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# A Review on Biodiesel as an Alternative Fuel for Diesel Engine Applications

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***Abstract: Many research works are being carried out to enhance the performances of internal combustion engines to meet out the current energy demand and to reduce the emission with the alternate fuels. Energy production is heavily dependent on fossil fuels that are not only diminishing, but also are considered the main cause of harmful emissions and global warming. Therefore using vegetable oils such as Jatropha, palm, algae and waste cooking oils as alternative fuels in diesel engines has drawn a great attention. Biodiesel from Jatropha, palm, algae and waste cooking oils is produced using the transesterification process. Biodiesel fuel is one of the environmentally friendly alternative energy that can reduce toxic gas emissions and at the same time reduces dependence on petroleum-based fuels. Therefore, the purpose of this paper is to provide a comprehensive review of biodiesel as an alternative fuel for diesel engine applications. A significant number of literatures from various journals were cited accordingly. The results of previous studies had shown that the use of biodiesel would mostly increase the amount of brake specific fuel consumption and nitrogen oxide gas while conversely reducing other toxic gas emissions. The study concluded that biodiesel and its blends have a bright future in the marine sector, provided some of the highlighted issues can be solved.***
***Keywords: Internal combustion engine, Diesel Engine, Biodiesel, Jatropha, Palm, Algae, Waste Cooking oil, Emission.***

## I. INTRODUCTION

Diesel fuel is widely employed as a major fuel in industry, power and transportation areas owing to its high efficiency. Pollutants such as carbon monoxide, smoke and hydrocarbons from diesel fuel combustion have a serious impact on human health and the environment. To facilitate lowering these emissions, fuel derived from a renewable source is highly promising [6]. Biodiesel and bio-alcohols are the potential fuels which could be used in current engines without much alteration [7]. These fuels have similar fuel properties to diesel. However, neat biodiesel in a diesel engine results in higher viscosity issues [8]. Hence, the viscosity of neat biodiesel should be lowered as far as possible to minimize the drawbacks mentioned. Many studies were attempted by blending the lower carbon–hydrogen (C–H) alcohols such as methanol and ethanol which resulted in phase separation leading to poor ignition [9][10]. To reduce this drawback, alcohols having a longer C–H chain and higher calorific value, namely butanol, pentanol and octanol, are potential additives to diesel–biodiesel blends [11]. Many studies explored the usage of higher C–H alcohols to diesel/biodiesel blends [12][13]. Devaraj et al. [14] have found that the addition of higher C–H alcohols (pentanol) to diesel reduces CO, NOx emissions. Yuvarajan et al. [15] confirmed that pentanol addition lowered biodiesel HC and CO emissions. Kishore Pandian et al. [16] also agreed with the result stating that the addition of pentanol to biodiesel fuel lowers its NOx emissions. Radhakrishnan et al. [17] evaluated the impact of adding different volumes of pentanol to palm biodiesel in a research engine. They found a 3.9% reduction in NOx emissions by including 20% volume of higher C–H alcohols to palm biodiesel. In addition, they also found that the usage of pentanol reduces CO and smoke emissions in a diesel engine. Yuvarajan et al. [18] observed the emission efficiency of cyclo-octanol with biodiesel. Cyclo-octanol addition results in lower tailpipe emissions at low, moderate and high loads. Further, cyclo-octanol also boosts the rate of dispersion in fuel. Pandian et al. [19] confirmed that hexanol addition lowered biodiesel (cashew nutshell) HC, CO emissions. Mahalingam [20] found that the addition of pentanol to biodiesel reduces CO, NOx emissions. Previous literature confirms that the addition of longer C–H chain and higher calorific value, namely butanol, pentanol and octanol, to diesel/biodiesel results in lower emissions and improved fuel efficiency.

### *A. Global Energy Trends*

Hydrocarbon or fossil fuels are accounting for more than 80% of today's world total supplied energy. Fossil fuel resources are becoming less day by day and approximately 65.5% of world oil reserves come from Middle East countries [28]. Fig. 1 shows the forecasts of world oil production based on present demand scenario. The maximum production is expected in between 2015 and 2020. After this period, world crude oil would gradually decline in production amount. The primary energy consumption forecast for the next twenty years is shown in Fig. 2. [30].

The increasing of world population and salary is a major factor behind the growing demand for energy. The world population is expected to increase to 8.8 billion by 2035, which will lead to more energy requirements.

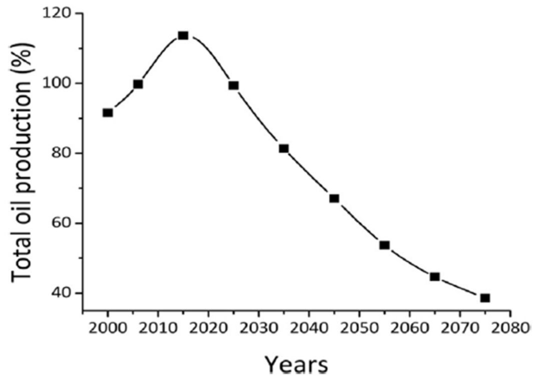


Fig. 1. World oil production forecast based on current scenario [29]

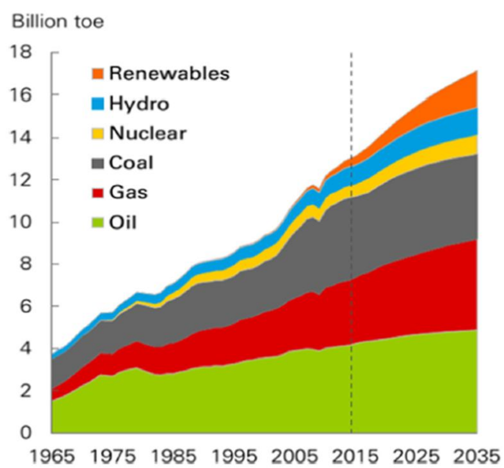


Fig. 2. Energy consumption growth forecast for 2015–2035 [30]

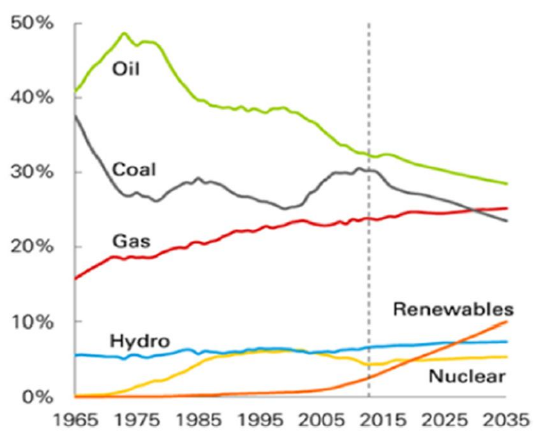


Fig. 3. Shares of primary energy forecast for 2015–2035 [30]

Fossil fuels will still remain the dominant energy source, accounting for more than three quarters of global energy in 2035, down 10% compared to 2015. However, renewable energy is expected to experience rapid growth with the consumption of 439 million tonne oil equivalent (Mtoe) in 2015, increased to 1715 Mtoe by 2035. This upward trend may be due to the lack of coal resources (0.2% decrease per year) and more stringent environmental regulations imposed by most countries in the future. Fig. 3 shows the past and future shares of different types of fuel for year 2015–2035. Oil and coal shares declined to 29% and 24% respectively by

2035, while gas fuel rose by 1%. Shares on renewable energy including biofuels that are growing dramatically from 3% in 2015 to 10% in 2035 will outstrip nuclear energy in the early 2020's and hydro energy in the early 2030's. Annual growth of renewable energy is expected to grow well at 7.1% per year for the next twenty years. The prospect of renewable energy is seen to be very promising in the near future. Their energy cost per British thermal unit (BTU) is declined. The method used is always improved either for use in buildings or vehicles. Most governments support renewable energy projects by giving incentives such as tax relief, grants and other forms of schemes. According to the Renewable Energy Policy Network (REN) report, renewable energy accounts for about 19.3% of the global energy consumed in 2015 [32]. This percentage comprises 9.1% from traditional biomass and 10.2% from modern renewable energy which include biodiesel fuel as well. The detailed composition of world energy consumption in 2015 is illustrated in Fig. 4. Biodiesel fuel has been internationally recognized and used by many countries including the European Union, the United States, Brazil and Asia. Table 1 lists the world's ten major biodiesel producers in 2016. The United States is the largest biodiesel nation with 5.5 billion litres of production. It is followed by Brazil with 3.8 billion litres, while third to fifth places are shared by Germany, Indonesia and Argentina with a production of 3 billion litres each, in a year. Most of the biodiesel feedstock comes from soybeans, palm oil, animal fat, coconut oil, olive oil, rapeseed and sunflower.

## II. BIODIESEL OVERVIEW

In short, biodiesel is monoalkyl esters of long chain fatty acids oils derived from renewable lipid sources such as vegetable oil or animal fat [33]. Pure biodiesel that contains 100% biodiesel is commonly referred as B100. Biodiesel blends with petroleum diesel is usually designated as BXX, where XX indicates the biodiesel percentage, for example B80 contains 80% of biodiesel and 20% of petroleum diesel [34].

