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The Concise Latest Report on the Advantages and Disadvantages of Pure Biodiesel (B100) on Engine Performance: Literature Review and Bibliometric Analysis

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A B S T R A C T

Currently, many countries are promoting B100 as the main fuel for diesel engines towards the transition to 100% renewable energy applications. However, due to its properties, B100 has both advantages and disadvantages to replace diesel oil. Therefore, a bibliometric analysis was carried out to evaluate the performance and emissions of a diesel engine with the B100 being tested on a multi-cylinder diesel engine for cars. Unfortunately, only 12 of the 127 selected articles are eligible to be reviewed in detail and none of them discusses all the key performance of diesel engines which include Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC), Cylinder Pressure (CPs), Heat Release Rate (HRR), NOx, and smoke. Through data synthesis, we found that the use of B100 provides advantages in engine noise, thermal efficiency, specific fuel consumption, and emissions under certain engine loads. On the other hand, it also has the potential to result in poorer performance, if there is no modification to engine components and the addition of additives. As a recommendation, the results of this analysis provide a guide for further research to examine the use of B100 with all diesel engine performance variables. Research paths can be developed with the wider potential to provide new arguments on various diesel engine technologies, engine capacities, B100 raw materials, and test environments.

1. INTRODUCTION

In the last decade, the issue of global warming and climate change continues to strengthen and it is associated with the use of oil-based fuels (Franta, 2021; Ginanjar Ahmad Zakky, 2020; Sinaga, 2020) which have more environmental risks from exploration, transportation, production, distribution, and consumption (Chettouh *et al.*, 2016). Natural damage in oil drilling areas (Harnani, 2018), cases of oil spills in the Gulf of Mexico and the Atlantic are other examples of environmental threats from fossil fuels (Bhattarai *et al.*, 2011; Soares *et al.*, 2020). In fact, a greater risk is reported in Nigeria, where oil spills are significantly correlated with humanitarian tragedy (Bruederle & Hodler, 2019).

On the other hand, efforts to find and implement alternative energy are also a strong challenge for many countries, regarding availability, prices, environmental balance, and also policies (Hadiyanto *et al.*, 2020; Kaniapan *et al.*, 2021; Panoutsou *et al.*, 2021; Yusoff *et al.*, 2021). The sustainability of the industrial and transportation sectors with renewable fuels continues to be carried out through the substitution of fossil fuels, either with a fully dedicated system or with a bi-fuel system or a hybrid system (Anderhofstadt & Spinler, 2020; Shao & Dessouky, 2020). The transition to the adoption of 100% renewable energy is a complex process, not only on technical issues, but also on political, economic, and social issues. For example, the expansion of the use of bioethanol will face the availability of land for food production (de Souza Ferreira Filho & Horridge, 2014).

For the transportation sector, the expansion of biodiesel for the internal combustion engine (IC) is more prospective than bioethanol for spark ignition (SI) engines. The properties of biodiesel, which are closer to diesel oil at competitive prices, make it a reasonable choice for a 100% transition. Raw materials for biodiesel production are also increasingly diverse, with the discovery of superior varieties of local plants that have been proven to produce good biodiesel, including:
(i)   Palm (Arifin *et al.*, 2019; Marlina *et al.*, 2020)
(ii) Coconut (Nanlohy *et al.*, 2020),
(iii) Nyamplung/Calophyllum inophyllum L. (Fadhlullah *et al.*, 2015; Fauzan *et al.*, 2020; Pambudi *et al.*, 2021),
(iv) Jatropha (Fajar & Setiapraja, 2014; Silitonga *et al.*, 2016),
(v)   Kemiri sunan/Reutealis trisperma (Supriyanto *et al.*, 2019; Supriyadi & Purwanto, 2018),
(vi) Waste cooking oil (Ayu *et al.*, 2019; Hadiyanto *et al.*, 2020),
(vii) Rubber (Supriyanto *et al.*, 2019), and
(viii) Plastic-derived fuels (Sunaryo *et al.*, 2021).

Especially for waste cooking oil, in addition to producing biodiesel, it also contributes to the environment by reducing the potential for waste from restaurants and the cooking oil-based food industry (Kolakoti *et al.*, 2021).

The technology for biodiesel production which includes starting materials, pre-treatment methods, reactors, and processing methods, catalysts, and testing methods is also developing rapidly (Hariyanto *et al.*, 2021; Mahlia *et al.*, 2020; Zetra *et al.*, 2021; Hidayat *et al.*, 2022). On the other hand, cleaner ethanol (Vohra *et al.*, 2014; Wahyu *et al.*, 2019; Waluyo *et al.*, 2020) with its different properties from gasoline and the relatively large price difference, requires major modifications to the engine components and increases driving operating costs, making it weaker in terms of market acceptance (Mudombi *et al.*, 2018).

As an alternative fuel with all its advantages, biodiesel also has several disadvantages, including a very high flash point causing delayed ignition, cold flow properties, and poor oxidation stability contributing to its disadvantages (Atabani *et al.*, 2012; Bukkarapu, 2019; Firoz, 2017).

Therefore, blending biodiesel with diesel oil is widely used to reduce its disadvantage. Although currently the use of pure biodiesel (B100) is the future target market and is commercially available, B100 research reports on multi-cylinder car engines are still limited, they are dominated by testing on low-speed single-cylinder engines (Ajith *et al*., 2021; Altaie, 2020; Arun *et al*., 2020; Kumar & Subramanian, 2020; Örs *et al*., 2020; Rameshbabu *et al*., 2020; Singh *et al*., 2020; Viswanathan *et al*., 2020; Yatish *et al*., 2021). Although the working principle is the same, car engines have complexities related to performance.

In addition, the performance of diesel engines is also more complex than gasoline engines, which include Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC), Cylinder Pressure (CPs), Heat Release Rate (HRR), NOx, and Smoke. Partial engine testing with some parameters, of course, cannot measure the overall performance of the B100, considering that these parameters influence each other. The reason this parameter is studied in depth is that the parameters of BTE and SFC are part of engine performance which are very important to analyze because they are related to the use of fuel in diesel engines. As it is known that the main purpose of using biodiesel fuel is to replace diesel fuel to reduce fossil fuel consumption. Likewise, parameters of the cylinder pressure and the heat release rate are representations of engine power that describe the combustion process in the cylinder so that knowing these two parameters can describe engine performance. The parameters of NOx and smoke emissions are important reviewed in this article that diesel engines contribute greatly to producing these emissions so that this is a concern in the world by setting thresholds for these emission levels as issued by the Ministry of Environment and Forestry and the European Union.

