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Experimental Investigation on Four Stroke Diesel Engine Fuelled With Tamarind Seed Oil as Potential Alternate Fuel for Sustainable Green Environment

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Abstract **– Pyrolysis is the irreversible thermo-chemical decomposition of organic material. This decomposition occurs at high temperatures in the absence of oxygen or any halogen. Tamarind seed used in this process is initially crushed, loaded, heated and processed to obtain oil. This oil is filtered using filter sheet. This oil is further heated to 100°c to remove the moisture content and maintained at the same temperature for some time (20-25 mins). This oil heated to 100°c is tested. Trans-esterification is done to check and modify the obtained oil to suit the engine conditions. After this test, the oil obtained is further tested in laboratory to test the Calorific value, Flash point, Flash fire. This pyrolysis oil obtained at these optimum process conditions were analysed for physical and chemical properties to be used as an alternative fuel. This oil is then added with diesel in the correct proportion where the mixture contains 90% of diesel and 10% of oil. Other proportion for this mixture is80% of diesel and 20% of oil. This oil mixed in correct proportion with diesel is fed and the engine performance is tested.**

Keywords: Pyrolysis, biomass, tamarind seed, fuel, analysis of oil

1. INTRODUCTION

The pyrolysis is used heavily in the chemical industry, for example, to produce methylene, many forms of carbon, and other chemicals from petroleum, coal, and even wood, to produce coke from coal.
The demand for energy increases globally at an alarming rate and it creates the energy crisis. In this concern, tamarind seed oil is considered as one of the promising fuel substitutes for diesel in diesel engines towards the green environment. Recent few years, Biodiesel has gained the global recognition as a renewable fuel for the compression ignition engines because of improved performance and lesser emissions. It is apparent that the selected biomass waste is a more promising feedstock for biofuel production. As the feedstock is available in large quantity in the world, the production of bio-oil is of great interest for pyrolysis study and is a novel matter of subject for future research.
India is the major producer of tamarind (Botanical name: Tamarind us Indica L.) on a commercial scale. Thailand has the largest plantations of the ASEAN nations, followed by Indonesia, Myanmar, and the Philippines. Tamarind, the fruit of a tropical tree, also known as ―date of India‖ is actually the fruit pod produced by a tall, semi evergreen tree grown primarily in India. Tamarind is an important adjunct/condiment used as a sour ingredient in Indian cookery. India produces about 0.25 million tones of tamarind pulp per annum The tree produces brown pod-like fruits, which contain pulp and hard-coated seeds. The fully formed seeds are hard, glossy-brown, and square shaped with rounded corners and edges; each is enclosed in a parchment. A mature tree may annually produce 150 to 225 kgs of fruits, of which the pulp may constitute 30 to 55%, the shells and fiber, 11 to 30%, and the seeds, 33 to 40%. Thus, a large quantity of tamarind seeds is available as agro-byproduct or waste.
The objective of our project is to extract oil from tamarind seed and converted into bio diesel .Since tamarind seeds are available in plethora, it proves to be a convenient source for bio diesel.

II. LITERATURE REVIEW

Kadera et al. (2013) conducted experiments on optimum extraction of tamarind seed oil from the tamarind seed through the fire tube heating transesterification process and concluded that tamarind seed oil as one of the suitable alternate fuel for diesel.
Shameer and Ramesh (2017) examined the performance consequences of an eco-friendly substance on the diesel engine and concluded that up to 20% biodiesel blend showed the close 18behavior of BTE, BSFC and tailpipe emissions with greater penalty of Nox when analysed with base fuel.

