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Waste Ziziphus Mauritianaseed (Jujube – Ezhandhapalam) To Sustainable Catalyst for Bio Diesel

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Abstract— ***As a result of the significant growth in both the population and transportation, the demand for conventional fuels such as petrol and diesel is growing, leading to depletion of these non-renewable resources. Researchers are exploring alternative fuels that are cost-effective and environmentally friendly, such as biofuels. Biofuels are considered an attractive alternative due to their low toxicity, no sulphur content, reduced emissions, and higher oxygen content. In this study, a combination of biodiesel (B10, B20, and B30) with ceric oxide (CeO2) nanoparticles is used to examine the performance, ignition, and exhaust emissions of a Common Rail Direct Injection (CRDI) compression ignition engine. Biodiesel produced from matured waste ziziphus mauritiana peels oil is considered as aproper alternative to traditional diesel fuel because of its similar physicochemical properties. Nanoparticles are being used to enhance the performance, ignition, and emission characteristics of biofuels. Ceric oxide nanoparticles were mixed with biodiesel blends using a magnetic stirrer. The experiment was carried out using the following biofuel samples: 10% biofuel mixed with 90% diesel (B10), 20% biofuel mixed with 80% diesel (B20), and 30% biofuel blended with 70% diesel (B30), with the addition of 100ppm ceric oxide nanoparticles to each blend (B10, B20, B30). The experimental engine was operated at a constant compression ratio of 17.5:1 and at a continuous speed under different loading conditions (0%, 25%, 50%, 75%, and 100%). The study found that improving the concentration of biodiesel in the blends and adding ceric oxide nanoparticles reduced harmful exhaust gas emissions from the CRDI engine. Increased brake thermal efficiency and lower emissions of carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) were the results of the use of ceric oxide nanoparticles, which also enhanced the engine's performance and emission characteristics. However, increasing the biodiesel concentration also resulted in increased nitrogen oxide (NOx) emissions. The study suggests that blending biodiesel with ceric oxide nanoparticles can be a viable alternative to traditional diesel fuel, further inspection is required to properly comprehend the long-term impacts of employing biodiesel mixes containing nanoparticles on engine longevity and emissions.***

Keywords: Zizphus Mauritiana seeds, Common rail direct injection, Nano-particles, Conventional fuel, Brake thermal efficiency.

I. INTRODUCTION

Bio diesel is mainly utilized to improve the reduction of fossil fuel which can be obtained infinitely. This provide the enormous ways to find the solution for the fuel price reduction. Even though it is effective method for reducing the usage of fossil fuel, it can be used the replacement for the normal diesel. The development of SAF is crucial to the decarbonization of the aviation sector because the sector now depends significantly on liquid hydrocarbon fuels.[1] For SAF to be a viable substitute for hydrocarbon fuels and a low freezing point are necessary characteristics. In this work, 38 non-edible feedstocks for SAF production were theoretically evaluated using an MCDA tool in accordance with global fuel requirements. Azadirachta indica, pequi, and ricinus communis were shown to be the top three feedstocks for making SAF. Unfortunately, several fatty acid-based characteristics of untreated biofuel from these sources fall short of the requirements for international aviation fuel. To validate the results, more experimental work must be conducted.[2]Citrus aurantium, a brand-new feedstock that yields biodiesel was produced utilising recyclable zirconium oxide nanoparticles synthesised from Alternanthera pungens aqueous leaf extract using non-edible waste seed oil (38% w/w).Response Surface Methodology was used to optimise the reaction parameters of methanol to oil molar ratio of 6:1, reaction time of 120 min, temperature of 87.5 °C, and catalyst loading of 0.5 wt%, resulting in the highest yield of 94%. Green nanoparticles of zirconium oxide were studied using scanner electron microscopy (SEM), X-ray diffraction (XRD), and energy diffraction X-ray (EDX), while synthesised biodiesel was studied using Fourier-transform infrared spectroscopy (FTIR), Gas Chromatography/Mass Spectrometry (GC/MS), and Nuclear magnetic resonance (NMR 1H and 13C)[3].The study uses 48 data sets for biodiesel based on edible and non-edible oils. The physico-chemical characteristics examined include kinematic viscosity, flash point, cloud point, pour point (PP), cold filter plugging point, cetane (CN), and iodine numbers. Genetic programming was used as the regression approach in this study (GP). GP offers general, non-parametric regression among variables, in contrast to multiple linear regression (MLR) methodologies that are described in the literature. In compared to the best MLR model for each property, the RSME associated lower for GP models, ranging from 3% for CN to 55% for PP, with the experimental database. More specifically, the dependency of characteristics on saturated and unsaturated methyl esters is well reproduced by the majority of GP regression models.[4].

