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Production of Biodiesel from Castor Oil with its Performance and Emission Test

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Abstract: ***With increase in the demand of petroleum products the prices of petrol & diesel are increasing worldwide. Hence alternative sources of energy for running our generators, automobiles etc. are being considered worldwide. Both the edible and non-edible vegetable oils can be used as the raw materials for the biodiesel. Industrially, the most common method for biodiesel production is a basic homogeneous reaction. It is usually produced by a transesterification reaction of vegetable or waste oil with alcohol, such as ethanol and methanol. Diesel and Castor oil methyl ester (Diesel, B25, B50, B75, B100) fuel blends are used for conducting the performance and emission in terms of load increments from no load to full load. The bio- diesel can be used as 25% blend with petroleum diesel in existing engines without any modification. The objective of this study is to compare the engine performance and emission results of biodiesel derived from used castor oil when applied in different proportions in engines.***

Keywords: Diesel, Biodiesel, Methanol, Castor oil, Diesel Engine, Emission, Performance

1. Introduction

Biodiesel is an alternative diesel fuel consisting of the alkyl monoesters of fatty acids derived from vegetable oils and animal fats .It has been the focus of a considerable amount of recent research because it is renewable and reduces the emission of some pollutants. In Europe, rapeseed oil-based esters have been widely used as an alternative diesel fuel.

A number of researchers have investigated vegetable oil-based fuels. Most have concluded that vegetable oils can be safely burned for short periods of time in a diesel engine. However, using raw vegetable oil in a diesel engine for extended periods of time may result in severe engine deposits, injector coking, and thickening of the lubricating oil. The high viscosity of raw oil reduces fuel atomization and increases fuel spray Penetration.

Higher spray penetration is thought to be partly responsible for the difficulties experienced with engine deposits and thickening of the lubricating oil. However, These effects can be reduced or eliminated through transesterification removes glycerol from the triglycerides and replaces it with radicals from Several researchers have observed that the exhaust emission are affected by the use of biodiesel

The use of vegetable oil for energy purposes is not new. It has been used world over as a source of energy for lighting and heating since time immemorial. As early as in 1900, a diesel-cycle engine was demonstrated to run wholly on groundnut oil at the Paris exposition. Rudolf Diesel, the inventor of diesel engine at the world exhibition in Paris presented the concept of using the bio fuels in diesel engine.

Energy is the basic need for economic development of any country. The single largest source of energy in India after coal is petroleum, about two third of which is imported from OPEC (Oil and Petroleum Exporting Countries) [3].

2. Need for Biodiesel

Due to the increase in price of petroleum and environmental concern about pollution coming from automobile emission, biodiesel is an emerging as developing area of high concern. The world is confronted with the twin crises of fossil fuel depletion and environmental degradation [1]. Alternative fuels, promise to harmonize sustainable development, management, energy conversion, environmental preservation and efficiency [1]. Vegetable oil is a promising alternative to petroleum products. The economic feasibility of biodiesel depends on the price of crude petroleum and the cost of transporting diesel over long distances to remote areas [1].

It is a fact that the cost of diesel will increase in future owing to increase in its demand and limited supply [1]. A great deal of research and development on internal combustion engines has taken place not only in the design area but also in finding an appropriate fuel [1]. Many researchers have concluded that biodiesel holds promise as a perfect alternative fuel for diesel engines, since biodiesel properties are very close to diesel. The fuel properties of biodiesel such as cetane number, gravity, heat of combustion, and viscosity influence the combustion and so the engine performance and emission characteristics because it has different physical and chemical properties than petroleum-based diesel fuel.

The consumption of diesel oil is several times higher than that of petrol fuel. Due to the shortage of petroleum products and its increasing cost, efforts are on to develop alternative fuel especially for biodiesel oil for its partial replacement [1]. It has been found that the vegetable oils are promising fuels because their properties are similar to that of diesel and are produced easily and renewably from the crops. Vegetable oils are non-toxic, renewable sources of energy, which do not contribute to the global CO_2 build up. In terms of the economical benefits, vegetable fuels could be used as an emergency energy source in the event of another petroleum fuel shortage.