Dhana Raju et al. (2016) conducted experiments on compression ignition engine with mahua seed oil as alternate feedstock and reported that the mahua seed bio-fuel blends shown enhanced BTE and lowered exhaust emissions when analyzed with conventional diesel.
Shelke et al. (2016) reported on the use of cottonseed oil as biodiesel and concluded that the cottonseed biodiesel can be used in blended form as an alternative fuel in any diesel engine without any modification.
Ashok et al. (2017) conducted a novel research on the production of biodiesel from lemon fruit rinds and concluded lemon peel biodiesel and its blends revealed better performance and lower emissions due to its lesser density and low boiling temperature.
Moshin et al. (2014) reported that the biodiesel could be used directly in a diesel engine without any modifications as suitable eco-friendly fuel.
Pali and Kumar (2016) reported the use of shorea robusta methyl ester as biodiesel and concluded that combustion study exposed in increasing trend in heat release rate and reduced ignition delay.
Dhana Raju and Kishore, 2017; Yilmaz and Atmanli, 2017 also noticed that significant reductions in exhaust emissions such as carbon monoxide, hydrocarbons and smoke emissions with the use of biodiesel over the diesel fuel.
Agarwal et al. (2008) investigated the production of biodiesel using the pyrolysis was the optimum approach in higher yields of biodiesel with lower viscosity.
Ashok et al. (2017) conducted a novel research on the production of biodiesel from lemon fruit rinds and concluded lemon peel biodiesel and its blends revealed better performance and lower emissions due to its lesser density and low boiling temperature.
Nagaraja et al., 2016 and Kumar and Loganathan, 2014 examined the corn seed oil as biodiesel on diesel engine and they were concluded that the corn oil methyl ester 20% blend has the potential to utilize as an alternative fuel for CI engines with no mechanism alteration, and also from the emission analysis they were concluded that the hydrocarbon and carbon monoxide decreases.
Theansuwan and Triratanasirichai (2011) reported about the extraction of biodiesel by using the transesterification process yields quality biodiesel in terms of fuel properties.
Li et al. (2015) investigated the effects of ternary fuel blend on the emission and combustion characteristics and noticed that the superior spray characteristics & better air-fuel mixture formation ability of n-Amyl alcohol content in the ternary blend yields in higher efficiency and lower exhaust emissions.
Kumar et al. (2016) investigated the use of advanced oxygenated fuel additives to reduce the oxides of nitrogen and other emissions from the engine exhaust of diesel engine. It was found that for 15% DMC blend, oxides of nitrogen was reduced by 46.1% and 39.3% reduction of Nox for the 45% pentanol blend.
Imdadul et al. (2017) investigated the different oxygenated fuel additives to reduce the SFC and the oxides of nitrogen with 70% diesel-20% biodiesel-10% pentanol ternary blend on single cylinder diesel engine and concluded that the addition of 1-pentanol as fuel additive to biodiesel blend shown marginal improvement in brake thermal efficiency and considerable reduction of smoke and the emissions.
Dhana Raju and Kishore (2017) reported that higher brake thermal efficiency obtained for 10% dimethyl carbonate addition to the tamarind seed methyl ester blend over diesel fuel.
Yamini et al. (2017) examined the effect of fuel additive on biodiesel and found that significant reduction in Hydrocarbon and smoke emissions and enhanced oxides of nitrogen emissions along with the improved thermal efficiency of diesel engine.
Dhanasekaran et al. (2017) conducted experimental work by using the restaurant yellow grease, n-pentanol and diesel as ternary blend showing the lower viscosity and density with the reduction in net energy content and noticed that the smoke intensity was decreased with the rise in 1-pentanol quantity in the ternary blended fuel.
Wei et al. (2014) investigated the influence of various concentrations of pentanol/diesel blends on diesel engine performance and their outcomes indicated that the BSFC improved with more concentration of pentanol in diesel and also noticed that oxides of nitrogen were increased by 8% at maximum load condition.
Harveer et al. (2015) reported the use of Sal methyl ester as the biodiesel feedstock in diesel engine and experimental results revealed that the brake thermal efficiency was decreased with all the biodiesel blends when analysed with diesel fuel.

III. BIOFUEL DESCRIPTION

A. tamarind seed

Tamarind tree or Tamarindus indica mainly belongs to the place of Africa; however, it has been grown in India and other subcontinents for many years. Presently, India is the biggest supplier of tamarind fruit in the world, which is popularly consumed for its various cuisine preparations. It is largely available in the states of Madhya Pradesh, Andhra Pradesh, Karnataka, West Bengal, and

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Tamilnadu. Tamarind seed is a by-product obtained from the processing of tamarind fruit. The tamarind seed used in the current investigation for the production of biodiesel were collected from locally available trees. It may contain the oil yield of 18-26%. Tamarind seed oil was generally extracted by means of hexane over the tamarind seed. It is a by-product of the commercial or non-commercial use of the tamarind for various purposes. Free fatty acid or oil comprise of 4.5-16.2% of the total composition. It is having higher amounts of unsaturated fatty acids. Every year in India, the available tamarind seed is in the range of 2, 00,000- 2, 50,000 tones was generated in tamarind fruit processing. From the dry seeds of tamarind, oil was obtained by means of solvent extraction technique. The heating value of tamarind seed oil was 92.5 % on volume concentration of diesel.

