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Performance and emissions of a diesel engine fueled by Tiska 68-based synthetic fuel blends

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This work compares and studies the performance and emissions of a single-cylinder diesel engine fuelled by diesel and blends of a fuel derived from used industrial oil. Tiska 48 used industrial oil is used as raw material. By transesterification of this oil, biodiesels were created and combined with diesel in proportions of 15%, 30% and 45%. Diesel engine emissions, performance, and combustion were calculated at a nominal speed of 1600 rpm and load variation. The procedure and experimental design for extracting the new fuel by transesterification are described in detail. The first part of the study focused on the identification and physicochemical characterization of the fuels in order to establish selection criteria for direct use on an engine test bench. The characteristics studied were liquid density, kinematic viscosity, dynamic liquid viscosity, acid number and flash point. A set of three mixing ratios was selected for fuel synthesis. The second part was devoted to bench tests carried out on a Kipor 178F diesel engine. Synthetic fuels were tested with 15%, 30% and 45% BT 68 fuel blends. A comparative study was carried out, highlighting engine performance and NO_x, CO, BFCS and EGT emissions for each fuel used. Blending pure diesel with synthetic fuel reduced carbon monoxide and NO_x emissions by 85% and 65%, respectively. The BFCS of the biodiesel combinations is in perfect agreement with that of pure diesel but slightly higher (around 9.12%) overall.

Key words: *transesterification, synthetic fuels, Tiska 68, performance and emission, diesel engine*

1. Introduction

The compression-ignition engine, once designed to run on vegetable oil rather than diesel, has made the history of internal combustion engines a rich one. German engineer Rudolf Diesel played a major role in developing this technology, paving the way for alternative, more environmentally friendly fuels. At that time, the lack of use of biodiesel was not due to growing demand but rather to political reasons, such as the high cost of producing biodiesel [26]. Fossil fuels have proved crucial to industry, agriculture, domestic use and transport development and growth. Although they play a fundamental role in these areas thanks to their availability, combustion efficiency and high calorific value, they are not a sustainable solution in the long term due to their depletion. This depletion of fossil fuel reserves remains a concern for policy-makers and energy experts worldwide [16, 21, 56]. In response to this problem, research has rapidly turned towards green, renewable, locally available and environmentally friendly alternatives. Engines powered by diesel, biodiesel and their blends produce particulate matter during combustion. Particulate matter emissions vary depending on the type of fuel used and the engine's operating conditions. The most well-known are nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons [15, 28, 37, 47]. Governments are increasingly implementing stringent regulations and emission standards to reduce these emissions as much as possible. Biodiesel, thanks to the similarity of its physical properties to those of fossil fuels, in particular diesel, is a promising energy source capable of solving the problem of depleting fossil fuel reserves, especially in developing countries that are heavily dependent on liquid fuel imports and are faced with the environmental and health impacts associated with pollution.

Used oils can be purified or converted into biofuel. The purification process involves several stages, including filtration, vacuum distillation and hydrogen treatment [52]. Once purified, these oils can be used as industrial lubricants or in engines. Conversion to biofuel, on the other hand, depends mainly on fatty acid content and the presence of contaminants. Oils rich in fatty acids are particularly suitable for biodiesel production [17]. The choice between purification for reuse and conversion into biofuel depends on the quality of the used oil and the final objective sought. Biodiesel made from recycled industrial oils and combined with conventional diesel may affect displacement resistance and cooling characteristics compared with conventional diesel [8, 10, 20, 31]. However, the extent of this influence depends on several factors, including the precise composition of the biodiesel, the mixing ratio with diesel and the engine's operating conditions. Importantly, results can fluctuate depending on the specific source of recycled oils and the biodiesel manufacturing process.

There are two processes for converting renewable raw materials into biodegradable fuel that is less polluting than conventional diesel: transesterification Different methods, adapted to the type and composition of the materials, are used to transform renewable raw materials into biodegradable fuels [4, 18, 32, 36, 42, 57]. which is the most widespread method, and esterification [36].

