Experimental Investigations on Schleichera Oleosa (SO) based biodiesel operated Indirect injection (IDI) diesel engine for Performance Enhancement and Reduction in Emissions

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Abstract. With India's demographic demand for more energy on the one hand and its deficit imports much oil to meet its demand, it is placing India under enormous economic sanctions. Exponential extraction and pollution of fossil fuel inspire and motivates researchers and scientists to explore the various alternatives. Schleicher Oleosa based biodiesel is one such fuel of its physical and chemical characteristics near conventional diesel to investigate its performance and emissions of the 4S, water-cooled, naturally aspirated IDI CI engine. The same findings were also compared with the SO straight vegetable oil and conventional diesel operation. Biodiesel output based on Schleichera Oleosa is similar to diesel operations with marginal pollution penalties.

Keywords : Schleicher Oleosa, biodiesel, straight vegetable oil, Performance, Emissions and Indirect Injection Engine

1. Introduction

Looking into the demography of India, the second-largest in population after China in the world with more than 1.35 billion, which contributes 5% of the world population. It is further expected that, in just a decade, the Indian population will surpass China's population and stood in first position [1, 2]. Further, the average age of Indian is just 29 years which is very young when comparing to 37, 48, 46 and 40 years in China, Japan, Europe and USA respectively [3]. In addition to this, the middle class
and upper-middle-class purchase capacity is also growing, which enhances the energy consumption exponentially. With a bird view, India’s primary energy consumption was grown up by more than 2% in the last year (2019) and stood in the third position after China and USA with 5.5% at global share [4]. In 2018, India imported 46% of total primary energy consumption and expected to be more than 50% in just a decade time even after substituting by renewable as well as biofuels [5]. As a rapid economic expansion, other than present pandemic COVID-19 time, India is one of the fastest-growing energy markets and expected to be sitting in the second position in global energy demand by next decade [6]. As per statistics of the BP, 2019 is seen that in the year 2018 itself, coal, natural gas, nuclear energy, hydro based electricity and renewable power contributed to 56%, 6%, 1%, 4% and 3% respectively [7].

Further, even the vehicle population also keeps on increasing. It is observed that, in FY 1951, at a maximum of 0.3 million vehicles and were raised to 253 million vehicles by FY 2017 [8]. Even pump sets being used by the agriculture sector in India is also very high, is touching nearly 27%, which is higher than any other usage [9]. Thus, fossil fuels produce much electricity, and their cost of importing them is continuing to increase, with more troubling pollution from them. Therefore, the topic of climate change and energy protection is becoming a much higher priority in light of environmental issues and rising energy prices today, and the quest for renewables worldwide has led to alternatives to energy. Since bio and renewable energy sources fall within the same section, bioenergy for the present study purpose has been seen as carbon neutral in comparison with renewable energy. The use of biofuel is not a new concept, as the diesel engine inventor Rudolf Christian Karl Diesel, proved during the Universal Exhibition in 1900 in Paris, his engine with peanut oil. Therefore it has a history of almost more than 100 years for biofuels. Hence, with the aforementioned points even, the small substitution of fossil fuels with eco-friendly, oxygenated, sulphur-free biofuels will improve the national economy and reduce the exhaust emissions. However, direct use of biofuels in diesel engines leads to deteriorated in performance of the engine when comparing to conventional regular diesel [10-14].

Viscosity is the main problem associated with all biofuels, which affects the atomisation and subsequently poor participation in the combustion. In order to overcome these viscosity related issues, different researchers identified various techniques like; blending, micro-emulsification, cracking and transesterification. However, transesterification was selected for this experimental work, which is widely accepted globally. Further, the transesterification process depends on the content of free fatty acids (FFA), (are the mono-carboxylic acids consists of double bonds in varying lengths, numbers and positions [15] composition. Further, unsaturated and saturated fatty acids take the main role in the transesterification process. For an IC engine fuel, it is always to choose the more content of saturated when comparing to unsaturated fatty acids. A saturated fatty acid consists of a single carbon bond, and it is effortless to crack when compared to unsaturated fatty acids having a double bond. This is quite the opposite with human beings requirements.

