Analysis of Green Fuel for Diesel Engine

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Abstract. We are One of the inconsumable oils that could be used to produce green fuel is Tamanu oil. It is derived from Tamanu green plant seeds. This research describes about the features, analysis that have been performed by an empirical study on using Tamanu oil as a raw material to generate green fuel in diesel engine. The green fuel Tamanu Methyl Ester Tamanu100 and its blends Tamanu30 and Tamanu60 are used in engine to test the efficiency of the fuel. The characteristics of the engine that are impacted such as brake thermal efficiency, brake specific energy consumption, unburned hydrocarbon, carbon monoxide, and release of NO\textsubscript{X} have been measured using Tamanu100 green fuel and the output of the tests have been contrasted with conventional fuel. It is noted that the green fuel resulted in trivial reduction in brake thermal efficiency. Release of hydrocarbon and carbon monoxide has lessened on using green fuel with substantial release of oxides of nitrogen. Also, the ignition characteristics such as cylinder gas pressure, ignition delay period have been detailed. The output from the experiments has been contrasted with conventional diesel fuel by applying various load conditions.

Keywords: Tamanu Methyl Ester, Emulsion, Brake Thermal Efficiency, Specific Energy Consumption.

1. Introduction

The raw material for engine that is fuel is getting exhausted as the consumption has increased. There is a widening gap between the supply and demand of fuel across the globe. Using petrol and diesel causes hazardous effect on the environment that causes respiratory disorders. Hence a look out for another fuel has risen [1]. Green fuels are accepted across the globe due to depletion of petroleum and diesel. Green fuels are decomposable, imperishable and very much habitat to the environment as they do not cause any harm in contrast to petroleum-based fuels. Green fuel is a combination of fatty acid methyl ester that are abstracted from any type of vegetable oil and animal fats [2]. Due to higher dependence on vegetable resources in India using that for green fuel has reduced hence an alternative fuel in nature such as in consumable oil resources from seeds have been analyzed. Inconsumable resource is obtaining overall consideration because they are found various countries across the globe specifically in wastelands that are inappropriate for cultivation food crops which removes disputes for food crops and are higher in efficiency and environment friendly they are also cost effective in contrast to consumable oils [3]. A significant drawback of Tamanuis it has higher level of free fatty acids that has to be cleaned while trans-esterification procedure is applied. The resultant of the transesterification procedure is very sticky oil.
that reduces the green fuel quality. The next stage in production of green fuel resulted in the green fuel that met the ASTM standards that had characteristics identical to petroleum diesel [4]. Low volumetrically energy capacity, high kinematic viscosity, poor cold-flow properties, inferior oxidation stability and high release of NO\textsubscript{X} are some demerits of utilizing green fuel that reduces its worldwide use. Nonetheless numerous research works have been done to evaluate the engine effectiveness, ignition and release of toxic gas features while using green fuel in CI engine. A Tamanu seed is an easily cultivable and widely accessible resource for green fuel trans-esterification in developing countries like India. There are no literatures available that informs about setting up Tamanu with diesel blends with 30%, 60% and 100% in a CI engine. Therefore, the current research focuses on the engine effectiveness, release of toxic gas and ignition features of direct injection diesel engine using various blends of Tamanu Like 30% Tamanu, 60% Tamanu and 100% Tamanu. The output of the investigation has been contrasted with conventional diesel propellant. Certain important features like brake specific energy consumption, brake thermal efficiency, heat release rate, in-cylinder pressure, unburned hydrocarbons, carbon monoxide, carbon dioxide, release of NO\textsubscript{X} and smoke density have been assessed.

