the milling of rice is high in FFA (6-8%)[10]. Physico-chemical properties[11] of RBO are: specific gravity, 0.916-0.921; refractive Index $^{25°C}$, 1.470-1.473; acid value, 4-120; saponification value, 181-189; iodine value, 99-108; peroxide value, 2max; and unsaponifiable matter, 3-5%.

Materials and Methods

Industrial grade RBO was procured from a local oil trader of Delhi, India. Diesel was purchased from the nearby petrol pump. All reagents used were of AR Grade.

Experimental Procedure

Acid number (85) of RBO was evaluated by ASTM D-664 to quantify the FFA content (42.5%) in oil. Due to very high FFA, RBO was converted into its

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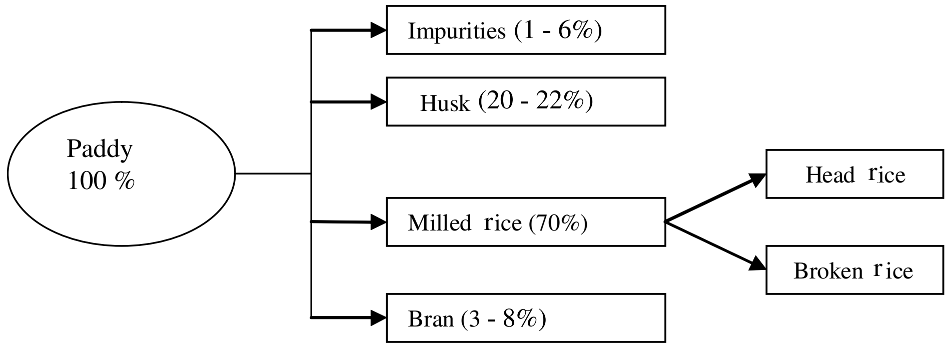

Fig. 1— Composition of raw rice

Table 1— Physico-chemical properties of rice bran oil biodiesel

Property	ASTM Method	Diesel	Rice bran oil biodiesel
Calorific Value, kJ/kg	D 4809	44585	41382
Density, g/cm^3 at room temperature	D-1298	0.831	0.872
Kinematic viscosity @ 40°C, mm^2/s	D-445	3.21	4.81
Acid No., mg.KOH/g	D-664	0.18	0.48
Pour Point, °C	D-97	-17	-4
Flash Point, °C	D-93	76	157
Copper strip corrosion	D-130	1A	1A
Ramsbottom carbon residue, % wt	D524	0.05	0.023
Sulfur, ppm	D-2622	340	11
Lubricity (HFFR Test)	D-6079	450	280
Cetane number	D-613	47.2	51.6

methyl ester by the two-stage process. In the first stage, RBO was reacted with CH_3OH in presence of an acid catalyst (H_2SO_4) to convert FFA into fatty ester. A specified amount (1000 g) of RBO was taken in a round bottom flask and heated up to 60-65°C. In a separate flask, CH_3OH (950 g) and H_2SO_4 (22 g) were taken and properly mixed and then transferred to the round bottom flask containing RBO. The mixture was stirred for 4 h and maintained at 60°C. It was allowed to cool overnight without stirring. When acid number of the mixture reached less than 1, the second stage was started. During this stage, mixture (1000 g) obtained from the first stage was taken in a round bottom flask and heated up to 60°C. Methanol (200 ml) and KOH (4.5 g) were properly mixed in other flask and then introduced into the round bottom flask containing the mixture from first stage. The mixture was stirred vigorously for 2 h and then allowed to cool overnight. Glycerol was separated by adding warm water at 60°C to the mixture. Glycerol and soap formed during the process settled down at the bottom. Top layer containing RBO methyl ester (91 %) was removed with the help of a separating funnel and washed two times with water and dried. Physico-chemical characterization indicated kinematic viscosity of RBO methyl ester (RBOME) near to that of diesel (Table 1).

Engine Test

Single cylinder, direct injection, diesel engine (M/s Perry & Co., India) used for this study is a portable, 4 kWh genset run by diesel fuel. It is widely used in India mostly for agricultural purpose and in many small and medium scale commercial purposes. It is a single cylinder, four stroke, vertical, water-cooled engine having a bore and stroke of 85 and 110mm respectively. The compression ratio is 16.7. At rated speed of 1500 rpm, it develops 4kWh power with diesel as fuel .It has a provision of loading electrically since it is coupled