Schleichera Oleosa (SO) biodiesel is an alternative biofuel for standard petro-diesel for the present investigation. Because of the Swiss botanist C. Schleichera, who contributed a lot for this specie, the name of the tree was kept as Schleichera. Size of SO tree is medium to big, mostly available in India, Myanmar, Sri Lanka, Timor and Java and can grow up to 45 feet. Further, the widespread use of SO seeds was not exceeded more than 4500 tonnes out of 60,000 tonnes available per year in India itself. From the Table 1, it is observed that saturated fatty acids of SO oil are high, i.e., 40.64 % when compared to other edible and non-edible oils, which enhances the oxidation stability index (OSI) in turn helps to extend the time to become oxidation and can avoid becoming high viscous. Otherwise,
one can add the antioxidants like in general 'Pyrogallol' or any other allied chemical to prolong or extend the oxidation of the oils, is a slightly costlier process. Even physicochemical properties of the SO oil is very nearer to diesel fuel, which promotes this fuel for the present experimental investigations.

**Table 1.** Composition of unsaturated and saturated fatty acids in edible and non-edible oils

| Sl.No | Description of the Oil | % of composition |
|-------|------------------------|-------------------|
|       |                        | Saturated Fatty Acids | Unsaturated Fatty Acids |
| 1     | Schleichera Oleosa (SO) | 40.64              | 57.96             |
| 2     | Nerium oleander L       | 33.14              | 66.53             |
| 3     | Pongamia Pinnata        | 24.96              | 72.65             |
| 4     | Jatropha Curcas         | 22.4               | 78.6              |
| 5     | Calophyllum inophyllum L. | 24.8          | 72.5              |
| 6     | Azadirachta indica      | 29                 | 70.7              |
| 7     | Hevea brasiliensis      | 18.8               | 80.6              |
| 8     | Madhuca Indica          | 31.6               | 64.4              |
| 9     | Arachis hypogaeae.      | 18.42              | 80.90             |
| 10    | Olea europaea           | 14.39              | 85.19             |

2. Materials & Methods

Selected SO oil was extracted from its seeds through the mechanical expeller at room temperature, available in Engines and Biofuels laboratory, Centre for Alternate Energy Research (CAER), University of Petroleum and Energy Studies (UPES), Dehradun. The process involved in biodiesel of SO oil preparation was taken place in Biodiesel production lab of the same university. In order to avoid the water content in the expelled oil for better conversion into esters, extracted oil was kept in an oven at a temperature of 100 0 C for at least 2 hours. As the FFA content of the chosen oil is over 2%, two-stage transesterification have been adopted. In stage one, FFA was reacted with alcohol in the presence of the acid catalyst and followed by in the second stage as FFA is reached less than 2%, trans-esterified in the presence of the alkaline catalyst. The Anhydrous Sodium sulphate used to remove the moisture content of the two stages for the trans-esterified products. It’s physicochemical properties shown in Table 2.

**Table 2.** Physico-chemical properties of the selected oils

| Sl. No | Description of the Property | SO SVO @ 40 0C | SO biodiesel | Diesel | Standards ASTM |
|--------|----------------------------|----------------|--------------|--------|----------------|
| 1      | Density, (kg/m³) | 865            | 857          | 840    | D1298          |
| 2      | Viscosity @ 40 0C, ( cSt) | 42.67          | 4.6          | 2.9    | D445           |
| 3      | Flash Point, 0 C | 149            | 137.8        | 52     | D93            |
| 4      | Heating Value, kJ/kg | 39,800         | 41,282       | 44,500 | D240           |
Prepared SO biodiesel is tested in 10 hp, IDI CI engine with mechanical fuel injection system and fuel injector with manufacturer recommended injection pressure 175 bar and static injection timing of 200 bTDC. 91 N-m eddy current dynamometer with all necessary instrumentation is being used to load the engine, as shown in Figure 1. AVL Di gas 5000 five gas analyser and 437 smoke meter being used to measure and record the engine-out emissions. Further, the indigenously designed sampling unit is being provided in the loop while measuring the emissions in order to avoid the fluctuations of the single-cylinder four-stroke engine.