### *A. Biodiesel Feedstock*

The first biodiesel fuel is peanut oil which was introduced by Rudolf Diesel in 1910 [34]. Since then, a variety of feedstocks were tested and utilized across the world. Currently, there are more than 350 species of plants that have been identified and potentially as a source of biodiesel [35][36]. Potential biodiesel feedstocks according to the country of origin are listed in Table 2. Selection of suitable feedstock for biodiesel production is very significant as it is associated with 75% of the total cost [37][38][39]. In addition, biodiesel fuel quality also depends on the type of resource use, production process and country of origin [40]. Generally, biodiesel sources can be classified into four main groups [33][38][41]:

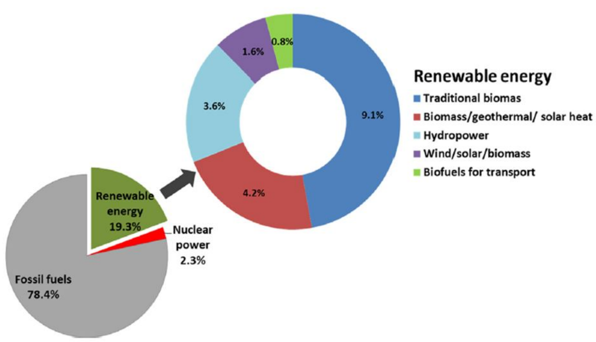


Fig. 4. World energy consumption in 2015

Table 1. World's major biodiesel producer in 2016

| Rank | Country | Biodiesel volume (Billion litres) |
|---|---|---|
| 1 | USA | 5.5 |
| 2 | Brazil | 3.8 |
| 3 | Germany | 3.0 |
| 4 | Indonesia | 3.0 |
| 5 | Argentina | 3.0 |
| 6 | France | 1.5 |
| 7 | Thailand | 1.4 |
| 8 | Spain | 1.1 |
| 9 | Belgium | 0.5 |
| 10 | Colombia | 0.5 |

Table 2. Potential biodiesel feedstock in each country

| Country | Biodiesel feedstock |
|---|---|
| USA | Soybeans and waste oil |
| Canada | Canola |
| Mexico | Animal fat and waste oil |
| UK | Rapeseed and waste oil |
| Germany | Rapeseed |
| Italy | Rapeseed and sunflower |
| France | Rapeseed and sunflower |
| Turkey | Rapeseed and sunflower |
| Spain | Linseed and sunflower |
| Greece | Cottonseed |
| Sweden | Rapeseed |
| Malaysia | Palm oil |
| Indonesia | Palm oil |
| Thailand | Palm oil and coconut oil |
| Philippines | Coconut oil |
| India | Jatropha and pongamia |
| China | Waste oil, rapeseed and waste oil |
| South Africa | Jatropha and castor |
| Brazil | Soybeans and palm oil |
| Argentina | Soybeans |
| Japan | Waste oil |
| Australia | Jatropha |
| New Zealand | Waste oil and tallow |

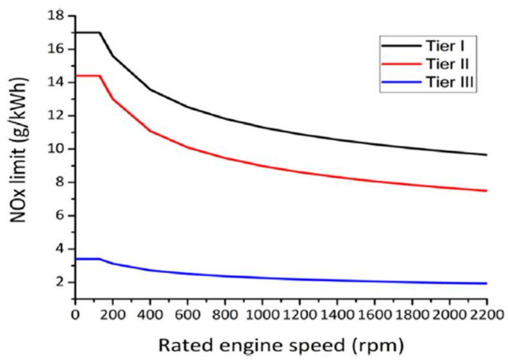


Fig. 5. MARPOL allowable limit for nitrogen oxide emissions. [27]

1) *Edible Vegetable Oil:* soybean, rapeseed, sunflower, palm, olive, rice bran, corn, coconut, canola, wheat, barley, groundnut, safflower, sesame seed, sunflower and peanut.
2) *Non-Edible Vegetable Oil:* algae, cotton seed, pongamia, mahua, jatropha, camelia, karanja, cumaru, jojoba, neem, linseed, moringa, tobacco seed and rubber seed.
3) Recycle and waste oil.
4) Animal fats.

Biodiesel is also classified as a first and second generation based on the feedstock used. The first generation term refers to the biodiesel derived from edible feedstock such as soybean, canola, coconut and others, while at the same time serving as a food source for humans. On the other hand, second generation biodiesel usually processes from nonedible feedstock including jatropha, waste oil and palm fatty acid distillate PFAD) [42].

### *B. Biodiesel Production Process*

Biodiesel extraction process involves a chemical reaction where biodiesel feedstock is mixed with alcohol (methanol or ethanol) and catalyst (Potassium Hydroxide). The by-product of this process is called Fatty Acid Methyl Ester (FAME) or biodiesel. There are four types of biodiesel production process namely; transesterification, micro-emulsion, pyrolysis, and dilution [43].

1) *Transesterification:* The most popular biodiesel production process is called transesterification. This process is very economical which involves low temperatures and pressures in addition to producing a high conversion efficiency [40]. Properties of end product biodiesel through this reaction are closer to diesel. Transesterification involves the chemical reaction of triglycerides (oils/fats) with alcohols to form esters and glycerol. The details of the chemical reaction of the transesterification process are shown in Fig. 6, whereby the catalyst is used to enhance the conversion and process response rates.

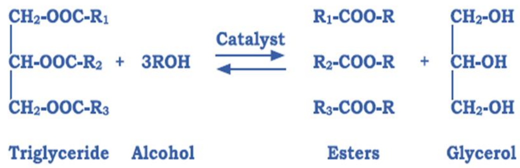


Fig. 6. Transesterification processes of triglycerides.

2) *Micro-emulsion:* Another method used to create biodiesel is through the micro emulsion process. Emulsions are defined as a system consisting of two liquid phases which are not mutually dissolving where one liquid phase is dispersed in another liquid. High viscosity problems in vegetable oils can be reduced by mixing with alcohol (methanol/ethanol) and surfactant. Micro-emulsion generally have dispersion particle sizes in the range of 1–150 nm [44]. Biodiesel produced from micro-emulsion processes are able to improve fuel spray characteristics [45].
3) *Pyrolysis:* Pyrolysis is defined as the thermal decomposition of a material at certain temperature when it is exposed to heat through the condensation of gas. Biodiesel Pyrolysis is the process of heating vegetable oil or animal fat in the absence of oxygen. Pyrolysis is a simple process, with less waste and no pollution compared to other processes. The goal of pyrolysis is to optimize biodiesel produced from raw materials with thermal methods [46]. There are previous studies claiming that the pyrolysis of triglycerides is suitable for diesel engines [46][47][48][49][50][51].
4) *Dilution:* Biodiesel fuel dilution can be achieved by mixing it with diesel fuel and ethanol solvent. The dilution process normally reduces viscosity and density of biodiesel. Low viscosity of biodiesel is good for improving engine performance [44]. Dilution with ethanol may increase the combustion characteristics of biodiesel because ethanol has a lower boiling point than biodiesel [34].

### *C. Biodiesel Blend*

Generally, there are two methods commonly used for biodiesel blends that are splash and manifold blending. Splash blending is when a certain amount of pure biodiesel is added to the tank and followed with petroleum diesel, which is added into the same tank with a certain ratio. Mixing of the two fuels will occur naturally. This method is preferred by biodiesel producers because it does not require high cost but sometimes it does not produce a blended mixture as desired. On the other hand, manifold or ratio blending is achieved by loading biodiesel and petroleum diesel into the tank at the same time and using a meter and valve at a common header. This method can deliver a better end product because it gets thoroughly mixed. Since both fuels are blended prior to entering the tank, the mixing problems associated with splash blending are eliminated.

### *D. Biodiesel Properties*

The properties of biodiesel depends on the type of raw materials used [52][53][54][55][56]. Some of these properties include viscosity, density, flash point, cetane number, acid value, oxidation stability, cloud and pour points. Different feedstocks will provide different proportions of biodiesel properties. The following section discusses the basic properties of biodiesel.

1) *Density:* The density of a substance is defined as the weight per unit volume of the material. The density of biodiesel is measured according to EN ISO 3675/12185 and ASTM D1298 [57]. According to this standard, density test should be carried out at 15 °C or 20 °C as the reference temperature [55]. Biodiesel fuels are found to have higher density compared to diesel fuel [58]. The density range of biodiesel fuel is mostly between 830 and 960 kg/m3 depending on the type of feedstock used [59]. Ropkins claimed that denser fuel contains more energy [53]. The weight of the biodiesel molecule is among the factors that contribute to the higher density of biodiesel fuel. The density of a fuel used has influence on the engine performance due to its impact on the injection spray pattern, injection timing and injected fuel amount [60]. Furthermore, denser fuel will have bigger size of fuel droplets [61].