tamarind seed

B. n-amyl alcohol as fuel additive

In recent years the use of fuel additives with diesel and biodiesel blends are gaining interest to enhance the engine characteristics and rapid reductions in exhaust emissions. The variety of ignition improvers used by the researchers in their experimental works are Dimethyl carbonate, Diethyl ether, Diethylene glycol, dimethyl ether, Di-n-butyl ether, Dimethoxymethane, Ethyl hexyl acetate, Methyl tert-butyl ether, Ethylene glycol mono-n butyl ether, Dimethoxy propane, methoxyethyl acetate, Methanol and Ethanol. The fuel additives are mainly used to improve the fuel properties up to certain extent for various fuels due to more stable, low viscosity value, higher cetane value and rich inherent oxygen concentration produces the clean combustion of fuels in the engine cylinder and lower the tailpipe exhaust emissions. In this current experimental work, n-Amyl alcohol also known as 1pentanol (C5 H12 O2) is chosen as the oxygenated fuel additive to the 20% tamarind seed methyl ester to know the engine characteristics and exhaust emissions.

IV. COMPONENTS DESCRIPTION

A. furnance

An induction furnace is an electrical furnace in which the heat is applied by induction heating of metal. Induction furnace capacities range from less than one kilogram to one hundred tonnes, and are used to melt metals and used to heat the other substance.

furnace

B.boiler

A boiler is a closed vessel in which fluid (generally water) is heated. The fluid does not necessarily boil. The heated or vaporized fluid exits the boiler for use in various processes or heating applications, including water heating, central heating, boiler-based power generation, cooking, and sanitation

boiler

C. condenser unit

In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, by cooling it. In so doing, the latent heat is given up by the substance and transferred to the surrounding environment.

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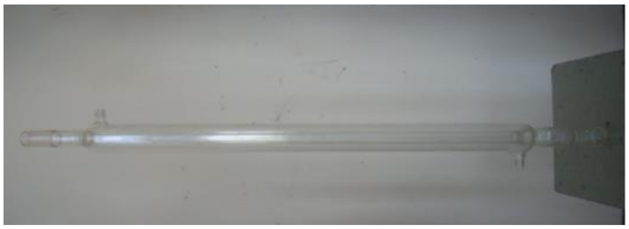
Condensers are used in air conditioning, industrial chemical processes such as distillation, steam power plants and other heat-exchange systems. Use of cooling water or surrounding air as the coolant is common in many condensers.



condenser

D. beaker

A beaker is a generally cylindrical container with a flat bottom. Most also have a small spout (or "beak") to aid pouring, as shown in the picture. Beakers are available in a wide range of sizes, from one millilitre up to several litres

beaker

E. rubber cork

A laboratory rubber stopper or a rubber bung is mainly used in chemical laboratory in combination with flasks and test tube and also for fermentation in winery.

rubber cork

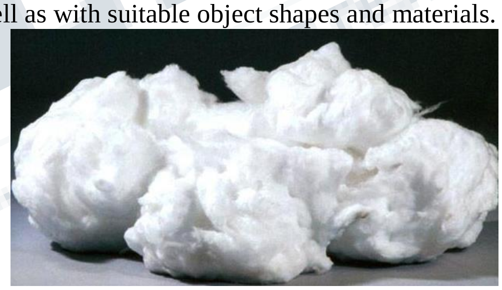
F.filter paper

Filter paper is a semi-permeable paper barrier placed perpendicular to a liquid or air flow. It is used to separate fine substances from liquids or air. It is used in science labs to remove solids from liquids. This can be used to remove sand from water.

filter paper

G.heat insulator

Thermal insulation is the reduction of heat transfer (i.e. the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence. Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and materials.



heating insulator

H. submersible pump

A submersible pump is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump cavitation, a problem associated with a high elevation difference between pump and the fluid surface. Submersible pumps push fluid to the surface as opposed to jet pumps having to pull fluids. Submersibles are more efficient than jet pump.

pump specifications:

Power : 9W

Lift : 0.7ft

Voltage : 220V

Frequency : 50 Hz

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submersible pump

V. PYROLYSIS

A. introduction

Pyrolysis is the thermal decomposition of materials at elevated temperatures in an inert atmosphere. It involves the change of chemical composition and is irreversible. The word is coined from the Greek-derived elements pyro "fire" and lysis "separating".

