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Performance evaluation of unmodified 3.74 Kw diesel engine using pongamia biodiesel (*Pongamia pinnata* L.) and its blends with petro diesel

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■ **ABSTRACT :** Import of petroleum products constitutes a major drain on our foreign exchange reserves (Rs.90, 000 crores / annum). The acid rain, global warming and health hazards are ill effects of increased polluted gases like SOx, CO and particulate matter in the atmosphere due to use of fossil fuels. Among the various alternative sources to petroleum products, oil from tree seed/crops has a potential for meeting the increasing requirements of diesel. The study indicated that use of biodiesel blends will not effect the performance of the engine. It can be recommended that addition of 20 to 40 per cent biodiesel to the petro diesel (B20 and B40) can conveniently used for the engine which in turn increases the brake power of the engine and increases the efficiency of the engine.

■ **KEY WORDS :** Biodiesel, Engine testing, Pump performance, Petro diesel

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India is the world's sixth largest consumer of energy and fifth largest in diesel consumption (Joshi, 2005). In India, the high-speed diesel is used up to 56.75 and 18.86 per cent for transport and agricultural sector, respectively. In India consumption of diesel is about five times more than gasoline. The energy demand for both industry and agricultural sectors is enormously increasing every year. The increase in energy demand for agricultural sector is mainly due to introduction of the machineries like tractors, power tillers, combine harvesters, power sprayers, irrigation pumps and other power operated machineries. The share of mechanical and electrical power has increased from 40 per cent in 1971 to 84 per cent in 2004 (Economic survey, 2005). The agriculture sector of the country is completely dependent on diesel for its motive power and to some extent for stationary power applications. Thus the increased farm mechanization in agriculture has further increased the requirement of this depleting fuel sources.

The alternative fuel technology usage will become more common in the coming decades for both automobile and stationery motive power applications in agriculture. The promising alternative is the usage of vegetable oils instead of fossile fuels. The esters produced from esterification process of vegetable oil present a very promising alternative to diesel fuel since they are renewable, non volatile and safer due to increased flash point, biodegradability, contain little or no sulphur. The main advantage of using of biodiesel is that its properties are similar to diesel fuel. Biodiesel being a superior fuel than diesel fuel from environment point of view. The use of diesel makes net addition of carbon to the atmosphere when burnt. The use of biodiesel also reduces dependence on crude of imports. As the flash point of the biodiesel is higher than diesel it has no storage problems. Biodiesel does not contain volatile organic compounds that give rise to poisonous and noxious fumes. It has no lead or sulphur to react and release of any harmful gases. Hence, an attempt has been made to study the performance of 3.73 Kw engine using biodiesel and it's blends with petro diesel under under different load conditions in the laboratory and also during water lifting using a centrifugal pump.

■ METHODOLOGY

The behaviour of high compression engine under different blend level is the objective of the present study. Biodiesel has higher cetane number, which results in higher combustion efficiency. Higher compression ratio engines increases fuel conversion efficiency (Ganesan, 2004). To study the performance of biodiesel and it's blends with petro diesel a vertical four stroke, single cylinder diesel engine was selected for the study. The specification of the engine are given in Table A.

A test rig was developed / fabricated to test the performance of the diesel engine. The engine is coupled to the prony rope brake dynamometer to measure the power (Fig. A). An orifice meter was used to measure the airflow rate and fitted to the air inlet port of the diesel engine. A U-tube vertical manometer with water column was used to measure the pressure difference across the orifice, one end of the U-tube was connected to the box and the other end was left free to the atmosphere. A thermocouple was fixed to the air chamber to measure the air inlet temperature. The fuel supply system of the engine was modified so as to determine the fuel consumption rate of the engine. A three way valve was used to which the inlet from the fuel tank was connected. A graduated measuring jar of 50 ml capacity and the fuel pump was connected to the other two ways. When the fuel is supplied from the graduated measuring jar, the time taken for the consumption of 50 ml of the fuel was recorded using a stopwatch.