3. Characterization of Castor Plant and Oil

The castor oil plant, Ricinus communis, is a species of flowering plant in the spurge family, Euphorbiaceae [2]. Castor is indigenous to the southeastern Mediterranean Basin, Eastern Africa, and India [2]. Castor seed is the source of castor oil, which has a wide variety of uses [2].

The comparative advantage of Castor is that its growing period is much shorter than that of Jatropha and Pongamia, and there is considerably greater experience and awareness among farmers about its cultivation [3].It is a fast-growing, suckering perennial shrub which can reach the size of a small tree (around 12 metres / 39 feet), as shown in Fig.1 [2].

Figure 1: Castor plant

The seeds contain between 40% and 60% oil that is rich in triglycerides, mainly ricinolein [4]. The seeds are contains ricin, toxin, which is also present in lower concentrations throughout the plant. The toxicity of raw castor beans due to the presence of ricin a poisonous substance. The toxin provides the castor oil plant with some degree of natural protection from insect pests, as shown in Fig.2.

Figure 2: Castor pod

Castor grows well under hot and humid tropical conditions and has a growing period of 4 to 5 months. Castor oil is a colourless to very pale yellow liquid with mild or no odour or taste. Castor oil properties indicate a very low pour and cloud points which make this biofuel a good alternative in winter conditions [3].It is hard non-drying oil that neither becomes stiff with cold nor unduly thin with heat hence is used as a lubricant for jet and racing cars engines. It is the only source of an 18-carbon hydroxylated fatty acid with one double bond in each of the fatty acid chain and ricinoleic acid make up about 89% of the fatty acid composition. The physico-chemical properties that were studied included: FFA, density, fire point, flash point, cloud point, specific gravity, calorific value and kinematic viscosity. The physical and chemical properties of the Castor oil as shown in the Table 1.

Table 1: Properties of Castor oil

Properties	*Castor oil*
FFA (%)	0.264
Density (Kg/m^3)	962.8
Fire point(^{0}C)	335
Flash point (^{0}C)	298
Cloud point (^{0}C)	15.8
Specific gravity	0.9628
Calorific value (kJ/kg)	35684.5
Kinematic Viscosity (mm^2/s)	109.53

4. Castor Oil in India

- India is the undisputed leader in castor oil production.
- India supplies over 70% of the total production of castor oil in the world.
- The Indian variety of castor has 48% oil content of which 42% can be extracted, while the cake retains the rest.
- Gujarat is the largest producer of Castor seed in India.
- Since the freezing point of castor oil biodiesel is high, it is suitable for cold climates.

5. Biodiesel Processing

The process of converting the raw vegetable oil into biodiesel, which is fatty acid alkyl ester, is named as transesterification. Transesterification being the most used method. Conversion is complicated if oil contains higher amounts of FFA (>1% w/w) that will be form soap with alkaline catalyst. The soap can reduce separation of the biodiesel from the glycerin fraction. Crude oil contains about more than 30 % FFA, which is far beyond the 1% level. Few researchers have worked with feedstock having higher FFA levels using alternative processes. Pretreatment step to reduce the free fatty acids of these feed stocks to less than 1% before transesterification reaction was completed to produce biodiesel. The reduction of FFA <1% is best if esterification followed by Trans-esterification.

5.1Esterification Process

Normally most of the oils are converted into biodiesel esters using the base catalyzed transesterification method. But there are certain exceptional cases wherein direct trans-esterification cannot be performed. Such cases appear in raw vegetable oils (Non edible oil) like Olive oil, Jatropha and Cotton seed oil, etc. because these raw vegetable oils possess high free fatty acid (FFA).

For determining whether the raw vegetable oils can be trans-esterified directly the acid value is the most important property that must be known. If the acid value <3 then the raw vegetable oil can be directly trans-esterified. If the acid value >3 then there is slight change in the production of biodiesel process. At first the oil undergoes esterification and then followed by transesterification.

In the esterification process the excess of the free acid gets reacted. The remaining acid content in the oil undergoes trans-esterification process. So this method is effective for oils that contain high free fatty acid (FFA) content.

5.2 Transesterification process

Transesterification also called alcoholysis is the displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis, except that an alcohol is worked instead of water. Suitable alcohols include butanol, methanol, ethanol, propanol, and amyl alcohol. Ethanol and methanol are utilized most frequently. This process is mostly used to reduce the viscosity of triglycerides, thereby enhancing the chemical and physical properties of biofuel and improve engine performance. Thus fatty acid methyl ester (also known as biodiesel) is obtained by transesterification.

