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Biodiesel Effects on the Emissions and the Performance of the Engine - A Review

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ABSTRACT
In the last 15 years, biodiesel instead of diesel has been progressively used to examine its impact on engine performance and emissions as a renewable, sustainable, and alternative fuel for compression ignition engines. Saturated and unsaturated long-chain fatty acid alkyl esters make up biodiesel, which is made through the transesterification of vegetable oils or animal fats. Engine manufacturers are concerned about the particles created by diesel and spark-ignition engines because they affect engine performance and wear, as well as their environmental effect. Despite certain application issues, it is now widely regarded as one of the most promising alternative fuels for internal combustion engines. The purpose of this study is to conduct a full assessment of engine performance and emissions using biodiesel derived from various feedstocks and compare them to diesel. According to the findings, using biodiesel results in significant reductions in PM, HC, and CO emissions, as well as undetectable power loss, increased fuel consumption, and increased NOx emissions on conventional diesel engines with no or little modifications. However, many more studies on engine modifications, low-temperature engine performance, new instrumentation and measuring technique, and so on are recommended when utilizing biodiesel as a diesel alternative.
KEYWORDS: Biodiesel, Biodiesel Emissions, Carbon Monoxide, Carbon Dioxide, Nitric Oxide, Sulphur Oxide, Smoke, Particulate Matter (PM)

1. INTRODUCTION

The globe has recently been confronted with an energy crisis as a result of fossil fuel depletion and environmental damage. Biodiesel is one of the most promising alternative fuels for dealing with these issues. It is renewable, biodegradable, non-toxic, and possesses properties similar to diesel fuel. It may be made from both vegetable oil and animal fats. Oils and fats are essentially triglycerides made up of three long-chain fatty acids. Because of their increased viscosity, these oils cannot be utilized as fuel. Transesterification is the process by which triglycerides are transformed into esters in order to lower viscosity. From one molecule of fat/oil, three smaller molecules of ester and one molecule of glycerin are formed. Glycerin is removed as a byproduct, and the esters are referred to as biodiesel [1]. While biodiesel shares many characteristics with regular diesel fuel, it also has several distinct characteristics that must be addressed when using it in existing and new engine technology. Due to its increased bulk modulus of compressibility, a property of soybean oil-derived biodiesel that is predominantly utilized in the United States, biodiesel can increase NOx emissions in engines utilizing pump-line–nozzle fuel systems. The fact that biodiesel can cause an increase in NOx in common rail engines is not explained by the change in compressibility, and it remains a study topic. This NOx impact can be effectively avoided by adding a cetane improver, adjusting the methyl oleate content in the biodiesel fuel (through a variety of methods including genetic manipulation of the soybean plant), or shifting the injection time to compensate for the fuel's advance. Like other oxygenated diesel fuels, biodiesel can minimize the quantity of soot generated in the diesel spray flame, resulting in lower overall particle emissions [2].

Some countries launched biofuel production systems in the 1990s, utilizing the methanol method and vegetable oil or residual fats as a starting source. Germany, in particular, developed a biodiesel production program. In Germany, the industrial units that produce biodiesel have a high level of automation. However, given to climatic conditions, they are only operational for a portion of the year. Biodiesel is distributed by approximately 1,000 petrol stations. Biodiesel was initially primarily employed in the fleets of large cities' vehicles. Biodiesel has a lower consumer price than fossil diesel. The difference could be as much as 12%, which can be explained by lower government taxes. In France, for example, biodiesel has been utilized in city buses in quantities up to 30% in fossil fuel (B30) to reduce vehicle emissions in major cities. The adoption of government choices such as tax reductions encourages the biodiesel chain. In Brazil, a government rule mandates the use of biodiesel blends containing 2% biodiesel in petroleum diesel (B2) by 2008. After then, the percentage will increase to 5%. (B5). This technique offers the advantage of lowering car emissions while leaving diesel engines unchanged [3]. India imports more than 80% of its petroleum and spends a significant amount of foreign currency for it. Due to the finite nature of fossil fuel resources, biodiesel is rising in popularity as a viable alternative fuel. The goal of the transesterification procedure is to reduce the oil's viscosity. Vegetable oil's main disadvantage is its high viscosity and low volatility, which results in poor combustion in diesel engines. The process of eliminating glycerides and mixing oil esters of vegetable oils with alcohol is known as transesterification. This technique lowers the viscosity to a level comparable to diesel, resulting in better combustion [4]. The performance and emissions of several biodiesels reported by various authors were investigated in this study.

