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Effect of supercharging on the performance of a DI Diesel engine with cotton seed oil

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Abstract

Diesel engines are the prime movers for heavy duty vehicles used in the transportation and agricultural sectors. Diesel engines meet their energy requirement from stored fuels, i.e. petroleum products. The twin problems of both depletion of scarce resources and atmospheric pollution caused by vehicles run on petro-products are enticing researchers to find a viable and immediate alternative to fossil fuels.

The physical and combustion properties of vegetable oils are close to those of petro-Diesel fuel, and in this context, vegetable oils can stand as an immediate candidate to substitute for stored fuels. Vegetable oils are produced from processing the seeds of various plants and, thus, are renewable in nature. Sustainable development of a country depends on the extent that it is managing and generating its own resources. This also helps in conservation of depleting non-renewable petro-products.

However, due to inherent high viscosity and low volatility, vegetable oils would pose problems, such as fuel flow and poor atomization, and constrain their direct use in engines without any modifications.

In the present investigation, the effect of supercharging is studied on the performance of a direct injection Diesel engine with the use of untreated cotton seed oil under varying injection pressures (IPs).

The performance of the engine is evaluated in terms of brake specific fuel consumption (BSFC), exhaust gas temperature and smoke density. It is observed that when cotton seed oil is used as a fuel, there is a reduction in BSFC of about 15% when the engine is run at the recommended IP and supercharging pressure of 0.4 bar (g) in comparison with the engine operation run under naturally operated conditions.

The investigation revealed that cotton seed oil, in general vegetable oils, can best be utilized if supercharging is employed at the recommended IP of the engine.

Keywords: Cotton seed oil; Direct injection; Naturally aspirated and supercharged engine; Base line test; Eco-friendly operation

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Nomenclature

Sp. gr	specific gravity
GCV	gross calorific value
KV	kinematic viscosity
IP	injection pressure
DI Engine	direct injection engine
BSFC	brake specific fuel consumption
BMEP	brake mean effective pressure
EGT	exhaust gas temperature
HSU	Hartridge smoke units
NA	naturally aspirated

1. Introduction

With the exponential growth of automotive vehicle population and increased stress on industrialization in developing countries, the impact of the twin problems of exhaust emissions and depletion of precious foreign exchange reserves for importing non-renewable petroleum crude and products to keep the vehicles moving will indeed be very severe. The atmospheric pollution in major cities due to automobiles has already reached alarming levels.

Oil technologists predict that over the next several decades, plant based oils will become just as essential for the transportation industry as fossil fuels, like gasoline and Diesel oil, are today.

Vegetable oils are mixtures of fatty acid molecules that contain carbon, hydrogen and oxygen atoms. The fatty acids present in it may be saturated, mono-unsaturated, or poly-unsaturated. The greater the number of double bonds, the more easily the compound reacts with oxygen from the air and goes bad, as kitchen fats and oils do after months on the shelfs.

An intensive search is being conducted in developing Diesel engine fuels and lubricants based on vegetable oils. Because of the high viscosity of vegetable oils, they hinder fuel jet penetration and atomization, result in higher fuel consumption and leave gummy deposits on the engine components upon combustion.

Barsic and Humke [1] studied the performance and emission characteristics of a DI naturally aspirated Diesel engine when operated on 100% sun flower oil, 100% peanut oil and 50% (by vol.) mixtures of either sun flower oil or peanut oil with #2 Diesel oil (i.e. Diesel fuel with less than 0.01% sulfur by weight) and compared the results with base line results obtained using #2 Diesel fuel. They adopted a rotary fuel injection pump with fuel flow adjusted to provide equal fuel energy input and observed that the engine power and thermal efficiency decreased slightly and emissions increased marginally. The attributed reasons were higher densities, higher viscosities, relatively lower heating values and thermal cracking of the vegetable oil fuel droplets at elevated temperatures.

