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Review Paper

A Review of Properties, Engine Performance, Emission Characteristics and Material Compatibility Biodiesel From Waste Cooking Oil (WCO)

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Abstract

Biodiesel is one of the renewable energy sources, non-fossil. The chosen feedstock should ideally be low-cost. Using waste cooking oil can reduce synthetic biodiesel's price by up to 70%. However, biodiesel has the advantage of lower heating value and higher density, causing increased fuel consumption and NOx emissions. Biodiesel has physicochemical properties such as a more significant cetane number than fossil diesel, a high flash point, and the absence of sulfur. This study identifies the potential availability of WCO as biodiesel and summarizes recent studies on the physiochemical properties of WCO biodiesel. This study also aims to clarify the use of WCO biodiesel on engine performance and exhaust emission characteristics (H.C., CO, CO_2, NOx) when this biodiesel is used. Engine type and biodiesel ratio were identified for all articles. This study also discusses the effect of adding nanoparticles on engine performance and exhaust emissions in WCO biodiesel. This study also clarifies material compatibility (corrosion, wear, and friction). The corrosion rate in various types of materials and corrosion testing methods. Finally, this paper presents the opportunity for WCO biodiesel to be very feasible to reduce fossil diesel use.

Keywords: Biodiesel WCO; Corrosion; Engine performance; Emission; Wear; Friction

1. Introduction

Energy consumption is rising globally due to rapid population expansion, urbanization, economic development, and industrialization [1]. Oil, coal, and gas are the main non-renewable energy sources that meet most of the world's energy needs. Fossil fuels will eventually run out [2]. 25% of all energy used worldwide is related to the transport sector, making it the largest energy consumer in the world [3]. Fossil fuels are being used extensively, which has caused a rapid depletion of their reserves and increased air pollution, including acid rain global warming [4], [5] and droughts' intensification [6].

A non-petroleum-based biofuel, biodiesel is one of the renewable energy sources by 2030 [7], it is predicted that biofuels will make up about 4-7% of the energy consumed worldwide. Due to its qualities, such as a greater cetane number than fossil diesel, a high flash point, and the absence of sulphur, biodiesel is widely acknowledged as a renewable fuel in the energy market [8]. However, NOx emissions have slightly increased overall. Noticed with the usage of oxygenated fuels such as biodiesel [9]. There is an increase in carbon monoxide, polyaromatics, smoke, etc., which reduces the net greenhouse effect [10]. Various sources can make biodiesel, including edible and non-edible oils, waste oil, and animal fats [11]. Few technological and financial limitations prevented the use of non-edible sources and edible oil as basic ingredients. The result was made more difficult by the limited feedstock supply for biodiesel production [12].

Approximately 95% of the world's biodiesel is made from edible oils. The price of edible oil and biodiesel has increased to 1.5 to 2 times that of diesel due to using edible oil in manufacturing biodiesel [13]. A significant obstacle to the commercialization of biodiesel is the price increase of raw materials, particularly vegetable oil [14]. Additionally, due to present manufacturing methods, biodiesel costs are increasing faster than diesel fuel [15]. Using non-edible or used cooking oil can cut the price of synthetic biodiesel by up to 70% [16]. The price of the finished product will be greatly reduced by using inexpensive oil, such as used cooking oil [17].

Waste cooking oil can be used for biodiesel production [18]. The chosen resource should ideally be low-cost and not have high requirements, such as food material, the shell should have a low level of free fatty acids (FFA) and minimum moisture content to increase the quality of the biodiesel produced [19]. The market price of these vegetable oils grew, which became a significant issue. Due to higher raw material costs, biodiesel production costs also increased. Unprofitable manufacture of biodiesel [20]. The price of the raw material, which makes up between 60 and 80 percent of the cost of production, significantly impacts the final cost of biodiesel [21].

Because it is derived from sources other than crops, used cooking oil (UCO), or waste cooking oil (WCO), biodiesel is an advanced biofuel or second-generation biofuel (**Figure 1**). It exhibits potential in production costs and quality [22]. Waste cooking oil is considerably less expensive than pure, refined vegetable oil. Waste oil disposal can harm the environment and people's health. A significant benefit over refined vegetable oils and fossil fuels is using cooking oil as a cheap feedstock for creating biodiesel [23]. Third-generation biofuel, made from microalgae, is a potential raw material with numerous advantages [24]. Microalgae as a source of biodiesel has several benefits over other plant biomass [25].

Even though the WCO price is low, it has a high water and impurity content, so pretreatment must be carried out before ester/transesterification processing [7]. Besides that, WCO biodiesel has disadvantages such as oxidation stability, low pour point, and flash point [26], which affect engine performance and exhaust emissions, wear and friction, and corrosion rates on materials in contact with WCO biodiesel. On the other hand, the physiochemical properties of WCO biodiesel are greatly influenced by the origin of the oil, frying temperature, water content, and the type of catalyst used.

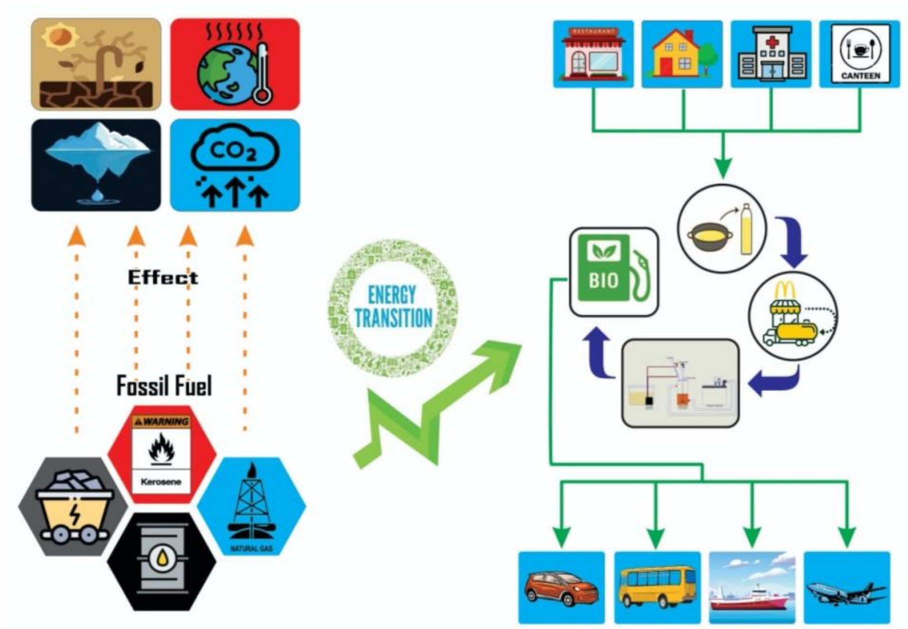

Figure 1. Utilization of WCO as a new energy source to replace fossil fuels

Although many researchers have published reviews on the recycling mode in biodiesel production methods in several countries [27], Biodiesel production from WCO uses various types of egg shells as heterogeneous catalysts [28], engine performance and exhaust emissions [29], Biodiesel production and influencing factors [30], use of modified eggshell waste as a catalyst for the production of high WCO FFA [31]. However, there is no thorough review of previous studies that comprehensively shows the relationship between the physiochemical properties of WCO biodiesel, material compatibility, engine performance, and exhaust emissions in one review paper. In the present paper discusses the potential of WCO in various countries as biodiesel feedstock, and the physiochemical properties of biodiesel from WCO are presented. The effect of biodiesel on engine performance (BP, Torsion, BTE, BSFC) and exhaust emissions (NOx, CO, CO_2, and HC). This paper also discusses the ability of WCO biodiesel to wear and friction on various materials. Furthermore, the corrosion rate characteristics of various types of materials (carbon steel, stainless steel, aluminium, copper, and cast iron) are also discussed. The main findings are presented in tabular form and bar chart, making it easier for researchers to see the development of research, and also suggests a number of future studies on biodiesel from WCO.

2. The Potency of WCO as Biodiesel Feedstock

After frying and other meal preparation activities, WCO is collected from homes, restaurants, hotels, and food processing facilities [32]. Waste cooking oil (WCO) can make goods in various industrial sectors, such as soap, oil paint, and biodiesel [33]. Due to its low cost and reduced size, manufacturing biodiesel from used cooking oil has recently attracted interest in several nations [34]. The value of global biodiesel production is predicted to reach 39.3 billion litres in 2027, up 9% from 2017 [35]. According to estimates, the U.K. produces 65,000 to 80,000 tonnes of WCO annually, while China's commercial and food processing industries produce 1,000,000 to 2,500,000 tonnes [36]. Various nations have gathered the estimated WCO amounts: Canada produces 125,000–135,000 tons annually. This is said to be 200,000 tonnes annually in South Africa. Malaysia produces 60,000 tons annually, compared to Japan's 6,000 tons [37].

According to data from the Ministry of Trade, Indonesia's exports of used cooking oil in 2019 reached US$37.31 million. The Netherlands is the largest export destination for used cooking oil, with 34.03% of all used cooking exports. This amount equals 13.46 million U.S. dollars, totalling 24,449 tonnes [38]. 29 million tons of used cooking oil (WCO) are produced annually worldwide. According to estimates, India alone produces 9.2 million tons of WCO each year, directly discharged into land or water bodies and pollutes the environment [39], [40]. Given that waste raw materials are readily available for the production of biofuels (biodiesel, bioethanol, biogas, etc.) utilizing various chemical and biological conversion processes, biofuels are a very appealing solution to address the energy crisis [41].

3. Generation of Biodiesel

The general definition of biodiesel is "monoalkyl esters of long chain fatty acids," which are often created by alcohol and different oils or animal fats being transesterified by an acid or base l [42] to produce glycerol as a byproduct and fatty acid methyl esters (FAME) as a product [43]. A variety of edible and non-edible oil sources, such as palm oil [44], the Calophyllum inophyllum [45], Reutealis trisperma [46], Ceiba pentandra [47], mustard oil [48], beauty leaf oil [7], microalgae oil [18], rubber seed oil [49], mahua oil, animal fats [50], waste cooking oil, etc. can be used for biodiesel production [18] The chosen resource should ideally be low-cost and not have high requirements, such as food material, the shell has a low level of free fatty acids (FFA). It must have minimum moisture content to increase the biodiesel quality [19]. Energy crops, which compete fiercely with human food for land, freshwater, and nutrients, are the main source of raw materials for manufacturing biofuels, creating the "food versus fuel" debate. Concerns regarding edible oils and energy usage for food production [40], [24]. The market price of these vegetable oils grew, which became a significant issue. Due to higher raw material costs, biodiesel production costs also increased. Unprofitable manufacture of biodiesel [20] the price of the raw material, which makes up between 60 and 80 percent of the cost of production, has a significant impact on the final cost of biodiesel [21]. Second-generation biofuels made from non-food biomass, such as agricultural waste and lignocellulosic raw materials, including wood, grasses, and forest leftovers, appear to be an intriguing option in and of themselves [18], [51].