Therefore, this article presents a concise literature review and bibliometric analysis on the advantages and disadvantages of the B100 which was tested on a multi-cylinder diesel engine with a capacity above 1 liter, which is considered more representative of real application conditions than single or twin cylinder engines. The literature were reviewed from search engine (Azizah et al., 2021). Then, the references and limitations reviewed are presented in detail in **Table 1** (see method section).

As the uniqueness of this work, we used VOSviewer to determine the topics studied (bibliometric analysis), as has been practiced by Hamidah et al. (2020) and Husaeni and Nandiyanto (2022). Key performance of diesel engine which includes Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC), Cylinder Pressure (CPs), Heat Release Rate (HRR), NOx, and Smoke is used in the search method for articles in the Scopus database. The iteration results by VOSviewer show they have a strong relationship, as presented in **Figure 1**. Therefore, the specific purpose of this work is to analyze the advantages and disadvantages of B100 in diesel engines by considering the combustion process which includes cylinder pressure, heat release rate, and engine performance including thermal efficiency, specific fuel consumption, and exhaust emissions including nitrogen oxide and smoke emissions.

Figure 1. Visualization topic area by VOSviewer (network visualization).

2. METHODS

2.1. Searching method and criteria

In the present work, we used Scopus as the single database. Searching on article titles, abstracts, and keywords were chosen because they are more representative of the keywords "B100", "performance", "emission". Therefore, the constraints were determined, only selected articles were continued in the discussion, and articles that were not included in the scope of the review were excluded, including:

(i) Articles from discontinued covered journals and from journals that are alleged to have not carried out a rigorous peer-review process;

(ii) Articles that are not included in the original research paper;

(iii) Inaccessible articles;

(iv) Articles that do not discuss engine performance;

(v) Articles mentioning B100 in the abstract and body text but not finding B100 testing in the methods and results; and

(vi) Articles that present tests on engines with small capacities, generally on single and twin cylinder engines, or the tests are not on vehicle engines.

The limitations of article selection in the Scopus database are presented in **Table 1.**

2.2. Screening for eligibility

Of the 127 articles that we obtained from the Scopus database, we found 26 articles that did not pass the initial screening process, 14 papers indicated that they were published in discontinued coverage journals, 2 papers from journals that were allegedly not peer-reviewed journals, 3 papers were not accessible, 1 paper did not discuss biodiesel, 3 papers did not discuss B100, 2 papers did not discuss engine performance, and 1 paper was a review paper. Then, from the second stage of selection, 88 papers were excluded because 82 papers were tested on single-cylinder diesel engines, 5 papers tested on small twin-cylinder engines, and 2 other papers were not confirmed. Finally, we got 12 articles that were selected and qualified for detailed review (Abdalla, 2018; Aydın, 2020; Esonye *et al.*, 2019; García-Martín *et al.*, 2018; Ge *et al.*, 2020; Ghadikolaei *et al.*, 2019; Hojati & Shirneshan, 2020; Isik, 2021; Odibi *et al.*, 2019; Santos *et al.*, 2017; Thangaraja & Srinivasan, 2019; Tosun & Özcanlı, 2021), as presented in **Figure 2**.

Table 1. Limitations of searching criteria.

No	Searching criteria	:	Limitation
1.	Database	:	Scopus
2.	Search within	:	Article title, abstract, keyword
3.	Search document	:	B100, performance, emission
4.	Type of access	:	All (All Open Access, Gold, Hybrid Gold, Bronze, Green)
5.	Year	:	2017-2021
6.	Subject area	:	Engineering, Energy, Chemistry, Environmental Science, Chemical engineering
7.	Document type	:	Article
8.	Publication stage	:	Final
9.	Source title	:	All (not specified)
10.	Keywords	:	All (not specified)
11.	Affiliation	:	All (not specified)
12.	Funding sponsor	:	All (not specified)
13.	Country	:	All (not specified)
14.	Source type	:	Journal
15.	Language	:	English
16.	Date access	:	June 20, 2021
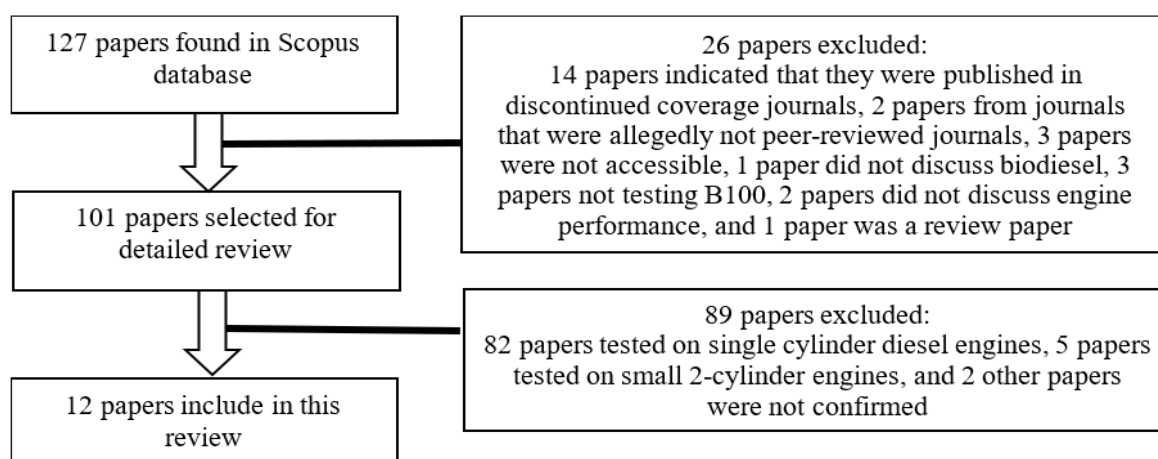
Figure 2. Content selection process and criteria.

3. RESULT AND DISCUSSION

3.1. Data Synthesis

This section describes the data synthesis from previous studies related to engine performance and emissions in diesel engines using B100. The key performance characteristics of diesel engines (Balasubramanian *et al.*, 2021) including Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC), Cylinder Pressure (CPs), Heat Release Rate (HRR), NOx, and Smoke were examined in 12 reviewed articles. The results of the synthesis data review are described in **Table 2** and **Table 3**, respectively.

Unfortunately, only 12 of the 127 selected articles are eligible to be reviewed in detail and none of them discusses all the key performance of diesel engines which include Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC), Cylinder Pressure (CPs), Heat Release Rate (HRR), NOx, and smoke, all article discusses partially. The data testing scope is presented in **Figure 3**.

