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Fueling India's Future: Vegetable Oils and Advanced Engine Technologies

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Abstract

India's energy security is threatened by the rapid depletion of conventional energy sources and increasing demand. The substantial expenditure on importing petroleum-based fuels not only strains the economy but also exposes it to global oil price volatility. Leveraging India's agricultural strengths, vegetable oils derived from oil seeds offer a promising alternative. However, these oils require modification to suit compression ignition (CI) engines through methods like blending, thermal cracking, or transesterification.

Despite these efforts, vegetable oil fuels often perform poorly in conventional diesel engines, causing issues like gum formation, filter clogging, and higher emissions. These problems stem from the oils' inherent properties, such as high viscosity and lower volatility. A potential solution lies in utilizing vegetable oils in low heat rejection (LHR) engines, designed to operate at higher temperatures, reducing ignition delay and improving combustion.

By incorporating ceramic-insulated components like thermal barrier coatings, LHR engines can enhance thermal efficiency, reduce energy losses, and eliminate complex cooling systems. This technology can significantly improve engine performance with vegetable oil fuels. By adopting LHR technology, India can reduce its dependence on imported fuels, promote sustainable energy solutions, and contribute to a cleaner environment.

Keywords: threatened, depletion, conventional, substantial, incorporating, sustainable, environment.

INTRODUCTION

The usage of vegetable oil in an engine depends on the properties of the oil. Their properties are almost closer to diesel, particularly cetane rating and heat values. These vegetable oils are renewable and are produced easily in rural and forest areas.

Vegetable oil based fuel is currently more expensive than petrol-diesel. But by increasing the production and by providing subsidies, the prices can be lowered down. Further by using glycerin as byproduct also the prices can be brought down. While considering about cost factor, we have to think about petroleum sources. They will become scarce within 25 to 30 years, and by that time we must have some alternative sources to run out millions of vehicles without disturbances. The other alternative fuels available are LPG, alcohol, vegetable oils etc. Further, these LPG sources are also limited. They may serve for another 30 to 40 years. So, next better choice is to go for vegetable oils.

These vegetable oil-based fuels are promising ones. Their uses do not require major engine, vehicle or infrastructure modification in existing facilities. Because, these vegetable oils are renewable, the promising feature of vegetable oil-based fuel cannot be over looked. However, their viscosity values are higher but can easily be overcome by heating them. Since these oils have slightly longer ignition delay, they are most suitable to use in low heat rejection engines. The five different vegetable oils that are tried in the LHR test engine are Jatropha Oil, Coconut Oil, Rice bran Oil, Cotton Seed Oil and Palm Oil.

CONCEPT REVIEW

The available research results on low heat studies are quite comprehensive. As might be expected innovative nature of this research area creates disagreements among researchers. Research studies are directed at many phases in low heat rejection (LHR) engine development including, but not limited to, heat transfer models, finite element analysis of the components, and optimization of exhaust heat utilization systems.

Both vegetable oils and alcohols such as Methanol, Ethanol are biomass derived renewable sources, but vegetable oils have properties more suitable to compression ignition engines compared to Alcohols [1,3]. Apart from these, they also produce aldehydes and ketones in their exhaust emission, which create associated environmental and health troubles.

Because of greater density, their heat value is comparable to diesel. Heat value decreases with increasing unsaturation as a result of fewer hydrogen atoms. The presence of molecular oxygen raises the stoichiometric A/F ratio. The properties of these oils depends very much on many factors like refining techniques, the extent of refining, oil seed growing climate and therefore may contribute to variations in test results [2].

The experimental results of Domingo et al. [4] indicate that the higher temperatures of the insulated engine cause reduction in the cylinder heat rejection that is in accordance with the conventional knowledge of convective heat transfer.

There is an improvement in the engine performance when these modified vegetable oils are used instead of base vegetable oils [6]. This improvement in performance can be attributed to good atomization of these modified fuels in the injector nozzle and a significant reduction in the viscosity.

The adiabatic or LHR Engine [5] insulates the engine combustion chamber with high temperature materials to allow “hot” operation with minimized heat transfer. Because of insulation the inside engine temperatures would tend to rise and at full load, un cooled combustion chamber wall temperatures could be as high as 1000-1500^{0}C.