Pyrolysis is most commonly used in the treatment of organic materials. It is one of the processes involved in charring wood. In general, pyrolysis of organic substances produces volatile products and leaves a solid residue enriched in carbon, char. Extreme pyrolysis, which leaves mostly carbon as the residue, is called carbonization.
The process is used heavily in the chemical industry, for example, to produce ethylene, many forms of carbon, and other chemicals from petroleum, coal, and even wood, to produce coke from coal. Aspirational applications of pyrolysis would convert biomass into syngas and biochar, waste plastics back into usable oil, or waste into safely disposable substances.

pyrolysis

B.tamarind seed into bio-oil

The conversion of tamarind seed into bio-oil by pyrolysis has been taken into consideration in the present work. The major components of the system were fixed bed fire-tube heating reactor, liquid condenser and collector. The crushed tamarind seed in particle form was pyrolyzed in an electrically heated fixed bed reactor. The products were liquid, char and gasses. The parameters varied were reactor temperature, running time, gas flow rate and feed particle size. The maximum liquid yield was 45 wt% at 400oC for a feed size of 3200 µm diameter at a gas flow rate of 6l/min with a running time of 30 min. The obtained pyrolysis liquid at these optimum process conditions were analysed for physical and chemical properties to be used as an alternate fuel. The results show the potential of tamarind seed as an important source of alternative fuel and chemical as well.

tamarind seed oil

VI. TRANSESTERIFICATION

The oil which is directly unsuitable for biodiesel due to viscosity. Transesterification is extracted from the seeds is considered as its high density, poor volatility and higher widely accepted as the best technique for enhancing the properties of the bio fuels. The transesterification process consists of 15litres of raw tamarind oil taken into a reactor and heated up to 70°C. After attaining required temperature, the solution containing the mixture of 3litres of methanol and 120 grams of potassium hydroxide (base catalyst) is poured into the reactor and the whole solution is maintained under constant stirring speed of 1500rpm for 180 min. The final solution is taken into a conical funnel and is allowed to settle down for 24h. After settling, the glycerol which is of high density stored at the bottom of the funnel is segregated and the remaining

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crude tamarind oil is gently washed with water. The yield rate of tamarind seed methyl ester from the transesterification process is found to be around 76%. The biodiesel produced from the above process is blended with diesel by 20% on volume basis to get TSME20. As per the ASTM standards, maximum blending concentration is restricted to 20% in the CI engine and plenty of research work carried out on biofuels suggests 20% blend as the optimum level. Among the three blends, better results were obtained for TSME20 biodiesel blend. From the experimental results, TSME20 is considered as an optimum blend and further experiments were conducted on the CI engine at various injection timings to analyse the performance and emission characteristics.

VII.EXPERIMENTAL INVESTIGATION

specifications of the engine
Brand : Kirloskar
Type :TVI single cylinder horizontal water cooled diesel engine
Bore : 87.5mm
Stroke : 110mm
Swept volume : 661cc
Compression ratio : 12-18
Power : 3.5 KW (1500rpm)
Connecting rod length : 234mm
Arm length : 185mm
Type of loading : Eddy current dynamometer

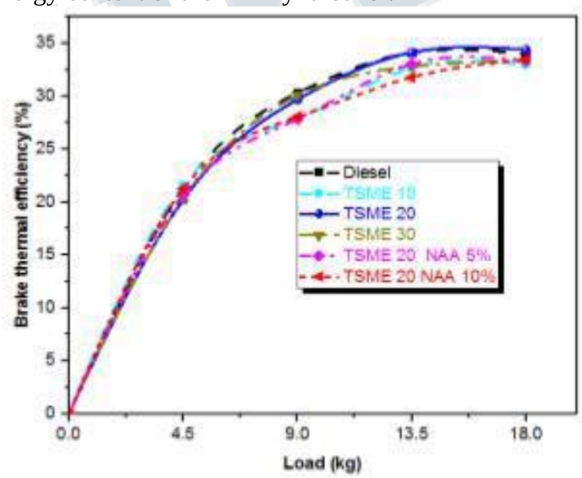
engine

the basic performance characteristics are,

✓ Brake Thermal Efficiency
✓ Brake Specific Fuel Consumption
✓ Combustion characteristics
✓ Heat release rate
✓ Delay period