Table 2. Review of data synthesis from engine performance characteristics and emissions using pure biodiesel (B100).

No	Raw material, Refs	Engine use	Method and Variable	Main finding (conclusion remark)
1.	African Pear (Dyacrodes edulis) Seed Oil (Esonye *et al.*, 2019)	Perkins 4:108	Experimental research methods and statistical tests using ANN. The variables studied included engine load (5-40 Nm), biodiesel blends (B20-B100), and engine speed (1500-3500 rpm).	1. Higher thermal efficiency than diesel oil at all engine loads. 2. Lower SFC than fossil diesel at all engine loads. 3. Higher NOx emission levels than diesel oil at all engine loads.
2.	Coconut (Thangaraja & Srinivasan, 2019)	3.298L, 70 kW	Experimental research with variables including BMEP 1.7-8.4 bar and an engine speed of 1000-2000 rpm.	1. Peak cylinder pressure is slightly lower than diesel oil at low and high loads. 2. Peak heat release rate is slightly lower than diesel oil at low and high loads. 3. Higher thermal efficiency than diesel oil at all engine loads. 4. NOx levels are lower at low loads, while at medium and high loads the Nox is higher than diesel oil.
3.	Crude palm oil (Ge *et al.*, 2020)	4-cylinder CRDI	Experimental research with variables including EGR rate (0-20%), fuel injection timing (14°-34°BTDC), and engine load (35 and 105 Nm).	1. The peak cylinder pressure does not show a significant difference from diesel oil at low and high loads. 2. The peak heat release rate did not show a significant difference from diesel oil at low and high loads. 3. Higher SFC than diesel oil at low and high loads. 4. NOx is higher than diesel oil at low and high loads.
4.	Waste cooking oil (García-Martín *et al.*, 2018)	2.0 TDI 140 hp	Experimental research at an engine speed of 1000-3000 rpm and engine load of 15%-45%.	1. SFC is higher than diesel oil at low and medium loads. 2. NOx is higher than diesel oil at low and medium loads.
5.	Safflower (Isik, 2021)	NWK22	Experimental research on biodiesel with the addition of alcohol (20%) and at engine load of 25-75%.	1. Lower cylinder pressure than diesel oil at medium load (75%). 2. Lower heat release rate than diesel oil at medium load (75%). 3. Lower thermal efficiency than diesel oil at low load, but higher at medium load. 4. Higher SFC than diesel oil at all engine loads. 5. NOx is higher than diesel oil at all engine loads.
6.	Safflower (Aydın, 2020)	2.4 L Diesel	Experimental research on biodiesel with the addition of methyl proxitol and ethyl proxitol catalysts (10%) and at engine load of 20-60%.	1. Lower cylinder pressure than diesel oil at medium load (60%) 2. Lower heat release rate than diesel oil at medium load (60%) 3. Thermal efficiency values are lower than diesel oil at low and medium loads. 4. SFC is higher than diesel oil at low and medium. 5. NOx is higher than diesel oil at low and medium loads.

Table 2 (Continue). Review of data synthesis from engine perfomance characteristics and emissions using pure biodiesel (B100).

No	Raw material, Refs	Engine use	Method and Variable	Main finding (conclusion remark)
7.	Soybean (Tosun & Özcanlı, 2021)	4D34-2A	Experimental research with the addition of nanoparticles (Al_2O_3) and hydrogen to biodiesel, at an engine speed of 1200-2800 rpm.	1. Higher SFC than diesel oil at full load. 2. NOx higher than diesel oil at full load.
8.	Soybean (Santos *et al.*, 2017)	D225-6	Experimental research on the fuel mixture (B5-B100) was carried out at engine load of 9, 18, and 27 kW	1. Higher SFC than diesel oil at low and medium loads. 2. NOx higher than diesel oil at low and medium loads.
9.	Vegetable-based (Abdalla, 2018)	Ford 1.8L	Experimental research on a biodiesel blend (B25-B100) and BMEP 1-6 bar.	1. Higher thermal efficiency than diesel oil at all engine loads. 2. Lower SFC than diesel oil at all engine loads. 3. Lower NOx than diesel oil at all engine loads. 4. Smoke was higher than diesel oil at low and medium, while lower levels were found at high loads.
10.	Waste cooking oil (Ghadikolaei *et al.*, 2019)	4434L	Experimental research on biodiesel blends (B0-B100) and the engine load of 5-95%,	1. Higher thermal efficiency than diesel oil at all engine loads. 2. Higher SFC than diesel oil at all engine loads. 3. NOx is higher than diesel oil at all engine loads. 4. Lower smoke than diesel oil at all engine loads.
11.	Waste cooking oil (Odibi *et al.*, 2019)	Cummins ISBe220 31	Experimental research with the addition of triacetin (4, 5, 8, and 10%) to the B100 at engine speeds of 1472, 1865, and 2257 rpm; and at engine load (25-100%).	1. Higher thermal efficiency than diesel oil at all engine loads. 2. Higher SFC than diesel oil at all engine loads.
12.	Waste cooking oil (Hojati & Shirneshan, 2020)	OM 355	Experimental research and thermodynamic simulation using MATLAB on variables that include: a. Biodiesel blends (B0-B100) b. Compression comparison (14-18) c. Engine load (25-100%)	1. Lower cylinder pressure than diesel oil at high load (100%). 2. Lower heat release rate than diesel oil at high load (100%). 3. Lower thermal efficiency than diesel oil at all engine loads. 4. NOx higher than diesel oil at all engine loads.