Large quantities of free fatty acids from non-edible oilseed plant species can be utilised to make biodiesel. Enzymatic and solvent extraction techniques are used to extract the oil from non-edible oilseeds.[5] Micro-emulsification, pyrolysis, dilution, and transesterification are steps which is invoved in the synthesis of biodiesel. Yet with the aid of government incentives to farmers who produce biodiesel, the quantity and accessibility of non-edible oilseeds in India will assist overcome the dependence on diesel and price swings. The development of cutting-edge technologies for oil extraction and production from indigenous non-edible oilseeds, along with improved varieties, elite planting materials, effective agronomic practises, will undoubtedly overcome the obstacles and pave the way for greater commercialization of biodiesel in India[6]. The transesterification process' catalyst efficiency is influenced by the oil, temperature, alcohol-to-oil molar ratio, and catalyst type. The obstacles that the homogeneous and heterogeneous catalysts encounterwere discussed in more depth in this work. Although enzymes can be used as a catalytic substitutes for the production of biodiesel, the cost of processing them is a major barrier.[7] . Due to the depletion of non-renewable fuels and the adverse effects of leftover fuels on the environment, the automotive industry needs an alternate source to provide thermal energy and a healthy environment. One of the greatest fuels to replace conventional fuels in diesel engines is biodiesel. Biofuel is a very appealing fuel.[8]. Biodiesel continues to be made from seed oils and vegetable oils. As comparison to fossil fuels, biofuel is less flammable, nontoxic, contains no sulphur, and emits less polluting gases. Because it is made from seeds and plants, biodiesel is considered one of the renewable energy. Due to their non-polluting qualities, biofuels continue to be the renewable energy source that is moving forward the fastest.[9].Plant-based fuels are potential alternative fuels and a sustainable source of energy since they cannot run out. Biofuels, which manufacture biodiesel using safer processes, have a high auto ignition temperature (cetane number 52–53), making it difficult to ignite and preventing sudden explosions in industry. One of the key components for using biofuels is the oxygen concentration. As a result of the biodiesel's high oxygen concentration (10–12%), it will produce less emissions. The majority of the country switched to biofuels, ethanol, and hydrogen-powered cars as the price of crude oil rose daily. Since biodiesel reduces dangerous exhaust emissions, biofuels enhance both human health and the environment.[10]. Wasted seeds are one of the finest sources for creating biofuels because using vegetable oil to generate biodiesel might result in food shortages. With increased usage of biofuels, engine exhaust gas emissions are decreased.[11].

The seed oils include characteristics like kinematic viscosity (2.781cst), water content (0.055vol%), calorific value (42.510 kJ/kg), density (0.931g/cm3), and others. They also contain fatty acids such saturated omega-3 fatty acids, monosaturated fatty acids, and poly saturated lipids. The most popular feedstock crops for biofuels are Jatropha, Soybean, Canola, Palm, Sunflower, and Safflower. A promising feedstock used to produce biofuels is tobacco seed oil.[12]. In choosing a seed, it is important to take into account that the feedstock must be naturally abundant and not cause a food shortage. Before usage, the oils produced from seed must first undergo transesterification, which is completed by adding methanol or ethanol. Seeds are a viable feedstock to produce biodiesel since transesterification produces both glycerin and biodiesel. The use of atomic, molecular, and supramolecular materials for industrial uses is known as nanotechnology. Over the past several years, this technology has attracted significant scientific attention. The goal of the research is to better understand how nanoparticles are formed, characterised, and detected. The biofuel with nickel-oxide nanoparticles in it increases thermal efficiency and decreases NOx by 9%.[13]. The nanoparticles are microscopic powder particles with sizes ranging from 1 to 100 nanometers (nm). The nanoparticles cannot be seen or identified by the human eye. The atoms that make up the larger number of nanoparticles have a diameter of 0.1 nm, whereas the nanoparticles have a diameter of 1 to 100 nm. Coarse particles are measured between 2,500 to 10,000 nm, while fine particles are measured between 100 and 2,500 nm. Fine particles are also known as particulate matter (PM2.5), and coarse particles are also known as dust (PM10). The most prevalent types of nanoparticles used in industry include cerium oxide (CeO2), carbon nanotubes, copper oxide (CuO), graphene oxide (GO), alumina oxide (Al2O3), titanium dioxide (TiO2), silica dioxide (SiO2), boron oxide (B2O3), and nanoclay[14]. Such material properties facilitated improvements in nanomaterial fabrication methods. Nanoparticles are used in a variety of industries, such as health care and cosmetics, to protect the environment and purify the air. They can exist naturally and in greater abundance or be created by combustion reactions. Carbon nanotubes are employed for medication delivery in the healthcare business, and antibodies also include them. Carbon nanotubes from the aerospace sector may be utilised to modify aeroplane wings. The thermal engineering field uses nanoparticles in a broad variety of ways to speed up and improve engine chemical reactions. Nano-added bioethanol and biofuels minimise NOx and hydrocarbon emissions from smoke.[15]. Biotechnology and nanotechnology working together can improve the generation of biofuels. Three varieties of biodiesel-diesel-nanoparticles (B20A30C30), biodiesel with nanoparticles (B100A30C30), and biodiesel-diesel are included in the combination (B20).[16]. Nanotechnology offers a potential approach for producing biofuels sustainably and overcoming challenges such as large molecular mass, high point of viscosity, and low pour point.