2. Material and methods

2.1 Green fuel preparation

Predominantly trans-esterification process is utilized to lessen the stickiness of vegetable oil to generate green fuel [5]. Triglyceride is made of three esters of fatty acid chain connected to glycerol backbone. Glycerol part of Triglyceride adds to maximum stickiness in vegetable oil. Free Fatty Acid portion has 10 times smaller amount of stickiness in contrast to the stickiness of vegetable oil. It is pivotal that the component in the raw material utilized for alkali-catalyzed trans-esterification must have free fatty acids. Fatty acids in the raw material might substantially have an impact on the ester yield and glyceride conversion in alkali-catalyzed trans-esterification process [6]. The fatty acids are changed by using methanol and acid catalyst to generate ester. Molar ratio of alcohol to oil is one of the main parameters that impacts the conversion efficiency, green fuel yield and production. In addition, it also raises the capability of blending and enhances the contact among alcohol and triglyceride. Besides, the surplus quantity of alcohol improves the green fuel purity. The maximum conditions for the reactants were found to be 16:1 methanol to oil ratio, 10 ml of H\textsubscript{2}SO\textsubscript{4} for 100 ml of oil, reaction temperature of 60 \textdegree C, and 45 min of reaction time along with a constant stirring rate on a magnetic stirrer. A trans-esterification method is applied using alkali catalyst. The maximum conditions for the reactants have been 16:1 methanol to oil ratio, 0.5 g concentration of Sodium hydroxide for 100 ml of oil, reaction temperature of 60 \textdegree C, 30 min of reaction time along with a constant stirring rate. Oil is refined by eliminating methanol when heating green fuel at 75 \textdegree C for about 30 min to eliminate trapped methanol and the output of green fuel had been around 85%. The varied physical and chemical properties of Tamanu have been assessed and a comparison has been done with diesel as shown in Table 1.

| Properties                          | Diesel | Tamanu |
|-------------------------------------|--------|--------|
| Acid Number (mg of KOH/g)           | -      | 0.38   |
| Calorific value (MJ/kg)             | 42.5   | 37.8   |
| Cetane Index                        | 38.5   | 58.7   |
| Density at 15\textdegree{C} (kg/m\textsuperscript{3}) | 827    | 874    |
| Kinematic viscosity at 40\textdegree{C} (mm\textsuperscript{2}/s) | 2.28   | 5.3    |
| Flash point \textdegree{C}          | 54     | 168    |
2.2 Experimental setup

To test the green fuel Kirloskar TAF-1 direct injection four-stroke single cylinder diesel engine that has certain specification as given in Table 2. The engine is joined with a Swing field electric dynamometer to apply load that is used to vary with a controller in the dynamometer as illustrated in Figure 1. The air flow rate is calculated by measuring the pressure difference of the U-tube manometer connected to the path of airflow pipe in the engine and the time taken for 10 cc of fuel is also noted using stop watch and weighted fuel tank for calculating fuel flow rate. AVL digas 444 exhaust gas analyzer is used for measuring engine exhaust emission such as HC, CO, CO₂, and NOₓ. Nevertheless, the release of toxic gas is computed in g/kW h according to the emission standard method used in non-road application engines. The AVL DIGAS 444 exhaust gas analyzer is used to measure the release of CO and CO₂ in percentage and release of HC and NOₓ as ppm. The measured CO, HC and NOₓ release are changed to ppm and further changed to g/kW h according to the standard release of toxic gas in the testing procedure.

![Figure 1. Experimental Setup Layout](image)

The Exhaust Gas Temperature is interpreted from the ChromelAlumel (K-Type) thermocouples which has a range of 200 LC to +1260 LC. AVL 437C Smoke meter that has a measurement range of 0–10 FSN is used to calculate the amount of smoke in the exhaust in FSN which is measured by passing a specific amount of exhaust gas through a white filter paper. A microprocessor is used to assess the filter paper blackening that is sensed by a photoelectric measuring head. An electro optical sensor is utilized to sense the TDC position by supplying voltage signals that are sent to A/D converter and then to data acquisition system to record the data. The pressure signals are also recorded by the data acquisition system. A Kistler transducer that has a sensitivity of about 79.5 pC/bar is used to measure the in-cylinder pressure and is mounted flush on the cylinder head for avoiding passaging effects. The in-cylinder pressure of the engine was measured using an AVL Pressure transducer. A high-speed computer based Digital Data Acquisition System is utilized for measuring the signals of in-cylinder pressure and TDC position. A 12-bit analog to digital converter is used to convert analog signals to digital form. The A-D converter had external and internal triggering facility with sixteen single ended channels. 100 continuous cycle data is recorded and the optimum increase in the rate of pressure, peak pressure has been ascertained by processing the signals. The uncertainty of engine parameters is ascertained by using square root method and the output is shown in Table 3.
Table 2. The Engine Specifications

| Parameter                      | Value  |
|--------------------------------|--------|
| Stroke length (mm)             | 110    |
| Bone diameter (mm)             | 87.5   |
| Connecting rod (mm)            | 255    |
| Compression ratio              | 17.5 : 1|
| Rated power (kW)               | 4.41   |
| Speed (rpm)                    | 1500   |
| Displacement volume (cc)       | 600    |
| Stroke type                    | 4 stroke engine |