2. EMISSIONS FROM BIODIESEL

Despite the fact that 350 oil-bearing crops have been found, only a few are suitable for biodiesel production, such as sunflower, rapeseed, palm, and jatropha. It has been discovered that biodiesel has similar combustion characteristics to diesel, and that the base catalyst outperforms acid catalysts and enzymes. The high viscosity oil induced injector coking and polluted the lubricating oil, implying that the engine performance was lower while utilizing vegetable oil/diesel blend. The results of the testing using refined oil blends showed a significant improvement in performance. Unburned hydrocarbon emissions from the engine were found to be higher on all fuel blends than on diesel. The performance and emissions of several biodiesels reported by various authors were investigated in this study. When comparing all fuel blends to diesel, the emission of nitrogen oxides from the engine was found to be greater. Moreover, carbon monoxide, carbon dioxide, nitrogen oxides, sulphur oxides, and smoke are the principal emissions released by biodiesel [4].

3. 1 CO emissions.

Chauhan et al [5] conducted an experiment in which they compared the combustion characteristics and emissions of petroleum diesel and biodiesel derived from Jatropha oil. The CO emission from Jatropha methyl ester and its blends is found to be lower than that of neat diesel fuel across the entire experimental range. CO decreases as the percentage of biodiesel in biodiesel-diesel blends increases, because biodiesel is an oxygenated fuel that contains oxygen, which aids in complete combustion. As a result, as the percentage of biodiesel in fuel increases, CO emissions decrease.

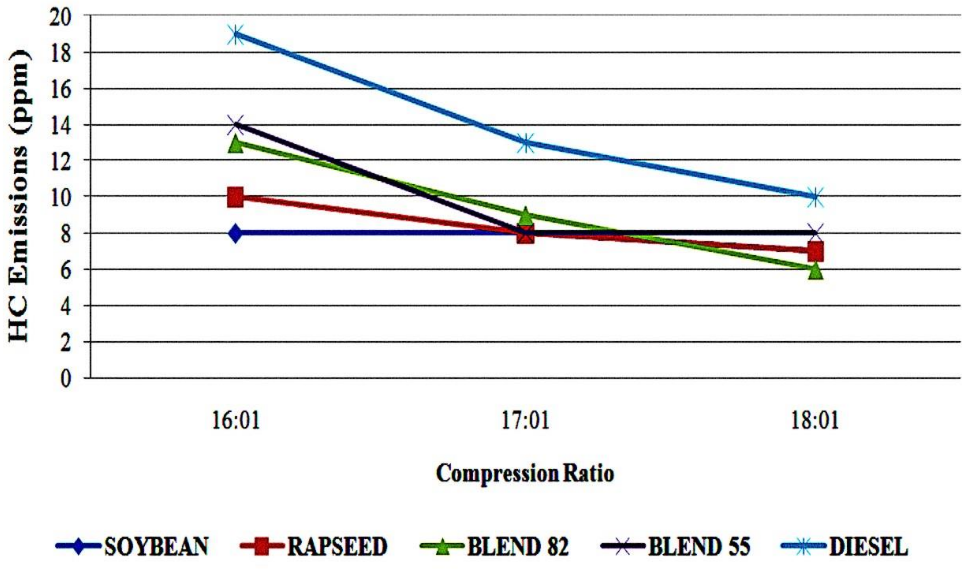

Fig. 1. CO Emission Variation with Different Fuel Blends for Different Compression Ratios at 50% Load [6]

Vivek Kumar Nema et al. found that the creation of carbon monoxide results in poor combustion, a lack of oxygen supply, and poor mixture preparation during the fuel combustion process. Figure 1 depicts the CO exhaust emission fluctuation for all fuels used in the experiment at various compression ratios and 50% load. When comparing all biodiesel blends to diesel, Figure 1 demonstrates that CO emissions have dropped as the compression ratio has increased [6].

3.2 CO2 emissions.

Biodiesel produces more CO2 emissions than diesel fuel. CO2 emissions from vegetable oil and its mixes are lower, according to Chauhan et al [5]. The results suggest that using Jatropha biodiesel and its mixes resulted in a small increase in CO2 emissions. Mbarawa [7] compares CO2 emissions from engines running on CSO (clove stem oil)–diesel blended fuels vs pure diesel. It is found that CO2 emissions rise as the percentage of CSO in the blend rises. The CO2 emissions from the 25% CSO–diesel blended fuel were only marginally higher than those from pure diesel. The CO2 emissions of the 50 percent CSO–diesel blend increased by 7.85 percent when compared to pure diesel fuel. The slightly increased fuel consumed for the 50 % CSO and 25 % CSO–diesel blended fuels results in higher CO2 emissions.