A. brake thermal efficiency

Indicates the deviation of brake thermal efficiency (BTE) with the engine load for the tested fuels. The BTE for all tested tamarind seed oil and along with diesel fuel increases with increase in load and followed the same trend. The maximum brake thermal efficiency was observed for the TSME20 blend was 34.41% and for diesel was 34%. TSME 20 biodiesel blend was 1.2% higher thermal efficiency than base oil at peak load condition. NAA addition to TSME 20 at various concentrations indicates the slight reduction in BTE when compared with diesel and also with 20% biodiesel blend. The maximum brake thermal efficiency for TSME 20 NAA 5% biodiesel was 33.65%, which is 1.01% lower than the diesel fuel. The marginal decrease in brake thermal efficiency was mainly attributed due to the lower energy content of the n-Amyl alcohol.



brake thermal efficiency variation with load

B. brake specific fuel consumption

The specific fuel consumption of any fuel mainly depends on the heat energy content, density, and viscosity. The specific fuel consumption of tested biodiesels decreases with increases in load and found a minimum value at full load condition. The BSFC initially decreases sharply with an increase in load up to 50% and then decreases marginally with an increase in load; however, TSME 20 showed the least value of 0.25 kg/kWh. The addition of NAA as ignition improver results in better combustion leads to decrease the BSFC with the load. The brake specific fuel consumption values were 0.252 kg/ kWh and 0.255 kg/ kWh for TSME20 5% NAA, and TSME20 10% NAA, and with diesel fuel it was 0.25 kg/kWh at maximum load. The reason for the marginal increase in BSFC of TSME20 NAA biodiesel blends is mainly due to the lower heating value of NAA. It was concluded that the

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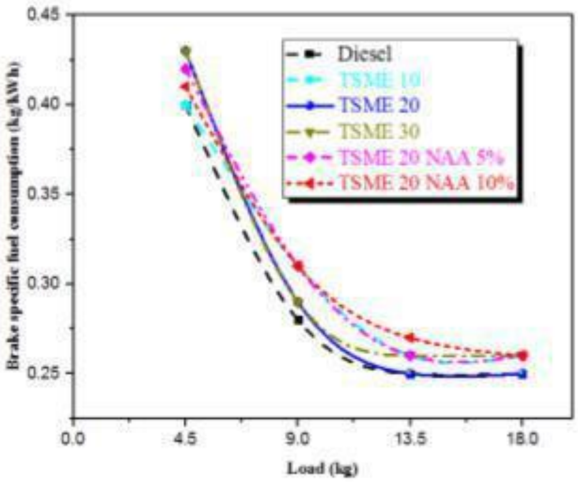
least value of BSFC for TSME20 blend was found to be 0.25 kg/kWh which is similar to the pure diesel.



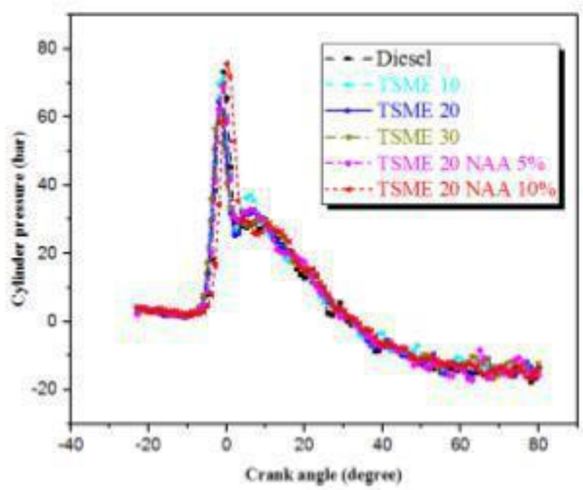
brake specific fuel consumption variation with engine load

C. combustion characteristics

The combustion of a fuel is one of the vital aspects which are to be analyzed in a diesel engine, as it directly deals with the specific fuel consumption, thermal efficiency, and steadiness of an engine. The phenomenon of combustion in an engine was clearly analyzed with the help of Pressure-Crank angle diagram, Heat release rate and the delay period. Combustion parameters were measured with AVL Pressure transducer GH14d/AH1 fixed at Cylinder head and AVL 365C Angle encoder was fixed on the crankshaft of an engine. The Pressure of cylinder and heat generation was measured by using AVL engine software.