6. Production of Biodiesel

6.1 Procedure of Making Biodiesl

The vegetable oils and fats are made up mainly of triglycerides. When, these triglycerides react chemically with alcohols in presence of a catalyst (base/acid) result in fatty acid esters. This methyl esters show striking similarity to petroleum derived diesel and are called "Biodiesel". Biodiesel is produced by transesterification of oil obtains from the seeds.

Figure 3: Experimental setup

In the preparation of biodiesel five distinct stages will be involved,
1) Heating of oil.
2) Preparation of alkaline mixture.
3) Adding of alkaline alcohol to oil and stirring the mixture.
4) Settling of separation of glycerol.
5) Washing of ethyl ester with water.

A flow chart detail for making biodiesel is given below, as shown in Fig.4:

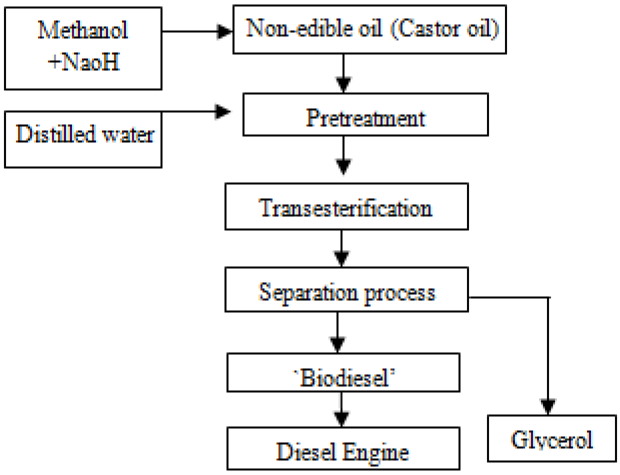

Figure 4: Flow chart of biodiesel production

6.2 Characterization of Diesel and Biodiesel

The prepared Castor oil methyl ester (COME) was mixed with diesel in five different proportions i.e. pure diesel, 25%, 50%,75% and 100% to prepare its blends i.e. COME25, COME50, COME75 and COME100. Kinematic viscosity of the Castor oil was determined with the help of Redwood Viscometer and Density of the fuel was found using mass and volume measurement apparatus. While Table 2 shows the prepared sample blends of diesel and Castor oil methyl ester.

Properties	*Diesel*	*B 25*	*B 50*	*B 75*	*B 100*
Density (Kg/m^3)	845.0	868.4	891.8	912.5	945.2
Flash point (^{0}C)	68	89.7	134	167	189.4
Cloud point (^{0}C)	-	-5	-9	-14	-19
Pour point (^{0}C)	- 6	- 15	- 27	- 31	-35
Kinematic Viscosity (mm^2/s)	3.51	4.82	7.85	13.7	16.5
Specific gravity	0.845	0.8684	0.8918	0.9125	0.9542

7. Performance and Emission Test

7.1 Performance Test

The performance and emission characteristics of engine are determined using Castor neat oil and their blends with pure diesel. These results are compared with pure diesel. By analyzing the graphs, it was observed that the performance characteristics are reduced and emission characteristics are increased at the rated load compared to those of diesel.

This is mainly due to lower calorific value, low flash point, high viscosity and delayed combustion process. From the analysis of graph, it can be observed that 25% of neat pure Castor oil mixed with 75% of pure diesel is the best suited blend for Diesel engine without heating and without any engine modifications. The concluded is castor oil can be used as an alternate to diesel, which is of low cost, easily available and low emission. This usage of bio-diesel has a great impact in reducing the dependency of India on oil imports.

Figure 5: Testing Engine setup

The engine was tested with pure diesel and prepared blends of castor biodiesel at diesel, 25%, 50%, 75%, and 100% loading at a speed of 1500 rpm only .Fuel consumption, brake power, brake thermal efficiency and exhaust gas temperature were measured with different blends of castor biodiesel. The engine specifications are shown in the Table 3.

