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The Assessment Of Biodiesel Exhaust And Health Effects: A Technical Perspective

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Abstract
The biodiesel is one of the promising alternatives for blending in diesel fuel. It reduces the dependence on diesel as well as reduces the CO_2, VOC and CO emissions accordingly. The NO_X emissions are increasing which affect the global warming. The optimum composition of biodiesel blend is 20% for without any change in diesel engine. But the emissions of diesel fuel mostly due to transportation sector are affected the human health as well. The dizziness, lungs problem/asthma, cancer, skin lesions and other symptoms have been generated due to high transportation emission pollution.
Keyword

Nomenclature:

B0	0 % bio diesel blended diesel	NOx	Nitrus Oxide
B20	20% bio diesel blended diesel	PM	Particulate matter
BMEP	Brake Mean Effective Pressure	PPM	Part per million
CC	Catalytic converter	RBF	Reformulated biodiesel fuel
CeO_2	Cerium(IV) oxide	SFA	Saturated fatty acids
CO	Carbon Monoxide	SLSD	Super-low sulfur diesel
CO_2	Carbon di oxide	SNCR	Selective Non-Catalytic Reduction
COBF	Canola oil **biodiesel** fuel	SO2	Sulphur dioxide
CVEs	crude oil volatile emissions	SOA	Secondary organic aerosols
EPA	Environmental Protection Agency	SOI	Start of injection
GHG	Greenhouse gas	TPM	Total particulate matter
HC	Hydrocarbon	VOCs	Volatile organic compounds
IVOC	Intermediate volatility organic compounds	WCO	Waste cooking oil
KME	Karanja methyl ester	WCOB	Waste cooking oil biodiesel
MGO	Marine gas oil	WSO	Water-soluble organics
NA	Nonanoic acid	WVO	Waste vegetable oil
NO_2	Nitrogen di oxide	µM	Micro meter

1. INTRODUCTION

As the global focus shifts toward cleaner, renewable energy sources, biodiesel has emerged as a promising alternative to petroleum-based diesel fuel. Derived from renewable biological sources like vegetable oils, animal fats, and algae, biodiesel has the potential to reduce greenhouse gas emissions, improve energy security, and decrease reliance on fossil fuels. Biodiesel, as a renewable energy source, offers a promising alternative to fossil fuels by reducing emissions and utilizing sustainable feedstock [1-3]. However, its emission characteristics vary depending on the feedstock and production methods used. Biodiesel generally results in lower emissions of carbon monoxide (CO), hydrocarbons (HC), and smoke compared to conventional diesel, although it may increase nitrogen oxides (NOx) emissions [4-6]. So many experimental works have been carried out by the researchers of various countries on various biodiesels and found the similar results. The choice of feedstock, such as high-acid oils and waste oils, and production methods like supercritical transesterification, can influence the emission characteristics of biodiesel [77]. Abed et al [8] investigated the impact of varying proportions of biodiesel in the blends, specifically analyzing mixtures such as B10 and B20, and their corresponding emissions compared to traditional diesel fuel. Tuan et al [9] evaluated the performance and emissions of different biodiesel fuels, specifically fish diesel oil (B20) and waste oil (BA20), in comparison to standard diesel fuel (B0) at various engine speeds and loads, highlighting the potential of biodiesel as an alternative fuel to reduce pollutants. The results indicated a significant reduction in emissions when using biodiesel fuels, with carbon monoxide (CO) emissions decreasing by 15.39% and 19.50%, non-burning hydrocarbons (HC) by 7.33% and 11.06%, and smoke emissions by 21.56% and 15.47% for B20 and BA20 respectively, although nitrogen oxide (NOx) emissions increased. Despite the benefits of use of biodiesel, its use can lead to increased NOx emissions. For example, B20 and BA20 blends showed increases in NOx emissions by 6.86% and 4.31%, respectively [9]. Similarly, biodiesel produced through supercritical transesterification showed higher NOx emissions compared to super-low sulfur diesel (SLSD) [7]. Waste cooking oil biodiesel (WCOB) blends, such as B30, have demonstrated by Su et al [10] and observed the reductions in CO, soot, and total hydrocarbon emissions by 13.3%, 31.4%, and 30.37%, respectively, under high-load conditions. Kanokkhanarat et al [11] examined the exhaust emission characteristics of diesel engines running on ethanol biodiesel blends, highlighting potential reductions in harmful emissions and contributing to environmental sustainability efforts.

Masera [12] introduced 2-Butoxyethanol as a novel biodiesel additive, which, when used in 50/50 biomixtures, resulted in increased in-cylinder pressure and reduced combustion duration. Additionally, the study explored a novel SNCR after-treatment design that effectively reduced NO emissions from the biomixtures, highlighting the potential for further emission reductions in biodiesel applications. Puchakayala et al [13] add the nanoparticles like CeO_2 and carbon nanotubes to biodiesel and results found significantly reduction of emissions. For instance, this additive reduces the NOx, HC, CO, and smoke emissions by 19%, 17%, 39%, and 25%, respectively, in waste cooking oil biodiesel. Nanoparticle-assisted biodiesel production can enhance combustion efficiency and reduce emissions, making it a viable strategy for improving biodiesel's environmental performance. It is highlighted the use of various nanocatalysts, such as titanium dioxide, zinc oxide, and graphene oxide, which have been shown to significantly increase the yield of biodiesel to more than 95%, thereby addressing the issue of low biodiesel yield and high production costs. It was discussed the enhancement of combustion and ignition characteristics of biodiesel in compression ignition engines through the addition of nanoparticles, resulting in increased brake power, reduced fuel consumption, and improved thermal efficiency, along with notable reductions in harmful emissions like NOx, HC, CO, and smoke.

Aljaafari et al [14] discussed the production of biodiesel from various organic materials and waste components, highlighting the importance of utilizing waste resources for transportation purposes to address the increasing demand for energy and the scarcity of fossil fuels. It also examined the health impacts of biodiesel emissions, particularly focusing on the higher risk of developing lung cancer for individuals exposed to diesel exhaust and the significant increase in symptom prevalence with NO_2 concentration, emphasizing the need for sustainable and renewable solutions to decrease pollution to the environment.