2) *Viscosity:* Viscosity is a term used to describe the measure of fluid resistance to flow due to the internal friction [62]. In diesel engines, viscosity of fuel is a crucial property because it affects fuel injection characteristics and in turn influence the quality of combustion [63]. Fuel with high viscosity would disrupt injection pump operations and cause the engine to lose power. However, too low fuel viscosity can cause leakage through the seal inside the injection pump [64][65]. Generally, the viscosity of biodiesel is higher than petroleum diesel because of its chemical structure and large molecular mass. Biodiesel can be more viscous at low temperatures because viscosity increases when the temperature decreases [57][66]. Kinematic viscosity test of biodiesel can be determined in accordance with ASTM D445 and EN ISO 3104 standards [67].
3) *Flash Point:* The minimum temperature at which fuel will burn when exposed to fire is called fuel flash point. This property is very important in terms of fuel storage, fuel handling and transportation. The biodiesel flash point may vary due to different feedstock used and other factors such as the residual alcohol content and chemical composition [68]. The flashpoint of biodiesel is higher than petroleum diesel, thus making it safer for transport and storage purposes [69][70]. The common standards for flash point measurements are ASTM D93 and EN ISO 3697. The flash point of biodiesel is higher than petroleum diesel, which is more than 150 °C [71].
4) *Cetane Number:* Diesel fuel ignition delay is measured through a Cetane number parameter. This is the time interval between the start of injection and start of combustion of the fuel in the engine cylinder. It is one of the important fuel properties that need to be considered during the selection of methyl esters for biodiesel production process [72]. Normally, higher cetane number fuel will have shorter ignition delay periods. Biodiesel has a higher cetane number than conventional diesel, which results in shorter ignition delays, thereby improving combustion efficiency [73]. In addition, biodiesel from animal fats have higher Cetane number than those biodiesel from vegetable oils [29]. Cetane number can be measured according to ASTM D613/EN ISO 5165 test methods [64].
5) *Calorific Value:* Calorific value is defined as the quantity of heating power generated during combustion under specified conditions. It is an extremely important parameter of fuel, which represents the amount of energy available that can be converted to useful works during the combustion process [74]. Higher calorific value of fuel will contribute to higher engine performance [64]. Based on mass, biodiesel fuel has 12% less calorific value compared to petroleum diesel [75]. The minimum heating value of biodiesel is 35 MJ/kg as prescribed in the EN 14213 standard [76].
6) *Acid Value:* Acid value is defined as the measurement of free fatty acid content in biodiesel. It is defined as the weight in milligrams of potassium hydroxide (KOH) required to neutralize 1 g of fatty acid in a biodiesel sample. Biodiesel possess more acid value compared to conventional diesel. Highly acidic fuels have the potential to cause corrosion in fuel supply systems, especially in fuel injectors [76]. ASTM D664 and EN 14104 standards are used to determine the acid value of biodiesel. Both standards define the maximum levels of acid number for biodiesel as 0.50 mg KOH/g [77].
7) *Cloud and Pour Point:* Cloud point is the temperature where one component of a mixture of liquids begins to solidify on cooling; resulting in visible cloudiness (wax crystals), while pour point is the temperature where fuel ceases to flow or pour. Cloud and pour points are determined using the ASTM D2500 and ASTM D97 procedures respectively [78]. Biodiesel fuels possess higher cloud and pour point values than petroleum diesel [58]. The behaviour of biodiesel during cold weather is an important parameter to be considered; too high cloud and pour point values can easily damage the engine systems at low temperature conditions [71][79]. These obstacles can be solved by blending biodiesel with diesel [59].
8) *Oxidation Stability:* Oxidation stability is a measure of fuel resistance to oxidation or degradation process. It is one of the essential characteristics of biodiesel since it is associated with fuel stability during storage. Oxidation may happen because of the presence of unsaturated fatty acids chain and that immediately react with oxygen once it exposed to air [71]. The quality of biodiesel is assessed through the oxidation stability. Biodiesel is more susceptible to stability degradation as compared to petroleum diesel due to its composition [78]. Oxidation stability test for biodiesel is performed according to the ASTM D7462 method.

### *E. Biodiesel Standards*

There are two main standards established for biodiesel; which are EN 14214 (European) and the ASTM 6751 (American) standards [80]. The requirements specified in these standards are almost similar, only slightly different on the desired application and the selection of test methods. Both standards specify the test methods and specifications of the pure biodiesel fuel and its blends.

### *F. Advantages of Biodiesel*

Biodiesel is classified as one of the alternative energy which has rapidly gained interest and increased in commercial availability. It has an excellent quality and offers some unique features as compared with other fuels. Among the features and benefits of biodiesel are as follows:

1) *Renewable* – Biodiesel, which is processed from plant and animal sources, is always renewable, unlike fossil fuels which will deplete.
2) *Versatile* – Biodiesel can be obtained from a wide range of feed stocks depending on the geographical location.
3) *Easy to Use* – Biodiesel can be applied in diesel engines as 100% or blend fuels without engine modification.
4) *Lower Emissions* – Biodiesel helps to reduce harmful gases from the engine. Some studies claim that 78% of greenhouse gases can be deducted using biodiesel [81].
5) *Biodegradable and Non-toxic* – Biodiesel has minimal environmental impact and is user friendly. It contains virtually no sulphur or aromatics. Biodiesel degrades faster than petroleum diesel. Flash point for biodiesel is higher than petroleum diesel, making biodiesel less flammable, safer to handle and easier to store.
6) *Higher Lubricity* – Biodiesel is a natural lubricant. Blending the biodiesel fuel with petroleum diesel has proven to increase lubrication, reduce engine wear and extend engine life cycle [82].
7) *Positive Energy Balance* – Although biodiesel consume fossil fuels in their production and transportation, but it has a very favourable energy balance [83].
8) *Less Dependence on Fossil Fuels* – The dependence on fossil fuels can be reduced with application of biodiesel although it cannot replace completely.

### *G. Limitations of Biodiesel*

Along with the many benefits discussed earlier, biodiesel also has some limitations and drawbacks as follows:

1) Higher viscosity and density – Higher viscosity and density value of biodiesel can sometimes create problems to the fuel injection system. A study by Tesfa et al. showed that it affects the operation of fuel filters and reduces fuel pump performance in compression ignition engines [84].
2) Lower energy content – Biodiesel has slightly less energy content than petroleum diesel. Some researchers reported that engine power was slightly lower with application of biodiesel [27][85][86]. Thus this will increase fuel consumption about 2–10% [39].
3) Higher cloud and pour point – Higher cloud and pour point is associated in biodiesel [58]. Solidification of biodiesel in cold weather can cause clogged filter and fuel lines that lead to engine system damage.
4) Higher NOx – The NOx emissions of biodiesel fuel is about 10% higher than petroleum diesel depending on the engine tuning state. Nitrogen Oxide is one of the gasses used in ozone formation and can cause acid rain once it gets dissolved in the atmospheric moisture.
5) Material compatibility – Biodiesel tends to deteriorate natural rubber materials such as hoses and seals. Biodiesel oxidation process can create catalytic effects on some metal [87].
6) Engine cold start – Biodiesel requires special handling in cold weather. Broatch et al. stated that engine operated with biodiesel have difficulty to start in cold weather and this can be overcome by fuel blending [88].
7) Variation in quality – Biodiesel has different end product quality based on the feedstock used.
8) Competition for resources – The use of human food resources as biodiesel feedstock has caused food crisis in some countries.
9) High cost – At present, the biodiesel costs are slightly higher than petroleum diesel.

## III. LITERATURE REVIEW

*F. Aydın & H. Öğüt*. [1] In this research the biodiesel was produced from safflower seeds by converting the raw oil obtained through dampening them via the rolling process, roasting at 90 0C and pressing into Safflower Oil Methyl Esther (Safflower Biodiesel) using the trans-esterification method. Experimental fuels were obtained in the forms of $D_{100}$, $B_{2.5}M_{2.5}2.5D_{95}$, $B_5M_5 2.5D_{90}$, $B_5M_{2.5}2.5D_{92.5}$, and $B_{2.5}M_5 2.5D_{92.5}$
by mixing the biodiesel fuel obtained from safflower with diesel fuel, adding bio-ethanol at the rates of 2.5 % and 5 %, and volumetrically in inverse ratio. Tests were conducted to determine the fuel properties of the mixed fuels obtained and the diesel fuel, their kinematic viscosity, density, water content, pH level, caloric value, flash point, clouding, pour and freezing points, copper bar corrosion test, iodine number, CFPP (Cold Filter Plugging Point) test and cetane number.

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Moreover, the mixtures obtained and the diesel fuel were tried and examined in a water-cooled, four-stroke, single cylinder diesel engine that had a direct injection fuel system. As a result of the experiments, performance characteristics of the test engine were obtained. Exhaust emission values (CO, CO2, HC, O2, SO2, NOx) were obtained from the exhaust stack of the test engine using the probe of the gas analysis device.

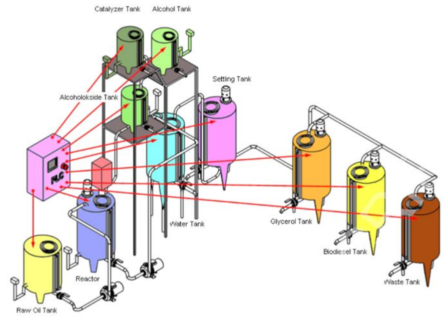

Fig. 7. Biodiesel production and programmable logic controller (PLC) facility. [21]

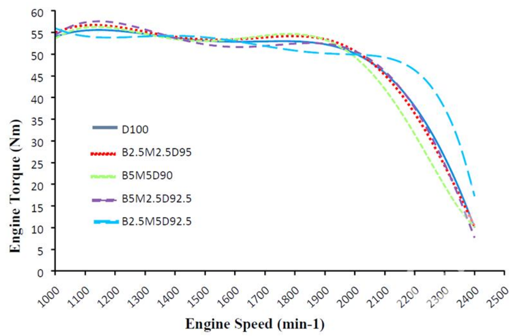


Fig. 8. Torque values of fuels depending on the engine speed. [21]

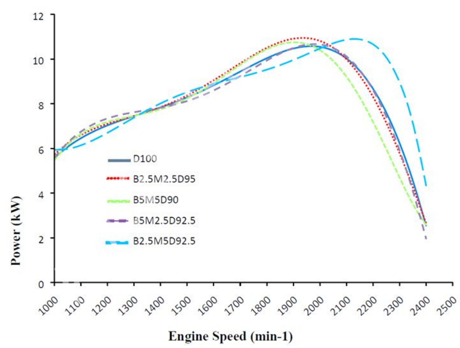


Fig. 9. Effective power values of fuels depending on engine speed. [21]