Because it is derived from sources other than crops, used cooking oil (UCO), or waste cooking oil (WCO), biodiesel is an advanced biofuel or second-generation biofuel. It exhibits potential in production costs and quality [22]. Waste cooking oil is considerably less expensive than pure, refined vegetable oil. Waste oil disposal can harm the environment and people's health. A significant benefit over refined vegetable oils and fossil fuels is using waste cooking oil as a cheap feedstock for creating biodiesel [23]. Third-generation biofuel, made from microalgae, is a potential raw material with numerous advantages [24]. Microalgae as a source of biodiesel has some benefits over other plant biomass [25].

4. Properties of WCO

Saturated and unsaturated monocarboxylic acids are combined with trihydric alcohol glyceride to form waste cooking oil. Triglycerides are transformed into diglycerides during transesterification with the help of a catalyst, which is next transformed into monoglycerides and then glycerol [52]. Impurities produced by chemical reactions during cooking or directly from raw foods are the main drawback of employing WCO. Water, free fatty acids (FFA), polar substances, and non-68 volatile substances are some of these substances that primarily impact homogeneous catalytic transesterification [10]. The length of the hydrocarbon chain, the level of unsaturation, and the impact of molecular packing largely determine the physical properties of biodiesel.

In contrast, the calculation of the thermodynamic properties of biodiesel is challenging because it involves components with high molecular weight and complex structures [3]. This B100 comprises five major components, including methyl palmitate, methyl oleate, methyl linoleate, methyl stearate, and methyl linoleate, just like other commercial biodiesel. Over 60% of the liquid volume is made up of unsaturated esters, and roughly 60% contain bis-allyl sites, which significantly impact the stability of B100 [43].

Biodiesel has gained popularity as an economical and sustainable form of transportation fuel over the past ten years [53]. The WCO is primarily obtained from fried vegetable oils and animal fats, which have a high proportion of saturated fatty acids (more than 65% by weight in this study), which is why biodiesel performs poorly at temperature flow [54]. Research has repeatedly proven that employing WCO produces low-quality fuel that needs additional purification despite lowering production costs. The low biodiesel production caused by the high FFA level, water, and other impurities in the feedstock, poor oxidation stability, and cold flow characteristics are the key issues with W.C. biodiesel, though [7]. For optimum engine performance and service life, contaminants such as water, extra reactants, unreacted glycerides, and residual catalysts must be removed from raw biodiesel [39]. The physicochemical properties of WCO biodiesel are tabulated in **Table 1**.

In producing biodiesel, several physiochemical properties such as cetane number, heating value, oxidation stability, pour point, iodine number, and cloud point must be considered for diesel engines. **Table 1** shows the physiochemical properties of WCO biodiesel. Most of the physiochemical properties of WCO biodiesel meet the ASTM 6751 standard. One of the essential properties of biodiesel is kinematic viscosity, where kinematic viscosity must meet ASTM D445 standards. Kinematic viscosity that is too high will affect the intake stroke of fuel with air [55]. The kinematic viscosity of WCO biodiesel that all researchers have produced has met ASTM D445 standards, as shown in **Figure 2**.

Furthermore, another essential property of biodiesel is density, where density is a property that influences the fuel injection process into the combustion chamber. The purity of biodiesel and unsaturated fatty acids affects density. Density will increase with decreasing unsaturated fatty acids. Biodiesel density is determined by the method given in the ASTM D1298 standard. **Figure 3** shows that most researchers have produced biodiesel density that meets ASTM D1298 standards (max 880 kg/m3). Chuepeng et al. obtained a very significant density (931 kg/m^3),

Table 1. Physicochemical properties of biodiesel waste cooking oil

Type WCO	Author	Kinematic viscosity (mm^2/s), 40 °C	Density (20 °C) kg/m3	Iodine value g (iodine/100g)	Heating value (MJ/kg)	Oxidation stability (h)	Acid Number (mmg KOH/g)	Flash Point (°C)	Pour Point (°C)	Cloud Point (°C)	CFPP (°C)	Cetane Number (C.N.)
WCO	[58]	4.318	-	-	41.1	0.45	0.49	160	6.1	9.8	7.2	57.95
WCO	[59]	3.69	874	-	44.13	-	0.39	175	-3.4	1.6	-2.54	70.24
WCO	[60]	3.12	876	-	38.431	-	-	133	3	3	-	51.4
WCO	[61]	5.2	879	-	-	-	0.97	96	-	9	-	-
WCO	[62]	4.4	878	-	38.85	-	-	189	-	-	-	51.34
WCO	[56]	4.63	886	-	-	-	0.37	172	-10	-5	-	-
WCO	[63]	4.7	898		36.89	-	-	73	-	-	-	53
WCO	[52]	5	880	-	35	-	-	170	6	19	-	47
WCO	[19]	3.8	871	-	-	-	0.31	124	-	-	-	-
WCO	[5]	3.58	881	128.381	-	-	-	170	-8.369	-1.428	-	44.315
WCO soybean	[64]	-	-	-	-	-	0.52	92	-4	1	-	51.3
WCO	[65]	3.8	880	-	-	-	0.1	120	-2	-5	-	54
WCO sunflower	[66]	5.05	850	70.5	39.5	-	-	90	3	6	-	48
WCO	[67]	4.45	861	-	40.6	-	0.38	154	-	-	-	61.5
WCO	[68]	-	892.6	-	42.83	-	-	176	-	-	-	63.63
WCO	[69]	4	883	-	39.5	-	-	120	-	-	-	52
WCO	[70]	2.2	878	-	38.85	-	-	190	-	-	-	51.34
WCO	[71]	4.6	880	-	39	-	0.5	-	-	-	-	51
WCO	[72]	4.76	870	-	38.30	-	-	151	4	7	-	57
WCO	[73]	5.83	912	-	38.08	-	-	176	-	-	-	51.48
WCO	[74]	4.54	879	36.80	-	-	0.41		2	12.17	-	-
WCO	[75]	4.77	886	-	44.9	-	0.41	181	-4	2	2	-
WCO	[76]	4.71	886	-	-	-	0.53	169	-11	23	-	-
WCO	[77]	5.1	883	-	39.5	-	-	120	-	-	-	55
WCO	[78]	6	880	33	41.39	-	0.8	140	-3	-1	-	56.67
WCO	[79]	4.45	885	-	39.05	-	-	-	-	-	-	51
WCO	[80]	3.1	931	-	37.3	-	-	-	-	-	-	63.5
WCO	[81]	4.18	865	-	39.48	-	0.302	202	-4.5	1	-	-
WCO	[82]	4.75	889	-	39.48	-	-	120	-	-	-5	51.62
WCO	[83]	-	870	-	-	-	0.175	90	-3	-	-	-
WCO	[66]	5.05	850	70.5	39.50	-	-	90	3	6	-	48
WCO	[84]	4	867.3	-	-	8.2	0.32	194	-	-	-	-
WCO	[85]	4.915	884	146.44	37.114	3.45	0.48	178	-6	0	-2	49.15
WCO	[86]	4.3	871	66.52	37.4	-	0.92	133	2	6	-	46
WCO	[87]	3.23	874	-	25.81	-	-	150	-	-	-	-
WCO	[88]	4.55	851	-	40.86	-	0.55	152.5	12	-2	-	62.5
WCO	[54]	4.72	878	-	-	2.5	0.32	170	-	-	6.5	53.5

which is, of course, over-density so that when used in diesel engines, it causes high BSFC.

The acid number of WCO biodiesel that several researchers have produced is shown in **Figure 4**. A few researchers produce WCO biodiesel that is greater than permitted (max 0.5 mg KOH/g). A high acid number exceeding the standard causes a decrease in oxidation stability, forming a gel and triggering a blockage in the fuel system.

A high flash point is significant in biodiesel transport, and a low flash point can cause fires during storage and transport. The flash point is influenced by alcohol residue during biodiesel production. The flash point of biodiesel is according to ASTM Standard D93, with a range of 100-170 °C. Many researchers still produce WCO biodiesel with a low flash point, and a small number of flashpoints resulting from WCO biodiesel production by several researchers exceeded the permitted standard limits (min 100 °C), as shown in **Figure 5**. The low flash point may be caused by residual alcohol during production. Differences in WCO feedstock and biodiesel purity can cause this striking difference in flash point.

