Pertanika J. Sci. & Technol. 19 (1): 117 – 127 (2011)
ISSN: 0128-7680

Biodiesel from Pungam Seed Oil and Its Effects on Engine Performance with a Computerized Engine Test Rig

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ABSTRACT

Vegetable oil has become more attractive recently because of its environmental benefits and better quality exhaust emission. A well-known transesterification process made biodiesel, pungam seed oil was selected for biodiesel production. Pungam seed oil is non-edible oil, thus, food versus fuel conflict will not arise if this is used for biodiesel production. A maximum of 75% biodiesel was produced with 20% methanol in the presence of 0.5% sodium hydroxide. The experimental investigations were carried out in an engine that is coupled with an eddy current dynamometer. The engine is a single cylinder water-cooled, direct injection diesel engine developing a power output of 3.7 kW at 1500 rev/min. The crank angle encoder measured the engine speed, whereas the piezo electric sensors measured the cylinder pressure and the fuel injection pressure. The experimental investigations were carried out for bio-diesel and diesel and the results were compared. From the experimental results, it is concluded that the use of bio-diesel as an alternative fuel leads to significant reduction in emissions and improved performance of diesel engines. This paper discusses the production process of biodiesel from Pungam seed oil and its performance in the compression ignition engine.

Keywords: Biodiesel, alternative fuel, Pungam seed oil, esterification

NOMENCLATURE

BD	Biodiesel
CI	Compression ignition engine
CO	Carbon monoxide
CO_2	Carbon dioxide
CRBO	Crude rice bran oil
DI	Direct injection
KOH	Potassium hydroxide
NA	Naturally aspirated
NaOH	Sodium hydroxide
NO	Nitrogen oxide
PM	Particulate matter
PSO	Pungam seed oil
PSOME	Pungam seed oil methyl ester
THC	Total unburned hydrocarbon

Received: 8 January 2010
Accepted: 10 June 2010
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INTRODUCTION

The concept of using vegetable oil, as fuel for diesel engine, has dated back to Dr. Rudolf Diesel's Development of diesel engine to run on vegetable oil. Demonstrated at the 1900 world exhibition in Paris, Rudolf tested peanut oil as a fuel for the engine. Bio-diesel meeting modern specifications has successfully been used in Europe for more than 20 years (Georing, 1982; Bagby, 1987). Transesterification is the process of reacting a triglyceride with alcohol in the presence of a catalyst to produce glycerol and fatty acid esters. The molecular weight of the ester molecule is roughly one-third that of a neat vegetable oil molecule and the ester has a viscosity approximately twice that of diesel fuel. In contrast, raw vegetable oil has a viscosity of 10-20 times that of diesel fuel. Viscosity of the fuel is of prime concern because of its spray pattern and deposit formation (Felderman, 1988; Mittlbach, 1992). Meanwhile, methyl esters of high erotic acid rapeseed oil perform similarly to diesel in both short- and long-run engine tests.

In the recent years, systematic efforts have been made by several researchers (Agarwal *et al*., 2001) to use vegetable oil like sunflower, peanut, soybean, rapeseed, palm, olive, cottonseed, linseed, jatropha, coconut, pungam, rubber seed, etc., as an alternative fuel for diesel. Most of the vegetable oil is edible in nature, and its continuous use has been suggested to have caused shortages in food supply and proven far expensive to be used as fuel at present. Very few non-edible vegetable oil types have been tried on diesel engine, and this leaves a lot of scope for further investigation in this area. It is important to note that the high viscosity of vegetable oil is responsible for these problems. Therefore, reducing the viscosity of vegetable oil is of the prime importance to make it suitable for diesel engines. Ramadhas *et al*. (2004) have suggested several ways for this purpose; among other, they proposed blending or diluting it with other oil, while pre-heating and transesterification are pre-dominant.

In India, only a small portion (<10%) of the total production of CRBO is processed into edible oil (Zullaikah *et al*., 2005), while the remaining high FFA CRBO is utilized for industrial applications such as cosmetics. Hence, more attention should be focused on this non-edible CRBO to test its suitability as a substitute for diesel oil. Even though the properties of high FFA CRBO-diesel blends are comparable with that of diesel (Saravanan *et al*., 2008a), there may be engine durability issues in the long run. In its unmodified form, glycerin that is present in the CRBO may create problems in the engine fuel injection system. By reducing the viscosity of the CRBO through Transesterification process (Meher *et al*., 2006), its structure will be modified and this makes it compatible with the engine fuel injection system.