Table 3. Testing scope of the selected reviewed articles

No	Raw material, Refs	Engine use	Method and Variable	Testing scope					
				BTE	SFC	CPs	HRR	NOx	Smoke
1.	African Pear (Dyacrodes edulis) Seed Oil (Esonye *et al.*, 2019)	Perkins 4:108	Experimental research methods and statistical tests using ANN. The variables studied included engine load (5-40 Nm), biodiesel blends (B20-B100), and engine speed (1500-3500 rpm).	Yes	Yes	No	No	Yes	No
2.	Coconut (Thangaraja & Srinivasan, 2019)	3.298L, 70 kW	Experimental research with variables including BMEP 1.7-8.4 bar and an engine speed of 1000-2000 rpm.	Yes	No	Yes	Yes	Yes	No
3.	Crude palm oil (Ge *et al.*, 2020)	4-cylinder CRDI	Experimental research with variables including EGR rate (0-20%), fuel injection timing (14°-34°BTDC), and engine load (35 and 105 Nm).	No	Yes	Yes	Yes	Yes	No
4.	Waste cooking oil (García-Martín *et al.*, 2018)	2.0 TDI 140 hp	Experimental research at an engine speed of 1000-3000 rpm and engine load of 15%-45%.	No	Yes	No	No	Yes	No
5.	Safflower (Isik, 2021)	NWK22	Experimental research on biodiesel with the addition of alcohol (20%) and at engine load of 25-75%.	Yes	Yes	Yes	Yes	Yes	No
6.	Safflower (Aydın, 2020)	2.4 L Diesel	Experimental research on biodiesel with the addition of methyl proxitol and ethyl proxitol catalysts (10%) and at engine load of 20-60%.	Yes	Yes	Yes	Yes	Yes	No
7.	Soybean (Tosun & Özcanlı, 2021)	4D34-2A	Experimental research with the addition of nanoparticles (Al_2O_3) and hydrogen to biodiesel, at an engine speed of 1200-2800 rpm.	No	Yes	No	No	Yes	No
8.	Soybean (Santos *et al.*, 2017)	D225-6	Experimental research on the fuel mixture (B5-B100) was carried out at engine load of 9, 18, and 27 kW	No	Yes	No	No	Yes	No

Table 3 (Continue). Testing scope of the selected reviewed articles.

No	Raw material, Refs	Engine use	Method and Variable	Testing scope BTE	SFC	CPs	HRR	NOx	Smoke
9.	Vegetable-based (Abdalla, 2018)	Ford 1.8L	Experimental research on a biodiesel blend (B25-B100) and BMEP 1-6 bar.	Yes	Yes	No	No	Yes	Yes
10.	Waste cooking oil (Ghadikolaei et al., 2019)	4434L	Experimental research on biodiesel blends (B0-B100) and the engine load of 5-95%,	Yes	Yes	No	No	Yes	Yes
11.	Waste cooking oil (Odibi et al., 2019)	Cummins ISBe220 31	Experimental research with the addition of triacetin (4, 5, 8, and 10%) to the B100 at engine speeds of 1472, 1865, and 2257 rpm; and at engine load (25-100%).	Yes	Yes	No	No	No	No
12.	Waste cooking oil (Hojati & Shirneshan, 2020)	OM 355	Experimental research and thermodynamic simulation using MATLAB on variables that include: a. Biodiesel blends (B0-B100) b. Compression comparison (14-18) c. Engine load (25-100%)	Yes	No	Yes	Yes	Yes	No
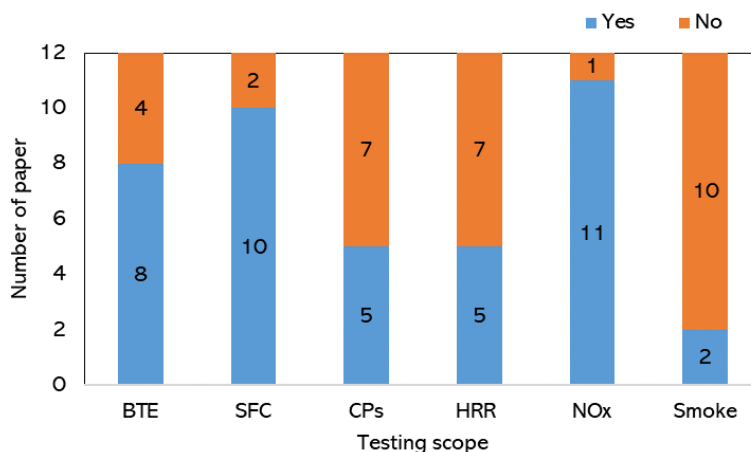
Figure 3. Testing scope comparison of the selected reviewed articles.

3.2 Discussion
3.2.1 Standard of B100

Like other fuels, biodiesel is not standardized by its material, but it is standardized by its properties. Biodiesel standards were developed in the 1990s to facilitate the growing use of alkyl esters-based biodiesel and its mixes as automobile fuels. In 1999, American Society for Testing and Materials (ASTM) International issued PS121, a preliminary standard for biodiesel. In 2002, the first ASTM standard (ASTM D6751) was adopted. **Table 4** shows the selected ASTM International requirements for B100, where these specifications are regularly updated and modified.

3.2.2 Combustion characteristics

3.2.2.1. Cylinder pressure and heat release

The use of B100 resulted in lower cylinder pressure and heat release rate than diesel oil and blended biodiesel especially at low and medium loads, as shown in previous studies (Aydın, 2020; Hojati & Shirneshan, 2020; Isik, 2021). Although it was tested with different types of B100, it also showed the same trend.

Isik (2021) explained that the peak of cylinder pressure and heat release rate with the use of diesel fuel (USLD) reached 80.55 bar and 69.15 J/o respectively at engine load is 75%, while the use of B100 fuel, the value was much lower. Hojati & Shirneshan (2020) also explained that the cylinder pressure drop reached 10.5% with the use of B100 fuel. Research from Aydın (2020) found that the heat release rate using diesel fuel was 73.01 J/CAD and the use of B100 fuel produced a value of 64.767 J/CAD at a load of 10.8 kW.

Aydin (2020) explained that the cylinder pressure drop in the B100 application was caused by poor atomization and mixing due to its high viscosity and density, which resulted in a longer ignition delay and shorter combustion duration. Hojati and Shirneshan 2020) also explained that the cylinder pressure drop was due to the lower LHV of biodiesel than diesel oil. The application of B100 causes the peak cylinder pressure to be closer to the top dead center (TDC) due to the higher cetane number so that the combustion process is more advanced. Therefore, increasing the compression ratio (CR) can increase the cylinder pressure to increase the temperature at the start of the injection, thereby increasing the rate of heat release. **Figure 4** shows the compression ratio (18:1) can increase cylinder pressure in the B100 application by 18.3%.

Table 4. Standard for B100.