3. Results & Discussion

3.1. Performance Parameters

Brake thermal efficiency (BTE) and brake specific energy consumption (BSEC) are two main essential parameters, which describes the performance of the engine. The same parameters are discussed in the following section.

3.1.1. Brake Thermal Efficiency (BTE)

Brake thermal efficiency is nothing but a ratio of the output power to the fuel energy as input given to the engine. The degree of conversion of chemical energy into mechanical is being viewed through the brake thermal efficiency. Figure 2 depicts the variation of BTE with increasing the load for different fuels. It is observed that, with increasing the load, BTE was increased up to 80% load and thereafter fall was noticed for all selected fuels, reason being that, an indirect injection engine, as heat transfer rate is high at full load due to its high surface to volume ratio [10, 22-28]. Maximum BTE with SO biodiesel is 28.61%, which is 4.18% higher than the SO straight vegetable oil and still 1.8 % lesser than the regular petro-diesel.
Figure 2. Brake thermal efficiency (BTE) versus variation of Engine Load

3.1.2. Brake Specific Energy Consumption (BSEC)

Figure 3. Brake specific energy consumption (BSEC) versus variation of Engine Load

Brake specific energy consumption (BSEC) indicates the amount of energy spent to produce one kW power for one hour time. Figure 3 illustrates the variation of BSEC with increasing the engine load. From the Figure 3, it is seen that, minimum BSEC is noticed with conventional diesel of 11834 kJ/kW-hr which is a marginal difference with SO biodiesel of 745 kJ/kW-hr and considerable difference with SO straight vegetable oil of 2,157 kJ/kW-hr. Increase in BSEC for the same power with SO oil as well as its biodiesel is due to the presence of the oxygen in the fuel leads to reduction in energy density when compared to petro-diesel [29].
It is experiential from the performance parameters that, SO biodiesel shown better performance at par with conventional diesel operation. There is a marginal difference between SO biodiesel and conventional diesel operation. Whereas, SO straight vegetable oil performance is very much far away from the conventional diesel operation is due to its viscosity otherwise all other properties nearby the regular diesel fuel.

3.2. Engine out Emissions
Emissions out from the exhaust are mirroring the performance of the engine. Though oxides of Nitrogen and Smoke are remarkable contributions in diesel engine emissions, Carbon Monoxide and Hydrocarbons also discussed in the following section

3.2.1. Oxides of Nitrogen

Zeldovich and Lavoie also named as expanded Zeldovich mechanism describes the formation of oxides of Nitrogen in a diesel engine [22]. Figure 4 describes the distinction of oxides of Nitrogen (NOx) with a variation of engine load. Maximum NOx was observed at the maximum efficiency point in all fuels. At this high-efficiency point SO biodiesel was registered at 422 ppm, which is 142 ppm higher than the SO straight vegetable oil and 8 ppm lower than the diesel fuel operation.

3.2.2. Smoke
The main reason in formation of Smoke emissions is due to the absence of sufficient oxygen during the combustion. Figure 5 witnesses the formation of smoke with a variation of engine load. With rising load, smoke emissions continue to grow as the air-fuel mixture becomes richer and richer. Smoke emission of 42 HSU, which is 20 HSU more than SO straight vegetable oil and 10 ppm less than diesel oil, at the maximum efficiency point with SO biodiesel was reported.

