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IMPACT OF TERT-BUTANOL ADDITIVE ON ATTRIBUTES OF DIESEL ENGINE POWERED WITH PONGAMIA BIODIESEL

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ABSTRACT
With the continuous and rapid depletion of fossil fuel reserves worldwide, the search for alternative energy sources has become increasingly important. Diesel engines are among the most efficient prime movers, making them a key focus in the transition to sustainable fuels. Growing concerns over environmental protection and long-term energy security necessitate the development of alternative fuels with properties comparable to conventional petroleum-based diesel.Biodiesel, derived from renewable biological sources such as rice bran, rapeseed, palm, canola, and used cooking oils, has emerged as a viable substitute. The present study investigates Pongamia oil-based biodiesel as a potential alternative fuel. In particular, the research explores the performance and emission characteristics of a single-cylinder diesel engine fueled with Pongamia biodiesel blends and supplemented with Tert-butanol as an additive.The Pongamia biodiesel was produced through the transesterification process and tested in various blend ratios with diesel—specifically 20%, 30%, and 40% biodiesel—alongside a constant 5% addition of Tert-butanol. Comparative analysis was conducted against neat diesel fuel. Results indicate that the biodiesel-Tert-butanol blends yield improved mechanical efficiency and reduced emissions, including lower levels of carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM). Among the tested blends, the D55P40TB5 configuration (55% diesel, 40% Pongamia biodiesel, 5% Tert-butanol) demonstrated the best overall engine performance and emission characteristics at full load conditions.

Keywords:
Pongamia biodiesel; Tert-Butanol; Performance; Emissions, Transesterification.

I. Introduction
Many vegetable oils can be used in diesel engines, including peanut oil, linseed oil, rapeseed oil, and sunflower oil. Vegetable oil has numerous advantages, including sustainability, reduced greenhouse gas emissions, regional development, and agricultural improvement. In the current energy scenario, majorly research is focused on sustainability energy and to emphasis on energy efficiency, use of renewable energy resources. Utility of diesel engines in transportation and power sectors are essential due to their higher efficiency. However, concerns over the long-term sustainability of petroleum-derived diesel, along with the implementation of progressively stringent environmental regulations, have driven the development and adoption of renewable diesel alternatives to mitigate these issues. Biodiesel production and utilization has been increasing rapidly nowadays and continue to do so. Worldwide energy consumption expected to be rise by 40% in 2040.

II. Literature
Nidigonda Gopikrishna et al. [1] conducted experiments using Jatropha biodiesel (JOBD15 and JOBD30) with 5%, 15%, and 25% exhaust gas recirculation (EGR) at half-load engine conditions. They found that biodiesel blends reduced CO, PM, and HC emissions compared to pure diesel but

increased NOx emissions, which EGR helped mitigate.Huiqiong Huang et al. [2] observed that increased EGR rates lowered cylinder pressure and temperature, which significantly decreased NOx emissions (up to 78.89% at 15% EGR), although BSFC increased and BTE decreased. Emissions of HC, CO, and soot increased with higher EGR.Qixin Ma and Quanchang Zhang et al. [3] found that B10P10 (10% biodiesel, 10% n-pentanol) showed stable combustion and reduced THC and CO emissions, particularly at medium engine speeds, suggesting ternary blends as effective alternatives. Ganesh Duraisamy et al. [4] and G. Eader et al. [5] reported that biodiesel lowers HC, PM, and CO but increases CO2 and NOx. EGR is essential for reducing NOx, although it reduces BTE. Low heat rejection (LHR) engines further aid in emission reduction.Satish Kumar et al. [6] echoed similar findings, noting that EGR reduces NOx effectively in LHR engines using Jatropha biodiesel, with a trade-off in brake thermal efficiency.Chetankumar Patel et al. [7] analyzed metal particulates in exhaust emissions and found higher levels of certain metals like Ca, Cu, Fe, and Zn in biodiesel blends.Karikalan Loganathan et al. [8] confirmed that biodiesel with EGR reduces NOx and is a promising alternative to fossil diesel. Miqdam Tariq Chaichan et al. [9] and [15] studied hydrogen and biodiesel dual fueling with EGR. While hydrogen increases NOx and engine noise, EGR mitigates these effects and reduces CO, HC, and PM emissions.Gautam Edara et al. [10] explored high-pressure injection with split and retarded injections combined with EGR. They found that split injection reduced smoke and improved combustion at higher EGR rates. Muthusamy Siva Kumar et al. [11] and A. Praveen et al. [12] tested biodiesel blends with nanoparticles (Al2O3 and TiO2), showing improvements in BSFC and emissions when combined with EGR.A. Ramos et al. [13] demonstrated differences in NOx emissions under real driving vs. NEDC cycles, highlighting inadequacies of current certification procedures.S.K. Mahla et al. [14] examined EGR's influence in CNG-diesel/biodiesel dual-fuel engines, noting decreased peak pressure and BTE, but also reduced emissions. Tingpu He et al. [16] studied alcohol additives (ethanol, butanol) with EGR and found improved premixed combustion, although ignition delay increased due to reduced temperatures.Varatharaju Perumla et al. [17] highlighted the socioeconomic benefits of using PME biodiesel, which showed decreased CO and HC but a slight increase in BSFC and reduced BTE. Md. Atiqur Rahman et al. [18] investigated hydrogen-enhanced biodiesel with EGR, finding reduced NOx and other emissions.A.J. Torregrosa et al. [19] showed that EGR reduced heat flux (up to 18%) and affected NOx-CO2 trade-offs.P. Dubey et al. [20] experimented with Jatropha biodiesel and turpentine blends, finding notable emission reductions (NOx by 4.72%, HC by 4.56%, CO by 42.5%).J. Narayana Reddy et al. [21] found lower emissions with retarded injection timing and higher injection rates when using Jatropha oil. Khalil Ibrahim Abass et al. [22] found that 30% EGR significantly reduced BTE, exhaust temperatures, and volumetric efficiency.Karikalan Loganathan et al. [23] studied the effects of heating Karanja oil blends. Heated blends showed improved viscosity, better BTE, and reduced emissions.C. Solaimuthu et al. [24] tested Mahua biodiesel blends with SCR and both CEGR and HEGR. All techniques reduced NOx effectively.