Biodiesel's specific fuel consumption (SFC), braking heat energy efficiency (BTE), and consistent chemical reaction in diesel type engines will all be improved or changed by including a Nano additive to it. Biodiesel's physiochemical properties, such as its melting point, boiling point, vapour point, extrinsic properties of pressure, and moles canister, can be improved by adding nano additions.

II. MATERIALS AND METHODS

2.1. Preparation of bio fuel

Oil from the seeds of Ziziphus mauritiana is still used to make the basic fuel. The GSO has a significant amount of fatty acids. The physicochemical components really resemble diesel and petrol [11]. In order to compare diesel (834 kg/m3), the density was raised to 843 kg/m3. Because Ziziphus mauritiana seed oil is made from plant seeds, it naturally has a higher oxygen content than diesel and generates less emissions as a result. As compared to diesel (2.5 mm2/s), the Ziziphus mauritiana seed oil viscosity was increased to 3.7 mm2/s, and the auto ignition temperature (Cetane number) was raised.[17] The Ziziphus mauritiana seed oil that was obtained underwent transesterification. Once base gasoline has been refined, methanol is added during a process called transesterification.

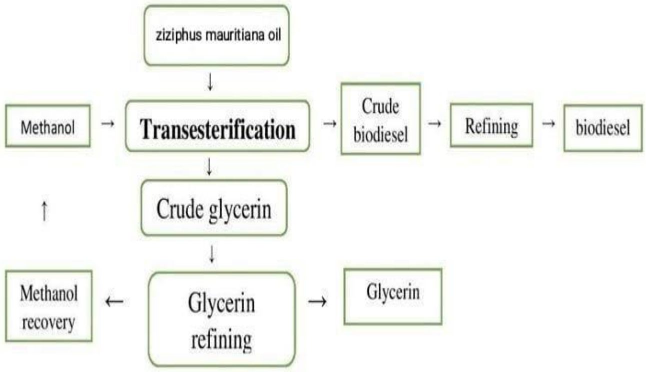

Fig.2.1. Preparation of biodiesel

2.2. Characterization of particle size and fuel test

The goal of the laboratory investigation was to determine the characteristics of the Nano additives added to the biodiesel made from Ziziphus mauritiana seed oil. The following characteristics were noticed during this investigation: density, viscosity, fire point, flash point, and calorific values. During this inquiry, the blend samples were designated as B10+100ppm, B20+100ppm, and B30+100ppm, as shown in Table 1. The experiment found that adding Ceric oxide micro particles to a biodiesel blend significantly increased the flash point, fire point, and real density.[18] A crucial aspect of any fuel is its calorific value, which is lower for the additive-blend sample than diesel but higher for biofuel. The biodiesel with a nano ingredient boosts brake heat energy efficiency while using less gasoline.