Goering et al. [2] studied the properties of different vegetable oils and modified hybrid fuels for automotive applications and reported that vegetable oils have acceptable cetane numbers (35–45), high viscosity (~50 cSt), high carbon residue, high flash points (220–285 °C) and pour points

(−6 to 12 °C) and appreciable heating value (88–94% of Diesel fuel), low sulfur content (<0.02% by wt.) and contain gumming impurities. Akor et al. [3] in their investigations detailed the production and energy balance characteristics of the palm oil system and provided information on the physical and chemical nature of palm oil and its derivatives. They also observed satisfactory performance of conventional Diesel engines and encountered a little lower efficiencies with palm oil Diesel fuel mixtures.

Bhattacharyya and Reddy [4] conducted a review on the use of vegetable oils as fuels for internal combustion engines. They reported that the major differences between Diesel fuel and vegetable oil included, for the latter, the significantly higher viscosities and moderately higher densities, lower heating values, rise in the stoichiometric fuel/air ratio due to the presence of molecular oxygen and the possibility of thermal cracking at the temperatures encountered by the fuel spray in the NA Diesel engines.

The exhaust emission characteristics of Diesel engines operated with vegetable oils have been studied by many researchers. However, a review of the research papers by Quick [5], Barsic and Lhumke [6] and Niehaus [7] revealed that with the use of vegetable oil based fuels, the harmful exhaust emissions, particularly sulfur related compounds and carbon monoxide, are considerably reduced as compared with Diesel operation.

Methanol along with jatropha curcas oil was used in a CI engine in dual fuel mode operation by Ravi et al. [8]. The methanol was carbureted with different jet openings, and they observed that the rate of pressure rise and peak pressures were high with neat jatropha oil operation. However, with methanol induction in the dual fuel mode operation, the rate of pressure rise and peak pressures were reduced considerably. The effect of IP has been investigated by Srinivasa Rao et al. [9] and Raju et al. [10] by adopting jatropha curcas oil in a single cylinder naturally aspirated DI Diesel engine, and they concluded that high fuel IPs could improve the engine performance.

In the literature review conducted by the authors, it is observed that no information is available on the performance of DI Diesel engines employing vegetable oils as fuel under supercharged conditions.

It is well known that supercharging improves the combustion process of Diesel engines [11]. An increase in pressure and temperature of the engine intake reduces ignition delay, resulting in a quiet and smooth operation with a lower rate of pressure rise. Thus, supercharging encourages the use of low grade fuels in Diesel engines. The increase in intake air temperature reduces the unit air charge and also reduces the thermal efficiency moderately, but the increase in the density due to the supercharging pressure compensates for the loss, and intercooling is not necessary except for highly supercharged engines.

The present paper deals with the effect of supercharging on the performance of a DI Diesel engine with the use of untreated cotton seed oil.

2. Experimental programme

A direct injection type Diesel engine is chosen with the following specifications for experimentation purpose.

Type	AV1, vertical cylinder
Make	Kirloskar
No. of cylinders	One
Cooling	Water cooling
Charging	Natural
Rated power	3.68 kW@1500 rpm
Bore	80 mm
Stroke	110 mm

The following set of experiments are conducted:

1. Constant speed (rated speed) performance tests maintaining steady jacket water temperature of 55 °C under NA conditions at the recommended fuel IP (180 bar) with Diesel fuel. This test is chosen as the base line test for comparison.
2. Constant speed performance tests maintaining steady jacket water temperature of 55 °C with cotton seed oil as fuel under NA conditions at three different fuel IPs viz. 180, 210 and 240 bar.
3. Constant speed performance tests maintaining steady jacket water temperature of 55 °C under supercharged conditions (supercharging pressures kept at 0.2, 0.3 and 0.4 bar (g)) at three different fuel IPs.
4. The physical properties (as detailed below) of cottonseed oil are determined and employed in the experiments: Sp. gr: 0.911, KV: 46.9 cSt, GCV: 39,400 kJ/kg. A DC shunt dynamometer (swinging field) is adopted for loading purposes. A two stage reciprocating air compressor is used for high pressure air supply. A suitable surge tank is fabricated to ensure a constant supply of air. The Nisalco make (Japan) smoke meter is used to measure smoke density in HSU.