Pungam oil has been converted into biodiesel by the transesterification method and the viscosity has been reduced to 4.8 centistokes from 21.4 centistokes. The free fatty acid (FFA) present in pungam oil has a greater influence in the process of converting it into bio diesel. This has been observed during the time of producing the biodiesel in the laboratory level. However, high viscosity and poor volatility lead to reduced thermal efficiency and increased hydrocarbon, carbon monoxide, and smoke emissions (Barsic, 1981; Ali, 1995; Joseph, 1982). Meanwhile, transesterification is one of the methods by which viscosity could drastically be reduced and the fuel could be adopted for use in diesel engine. The transesterification process involves reacting vegetable oil with alcohol, such as methanol or ethanol, in the presence of a catalyst (usually sodium hydroxide) at about 70°C to give the ester and the by-product, glycerin (Korbitz, 1995).

However, the dual fuel engine gives a poor part load performance, and HC and CO emissions are higher (Kumar *et al*., 2001). For agricultural applications, where small amounts of fuel are consumed in every engine, the use of neat vegetable oil is likely to be more attractive than the transesterified oil (biodiesel), as no chemical processing is needed. As mentioned earlier, several vegetable oil types have been tested in engines. Among these, jatropha oil was found to be promising. It is non-edible, as well as possesses a high calorific value and cetane number. In addition, it is also non-toxic. More importantly, water requirement for the jatropha plant is negligible and it can also grow anywhere even on sandy oil. Meanwhile, the calorific value and the cetane number of jatropha oil are comparable to diesel, but the density is higher. Carbon residue of jatropha oil is very high, and this can lead to high smoke levels and injector coking. It is important to note that coking of the injector leads to poor fuel atomization (Srinivasa *et al*., 1991). The flash point of jatropha oil is higher than the diesel, and hence, it is safer to use it in the engine. With advanced injection timing, there is more time available for mixture formation, and this can further lead to a better combustion, as well as improved performance and also reduction in HC and CO emissions (Karim, 1983; Narayana, 2004). In particular, increased injector opening pressure has a significant effect on the performance and the emissions of diesel engines. Meanwhile, an increase in injection pressure has been found to enhance the atomization at the nozzle outlet, resulting in a more distributed vapour, and hence, a better mixing. When the injection pressure is increased, fuel particle diameter reduces. Since mixing of fuel and air improves during the ignition delay period, HC and smoke levels will also reduce. A very high injection pressure will lead to fine droplets and this can adversely affect fuel distribution in air.

The main objectives of the present work were to produce biodiesel from non-edible pungam seed oil and to find the fuel properties of the biodiesel with the engine performance and to compare them with diesel fuel.

EXPERIMENTAL METHODS

The engine is coupled with an eddy current dynamometer. The ester of pungam oil was injected into the engine through the existing conventional injection system. However, two separate fuel tanks were used; one for diesel fuel and the other for the ester of pungam oil. Both the fuels were injected at the room temperature only. A fuel changing arrangement was provided to change one fuel mode to another.

The Experimental Setup

The experimental setup is a computerized test rig, as shown in *Fig. 1*. As stated earlier, the engine is coupled with an eddy current dynamometer. The instrument, like crank angle encoder, pressure sensor, injection sensor, and the flow transducers for measuring the fuel flow and airflow, have also been incorporated in the experimental setup.

Fig. 1: Computerized engine experimental setup

The Experimental Procedure

Diesel and biodiesel were injected into the engine cylinder through the existing fuel injector without any modification made to the engine. The fuels were injected at the room temperature only. A fuel-changing mode was provided to change one fuel mode to another. The engine was first made to run by supplying the diesel fuel to the engine, and then the fuel cock was shifted to supply the bio diesel fuel to the engine from a separate tank. The crank angle encoder measured the engine speed, while the piezo electric sensors, which have been mounted in the cylinder head, were used to measure the cylinder peak pressure, cylinder peak temperature and fuel injection pressure. The flow transducers measured the fuel flow and the airflow. The signals that were obtained from various sensors were fed into the engine indicator so as to store the data and interface with the computer. The stored data were analyzed using the engine software. The respective sensors carried out observations, i.e. the crank angle encoder measured the engine speed, while the cylinder pressure and fuel injection pressure were measured by the piezo electric sensors. The signals that were obtained from various sensors were fed into the engine indicator to store the data and interface with the computer.