Zandie et al [15] highlighted the blending gasoline with diesel–biodiesel mixtures can enhance combustion characteristics by elongating ignition delay, increasing heat release rate, and raising in-cylinder pressure at high loads, while also shortening combustion duration and suppressing emissions of soot, carbon monoxide, and unburned hydrocarbons. It was identified that the addition of gasoline improves fuel economy at medium and high loads, although it slightly increases nitrogen oxides emissions and partially disrupts combustion stability, indicating a trade-off between emissions and efficiency that needs to be addressed for wider adoption. The United States National Biodiesel Board's emissions reduction index showed significant decreases in total hydrocarbons, polycyclic aromatic hydrocarbons, carbon, and sulfur emissions by 67%, 80%, 48%, and 100%, respectively, when biodiesel was used wholly as a transportation fuel, indicating the positive impact of biodiesel on reducing harmful emissions [16].

The emissions of gaseous pollutants and particle size distributed water-soluble organics (WSO) from a diesel vehicle fuelled with ultralow sulphur diesel (B0) and 10 (B10), 20 (B20), and 30% (B30) biodiesel blends in a chassis dynamometer tested under transient mode [17]. Rajkumar and Thangaraja [18] highlighted the importance of restoring the start of injection (SOI) of biodiesel fuel to that of diesel fuel and utilizing fuel formulation techniques to alleviate the biodiesel-NO_x penalty. The findings indicate that while binary blends of karanja and coconut biodiesel do not significantly alter emission characteristics at lower speeds, they demonstrate a beneficial effect on NO emissions at higher speeds. Sharma and Ganesh [19] investigated the production of reformulated biodiesel fuel (RBF) by blending individual biodiesels derived from various oil feedstocks, specifically focusing on improving the level of saturated fatty acids (SFA) while decreasing unsaturated fatty acids. This approach aims to enhance the combustion properties and reduce emissions associated with biodiesel use in compression ignition engines. The experimental results was demonstrated that the reformulated biodiesel samples (RBF-I and RBF-II) exhibit improved combustion characteristics, such as higher cylinder pressure and advanced start of combustion compared to diesel fuel, while also achieving a significant reduction in nitric oxides emissions by 20% and a decrease in carbon dioxide emissions by approximately 35%. The study of Xu et al [20] provided a comprehensive life-cycle analysis of greenhouse gas emissions for biodiesel and renewable diesel production from various feedstocks, including oilseed crops, distiller's corn oil, used cooking oil, and tallow, highlighting the emissions reductions achieved compared to petroleum diesel. It identifies key factors influencing life-cycle GHG emissions, such as fertilizer use, nitrous oxide emissions from crop farming, energy use for grease rendering, and the energy and chemicals required for biofuel conversion, emphasizing the differences in emissions between biodiesel and renewable diesel production routes.

While biodiesel offers significant reductions in certain emissions, the increase in NOx emissions remains a challenge. Advances in production techniques and the use of additives like nanoparticles are crucial for optimizing biodiesel's emission profile and making it a more competitive alternative to fossil fuels. However, while biodiesel is generally regarded as a cleaner fuel compared to traditional diesel, the health effects associated with its exhaust emissions are not yet fully understood. This highlights the pressing need for in-depth research into the potential health risks posed by biodiesel exhaust.

2. The Composition of Biodiesel Exhaust

Biodiesel exhaust, like that of conventional diesel, contains a mixture of particulate matter (PM), gases (such as carbon monoxide, nitrogen oxides, and hydrocarbons), and volatile organic compounds (VOCs). By using nonanoic acid (NA) as a model fatty acid, coexisting Fe(III), even at concentrations as low as 1 μM, markedly enhanced the photochemical release of NA-derived volatile organic compounds (VOCs) such as octanal and octane into the air [21]. According to the study of Dagaut et al [22] the combustion of conventional fuels (Diesel and Jet A-1) with 10-20% vol. of oxygenated biofuels (ethanol, 1-butanol, methyl octanoate, rapeseed oil methyl ester, diethyl carbonate, tri (propylene glycol) methyl ether, i.e., CH3(OC3H6)3OH, and 2,5-dimethylfuran) and a synthetic paraffinic kerosene was studied. Many researchers have worked on experimental evaluation of biodiesel fuels for both performance assessment and emission characteristics evaluation. The main emissions which was measured by the researchers are CO_2, CO, HC, NOx, PM and VOC etc. The main causes of these polluting elements and their effect are presented which are PM, CO, NOx, and VOC.

2.1 Particulate Matter:

Biodiesel generally produces lower levels of particulate matter compared to conventional diesel. This is largely due to the higher oxygen content in biodiesel, which promotes more complete combustion. However, the size and chemical composition of the particulates can differ, which could have different health impacts. Evtyugina et al. [17] studied the PM chemical composition from a diesel engine fuelled with ternary fuel

The results for the EURO IV diesel engine showed that the PM and toxic organic pollutant emissions were reduced with increases in the blending ratio up until the B60 scenario when compared to the D100 scenario, and the biodiesel effect on the emissions from EURO III engine was more pronounced because of its lower combustion efficiency, and therefore the improvement in combustion using biodiesel resulted in greater PCDD/F reductions [23]. Bhangwar et al [24] provides an overview of the characteristics and health impacts of particulate matter (PM) emissions, as well as the effects of various fuels, including biodiesel and oxygenated additives, on PM emissions from diesel engines. This contributes to a better understanding of how different fuel compositions can influence engine performance and emissions.

Because the composition of diesel particulates determines the impact of biodiesel on total particulate matter (TPM), the effect varies depending on the engine and test cycle. According to the majority of research, using biodiesel can reduce TPM emissions by as much as 25–50%. The particulate matter will be increasing with the engine load for diesel engine as shown in figure 1. It is revealed that the particulate released from biodiesel are less than diesel.