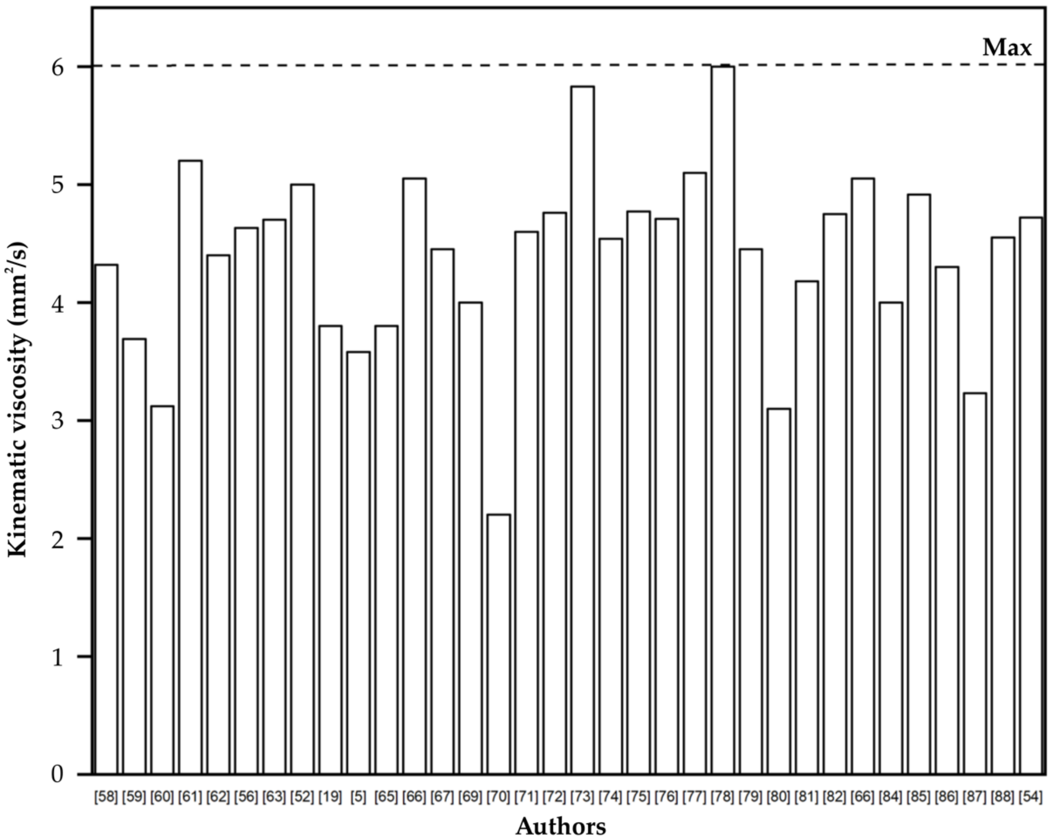

Figure 2. Kinematic viscosity of produced biodiesel WCO

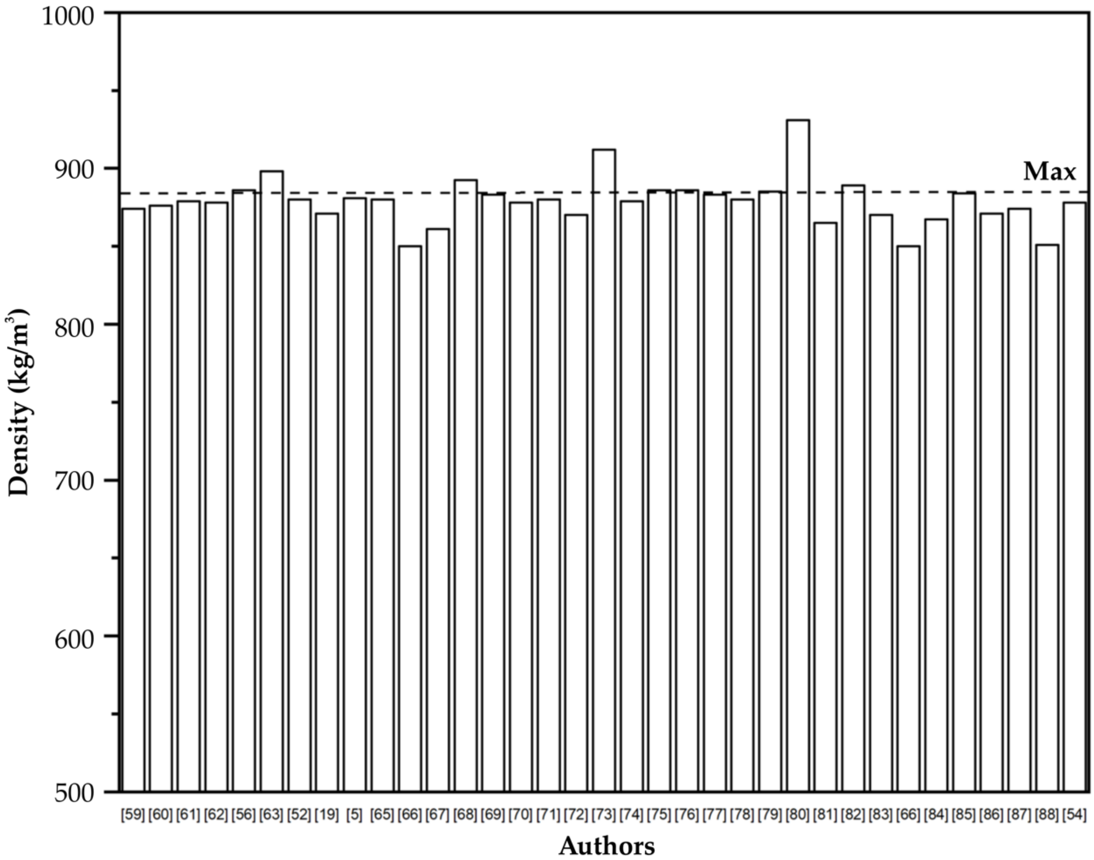

Figure 3. Density of biodiesel WCO

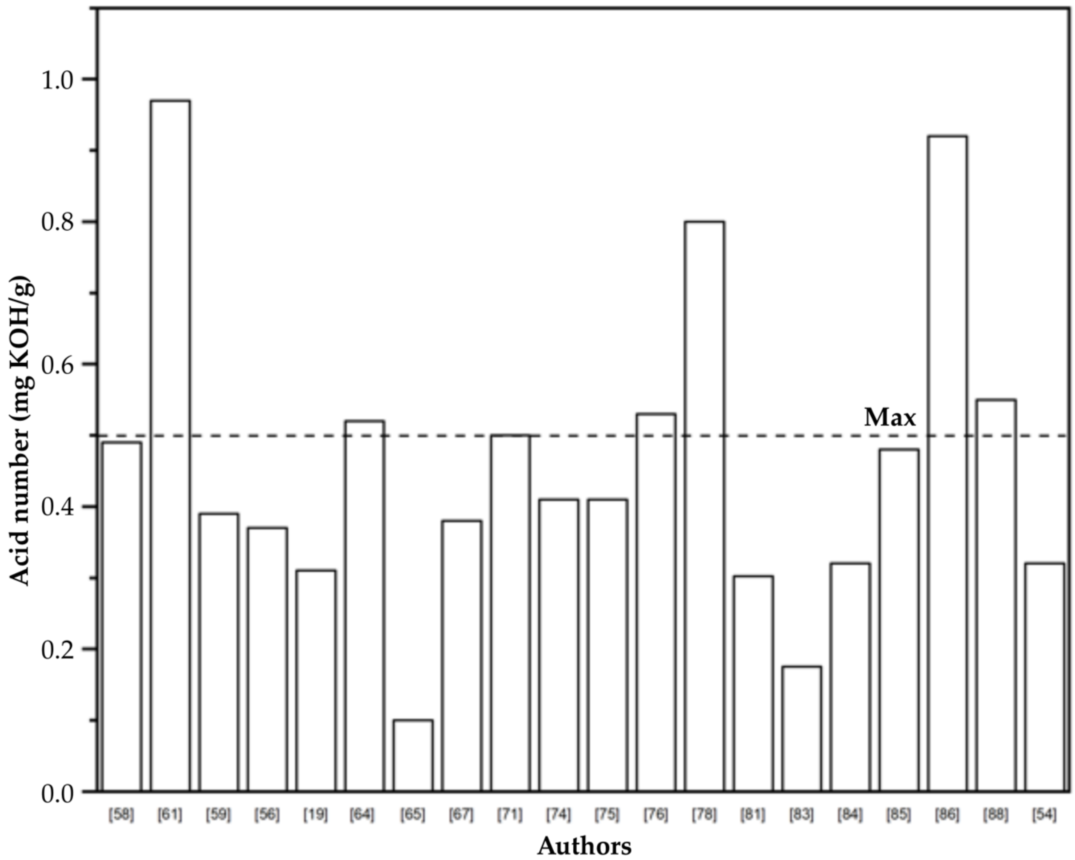

Figure 4. Acid number of biodiesel WCO

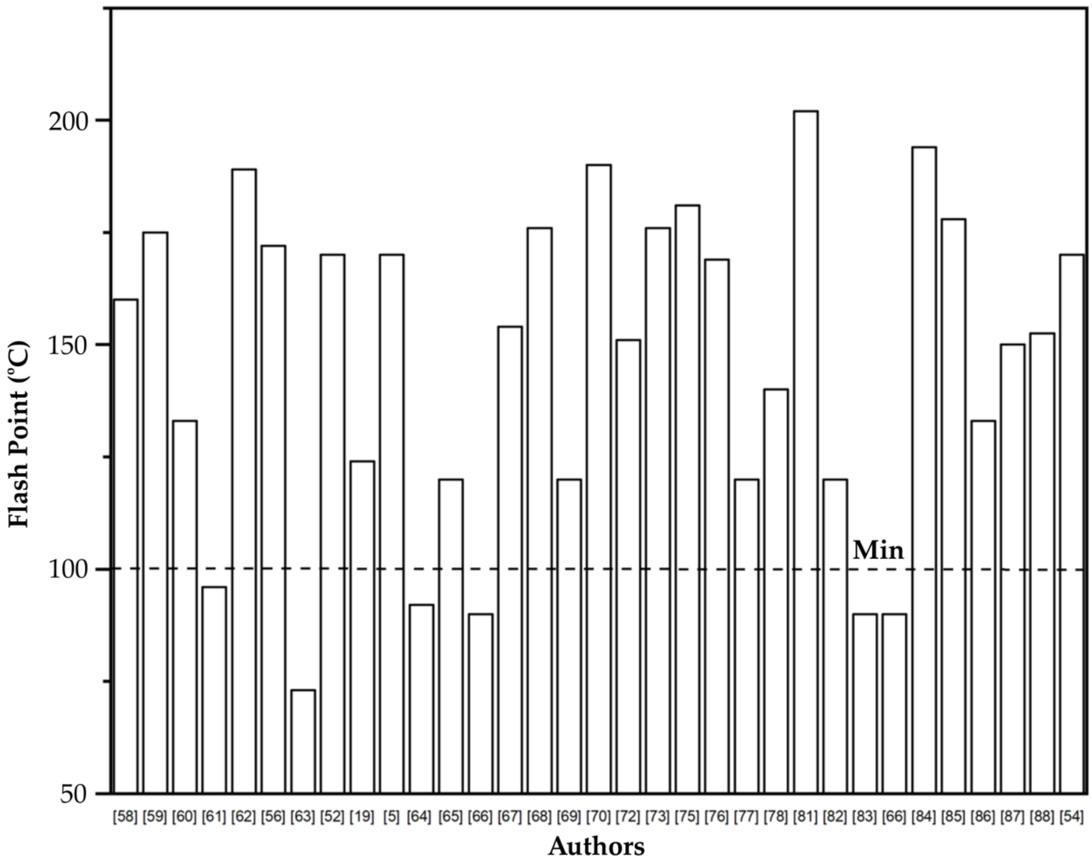

Figure 5. The flash point of WCO biodiesel

On the other hand, a low pour point is needed so that it can still flow at low temperatures. Table 1 shows that all WCO biodiesel produced does not meet the standard (-15 to -16 °C). Most biodiesel WCO comes from palm oil containing highly saturated fatty acids (stearic and palmitic). The pour point testing of biodiesel refers to the ASTM 7525 standard. Table 1 and Figure 6 show the cloud point of Biodiesel from many researchers where most have not reached the ASTM standard, where the minimum temperature is -3 to -12 °C. Only Nirmala et al. [56] produced biodiesel that meets the standard with cloud point (-5 °C), and most have not reached permissible means.