CO2 emissions rise according to fuel consumption in mass as the load increases (Fig. 2). At large loads, it seems that the CO2 quantities and gas temperatures have been separated into two groups. Higher exhaust temperatures and CO2 emissions from B20, B35, and RME (Rapeseed methyl ester) are rather closely correlated with the observed stratification in the brake thermal efficiency curves. The slightly greater fuel consumption for blends B20, B35, and plain RME is reflected in the increased CO2 emissions. In the case of biodiesel, higher CO2 emissions should be less of a concern because, during the coming summer, the ultimate sun energy will use a large portion of the CO2, producing new hydrocarbons by raising oil crops and releasing oxygen to be freed to the open blue sky, allowing Nature to recover [8].

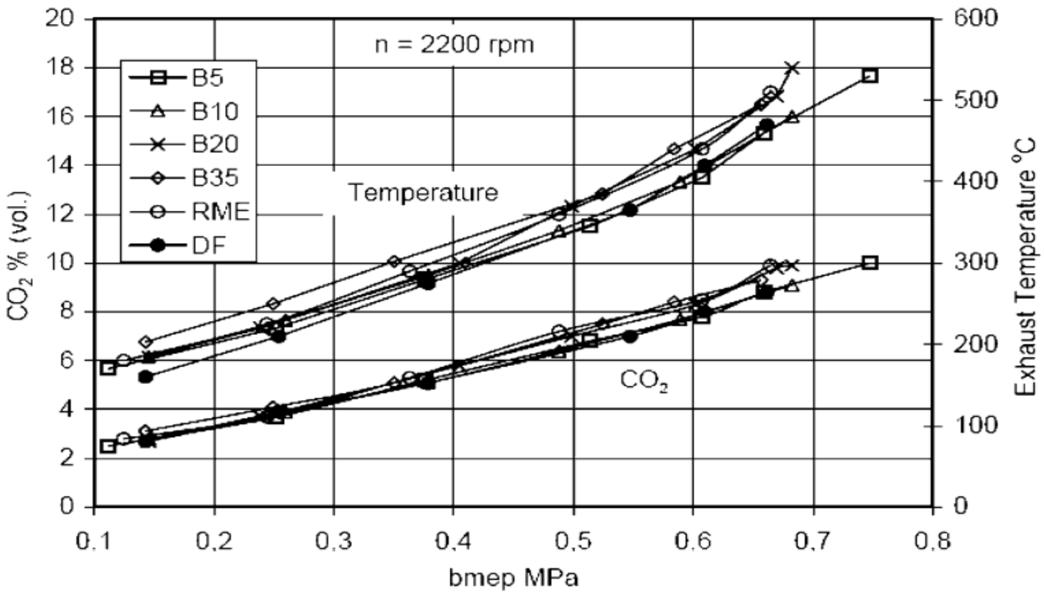

Fig. 2. The effects of engine load on exhaust gas temperatures and carbon dioxide emissions (bmep) [8].

According to M. Mani et al, the amount of CO2 emitted by waste plastic oil is smaller than that produced by diesel. This could be due to late fuel combustion, which results in insufficient CO oxidation [9]. Higher CO2 emissions are attributed to the presence of oxygen in biodiesel and the considerably lower carbon content of biodiesel for the same amount of gasoline used. The theories suggested include that biodiesel's high viscosity decreases cone angle, which leads to less air entrainment in the spray, causing full combustion to be hampered [10].

3. 2 NO_x emissions

NO (Nitric oxide) and nitrogen dioxide are among the nitrogen oxides in the emissions. The generation of NOx is strongly influenced by the temperature, oxygen content, and reaction time in the cylinder. Figure 3 demonstrates the relationship between nitrogen oxides and braking power. The amount of NOx emitted by the waste plastic oil process has increased. For diesel, NOx levels range from 12.15 g/kWh at 25% of rated power to 7.91 g/kWh at rated power, while for waste plastic oil, NOx levels range from 14.68 g/kWh at 25% of rated power to 8.93 g/kWh at rated power. The greater heat release rate and combustion temperature are the causes of the increased NOx. CI engines are usually run low, yet they nevertheless release a lot of NOx. NO levels rise with high loads due to greater peak pressures and hence temperatures, as well as bigger areas of near to stoichiometric burnt gas. Increased NOx may also be due to increased ignition delay of waste plastic oil, which promotes premixed combustion by providing more time for fuel to be injected prior to ignition [9].