According to some studies, biodiesel is made up of alkyl esters derived from vegetable and animal oils, with varying physicochemical properties depending on the raw material used and the synthesis method [33, 38, 40]. However, other sources consider that the mixture of diesel and vegetable oil is also biodiesel [5, 25, 43]. The physicochemical properties of biofuels are crucial to air-fuel mixture formation, auto-ignition and combustion in engines. They influence their efficiency, emissions and durability. Researchers continue to explore these aspects to develop more efficient and environmentally friendly engines.

Several approaches to predicting biodiesel properties have been discussed in the literature [2, 3, 6, 27, 50, 53].

The experimental approach, despite its laborious and costly nature, remains indispensable for predicting these properties. Compared with approximate numerical models, these approaches are favored because they can obtain precise, reliable data on biodiesel properties such as density, viscosity, flash point and thermal stability. This approach examines the physical characteristics (flash point, density, kinematic and dynamic viscosity, etc.) of biodiesels and their blends with fossil diesel in accordance with current standards EN 590 [51] as well as ASTM D6751 and EN 14214 standards [1]. Figure 1 summarises the approaches used to predict biodiesel properties.

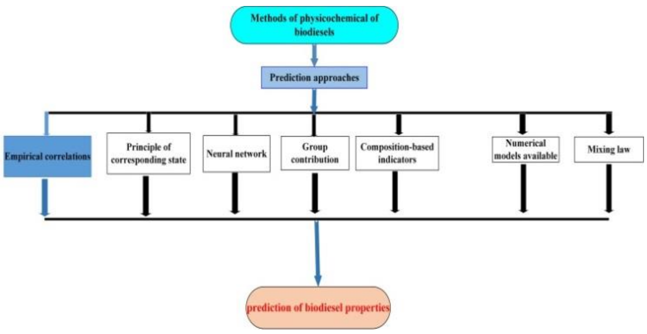

Fig. 1. Approaches used to predict biodiesel properties

Producing and characterizing biodiesel is not enough to bring it to market. It is essential to examine its impact on engine operation and pollutant emissions.

Numerous experimental and numerical studies have been carried out to analyze the impact of biodiesel, whether used alone or blended with pure diesel, on engine performance and pollutant emissions.

An experimental study was conducted by Dhande and Navale [13] in a single-cylinder, four-stroke diesel engine using neem oil-based biodiesel and blends with fossil diesel. The biodiesel was produced by transesterification. Three different blends, B10, B15 and B20, were produced by combining neem biodiesel with conventional diesel. These blends were compared with pure diesel fuel in engine performance tests. They found improved fuel consumption and brake thermal efficiency for all blend combinations with increasing load. Compared with pure diesel, levels of hydrocarbons (HC), carbon monoxide (CO) and smoke opacity also fell. Nitrogen oxides increased with increasing load for all blends compared with pure diesel. According to the results of the study, neem biodiesel is presented as a practical and effective alternative to traditional diesel fuel due to its ability to improve engine efficiency and reduce emissions.

In their research, Kumar et al. [29] studied the importance of using biodiesel from cooking oil in diesel engines. After mixing diesel and 1-pentanol, the experiments were carried out with a four-stroke, single-cylinder diesel engine, which impacted engine power and environmental pollution. The tests were carried out using a four-stroke, single-cylinder diesel engine. The results indicate that the higher ignition index and overall performance index values of 4.34×10^{-4} mass/min°C^2 and 13.71×10^{-6} $mass^2$ /min^2 °C^3, respectively, for D70B20P10 (70% diesel, 20% biodiesel and 10% 1-pentanol by volume), testify to better combustion performance. For fuels blended with 1-pentanol, carbon monoxide and unburned hydrocarbons emissions dropped considerably, from 40% to 52% and from 30.76% to 46.15% compared with diesel at full load. Of all the fuels tested at full load, D70B20P10 also demonstrated a thermal efficiency improvement of 28.68%, but slightly less than that of diesel (29.56%). Due to its exceptional combustion characteristics, diesel outperformed both in terms of cylinder pressure of 77 bar and heat release rate (HRR) of 41.1 J/ºCA. The addition of 5–10% 1-pentanol to the blend resulted in improved combustion, higher cylinder pressure and higher HRR due to improved fuel atomization and higher oxygen content.