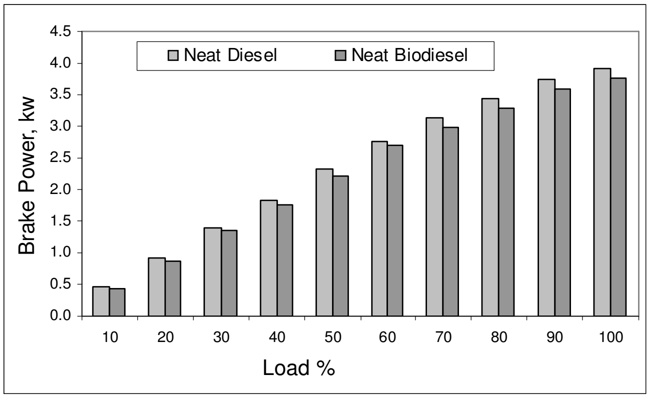

Fig. 2— Brake power vs percent load

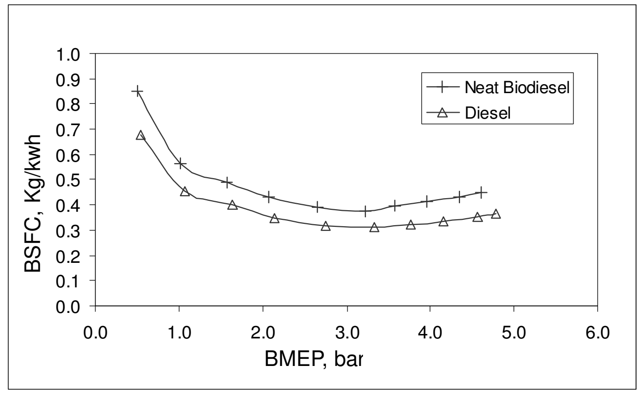

Fig. 4 — BSFC vs BMEP

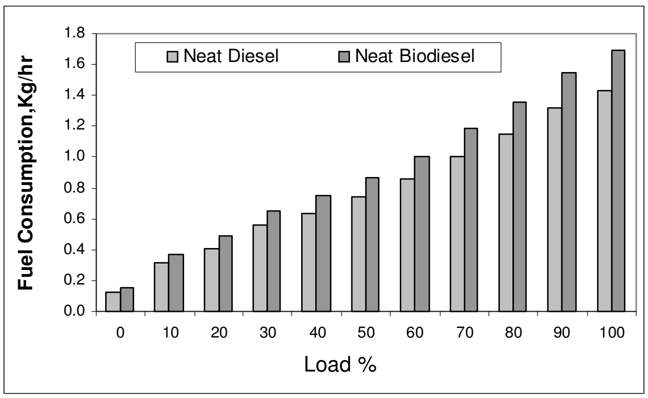

Fig. 3 — Fuel consumption vs percent load

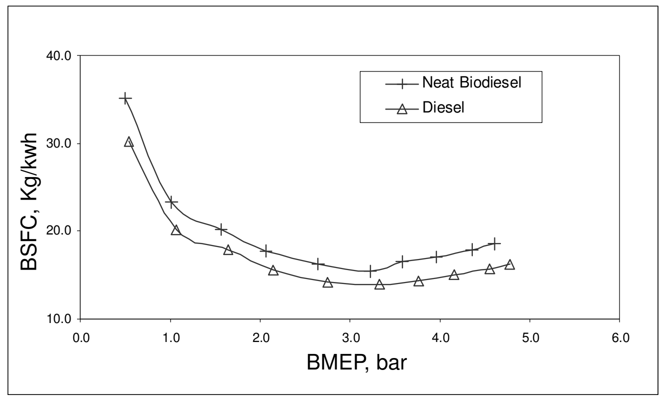

Fig. 5 — BSEC vs BMEP

with a single-phase alternator through flexible coupling. The engine can be hand started using decompression lever and is provided with centrifugal speed governor. The inlet valve opens at 4.5° Before Top Dead Center (BTDC) and closes at 35.5° After Bottom Dead Center (ABDC). The exhaust valve opens 35.5° Before Bottom Dead Center (BBDC) and closes 4.5° After Top Dead Center (ATDC). The 220 V AC alternator coupled with engine has sufficient capacity to absorb the maximum power produced by the engine. Fuel injection pressure was maintained at 200 bar throughout the experiment. The engine was tested with 20, 40, 60, 80% and full rated output and the rated speed of 1500 rpm only. The engine ran smoothly throughout the study and no major problem was reported. The engine produced the rated power and 10 % excess power without any difficulty.