3.2.3. Carbon Monoxide

![Figure 6. Carbon Monoxide versus variation of Engine Load](image)

Figure 6. Carbon Monoxide versus variation of Engine Load

Figure 6 explains the formation of Carbon Monoxide with a change in engine load. The 2-step process involved in the formation of CO emissions. One of the main reason in formation of the CO is rich mixture formation. This is evident from Figure 6 that as load increases, CO emissions increased due to rich mixture formation as load increases. At full load, the highest amount of CO emissions noticed. At maximum efficiency point, SO biodiesel CO emissions are of 0.44% by volume, which is 0.39% by volume lesser than the SO SVO and 0.37% by volume higher than the regular diesel operation.

3.2.4. Hydrocarbons

![Figure 7. Hydrocarbon versus variation of Engine Load](image)

Figure 7. Hydrocarbon versus variation of Engine Load
Though various parameters influencing in formation of hydrocarbons, viscosity plays a significant role in this experimental investigation. Figure 7 demonstrates that, the formation of hydrocarbon with increasing the engine load. SO biodiesel attempted 9 ppm HC emissions at best efficiency point which is 6 ppm lower than the SO SVO and just 2 ppm higher than the diesel fuel operation.

4. Conclusion

The experimental investigation was carried out on a 10 hp, four-stroke, water-cooled, constant speed, Indirect injection, naturally aspirated, vertical lister oil engine with SO biodiesel and compared its results with SO based straight vegetable oil and conventional diesel operations. Moreover, results were drawn at the highest efficiency point:

- Being IDI engine, as heat transfer rate is high at full load due to high surface to volume ratio, maximum efficiency was achieved at 80% load rather than a full load
- Maximum BTE of 28.61% which is 4.18% higher than the SO SVO and 1.8% lesser than the conventional diesel operation
- BSEC of 12579 kJ/kW-hr was recorded with SO biodiesel which is 2,157 kJ/kW-hr higher than the SO SVO and 745 kJ/kW-hr beyond the regular diesel operation
- Oxides of Nitrogen of 422 ppm reported, which is 142 ppm on top of the SO SVO and 8 ppm lesser than the petro-diesel operation
- Carbon Monoxide of 0.44% by volume as traced with SO biodiesel, which is 0.39% by volume lesser than the SO SVO and 0.37% higher than the diesel operation
- Hydrocarbons of 9 ppm noted with SO biodiesel, which is 6 ppm higher than the SO SVO and 2 ppm higher than the traditional diesel operation.

SO biodiesel has shown better performance and marginal effects on exhaust out emissions at par with diesel operation. Further, as SO oil contains up to 12% Oxygen by weight, by its nature leads to lowering the energy density, which increases the fuel consumption for the same power when comparing to regular petro-diesel operation. In addition to this, the viscosity of the SO straight vegetable oil makes coarser atomisation which affects the mixture formation affects the combustion. This makes deterioration of SO SVO when compare to SO biodiesel and conventional diesel operations. However, SO biodiesel has shown better performance at par with the regular petro-diesel.

5. Future Scope of the work

Since cyanogenic compounds in the SO Biodiesel are present within the range of 0.03% to 0.05% as hydrogen cyanides (HCN), exhaust emissions from the engine needs to be checked, before going to the atmosphere, and required proper pre-treated.

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7. Nomenclature

| Acronym | Description             |
|---------|-------------------------|
| SO      | Schleichera Oleosa      |
| BD      | Biodiesel               |
| SVO     | Straight Vegetable Oil  |
IDI - Indirect Injection
CI - Compression Ignition
NOx - Oxides of Nitrogen
CO - Carbon Monoxide
HC - Hydrocarbon
BTE - Brake Thermal Efficiency
BSEC - Brake Specific Fuel Energy Consumption
Ppm - Parts per Million
HSU - Hartridge Smoke Unit
FFA - Free Fatty Acids
UPES - University of Petroleum & Energy Studies
FY - Financial Year
OSI - Oxidation Stability Index

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