Kale and Krishnasamy [22] focused their research on reducing the problems associated with pollutant emissions and the performance of agricultural diesel engines. In this systematic experimental study, a modified agricultural diesel engine was used. According to their findings, total emissions of nitrogen oxides and smoke were below 2.8 and 0.0007 g/kWh, respectively, for all biofuel-petrol blends studied under all engine load conditions. A significant 25% improvement over the conventional diesel engine was observed using a blend of 60% ethanol/34% gasoline/6% 2-EHN in the engine at 4.63 bar BMEP (86% rated load), achieving a thermal efficiency of 42%. The ideal solution achieved an engine load range from 20% to 89% of normal load. Overall, a compact, efficient and environmentally friendly combustion engine design was developed, which could be used with various biofuels over a wide load range. An experimental study was carried out by Doppalapudi et al. [14] to evaluate the performance, emissions and combustion characteristics of diesel engines using Tucuma and Ungurahui biodiesel blends. The engine underwent four tests using diesel as the reference fuel. The engine was tested at full load and the results were analyzed as a function of braking power (BP). The results show that the biodiesel blends exhibited combustion behavior comparable to that of diesel. In addition to diesel, TB10 and UB10 demonstrated improved brake thermal efficiency (BTE) and lower brake-specific fuel consumption (BSFC). Due to the increase in BP, a slight increase in HC emissions was observed for all blends, with the exception of TB10, against diesel. There was also a slight increase in CO emissions for all blends with higher BP. Both fuels showed a slight increase in NO_x emissions, with UB10 showing lower NO_x levels than the other blends. According to the study, TB10 showed superior performance (comparable to diesel) and higher combustion rates (better than diesel); however, emissions such as CO and NO_x are slightly higher than the others. According to the study, combining TB10 and UB10 with alcohols, ethers and nanoparticles is recommended to reduce NO_x and CO emissions.

Numerous other studies in the literature aim primarily to assess the performance, emissions and combustion characteristics of diesel engines using biodiesel blends [9, 24, 48, 49]. However, the adverse effects of biodiesel on engine performance restrict its direct use in diesel engines [29, 55].

This research aims to explore the possibility of extracting new fuels from industrial waste oils and testing them directly on diesel engines so that they can replace or supplement fossil fuels, thereby reducing environmental pollution and supporting the economies of developing countries where demand for fossil fuels is growing steadily. In the first part, we discuss the specifics of the transesterification process, as well as the physical and chemical description of biodiesel from synthetic fuel derived from Tiska 68 industrial oil. In addition, it concerns the thermal evolution of the densities and viscosities of the synthetic fuel liquids. In addition, the total acid number and flash point of biodiesel are also evaluated. The chemical composition of biodiesel is determined using gas chromatography combined with mass spectroscopy. The characteristics of synthetic fuels are compared with those of used cooking oil biodiesel and pure diesel. Based on current constraints and standards, various analyses from this study provide a better understanding of the blending limits and storage capacities of used cooking oil biodiesel and synthetic fuel. In the second part, experimental results are obtained from an engine test bench using blends of used cooking oil biodiesel and synthetic fuel to power a single-cylinder direct-injection diesel engine. Based on the results of the first part, blending limits are defined. A comparative study is carried out on specific carbon monoxide emissions, specific nitrogen oxide emissions and fuel consumption when the engine is running on biodiesel, synthetic fuel and conventional diesel.

2. Materials and methodology

2.1. Production of biodiesel from Tiska 68 waste oil

This study used Tiska 68 waste oil produced by the North African (Algerian) company Naftal, a branch of the Sonatrach group [35, 44]. Mainly used to lubricate machine tools and hydraulic systems, this synthetic oil has a viscosity index of 68, giving it excellent resistance to high temperatures and water [35].

The multi-step transesterification method was used to produce SF_Tiska 68 biodiesel, as shown in Fig. 2. The triglyceride of vegetable oil is combined with an alcohol to produce glycerol and a mixture of monoesters to form a biofuel [23, 46, 58]. 250 millilitres of oil are mixed with 75 millilitres of methanol and 3.5 grams of catalyst on a hot plate to produce 75% biodiesel and 25% glycerine. Equation (1) below illustrates the procedure. Biodiesel and glycerine are produced by mixing 250 millilitres of oil with 75 millilitres of methanol and 3.5 grams of catalyst on a hot plate. The procedure is illustrated by equation (1) below:

$$\begin{gathered}\text{250 ml oil} + \text{75 ml methanol } + \text{3.5 g catalyst} \rightarrow \\ \text{75\% biodiesel} + \text{25\% glycerine}\end{gathered} \tag{1}$$