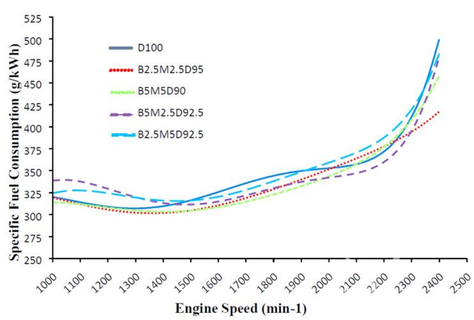


Fig. 10. Specific fuel consumption values of fuels depending on engine speed. [21]

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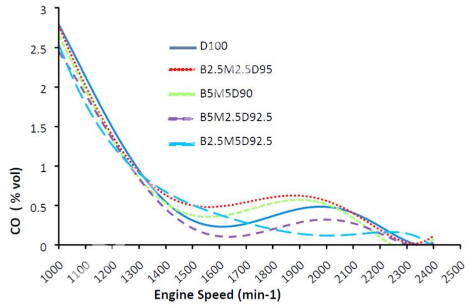



Fig. 11. CO emission values of fuels depending on engine speed. [21]

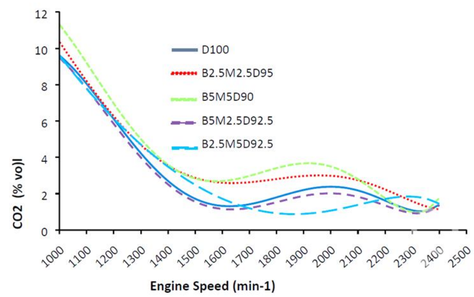



Fig. 12. CO2 emission values of the fuels depending on engine speed. [21]

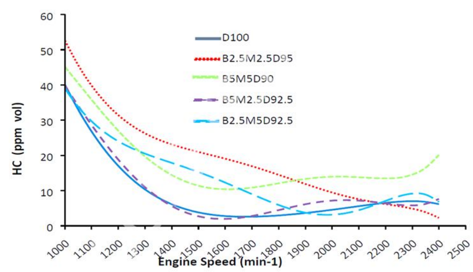



Fig. 13. HC emission values of the fuels depending on engine speed. [21]

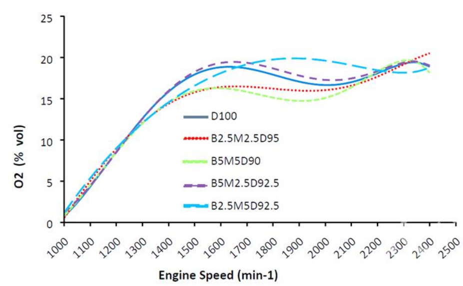



Fig. 14. O2 emission values of the fuels depending on engine speed. [21]

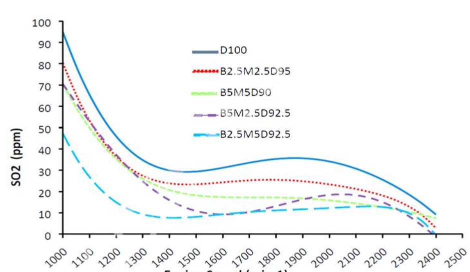



Fig. 15. SO2 emission values of fuels depending on engine speed. [21]

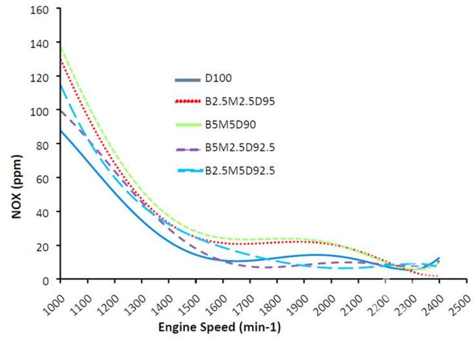



Fig. 16. NOx emission values of fuels depending on engine speed. [21]

Table 3. Technical specifications of the test engine. [22]

| Super Star Engine | Units | Value |
|---|---|---|
| Working principle | --- | 4 stroke, direct injection |
| Cylinder Bore | mm | 108 |
| Stroke | mm | 100 |
| Cylinder Number | ---- | 1 |
| Cylinder Volume | lt | 0,92 |
| Compression Ratio | --- | 17:1 |
| Maximum Power | HP | 15 (2100 $min^{-1}$) |
| Maximum Torque | Nm | 60 (1100 $min^{-1}$) |
| Maximum Speed | $min^{-1}$ | 2600 |
| Cooling System | --- | Water Cooling |
| Injection Advance | $kg/cm^2$ | 175 |
| Injection Advance | derece | 28-35 ° (Crank Shaft angle) |

Table 4. Technical specifications of the hydraulic dynamometer. [23]

| Type | Units | Value |
|---|---|---|
| Braking Torque Range | Nm | 0-1700 |
| Operating Speed | $min^{-1}$ | 0-7500 |
| Trunk Weight | kgf | 45 |
| Total Weight | kgf | 110 |
| Trunk Diameter | mm | 350 |
| Torque Length | mm | 350 |

Table 5. Specifications of Mobydic 5000 exhaust emission analyzer device. [24]

| Mobydic 5000 | Units | Value |
|---|---|---|
| CO | % Vol | 0-10 |
| $CO_2$ | % Vol | 0-20 |
| HC | ppm Vol | 0-10000 |
| $O_2$ | % Vol | 0-21 |
| $SO_2$ | ppm | 0-500 |
| $NO_x$ | ppm | 0-5000 |
| Lambda (λ) | --- | 0-5 |
| Response Time | s | < 10 |
| Measure Flow | lt/min | 05-7 |

Table 6. Names of the fuels and their volumetric constitution percentages. [21]

| Fuels | Diesel | Bioethanol | Biodiesel |
|---|---|---|---|
| $D_{100}$ | 100 | 0 | 0 |
| $B_{2.5}M_{2.5}D_{95}$ | 95 | 2.5 | 2.5 |
| $B_5M_5D_{90}$ | 90 | 5 | 5 |
| $B_5M_{2.5}D_{92.5}$ | 92.5 | 5 | 2.5 |
| $B_{2.5}M_5D_{92.5}$ | 92.5 | 2.5 | 5 |

In this particular research, experiment was conducted on a single-cylinder, four-stroke and water cooled diesel engine, the biodiesel fuel which is transformed from safflower oil through the transesterification method was combined volumetrically with 2.5% and 5% diesel fuel with bioethanol addition and also in reverse proportion were used. In experiments, the fuels obtained in the form of $D_{100}$, $B_{2.5}M_{2.5}2.5D_{95}$, $B_5M_52.5D_{90}$,

$B_5M_{2.5}2.5D_{92.5}$, and $B_{2.5}M_52.5D_{92.5}$ are used. The data obtained by searching the features of that fuels, engine performances and exhaust emissions were presented by following graphics. After the experiments, the optimum mixture of engine fuel is $D_{100}$ if the evaluation is according to performance and $B_{2.5}M_52.5D_{92.5}$ fuel if the evaluation is according to emissions.

*K.A. Abed, M.S. Gad, A.K. El Morsi, M.M. Sayed & S. Abu Elyazeed.* [2] Energy production is heavily dependent on fossil fuels that are not only diminishing, but also are considered the main cause of harmful emissions and global warming. Therefore using vegetable oils such as Jatropha, palm, algae and waste cooking oils as alternative fuels in diesel engines has drawn a great attention. Biodiesel from Jatropha, palm, algae and waste cooking oils has been produced using the transesterification process. Biodiesel from different feedstock is mixed with diesel oil in different proportions e.g. B10 and B20. Biodiesel physical and chemical properties are measured according to ASTM standards. A ‘‘single cylinder diesel engine” is employed as the test engine in the present work. Exhaust emissions such as CO, CO2, NOx, HC, and smoke are measured and compared with diesel oil. CO, HC, CO2 and smoke emissions are lower for biodiesel mixtures B10 and B20 (Jatropha, algae and palm) compared ‘‘to diesel fuel”. CO2 emissions from biodiesel blends B10 and B20 produced from waste cooking oil are higher compared to diesel fuel. NOx emissions from all biodiesel mixtures B10 and B20 increases than diesel fuel for all biodiesel blend B10 and B20.

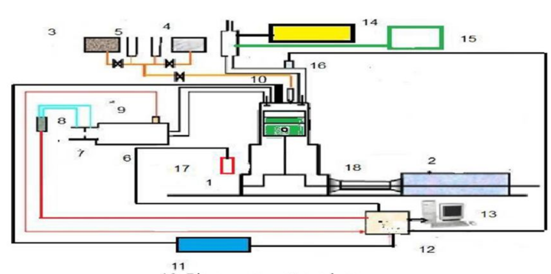
Table 7. Diesel engine technical specifications, [25]

| Engine parameters | Specification |
|---|---|
| Engine model | DEUTZ F1L511 |
| Number of cylinder | 1 |
| Bore | 100 mm |
| Stroke | 105 mm |
| Displacement | 824 $cm^3$ |
| Rated power | 5.775/7.7 kW/hp |
| Rated speed | 1500 rpm |
| Injection point BTDC | 24 °C.A |
| Type of Injection | Direct injection |
| Type of cooling | Air cooling |

Table 8. Physical and chemical properties of biodiesel blends as compared to diesel fuel according to ASTM standards.