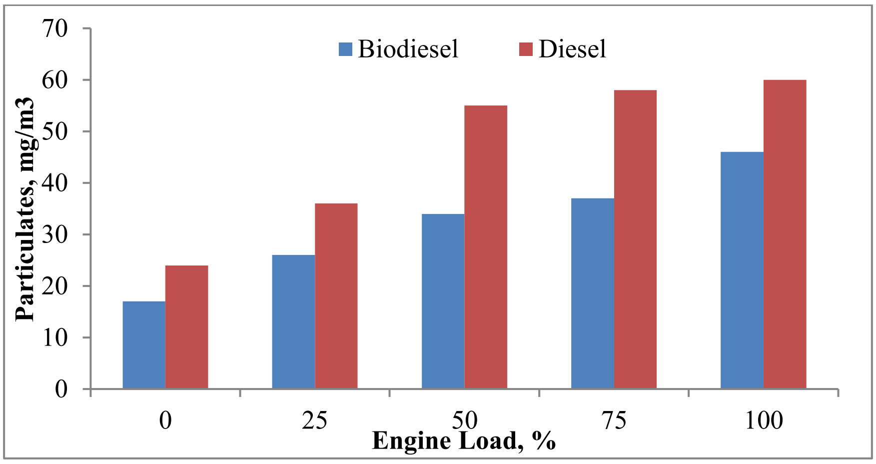

Figure 1: variation of particulate emission with percentage of engine load

2.2 Carbon Monoxide (CO) and Carbon di oxide:

While biodiesel has been found to emit lower levels of carbon monoxide compared to conventional diesel, it can still contribute to air pollution in environments where engine maintenance is poor or where there is incomplete combustion.

Buses powered by biodiesel have 68% fewer tailpipe emissions of particles smaller than 10 microns than buses powered by petroleum diesel. CO emissions from the tailpipe are 46% lower. Tailpipe SOx emissions are totally eliminated by biodiesel. When biodiesel is used instead of petroleum diesel, net CO_2 emissions are reduced by 78.45%. Urban buses' CO_2 emissions decrease by 15.66% for B20. The figure 2 shows the percentage reduction in carbon emissions with respect to the percentage increment in biodiesel blends, it observed that the carbon emissions have decreased with increasing the biodiesel quantity in diesel fuel [25]. The similar results for CO and CO_2 is observed from figure 3 [26] and 4 [27]. But in some results the CO_2 emissions slightly increased was compared to fossil diesel fuel and the CO_2 emitted from fossil diesel fuel is hard to absorb by plants as compared to CO_2 emitted by biodiesel. So the emitted from biodiesel is less hazardous to human health as compared to CO_2 emitted from fossil fuel.