The oil is prepared by measuring 250 ml into a beaker and heating it to a temperature of 65°C. Next, the required reagents are introduced into a suitable reactor, which contains used industrial oil and our alcohol, which is methanol (CH_3OH). KOH (potassium hydroxide) or NaOH (sodium hydroxide) stimulate the chemical reaction. This catalyst is vital as it intensifies the transesterification reaction, which is the first stage in transforming oil into biodiesel. Transesterification occurs under specific conditions, which differ according to the catalyst used, such as KOH. It takes place in open air and at temperatures ranging from 55°C (131 F) to 65°C (184 F). During the reaction, the temperature was monitored every 3–5 minutes, as the reaction is isothermal and produces heat up to 110°C (230 F). After introducing the oil/alcohol mixture into the reactor, transesterification continues for some time. To simplify the reaction, it is essential to have a system for heating and stirring the reactor. After the reaction, the oil metamorphoses into an ester, modifying its physicochemical characteristics such as viscosity, density and molar mass. Once the esters are formed, a decantation step is carried out to separate the biodiesel from the residual glycerol. At the bottom of the vessel, glycerol, which is denser than biodiesel, settles. This gravity settling took place in the reactor during a 24-hour rest period. The two phases separate naturally during this period, allowing the clarified biodiesel to be collected in the upper part of the vessel once the glycerol has settled to the bottom. To remove impurities such as residual glycerine, excess alcohol, traces of catalyst, and soaps and salts produced by homogeneous catalysis, the biodiesel was washed with distilled water at 4°C for 24 hours. Drying the washed biodiesel involved removing the water by heating it to a temperature of up to 100°C. The preparation process was completed by filtering the prepared biodiesel to remove contaminants. The transesterification reaction calculated has an acceptable average yield, close to 64.83 and 78.20% for BT68 and BWCO, respectively. On the same sample, on May 18, 2022, and October 31, 2022, two measurements were carried out to monitor the deterioration of the synthetic fuel after 6 months. The transesterification product was produced using KOH as a catalyst. The results of these two acidity measurements were 0.08 and 0.23 mg KOH/g, respectively. The different properties of Tiska 68 oil, biodiesel from Tiska 68 oil and conventional diesel are shown in Table 1.

2.2. Analysis of the physicochemical properties of biodiesel fuels

Depending on the material used and the manufacturing process, biodiesels have various physicochemical attributes [6, 34]. The influence of biodiesel's physicochemical attributes on generating NO_x and other emissions associated with the combustion of various fuels is significant [7, 12]. The physicochemical appearance of biodiesel is generally comparable to that of methyl and ethyl esters. The physicochemical properties evaluated in this work include kinematic, dynamic viscosity, and density. The quality of biodiesel can be influenced by various factors, which can be seen in its chemical and physiological properties [41]. Table 1 shows the physical and chemical characteristics of Tiska 68. Tiska 68 used industrial oil, cooking oil (BWCO) and Tiska 68 oil biodiesel (BT68), and BWCO.

Viscosity, density and flash point measurements were carried out on commercial diesel (DF), synthetic fuel (BT68) and combinations comprising 0%, 100%, 75%, 5% and 25% diesel, respectively, combined with 100%, 0%, 25%, 50% and 75% synthetic fuel (DF, BT68_100, BT68_75, BT68 _50 and BT68_25. Chemical and physical properties were also assessed on WCO (WCO100) and combinations comprising 75% biodiesel + 25% DF (BWCO75), 50% biodiesel + 50% DF (BWCO50), and 25% biodiesel + 75% DF (BWCO25). The density of each fluid is measured continuously over a temperature range from 15°C to over 80°C, for certain physicochemical characteristics, such as density, kinematic viscosity, flash point and acid number, combinations of biodiesel, pure diesel and Tiska 68 used oil were tested in accordance with ASTM D6751 and EN 14214. Table 2 shows the specifics of the various analyses carried out on the samples.