FABRICATION OF INSULATED COMPONENTS

A detailed study was carried out as a preliminary to the design of the insulated components. The insulated engine components, which include piston, liner, cylinder head and valves, are fabricated to constitute the combustion chamber of the low heat rejection engine.

Piston Insulation

The aim of insulating the piston was to reduce the rate of heat transfer from the crown to the skirt and the maximum possible area of the crown had to be insulated to achieve this goal. In this design, air with its low thermal conductivity was used as the insulating medium. An air-gap was provided between a metallic crown and the standard piston made of aluminium alloy. The two pieces were separated by gaskets of suitable materials and fastened. During the part of the work it was decided to study the performance of the engine with a piston insulated with an air-gap and a crown made of a material of high thermal conductivity and low specific heat. Such a design would increase the rate of heat transfer from the hot combustion gases to the crown during the expansion stroke and from the crown to the fresh charge during the suction and compression strokes of the next cycle. The crown thus had to act as a reservoir of heat. Brass, with its high thermal conductivity was the material suitable to meet the above demand.

In the first instance, Brass crown was fitted on aluminium piston with 2.0 mm air-gap, in order to investigate the effect of air-gap alone. The total height of the standard aluminium piston was reduced by 9.0mm at the top by machining. Brass crown of 7.0 mm thickness was turned out of aluminium alloy rod of 85 mm to the shape of the standard piston crown. The hemispherical shape was turned using concave and convex turning tool. A thickness of 5mm was maintained on the flange and bowl area of the crown. The recess for valve clearance was provided by end milling. The Brass crown was separated by gaskets made of copper and stainless steel from the aluminium body. The stainless-steel gasket is introduced to minimize the heat loss through gasket.Fig.2 shows the constructional details of Brass crown with Airgap.

Cylinder Liner Insulation

The reciprocating movement of the piston within the bore was a hindrance to insulate the liner on its inner surface. It was hence decided to insulate the outer surface of the liner by providing an air-gap.

In this case air with its low thermal conductivity was used as the insulating medium. A thin mild steel sleeve was circumscribed over the cast iron liner maintaining a 2mm layer of air in the annular space between the liner and the sleeve. The joints of the sleeve were sealed to prevent seepage of cooling water into the air-gap region.Fig.2 shows the constructional details of the air gap liner. Insulation of the liner brought about considerable reduction in the heat lost to the cooling water and an increase in overall thermal efficiency of the engine.

Cylinder Head Insulation

Ceramic coating is a simpler method of insulation for cylinder head compared with other methods. The head was insulated by coating the area exposed to the combustion chamber with PSZ. The combustion chamber area of the cylinder head was machined to a depth of 0.5 mm. The surface was then sand blasted to form innumerable pores for ceramic deposition.

Insulation of Valves

The bottom surfaces of the valves were machined to a depth of 0.5mm and coated with PSZ material of equal thickness. With the valves assembled on the cylinder head the area of the combustion chamber was about 90-92% of the total area.

EXPERIMENTAL SET UP AND MEASUREMENTRS

The experimental set up is designed to suit the requirements of the present investigations. The engine used for the experimental investigations was a Kirloskar, single cylinder, four stroke, water cooled, vertical and direct injection diesel engine. This engine can with stand higher pressures encountered and also used extensively in agricultural and industrial sectors. Therefore this engine is selected for carrying experiments. Moreover necessary modifications on the piston crown liner and the cylinder head can be easily carried out in this type of engine. Hence this engine is selected for the present work.

The CI engine is converted into a LHR engine by applying a ceramic (PSZ) coating on the cylinder head, valves and on the exhaust port. Two types of insulation combustion surfaces have been used in the present study. They are air gap insulation and using thermal barrier pistons. Brass crown of piston was designed and fabricated with the aim of utilizing its higher heat regenerative capacity.

Fig.1 BRASS CROWN PISTON WITH AIR GAP

Sets of experiments are conducted with five vegetable oils (Coconut, Ricebran, Cotton Seed, Palm, Jatropha) to evaluate the performance of LHR engine.