Oxidation stability is a critical property of biodiesel. Saturated fatty acids influence this oxidation stability. In general, biodiesel's oxidation stability is lower than diesel oil's. Table 1 and Figure 7 show that only a few researchers present oxidation stability in their papers, even though it is an essential parameter in biodiesel. When biodiesel undergoes oxidation, it causes an increase in density, viscosity, and peroxide value, affecting poor atomization quality and reducing ignition [57]. Most of the biodiesel produced does not meet permitted ASTM 6757 standards. The Oxidation stability testing of biodiesel refers to ASTM 7525 standards.

The delay time between fuel injection and ignition is called the cetane number. The cetane number shows the quality of fuel combustion. In general, biodiesel has a higher cetane number than diesel. According to Standard ASTM 6751, the minimum cetane number in biodiesel is 47. Most WCO biodiesel has a Cetane number that meets the minimum standard (Figure 8).

The cloud point is the temperature at which wax crystals begin to form in the fuel at low temperatures. Thickening of the oil due to the formation of wax crystals causes blockage of the injectors and fuel filters in internal combustion engines. Figure 9 shows the cloud point on WCO biodiesel. The Cloud point testing refers to the ASTM D2500 standard. WCO biodiesel synthesized from WCO oil does not meet ASTM D6751 standards because biodiesel generally begins to form wax crystals above 0 °C.