D. heat release rate

The heat release rate variation of tested fuels with crank angle at maximum load condition of the diesel engine. It shown useful data related to the burning process of fuel in the combustion space and delay period. Heat release rate of tamarind seed methyl ester along with NAA additive blends and diesel fuel followed the same nature of heat generation during the period of combustion process was noticed in Figure 6. The amount of heat generation for the TSME 20 NAA 10% blend was marginally higher than the diesel fuel at maximum load condition and the maximum heat release rate occurred for tamarind seed methyl ester 20% with the 10% addition of n-Amyl alcohol blend and It was found that 71.16 kJ/ crank angle at -1° before TDC and it was 1.86% higher than diesel at maximum load condition. It is mainly attributed due to better mixing nature and more oxygen presence of NAA fuel additive. It was observed that the maximum heat release rate for all tested fuels occurred at –1° before TDC and the corresponding maximum heat release rate was obtained for diesel, TSME 20, TSME 20 NAA 5% and TSME 20 NAA 10%



heat release rate variation with crank angle

E. delay period

The variation of ignition delay period (IDP) at different engine loads for diesel, TSME blends and TSME 20 with 5% and 10% concentrations of NAA is presented. The addition of n-amyl alcohol at different concentrations to the 20% tamarind seed methyl ester significantly decreases the delay period when compared to the diesel at all operating conditions. Due to enhanced fuel-air mixing and availability of inherent oxygen in the biodiesel and the NAA fuel additive results in reduction of delay period. The reduced in ignition delay period of TSME NAA 10% biodiesel blend leads to an increase in the peak cylinder pressure in the combustion process. It is noticed that 20% tamarind seed methyl ester biodiesel blend is shorter delay period than other tested fuels at all load conditions. The minimum ignition delay period for the TSME 20 blend is found to be 18° crank angle.

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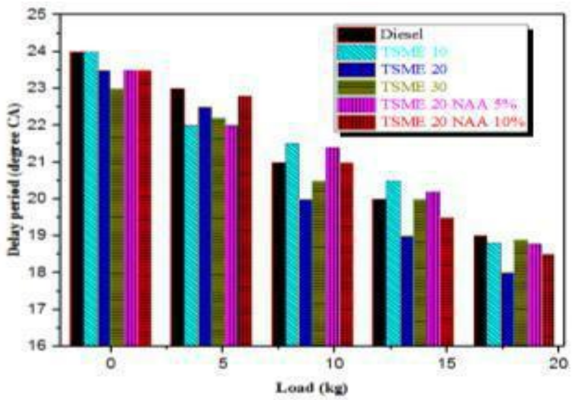
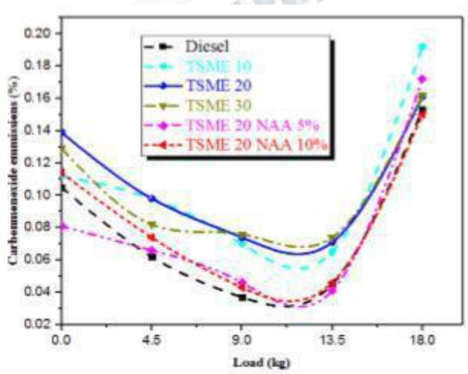


ignition delay period variation with crank angle

VIII.EMISSION CHARACTERISTICS

A. carbon monoxide emissions

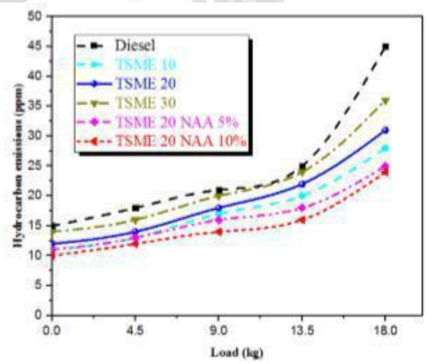
The carbon monoxide deviation with engine load for different tamarind seed biodiesel blends and diesel fuel. It was mainly formed due to the incomplete combustion and also the CO formation depends on factors such as air-fuel ratio, injection pressure and fuel injection timing and the nature of the fuel. It was noticed that CO emissions of biodiesel blends and diesel followed the same trend with respect to increasing in load but the CO emissions were maximum at peak load condition due to incomplete combustion. When the additions of NAA at various concentrations to TSME 20 biodiesel blend, it was found that the formation of CO decreases with increase in load and least CO formed at full load. The CO formed for TSME 20 with NAA 5% and 10% addition as 0.17%, and 0.15% whereas for the diesel fuel at full load was 0.162%. From the experimental results revealed that the addition of n-Amyl alcohol to the biodiesel reduces the carbon monoxide formation with increasing the engine load and minimum at the full load condition.