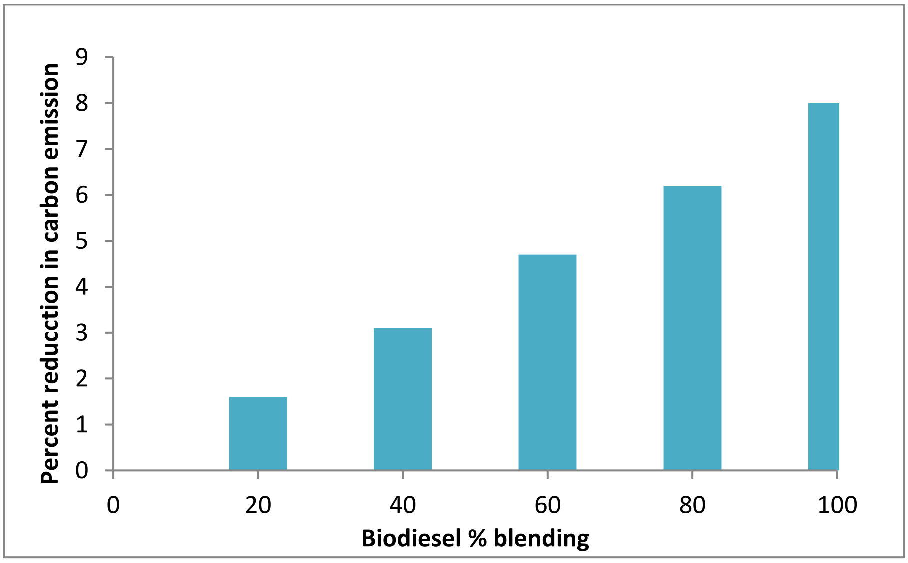

Figure 2: Effect of Biodiesel Blend Level on CO_2 Emissions

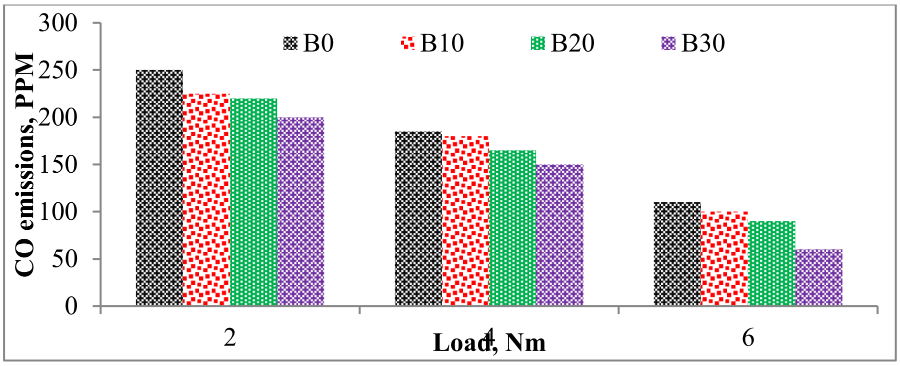

Figure 3: CO emissions at constant engine speed 1500 RPM

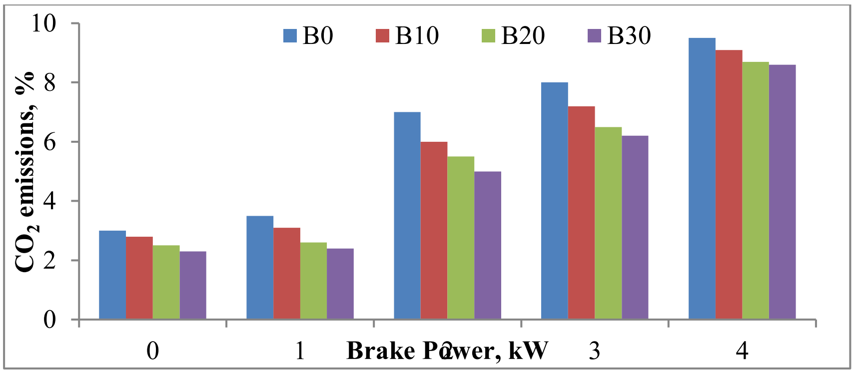

Figure 4: Variation of $CO_2$with brake power for PSB blends

2.3 Nitrogen Oxides (NOx):

Biodiesel's impact on nitrogen oxides is more complex. Some studies have shown an increase in NOx emissions, which are associated with respiratory and cardiovascular diseases, while others report no significant difference compared to regular diesel. This variation could depend on factors like engine type, operating conditions, and biodiesel blend level. Sheehan et al [25] experimentally analysed the emissions of NOx from biodiesel and petroleum fuels for diesel engine installed in the urban busses which are affecting the pollution in transportation sector. It was observed that the urban buses with B100s emit 13.35% more NOx during their life cycle. NOx emissions are reduced when biodiesel and petroleum are blended proportionally. Emissions from the life NOx cycle are up 2.67% in B20. Increases in NOx tailpipe emissions are directly responsible for the majority of this rise. For instance, B100 raises NOx tailpipe levels by 8.89%.

The similar experimental study was carried out by Chauhan et al [28] and its results are shown in figure 5. It is observed that the NOx emission are increasing with increasing the load and the similar results of increasing NOx for increasing the percentage of biodiesel blends in diesel fuel.

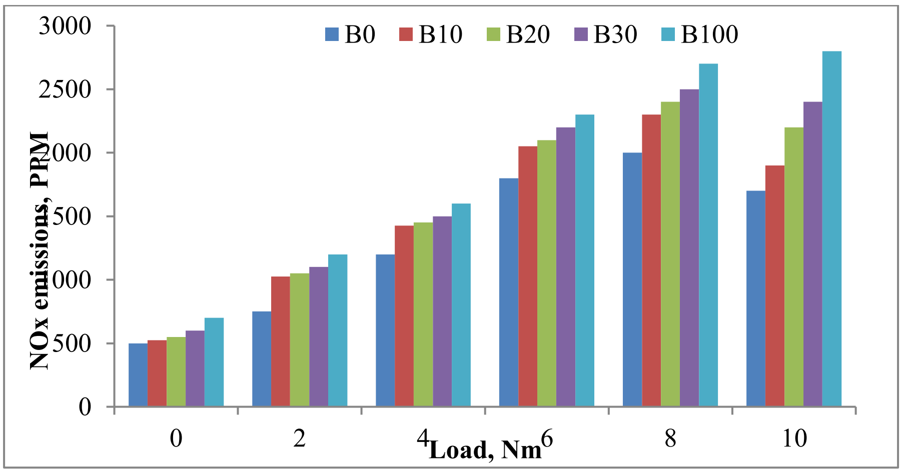

Figure 5: Variation of NOx with brake mean effective pressure

2.4 Volatile Organic Compounds (VOCs):

Biodiesel exhaust can also release VOCs, which can contribute to the formation of ground-level ozone—a key component of smog. In this paper, the combustion and emissions characteristics including volatile organic compound (VOC) of a common rail direct injection diesel engine fueled with palm oil biodiesel blends contained 0, 10, 30, and 100% (by volume) biodiesel at low idle speed, i.e., 750 rpm [29]. WCO biodiesel is a cleaner fuel comparing to conventional MGO on ship auxiliary engines with regard to the reductions in gaseous IVOC emissions and corresponding SOA productions, implying that fuel-component-based SOA predicting model should be used with more cautions when assessing SOA production of WCO and MGO exhausts [10]. The effects of the biodiesel blend fuel on VOC emissions from diesel engine exhausts in comparison with those from diesel fuel were examined, and the results showed that B20 has much lower total VOC emission, decreasing by 61.2% on average [30]. The volatile organic compounds (VOC) from diesel engines, including formaldehyde and benzene, are of concern and remain as unregulated harmful substances as discussed by the authors, and these substances are positively correlated [31].

Armfield CM-12 automotive light-duty diesel engine operated on a transient drive cycle was used to generate PM from various waste vegetable oil (WVO) and soybean biodiesel blends [33]. The VOC formation in the different engines (diesel or spark ignition) was presented and the aircraft emissions can be very intense locally, on the airport area and they can inject pollutants directly in the free troposphere [33]. Wang et al [34] investigated VOC emissions from vehicles using gasoline, diesel, and liquefied petroleum gas (LPG) as fuel.

Jobson et al [35] experimentally assessed the chemical ionization mass spectrometry using H_3O^+ proton transfer in an ion drift tube (PTR-MS) was used to measure volatile organic compound (VOC) concentrations on-line in diesel engine exhaust as a function on engine load.

White and Jobson [36] was assessed the diesel exhaust in real time using a proton-transfer-reaction mass spectrometer (PTR-MS) to determine the effect of an after-treatment catalyst on gas phase volatile organic compounds (VOCs). A critical analysis of the overall scale of global emissions of VOCs from all stages of oil processing based on data reported in the literature is provided to highlight the necessity of implementing control measures to regulate crude oil volatile emissions (CVEs) in primary steps of extraction-to-refinery pathways of crude oil processing [37, 38]. The degradation of air quality by the release of volatile organic compounds (VOCs) into the air particularly harms human health and our environment as mentioned in this paper, and this degradation can be accelerated by the use of VOCs [39]. The most harmful VOCs emitted from a diesel engine fueled with Conventional diesel fuel (CDF) is presented in figure 6 for various loads as 30Nm, 80Nm, and 130Nm [29]. It is observed that the Chloroform and Toluene are less emitting as compared to Benzene, and the percentage of chloroform is observed slightly higher than Toluene.