Table 3: Engine specifications

Type	four stroke, water cooled, direct injection
Capacity	550cc
Rated power	5.2 kW@1500rpm
Bore x stroke	87.5x110mm
No of cylinder	1
Compression ratio	17.5:1

7.2 Emission test

Increasing concern about combustion related pollutants, such as total organic carbon, particulate matter (PM), CO, , sulphur and nitrogen oxides, metals and volatile organic compounds (VOCs), amongst others, is driving governments to put more stringent requirements on fuel regulations. Exhaust emissions from diesel burning in motor vehicles contain hundreds of compounds, either in the exhaust gas or particulate phases. Several of compounds are proved, such as formaldehyde, benzene, acrolein, sulphate, PAHs, etc.

Amongst vehicular fuels, diesel also produces larger quantities of fine particulate matters, which consists basically of carbonaceous material, soluble organic fraction (SOF), sulphate and metals. As a consequence, the use of alternative biofuels in order to reduce the environmental impacts of diesel emissions has been extensively investigated Trends in the regional use of biomass-derived fuels, such as methanol, biodiesel and agricultural residues - as a proposed control initiative against elevated carbon monoxide levels in urban areas - have expanded to a global scale.

From a standard point of the air quality in large urban centres, especially those to which public transportation is largely dependent on heavy-duty diesel vehicles, as is the case of the majority of Brazilian cities, several studies have pointed to the fact that biodiesel burning, either pure or in mixtures with diesel, can reduce the emissions of carbon monoxide (CO), particulate matter (PM), total hydrocarbons (THC) and sulphur compounds, although quite different conclusions can also be found related to other substances, since an increase in NOx and SOF (soluble organic fractions) emissions is also reported.

8. Result

In the current investigation, it has confirmed that castor oil may be used as resource to obtain biodiesel fuel. The final result shows that alkaline catalyzed transesterification is a promising area of research for the production of biodiesel in large scale. The Effects of different parameters such as time, temperature, reactant ratio and catalyst concentration on the biodiesel yield were analyzed.

This all-round study of biodiesel production from castor oil has been carried out. The best combination of the parameters was found as 9:1 molar ratio of Methanol to oil, 0.8% NaoH catalyst, 60°C reaction temperature and 2 hours of reaction time.
Catalysts used for the production of biodiesel are sodium hydroxide and sulfuric acid. Different values were carried out for these catalysts varying the catalyst concentration, oil to methanol ratio, reaction temperature and time. The Effects of various parameters on biodiesel quality are discussed below:

Table 4: Catalyst variations

Molar Ratio (ml)	*NAOH (mg)*	*Temperature (^0c)*	*Time (hr)*	*Yield (%)*
3:1	0.2	60	2	78
3:1	0.4	60	2	81.3
3:1	0.6	60	2	82
3:1	0.8	60	2	84.4

Table 5: Molar ratio variations

Molar Ratio (ml)	*NAOH (mg)*	*Temperature (^0c)*	*Time (hr)*	*Yield (%)*
3:1	0.2	60	2	81
6:1	0.2	60	2	83.3
9:1	0.2	60	2	85.1
12:1	0.2	60	2	79.4

Table 6: Temperature variations

Molar Ratio (ml)	*NAOH (mg)*	*Temperature (^0c)*	*Time (hr)*	*Yield (%)*
3:1	0.2	60	2	85
3:1	0.2	62	2	82.3
3:1	0.2	64	2	81
3:1	0.2	66	2	79.4

Table 7: Time variations

Molar Ratio (ml)	*NAOH (mg)*	*Temperature (^{0}c)*	*Time (hr)*	*Yield (%)*
3:1	0.2	60	2	86.7
3:1	0.2	60	2.30	84.3
3:1	0.2	60	3	82
3:1	0.2	60	3.30	80.5

9. Conclusion

The objective of this project was to characterize the effect of oxidation on the exhaust emissions from a biodiesel-fueled engine. Based on the experimental results, the following final conclusions can be drawn.

The brake power of biodiesel was nearly the same as with diesel, while the specific fuel consumption was higher than that of petro diesel. Carbon deposits inside the engine were normal, with the exception of inlet valve deposits.

The engine performance of the oxidized and unoxidized biodiesels and their blends was similar to that diesel fuel with nearly the same thermal efficiency, but with higher fuel consumption reflecting their lower energy content.