carbon monoxide variation with engine load

B. hydrocarbon emissions

The variation of hydrocarbons for diesel and tamarind biofuel blends with respect to engine load. The hydrocarbon emissions for tested tamarind biodiesel fuels were lower over the diesel fuel in the entire load operation and also for the addition of n-Amyl alcohol, the hydrocarbon emissions were significantly decreased when compared with the diesel at full load. The HC emissions for the diesel and TSME biofuel blends (10%, 20%, and 30%) were 45 ppm, 28 ppm, 31 ppm and 36 ppm at maximum load condition. The minimum HC emission was found for TSME20 NAA 10% of 24 ppm and there was a reduction of 46.6% HC for this fuel additive blend over diesel fuel. This is due to inherent more oxygen presence in tamarind seed oil leads to better combustion. It was found that the HC emissions were increases with increase in blend concentration and HC formation was higher for TSME 30% biodiesel blend. It was mainly due to higher viscosity and weak mixture formation of diesel and the biodiesel. It was also noticed that the addition of NAA was reduced the HC formation at part load condition up to 75% when compared with the biodiesel blends of TSME and also with diesel. From the below, it was concluded that significant reduction in HC emissions for the biodiesel blends with NAA addition when compared to the diesel fuel.



hydrocarbons (hc) variation with engine load

C. nitrogen oxide emissions

The nitrogen oxide mainly generated in diesel engine due to the presence of elevated temperature and accessibility of oxygen during the combustion process. The variation of nitrogen oxide (NOX) emissions of tamarind seed methyl ester and base fuel with respect to engine load. The availability of oxygen and higher exhaust gas temperature in biodiesel blends produces the higher NOX formation. It was also found that the NOX level increases with increasing the engine load for all the experimentally tested fuels. The diesel engine rated capacity is 5.2 kW. It

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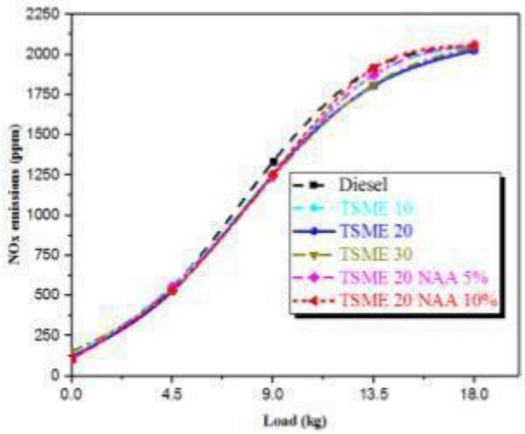
was shown that NOX emissions were marginally lower for TSME20 biodiesel of 2026 ppm as compared to diesel fuel of 2056 ppm. It was mainly attributed due to the low energy content of the tamarind seed oil. The addition of NAA for the TSME20 with concentration 5% and 10% increases the NOX emissions. The maximum NOX emissions were found with the TSME 20 NAA 10% at full load condition of 2109 ppm and it was 2.5 % higher than the diesel fuel and it was also noticed that NOX formation for NAA added biodiesel blends were marginally higher than diesel.

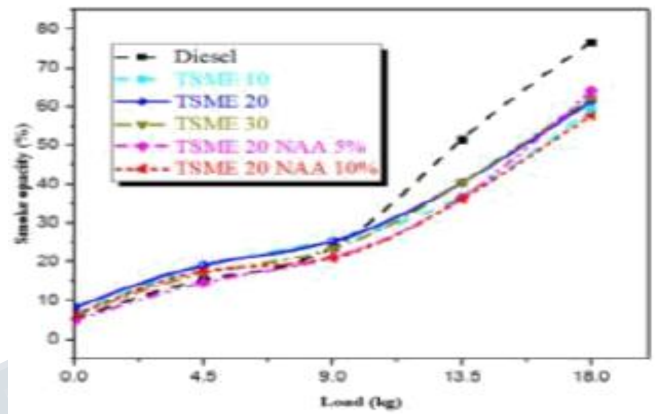


nitrogen oxide (nox) emissions variation with load

D. smoke capacity

The smoke capacity is a measure of soot content or soot concentration in the exhaust emissions. Indicates the variation of soot concentration or smoke opacity for tested tamarind biodiesel blends and diesel fuel. The soot content of the exhaust gas was determined from the blackening of sample paper and the effective length. The smoke opacity was measured as the percentage. it is noticed that smoke opacity decreases for all biodiesel blends when compared to diesel at maximum load condition. The smoke concentration for the biodiesel blends (TSME 10, 20 and 30) were 59.3%, 61.4% 62.3 %, respectively and for diesel, it was 76.6% at full load. The smoke opacity level for TSME 20 is 19.84 % lesser than the diesel fuel at maximum load condition. The early start of combustion for biodiesel blends and advanced injection timing can further reduce the formation of smoke emission. The addition of small concentration of NAA to the TSME 20 blend, there was a significant reduction in smoke opacity when analyzed with biodiesel blends and the diesel fuel.