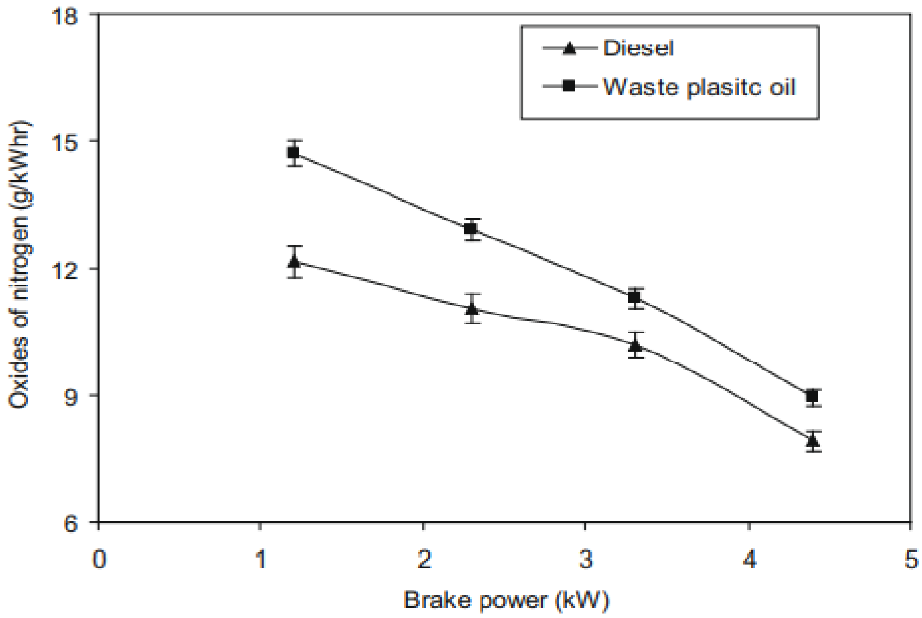

Fig. 3. Variation in nitrogen oxides as a result of brake power [9].

Biodiesel has a greater cetane number and a lower flash point than diesel, according to the explanations. Increasing the cetane number reduces the size of the premixed combustion by reducing the ignition delay, resulting in a lower NOx formation rate because the combustion pressure rises more slowly, allowing more time for cooling through heat transfer and dilution, and thus resulting in lower localized gas temperatures. Biodiesel's lack of aromatic and polyaromatic hydrocarbons decreases the flame temperature, resulting in fewer NOx emissions. In addition, a shorter ignition delay owing to a higher cetane number would allow for less air/fuel mixing time before the premixed burning phase. As a consequence, during the premixed phase, a weaker mixture would be created and burned, resulting in lower NOx generation [11, 12]. Many comparison tests have been conducted to determine the impact of biodiesel content on NOx emissions. An ultra-low sulphur diesel fuel is used to conduct clean biodiesel engine tests. When the ignition delay was increased by 80–100%, ultra-low levels of NOx and soot were attained. The power loss for the diesel and biodiesel fuels was less than 20% and 10%, respectively, under the examined low load conditions. This finding was a significant improvement over prior port-injection test results, which had various drawbacks, including significant engine oil dilution [13]. Sahoo et al. investigated the optimum biodiesel concentration in terms of NOx emissions. There are two major conclusions that can be drawn. First conclusion is that NOx emissions are a direct result of engine load. This is expected since the temperature of the combustion chamber rises as the load rises, and NOx production is a temperature-dependent phenomena. The second crucial point to note is that NOx emissions are reduced by about 4% when using biodiesel fuel. Lower NOx emissions could be owing to lower combustion chamber temperatures when utilizing biodiesel. This is also evidenced by the biodiesel-fueled engine's lower exhaust temperatures [14]. NOx emissions are reduced as fatty molecules become saturated. Due to increased saturation level and cetane number, all animal fat biodiesels, including beef tallow, lard, and chicken, exhibited lower NOx levels than soy oil based biodiesel, according to Wyatt et al [15].