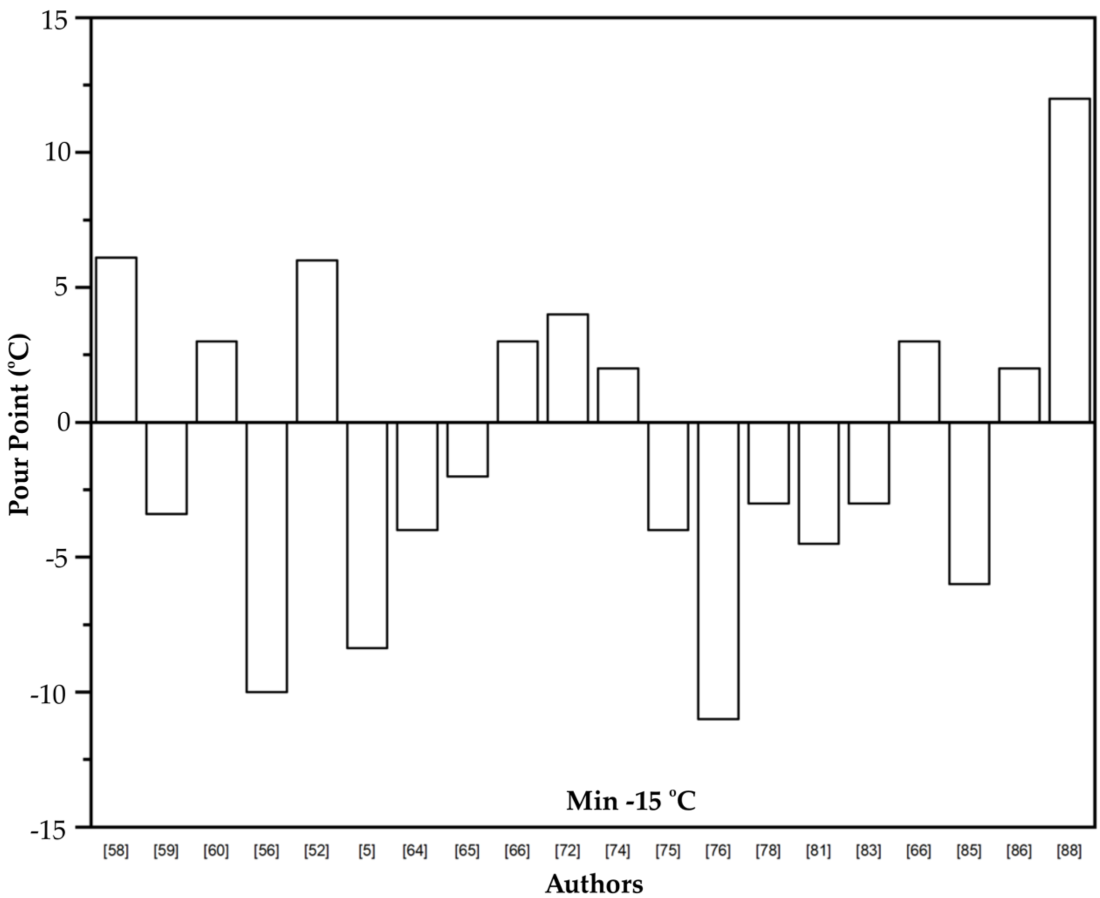

Figure 6. Pour point of WCO biodiesel

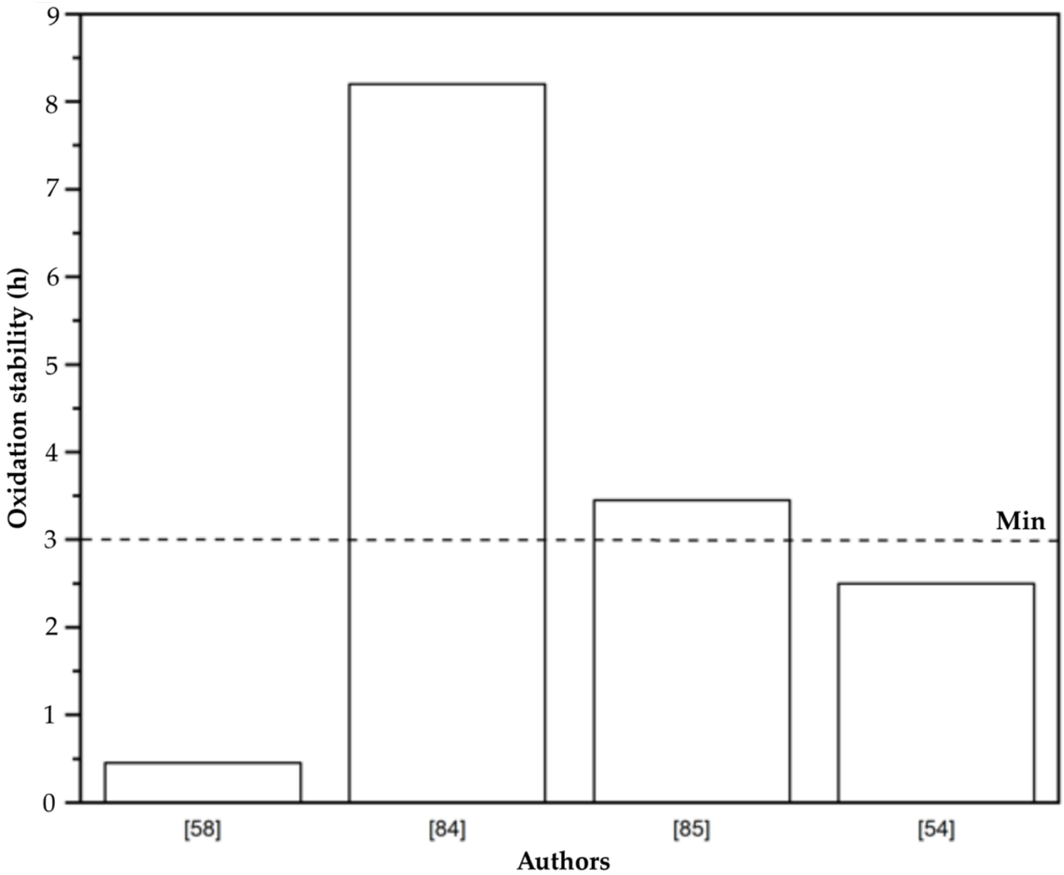

Figure 7. Oxidation stability of biodiesel WCO

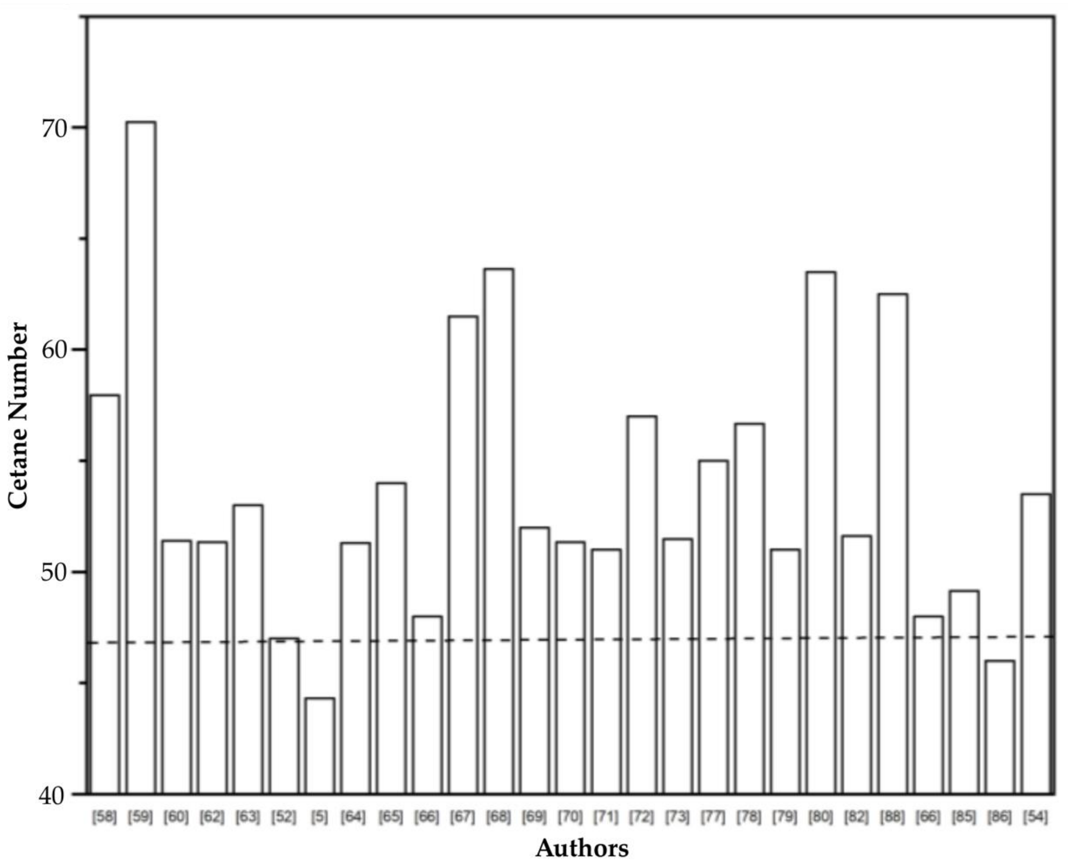

Figure 8. Cetane number of WCO Biodiesel

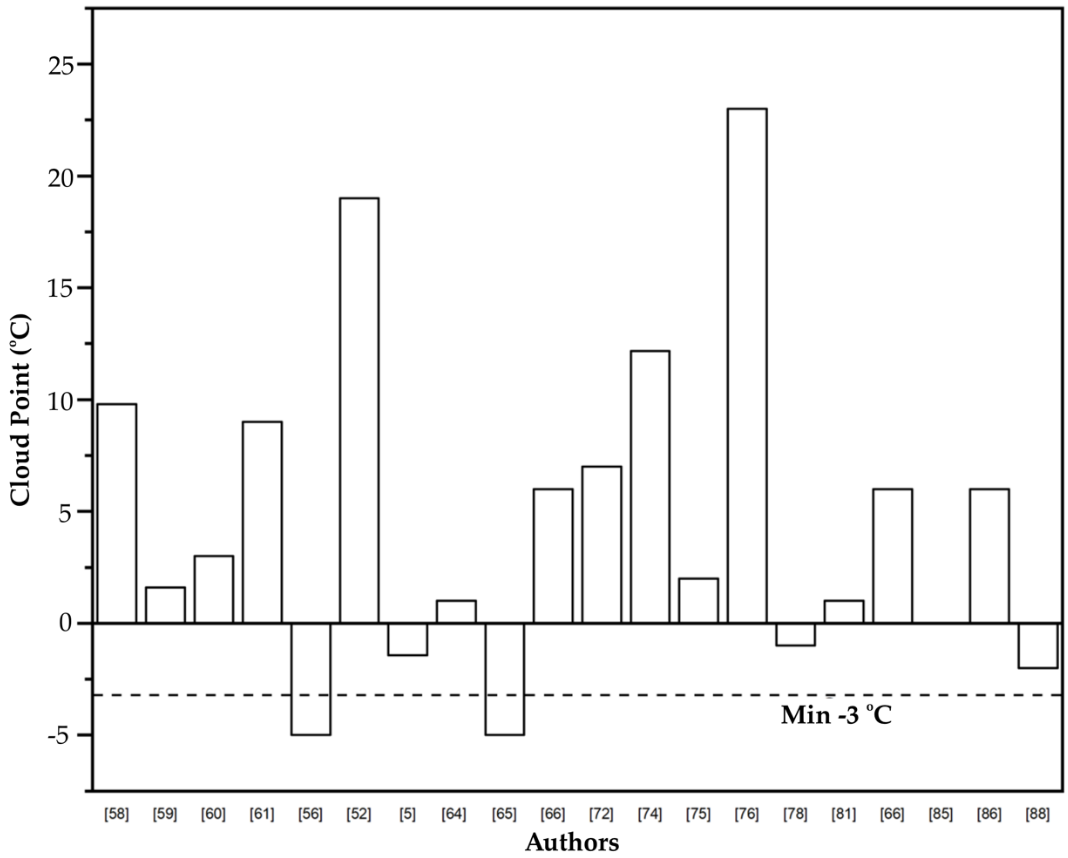

Figure 9. Cloud point of biodiesel WCO

The ability of a fuel to pass through the filtration without clogging is called the cold filter plugging point (CFPP). CFPP testing follows ASTM 6371 standards with a maximum temperature of 19 °C. **Figure 10** shows the cold filter plugging point WCO biodiesel produced by several researchers. The biodiesel produced by the authors meets permitted standards ASTM 6751 (**Figure 10**). This test is vital to assess the ability of biodiesel when operating in cold climates without clogging the fuel filter.

5. Engine Performance of WCO Biodiesel

Diesel engines are crucial in efficiently utilizing these technologies in transportation, power generation, and industry [9]. About 22% of all global greenhouse gas emissions are already attributed to the transportation industry [89]. Numerous parameters, including performance, combustion, and emission characteristics, can be considered while analyzing biodiesel [56]. Understanding the thermodynamic properties of biodiesel and its derived qualities is crucial for developing the best methods for producing and purifying the fuel and enhancing its performance in engines [3]. According to Cheung et al. [90], the volatile mass fraction of the particles increases, and the ignition temperature of the soot falls as the amount of biodiesel in the fuel or engine load reduces.

Compared to fossil diesel, WCO biodiesel has different spraying, atomization, and fuel vaporization properties, which eventually affect fuel performance, combustion, and emission characteristics [91]. Due to its higher viscosity and higher momentum than B20 and diesel fuels, B100 has narrower spray angles but higher nozzle penetration and velocity fuels [91], [92]. The effect of parameters on the engine's performance with emission characteristics and combustion characteristics of biodiesel has been studied in these works. For instance, (These works have investigated the impact of parameters on engine performance with emission characteristics and features of combustion.

6. Effect of Addition of Nano Particle on Engine Performance

A diesel engine's combustion process determines its output and exhaust emission

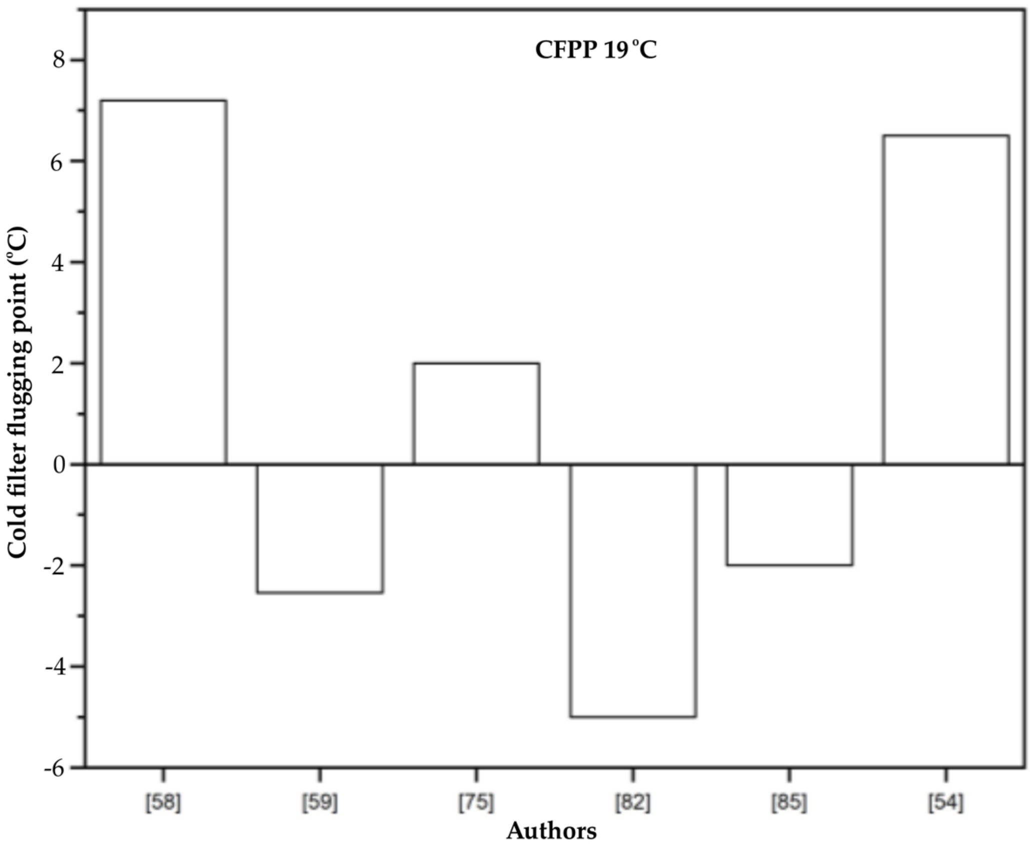

Figure 10. Cold filter plugging point of Biodiesel WCO

characteristics. The combustion of the fuel in the cylinder is influenced by several factors, including fuel characteristics, compression ratio, load, speed, fuel injection pressure, timing, combustion chamber shape and location of injectors, number and size of injection nozzle holes, fuel spray pattern, air swirl, fuel injection quantity, piston design, etc. [85]. Since nanomaterial-dispersed fuel exhibits better mechanical, physical, thermal, and chemical properties, phenomena, and processes than traditional materials, many researchers have concentrated on it for greater performance [37]. WCO biodiesel slightly reduces the brake thermal efficiency, increasing specific fuel consumption [82]. Mixing the two types of WCO residual frying oil (sunflower) also reduces the brake thermal efficiency, increasing specific fuel consumption [93]. The higher WCO Biodiesel viscosity causes a longer injection delay [82].

The comparison with diesel fuel revealed that biodiesel fuels validated reductions in engine torque, braking power, CO2, UHC, and smoke opacity but increased fuel consumption, exhaust gas temperature, NO_X, and CO_2 emissions related to brakes. The higher injection pressure, on the other hand, led to an up to 210 bar increase in engine torque, braking power, and brake thermal efficiency. In addition, while NO_X and CO_2 emissions increased, the increased injection pressure reduced UHC and smoke opacity. The outcomes demonstrated the viability of using fuel mixtures in a diesel engine without making any adjustments. When the findings were generally assessed, the best fuel injection pressure was determined to be 210 bar WCOB, and fuel mixes [85]. The higher fuel injection pressure increased engine torque, braking power, and BTE ratings up to 210 bar. Moreover, the higher fuel injection pressure resulted in a rise in NOX and CO_2 emissions and an increase in NOX and smoke opacity while reducing unburned H.C. and smoke opacity [85].