Biodiesel fuels can be performance improving additives in compression ignition engines. Performance testing showed that while the power decreased and the brake specific fuel consumption increased for all of the biodiesel samples, compared diesel fuel, the amount of the changes were in direct proportion to the lower energy content of the biodiesel.

9.1 Carbon Monoxide Emission

Figure 6 shows the CO emission increases with for diesel and biodiesel. The biodiesel produces a high amount of carbon monoxide that diesel at all load condition. The highest value of CO at 25% blend of castor oil is 3.51% in respect to the value of 1.54% for diesel.

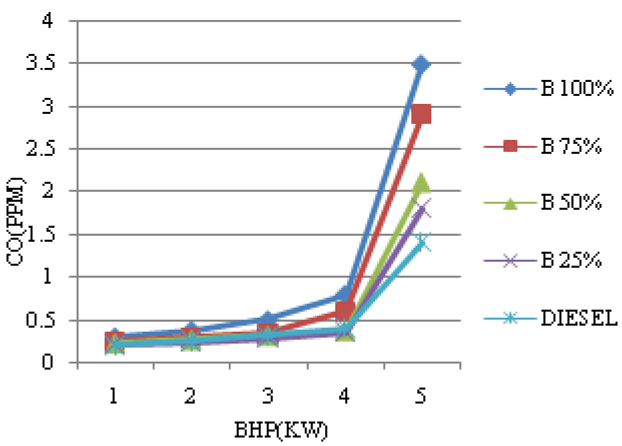

Figure 6: BHP Vs Carbon Monoxide

9.2 Unburnt Hydrocarbon Emission

Figure 7 shows the variation of unburnt hydrocarbon emissions with brake power output for castor oil and its blends with diesel in the test engine. Biodiesel shows considerably less HC emissions than diesel fuel. This should be than the availability of sufficient amount of oxygen in a biodiesel which enable the complete combustion when compared to diesel combustion. UHC of 25% blend of castor oil has lower emissions compared with all other blends. While, UHC of 25% and 50% blends of castor oil compared well.

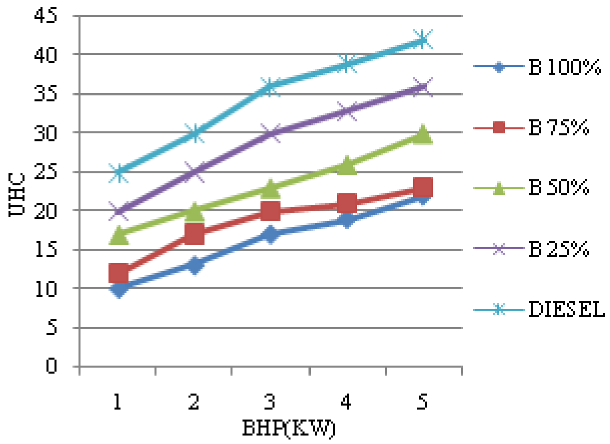

Figure7: BHP Vs Unburned Hydrocarbon

9.3 Smoke Emission

Figure 8 shows the variation of smoke emissions with brake power output for castor oil and its blends with diesel in the test engine. Diesel has higher smoke emission compared with all other blends of castor oil. 75% blend of the castor oil smoke opacity is well comparable with diesel. The smoke level for biodiesel is low compared to diesel at all loads, Reason due to the high oxygen content and lower sulphur content of biodiesel. Smoke of neat castor oil has lowest values compared with all other blends and diesel.

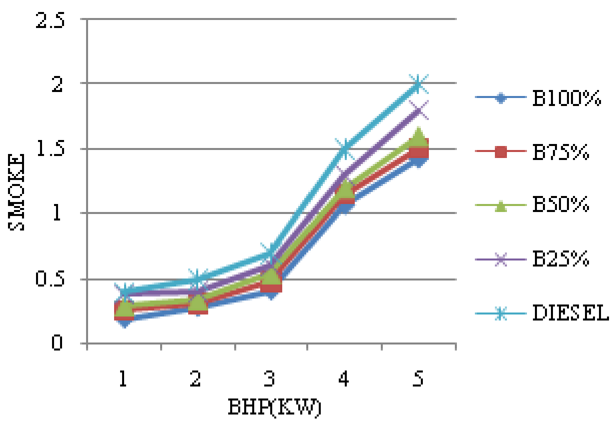

Figure 8: BHP Vs Smoke

9.4 NO_x Emission

Figure 9 shows the variation of nitrogen oxides emissions with brake power output for castor oil and its blends with diesel in the test engine. NOx of 25% blend of castor oil is slightly lower than that of diesel. Diesel has higher NOx emissions compared with all other blends throughout all operating loads. NOx emissions neat castor oil has maximum value at 81.95% of rated loads and exhibited lower emission rate compared with all other blends at all load. Generally NO_x emission higher for biodiesel compared to the diesel.