3. 3 Sulphur oxide

Sulphur in a fuel is an unwanted ingredient that causes more soot particles to form during combustion [16]. High-sulfur fuels damage down engines and shorten catalyst life. Sulphur emissions are hazardous to human health; when sulphur oxides are dissolved in rainwater, sulphur creates oxides of sulphur and sulpheric acid, resulting in acid rain, which is a significant cause of cancer [17]. The amount of total sulphur in the fuel samples was compared to the blends. As illustrated in Figure 4, the ASTM (American Society for Testing and Materials) maximum and minimum values were also included. Except for the B100 biodiesel, which is less than the minimum requirement value, all of the blends meet ASTM criteria. Because of the lower sulphur concentration, there was less of a propensity for sulphur (IV) oxide to be released into the environment during the combustion of diesel fuel. Figure 1 depicts the sulphur concentration in biodiesel mixes. The amount of sulphur in the blends reduces as the percentage of biodiesel increases. The petro diesel has a sulphur concentration of 0.202 by weight, according to the test. With an increase in biodiesel percentage from 5% to 10% and 15% to 20%, it decreased to 0.191, 0.181, 0.171, and 0.155, respectively. This demonstrates that wild grape seed biodiesel can reduce sulphur dioxide emissions into the atmosphere. The pure biodiesel has a sulphur level of 0.04 wt percent, which was not caught on the table. This is within the ASTM D5453 standard range, which allows for a maximum total sulphur level of 0.05 wt% in a specific biodiesel [18].

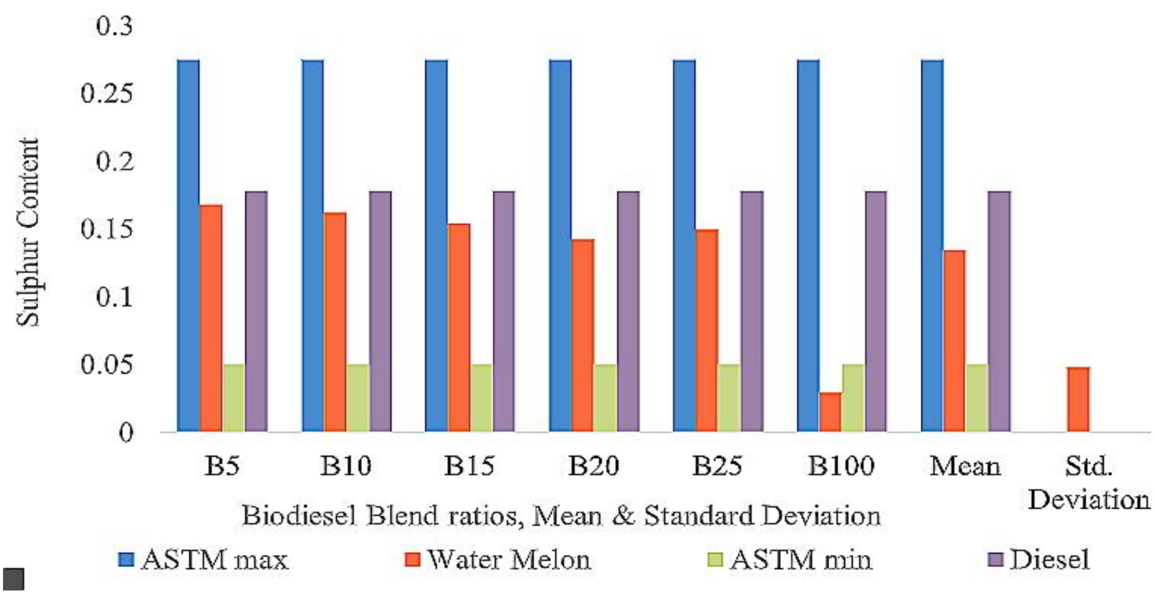

Fig. 4: Sulphur substances index in watermelon biodiesel and blends [18]

3. 4 Smoke and PM (Particulate matter)

All biodiesel mixes' smoke opacity emissions with engine load were presented in Figure 5. With an increase in engine load, there was an "increase in smoke output." This occurred as a result of increased fuel consumption, which resulted in a rich air-fuel combination. Smoke emissions were reduced because the fuel included more oxygen molecules and had a lower carbon content than diesel oil, resulting in improved combustion.3.4 HC emissions [19].