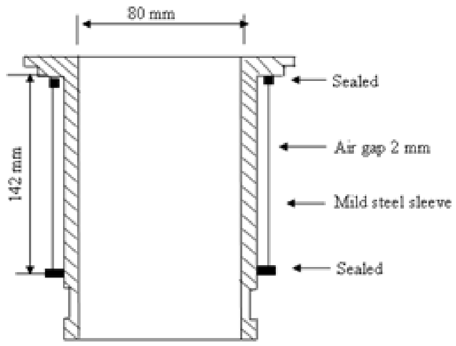

FIG 2 AIR GAP INSULATED LINER

RESULTS

Five vegetable oils are tested in LHR engine for performance, emission and combustion characteristics. The results of the experiments are shown in Figures.

Comparison of Five Vegetable Oils In LHR Engine

<u>Brake Thermal Efficiency</u>

The variation of brake thermal efficiency of five vegetable oils tested in LHR engine with Brake Power output is shown in Fig.1. The brake thermal efficiency of Jatropha oil is higher throughout the load range followed by Rice bran oil. The thermal efficiency of Jatropha oil is significantly higher compared to other oils at part loads. This higher thermal efficiency of Jatropha oil in LHR engine is due to high in-cylinder temperature, which helps in better vaporization and faster combustion of the fuel injected into the combustion chamber.

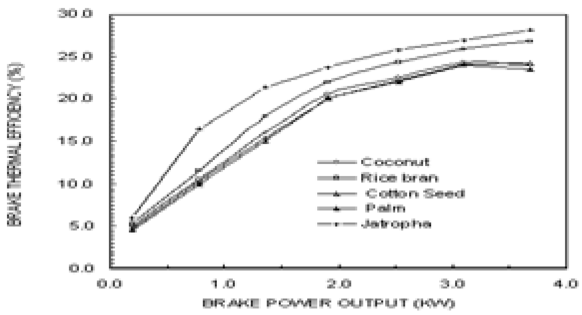

Fig. 1 Comparison of brake thermal efficiency with power output for five vegetable oils in LHR engine.

<u>Volumetric Efficiency</u>

The variation of volumetric efficiency with power output is shown in Fig.2 that relatively due to lower cylinder wall temperatures the volumetric efficiency is higher for Jatropha oil. The volumetric efficiency is badly affected in the case of Rice bran, cotton seed and palm oils. The volumetric efficiency drop is more for palm oil and less for Jatropha oil when observed for a complete power range.

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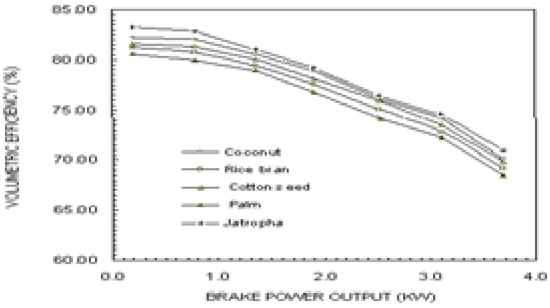

Fig. 2 Comparison of volumetric efficiency with power output for five vegetable oils in LHR engine.

Exhaust Smoke Intensity

The exhaust smoke intensity is lowest for Jatropha oil as seen from the Fig.3 and Fig.4. However, smoke intensity increases with the engine load. Smoke intensities of other oils have shown the similar trend that of the Jatropha oil but marginally higher. This lowest smoke emission for Jatropha oil is due to better vaporization, faster and more efficient combustion of injected fuel in the hot environment inside the LHR test engine and also due to higher oxidation rate of the soot formed.

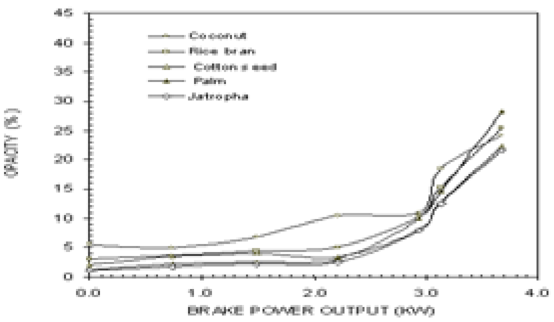

Fig .3 Comparison of Opacity with power output for for five vegetable oils in LHR engine.