Fig. A: A view of engine test rig

The speed of the engine was measured by a non contact type magnetic sensor, mounted on the drum of the dynamometer and it produces one pulse per revolution and with no error in the digital display output. The speed was recorded manually by reading displayed in the digital indicator. A parallel flow heat exchanger type exhaust gas calorimeter was used to measure the heat carried away by the exhaust gases. The exhaust gas from the engine was connected to the inner tube inlet pipe of parallel flow heat exchanger. The outlet of water from the engine was connected to the outer tube inlet of the parallel flow heat exchanger.

A twelve channel digital temperature with iron – constantan thermo couples was used to measure the temperatures at various locations in the engine test rig. The thermocouples were located at air inlet chamber to measure air inlet temperature, water inlet to the engine, water out let pipe, exhaust gas outlet pipe, calorimeter water inlet, water outlet, gas inlet, and gas outlet.

The engine performance was evaluated using IS test code 9935-1981. The blends were selected with an increment of 20 per cent of XX value up to 100 per cent blend level and designated as B20, B40, B60, B80 and B100, respectively. The petro diesel is designated as B0. During the test, speed, brake load, fuel consumption, water flow rate, manometer reading and various temperatures were noted down. The test was carried at five load settings *viz.,* No load, 25 per cent load, 50 per cent load, 75 per cent load and 100 per cent load. During each load, the various observations such as various temperatures, engine speed, fuel consumption, U tube manometer reading, exhaust gas profile *etc.* were recorded.

The performance of the 3.73 kW engine was tested using biodiesel and it's blends with petro diesel in operating a centrifugal pump. A centrifugal pump of matching capacity was coupled to the engine using a flange coupling (Fig. B). The performance of the engine was tested for lifting water using different blends and various parameters were recorded.

Table A : Specification of the diesel engine

Specification	Remarks
Make	M/s. Rocket Engineering, Kolhapur, Maharastra state
Description	Four stroke, single cylinder engine
Fuel used	Diesel
Bore	80 mm
Stroke	110 mm
Piston displacement	50.272.cm^3
Speed	1500 rpm
Compression ratio	16:1
Output rated power	3.73 kW (5 hp)
Cooling system	Jacket type water cooling system
Lubricating system	Forced feed type

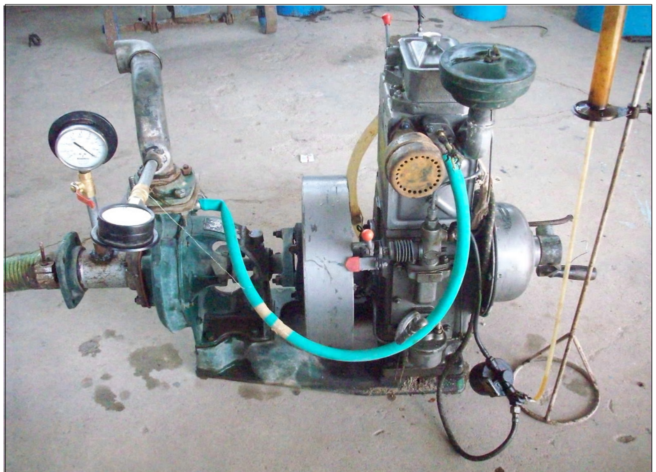

Fig. B: Engine coupled to centrifugal pump

RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Engine load test under laboratory conditions :

The various parameters of the engine like brake power, brake specific fuel consumption, brake thermal efficiency, volumetric efficiency and air fuel ratio at different loads for different blends of pongam biodiesel were calculated.

Engine speed :

The engine speed at different loads for various blends of biodiesel was recorded and the results are presented in Table 1. It was observed that as the load increased the engine speed decreased for petro diesel. Like wise same trends were observed for all the blends tested. In case of B20 and B40 the speed obtained at different loads was almost equal to that of B0. The maximum engine speed of 1480 rpm was observed for B0 at no load while, the minimum speed (980 rpm) was observed for B100 at full load. The results of the present study are similar to the findings of Yaranal (1997) for different vegetable oil blends with diesel and Anuraj (2008) for jatropha biodiesel where they reported that as the per cent of biodiesel increases in diesel, the speed of the engine decreased with increase in the load. The decrease in speed in case of B100 was 19.40 per cent as compared to diesel at full load.