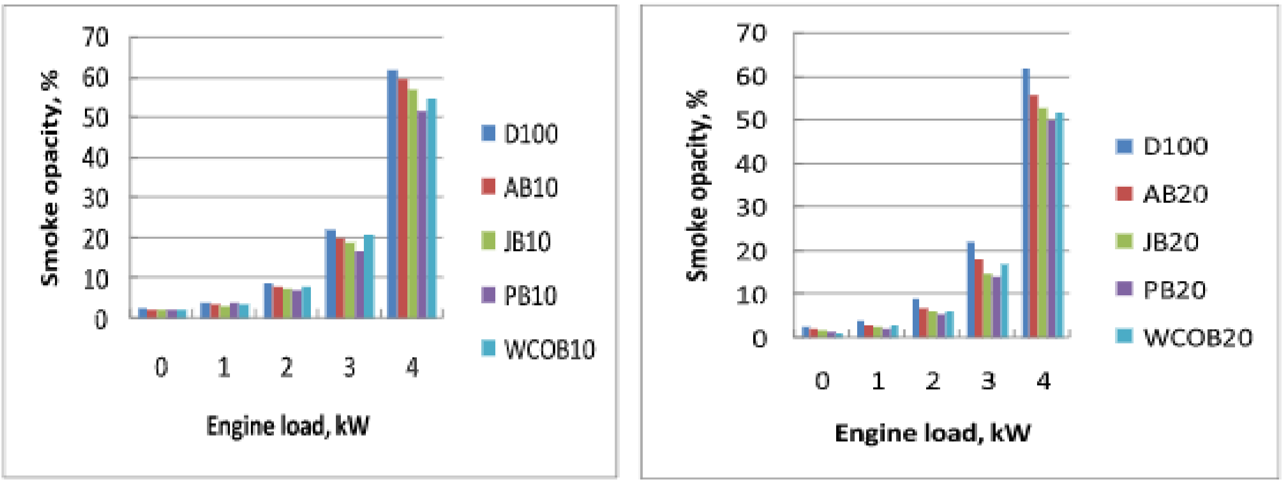

Fig. 5: Variation of biodiesel smoke emissions as a parameter of engine load [19]

PM (Particle matter) emissions from diesel engines have long been a source of worry for engine manufacturers since they have an impact on engine performance and the environment. When particles are re-circulated to the engine using EGR (Exhaust Gas Recirculation), they may cause deposit development in the combustion chamber, fouling of the exhaust gas recirculation, and increased wear [20]. PM is described as particle-phase chemicals released by diesel engines in an EPA (Environmental Protection Agency) report [21]. EC (Elements of carbon), OC (organic carbon), sulfate, trace elements, nitrate, water, and unknown components make up the majority of diesel particles. In general, PM's chemical makeup has a significant influence on human health and the environment [22].

Particles coming from the submicron are usually produced in every one of three ways. The accumulation mode particles are mostly made up of carbonaceous agglomerates. Fine ash particles either adorn existing particles or form distinct solid particles in the nucleation mode. Semi-volatile droplets typically contribute the most to the number concentration of nucleation mode particles. The generation of particles in a heavy-duty diesel engine during combustion, dilution, and cooling is frequently as follows, especially under normal cruising conditions. Carbonaceous particles form during the combustion process and huge amounts of particles are oxidized in the first stage [23, 24]. The generation of particles during combustion, dilution, and cooling in a heavy-duty diesel engine is frequently as follows, especially under normal cruising conditions. Carbonaceous particles form during the combustion process and huge amounts of particles are oxidized in the first stage. Furthermore, carbonaceous particles might develop as a result of lubricating oil entrained in the fuel. Metallic additives in lubricating oil have been shown to be converted to gas-phase compounds, which subsequently undergo gas-to-particle conversion when the combustion products expand and cool. The majority of the particles are terminated by decorating accumulation mode particles, but if the ratio of ash and carbonaceous accumulation mode particles is high enough, separate ash nucleation can also be formed [22, 24].

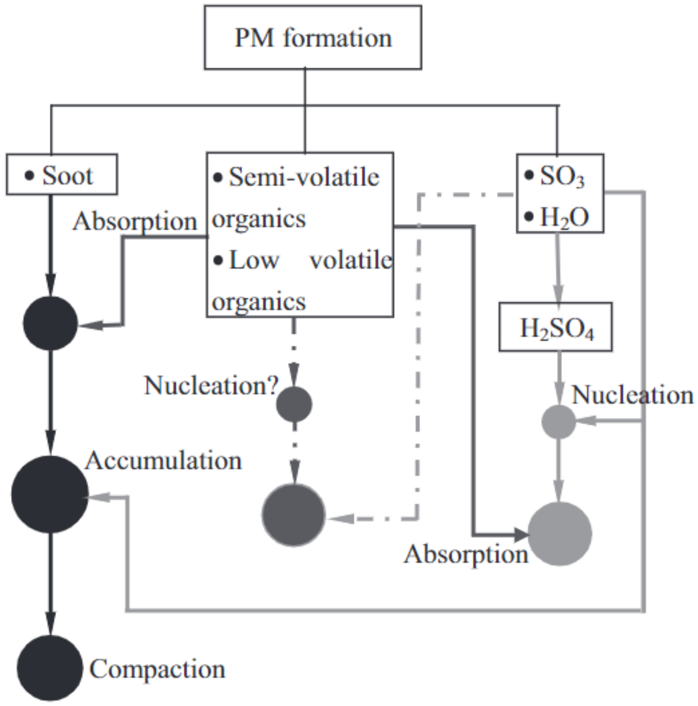

Fig. 6: During exhaust dilution and cooling, a simplified mechanism of condensation and nucleation is depicted.