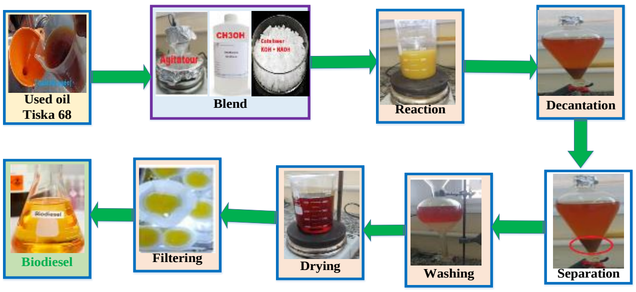

Fig. 2. Steps in the process of producing biodiesel from Tiska 68

Table 1. Some properties of Tiska 68 oil, BT68 biodiesel, WCO biodiesel and conventional diesel

<table>
<tr><td>Property</td><td colspan="2">Tiska 68 oil</td><td>BT68</td><td>WCO</td><td>DF</td><td colspan="2">Normes</td></tr>
<tr><td>Density, g/cm^3</td><td colspan="2">/</td><td>0,87</td><td>0,8932</td><td>0,82</td><td colspan="2">ASTMD445-12</td></tr>
<tr><td>Cetane value</td><td colspan="2">/</td><td>/</td><td>/</td><td>52,5</td><td colspan="2"></td></tr>
<tr><td>Kinematic viscosity at 40°C, Pa·s</td><td colspan="2">62.2–74.8</td><td>80.7404</td><td>5.2739</td><td>1.6524</td><td colspan="2">ASTMD445-12</td></tr>
<tr><td>Flash point, °C</td><td colspan="2">/</td><td>236</td><td>172</td><td>58</td><td colspan="2">ASTMD92-12b</td></tr>
<tr><td rowspan="3">Tiska 68</td><td colspan="2">Viscosity at 40°C [mm²/s]</td><td>Acidity</td><td colspan="4">Mass fractions</td></tr>
<tr><td>υ_{40} Oil min</td><td>υ_{40} Oil max</td><td>mg KOH/kg</td><td>% Sulfur</td><td>% Phosphore</td><td>% Calcium</td><td>% Zinc</td></tr>
<tr><td>61.2</td><td>74.8</td><td>0.45 max.</td><td>0.048–0.058</td><td>0.022–0.030</td><td>0.0033–0.0042</td><td>0.028–0.038</td></tr>
</table>

Table 2 . Equipment and procedures used for sample analysis

Measured properties	Equipment
Density at 15°C [kg/m^3]	Anton Paar DMA 35
Kinematic viscosity (at 40°C) [mm^2/s]	Anton Paar DMA 35
Flash point [◦C]	Cleveland Open Cup flash point tester
Acid value [mg KOH/g]	TitroLine 6000

2.3. Experimental set-up

This study uses a single-cylinder, four-stroke, direct-injection, compression-ignition Kipor 178 F engine in connection with a DC generator within a genset. Small generators and other equipment frequently use the air-cooled Kipor 178 F. Table 3 shows the engine's technical specifications. Pure diesel and biodiesel were stored in dedicated tanks. A load bank fed a dynamometer, which was connected to the engine. A gas analyzer was used to measure exhaust emissions. A computerized data acquisition system recorded experimental data, including braking power, brake thermal efficiency, brake-specific fuel consumption and exhaust gas temperature. Speeds selected included 1400 rpm, 1500 rpm and 1600 rpm, each with five (05) loads. A test with commercial diesel heated to 40°C (the standard) was carried out. Each synthetic fuel is blended with diesel in proportions of 15%, 30% and 45%. The photographic view and schematic perspective of the experimental set-up are shown in Fig. 3 and 4 respectively.

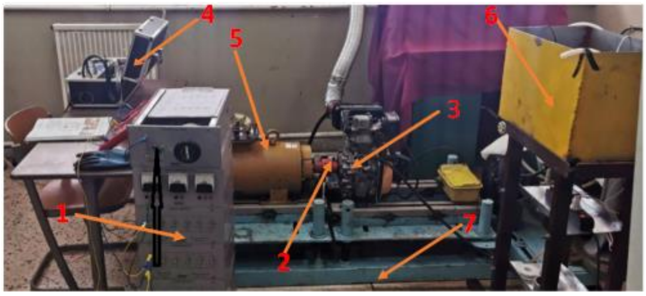

Fig. 3. Photographic view of engine set-up: 1 – rheostat and load resistors, 2 – coupling, 3 – diesel engine, 4 – gas analyzer, 5 – DC generator, 6 – fuel preheater, 7 – baseplate