Brake power :

The brake power developed at different loads using various blends of biodiesel was calculated and the results are presented in Table 2. It was observed that as the load increased, the brake power developed also increased. The same trend was observed for all the blends tested. This was due to increase in fuel consumption with increase in load. A maximum brake power of 3.039 kW was developed in case of B20 followed by B40 (3.027), B0 (2.982) B60 (2.892), B80 (2.684) and a minimum of 2.402 kW in case of B100 at full load. The higher values observed for B20 and B40 may be due to the complete combustion of fuel. While the lower values observed for B60, B80 and B100 may be due to the decrease in calorific value of blend with increase in biodiesel percentage. The brake power developed using B20 and B40 were at par with that of B0 for different loads tested. Similar results have been reported by Raheman and Phadatre (2004) for testing of 10 hp diesel engine with esterified pongamia biodiesel and its blends with petro diesel. The results are in agreement to the findings of Anuraj

Table 1 : Engine speed at different loads for various biodiesel blends tested

Load	Engine speed (rpm)					
	B0	B20	B40	B60	B80	B100
No load	1480	1480	1440	1420	1380	1300
25%	1390	1410	1375	1320	1300	1250
50%	1320	1340	1325	1250	1215	1155
75%	1260	1280	1285	1200	1155	1085
100%	1216	1240	1235	1180	1095	980

Table 2 : Brake power at different loads for various biodiesel blends tested

Load	Brake power (kW)					
	B0	B20	B40	B60	B80	B100
No load	0	0	0	0	0	0
25%	0.852	0.864	0.843	0.809	0.797	0.766
50%	1.618	1.642	1.624	1.532	1.489	1.416
75%	2.316	2.353	2.362	2.206	2.123	1.995
100%	2.981	3.039	3.027	2.892	2.684	2.402

(2008) for testing of power tiller engine using jatropha biodiesel and its blends with petro diesel. Hence, it may be concluded that use of B20 and B40 blends increases the brake power of the diesel engine at all loads but the use of blends B60, B80 and B100 decreases the brake power

Brake specific fuel consumption :

The fuel consumed per unit brake power developed at different loads using various blends of biodiesel was calculated using fuel consumption and brake power developed. The results are presented in Table 3. For all blends tested, brake specific fuel consumption decreased with increase in load. This is due to the higher percentage of increase in brake power with load compared to fuel consumption. A minimum brake specific fuel consumption of 0.295 kg $kW^{-1} h^{-1}$ was observed for B20 as compared to the maximum (0.452) for B100 at full load. The brake specific fuel consumption for B20 and B40 were 1.8 to 10.87 per cent lower than that of B0, while in case of B60-B100, the brake specific fuel consumption was 14 to 32 per cent higher than that of B0. This reverse trend was observed due to the lower calorific value with increase in biodiesel percentage in the blends. Hence, use of blends B20 and B40 decreased the brake specific fuel consumption while blends B60, B80 and B100 increased the brake specific fuel consumption compared to B0. Similar results were reported by Raheman and Phadatre (2004) for testing of 10 hp diesel engine with esterified pongamia biodiesel and its blends with petro diesel. They reported that the brake specific fuel consumption for B20 to B40 was 0.4 to 7.4 per cent lower than that of B0 and in case of B60 to B100 the brake specific fuel consumption was 11 to 4.6 per cent higher than that of diesel.

Brake thermal efficiency :

The brake thermal efficiency of the engine at different loads using various blends of biodiesel was calculated and presented in Table 4. It was observed that the brake thermal efficiency increased with the increase in load for all blends tested. This was due to the reduction in heat loss and increase in power with the increase in load. The maximum brake thermal efficiencies of 30.886 and 29.546 per cent were obtained for B20 and B40, respectively at full load which were 17.97 and 12.40 per cent higher than that of B0. The maximum brake thermal efficiencies obtained at full load for B60, B80 and B100 were 26.847, 25.432 and 22.025 per cent, respectively. The lower brake thermal efficiencies for B60 to B100 could be due to reduction in the calorific values and increase in fuel consumption as compared to B20 and B40. These findings are similar to the findings of Raheman and Phadatre (2004), where they reported that thermal efficiency was 26.79 and 26.19 per cent for B20 and B40, respectively at full load and which was higher than that of petro diesel (24.62%).