Dilution and cooling at the tailpipe cause semi-volatile molecules, primarily volatile hydrocarbons from lubricating oil and sulfuric acid, to convert to particles, causing nucleation and adsorption/condensation on the existing particles. There is a competition between nucleation and adsorption during the diluting and chilling process, and the low concentrations of accumulation mode particles and quick dilution favor nucleation over adsorption. Figure 6 depicts a more simplified method for condensation and nucleation during the exhaust dilution and cooling process [22].

4. ENGINE PERFORMANCE

Engine performance with biodiesel and its mixes is influenced by air turbulence, air–fuel mixture quality, fuel injection pressure, ignition delay, fuel spray pattern, and fuel characteristics, to name a few. Furthermore, it varies depending on biodiesel quality and origin, as well as engine operating factors such as speed, load, and so on. Most research have studied performance indicators such as braking torque, brake power, BTE (brake thermal efficiency), EGT (exhaust gas temperature), and BSFC (brake specific fuel consumption) in CI (Compression Ignition) engines utilizing various forms of biodiesel [25].

The difference in in-cylinder peak pressure between diesel and diesel–biodiesel blends is not significant and is within 1%, according to an investigation of combustion parameters such as cylinder pressure, peak pressure, ignition delay, heat release, and cumulative heat release rate of biodiesel blends and diesel. The ignition of biodiesel occurs 1–211CA sooner than that of diesel. As is common for normally aspirated engines, both diesel and biodiesel fuels experience quick premixed combustion followed by diffusion combustion. Both fuels have extremely similar immediate and cumulative heat release rates. The combustion properties of biodiesel fuel mixes and straight biodiesel have been shown to be similar to those of standard diesel combustion [26]. Fuel combustion is one of the most critical processes that affects engine performance, emission characteristics, and durability. In-cylinder pressure, ignition delay, combustion duration, heat release, and cumulative heat release rate are essential metrics that indicate the combustion process efficacy [27]. The other combustion characteristics may be estimated from the in-cylinder pressure, which can be obtained straight from the engine. Using the in-cylinder pressure and the shape of the crank and connecting rod, the heat release rate is calculated using the first equation of thermodynamics [28].

Due to its lower energy content, biodiesel delivers 3-5 percent less engine power and torque than diesel. It's measured in kWh/litre of gasoline or gm/kWh as BSFC. Deposits and clogging issues have been extensively observed, and are often linked to poor biodiesel quality or to its lower oxidation stability, resulting in increased engine wear when using biodiesel. Due to its increased oxygen content and lack of "aromatic chemicals" and sulphur, biodiesel produces significantly less air pollution. When compared to biodiesel, NOx levels are somewhat greater, although this may be mitigated by good engine timing. Clogging of the filters and/or choking of the injectors are common difficulties with diesel engines running in cold weather. In the operational range of climatic temperatures, the use of flow enhancing additives and "winter blends" of biodiesel and kerosene has proven beneficial. B100 is capable of operating at temperatures as low as 5°C. The winter mixes have proven effective at temperatures as low as -20°C or below, owing to additives that narrow the range by roughly 5-8°C [29].

Figure 7 shows the engine power fluctuation as a function of engine speed at full load. The power grows with rising engine speed until it reaches a maximum value, as indicated in the graph, and then falls with increasing engine speed. At the same time, engine power is increasing in response to the addition of biodiesel to the blend. The power increases initially when the biodiesel content in the mix is increased, reaches a maximum value, and then drops as the biodiesel percentage is increased further. Despite the fact that adding biodiesel to diesel reduces its heating value, more power was produced in the tests. There are several reasons for this. Firstly, biodiesel contains around 10% (by weight) oxygen, which may be utilised in combustion, especially in the fuel-rich zone. This might be the cause of more complete combustion, which would increase torque and power. Second, diesel fuel is poured volumetrically into the diesel engine cylinder, and the density of the biodiesel blend is higher than that of diesel fuel. As a result, the engine receives a higher mass flow rate for the same fuel volume, resulting in increased torque and power. Meanwhile, the more viscous the blend, the less internal fuel pump leakage is visible. The torque and power are both increased as a result of this. The power rises with the addition of biodiesel content in the blend until it reaches a maximum value (4.49 kW) in the B20 mix. As the biodiesel concentration in the blend rises, the power falls below that of diesel fuel (4.25 kW) [30].