Physical and chemical properties of biodiesel blends as compared to diesel fuel according to ASTM standards.

| Biodiesel Blends | Density at 15.56 °C, $kg/m^3$ ASTM D-4052 | Kinematic Viscosity at 40 °C, $mm^2/s$(cst) ASTM D-445 | Flash Point, °C ASTM D-93 | Heating Value, kJ/kg ASTM D-224 | Cetane Number ASTM D-13 |
|---|---|---|---|---|---|
| Diesel oil | 829 | 2.8 | 75 | 42,000 | 45 |
| Jatropha biodiesel (B20) | 845 | 5.2 | 88 | 40,000 | 53 |
| Jatropha biodiesel (B10) | 835 | 3.5 | 83 | 41,500 | 48 |
| Palm biodiesel (B20) | 835 | 2.82 | 71.5 | 41,206 | 60 |
| Palm biodiesel (B10) | 833 | 2.49 | 69 | 41,780 | 51 |
| WCO biodiesel (B20) | 855.8 | 2.98 | 60 | 43,953 | 60.71 |
| WCO biodiesel (B10) | 856.4 | 2.85 | 69 | 47,021 | 59.53 |
| Algae biodiesel (B20) | 843.8 | 4.8 | 90 | 37,866 | 70 |
| Algae biodiesel (B10) | 840.5 | 3.31 | 83 | 40,017 | 56 |



1. Diesel engine
2. AC generator
3. Diesel tank
4. Fuel tank
5. Burette
6. Air surge tank
7. Orifice
8. Pressure differential meter
9. Intake air temperature thermocouple
10. Piezo pressure transducer
11. Charge amplifier
12. Data acquisition card
13. Personal computer
14. Exhaust gas analyzer
15. Smoke meter
16. Exhaust gas temp. thermocouple
17. Proximity switch
18. Cardin shaft

Fig. 17. Schematic diagram of a diesel test engine [25]

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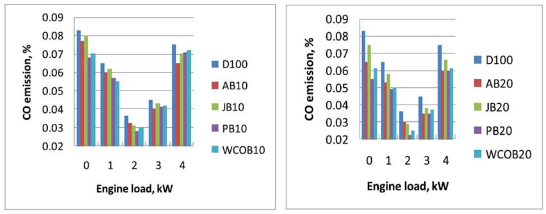


Fig. 18. Variation of CO emission with engine load for biodiesel blends.

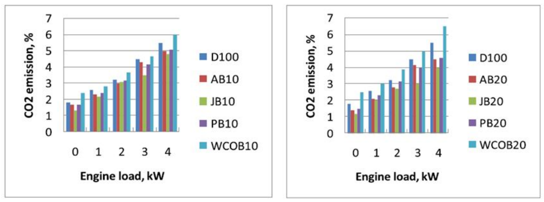


Fig. 19. Variation of CO2 emission with engine load for biodiesel blends.

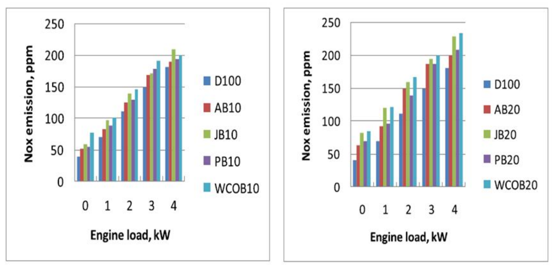


Fig. 20. Variation of NOx emission with engine load for biodiesel blends.

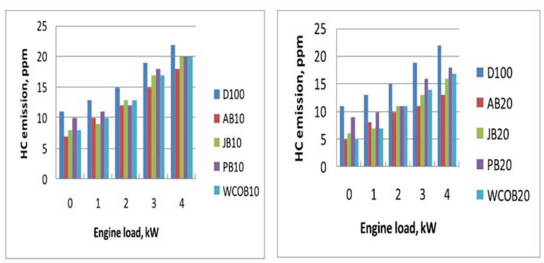


Fig. 21. Variation of HC emission with engine load for biodiesel blends.

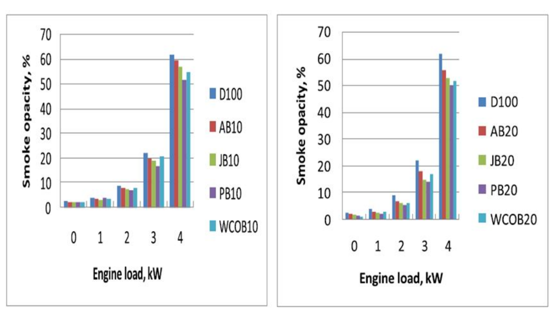


Fig. 22. Variation of smoke emission with engine load for biodiesel blends.

A single cylinder diesel engine was run using different sources of biodiesel such as Jatropha, palm, algae and waste cooking oil biodiesel blends B10 and B20. Exhaust emissions were examined at different engine loads of 1, 2, 3 and 4 kW and a constant engine speed of 1500 rpm. Exhaust emissions such as CO, CO2, NOx, HC and smoke emissions were examined and compared with diesel fuel.

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The following conclusions could be summarized as:
1) CO, HC and smoke emissions were lower for the tested four biodiesel types (Jatropha, algae and palm and waste cooking oil) mixtures B10 and B20 as compared to diesel fuel.
2) CO2 emissions from biodiesel blends B10 and B20 produced from waste cooking oil were higher compared to diesel fuel and the other biodiesel fuel.
3) NOx emissions; from biodiesel mixtures, B10 and B20 increased compared with diesel fuel for the examined biodiesel blends.
4) The obtained results were compared with previous results of other authors. This comparison showed accepted conformity.

*Yuvarajan Devarajan, Dineshbabu Munuswamy, Beemkumar Nagappan & Ganesan Subbiah.* [3] This work examines the effect of butanol as an oxygenated additive to lower carbon monoxide, smoke, nitrogen oxide and hydrocarbon emissions and to improve the performance aspects of Calophyllum inophyllum (Punnai) biodiesel. Singlecylinder, oil-cooled compression ignition engines are employed in this work. Neat Punnai biodiesel (P100) is blended with butanol at 10% and 20% by volume and labelled as B10P90 and B20P80, respectively. Methanol and alkaline catalyst (KOH) were used for the transesterification process for biodiesel production. The transesterification technique yielded 88% biodiesel from raw Punnai oil. Engine tests resulted in lower CO, smoke, NOx and HC emissions when fuelled with both butanol blends when compared to P100. In addition, BSFC (brake-specific fuel consumption) reduced and BTE (brake thermal efficiency) increased with the inclusion of butanol blends (B10 and B20) to neat Punnai biodiesel.

Table 9. Properties of tested fuels

| Properties | P100 | B10P90 | B20P80 | Diesel | Allowable limit | Method |
|---|---|---|---|---|---|---|
| Density @ 15 °C, gm/cc | 0.77 | 0.75 | 0.73 | 0.75 | 0.65–0.86 | ASTM D4052 |
| Kinematic viscosity @40 °C, $mm^2/s$ | 4.8 | 4.5 | 4.2 | 2.7 | 1.9–6.5 | ASTM D445 |
| Calorific value, kJ/kg | 37,698 | 38,125 | 38,623 | 42,500 | > 15,000 | ASTM D240 |
| Flash point, °C | 154 | 155 | 157 | 45 | > 40 | ASTM D824 |
| Cetane index, CI | 54 | 55 | 55 | 47 | > 47 | ASTM D976 |

Table 10. Specification of the experimental setup

| | |
|---|---|
| Make | Kirloskar |
| Stroke | 4 |
| Cylinder | Single |
| Rated power | 5.5 kW |
| Rated speed | 1500 rpm |
| Bore diameter (D) | 87.5 mm |
| Stroke (L) | 110 mm |
| Compression ratio | 17.5:1 |
| Injection timing | 17°bTDC |

Fig. 23. Photographic view of the experimental setup

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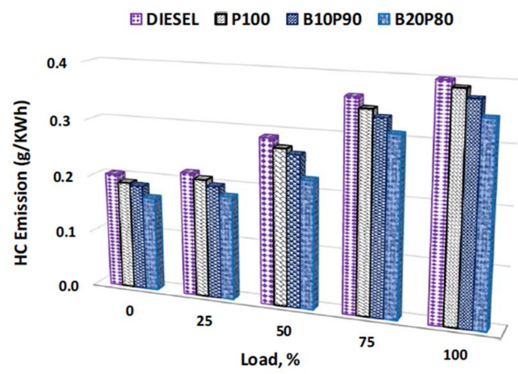