Fig.2.2. Ceriumoxide (CeO_2)

2.3. Blending of ceric oxide nano additives with biodiesel

Ceric oxide (CeO2) nanoparticles are blended with biodiesel made from Ziziphus mauritiana seed oil to create the nanoparticle biofuels. The best approach for dispersing the nanoparticles in biodiesel made from Ziziphus mauritiana seed oil is the magnetic stirrer technique (base fuel). The majority of nanoparticles use surface area and hence external energy [13]. Thus, try to create nanoparticles that are stable in the base fluid. The deposit of particles was controlled. Magnetic stirrer mechanism was used in order to disseminate the nanoparticles towards the base fuel.[19] A certain amount of material was added, mixed for 50 minutes, and then added to the biofuel. Finally, it will become a stable Nanofluid.

Fig. 2.3. Testing blends

TABLE-1: Properties of Diesel, B10, B20, B30

Properties	Diesel	B10	B20	B30
Density(Kg/m^3)	840	861.4	865.7	845.5
Calorificvalue(KJ/Kg)	42,452	40,234	41,172	41,119
Kinematicviscosity at50^{0}C (mm^2/s)	2.5	3.4	3.31	3.41
Firepoint in ^{0}C	67	64.5	72.7	76.9
Flashpoint in ^{0}C	47	51	56	58
Boilingpoint in^{0}C	254	NM	NM	NM
Cetanenumber	52.5	51.7	52	53.2
Latentheatofvaporization (KJ/Kg)	262	NM	NM	NM
Surfacetension (mN/m)@70^{0}C	23.25	NM	NM	NM

III. EXPERIMENTAL SETUP

A 4-stroke diesel engine with one cylinder and 5.2 KW of power is used in the experimental arrangement. Reduced fuel economy is achieved via the direct injection and dual mode operation of the engine. Engine is loaded using an ECD(eddy current dynamometer), and the load is measured using load cells and strain gauges. A mass flow sensor and the burette technique are used, respectively, to monitor the air flow rate and fuel consumption. During the experiments carried out under various load situations, cooling water is delivered to the engine using rotameters, and information is gathered using a huge number of sensors.

The engine's power, efficiency, temperature, and gasoline usage are all estimated using the engine software. The engine's outputs of Carbon monoxide (CO), Hydro carbons (HC), Carbon dioxide (CO2), Oxygen (O2), NOX, and opacity are all measured using a gas analyser and smoke metre. The statistics on efficiency, combustion, and emission are tallied after the findings are evaluated using a computerised acquisition system. The MODTRAN smoke metre gives the anticipated performance and outcomes

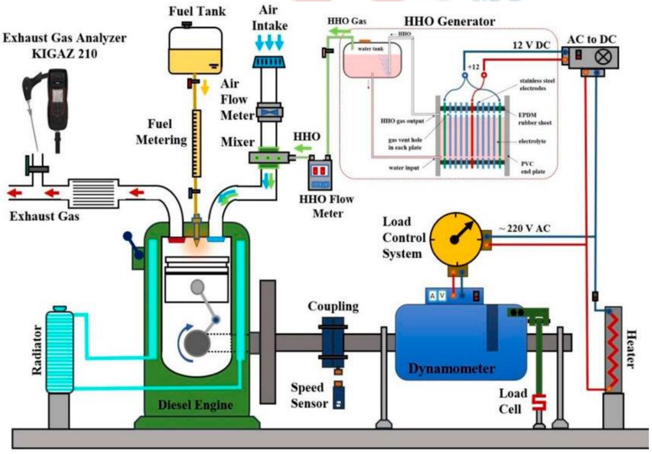

Fig.3.1 Experimental setup

- Rated power-5.2KW
- Speed -15000rpm
- Compression ratio -17.5
- No. of cylinders-1
- Stroke – 110mm
- Bore- 87.5
- Loading-eddy current type dynamometer
- Ignition-compression ignition
- Rotameter-engine cooling 40-400LPH
- Calorimeter -type-pipe
- Airflow transmitter- pressure transmitter
- Fuelflowmeter- DP transmitter
- Load sensor -load cell, type strain-gauge
- Temperature sensor- typeRTD, PT100 and thermocouple
- Crank angle sensor- resolution 1^0, speed 5500rpm
- Cooling – water

IV. RESULT AND DISCUSSION

4.1. Brake Thermal Efficiency (BTE)

Brake Thermal Efficiency (BTE) is a measurement of an engine's capacity to convert the heat from combustion into useable mechanical energy. By comparing the engine's braking power output to the amount of heat generated per unit of fuel, the BTE is computed. It is obvious from the line graph showing the history of BTE under various loading circumstances that as engine load increases, BTE also rises. This is because when braking power output increases, the engine is able to use more of the heat produced during combustion. According to the testing, the BTE values for diesel, B10+100 ppm, B20+100 ppm, and B30+100 ppm were 32.03, 31.01, 29.85, and 33.22, respectively. It is interesting to notice that for all concentrations, diesel has the highest BTE compared to biodiesel mixes. Moreover, because of its oxygen content and viscosity, B10 displays a similar BTE to diesel.