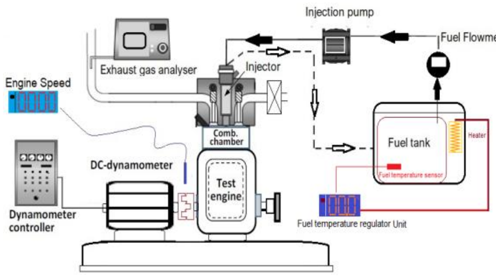

Fig. 4. Schematic view of engine set-up

Table 3. Engine specifications

Model	KM178 (A) M
Type	1 cylinder, 4-stroke, air-cooled, direct injection
Bore × stroke	78 mm × 62 mm
Displacement	0.296 dm^3
Rated power	3.68 kW at 3000 rpm
Fuel consumption/ nominal speed r/min.	276.1 g/kWh at 3000 rpm 285.6 g/kWh at 3600 rpm
Compression ratio	20:1
ADM	AOA 8.5° bTDC, RFA 44.5° aTDC
ECH	AOE 55.5° bTDC, closed 8.5° bTDC

3. Results and discussion

This section looks at the performance and emissions of a compression-ignition engine fuelled with different combinations of biodiesel from Tiska 68 used oil. On a volume basis (% v/v), three blends (BT68 _25, BT68 _50 and BT68 _75) containing 25%, 50% and 75% biodiesel combined with conventional diesel were prepared. Each mixture was tested at an unvarying rate, and the charge increased by 25% until it reached a peak. The load was 0.0004 kg for all three combinations (1400 rpm, 1500 rpm and 1600 rpm). The engine used pure diesel, modifying the load by 25% in full-load mode to maintain a fixed speed of 1600 rpm and a compression coefficient set at 17. The engine was then tested on BT68 _25, BT68 _50 and BT68 _75 blends to assess performance and emissions. The results were recorded using the software included in the test bed. Each experiment was carried out under identical conditions. The following sections illustrate fluctuations in fuel consumption, emissions such as carbon dioxide, carbon monoxide and hydrocarbons for each of the three combinations, as well as the load criteria mentioned above.

3.1. Physicochemical properties

Physicochemical characteristics are essential for parametrically assessing the performance of biodiesel during combustion [6]. These attributes include viscosity, density and flash point. They have a direct impact on biodiesel combustion, emissions and energy efficiency.

Dynamic viscosities and kinematics. The dynamic viscosities of biodiesels derived from Tiska 68 waste oil, WCO and pure diesel are shown in Fig. 5. This parameter is essential for assessing the resistance to fuel flow in the injection system under real-life dynamic conditions, such as high pressures and speeds. It indicates the liquid's resistance to flow or deformation, which influences the injection process, fuel atomization, spray range in the engine's combustion chamber and the lubricating properties of the fuel [18]. These tests were carried out in accordance with the requirements of EN 14214 3104, at a temperature of 40°C. According to the results of this study, pure diesel has the lowest viscosity, while WCO biodiesel has a slightly higher viscosity (around 1.12%) than pure diesel in all temperature ranges. This can be explained by the fact that, on the one hand, standard diesel is essentially made up of hydrocarbons – fairly simple carbon chains. These molecules are intermediate in size and have a structure that favors their flow. On the other hand, biodiesel is made from vegetable and animal oils and fats. These oils have longer carbon chains and elaborate structures, including ester groups, making biodiesel more viscous than conventional diesel. These variations in molecular composition result in greater resistance to flow, which could explain biodiesel's higher viscosity.