Property	Reference Test Methods*	Grade No.1-B S15	Grade No.1-B S500	Grade No.2-B S15	Grade No.2-B S500
Sulfur, % mass (ppm), max	D5453	0.0015 (15)	0.05 (500)	0.0015 (15)	0.050 (500)
Cold soak filterability, s, max	D7501	200	200	360	360
Monoglycerides, % mass, max	D6584	0.40	0.40	-	-
Requirements for All Grades					
Calcium and Magnesium, combined, ppm, max	EN14538	5	5	5	5
Flash point (closed cup), °C, min	D93	93	93	93	93
Alcohol Control: One of the following must be met					
(1) Methanol content, mass%, max	EN14110	0.2	0.2	0.2	0.2
(2) Flash point, °C, min	D93	130	130	130	130
Water and sediment, % volume, max	D2709	0.050	0.050	0.050	0.050
Kinematic viscosity, mm^2/s, 40°C	D445	1.9-6.0	1.9-6.0	1.9-6.0	1.9-6.0
Sulfated ash, % mass, max	D874	0.020	0.020	0.020	0.020
Copper strip corrosion	D130	No. 3	No. 3	No. 3	No. 3
Cetane number, min	D613	47	47	47	47
Cloud point, °C	D2500	Report	Report	Report	Report
Carbon residue[a], % mass, max	D4530	0.050	0.050	0.050	0.050
Acid number, mg KOH/g, max	D664	0.50	0.50	0.50	0.50
Free glycerin, % mass, max	D6584	0.020	0.020	0.020	0.020
Total glycerin, % mass, max	D6584	0.240	0.240	0.240	0.240
Phosphorus content, % mass, max	D4951	0.001	0.001	0.001	0.001
Distillation temperature, 90% recovered (T90)[b], °C, max	D1160	360	360	360	360
Sodium and potassium, combined, ppm, max	EN14538	5	5	5	5
Oxidation stability, hrs, min	EN15751	3	3	3	3

*Other test methods may be used; [a]Carbon residue shall be run on the 100% sample; [b]Atmospheric equivalent temperature

3.2.2.2. Combustion noise

The use of B100 can lower the noise level than the use of diesel oil under low and medium loads. Balasubramanian *et al.,* (2021) explained that the noise level in the use of diesel fuel is 88 dB[A] and the use of B100 fuel is 86 dB[A] at medium load. However, at high loads, the noise level of B100 is higher than that of a blend of biodiesel and pure diesel oil. It is caused by the high oxygen content in B100 which causes the fire to extinguish, causing incomplete combustion and pressure variations in the cylinder (Balasubramanian *et al.,* 2021).

3.2.3 Engine performance

3.2.3.1. Thermal Efficiency

The use of B100 resulted in higher thermal efficiency than diesel oil and blended biodiesel at all engine loads (low, medium, and high) as reported in previous studies (Abdalla, 2018; Esonye *et al.,* 2019; Ghadikolaei *et al.,* 2019; Odibi *et al.,* 2019; Thangaraja & Srinivasan, 2019). The use of B100 includes waste cooking oil (Odibi *et al.,* 2019), vegetable (Abdalla, 2018), coconut (Thangaraja & Srinivasan, 2019), waste cooking oil (Ghadikolaei *et al.,* 2019), dan seed oil (Esonye *et al.,* 2019). Odibi *et al.,* (2019) explained that the increase in thermal efficiency in the use of B100 is due to the high input energy being converted into work. Thangraja & Srinivasan (2019) also explained that biodiesel has a high oxygen content thereby increasing combustion efficiency and lower friction losses due to better lubrication of biodiesel thereby increasing thermal efficiency, as shown in the following **Figure 5**. The same explanation was also reported by Esonye *et al.,* (2019) that the maximum value of BTE is obtained at the use of B100 fuel of 45% while the use of diesel fuel reaches a maximum value of 26% at full load.
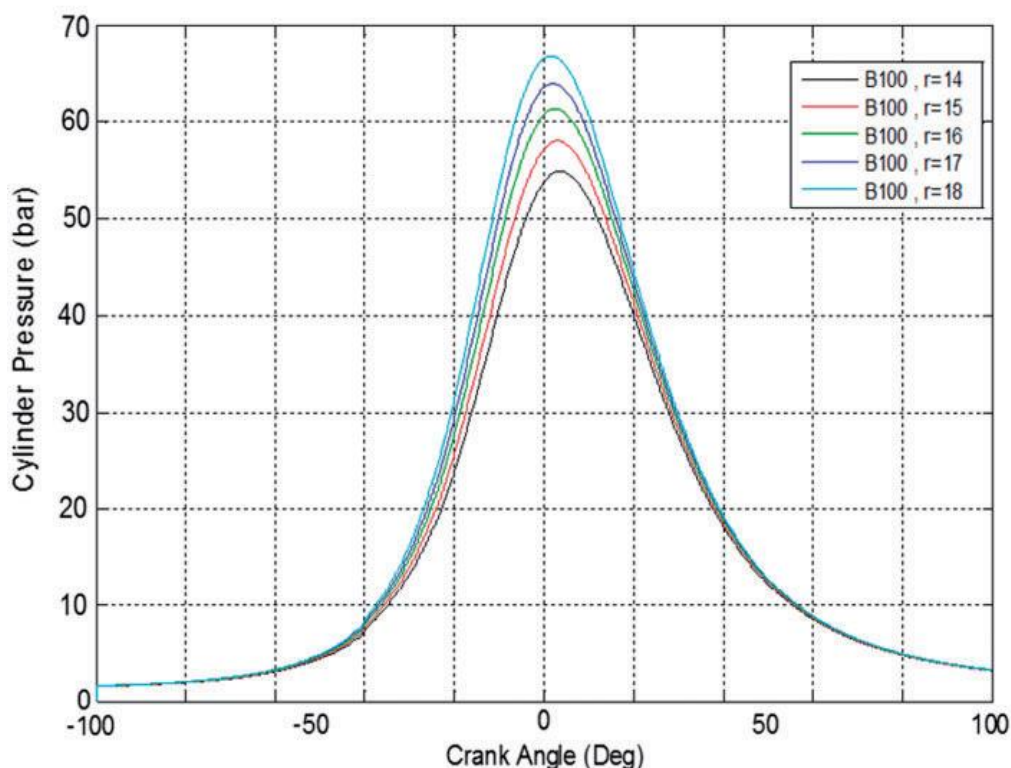
Figure 4. Effect of compression ratio on cylinder pressure with B100 application (Hojati & Shirneshan, 2020).