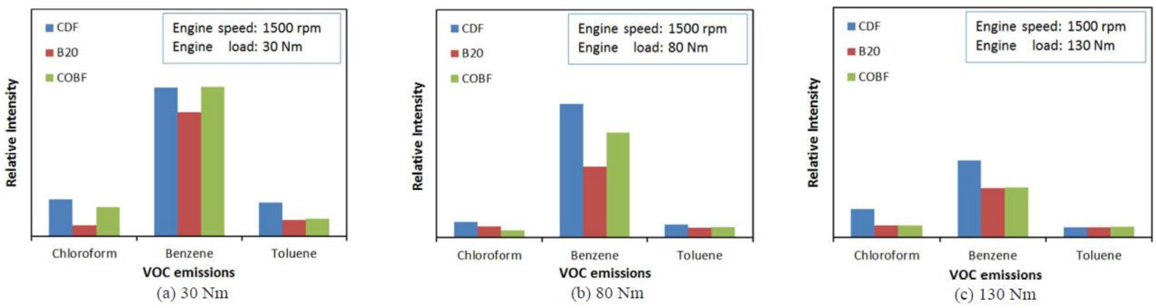

Figure 6: The most harmful VOCs emitted from a diesel engine fueled with CDF, B20, and COBF at (a) 30 Nm, (b) 80 Nm, (c) 130 Nm. [Ge et al 2018]

2.5 HC Emissions:

Generally speaking, incomplete combustion produces unburned hydrocarbon emissions (HC), which are hydrogen-carbon compounds. The geometry of the combustion chamber, wall deposits, crevice volume, and engine operating conditions all affect the emissions of HC [26]. Compared to petroleum diesel, B100 has 35% more HCs overall in its life cycle. On the other hand, the bus's exhaust emits 37% less HC **[25]**.

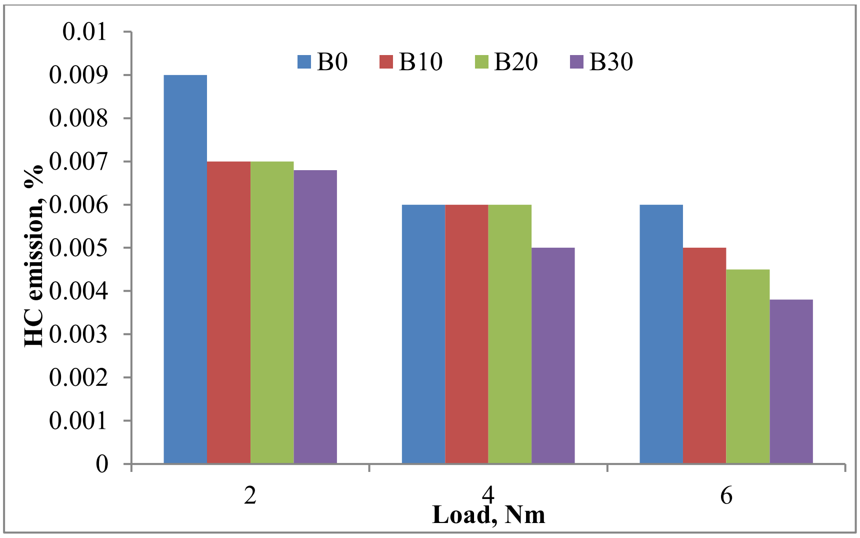

Figure 7: HC emissions at various loads for constant speed DI engine [Jalaludin et al 2020]

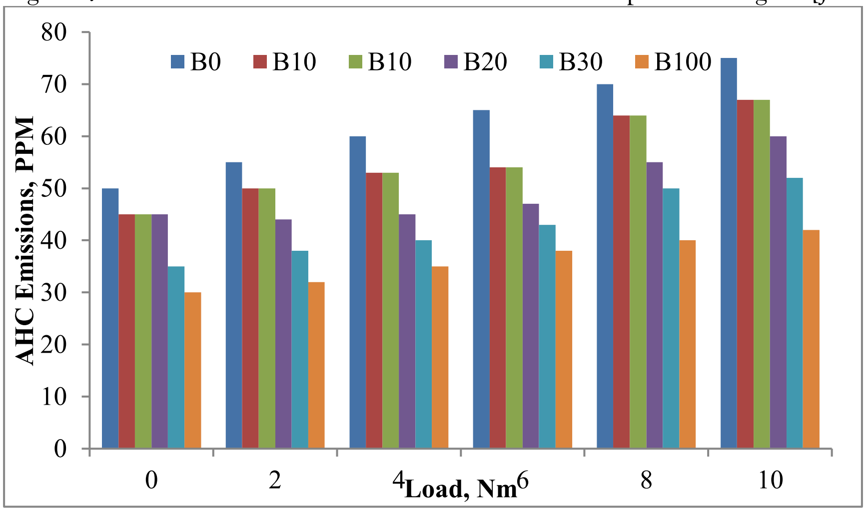

Figure 8: Variation of hydrocarbon with brake mean effective pressure [28]

Table 1: Emissions from diesel and petrol engines fueled with biodiesel

Pollutant emission	Level in diesel exhaust gas	Level in gasoline/petrol exhaust gas	Reason for occurrence
Hydrocarbons (HC)	Low	High	Incomplete combustion, rich air-fuel mixture, misfire, fuel sticking to cylinder walls
Carbon monoxide (CO)	Low	High	Incomplete combustion, lack of air/oxygen
Nitrogen oxides (NOx)	High	Low	High combustion temperature, oxygen in excess (lean air-fuel mixture)
Particulates (PM)	High	Low (also High for direct injection)	Incomplete combustion, rich air-fuel mixture

3. Health Implications Engine Exhaust

The inhalation of exhaust from any diesel fuel, including biodiesel, has been linked to a range of adverse health effects. These effects are primarily due to the fine particulate matter and harmful gases present in the exhaust.