Studies on emissions revealed that TPA-catalyzed biodiesel reduced NOx by 19% [86]. To increase performance, several researchers turned their attention to fuel that contains nanomaterials since they demonstrate superior mechanical, physical, thermal, and chemical characteristics, phenomena, and processes to those of conventional materials. MgO nanoparticles are added to WCO biodiesel blends to increase internal combustion engines' performance, emissions, and combustion characteristics. According to Ranjan [87], the impact of MgO nanoparticles on WCO biodiesel blends' cold flow characteristics, engine performance, emission, and combustion. Nanoparticle mixed fuel wax has superior combustion analysis than other test fuels and is comparable to PBD.

The impact of nanoparticles dissolved in biodiesel from waste cooking oil (WCO) on the engine's thermal characteristics is examined. Cerium oxide (CeO_2) and magnesium (MgO) nanoparticles are combined with the various biodiesel-diesel mixes (B20, B40, and B60) utilizing ultrasonic technology. The addition of Cerium Oxide (CeO_2) and Magnesium (MgO) nanoparticles to various WCO biodiesel blends has been shown to increase VCR engine performance attributes (BTE and mechanical efficiency) when compared to pure diesel [37].

6.1. Brake-Specific Fuel Consumption BSFC

The amount of fuel used to generate 1 kW of power in an hour is known as brake-specific fuel consumption (BSFC) [92], [94]. The loss of heating value is indicated by BSFC [95]. According to Yesilyurt et al. [85], the lower heating value of the biodiesel is the reason for the increased fuel use in the cylinder. The density and viscosity of the fuels are the key determinants of BSFC. Generally speaking, biofuel results in a higher BSFC than O.D. fuel. The rise in BSFC is evident, given that biofuels have a higher density and lower calorific value than diesel fuel [96]. The interaction between the fuel injection system and fuel characteristics like oxygen content, viscosity, calorific value, density, etc., determines how biodiesel affects engine performance. Because biodiesel is denser than standard mineral diesel [56], more of it must be injected in the same amount of time, increasing the brake-specific fuel consumption (BSFC) [56], [97]. According to Yesilyurt [85], biodiesel and its blends' BSFC was discovered to be higher than diesel fuel. Diesel fuel's lowest BSFC was noted at 190 bar of fuel injection pressure. According to another study, a greater BSFC has been seen when comparing blended fuels and pure biodiesel to pure diesel due to biodiesel's lower calorific value than diesel. Between 0.16 and 0.65 MPa of engine load, BTE rises [98]. According to Can et al. [93], adding 5% and 10% of biodiesel increased BSFC slightly (up to 4%). As engine load rises, BSFC often declines as well. The lower heating value of biodiesel fuels, which is around 10.5% lower than diesel fuel due to oxygen content, can be used to explain the increased BSFC. However, as evidenced by the lower BSFC [56], WCO Biodiesel performs better in engines than biodiesel made from algal oil. According to Reddy et al. [99], the BSFC in the B20 mixture of waste cooking oil, biodiesel, and additional CaO nanoparticles employed as an additive diminishes as the load increases.

Table 2 shows an overview of WCO biodiesel engine performance and exhaust emissions. The BSFC biodiesel WCO (B100) test results generally improved compared to conventional diesel. The highest increase in BSFC was seen by Sahabdeen et al. [86] at 57%, and the lowest was 2% obtained by Kataria et al. [100] compared to conventional diesel. Sahabdheen et al. [86] found that the higher BSFC compared to other researchers is possible because the density of the biodiesel produced does not fulfill the standard (890 kg/m3), while the minimum standard is (880 kg/m3), causing fuel consumption to increase significantly. Furthermore, this is also because the calorific value obtained is deficient (35.6 MJ/kg). On the other hand, the cetane number obtained is also low, around 42, causes a delay in combustion, which causes an increase in BSFC. Following standard ASTM 6751, the minimum value of cetane number biodiesel is 47.

6.2. Specific Energy Consumption

Both brake thermal efficiency and brake-specific fuel consumption have increased. While the NOx and NO2 emissions rise, the H.C. and C.O. emissions decline [101]. The diesel injector can be adjusted to fix this issue [102]. At high engine loads, smoke opacity and particle mass concentrations are dramatically reduced [101]. Higher cetane fuels have quicker ignition times, which could result in increased soot production because there isn't enough time for the fuel and environment to combine before combustion starts [103]. Due to the increased fuel viscosity and density, the WCO biodiesel had a longer injection delay and higher injection speed, according to the results of the injection rate test. Compared to diesel, WCO biodiesel had a smaller spray angle and longer liquid tip penetration length, indicating inadequate air-fuel mixing [70]. The

Table 2. Performance and emission of biodiesel WCO – diesel blends

Biodiesel	Blends	Engine Specification		Engine Performance				Emissions				Ref
		Cylinder	Compression ratio	Power	Torque	BSFC	BTE	NOx	CO	CO_2	HC	
WCO	B100	1	-	-	-	↑ 10.52%	↓ 9%	↑ 18%	↓ 20%	↑ 26.67%	↓ 11.11%	[117]
WCO		2							↓ 20%		↓ 28.5%	[9]
WCO	B100	1	17.5:1	-	-	↑ 4,2%	↓5.9%	↑ 9%	↓ 114%	↑ 21%	↓ 550%	[56]
WCO	B100	1	17.4:1	-	-	-	-	↑ 42.85%	↓ 48.14%	-	↓ 100%	[62]
WCO sunflower	B10	1	18:1	-	-	↑ 4%	↓ 2.8%	↑ 8.7%	↓ 7%	↑ 5%	-	[93]
WCO	B100	1	18:1	↓ 25,92%	-	↑ 26.31%	-	-	-	-	-	[118]
WCO	B50	-	-	↓ 6.70%	↓ 5.2%	↑ 9%	↓ 8.4%	↑ 19%	↓ 26.3%	↑ 38.5%	-	[95]
WCO		1	17.5:1									[101]
WCO	B100	1	17.5:1	-	-	↑ 12.5%	↓ 18%	↑ 90%	↓ 15%	-	↓ 23%	[69]
WCO	B100	1	18:1	-	-	↑ 38.4%	↓ 26.1%	↑ 10.66%	↓ 44.05%	-	↓ 36.22%	[72]
WCO	B100	1	17.5:1	-	-	↑ 20.83%	↓ 36.36%	↑ 120%	↓ 8.34%	-	↓ 20%	[77]
WCO	B20	-	-	-	-	-	-	↑ 7.23%	↓ 24%	-	↓ 37.73%	[113]
WCO	B100	2	18.5:1	-	-	↑ 27.27%	↓ 7.11%	↑ 1%	↓ 11,11%	↑ 7.35%	↓ 3.7%	[114]
WCO	B100	1	18:1	-	-	↑ 18.9%	↓ 10%	-	↓ 72.4%	-	↓ 40.5%	[80]
WCO	B20	1	-	-	-	↑ 12%	↑ 6.25%	-	↓ 14.28%	↓ 20.83%	↓ 87.5%	[108]
WCO+ Propanol	B10	1	18:1	-	-	↑ 5.26%	-	↑ 16.67%	↓ 15.8%	-	-	[119]
WCO+CaO	B20	1	17.5:1	-	-	↑ 12%	↑ 18.51%	↑18.14%	↓ 100%	-	↓ 86.95%	[99]
WCO	B10	4	17:1	-	-	↑ 2%	↓ 0,98%	↑ 4%	↓ 27.27%	↑ 7.14%	↓ 11.11%	[107]
WCO	B20, B100	1	18:1	-	-	↑ 28%	↓ 3.34%	↑ 35.71%	↓ 33.34%	↑ 17.24%	-	[82]
WCO	B0, B20,B40, 450	6	-	↓ 5,8%	↓ 4,9%	↑ 9%	↓ 5,9%	↑ 11.11%	↓ 38.89%	↑ 27.27%	-	[95]
WCO sunflower	B10, B20, B30	1	17.5	-	-	↑ 14.28%	↓ 4.17%	↑ 25%	↓ 50%	↑ 33.34%	↓ 55.55%	[68]
Poppy20% WCO	B10	4	22.6	↓ 3.84%	↓ 4.28%	↑ 3.34%	↓ 6.45%	↑ 7.5%	↓ 23.68%	-	↓ 16.6%	[109]
WCO	B100	1	-	↓ 52.72%	↓ 27.52%	↑ 28.78%	↓ 13%	↑ 9.76%	↓ 42.25%	↑ 49%	↓ 120%	[85]
WCMO	B100	1	17.5:1	-	-	↑ 57%	↓ 17.64%	↑ 10.5%	↓ 34.48%	↑ 50%	↑ 80%	[86]
WCMO	B100	1	17.5:1	↓ 16%	-	↑ 10.37%	↓ 27.4%	↑ 9.09%	↓ 110.81%	↑ 12%	↓ 599%	[87]
WCMO	B5, B100	1	-	↓ 4.76%	-	-	-	↑ 28.20%	-	↑ 2.85%	-	[88]
WCO	B100	4	17.3: 1	-	↓ 10.29%	↑ 13.63%	-	↑ 14.81%	↓ 6.66%	-	↓ 175%	[54]
WCO	B10	1	20.3	-	-	↑ 7.4%	↓ 3.7%	↑ 2%	↓ 30%	-	↓ 316%	[120]
WCO	B100	1	17.5	-	-	↑ 17.64%	↓ 2.85%	-	-	-	-	[98]
WCO	B100	1	-	↓5.56%	-	↑ 3%	↑ 14.2%	↑ 16.36%	↓ 73.34%	-	↓ 83.34%	[100]
	B100	1	-	-	-	↑ 10%	↓ 6%	↓ 6%	↓ 25.0%	-	↑ 15%	[121]
WCO	B10, B20, B30, B100	4	19.0:1	-	-	↑ 16.94%	↓ 5.2%	↑ 18.42%	↓ 44.73%	-	↓ 37.5%	[111]

excellent flame spot was pushed farther downstream as the injection pressure was raised. As a result, the flame stabilized farther from the injector nozzle. Due to the cooler flame being closer to the injector [79], the WCO injection had a shorter launch length than diesel. WCO biodiesel exhibited a somewhat lower cylinder peak pressure than diesel combustion. Due to a somewhat longer ignition delay than diesel, WCO biodiesel demonstrated a greater pre-mixed combustion peak [70].