Hydrocarbons

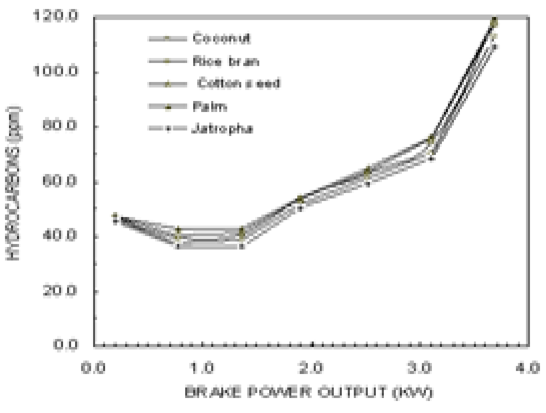

Fig. 5 Comparison of Hydrocarbons with power output for fivevegetable oils in LHR engine.

Fig.5 shows the comparison of un-burnt hydrocarbon emissions of all the five vegetable oils with brake power output. Un-burnt hydrocarbon emissions of all vegetable oils are marginally higher than Jatropha oil. Poor mixing of these oils with air may be one of the reasons for this. Due to insulation in LHR engine, combustion rate has increased very much in the case of Jatropha oil compared to combustion rates of other oils.

Carbon dioxide Emission

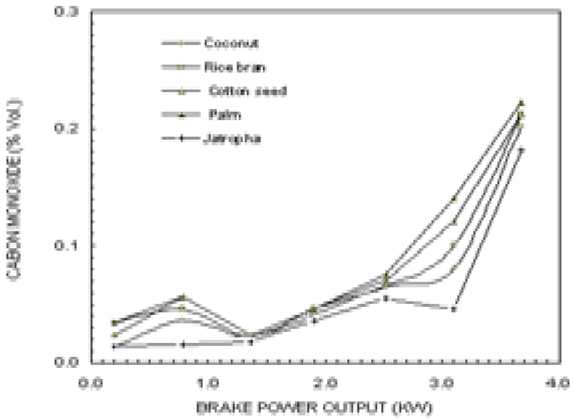

Fig. 7 Comparison of CO emission with power output for five vegetable oils in LHR engine.

Carbon dioxide levels in the exhaust of base engine and all the five vegetable oils with brake power output are shown in Fig.6. Because of better and complete combustion, Carbon dioxide levels are higher for Jatropha oil used in LHR engines. It indicates that the level of Carbon dioxide (CO_2) in the exhaust is highest for Jatropha oil. Higher Carbon dioxide (CO_2) in the exhaust is an indication of complete or better combustion.

Carbon Monoxide Emission

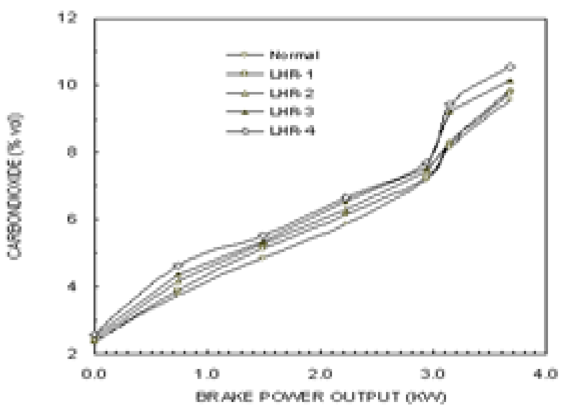

Fig. 6 Comparison of Carbondioxide with power output for five vegetable oils in LHR engine.

Carbon monoxide emission levels are also lower with Jatropha oil as compared to other vegetable oils as seen

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in the Fig.7. The curves of other vegetable oils are almost merged and shown the similar trends that of Jatropha oil.

Exhaust Gas Temperature

Exhaust gas temperature variation with respect to Brake Power output for all the vegetable oils are compared in the Fig.8. Exhaust temperature curves of Jatropha, Coconut oils have merged and difficult to differentiate them and expectedly lowest compared to other oils. Exhaust temperatures are highest in the case of palm oil.

Ignition Delay

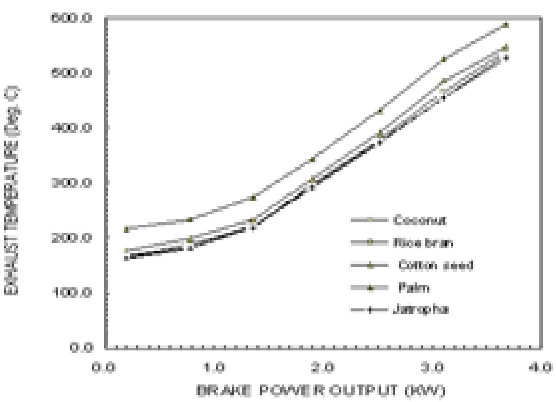

Fig. 8 Comparison of exhaust temperaure with power output for five vegetable oils in LHR engine

Fig. 9 shows the variation of ignition delay with Brake Power output for all the vegetable oils. The test results indicate highest ignition delay for coconut oil among all the vegetable oils. The ignition delay is shortest for Rice bran oil. However, the variation of ignition delay for other oils is in between.