However, other studies also reported the use of B100 resulted in lower thermal efficiency than diesel oil especially at low and medium loads, as reported by Aydın, (2020), Hojati & Shirneshan (2020), Isik (2021), and Balasubramanian *et al*., (2021). The decrease in thermal efficiency can be seen in **Figures 6** and **Figure 7**.
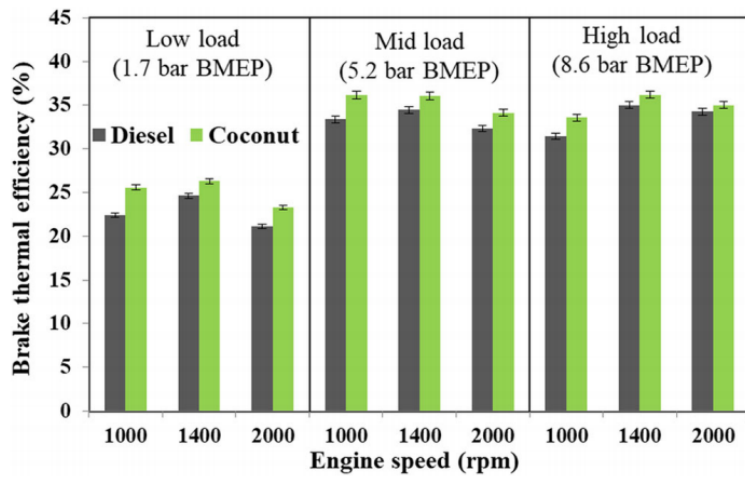

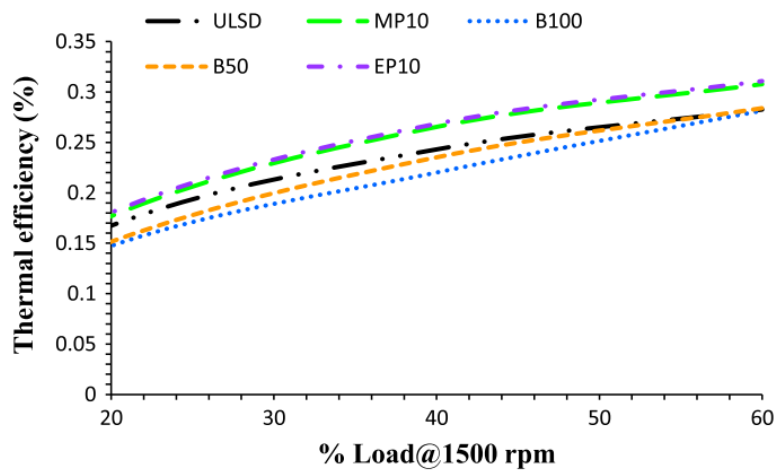**Figure 5.** Brake thermal efficiency function engine speed (Thangaraja & Srinivasan, 2019).
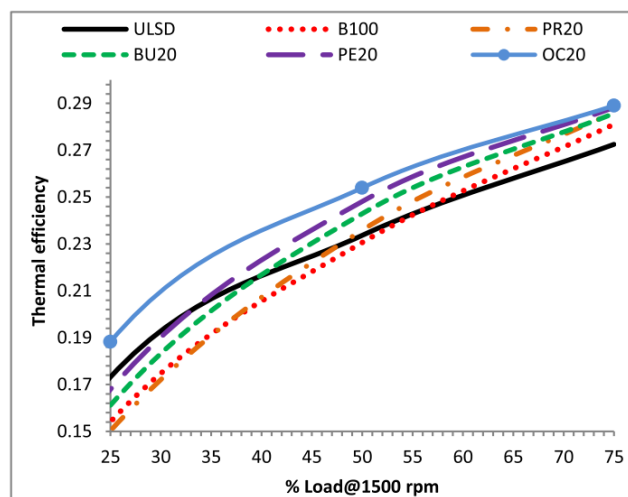

Figure 6. Brake thermal efficiency function load (Aydin, 2020).

Figure 7. Brake thermal efficiency function load (Isik, 2021).

Aydın (2020) described the decrease in thermal efficiency with B100 caused by poor combustion efficiency due to spray atomization. Balasubramanian et al., (2021) also explained the decrease in thermal efficiency that occurred in B100 due to its high viscosity and low heating value, as also described by Sudarmanta et al., (2020) However, thermal efficiency in B100 applications can be improved through; (1) increasing the compression ratio (CR) (Hojati & Shirneshan, 2020), (2) adding ethyl proxitol and methyl proxitol catalysts to B100 (Aydın, 2020), and adding alcohols such as pentanol, butanol, and octanol to B100 (Isik, 2021). One of the results of efforts made to improve thermal efficiency is shown in **Figure 8**.

Based on **Figure 8**, the addition of alcohol pentanol (PE20) and Octanol (OC20) into B100 can increase thermal efficiency. The average thermal efficiency increase is 7% with the addition of OC20 to the B100. The inclusion of alcohol in B100 improves evaporation properties and mixing characteristics (Isik, 2021).

3.2.3.2. Specific fuel consumption (SFC)

The use of B100 resulted in higher specific fuel consumption (SFC) of blended diesel and biodiesel oil at all engine loads, as reported by previous studies (Aydın, 2020; García-Martín et al., 2018; Ge et al., 2020; Ghadikolaei et al., 2019; Isik, 2021; Odibi et al., 2019; Santos et al., 2017; Tosun & Özcanlı, 2021). The increase in specific fuel consumption is shown in **Figures 9** and **Figure 10.**

Balasubramanian et al., (2021) also explained that the increase in SFC with B100 was caused by its high density and low heating value, the same statement was also explained by Ge et al., (2020), Aydin (2020), Tosun & Özcanlı (2021), Santos et al., (2017), Ghadikolaei et al., (2019), García-Martín et al., (2018). García-Martín et al., (2018) further stressed that in addition to the low calorific value of B100, its high viscosity inhibits the atomization and vaporization process of the fuel thus worsening the combustion process.

However, other studies also reported that the use of B100 resulted in lower SFC than diesel oil, as reported by Abdalla (2018), Thangaraja & Srinivasan, (2019), Isik (2021), and Esonye et al., (2019). Thangaraja & Srinivasan (2019) explained that the specific fuel consumption of B100 application is lower than that of pure diesel oil, it is related to basic energy, where biodiesel performs better than diesel oil, as shown in **Figure 11**.
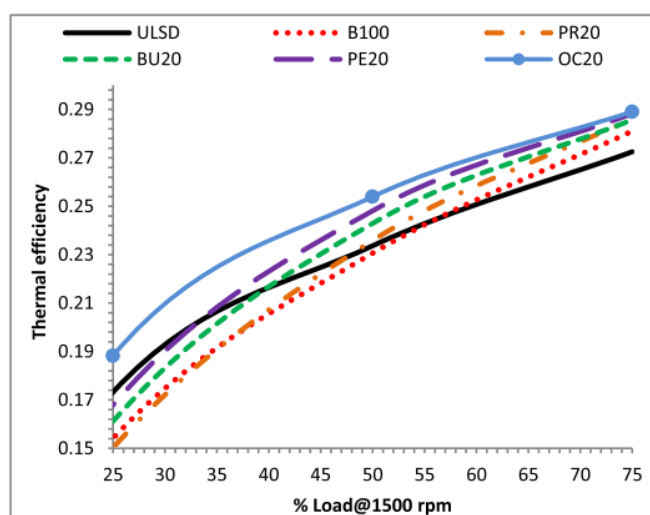