Specification of the Engine

The specifications of the engine are as follows:

TABLE 1
Specifications of the engine

Engine model	COMET
No of cylinder	One
Orientation	Vertical
No of stroke	4 strokes
Ignition system	Compression ignition
Bore and stroke	80 mm x110 mm
Arrangement of valves	Overhead
Rated power	3.5 kW @ 1500 rpm
Cooling medium	Water cooled
Combustion chamber	Open chamber (Direct injection)
Compression ratio	18:1
Displacement volume	553 cc

Fuel Properties

It is important to note that the performance of the CI engines is greatly dependent upon the properties of the fuel, among which viscosity, volatility, lubricity, calorific values are very important. In this work, the effects of temperature on viscosity with neat diesel fuel and different biodiesel mixture were investigated. The properties of the neat diesel fuel and PSOME were determined and tabulated in Table 2.

Since there are no direct volatility data available for biodiesel, it can be explained with the help of distillation temperature. The higher the volatile fuels, the lower the distillation temperature. Similarly, since the diesel fuel (90% = 325°C) has lower distillation temperature than that of biodiesel (90% = 360°C), the neat biodiesel has a low volatility.

TABLE 2
Properties of the pungam oil

Properties	Diesel fuel	PSOME	Raw PSO	ASTM method
Density kg/m^3@15°C	840	915	938	D1298
Kinematic viscosity Cst @ 40°C	4.59	10.33	46.53	D445
Flash point °C	174	200	275	D2500
ASH (% by mass)	0.06	0.04	Nil	D3176
Calorific value (Cal/gm)	10127	9824	9767	D5865

PERFORMANCE RESULTS

TABLE 3

Performance results for the pungam oil

Load	Brake power	TFC	Air	SFC	Vol Eff	Torque	BMEP	HBP	HJW	HGAS
kg	kW	CC/m	mmWC	kg/kW-hr	%	kgm	Bar	%	%	%
0.12	0	8.19	40.88	10.214	67.5	0	0	0.84	19.69	20.07
0.76	0.25	0	38.97	0	66.11	0.15	0.34	0	18.43	0
3.03	0.98	12.41	38.15	0.631	65.96	0.61	1.35	13.58	17.2	17.16
5.79	1.86	16.53	36.88	0.443	65.31	1.16	2.58	19.35	16.02	16.02
8.84	2.82	16.12	36.21	0.285	65.17	1.77	3.94	30.09	20.75	20.75

TABLE 4

Performance result for the diesel fuel

Load	Brake power	TFC	Air	SFC	Vol Eff	Torque	BMEP	HBP	HJW	HGAS
kg	kW	CC/m	mmWC	kg/kW-hr	%	kgm	Bar	%	%	%
0.12	0	10.54	91.89	15.085	80.84	0	0	0.57	48.68	22.31
0.76	0.23	11.28	89.55	12.37	73.19	0.14	0.26	3.17	47.22	22.24
3.03	0.91	13.50	82.55	4.22	50.24	0.55	1.03	10.97	42.84	22.05
5.79	1.88	16.37	85.41	0.48	37.07	1.15	2.14	19.21	39.01	23.59
8.84	2.54	18.24	91.39	0.357	34.1	1.56	2.9	23.99	37.13	25.21