Table 3. The percentage of uncertainty parameter

| S. No. | Parameter                          | % of Uncertainty |
|--------|------------------------------------|------------------|
| 1      | Brake power (kW)                   | 0.6              |
| 2      | Brake Thermal efficiency (%)       | 0.7              |
| 3      | Air flow rate (kg/s)               | 0.5              |
| 4      | Brake specific fuel Consumption (kg / kWh) | 1.2 |
| 5      | Exhaust gas temperature (°C)       | 0.5              |
| 6      | Hydro carbon emission (ppm)        | 0.3              |
| 7      | Carbon monoxide (%)                | 0.2              |

3. Results and discussion

Experiments for the study have been done by allowing the engine to warm up for a certain period of time. The investigations are done at injection timings of 23°CA b TDC and injection pressure of 200 bar. The engine effectiveness, ignition and release of toxic gas have been acquired at varied loads of 0%, 25%, 50%, 75% and 100%.

3.1 The brake thermal efficiency

A comparison of the varied green fuel blends has been done to access the engine features such as engine effectiveness, brake thermal efficiency, brake specific energy consumption and brake specific fuel consumptions. An engine’s capability to change the fuel’s heat energy into mechanical energy denotes the Brake thermal efficiency of the engine. Figure 2 illustrates the brake thermal efficiency of Tamanu green fuel by using different blends of green fuel. The brake thermal efficiency of CI green fuel is lesser than that of diesel since it is highly dense, sticky and has lesser calorific value than that of green fuel. The brake thermal efficiency of green fuel decreases when there is increase in the percentage of green fuel in the green fuel-diesel blends as there is lesser calorific value with increasing concentration of green fuel in the blends. This happens because of the uneven ignition due to less atomization and vaporization of blends since the stickiness and density is high [7].
3.2. The Brake Specific Fuel Consumption

A higher level of BSFC has been noted than that of diesel because of the low calorific value of Tamanu green fuel and the modification in ignition features. Higher level of propellant is has to be supplied to the engine such that the same input energy is sustained. The level of Tamanu green fuel sprayed by the injector is higher than that of diesel by suing the same volume due to its high density [8]. Figure 3 illustrates the deviation of BSFC for various percentages of green fuel-diesel blends. BSFC of green fuel blends surges up on increasing the ratio of green fuel in the green fuel-diesel blend since lesser calorific value of green fuel on increasing the proportion of green fuel. The lesser calorific value ensues increased supply of fuel to the engine to generate same amount of brake power consequently higher level of fuel consumption.

3.3. Brake Specific Energy Consumption

BSEC indicates the engine effectiveness to acquire energy from the propellant to generate unit power. The specific energy consumption is an exact measure in contrast to specific fuel consumption to compare fuels with varied calorific values [9]. An illustration of the deviation in brake specific energy consumption under varied injection timings is shown in Figure 4. The BSEC of green fuel is high in contrast to that of diesel fuel. Possible reasons for higher brake specific energy consumption are the
low calorific value, high viscosity and boiling point. The brake specific energy consumption is an exact parameter to compare fuels with varied calorific values. The upsurge in the proportion of blends in the green fuel results in increase of BSEC since calorific value of the fuel decreases on increasing the proportion of blend.

![Graph showing variation of BSEC versus BMEP](image)

**Figure 4.** Variation BSEC versus BMEP

### 3.4. Release of Unburned Hydrocarbon Emission

Values of HC, CO, NO\(_X\) and smoke are acquired on using diesel and Tamanu blends of fuel. The cause of HC release is due to the incomplete ignition of fuel. The release of UBHC is lesser for green fuel due to improved ignition. There is an improvement in ignition due to high cetane index and higher level of gas temperature of the green fuel that causes shorter ignition delay [10]. The UBHC release from green fuel reduces on increasing the level of Tamanu in diesel blends as depicted in Figure 5. Higher level of molecular oxygen and cetane content in green fuel causes complete ignition of the fuel.

![Graph showing variation of UBHC versus BMEP](image)

**Figure 5.** Variation of UHC versus BMEP
3.5. Release of Carbon Monoxide Emission

Partial oxidation of elements in carbon causes formation of carbon monoxide that is very hazardous in nature. CO contributes to a major percentage in forming ground level ozone. Figure 6 illustrates the deviation in release of CO. The release of CO from Tamanu green fuel is lesser in contrast to that of diesel. This is because availability of high level of oxygen concentration in the green fuel that facilitates complete oxidation of CO [11]. There is a very minute upsurge in release of CO that is caused due to shorter ignition delay; ignition is delayed because of the high temperature and cylinder pressure and the inferior premixed combustion phase with respect to retarded injection timing. The release of CO is due to lower temperature along with insufficient air supply during ignition. The variation in release of CO has the same trend as that of release of HC. On increasing the green fuel proportion in the blends there is lesser level of CO release. On increasing the proportion of green fuel leads to an increase in the oxygen concentration of the green fuel that aids complete ignition.