3. Results and discussion

The test results obtained in the above experiments are discussed below.

The recommended fuel IP of the engine under consideration is 180 bar. The variation of BSFC with BMEP is plotted in Fig. 1 when tests are conducted on the engine with cottonseed oil as a fuel at three different IPs under the NA condition. It can be observed from this figure that the engine is giving economical operation at the recommended IP over the entire load range. This is explained as follows. Any attempt to raise the IP above the recommended value will certainly improve the degree of atomization of the fuel, but the optimum droplet size leading to an efficient combustion process is probably achieved with the recommended IP itself.

Effect of supercharging can be observed in Fig. 2, for different supercharging pressures at the recommended IP. It is evident from the figure that as the supercharging pressure is increased, the BSFC is gradually lowered, and the lowest values of BSFC are observed for the supercharging pressure of 0.4 bar (g). The variation of EGT with BMEP is plotted in Fig. 3 at an IP of 180 bar for different supercharging pressures. The exhaust temperatures are lower at a supercharging pressure of 0.4 bar (g), indicating lower exhaust gas losses and supporting the lower BSFC values observed in Fig. 2 with this supercharging pressure.

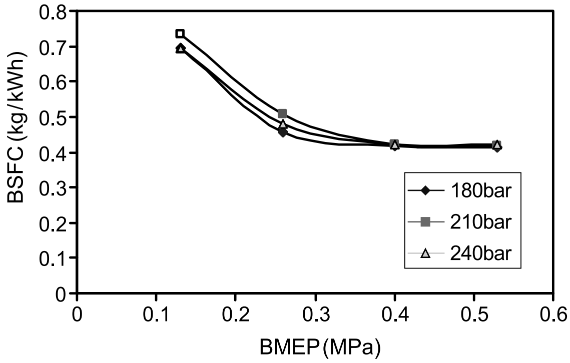

Fig. 1. Variation of BSFC with BMEP at three different IPs under NA conditition.

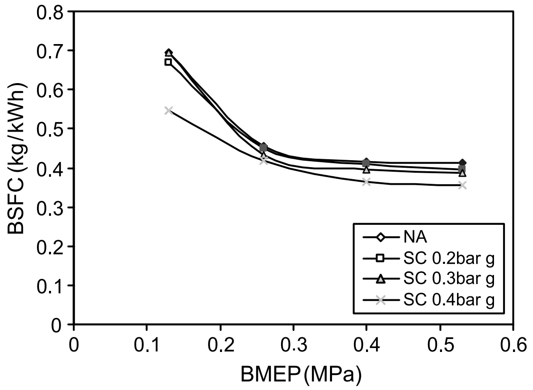

Fig. 2. Performance comparison with and without supercharging at the recommended IP.

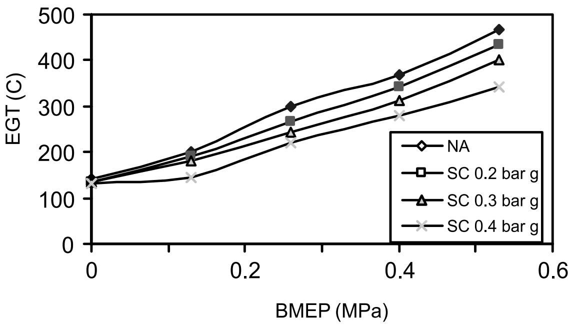

Fig. 3. Variation of EGT with BMEP at the recommended IP.

To examine whether the IP that produces the optimum droplet size differs from the recommended value under supercharged conditions, another set of experiments is performed with varying IP keeping the supercharging pressure constant at 0.4 bar (g). Fig. 4 shows the test results

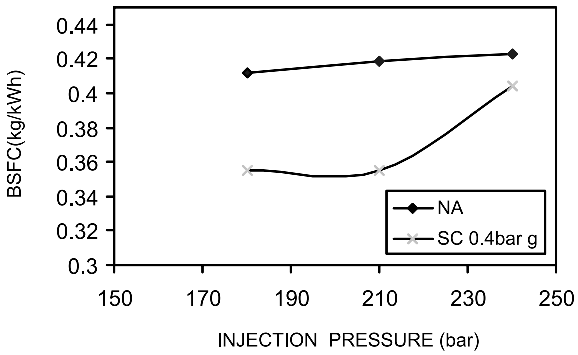

Fig. 4. Variation of BSFC with fuel IP at full load.