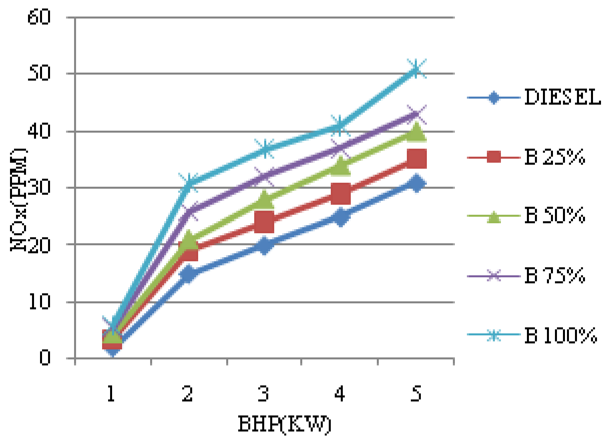

Figure 9: BHP Vs Oxides of Nitrogen

9.5 Brake Thermal Efficiency

Figure 10 shows the variation of brake thermal efficiency (BTE) with brake power output for castor oil and its blends with diesel in the test engine. Brake thermal efficiency of 25% blend of castor oil compared well with diesel and exhibited the highest value at 79.94% of total load. The maximum BTE at 25% blend of castor oil is 23.21% obtained at 4 Kw against the 24.3 %, for pure diesel.

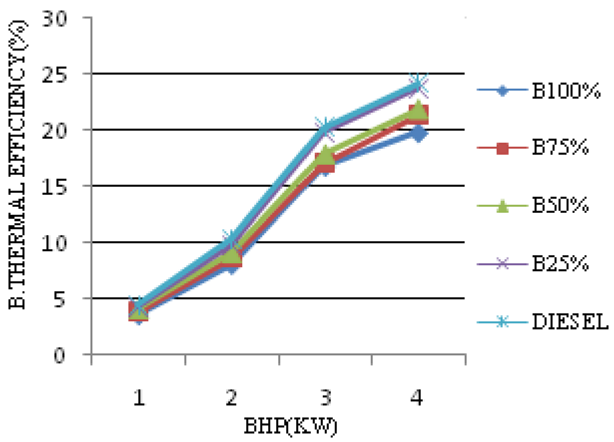

Figure10: BHP Vs Brake Thermal Efficiency

9.6 Brake Specific Fuel Consumption (BSFC)

Figure 11 shows the variation of brake specific fuel consumption with brake power output for castor oil and its blends with diesel in the test engine. Diesel has lower BSFC value compared with all other blends, whereas 25% blend of castor oil has lower BSFC values. At the maximum thermal efficiency load of 25% blend, the bsfc of castor oil is 0.342 Kg/Kw- hr, corresponding to the 0.281 value for diesel.

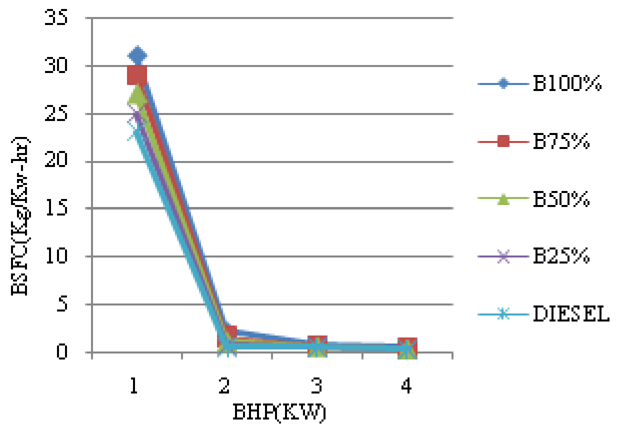

Figure 11: BHP Vs Brake Thermal Efficiency

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