6.3. Brake Thermal Efficiency (BTE)

Thermal braking efficiency measures the engine's capacity to transform chemical energy from fuel into mechanical energy [104]. The ratio of a motor's mechanical energy output to the total thermal energy given is known as brake thermal efficiency (BTE). The calorific value, density, and viscosity of fuel all significantly impact AHO [56]. Many investigations have focused on the effects of biodiesel on the combustion, performance, and emissions characteristics of diesel engines. Most literature shows no significant changes in brake thermal efficiency (BTE) when using biodiesel. Numerous studies have examined how biodiesel affects how diesel engines burn, function, and emit emissions. The majority of the literature indicates that utilizing biodiesel does not significantly alter brake temperature efficiency (BTE).

The impact of injection pressure and timing on DI diesel engines running on biodiesel made from used cooking oil was studied [105]. The brake thermal efficiency significantly increased due to the interaction between an advanced injection time of 25.5ObTDC and a greater injection pressure of 280 bar. BTE rises from 0.16 to 0.65 MPa with increased engine load but falls from 0.65 to 0.73 MPa. Due to the extremely high fuel-to-air ratio, partial combustion results in a drop in BTE at a heavy load of 0.73 MPa [98]. Performance-wise, mixing biofuels with diesel fuel often results in higher brake-specific fuel consumption (BSFC) but lower thermal braking efficiency (BTE) [56]. These related results demonstrated that, due to the declining trend in BSFC, BTE exhibits an increasing trend along with an increase in motor load. Generally speaking, as biodiesel content increased, the BTE of the engine burned with the blends dropped [93]. According to Muvva et al. [106] comparison of diesel, the fuel blend consists of 80% diesel, 20% biodiesel from used cooking oil, and 100 mg/ml alumina nanoparticles. They concluded that the tested fuels did not significantly differ in terms of the thermal efficiency of the brakes. The variation was brought on by the WCO mixed fuel's reduced calorific value and increased viscosity.

In general, the BTE of diesel is higher than biodiesel (B100), increasing the ratio of biodiesel in diesel reduces the BTE. **Table 2** shows that the lowest brake thermal efficiency was obtained by Wu et al. [107], which was done by mixing 10% biodiesel in diesel. This is proven by a slight decrease in BTE compared to conventional diesel. Furthermore, the highest reduction in BTE was found by Gad et al. [77] (36.36%). This is possible because the density of biodiesel slightly exceeds the permitted biodiesel standard of 883 kg/m^3. However, several researchers, Pauline et al. [108], Kataria et al. [100], and Reddy et al. [99], found different facts as usual, where the BTE was higher than conventional diesel, 6.25%, 14.2%, and 18.51% respectively. This is undoubtedly very interesting to study in more depth to find the relationship between BTE and several related factors.

6.4. Brake Power and Torque

Braking power (B.P.) is the overall power generated by a motor at the output shaft. It can be described as the total useable energy an engine produces each second. BTE and B.P. are inversely correlated [56]. Similar results were observed by Chuah, et al. [95] for B.P. in blended biodiesel and diesel fuel. This trend grew with increasing engine speed, starting at 1,000 rpm and peaking at 1,900 rpm. It dropped above this engine speed due to a more vital frictional force. This is caused by biodiesel's lower energy content, higher density, and higher viscosity than diesel, resulting in poor atomization, mixture formation, and low combustion efficiency. Chuah, et al. [95] claimed that all biodiesel blends tested typically deliver lower peak torque at a lower engine speed of 1150 rpm than diesel fuel. This is mainly due to the reduction in the calorific value of biodiesel. A higher O content in WCOME leads to lower torque than diesel fuel.

Compared to diesel, the calorific value of biodiesel is generally lower, causing a decrease in the brake power produced. The brake power review found by several researchers is presented in **Table 2**. The highest reduction in BP was found by Yesilyurt et al. [85] (52.72%), and the lowest was 3.84% by Bhuiya et al. [109]. Yesilyurt et al. found a reduction in BP of 52.72% compared to diesel, and this was mainly due to the density and kinematic viscosity being relatively high so that they did not meet the permitted standards of 32.52 mm^2/s and 920 $kg/m^{3,}$ respectively. The torque of the machine is generally comparable to brake power; the highest decrease in torque value was found by Yesilyurt et al. [85] at (27.52%), and the lowest by Bhuiya et al. [109] at (4.28%).

6.5. Emission Characteristics of WCO Biodiesel

Particle number density Due to less oxygen in the molecular structure, waste cooking biodiesel had the least decline in PM level [110]. Under 100% load, the PM content of WCB20 fuels falls by 40.06% compared to diesel. Particles from diesel exhaust can lead to cardiovascular illness, respiratory problems, and bad lung health effects. Genotoxicity, carcinogenicity, and mutagenicity have also been linked to particles from diesel and biodiesel emissions [88]. At 50% engine load, there were significant trace quantities of the metals Ca, Cu, Fe, K, Mg, Na, Zn, and Al, but Ba, Cd, Cr, Mn, and Mo had significantly lower trace amounts. Since biodiesel engines were found to have lower particle concentrations of most trace metals than baseline mineral diesel, trace metal emissions from biodiesel engines may be more ecologically friendly than those from mineral diesel [97].

Ternary biodiesel's CO2 and NOx emission values (WTC, WCO, and Diesel) are higher than those using Diesel oil [58], [93]. The higher density of biodiesel compared to diesel oil is the cause of the increase in CO2 numbers. Besides that, the fuel injection system is not compatible with changes in density [58]. Besides that, excessive oxygen during the combustion process takes place as a cause of higher CO2 emission content [58], [82]. High oxygen content will form the formation of nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N2O) in combustion chemistry, often referred to as NOx [58], [82]. This contradicts the statement of Hwang and Gupta [70] that an increase in oxygen in the combustion process reduces NOx emissions. Increasing the biodiesel mixture up to B30 affects reducing the concentration of Hydrocarbon (H.C.) and Carbon monoxide (C.O.) but increases the concentration of NOx [111].

6.6. Unburned Hydrocarbon Emissions

Unburned hydrocarbon emissions are reliant on the presence of oxygen. The H.C. emissions decrease with increasing oxygen content [56]. The gaseous and particle emissions of a 4-cylinder naturally aspirated direct injection diesel engine running on various blended ratios of biodiesel and diesel are investigated [90]. The findings indicate that using biodiesel lowers the level of H.C. Compared to diesel fuel, biodiesel blends had lower H.C. emissions [68]. Higher payloads result in lower hydrocarbon emissions, but higher biodiesel contents produce higher emissions. Due to the larger density of biodiesel and the more difficult fuel atomization caused by the higher viscosity of biodiesel than diesel oil, a greater mass was injected [112]. Adding additional Ce0.5Co0.5 nano-composite oxide (100 ppm) as an additive decreased UBHC exhaust emissions by 40.74% [113].

Hydrocarbon emission values decrease as engine speed increases. Afterward, increasing the ratio of biodiesel in diesel also reduces the value of hydrocarbon emissions. Almost all findings show a decrease in HC emission values at full load. The highest reduction in HC value was found by Ranjan et al. [87], namely 599%, and the lowest was found by Balasubramanian et al. [114] (3.7%) compared to conventional diesel. Different results were found by Sahabdheen et al. [86], where the hydrocarbon emission value was 80% higher compared to diesel.

6.7. Carbon Monoxide Emissions

Due to the flame front approaching the gap volume and the comparatively cool cylinder liner, C.O., a poisonous gas, is produced during incomplete combustion. Diesel fuel emits more C.O. than biodiesel blends do. This was due to the higher O-element content in biodiesel mixes, which improved combustion [95]. Chacko [115] examines the impact of graphene-based nanoparticles, specifically graphene oxide (G.O.) and graphene nanoplatelets (GNP), as fuel additives on the combustion and emission characteristics of a turbocharged diesel engine.

According to Abed [68], biodiesel blends emit less carbon monoxide than regular diesel fuel. Increased CO emissions result from a higher biodiesel content in the fuel mixture. Reduced fuel atomization is the primary factor in C.O. production in diesel engines [112]. CaO nanoparticles added to biodiesel have a lower carbon monoxide content than diesel [99]. The additive was given a tiny dose of WCO alumina. C.O. emissions were impacted by biodiesel. Because of the higher viscosity, the C.O. emissions increased somewhat but steadily decreased for the blended fuels [106]. According to Akram et al. [113], Ce0.5Co0.5 nanocomposite oxide performed somewhat better than CeO2 at reducing exhaust emissions from the combustion of different biodiesel blends. Ce0.5Co0.5 nano-composite oxide was added and decreased C.O. emissions in the exhaust by 24.18% (100 ppm).

The lack of oxygen in the combustion chamber causes increased CO emissions. CO emissions produced by internal combustion engines vary greatly depending on the excess air factor. Furthermore, cetane number and high oxygen content in biodiesel increase combustion efficiency, reducing CO emissions. The highest reduction in CO emissions (110.81%) was found by Ranjan et al. [87], and the lowest was (6.66%), which was the result of Gao et al. [54], as shown in **Table 2**.

6.8. Carbon Dioxide

The high number of carbon and oxygen atoms in biodiesel causes increased CO2 emissions during combustion compared to diesel [85]. In general, CO_2 emissions increase with increasing load and the ratio of biodiesel in diesel, and conversely, CO_2 emissions continue to decrease with increasing engine speed. Apart from that, the CO2 emissions produced by biodiesel are higher than those from diesel. The research results of several authors are presented in **Table 2**. The most significant increase in CO_2 emissions (50%) compared to other authors was found by Sahabdheen et al. [86], and the lowest (5%) was found by Zare et al. [94].