Volumetric efficiency :

The results pertaining to volumetric efficiency of the engine obtained at different loads for various blends of biodiesel tested are presented in Table 5. It was observed that for all blends tested, the volumetric efficiency decreased with the increase in load. This could be due to the reduction in actual swept volume of air intake during higher loads. The volumetric efficiency obtained for B0 was maximum (65.37 %) at no load and it was minimum for B100 (50.74 %) at full load. The reduction in volumetric efficiencies for the blends tested may be due to their density differences. These results are in agreement with the findings of Yarnal (1997) where he tested the blends of sunflower

Table 3: Brake specific fuel consumption at different loads for various biodiesel blends tested

Load	Brake specific fuel consumption (Kg $kW^{-1} h^{-1}$)					
	B0	B20	B40	B60	B80	B100
No load	0	0	0	0	0	0
25%	0.571	0.518	0.580	0.640	0.655	0.731
50%	0.387	0.387	0.410	0.441	0.457	0.528
75%	0.337	0.316	0.368	0.389	0.408	0.456
100%	0.321	0.295	0.325	0.361	0.383	0.452

Table 4 : Brake thermal efficiency at different loads for various biodiesel blends tested

Load	Brake thermal efficiency (%)					
	B0	B20	B40	B60	B80	B100
No load	0	0	0	0	0	0
25%	14.778	17.560	16.551	15.114	14.861	13.59
50%	21.810	23.560	23.426	21.976	21.341	18.840
75%	25.035	28.835	26.102	24.865	23.891	21.828
100%	26.28	30.886	29.546	26.847	25.432	22.025

and groundnut oil with diesel and reported that the volumetric efficiency was lower than that of diesel and also the volumetric efficiency deceased as the levels of load increased.

Air fuel ratio :

The air fuel ratio of the engine at different loads using various blends of biodiesel were calculated and presented in Table 6. From the table it could be observed that as the load increased the air fuel ratio decreased for each of the blend tested. This is mainly due to increase in the fuel consumption at higher loads. The maximum value of air fuel ratio was 41.98 for B0 at no load and the minimum value of 11.66 for B100 at full load of 100 per cent. The higher values of air fuel consumption for B20 at all loads compared to other blends is responsible for higher brake power which indicates sufficient oxygen is available for combustion of the fuel.

Engine performance characteristics :

The various parameters of the engine like break power, specific fuel consumption and break thermal efficiency at different loads and for different blends of pongamia biodiesel were plotted against the engine speed (Fig. 1 to 6). In all the blends tested, the trends of the performance characteristics curves were similar. This indicated that the characteristics of the engine are not at all affected by using the different blends. Also it is observed that, as the load on the engine increased, brake power and brake thermal efficiency increased, but the brake specific fuel consumption was found to decrease. Further, it was observed that for the best efficiency of the engine it should be operated at maximum load or about 80 per cent of the rated load where, the brake power developed and brake thermal efficiency were maximum, while the brake specific fuel consumption was minimum.

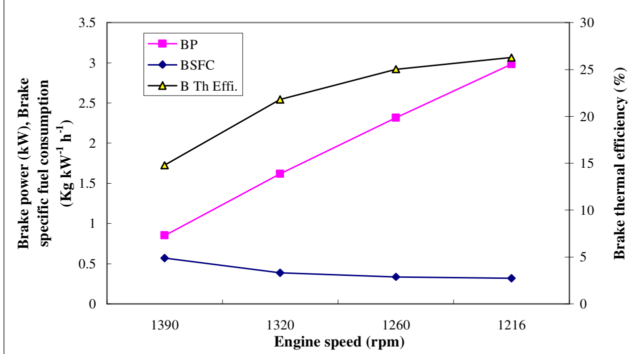

Fig. 1: Characterstics curves of the engine for B0 at different loads

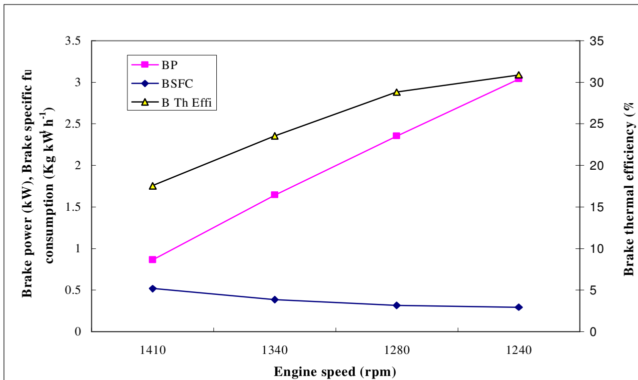

Fig. 2: Characterstics curves of the engine for B20 at different loads

Table 5 : Volumetric efficiency at different loads for various biodiesel blends tested