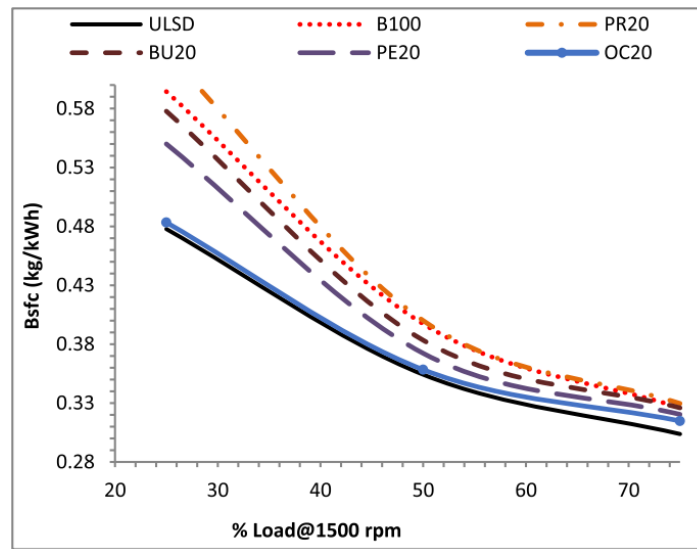**Figure 8.** Effect of adding alcohol on B100 (Isik, 2021).

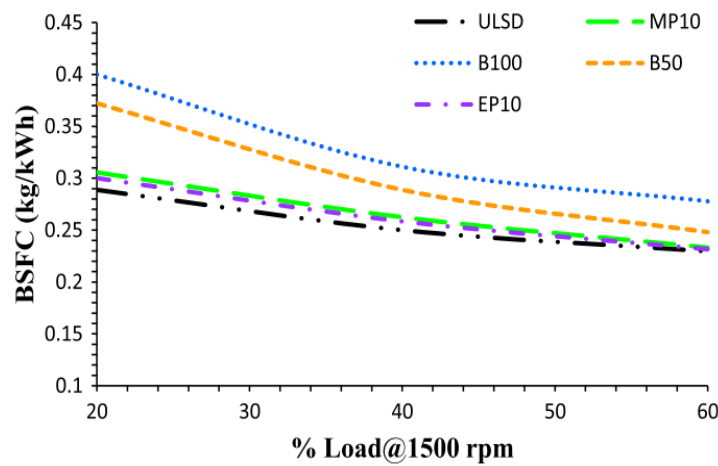**Figure 9.** Specific fuel consumption function load (Isik, 2021).

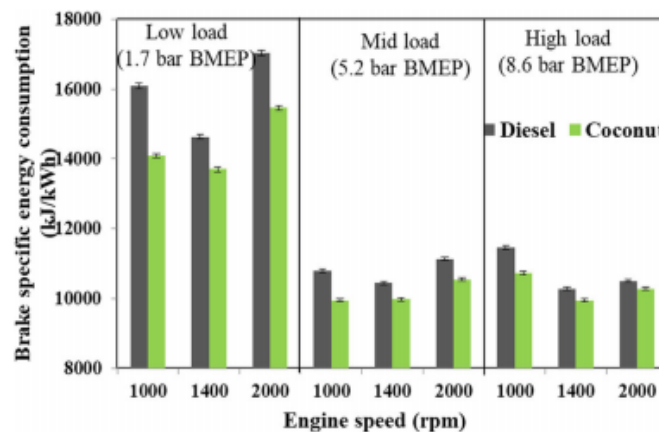**Figure 10.** Specific fuel consumption function load (Aydin, 2020).

Figure 11. Specific fuel consumption function engine speed (Thangaraja & Srinivasan, 2019).

3.2.4 Emission

3.2.4.1. Nitrogen oxide (NOx)

Diesel engines have high NOx emissions due to their high combustion temperature (1800 K), thus accelerating the reaction between nitrogen (N_2) and oxygen (O_2) (Aydın, 2020; Isik, 2021). The use of B100 resulted in higher NOx levels compared to

diesel oil in all engine loads, as shown in previous studies (Aydın, 2020; Esonye *et al.,* 2019; García-Martín *et al.,* 2018; Ge *et al.,* 2020; Ghadikolaei *et al.,* 2019; Hojati & Shirneshan, 2020; Isik, 2021; Santos *et al.,* 2017; Thangaraja & Srinivasan, 2019). The increase in NOx emission is shown in **Figure 12** and **Figure 13.**

García-Martín *et al.,* (2018) attributed the increase in NOx emission in B100 application to the high oxygen content. The authors further stressed that the increase in NOx emission in B100 application was due to the high oxygen content and low calorific value, leading to higher fuel consumption compared to diesel fuel. Hojati & Shirneshan

(2020) also explained that the high NOx content in the B100 application was caused by the high viscosity and higher cetane number which caused a lower autoignition time which increased the temperature inside the cylinder. Meanwhile, Ghadikolaei *et al.,* (2019) explained that biodiesel produces quite high temperatures because there are many oxygen-rich areas in the combustion chamber. Furthermore, Santos *et al.,* (2017) also explained that high oxygen content accelerates the rate of formation of NOx emissions. Esonye *et al.,* (2019) described the high oxygen content of B100 resulting in high temperatures that favor NOx formation.
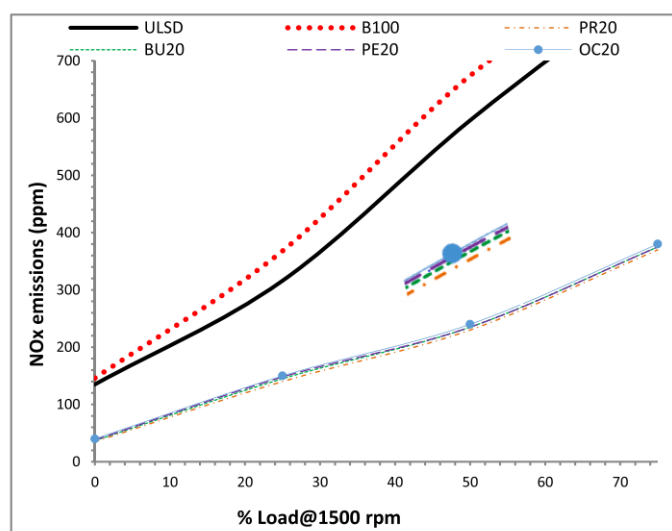