3.1 Health effect due to CO emissions

The carbon monoxide affect the human health in several ways like: reduced oxygen delivery, headaches, chest pain, skin lesions etc. The amount of oxygen that can reach organs like the heart and brain is decreased when CO binds to hemoglobin in the blood. These Dizziness, headaches, and exhaustion are typical side effects of CO exposure. People with cardiovascular disease may get angina, or chest discomfort, as a result of CO. Dizziness, disorientation, unconsciousness, and even death can result from extremely high CO levels. Weeks after exposure to CO, neurological impairments such memory loss may manifest. Skin lesions from severe CO poisoning may be confused with burns or other injuries. The groups are especially categorised at risk for negative health effects from CO exposure as follows: pregnant women, newborns, the elderly, those with anemia, and those with a history of heart or respiratory conditions. When exposure ceases, CO poisoning symptoms can be reversed and eventually go away. However, symptoms may last up to two weeks, and it may take up to 24 hours for CO to escape your body [40, 41]. The CO emission effect symptoms on human health are shown in figure 9. It mainly affects the lungs, mind, eyes and stomach.

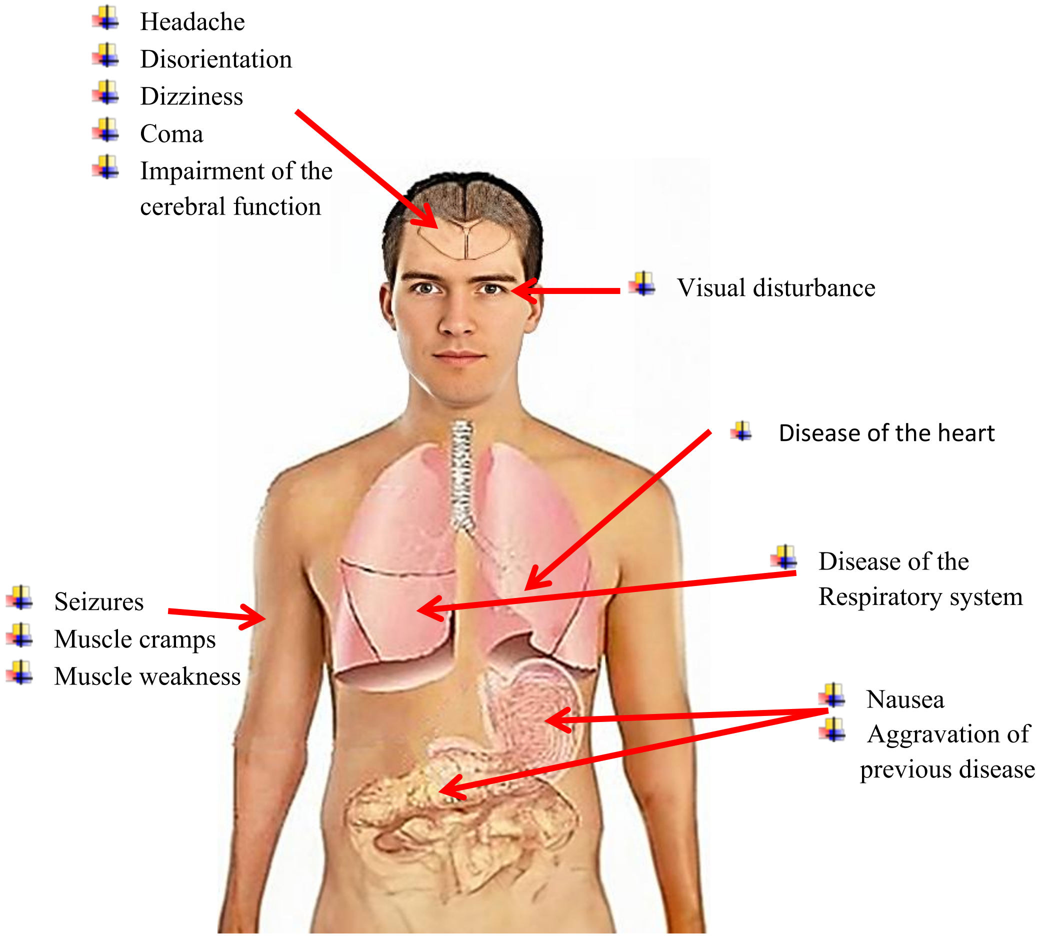

Figure 9: Symptoms of carbon monoxide poisoning

3.2 Health effect due to NOx emissions

Emissions of nitrogen oxides (NOx) can harm human health in a number of ways, such as: Low NOx levels can cause coughing, shortness of breath, fatigue, and nausea by irritating the eyes, nose, throat, and lungs. Excessive concentrations may result in edema, spasms, and quick burning of the throat and upper respiratory tract tissues. Chronic pulmonary disease can result from prolonged exposure. Premature death may result from NOx aggravating pre-existing cardiac disease. Children, the elderly, and people with asthma are typically more vulnerable to the negative health consequences of NOx. The Other health effects due to higher emissions of NOx are: It Causes the fluid build-up in the lungs; reduce oxygenation of body tissues; the cause of serious burns to the skin or eyes and cause of methemoglobinemia [42, 43]. The figure 10 shows the Symptoms of NOx poisoning on human health and it is observed that the NOx affects the lungs, skin, eye, heart and immune system.