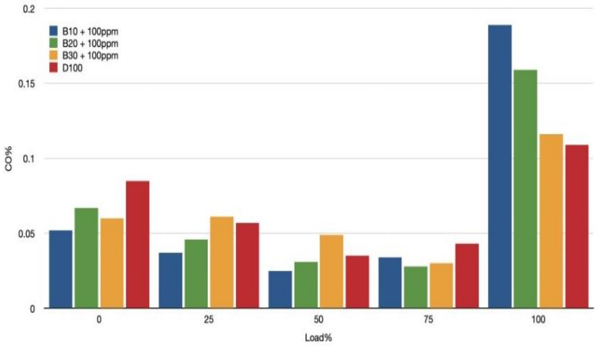

Fig 4.1 Brake Thermal Efficiency

4.2. Brake Specific Fuel Consumption (BSFC)

The fuel consumed to create heat per unit of time is measured by a statistic called Brake Specific Fuel Consumption (BSFC). The BSFC may be estimated by dividing the engine's fuel consumption by the output power it generates. The SFC (Specific Fuel Consumption) figures are shown in Fig. 4.2 for various loading scenarios. The graph shows that fuel usage reduces with increasing engine load. This is explained by the improved combustion process brought on by the usage of nanoparticles, which results in lower fuel use. The test findings are 0.27 (kg/kWh), 0.28 (kg/kWh), 0.29 (kg/kWh), and 0.25 (kg/kWh), respectively, for B10+100 ppm, B20+100 ppm, B30+100 ppm, and diesel. It is interesting to observe that for all concentrations, diesel has the lowest BSFC rating when compared to biodiesel blends. Moreover, because of its surface volume percentage and oxygen cushion, B10 displays a BSFC value that is more similar to that of diesel.

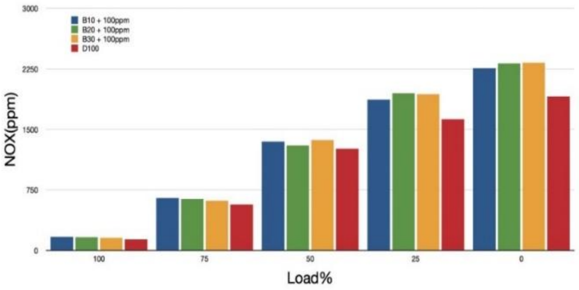

Fig.4.2. Brake Specific Fuel Consumption

4.3. Carbon Monoxide Emission (CME)

The graph in 4.3 illustrates how carbon monoxide (CO) emissions vary across all blends. CO is a combustible, colourless, and odourless gas that, if inhaled in large quantities, can be dangerous. The graph demonstrates a direct relationship between engine load and CO emissions, indicating that CO emissions increase as engine load increases. CO emissions are 0.216%, 0.181%, 0.109%, and 0.104%, respectively, according to the test findings for B10+100 ppm, B20+100 ppm, B30+100 ppm, and diesel. It is important to note that B30 has the lowest CO emissions of any blend due to adding nanoparticles and increasing the amount of biodiesel, which enhances the chemical reaction and gives more oxygen. Comparison to biodiesel blends, diesel has the highest CO emissions across all concentrations. Also, because to the improved ignition, B30 shows CO emissions that are more similar to those of diesel.