The literature strongly supports the viability of biodiesel and its blends as alternatives to fossil diesel in compression ignition engines. EGR emerges as a common and effective method to reduce NOx emissions, although it often results in increased HC, CO, and soot emissions and slightly reduced engine performance (BTE, BP). Additives like alcohols, nanoparticles (Al2O3, TiO2), and hydrogen also enhance emission profiles and combustion characteristics. Technologies like LHR engines, fuel preheating, and dual-fuel systems further contribute to optimizing biodiesel usage.

2.1 Pongamia oil biodiesel

The calculated density of Pongamia biodiesel ranges from 860 to 900 kg/m³, while diesel falls between 800 and 850 kg/m³, indicating that Pongamia biodiesel closely meets the ASTM standard limits. Its measured kinematic viscosity is 4.2 cSt at 30 °C, which lies within the ASTM-specified range and is comparable to diesel's viscosity of about 2.2 cSt. The flash point of Pongamia biodiesel is recorded at 168 °C, significantly higher than the ASTM D6751 minimum requirement of 93 °C, demonstrating

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enhanced safety during handling and storage. In comparison, conventional diesel has a flash point of around 80 °C. However, the higher flash point can cause a delayed ignition start in the engine, which may lead to increased NOx emissions. The measured calorific value of Pongamia biodiesel is 39,270 kJ/kg, which is close to diesel's value of 42,000 kJ/kg.


Figure : 2.1,Pongamia Oil Biodiesel


Figure: 2.2,Tert Butonal

2.2 Tert butonal

Tert-Butyl alcohol (TBA) is commercially synthesized as a co-product during the production of propylene oxide via the hydroperoxide process, where isobutane serves as a precursor. Alternatively, TBA can be produced through the acid-catalyzed hydration of isobutylene or via a Grignard reaction involving acetone and methylmagnesium chloride. In its pure form, tert-butyl alcohol appears as a colorless liquid or crystalline solid, characterized by a distinct camphoraceous (mothball-like) odor. Tert-Butyl Alcohol (TBA) is a tertiary alcohol structurally characterized by a hydroxy group substituted at the second carbon of isobutane. It is the simplest tertiary alcohol and is recognized as a human xenobiotic metabolite. It is commercially produced as a co-product during propylene oxide synthesis via the hydroperoxide process using isobutane as a feedstock. Alternative synthesis methods include acid-catalyzed hydration of isobutylene and the Grignard reaction between acetone and methylmagnesium chloride.Pure tert-butyl alcohol is a colorless compound that may appear either as a liquid or a crystalline solid under ambient conditions. It is characterized by a distinct camphoraceous odor, often described as similar to that of mothballs. Compared to lower alcohols such as ethanol, tert-butanol and other higher alcohols exhibit higher cetane numbers and lower latent heats of vaporization. These properties enhance their potential as alternative fuels for compression-ignition (diesel) engines. Benefits include improved safety characteristics, lower kinematic viscosity, and reduced exhaust emissions relative to conventional diesel fuel.