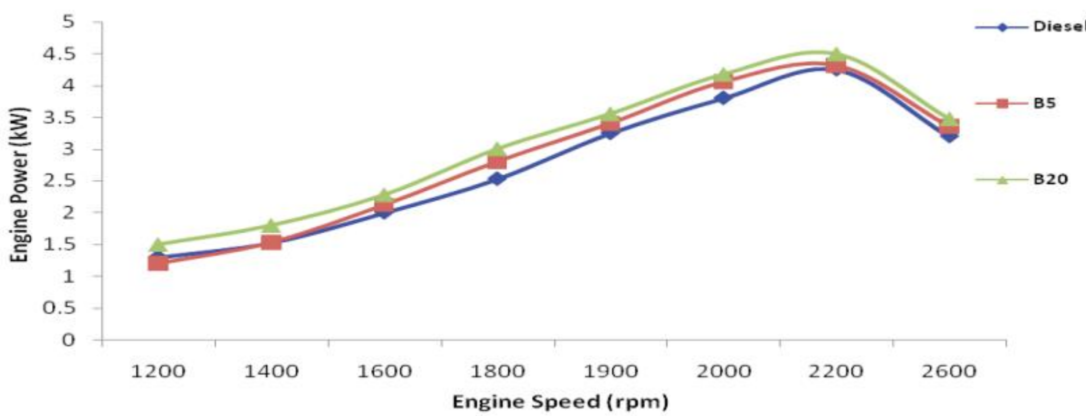

Fig 7. Alteration of engine power in contrast to engine speed [30].

The combination of biodiesel and CNG (Compressed Natural Gas), according to R. Mohsin et al., raises the reading as engine speed increases. Biofuel-DDF(Diesel Dual Fuel) provides the most engine power compared to PD, B20, and Biofuel-DDF owing to the presence of CNG, and it is closer to completion due to the larger calorific value of PD (Petrol Diesel) compared to biodiesel. Furthermore, the engine torque measured in their study revealed that all types of biodiesel blends and CNG had a similar effect, with a decrease in torque as engine power increased. When compared to other types of fuels, the combination of B20 and CNG (B20-DDF) exhibited the best results since it provided the most torque at low speeds (1000 RPM) and had a greater range of emission reduction, which was 20% at maximum speed (2500 RPM)4.2 Brake specific fuel consumption [31].

5. CONCLUSION

It may be assumed that biodiesel production from various feedstocks has the potential to be used as an alternative energy source, and that biodiesel use can help to reduce reliance on fossil fuels. Variations in the nature of the performance and emissions of the diesel engine are impacted by differences in the properties of biodiesel. The following conclusions can be arranged based on review of the above existing studies:

- The amount of CO2 emissions can rise depending on fuel consumption in mass as the load increases.
- Biodiesel has a lower C/H ratio than diesel, so it emits less CO. However, the amount of CO emissions reduction is independent of the proportion of biodiesel in the fuel.
- The generation of NO_x is strongly influenced by the temperature, oxygen content, and reaction time in the cylinder. Increased amount of NO_x may also be due to increased ignition delay of waste plastic oil, which promotes premixed combustion by providing more time for fuel to be injected prior to ignition.
- NO_x emissions are reduced as fatty molecules become saturated.
- The amount of sulphur in the blends reduces as the percentage of biodiesel increases. This proves that wild grape seed biodiesel can reduce sulphur dioxide emissions into the atmosphere.
- Dilution and cooling at the tailpipe cause semi-volatile molecules, primarily volatile hydrocarbons from lubricating oil and sulfuric acid, to convert to particles, causing nucleation and adsorption/condensation on the existing particles.
- Due to its lower energy content, biodiesel delivers 3-5 percent less engine power and torque than diesel.
- Clogging of the filters and/or choking of the injectors are common difficulties with diesel engines running in cold weather. In the operational range of climatic temperatures, the use of flow enhancing additives and "winter blends" of biodiesel and kerosene has proven beneficial.
- The power increases initially when the biodiesel content in the mix is increased, reaches a maximum value, and then drops as the biodiesel percentage is increased further.

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