Fig. 24. Variation in HC emissions with load

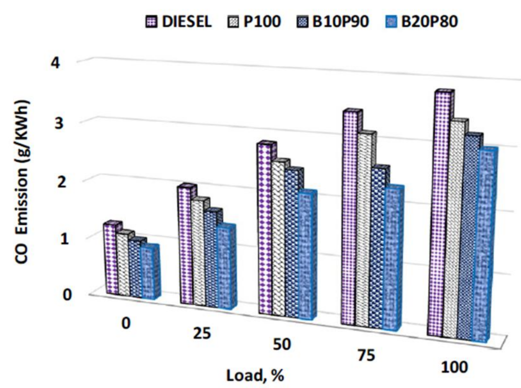


Fig. 25. Variation in CO emissions with load

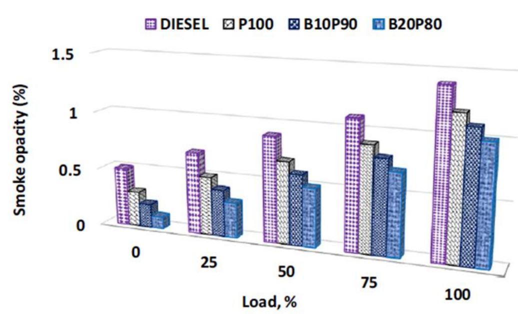


Fig. 26. Variation in smoke opacity with load

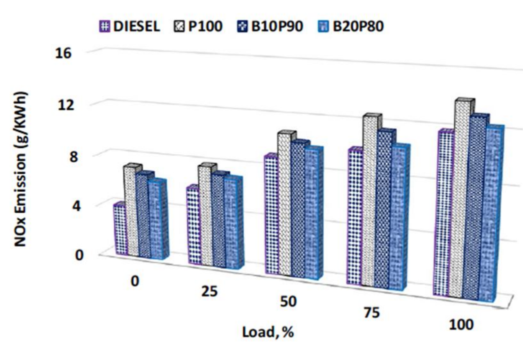


Fig. 27. Variation in NOx emissions with load

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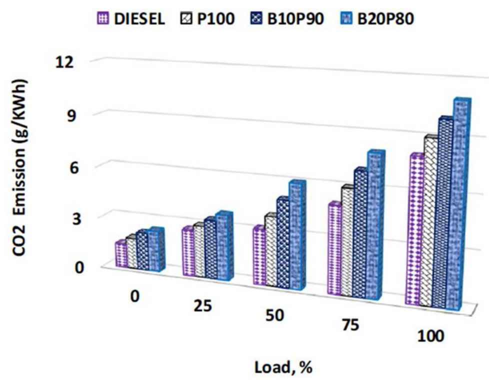


Fig. 28. Variation in CO2 emissions with load

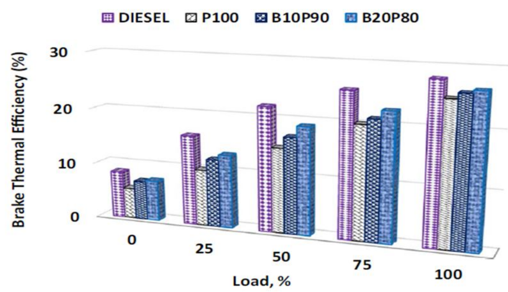


Fig. 29. Variation in BTE with load

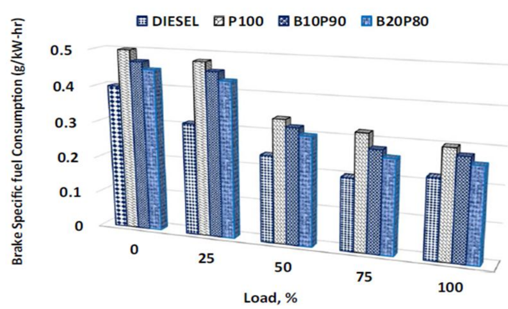


Fig. 30. Variation in BSFC with load

The consequence of using butanol as a higher alcohol up to 20% in volume on the emission and performance pattern of Punnai biodiesel/butanol blends was investigated.

The following conclusions arise from this study.

*a)* B10P90, B20P80 blends showed the potential results of significant physicochemical properties.
*b)* Smoke opacity decreased for B10P90 with the reduction being even greater for B20P80. Smoke opacity hardly increased due to the dominance of oxygenated conditions for B10P90, B20P80 blends.
*c)* NOx emissions for B10P90, B20P80 blends displayed comparable behaviours under all conditions. NOx emissions lowered with an increase in butanol percentage in the blends.
*d)* The HC emissions were lower for B10P90, B20P80 than P100 under all conditions. This is because of their higher cetane number.
*e)* Increasing butanol content in the P100 improved CO emissions. Butanol has a high heat of vaporization, which enhances the oxidation reaction.
*f)* The BTE of test fuels is: diesel > B20P80 > B10P90 > P100.
*g)* The BSFC of test fuels is: diesel < B20P80 < B10P90 < P100.
*h)* B20P80 demonstrated better emissions and performance patterns among all tested fuels at testing conditions.

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*M. Vijayakumar & P. C. Mukesh Kumar.* [4] Many research works are being carried out to enhance the performances of internal combustion engines to meet out the current energy demand and to reduce the emission with the alternate fuels. In this experimental investigation, the performances and emission characteristics of compression ignition engine were studied by using electronic fuel fumigation method. The lemongrass biodiesel blended with 20% of biodiesel and 80% of diesel (B20) was used as primary fuel and 1-propanol is used as secondary fuel for fumigation. The Kirlosker, single cylinder four stroke, direct injection, and water cooled engine was taken for conduction of tests. The speed of the engine is maintained constant and the engine load was varied in the range of 0%e100% and fumigation injection timing is varied in the range of 1 ms, 3 ms and 5 ms to study the engine parameters. It is studied that the brake thermal efficiency of fumigation fuel at 5 ms is 6.7% higher than diesel and at 3 ms is 3.1% higher than the diesel fuel at 100% load. The specific fuel consumption at 5 ms is 16 % higher than the reference diesel fuel. The 5 ms 1-propanol fumigation produces the maximum HC and CO with minimum smoke and NO because of lower combustion temperature and incomplete combustion. The SFC of fumigation fuel at 5 ms is 18.6% higher than diesel at 100% load and 23 % higher than diesel at 80% load. The net heat release of fumigation fuel (1-propanol) at 1 ms produces 2% higher than the reference diesel at crank angle of 360. The fumigation fuel (1-propanol) injection timing at 5 ms produces more percentage of CO at different load conditions. It is also studied that the minimum level of CO is 0.38 % at 40% load condition. The fumigation fuel at 5 ms injection timing produces minimum percentage of $CO_2$ at different load conditions. The minimum level of $CO_2$ is 9.3% at 80% load condition. The other emissions are also analyzed and recorded the levels based on the load condition.

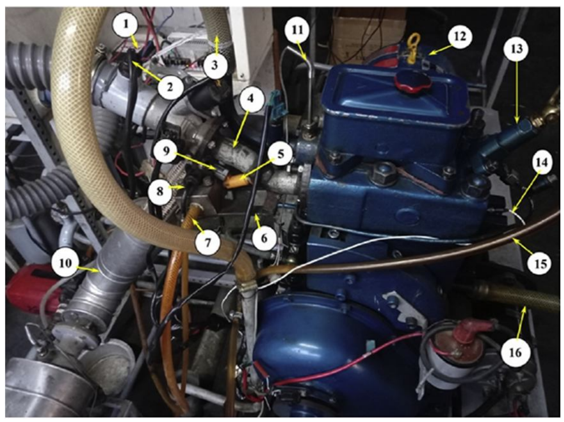

Fig. 31. Photograph of the experimental setup. 1. ECU, 2. Air flow measuring sensor, 3. Engine cooling water outlet, 4. Inlet Manifold, 5. Electronic fumigation injector, 6. Fumigation injector bed, 7. Fumigation fuel inlet, 8. Fumigation fuel return line, 9. ECU signal connections, 10. Exhaust gas pipe line, 11. Cooling water temperature sensor (out), 12. Eddy current dynamometer, 13. Primary fuel injector, 14. Pressure sensor, 15. Primary fuel return line, 16. Engine cooling water inlet

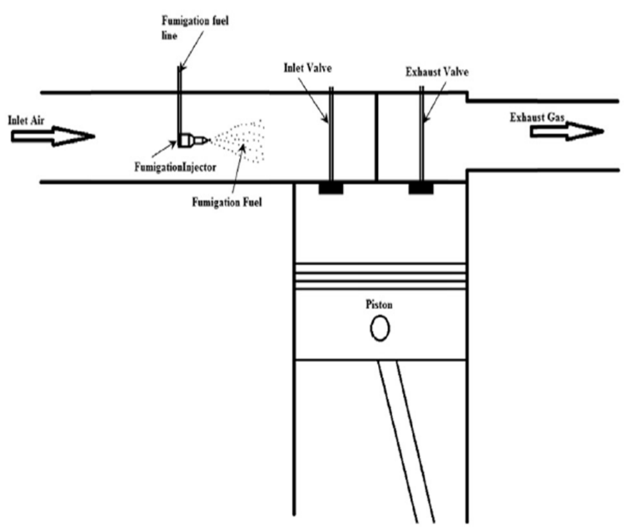


Fig. 32. Schematic diagram of fumigation of fuel.