of these experiments. It can be observed from this figure that the performance is deteriorating with increased IP under the supercharged condition also. This is due to the fact that higher IPs are bound to reduce the depth of penetration of fuel spray, and hence, the fuel might have got impregnated on the cylinder wall, thus reducing the effective amount of fuel undergoing complete combustion. This may also be attributed to the fact that small oil droplets would undergo thermal cracking at the temperatures attained in the engine operation.

For comparison purposes, the BSFC values of the engine run with Diesel fuel under the NA condition, employing an IP of 180 bar, and the BSFC values of the engine with cottonseed oil operation at the same IP and at a supercharging pressure of 0.4 bar (g) are shown in Fig. 5. The figure also includes the variation of BSFC when the engine is run with cottonseed oil without supercharging. It can be observed that the BSFC values in the case of cottonseed oil without supercharging are on the higher side compared to Diesel operation under the NA condition [12]. Ali and Hanna [13] in their review paper also reported a similar observation, quoting the work of Pryor et al. [14] who conducted the experiments on a three cylinder, 2600 series Ford Tractor engine with 100% crude soybean oil and #2 Diesel fuel (i.e. Diesel fuel with less than 0.01% sulfur by weight). It was observed that the power outputs of the engine running on these two fuels were more or less the same, but the BSFC with 100% crude soybean oil was 11–13% greater at all loads compared to Diesel fuel operation. It can be observed from the same figure that the BSFC with cottonseed oil under supercharged operation (supercharging pressure of 0.4 bar (g)) is very close

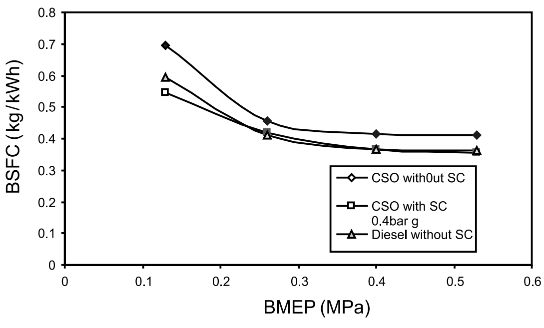

Fig. 5. Performance comparison of engine with two different fuels at the recommended IP.

to that of Diesel operation under natural aspiration. It can, therefore, be concluded that supercharging is essential when we want to adopt untreated vegetable oils for developing the power with a low specific fuel consumption compared to Diesel operation.

The following table presents the percentage reduction in smoke density at full load operation with different supercharging pressures at the recommended IP. It is evident from the tabulated values that supercharging operation is beneficial in the context of a clean environment also when the engines are operated with untreated vegetable oils.

Operating condition (BMEP)	Percentage reduction in smoke density (HSU) with respect to NA condition		
	Supercharging pressure (bar (g))		
	0.2	0.3	0.4
0.53 bar (full load)	58.3	75	83.3

4. Conclusions

1. Raising the IP to a value higher than the recommended IP (for Diesel) does not contribute to any improvement in the performance of the engine while operating on cottonseed oil as the fuel under the NA condition.
2. With an increase in supercharging pressure, the performance of the engine is gradually improving while maintaining the recommended IP with cottonseed oil as fuel. There is a reduction of about 15% in BSFC at full load with a supercharging pressure of 0.4 bar (g) compared to the naturally operated condition.
3. While operating even under the supercharged condition, no improvement is observed in the engine performance with increase in IP.
4. Supercharging is essential when we want to adopt untreated vegetable oils for developing the power with a low specific fuel consumption compared to Diesel operation.
5. The percentage reduction in smoke density is more as the supercharging pressure is increased, and the engine performance with untreated vegetable oils can be regarded as an eco-friendly operation.

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