It was mainly due to higher volatility and oxygen enrichment provided by n-Amyl alcohol in enhancing the fuel evaporation and leads to better combustion. The smoke intensity of TSME 20 NAA 10 was 54.01% and it was 29.49 % lower than the diesel fuel at the maximum load. Therefore small volumes of NAA addition to the TSME fuel could effectively reduce the smoke concentration.



smoke opacity (so) variation with engine load

IX. RESULTS AND DISCUSSIONS

After the extraction of Bio-Fuel, it is important to estimate its properties and compare it with that of ASTM standards so that we can confirm that we had obtained bio-fuel. The properties of the bio-oil indicate its degree of purity. Some important properties are:

1. Flash and Fire Point
2. Viscosity
3. Specific gravity
4. Calorific Value
5. Pour Point

PROXIMATE ANALYSIS
table

SI.no	Parameters	Method	result
1	Moisture(%)	IS:1350(PART 1)	55.5
2	Ash content(%)	-	0.11
3	Volatile matter(%)	-	65
4	Fixed carbon by difference(%)	IS:1350(PART 1)	9.57

ULTIMATE ANALYSIS

Sl.no	Parameters	Method	Result
1	Moisture (%)	IS:1350 (PART II)	55.65
2	Mineral water (%)	-	0.12
3	Carbon (%)	-	22
4	Hydrogen (%)	-	9.59
5	Nitrogen (%)	-	0.22
6	Total Sulphur (%)	-	0.04
7	Oxygen by difference (%)	-	44.39
8	Gross Calorific Value (kJ/kg)	IS:1448 (PART 6)	42128
9	Viscosity @40°C (cst)	IS:1448 (PART 25)	7.27
10	Flash point by COC method (°C)	IS:1448 (PART 69)	159
11	Fire point by COC method (°C)	IS:1448 (PART 69)	170
12	Pour point (°C)	IS:1448 (PART 10)	Below Minus 15

X. CONCLUSION

In this experimental study, tamarind seed oil was considered as potential alternate fuel for diesel in compression ignition engine. The performance, combustion, and emission characteristics of tamarind seed biodiesel blends along with n-Amyl alcohol as an oxygenated fuel additive for TSME20 are evaluated and compared with base fuel. From the experimental outcomes, the following conclusions are drawn.

• The novel use of Tamarind seed methyl ester (TSME) is an important source of green fuel for the diesel engine towards the sustainability of energy and the environment. The TSME-NAA biodiesel blends shown improved engine characteristics when analyzed with diesel and also other blends of tamarind seed methyl ester.

• Among all the tested fuels, TSME 20 showed better performance and lower emission characteristics. The maximum brake thermal efficiency is 34.4% when compared to diesel of 34%, which is 1.17 % higher.

• The maximum heat release rate occurred for tamarind seed methyl ester
20% with the 10% addition of n-Amyl alcohol blend and It is found that 71.16 kJ/ crank angle at -1° before TDC and it is 1.86% higher than diesel at maximum load condition. It is also observed that maximum gas pressure in the cylinder has occurred 9°–11° after TDC for the tested fuels and the maximum cylinder pressure is found for TSME 20 biodiesel blend, which is 68.18 bar and it is slightly higher than diesel fuel.

• The CO, HC, and Smoke opacity emissions are lower in the case of TSME and NAA blends than that diesel. However, the NOX emissions are higher for NAA blended fuel as compared to other blends and also with diesel

• The addition of small concentration of NAA to the TSME 20 blend, there was a significant reduction in smoke opacity when analyzed with biodiesel blends and the diesel fuel. The smoke intensity of TSME 20 NAA 10% is 29.49 % lower than the diesel fuel at the maximum load. From the experimental findings, it is concluded that TSME 20 with NAA 10% biodiesel blend gives better performance and lower emission characteristics when analyzed with diesel. Finally, the tamarind seed oil is a suitable and potential alternate fuel for replacing the diesel partially or completely in diesel engine towards the energy sustainability and eco-environment.

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