Load	Volumetric efficiency , %					
	B0	B20	B40	B60	B80	B100
No load	65.37	63.3	62.85	61.89	61.72	61.71
25%	58.52	54.05	53.45	52.59	52.18	51.68
50%	55.88	53.45	52.81	51.83	51.65	51.35
75%	54.2	53.79	52.25	51.43	51.31	51.2
100%	53.767	52.73	51.48	51.22	51.20	50.74

Table 6 : Air fuel ratio at different loads for various biodiesel blends tested

Load	Air fuel ratio					
	B0	B20	B40	B60	B80	B100
No load	41.98	48.02	44.06	42.27	39.22	36.44
25%	40.51	41.69	37.12	33.46	32.11	28.62
50%	29.42	28.16	26.23	23.96	22.89	19.77
75%	21.83	23.14	19.27	17.93	17.05	15.12
100%	17.06	18.22	16.11	14.47	13.88	11.66

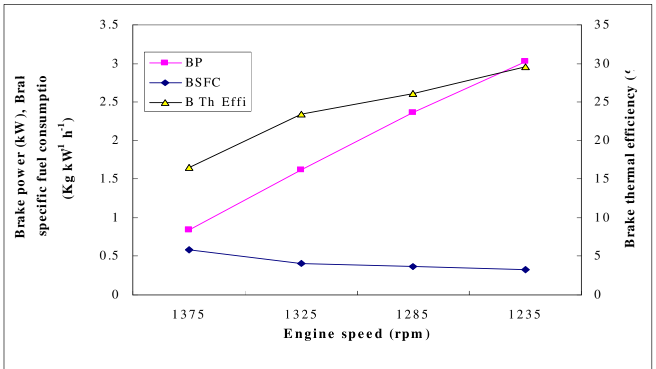

Fig. 3: Characterstics curves of the engine for B40 at different loads

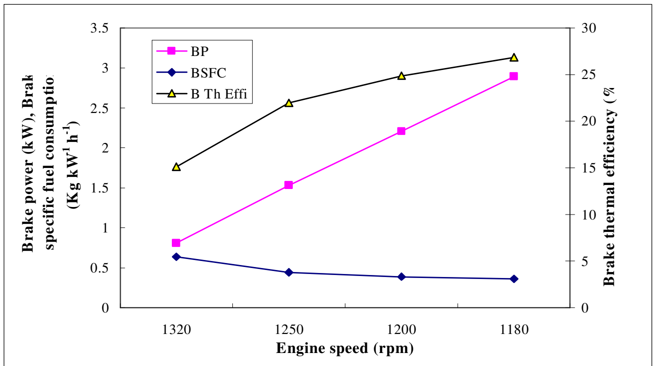

Fig. 4: Characterstics curves of the engine for B60 at different loads

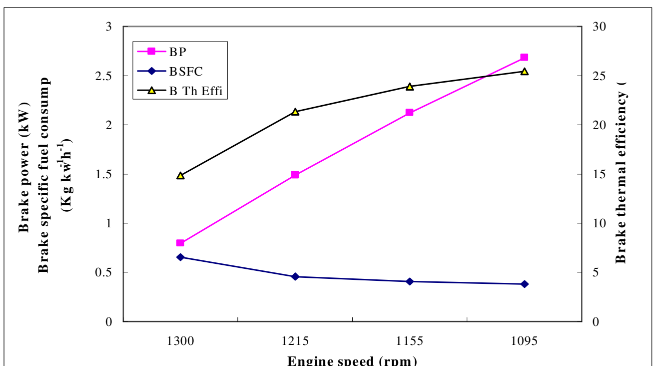

Fig. 5: Characterstics curves of the engine for B80 at different loads

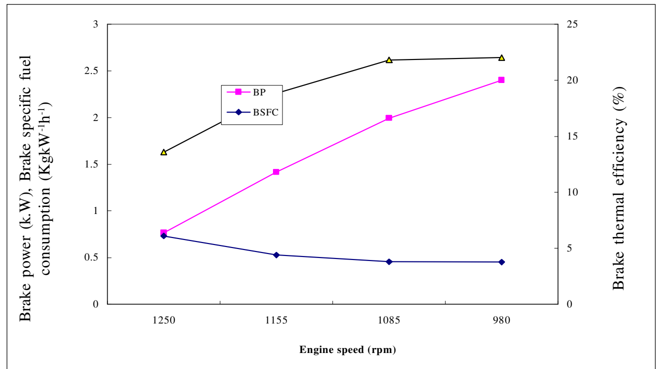

Fig. 6: Characterstics curves of the engine for B100 at different loads

Performance of diesel engine with biodiesel and its blends for water pumping :

The centrifugal pump coupled to the engine was tested for its performance. The various parameters like speed, time to consume 50 cc of the fuel, inlet pressure and outlet pressures were recoded. Using these values discharge and water horse power of pump developed using different blends are calculated and presented in Table 7. It was observed that speed, delivery pressure, discharge and water horse power of the pump increased with the addition of biodiesel with petro diesel up to 40 per cent whereas, they decreased beyond B60 to B100. A maximum speed of 1350 rpm was recorded for B40 followed by B20 (1320), B60 (1300), B0 (1280), B80 (1210) and a minimum of 1190 rpm was observed for B100. The maximum discharge of 13.67 l s^{-1} was observed for B40 whereas it was minimum (11.43 l s^{-1}) for B100. A maximum water horse power of 0.36 hp was developed by the engine using B40 and B60 while a minimum of 0.30 hp was developed using B100.