![Figure 6. Variation of CO versus BMEP](image)

3.6. Release of Oxides of Nitrogen Emission

Figure 7 illustrates the deviation in release of NO\textsubscript{X}. The NO\textsubscript{X} is formed due to the existence of higher level of oxygen content and high temperature. The proportion in release of NO\textsubscript{X} upsurges on increasing the proportion of green fuel in the blends.

![Figure 7. Variation of NO\textsubscript{X} versus BMEP](image)
The elevated density of green fuel too plays a role in the formation of NO\textsubscript{X} release [12]. In contrast to diesel the release of NO\textsubscript{X} on using Tamanu green fuel is high. The reason for higher emission is because of higher level of ignition temperature that causes improved ignition as high molecular oxygen exists in the green fuel. Due to reduced mixing time and curtailed delay in ignition slow burning rate and slow rise in pressure and temperature subsist.

3.7. Release of Smoke Opacity Emission
The release of smoke on using green fuel is less as compared with diesel on applying higher load. At higher load due to the existence of high level of oxygen content in green fuel and higher BTE that completely converts large sized carbon atoms into CO because of complete ignition causes lesser smoke [13]. Figure 8 depicts the deviation in smoke on using varied concentrations of green fuel blends. The level of smoke released lessens on increasing the proportion of green fuel in the blend of green fuel and diesel but for Tamanu100. The release of smoke by using diesel is high in contrast to green fuel and its blends with diesel. The lesser smoke opacity of green fuel is because of existence of aromatic compounds in the green fuel and a lesser carbon to hydrogen ratio in contrast to conventional diesel fuel.

![Figure 8. Smoke Opacity Verses Brake power](image)

3.8. In Cylinder Pressure
Ignition parameters such as in-cylinder pressure, ignition delay and heat release rate are discussed in the following section. The increase in the rate of pressure establishes the smooth movement of gas pressure that pushes to the crank-shaft and smooth functioning of the engines. The proportion of cylinder pressure by suing diesel is high in contrast to using green fuel that is depicted in Figure 9 and there is lesser pressure on the cylinder on increasing the proportion of green fuel in the green fuel-diesel blend. The calorific value of the fuel determines the in-cylinder gas pressure [14]. In general, the in-cylinder gas pressure while using green fuel is lesser in...
3.9 Combustion delay
The disparity in the start of the injection and start of combustion causes the ignition delay. The ignition delay on using Tamanu green fuel is lesser as compared with diesel due the high cetane number depicted in Figure 10. The ignition delay reduces on increasing the load. The reason for increasing the load is the reduced exhaust gas dilution and higher cylinder pressure and temperature [15]. The delay in ignition lessens on increasing the proportion of green fuel in the blends since there is decrease in cetane number.

4. Conclusion
Tamanum ethyl ester has been acquired from the plants and the procured green fuel is blended with diesel in the proportion of Tamanu30, TAMANU60 and TAMANU100 to test engines. The engine effectiveness, releases of toxic gas and ignition characteristics of different blends of Tamanu green fuel have been contrasted with those of the fossil fuel diesel. The Blends of Tamanu can be used in engines without modifying the parameters in the diesel engine because properties of Tamanu and
diesel fuel are same. The BTE is high on using diesel in contrast to Tamanu green fuel whilst it reduces on increasing the proportion of green fuel in the blends. BSFC and BSEC raises on increasing the ratio of Tamanu green fuel in the blends. On increasing the ratio of Tamanu green fuel in the blends causes lesser release of HC, CO and smoke emissions whilst the release of NOx is high.

Combustion parameters of the engine like in-cylinder pressure, ignition delay and heat release rate are acquired by using Tamanu fuel and the outcome of the usage are according to the norms in contrast to diesel. It has been concluded that Tamanu is an appropriate alternative fuel for conventional diesel. It is widely acceptable as it does not cause any harm to the environment. Moreover, research on using varied green fuel blends with diesel at varied ratios could decide the best situation to use green fuel.

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