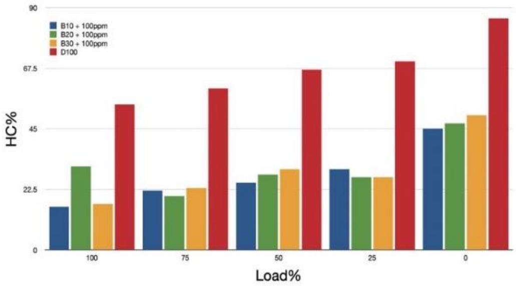

Fig 4.3 Carbon Monoxide Emission (Co)

4.4. Hydrocarbon Emission (HE)

In Figure 4.4, the changes in Hydrocarbon (HC) emissions for all blends under various loads are depicted. HC is an acronym for hazardous carbon, which refers to organic emissions that have the potential to affect both human health and the environment. According to the line graph, HC emissions rise together with the engine load. This is because the amount of biofuel in the mix immediately inversely correlates with the HC emissions. According to test results, HC emissions for B10+100 ppm, B20+100 ppm, B30+100 ppm, and diesel were 51 ppm, 49 ppm, 52 ppm, and 87 ppm, respectively. Diesel has the greatest HC emissions out of all mixtures. Due to unburned fuel particles, B30 produces HC emissions that are closer to those of diesel.

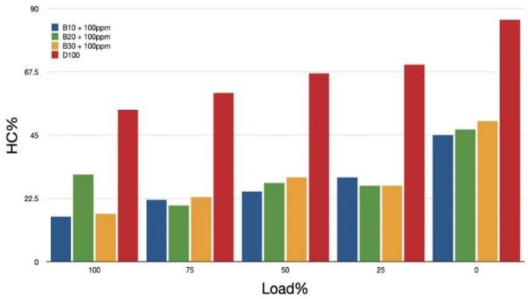

Fig 4.4 Hydrocarbon Emission(HC)

4.5. Nitrogen Oxides (NOx)

Figure 4.5 displays the history of NOx under various loading conditions. One of the dangerous pollution gases is the discharge of nitrogen oxide. The line graph demonstrates that NOx rises as the load increases.. The test findings for diesel, B10+100 ppm, B20+100 ppm, and B30+100 ppm are 2133 ppm, 2223 ppm, 2243 ppm, and 1909 ppm, respectively. Due to the large volume of biodiesel and higher oxygen content in blend B30, there are substantial levels of NOx emissions. Better combustion will result from the incorporation of nanoparticles. As the load grows, the engine's temperature and pressure rise, which is what causes the NOx emission to rise. For all blends, diesel has the lowest NOx emissions relative to biodiesel. Because there is less oxygen present, B10 discovers that NOx and diesel are more closely related.

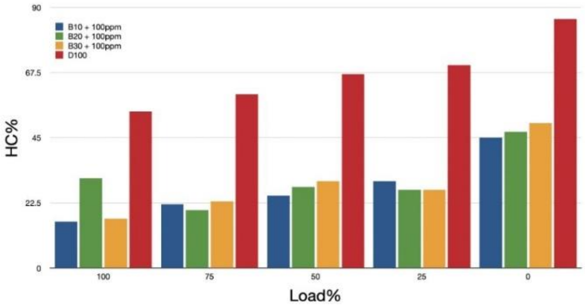

Fig 4.5 Nitrogen Oxides(NOx)

V. CONCLUSION

From the results of the experiment, the following observations on the impact of ceric oxide nanoparticles were made in Ziziphus mauritiana seed Effects of biodiesel oil on ignition behaviour and engine performance:

Diesel and biodiesel made from Ziziphus mauritiana seed oil have nearly identical Brake Thermal Efficiencies (BTE) under all loading conditions.

Carbon monoxide (CO) emissions may have been reduced with the addition of a significant amount of biodiesel generated from Ziziphus mauritiana seed oil.

With an increase in the amount of biodiesel made from Ziziphus mauritiana seed oil, carbon dioxide (CO2) emissions decline.

Using a higher ratio of biodiesel and cerium oxide (CeO2) nano additions, the hydrocarbon (HC) emission was lowered.

Nitrogen Oxides (NOx) emission increases as engine load increases.

VI. ACKNOWLEDGEMENT

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REFERENCES

[1] M. Mofijur, Shams ForruqueAhmed ,Zahidul Islam Rony, Kuan Shiong Khoo , Ashfaque Ahmed Chowdhury M.A, alam a , Van Giang Le, Irfan Anjum Badruddin, T.M. Yunus Khan: Screening of non-edible (second-generation) feedstocks for the production of sustainable aviation fuel (2023), doi.org/10.1016/j.fuel.2022.125879.

[2] Rozina, Mushtaq Ahmad, Muhammad Zafar: Conversion of waste seed oil of Citrus aurantium into methyl ester via green and recyclable nanoparticles of zirconium oxide in the context of circular bioeconomy approach(2021), doi.org/10.1016/j.wasman.2021.10.001.