The performance of the engine in terms of discharge and water horse power developed using different blends is shown in Fig. 7.

From the Fig. 7, it was observed that as the percentage of biodiesel increased, the discharge and water horse power developed by the engine also increased up to B40 and it was at par with B60. This may be due to fact that, the addition of biodiesel resulted in complete combustion of the fuel. But, with the addition of biodiesel with petro diesel beyond B60,

Table 7 : Pump operating parameters

Sr.No.	Types of blend	Speed rpm	Pressure kg cm^{-2}	Discharge, l s^{-1}	WHP Hp
1.	B0	1280	1.5	12.29	0.33
2.	B20	1320	1.6	13.06	0.35
3.	B40	1350	1.6	13.67	0.36
4.	B60	1300	1.2	13.58	0.36
5.	B80	1210	1.4	11.83	0.32
6.	B100	1190	1.1	11.43	0.30

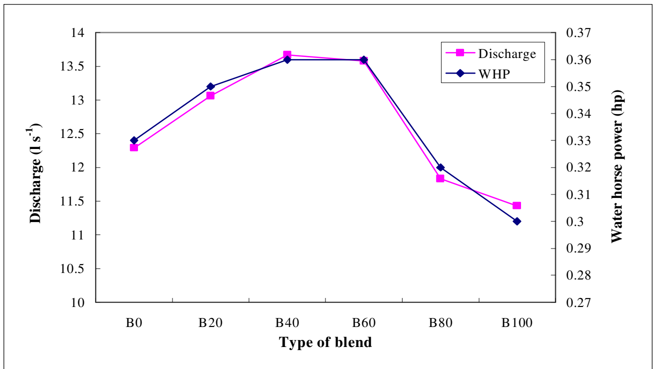

Fig. 7: Discharge and water horse power of the pump using different blend of biodiesel

the discharge and water horse power decreased. This may be due to lower calorific value of the blend as a result of increase in percentage of biodiesel in petro diesel which resulted in lower brake power developed by the engine. Hence, using the blends B20, B40 and B60 seems to be efficient as the discharge and speed are higher compared to diesel. These results are similar to the load test findings. Hence, it can be concluded that use of biodiesel blends will not effect the performance of the engine. It can be recommended that addition of 20 to 40 per cent biodiesel to the petro diesel (B20 and B40) can conveniently used for the engine which in turn increases the brake power of the engine.

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