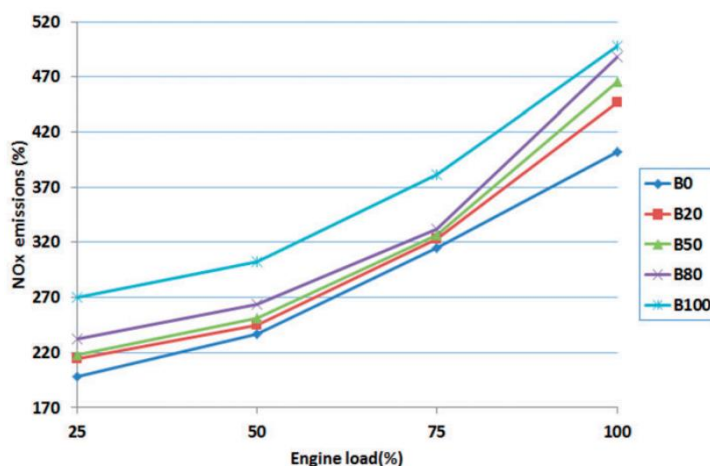**Figure 12.** NOx emission function load (Isik, 2021).

Figure 13. NOx emission function load (Hojati & Shirneshan, 2020).

However, other studies also revealed that the use of B100 resulted in lower NOx levels than the use of diesel oil, as reported by Abdalla (2018) and Balasubramanian *et al.,* (2021). Abdalla (2018) explained that the decrease in NOx with B100, as shown in **Figure 14**. This is caused by the high-water content, thereby lowering the combustion temperature.

3.2.4.2. Smoke

Diesel engines have high levels of smoke emissions because diesel belongs to the paraffin family with a long carbon chain. The use of B100 produces lower levels of smoke emissions compared to diesel oil at all engine loads, as revealed by Ghadikolaei *et al.,* (2019). He explained that the reduction in

smoke emissions of 57.1% with B100 is due to the high oxygen content and shorter carbon chain of biodiesel fuel.

However, another study also revealed that the use of B100 produces high levels of smoke at low and medium loads as reported by Abdalla (2018) and Balasubramanian *et al.,* (2021). The increase in smoke emission is shown in **Figure 15.**

Furthermore, Balasubramanian *et al.,* (2021) explained that the increase in smoke emissions at low and medium loads due to the rich air-fuel ratio and poor atomization so that the potential for smoke emission was greater, while at high loads, less smoke due to the availability of more oxygen, it resulted in the fuel-air ratio can be streamlined for lower smoke formation.
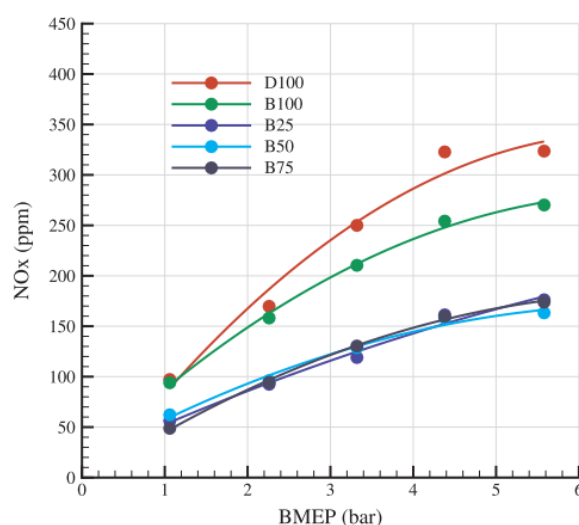

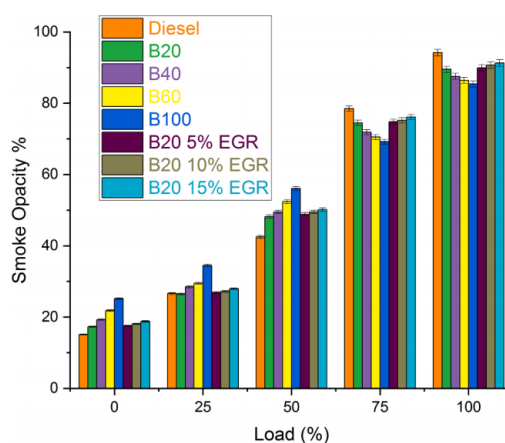**Figure 14.** NOx emission function BMEP (Abdalla, 2018).

Figure 15. Smoke opacity emission function load (Balasubramanian *et al.,* 2021).

4. CONCLUSION

The use of B100 in diesel engines provides advantages and disadvantages to engine performance and emissions. After a schematic literature review has been carried out, several advantages and disadvantages can be reported as follows:

(i) **Advantages**- the use of B100 results in lower noise levels compared to diesel oil. Thermal efficiency with B100 in diesel engines can be increased due to the high oxygen content to improve the combustion process and the rate of combustion speed, although some literature describes a decrease in thermal efficiency at low and medium loads. In terms of fuel consumption, the implementation of B100 can reduce the specific fuel consumption (SFC), although some literature describes an increase in SFC. Finally, the use of B100 can reduce smoke due to its high oxygen content and short carbon chain, although some literature describes an increase in smoke values at low and medium loads.

(ii) **Disadvantages-** the use of B100 can decrease cylinder pressure and heat release rate compared to diesel oil, but the pressure drop can be improved by increasing the compression ratio, adding alcohol, and adding a catalyst to B100. On the emission side, the use of B100 increases NOx emissions due to the increase in combustion temperature. That's because of the high oxygen content, although some literature also describes a decrease in NOx.

In general, of the 12 articles that were reviewed in depth, none of them fully discussed the key performance characteristics of diesel engines which include BTE, SFC, CPSs, HRR, NOx, and smoke. Therefore, this review provides guidance for further research to examine the use of B100 in diesel engines with all diesel engine performance variables. The research path can be developed with a wider potential to provide new arguments for different variations of diesel engine technology, variations in diesel engine dimensions, variations in B100 raw materials, and variations in test environments. In conclusion, with its weaknesses that can be covered, the B100 becomes a promising diesel engine fuel for now and the future. Besides its superior characteristics in engine performance and emissions, the use of B100 as renewable energy is an effort to realize sustainability in the transportation and industrial sectors.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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