[3] Dario Alviso, Guillermo Artana, Thomas Duriez: Prediction of biodiesel physico-chemical properties from its fatty acid composition using genetic programming (2020), doi.org/10.1016/j.fuel.2019.116844

[4] Onukwuli Dominic Okechukwu, Ezeugo Joseph, Ude Callistus Nonso, Nwosu-Obieogu Kenechi: Improving heterogeneous catalysis for biodiesel production process (2022), doi.org/10.1016/j.clce.2022.100038

[5] L.C. Meher, D. Vidya Sagar, S.N. Naik: Technical aspects of biodiesel production by transesterification—a review (2006) doi.org/10.1016/j.rser.2004.09.002.

[6] Vijay Kumar Mishra, Rachna Goswami: A review of production, properties and advantages of biodiesel (2017), doi:10.1080/17597269.2017.1336350

[7] L.C. Meher, D. Vidya Sagar, S.N. Naik: Technical aspects of biodiesel production by transesterification (2004), doi:10.1016/j. rser2004.09.002

[8] Patrick T Sekoai, Cecil Naphtaly Moro Ouman, Stephanus Petrus du Preez, PhillimonModisha, Nicolaas Engelbrecht, Dmitri G. Bessarabov, Anish Ghimire: Application of Nanoparticles in biofuels (2018), doi: 0.1016/j.fuel.2018.10.030

[9] V.S. Shaisundaram, M. Chandrasekaran, R. Muraliraja, Mohanraj Shanmugam, S. Baskar, Arun Bhuvendran: Investigation of Tamarind Seed Oil biodiesel with aluminium oxide nanoparticle in CI engine (2020), doi: 10.1016/j.matpr.2020.06.597

[10] R. Sridhar, V.S. Shaisundaram, S. Baskar, S. Ramasubramanian, G. Sathiskuamr, S. Sivabalan: Investigation of grape seed oil biodiesel with cerium oxide nanoparticle in CI engine (2020), doi: 10.1016/j.matpr.2020.06.595

[11] N. Usta, B. Aydogan, A.H. Con, E. Uguzdogan, S.G. Ozkal: Properties and quality verification of biodiesel produced from tobacco seed oil (2010), doi: 10.1016/j.enconman.2019.12.021

[12] C. Srinidhi, Dr. A. Madhusudhan: A Diesel Engine Performance Investigation Fuelled with Nickel Oxide Nano Fuel-Methyl Ester (2017), VOL.7, No.2,2017

[13] K. A. Sateesh, V.S. Yaliwal, Manzoore Elahi M. Soudagar, N.R. Banapurmath, H. Fayaz, Mohammad Reza Safaei, Ashraf Elfasakhany, Ahmed I, EL-Seesy (2021)

[14] Hwanam Kim, Byungchul Choi: The effect of biodiesel and bioethanol blended diesel fuel on nanoparticles and exhaust emissions from CRDI diesel engine (2009), doi: 10.1016/j.renene.2009.04.008

[15] A. Prabu: Nanoparticles as additive in biodiesel on the working characteristics of a DI diesel engine (2017), doi: 10.1016/j.asej.2017.04.0041

[16] Gurpinder Singh, Saroj Kumar Mohapatra, Satishchandra S. Ragit& Krishnendu kundu: Optimization of biodiesel production from grape seed oil using Taguchi's orthogonal array (2018), doi: 10.1080/15567036.2018.1495778

[17] Carmen Maria Fernandez, Maria Jesus Ramos, Angel Perez, Juan Francisco Rodriguez: Production of biodiesel from winery waste; Extraction, Refining and transesterification of grape seed oil (2010), doi: 10.1016/j.biortech.2010.04.014

[18] D. Arunkumar, M. Ramu, R. Murugan, S. Kannan, S. Arun, Sanjeevi Baskar: Investigation of heat transfer of wall with and without using phase change material (2020), doi: 10.1016/j.matpr.2020.01.220

[19] N.R. Banapurmath, P.G. Tewari, R.S. Hosmath: Experimental investigations of a four-stroke single cylinder direct injection diesel engine operated on dual fuel mode with producer gas as inducted fuel and honge oil and its methyl ester (HOME) as injected fuels (2007), doi: 10.1016/j.renene.2007.11.017

[20] R. W. Pitz, C. M. Penney, C. M. Stanforth, W. M. Shaffernocker: Advanced smoke meter development survey and analysis (1984)