2.3 Transesterification process

Biodiesel was synthesized from crude Pongamia pinnata oil via transesterification with methanol using sodium hydroxide (NaOH) as the catalyst. Vegetable oils can be transesterified by heating them with a stoichiometric excess of methanol—often containing trace amounts of water—in the presence of either an acidic or basic catalyst to promote the reaction. Both acid-catalyzed esterification and base-catalyzed transesterification steps were employed sequentially to obtain the final biodiesel product.Catalysts are employed to enhance reaction kinetics and improve overall yield. Comparative studies indicated that NaOH outperformed potassium hydroxide (KOH) in terms of biodiesel yield under similar reaction conditions. To drive the reversible transesterification reaction toward product formation, an excess of methanol is utilized to shift the equilibrium toward methyl ester production.Several critical parameters influence the efficiency and outcome of the transesterification process, including the catalyst type (alkaline, acidic, or enzymatic), the molar ratio of alcohol to vegetable oil, reaction temperature, purity of reactants (notably water content), and the free fatty acid (FFA) concentration in the feedstock. Optimization of these variables is essential for maximizing biodiesel yield and quality.A maximum oil-to-ester conversion efficiency of 94% was achieved at a

1:10 molar ratio of Pongamia oil to methanol, with the reaction carried out at 60–65 °C. The key fuel properties of the resulting Pongamia oil methyl esters (biodiesel) were found to be in close agreement with the specifications outlined in the ASTM standards. The slight reduction in the calorific value of the biofuel may lead to a marginal increase in specific fuel consumption. Its cetane number, measured at 49, complies with ASTM standards and is comparable to that of diesel, which typically ranges from 51 to 60.Pongamia oil is processed into biodiesel and it will be used as per the blend ratio of D75P20 and D65P30 namely. D75P20 means 20% of biodiesel addition with remaining percentage volume of diesel, and similarly D65P30 means 30% of biodiesel addition with remaining percentage volume of diesel and using these fuels at different operating conditions and these results are to be compared with pure diesel performance.

2.4 Experiemntal Setup

The experimental investigation was carried out on a single-cylinder, four-stroke, direct-injection diesel engine manufactured by Kirloskar, rated at 5.2 kW. The engine was coupled to an eddy current dynamometer for precise control and measurement of load during testing, with its detailed specifications presented in Table 5. During all trials, the engine operated at a constant speed of 1500 rpm and a steady fuel injection pressure of 200 bar to maintain consistent operating conditions.
Performance evaluation was conducted under five distinct load conditions—0%, 25%, 50%, 75%, and 100% of the rated capacity. For each load, measurements were taken for fuel flow rate, exhaust gas emissions (CO, CO_2, HC, NO_x, and O_2), and smoke opacity. Combustion characteristics were examined using LabVIEW-based software specifically developed for internal combustion engine diagnostics, enabling detailed analysis of in-cylinder processes.
The primary aim of the study was to evaluate the impact of fuel modification through biodiesel and nanoparticle incorporation on engine performance, combustion behavior, and emission characteristics. The fuels tested included diesel blended with Pongamia oil methyl ester (POME) and 5% tert-butanol (by volume). All experiments were performed under identical conditions—fixed compression ratio, injection timing, and injection pressure—to ensure that observed variations were solely due to changes in fuel composition.
Each test was repeated three times to ensure the reliability and reproducibility of the data. The resulting observations were used to evaluate the impact of Tert-butanol-enhanced biodiesel blends on various engine parameters, including efficiency, combustion behavior, and emission levels. A graphical representation of the experimental setup and methodology is provided in Figure 3.The specifications of experimental setup is shown in Table 2.Exhaust gas analyzers, measure the composition of gases, particularly from combustion sources, using various sensors and techniques to analyze gases like CO, CO2, NOx, and hydrocarbons, helping to assess combustion efficiency and emissions.

Fig: 3 Experimental engine setup

Table 1 Specifications of experimental setup

Engine	Make Kirloskar, ModelTV1, Type1cylinder, 4stroke Diesel, Water cooled, power 5.2Kw at stroke110mm, bore 87.5mm. 661cc, CR17.5
Speed	1500 rpm
Dynamometer	Eddy current, water cooled
Crank Angle Sensor	1° resolution, operational up to 5500 RPM, with TDC.
Data acquisition device	NIUSB-6210,16-bit,250kS/s.
Piezo-sensor	Range 5000PSI, with low noise cable
Temperature sensor	RTD, PT100 and Thermocouple, TypeK
Load sensor	Loadcell, type strain gauge, range0-50Kg
Software	“Enginesoft” software

2.5 Results and discussion

Brake Thermal Efficiency (BTE)

All fuels showed increasing BTE with load. Diesel (D100) had the lowest values, while biodiesel–tert-butanol blends gave better efficiency. The blend D55P40TB5 recorded the highest BTE (30.66% at 75% load), nearly 45% higher than diesel, owing to the oxygenated and volatile nature of the additives that supported complete combustion.

Brake Specific Fuel Consumption (BSFC)

BSFC reduced with higher load for all cases. Diesel showed the lowest values due to its higher heating value, whereas blends required more fuel because of their lower energy density. Still, their combustion was more complete, keeping BSFC at acceptable levels.

Carbon Monoxide (CO) Emissions

Diesel showed the maximum CO, whereas biodiesel blends produced less due to more efficient oxidation of CO to CO_2.

III. Conclusion

Pongamia biodiesel with tert-butanol is a feasible diesel substitute. Blends, especially D55P40TB5, enhanced efficiency and reduced HC and CO emissions. BSFC was slightly higher because of lower fuel energy content, while NOx rose with biodiesel ratio. Overall, the blends improve performance and emission characteristics, making them suitable for cleaner energy applications.

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