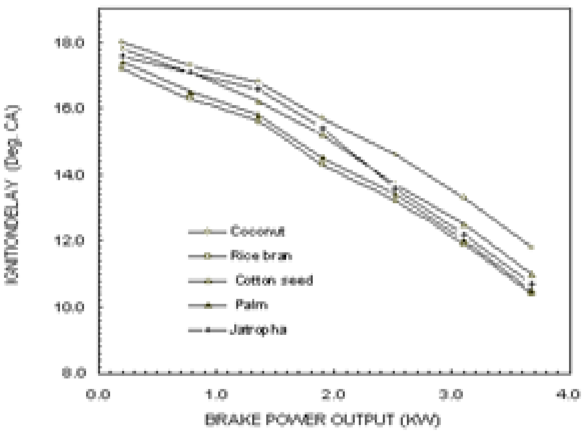

Fig. 9 Comparison of ignition delay with power output for five vegetable oils in LHR engine.

Peak Pressure

The peak pressure variation with respect to the power output is shown in Fig.10. The peak pressure is higher for the Rice bran oil compared to other oils. The engine with coconut oil at the rated load shows a lower peak pressure. For Rice bran oil the peak pressure increases from 49Kgf/cm^2 at no load to 75Kgf/cm^2 at full load and for coconut oil pressure increases from 45Kgf/cm^2 at no load to 70Kgf/cm^2 at full load For Jatropha oil, the peak pressure increases from 47.8Kgf/cm^2 at no load to 73.4Kgf/cm^2 at full load. This may be due to the drop in ignition delay and hence reduction in the fuel accumulated during the delay phase of combustion.

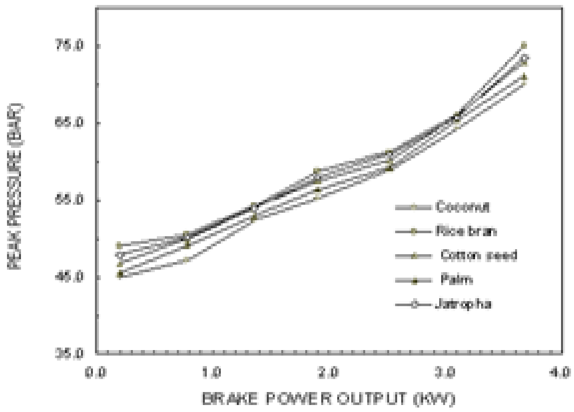

Fig.10 Comparison of Peak pressure with power output for five vegetable oils in LHR engine.

CONCLUSIONS

Based on the experimental results the following conclusions are drawn. These conclusions are drawn based on short-term investigations on engine test bed.

1. The performance of Jatropha oil is found to be superior compared to other oils when tested in the LHR test engine.

2. The emissions like smoke, un-burnt fuel and carbon monoxide are found to be lowest with Jatropha oil. For other oils these emissions are higher.

3 The ignition delay is also found to be shorter with this fuel which shows lesser tendencies towards knocking.

4 The volumetric efficiency is higher with this Jatropha oil.

5. Among the vegetable oils tested, the exhaust temperatures are found to be lowest in the case of Jatropha oil. Heat losses in the engine are reduced with the usage of Jatropha oil, because exhaust gas temperatures are lower, when compared to other vegetable oils.

6. The problem of carbon deposition on injector tip, piston head, valve faces were observed with the vegetable oils.

7. Flash and Fire points of Jatropha oil are comparatively higher than that of diesel. Thus the risk of fire hazards gets reduced. Therefore handling and storage is safer.

8. Economic studies reveal that vegetable oils are not economic as that of diesel at present. But in future this can be recommended when fossil fuels get depleted

All the above investigations are fruitful and these results are expected to lead to substantial contribution to the development of a LHR engine to run on vegetable oil.

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