Table 11. Engine specifications.

| Particulars | Specifications |
|---|---|
| Manufacturer | Kirloskar |
| Type | Four stroke, single cylinder, Direct injection, VCR engine |
| Bore | 87 mm |
| Stroke | 110 mm |
| Compression ratio | 18:1 |
| Engine speed | 1500 RPM |
| Fuel injection pressure | 210 bar |
| Injection timing | 23° BTDC |
| Cooling system | Water cooled engine |

Table 12. Fuel properties.

| Properties | Diesel | Lemon Grass | 1-Propanol |
|---|---|---|---|
| Viscosity at 40 °C Cst | 3.25 | 4.18 | 2.8 |
| Density kg/m$^3$ at 15 °C | 835 | 984 | 803 |
| Cetane Number | 50 | 38 | 15 |
| Flash Point | >52 °C | 150 °C | 22 °C |
| Auto Ignition Temperature °C | >250 °C | - | 371 |
| Heating Value MJ/kg | 44.8 | 36.27 | 30.68 |

Table 13. Uncertainty and measuring range of gas analyzer and smoke meter.

| S.No | Parameters | Accuracy |
|---|---|---|
| 1 | Airflow | 0.6481 % |
| 2 | Fuel flow | 0.7319 % |
| 3 | Engine Power | 0.9434 % |
| 4 | Exhaust gas Temperature | ±5 °C |
| 5 | Viscosity | 0.7 % |
| 6 | Cylinder Pressure | 0.61644 % |
| 7 | Brake power | 1.087% |
| 8 | Fuel consumption | 0.25% |
| 9 | Friction power | 0.25% |
| 10 | Brake thermal efficiency | 1.116% |
| 11 | CO | ±0.03 % |
| 12 | $CO_2$ | ±0.5 % |
| 13 | HC | ±10 ppm |
| 14 | $O_2$ | ±5 % |
| 15 | NO | ±10 ppm |
| 16 | SMOKE | ±1 % |

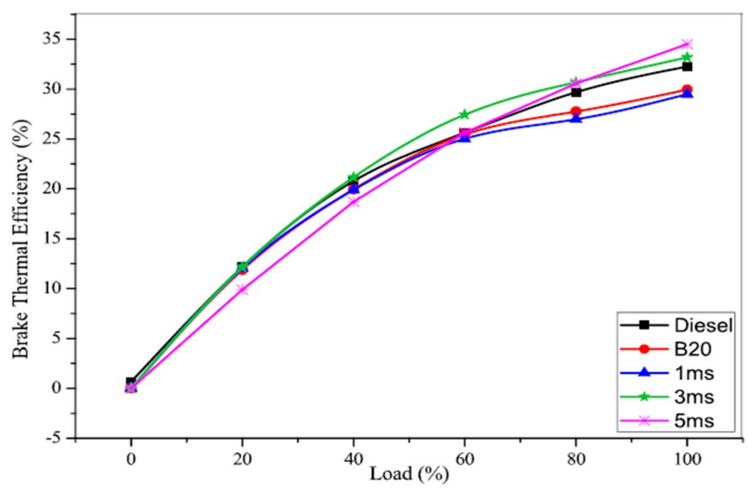


Fig. 33. Variation of Brake Thermal Efficiency with load.

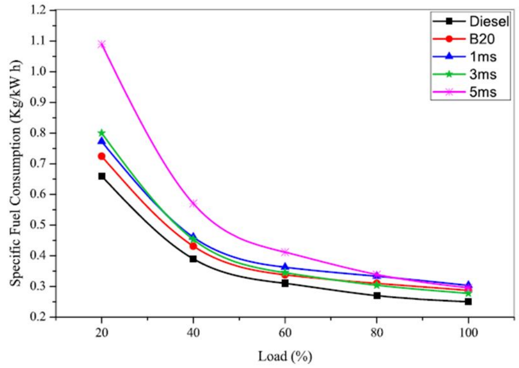


Fig. 34. Variation of Specific Fuel Consumption with load.

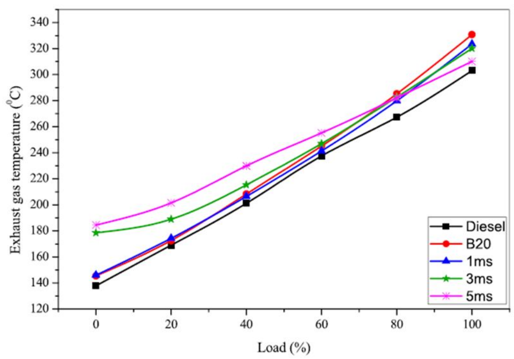


Fig. 35. Exhaust gas temperature vs load.

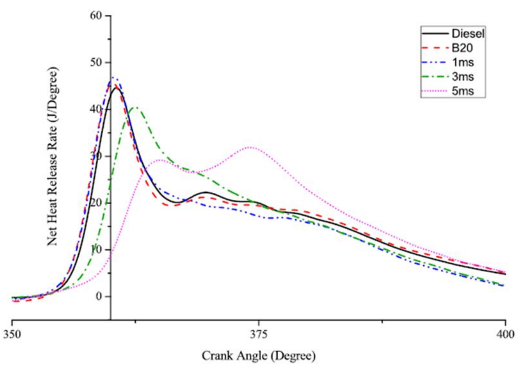


Fig. 36. Net heat release rate with crank angle at 80% load.

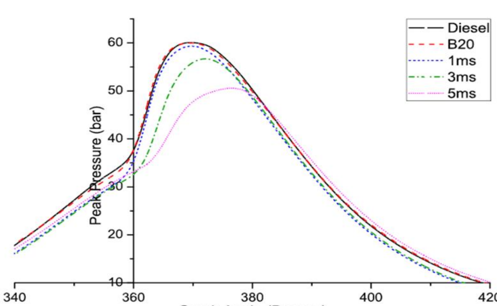


Fig. 37. Effect of cylinder peak pressure on fumigation timing at 80% load.

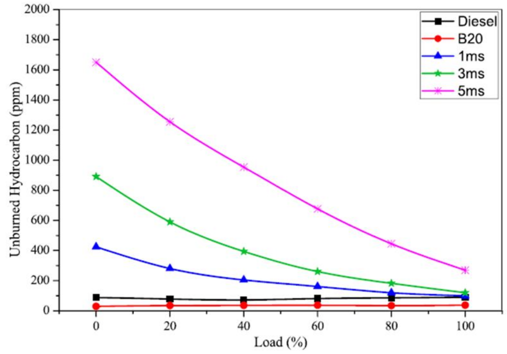


Fig. 38. Variation of exhaust hydrocarbon with load.

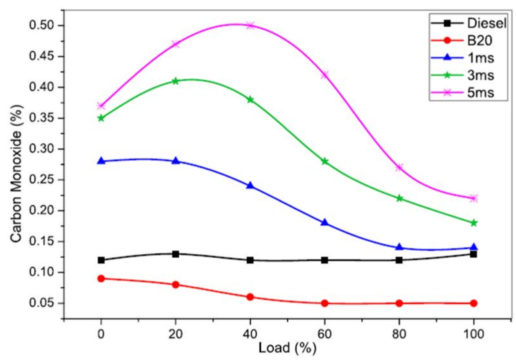


Fig. 39. Variation of carbon monoxide emission with load.

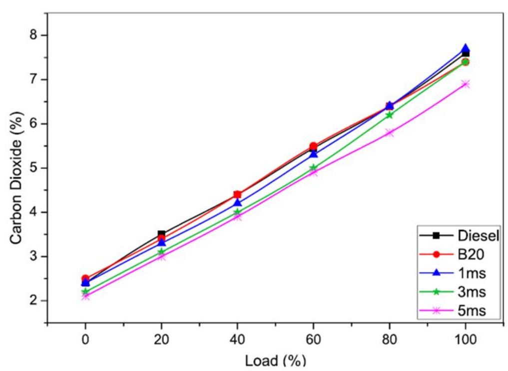


Fig. 40. Exhaust Carbon Dioxide vs loads.

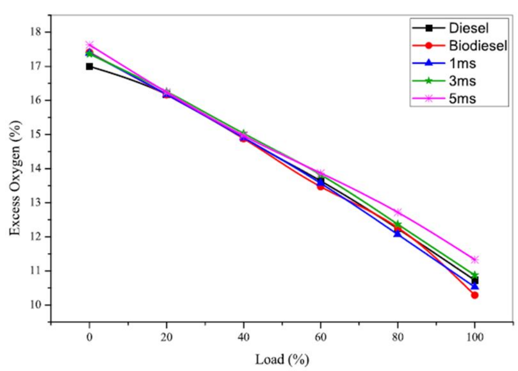


Fig. 41. Variation of excess oxygen with load.

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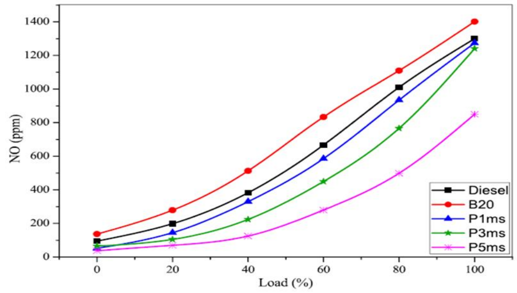


Fig. 42. Variation of nitrous oxide with different percentage of loads.

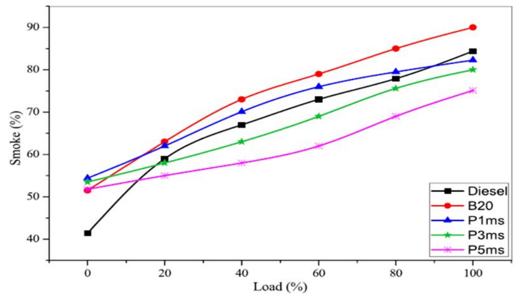


Fig. 43. Smoke particulate with loads.

In this experimental analysis, the performance and emission characteristics of single cylinder four stroke diesel engine handling lemongrass biodiesel blended with 20% of biodiesel and 80% of diesel (B20) as primary fuel and 1-propanol as secondary fuel for fumigation were studied with different load conditions and at different fumigation injection timings. The following are the observations made out of this experimental work:

The brake thermal efficiency of fumigation fuel at 5 ms is 6.7% higher than diesel and at 3 ms is 3.1% higher than the diesel fuel at 100% load. The SFC of fumigation fuel at 5 ms is 18.6% higher than diesel at 100% load and 23 % higher than diesel at 80% load. The B20 blend gives 6% and 9.15% higher exhaust temperature than the diesel at 80% and 100% load respectively. The net heat release of fumigation fuel (1- propanol) at 1 ms produces 2% higher than the reference diesel at crank angle of 360. The fumigation fuel (1-propanol) injection timing at 5 ms produces more percentage of CO at different load conditions. Also studied that the minimum level of CO is 0.38 % at 40% load condition. The NO level is 34.61% lower than the diesel at 100% load condition. The fumigation fuel at 5 ms injection timing produces minimum percentage of CO2 at different load conditions. The minimum level of CO2 is 9.3% at 80% load condition. The exhaust of fumigation fuel at 5 ms injection timing gives maximum excess oxygen percentage at different load conditions. The excess oxygen of fumigation fuel at 1 ms level is 4.1% lower than the diesel at 100% load condition. Therefore it is concluded that the fumigation effect on engine performance and emissions gives considerable favorable outcome at different injection timings and at 80%e100% load condition. The future work is required to optimize the fumigation fuel injection timing for optimum engine performance and reduced emissions.