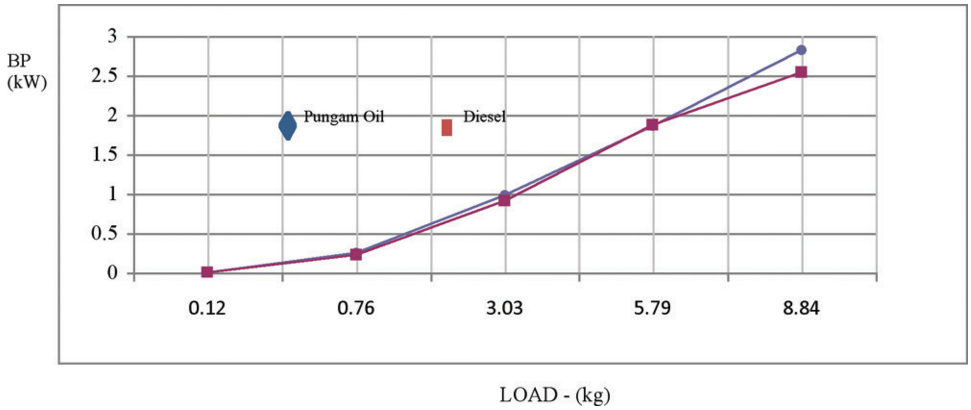

Fig. 2: Brake power vs. load

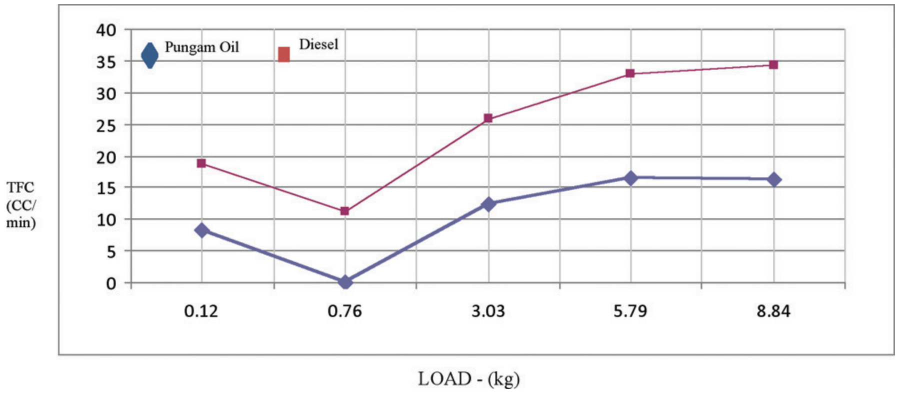

Fig. 3: Total fuel consumption vs. load

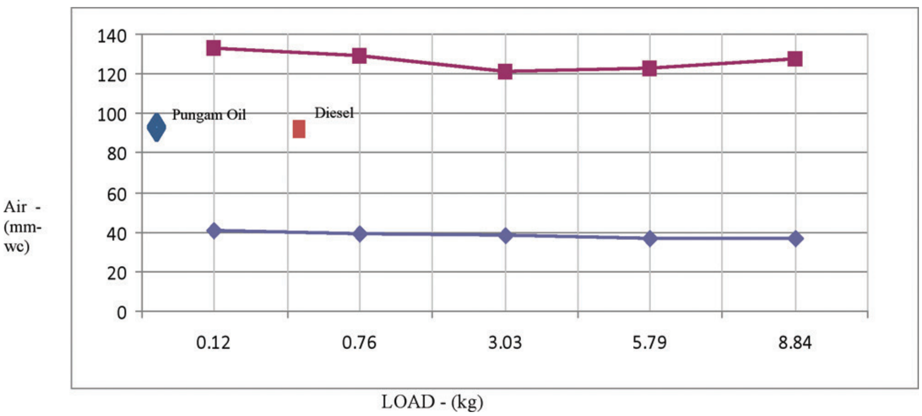

Fig. 4: Air flow vs. load

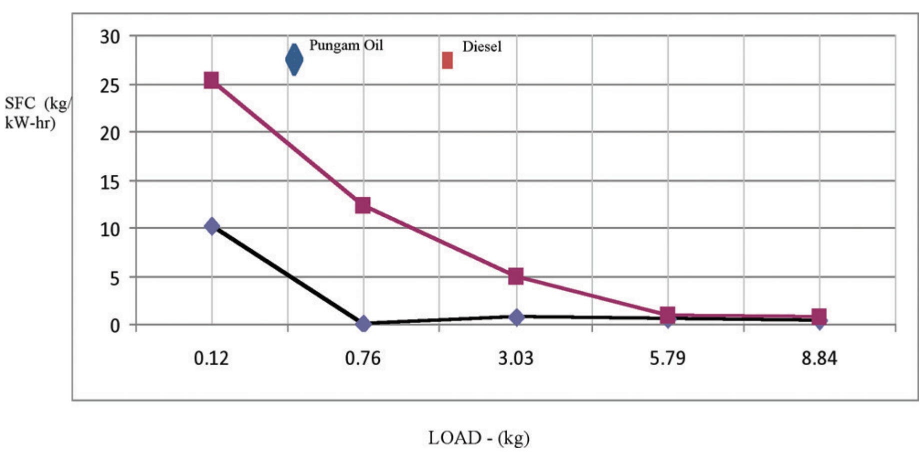

Fig. 5: Specific fuel consumption vs. load

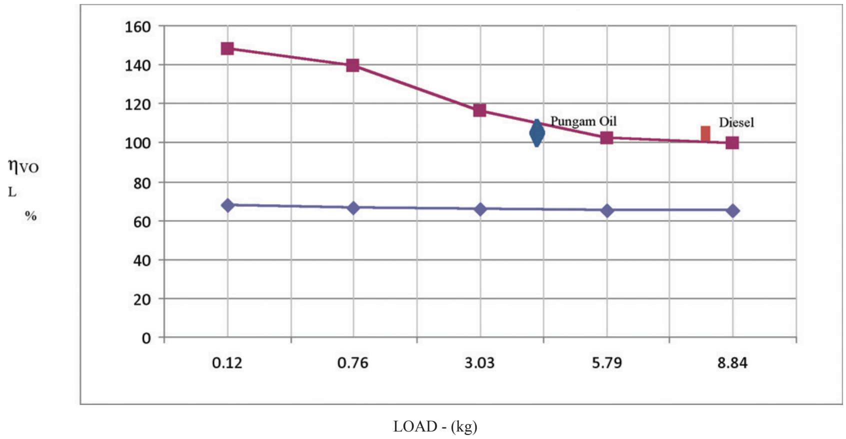

Fig. 6: Volumetric efficiency vs. load

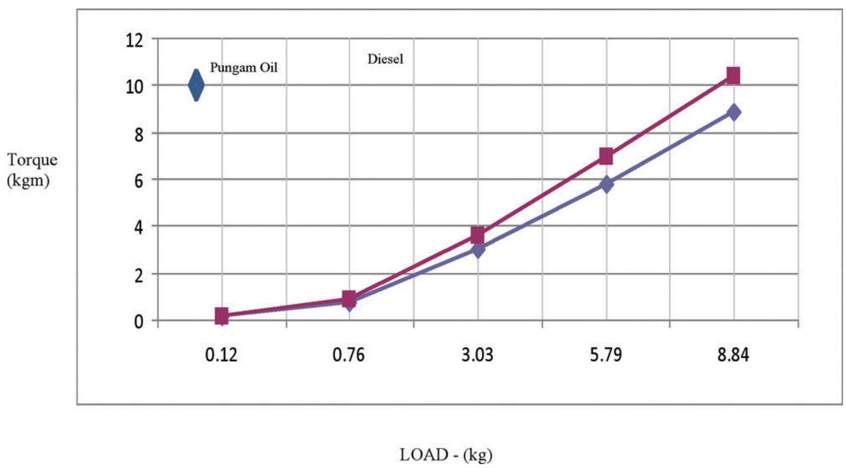

Fig. 7: Torque vs. load

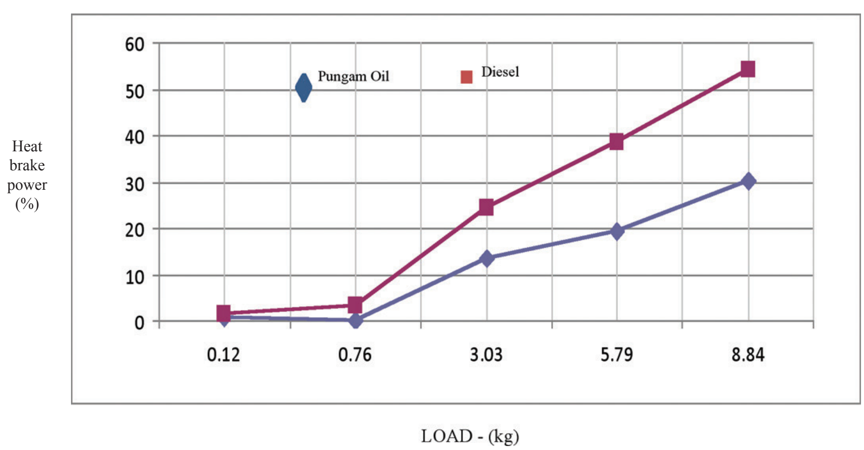

Fig. 8: Heat brake power vs. load

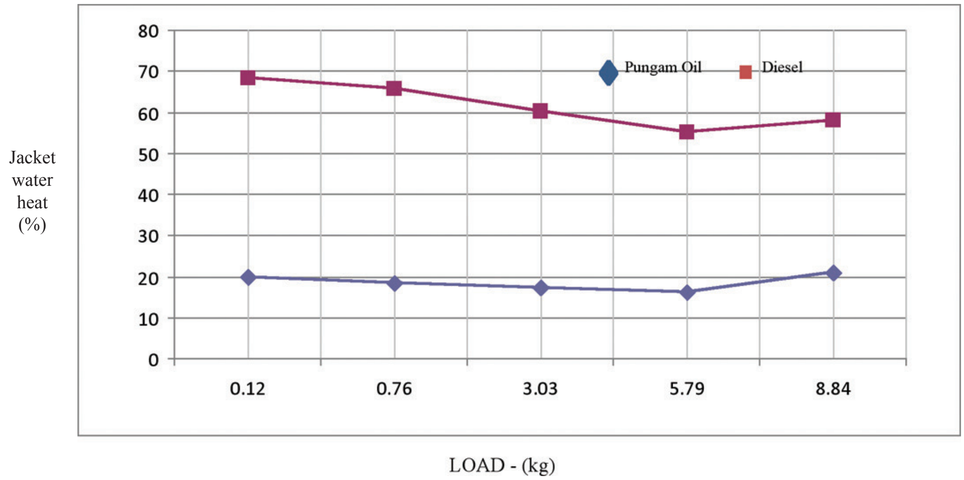

Fig. 9: Jacket water heat vs. load

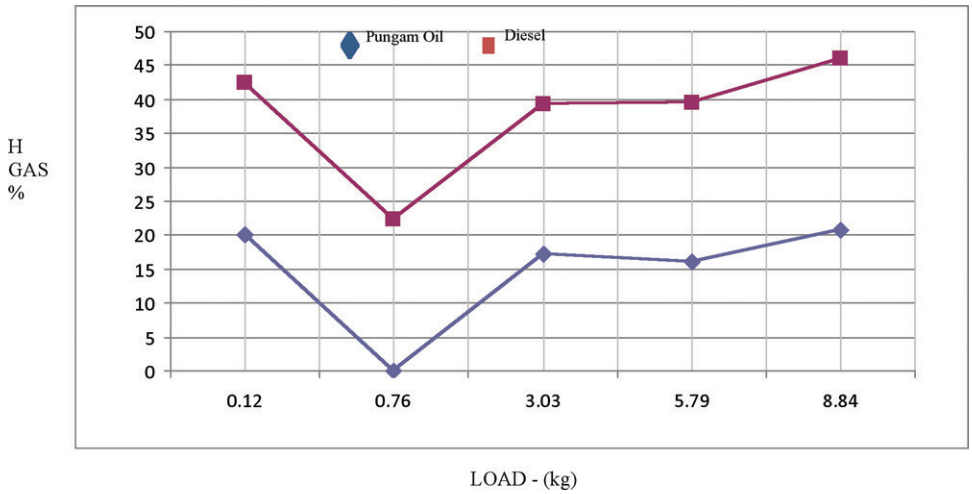

Fig. 10: Exhaust gas heat vs. load

RESULTS AND DISCUSSION

Based on the performance curves, there is not much variation in term of the volumetric efficiency under various loads for the pungam oil, whereas there is a drastic variation for diesel. Moreover, it could also be observed that when operating with pungam oil, the break thermal efficiency of the engine increased only marginally, ensuring the suitability of the pungam oil as a replacement for diesel fuel. Meanwhile, the total fuel consumption is less for pungam oil than diesel fuel. The specific fuel is almost the same for both pungam oil and diesel fuel after reaching 50 percent of load. Consequently, pungam oil can be effectively used in diesel engine without any modification. In other words, the use of the pungam oil as diesel fuel can improve the agriculture economy, diminish the indecision of fuel availability and achieve more environmental benefits at the same time.

CONCLUSIONS

The experimental results have shown the comparison between the performance and the combustion characteristics of the C.I engine using the pungam oil as a fuel, which are almost matching the diesel mode of operation. This justifies that the attempt made to use of pungam oil as a fuel in the C.I engine is very effective and that the oil can be used as an alternative fuel without having to do any modification to the engine. Due to the lower calorific value of the pungam oil, however, it was found that the brake power of the engine was higher when the load was increased. Meanwhile, the specific fuel consumption was also lower for the pungam oil as compared to diesel.

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