Results and Discussion

The power (Fig. 2) developed by engine at varying load for diesel and biodiesel suggests that maximum power is higher in case of diesel (3.911 kW) than biodiesel (3.757 kW). This is primarily because of less heating value of biodiesel as compared to diesel. Variation of fuel consumption rate for diesel and biodiesel of RBO (Fig. 3) suggests that fuel flow rate is marginally higher in case of RBOME than diesel. Higher density of biodiesel leads to more discharge of fuel for the same displacement of the plunger in the fuel injection pump, thereby increasing fuel consumption rate. Brake specific fuel consumption (BSFC) (Fig. 4) is higher for RBOME than diesel at the entire brake load, because of less heating value and more consumption of RBOME as compared to diesel in the engine. BSFC for RBOME and diesel are as follows: minimum load, 0.848, 0.687; and at maximum load, 0.450, 0.367 kg/kWH.

Since, both the fuels have different calorific values, viscosity and density, BSFC is not a reliable tool to compare the fuel consumption per unit power developed. A better approach is to compare the two fuels on the basis of energy required to develop unit power output, known as brake specific energy consumption (BSEC). The BSEC (Fig. 5) corresponding to maximum load for diesel was 16.311 kJ/kWh whereas for biodiesel it was 18.603 kJ/kWh, which suggests that energy required by biodiesel to develop unit output is more in comparison to diesel.

Brake Thermal Efficiency (BTE) (Fig. 6) for RBOME and diesel are as follows: at minimum load, 10.53, 11.88%; at maximum load, 19.35, 22.07 %.

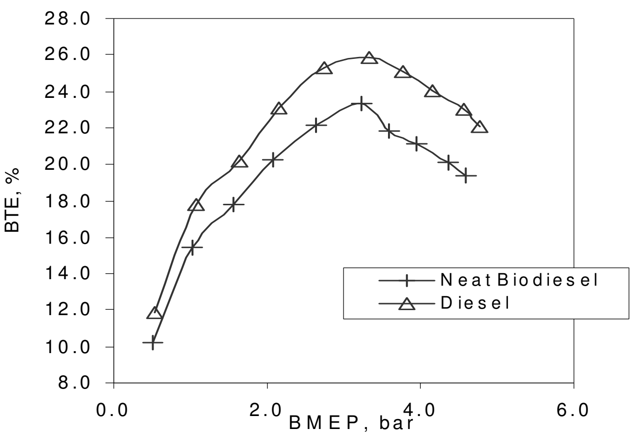

Fig. 6 — Brake thermal efficiency (BTE) vs BMEP

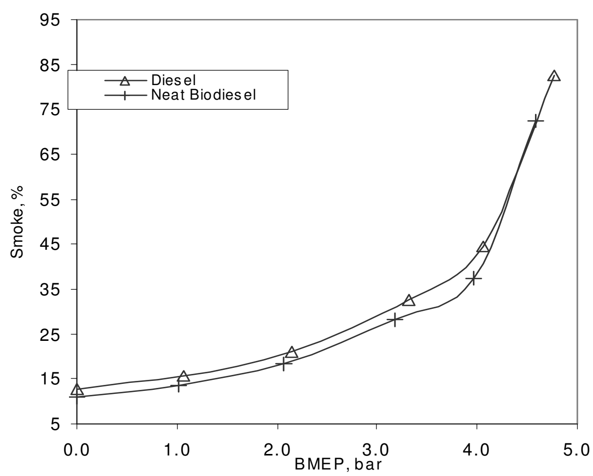

Fig. 7 — Smoke opacity vs BMEP

Efficiency is observed higher in case of diesel than the biodiesel at all values of loads. This could be attributed to inbuilt 10% oxygen content in biodiesel, which helps in better combustion and higher cetane rating of the fuel. Smoke opacity (Fig. 7) has been observed higher in case of diesel than the methyl ester at all value of loads. This is probably because of inbuilt oxygen content and lower sulfur content in biodiesel.

Conclusions

Biodiesel made from high FFA RBO using a two-stage formulation process had viscosity and density similar to diesel. Calorific value of biodiesel was around 7% lower that of diesel. Flash point of biodiesel is quite high as compared to diesel making it safer to store and transport. Sulfur in biodiesel is very low as compared to diesel and is an important feature in term of reduction of SO_2 from the exhaust emission. The HFFR test suggests that lubricity of biodiesel in comparison to diesel is higher. Cetane number is also higher of biodiesel than diesel. Biodiesel was used as a fuel in an unmodified, small capacity diesel engine. The power developed from the engine with biodiesel as a fuel was 4% lower as compared to diesel, because of lower heating value of biodiesel. BSFC and brake specific energy consumption were also higher due to same reason. BTE was higher in diesel as compared to biodiesel. Smoke opacity was lesser of biodiesel than diesel making it more environmental friendly fuel. The study suggests that it is possible to convert high FFA RBO into biodiesel, which has similar properties to diesel and can be used to fuel an existing unmodified diesel engine without any difficulty.

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