*C.W. Mohd Noora, M.M. Noora & R. Mamata.* [5] Transportation and shipping activities are major contributor to air pollution at sea where most of it occurs as a result of exhaust emissions from ships. Stringent emission limitations enforced by the International Maritime Organization have hastened the need to find a new alternative fuel for marine diesel engines. Thus, biodiesel fuel was chosen as one of the environmentally friendly alternative energy that can reduce ship toxic gas emissions and at the same time reduces dependence on petroleum-based fuels. Therefore, the purpose of this paper is to provide a comprehensive review of biodiesel as an alternative fuel for marine diesel engine applications. This review covers the biodiesel fuel background, engine performance, history, recent progress, engine warranty, issues, challenges, and possible solutions on using biodiesel for marine applications. A significant number of literatures from indexed journals were cited accordingly. The results of previous studies had shown that the use of biodiesel would mostly increase the amount of brake specific fuel consumption and nitrogen oxide gas while conversely reducing other toxic gas emissions. Although a number of issues and challenges arise, most marine engine manufacturers give conditional warranty against the use of biodiesel in the engines. The study concluded that biodiesel and its blends have a bright future in the marine sector, provided some of the highlighted issues can be solved.

Table 14. Marine fuel type and grades [26]

| Fuel type | Fuel grades | Common industry name |
|---|---|---|
| Distillate | DMX, DMA, DMB, DMZ | Gas oil or marine gas oil, marine diesel oil |
| Intermediate | IFO 180, 380 | Intermediate fuel oil |
| Residual | RMA-RMK | Fuel oil or residual fuel oil |

Table 15. Properties comparison of biodiesel, automotive and marine fuels [26]

| Property | Biodiesel EN14214 | Automotive diesel EN590 | Marine diesel ISO 8217 | Heavy fuel oil ISO 8217 |
|---|---|---|---|---|
| Density/15 °C, kg/m$^3$ | 860–900 | 820–845 | < 900 | 975–1010 |
| Viscosity/ 40 °C, cSt | 3.5–5.0 | 2.0–4.5 | < 11 | < 700/50 °C |
| Flashpoint | > 120 | > 55 | > 60 | > 60 |
| Cetane no. | > 51 | > 51 | > 35 | > 20 |
| Ash content, % | < 0.01 | < 0.01 | < 0.01 | < 0.2 |
| Water content, ppm | < 500 | < 200 | < 300 | < 5 000 |
| Acid no. (TAN) | < 0.5 | – | – | – |
| Sulphur, ppm | < 10 | < 350 | < 200,000 | < 50,000 |
| Calorific value, MJ/kg | 37.5 | 43 | 42 | 40 |

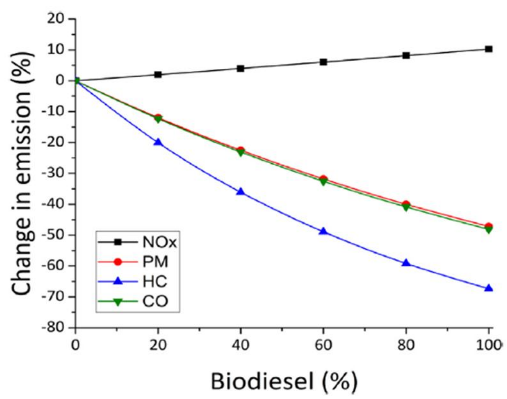


Fig. 44. Relationship between the percentage of biodiesel and percentage change in emissions [31]

The use of marine fuels blended with these biodiesels can be considered as the proper way to reduce air pollution at sea and simultaneously meet IMO regulations. Most marine engine makers are aware of the biodiesel advantages by providing conditional warranty, provided the biodiesel meet the standards of ASTM D6751 or EN14214. Therefore, effective strategies and potential solutions have been proposed in the previous section to realize the goal of this alternative fuel use in the marine industry. Furthermore, official mandate by the government and international bodies such as IMO is able to encourage and promote the application of biodiesel in the marine industry.

## IV. CONCLUSION

Outcome of the previous studies have indicated that biodiesel fuel is suitable for use as an alternative fuel for marine engine applications. Many reports have revealed that alternative fuels derived from vegetable oil and animal fats were found to be environmentally friendly, renewable, non-toxic, biodegradable, sulphur free and aromatic. Biodiesel typically contains slightly low energy as compared to petroleum diesel; however, it also contains no sulphur and contributes to better environmental conditions. At present the average percentage of allowable biodiesel is not more than 20%, although there are a handful of manufacturers that allow the use of B100. Despite the fact that biodiesel has a lot of advantages, there are some obstacles that arise, such as fuel stability, higher production and feedstock costs, material compatibility & cold flow properties. Barriers to production costs and fuel economy can be mitigated by the use of a new source of feedstock from second and third generation biodiesel. Research on new sources such as algae & waste oil is seen to have grown rapidly lately. The role of biodiesel is not to replace the existing fossil fuel, but more towards the establishing of balance energy policy that could benefit the international community. Last but not least, the authors believe that biodiesel has a bright future as a green alternative energy for diesel engine applications.

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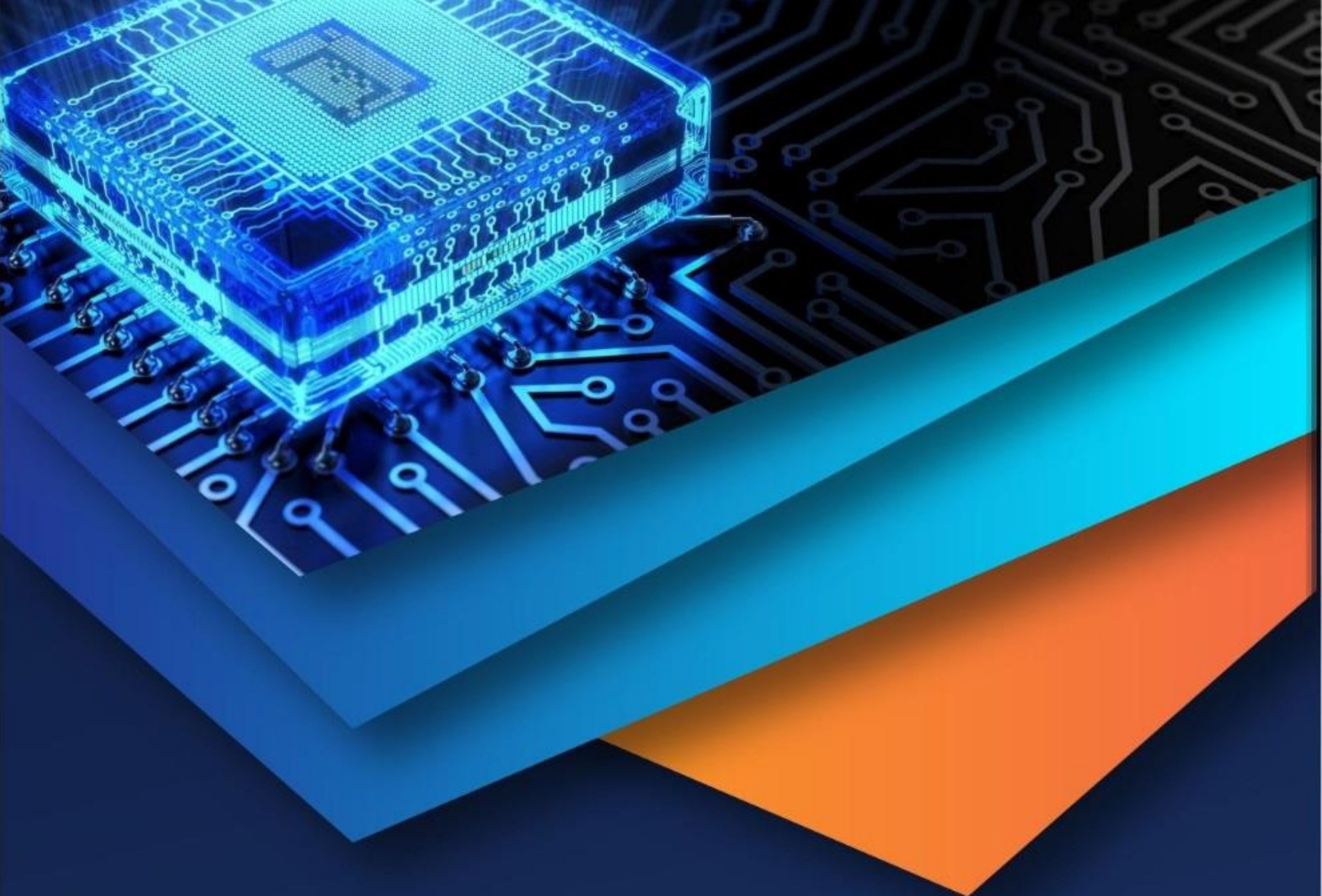


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