6.9. Oxides of Nitrogen (NOx) Emissions

Hwang [62] studied the impact of injection parameters on combustion and emission characteristics in a direct injection common rail diesel engine powered by waste cooking oil biodiesel. The findings showed that nitrogen oxide (NOx) biodiesel emissions were comparatively greater than diesel [56]. Biodiesel blends had higher NOx emissions than pure diesel [68]. For all engine loads, NOx emissions rose on the B5 and B10 biodiesel fuel mixes by 6.4% and 8.7%, respectively. It is generally known that combustion temperature, oxygen concentration, and time all affect the generation of NOx emissions [93]. According to Reddy et al. [99], the addition of CaO nanoparticles causes nitrogen oxide emissions to increase. Low loads led to a more significant increase in NOx [112]. The little increase in NO_X production when biodiesel fuel blends are used in place of diesel oil is likely caused by oxygen present in the molecular structure of the fuel [112]. Up to 50% load, NOx emissions for biodiesel blends are marginally lower and rise as load increases. One of the causes of NOx variation may be an increase in fuel viscosity and a decrease in cetane index [106]. The impact of cerium oxide and cerium composite oxide as nano additives on waste oil-based biodiesel's gaseous exhaust emission profile at full engine load was studied by [113]. Using $Ce_{0,5}Co_{0,5}$ nanocomposite oxide (100 ppm) as an additive, NOx emissions from exhaust were reduced by 13.96%.

The engine test results and exhaust emissions for diesel and biodiesel fuel are shown in **Table 2**. Diesel shows lower NOx emissions than WCO biodiesel. The highest increase in NOx emissions (120%) was found by Gad et al. [77], and the lowest (1%) was obtained by Balasubmaramian et al. [114].

6.10. Smoke or PM Opacity

The term "smoke opacity" (SO) describes how easily one can see through a fuel's exhaust fumes. The smoke density of the fuel is better and lower the cleaner the combustion. Numerous factors, including flash points, oxygen content, combustion temperature, etc., affect the opacity of smoke [56]. Hwang [62] investigated the impact of the injection pressure and timing on the smoke emission of biodiesel fuel. As injection pressure and timing are increased, the biodiesel smoke level drops. The 280 bar biodiesel operation at the injection time of 25.5ObTDC results in the lowest smoke opacity of 34.9% [116]. reported that burning a mixture of treated waste cooking oil (TWCO) and diesel significantly reduced smoke opacity. Reduction in smoke opacity (SO) from WCOBD compared to CD shows the clean burn trend [56], but smoke opacity increased when the CaO nanoparticles were added [99]. The smoke opacity values depend on engine speeds and fuel injection pressure. The minimum smoke opacity values for fuel samples were at 210 bar, and 3200 rpm for the B100 fuels was 1.73 l/m [85]. **Table 2** shows several studies on performance and emission for WCO biodiesel-diesel blends.

7. Wear and Friction

Lubrication serves some reasons, including lowering the coefficient of friction between two contact surfaces, reducing wear, and increasing cooling caused by moving contact surfaces [122]. Typically, petroleum fuels are used to make lubricants [123]. A lubricant is used to reduce wear and friction between interacting surfaces. Wear and heat can be reduced to insignificant or tolerable levels but cannot entirely remove Ameen [124]. Due to its superior lubricating performance, biodiesel can efficiently minimize engine component wear and increase engine life [76].

Moreover, it has good lubricating characteristics, a low viscosity, a high octane number, and a high flash point [60]. According to Hisham [122], at 5% and 10% volume concentrations of used cooking oil, the coefficient of friction-specific wear rate (W.R.) increased. The SEM image reveals that the sample surface experienced minor wear, pitting, and severe delamination as the load was raised. Additionally, according to Ameen [124], employing a lubricant made of leftover cooking and soybean oil is reasonably practical [124]. According to Singh [126], the blend had a 10% lower wear rate and COF than SAE20W40 and higher ratios. **Table 3** shows wear and friction on various materials of WCO biodiesel.

8. Corrosion Rate Characteristics

The drawback of biodiesel is that long-term storage reduces its oxidative stability and causes corrosion in material transit or metal storage tanks [84]. It is well known that biodiesel corrodes metal

Table 3. Wear and friction on various materials of WCO biodiesel

Test Fuel	Test Equipment	Materials	Operation condition/adjustment	Wear and Friction Characteristics Comparison with Diesel Fuel	Ref.
B10+SAE20W40	HFRR and Pin on disc	Cylinder liner piston ring	105 °C, Normal load 40 N for 180 min, track length 20 mm, Relative sliding velocity of disk and pin 1.046 m/s, speed 500 rpm, test oil flow rate 17 gm/ min,	WSD, SFR, and COF ↑ with the ↑ biodiesel concentration and	[123]
SAE 40+ 5-10%WCO	Reciprocating	Piston skirt (Al6061)	rotational speeds (200-300 RPM), volume concentration (5% and 10% of waste cooking oil), and loads (2 kg, 5.5 kg, and 9 kg), time 10 min	COF and W.R. ↑ with the volume concentration of waste cooking oil	[122]
Soybean oil + WCOME	Pin on disc	AISI 52100 100Cr6	100, 300, 500 rpm; 5, 10 and 20 N loads, sliding velocities, and 500 m	the mixture of soybean oil used frying oil FAMEs are eco-friendly lubricants as a candidate.	[124]
WCO and Calopylum Inophyllum	Four ball tester	Steels	75 °C, Load 40 kg, and spindle speed 1200 rpm	The mixture of biodiesel and diesel significantly ↓ WSD and ↑ CoF. A mixture of biodiesel and lubricant (25:75) significantly ↓ WSD.	[125]

parts more than petroleum diesel [127]. Carbon steel is the most frequently used material to create gasoline tanks [128]. According to Fazal [129], the oxidation of iron from Fe to Fe^{2+} and then to Fe^{3+} is the primary mechanism by which ferrous metals corrode. However, the type of alloy, corrosive media, and atmosphere affect how quickly something will corrode. The formation of FeO and Fe_2O_3 oxides is nearly particular on ferrous metal surfaces exposed to biodiesel. The concentration and type of compounds that develop on ferrous metal exposed to biodiesel fluctuate with immersion time [129].

There are not many studies on metal corrosion in WCO biodiesel. The impact of temperature immersion was studied by [127]. It was discovered that the copper led to more severe biodiesel breakdown and chain breakage. It was discovered that the corrosion rate of copper was around 100 times more than that of mild steel, Al7075, and Al1050 and was 10 times greater than that of brass. Over 960 hours of exposure, it was discovered that brass exposed to B100 corroded at a greater rate than brass exposed to B0. Regarding fuel quality and corrosion properties, B10 is an acceptable substitute for diesel [130].

The introduction of antioxidants increases the biodiesel stability of used cooking oil and slows down the breakdown of biodiesel. Antioxidants also slow down the corrosive reactions that attack steel and copper, reducing the corrosion rate [84]. In this regard, some research published in the literature has demonstrated improved biodiesel storage stability. Deyab [128] mentioned that antioxidants were added to the B20 biodiesel blend. With a 95% efficiency in B20, butyl hydroxytoluene (BHT) offers decent carbon steel corrosion preventive capabilities [128]. The impact of antioxidants (tert-butylhydroquinone, curcumin, propyl gallate, and butyl hydroxyanisole) on biodiesel and metal surfaces was studied by Serquira et al. [84]. The findings demonstrated that all antioxidants inhibited the breakdown of biodiesel because of their antioxidant capabilities. Subedi [131] studied the phenomena with a strong corrosion inhibitor effect of V. Negundo plant extract on aluminium and copper metals in B100 and B10. The most excellent corrosion inhibition efficiency for copper metal was around 96% and 60% in B100 and B10, respectively, while the maximum corrosion inhibition efficiency for aluminium metal was roughly 83% in both B100 and B10. The Corrosion rate on various materials after contact with biodiesel WCO is tabulated in **Table 4**.

9. Conclusion and Future Scope of Work

Recycling WCO as biodiesel has drawn countries to mass production because the raw materials are easily obtained. Utilizing WCO as a low-cost biodiesel feedstock source has major advantages over fossil diesel and refined vegetable oil. WCO generates fuel of poor quality that needs to be refined. The main issues are low biodiesel yields brought on by high levels of free fatty acids (FFA), the presence of water, and other contaminants, such as polar molecules and non-stability. The biodiesel WCO has poor oxidation stability and cold flow characteristics compared to biodiesel WCO. Furthermore, biodiesel WCO has a high Cetane number, iodine value, kinematic viscosity, density, cloud and pour point, cetane number, and density. However, they have low heating values and flash points.

The biodiesel WCO has a higher viscosity than diesel oil, which makes it harder to atomize and necessitates injecting a more significant mass amount. This leads to higher fuel consumption, longer delays, and peak injection rates. The biodiesel WCO produces low engine torque and brake thermal efficiency (BTE) but greater NOx

Table 4. The corrosion rate of materials biodiesel WCO

Materials	Methode	Biodiesel	Time immersion (hour)	Corrosion rate (mm/year)	Ref
Carbon Steels	Immersion	B100	1,200	0.00043	[128]
Carbon Steels	Immersion	B100	2,000	0.04	[84]
Copper	Immersion	B100	2,000	0.2	[84]
Mild Steels	Immersion	B100	270	< 0.00004	[127]
Al 1050/ Al 7075	Immersion	B100	270	< 0.0012	[127]
Copper (Cu30Sn)	Immersion	B100	270	< 0.08	[127]
Brass	Immersion	B100	270	< 0.0075	[127]

emissions. Compared to diesel, the rate at which different materials corrode after coming into contact with biodiesels increases. Antioxidants added to biodiesel WCO effectively lower copper and steel corrosion rates. Engine component wear can be effectively reduced, and engine life can be increased with biodiesel WCO. It was discovered that particles originating from diesel fuel engines had fewer trace metals.

In contrast, increased concentrations of biodiesel result in higher emissions and higher load power results in lower H.C. emissions and more CO_2. Compared to standard mineral diesel, the emissions from engines running on biodiesel are more environmentally friendly. The amount of trace metals in particles that came from diesel-fueled engines was found to be lower. A higher load produces lower CO and hydrocarbon (H.C.) emissions and higher NOx and CO_2, while higher biodiesel concentration produces higher emissions.

There are enough chances to enhance the physiochemical characteristic of biodiesel WCO, particularly in low-quality oils. The development of natural antioxidant and purification technology will be critical to improve biodiesel's oxidation stability, which will impact the rate at which metals corrode. The emissions from biodiesel engines are less harmful to the environment than those from conventional mineral diesel.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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All data are available from the authors.

Competing interests

The authors declare no competing interest.

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