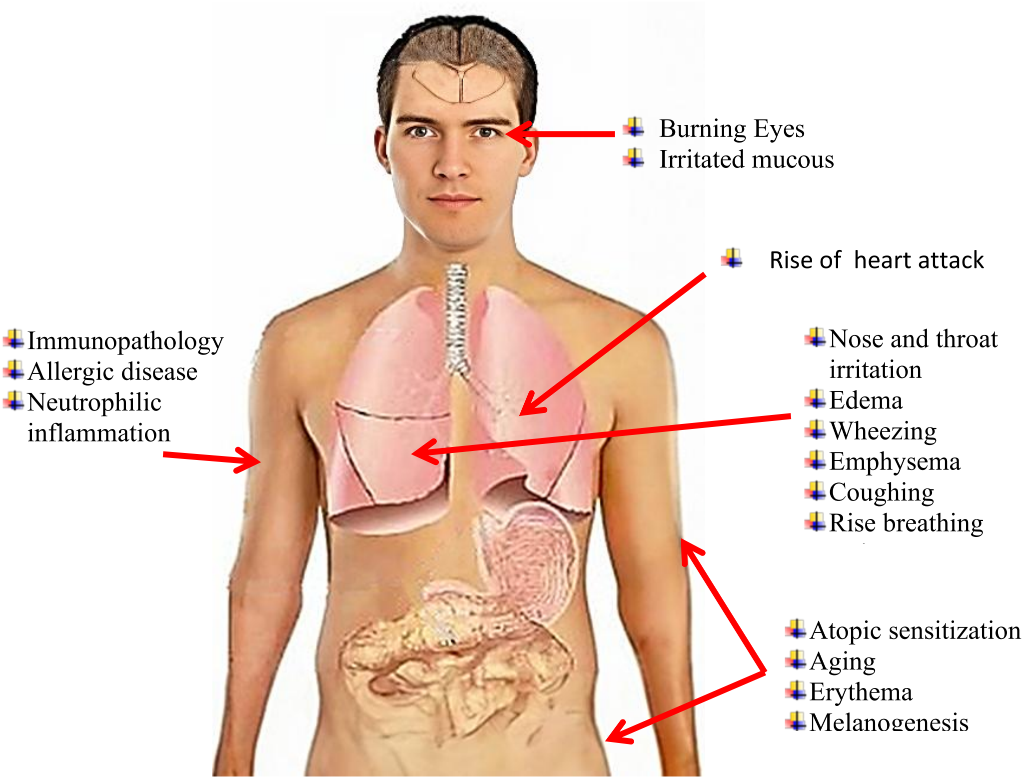

Figure 10: Symptoms of NOx poisoning

3.3 Health effect due to PM emissions

The particles' ability to cause health issues is directly correlated with their size. Particles as small as 10 micrometers can enter your lungs deeply and some of them can even enter your bloodstream. Particle pollution may be especially harmful to older adults, children, pregnant women, and people with heart and respiratory conditions. The heart and lungs both may be impacted by exposure to such particles. Exposure to particle pollution has been linked in numerous scientific studies to a number of issues, such as early death in patients with lung or heart illness, non-fatal heart attacks [45, 46]. The figure 11 shows the health effect due to PM and it is observed that the PM affects the aspiration system mainly lungs.

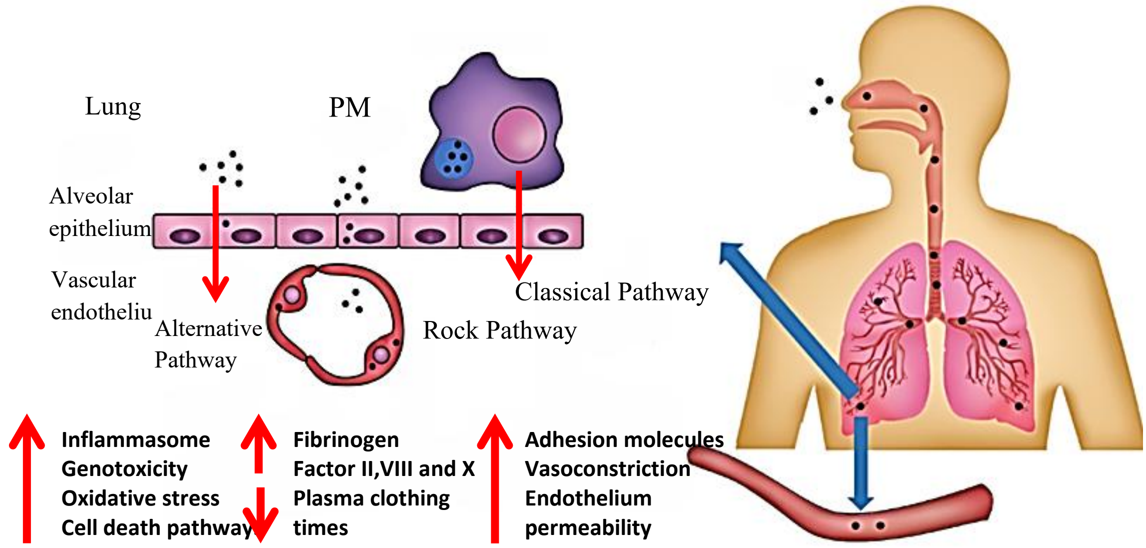

Figure 11: Health effect due to PM

3.4 Health effect due to VOCs

Volatile Organic Compounds (VOCs) are a group of organic chemicals that easily evaporate at room temperature. They are found in a variety of products, such as paints, solvents, cleaning agents, air fresheners, and even some building materials. While VOCs are useful in many industrial and consumer applications, they can have various effects on human health, especially when inhaled over time or in high concentrations. Exposure to VOCs, particularly in poorly ventilated spaces, can lead to irritation of the eyes, nose, and throat. This can result in symptoms like coughing, wheezing, sore throat, and nasal congestion. Many VOCs, including formaldehyde and benzene, can cause headaches, dizziness, or lightheadedness, which can be particularly noticeable in indoor spaces with high concentrations of VOCs. Some VOCs can lead to feelings of fatigue, nausea, and a general sense of being unwell. These symptoms are often temporary and may resolve once the individual is no longer exposed to the VOCs. VOCs also generate some long term disease in human health. Figure 12 represents the health effect due to VOCs. Where, chronic exposure to VOCs can contribute to the development of respiratory conditions like asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). Prolonged inhalation of certain VOCs can damage lung tissue, making breathing more difficult. Some VOCs are known or suspected carcinogens. For example, benzene has been linked to leukemia, and formaldehyde is associated with various cancers, including nasopharyngeal and sinonasal cancers. Long-term exposure to VOCs, especially in high concentrations, can affect the nervous system. Symptoms may include memory problems, difficulty concentrating, and changes in mood or behavior. In severe cases, it may even contribute to permanent neurological damage. Some VOCs, like carbon tetrachloride and trichloroethylene, can damage the liver and kidneys if exposure is prolonged or in high doses. This damage can lead to long-term health issues and organ dysfunction.

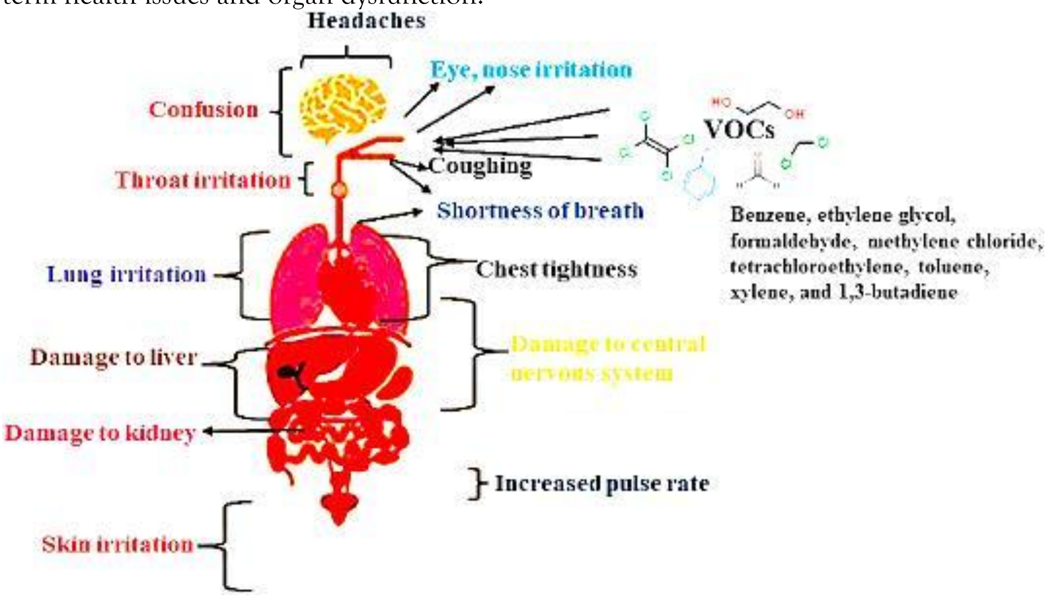

Figure 12: Health effect due to VOC's [47]

Mild CO_2 exposure might cause tiredness and headaches. Rapid breathing, disorientation, raised cardiac output, rising blood pressure, and a rise in arrhythmias can all happen at higher amounts. Suffocation mortality may result from breathing oxygen-depleted air brought on by excessive CO_2 concentrations.

The health risks associated with biodiesel exhaust are not yet as well studied as those of conventional diesel, but the following potential effects should be considered: **Respiratory Effects**: Exposure to particulate matter from diesel exhaust is known to exacerbate respiratory conditions like asthma and bronchitis. Though biodiesel produces fewer particulates than petroleum diesel, there is still concern that the different chemical composition of the particulates could have distinct effects on lung health. **Cardiovascular Health**: Diesel exhaust, including that from biodiesel, has been associated with cardiovascular issues, such as increased risk of heart attacks, stroke, and hypertension. The presence of elevated NOx emissions and other reactive gases could potentially contribute to these risks, especially in urban environments with high traffic emissions. **Cancer Risk**: Diesel exhaust has been classified as a human carcinogen, particularly due to the presence of polycyclic aromatic hydrocarbons (PAHs) and other chemicals in particulate matter. While biodiesel is thought to produce fewer PAHs, the long-term cancer risk from biodiesel exhaust needs further investigation. **Developmental and Neurological Effects**: There is growing evidence suggesting that exposure to air pollution, including diesel exhaust, can impact neurological and developmental health. Children, in particular, may be more vulnerable to the effects of particulate exposure, which can affect cognitive development and increase susceptibility to neurological diseases later in life.

4. The Need for Research

Despite the known advantages of biodiesel in terms of reducing some environmental pollutants, the health impacts of biodiesel exhaust remain under-researched. Comprehensive studies are necessary to fully assess the long-term health consequences of exposure to biodiesel exhaust, particularly in populations that are regularly exposed, such as truck drivers, urban residents, and workers in industries reliant on diesel-powered machinery. Key areas that require further investigation include [48-50]:

- **Toxicological Studies**: More research is needed to understand the specific chemical composition of biodiesel exhaust, including any novel toxicants it might contain.
- **Epidemiological Research**: Long-term studies on individuals exposed to biodiesel exhaust will be crucial to determine its effects on respiratory and cardiovascular health, as well as its potential carcinogenicity.
- **Comparative Studies**: Research comparing the health impacts of biodiesel exhaust with conventional diesel and other alternative fuels is essential for understanding the relative risks.
- **Emissions from Different Biodiesel Blends**: Since biodiesel is often used in blends with petroleum diesel, research should focus on understanding how varying concentrations (e.g., B20, B50) of biodiesel affect emissions and health outcomes.
- **Catalytic Converter:** The use of catalytic converter (CC)is reducing the emissions through engine and the research in cost reduction of CC to use it in all type of engines is necessary.

5. CONCLUSION

Biodiesel holds promise as a cleaner, more sustainable fuel source, but as with all alternative energy technologies, the potential health impacts of its exhaust must be carefully examined. The need for research on the health effects of biodiesel exhaust is critical to ensuring that its benefits are not overshadowed by unforeseen health risks. Comprehensive studies will help policymakers and public health officials make informed decisions about the use of biodiesel and the protection of public health in a world that is increasingly turning to renewable energy sources.

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