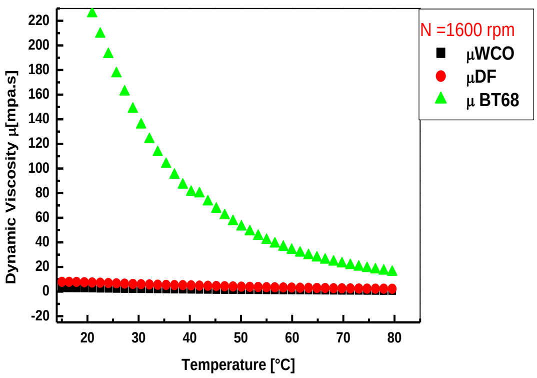

Fig. 5. Dynamic viscosity of BT68 oxygenated fuel depending on temperature

BT68 biodiesel, on the other hand, showed a parabolic curve from 20°C to 80°C, followed by linear fluctuation at other temperatures. These findings indicate that it is possible to use BT68 biodiesel without significantly increasing resistance to fuel movement in the device, or disturbing injection, atomization and combustion conditions. Furthermore, incorporating additives into BT68 biodiesel could help reduce its viscosity. Kinematic viscosity tests were also carried out on BT68 biodiesel. These tests were carried out in compliance with standard EN 14214 3104 criteria, under a climate of 40°C. Figure 6 shows the kinematic viscosity of the liquid at 40°C, based on the blending ratio between synthetic fuel and diesel. Consideration of kinematic viscosity is crucial to the characteristics of biodiesel. An adequate value promotes fuel fluidity and influences the operation of injection devices, particularly at low temperatures [50]. Due to inadequate fuel atomization, excessive viscosity can lead to deposits and soot [50]. The standard viscosity cut-off level was 10.29 mm²/s for blends of 75% biodiesel with pure diesel. A set of three blending ratios were chosen for the synthetic fuel. Explicitly, blending ratios of 15%, 30% and 45% are explored on an engine test bench.

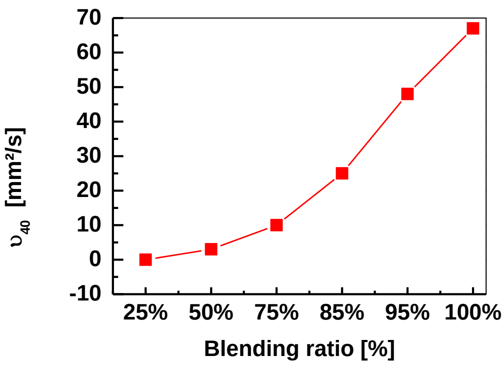

Fig. 6. Kinematic viscosity of BT68 depending on temperature at 40°C depending on the mixing ratio

Liquid density. The energy content of diesel is determined by its density. Indeed, fuels with a high density usually contain more energy, which optimizes engine performance. Higher density promotes more efficient combustion by delivering a greater volume of energy. This optimization is reflected in higher power output and lower pollutant emissions. Excessive density, however, can result in overspray with a large Mean Jump Diameter (MSD), likely to strike the piston walls [39]. On the other hand, too low a density restricts the possibility of air-fuel mixing due to the limited mobility of droplets in the combustion chamber [19]. Figure 7 illustrates the temperature-related density fluctuation for oxygenated fuels, WCO, Tiska 68 oils and their combinations, in comparison with the thermal density change of commercial diesel.

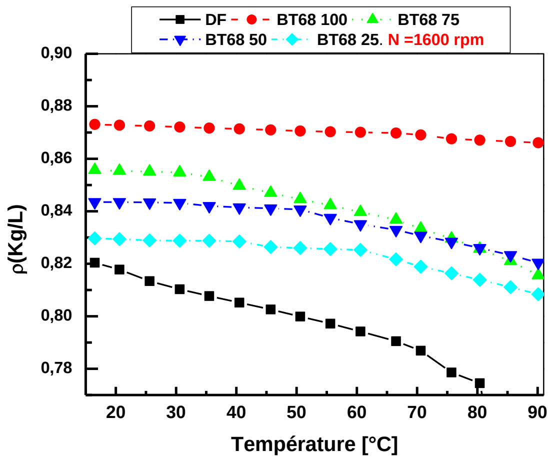

Fig. 7. Density of oxygenated fuels extracted from WCO and BT68 versus temperature

In contrast to viscosity, the mass density of the fuels studied decreases with increasing temperature over the entire temperature range studied. This is generally true for most liquids such as diesel and blends. Density decreases as the percentage of biodiesel in the blend decreases. Pure diesel has a lower density than biodiesel and blends Pure diesel had lower density than biodiesel and blends with a calculated difference of 6.06%, 4.14%, 3.6% and 2.27% for BT68100, BT68 75, BT68 50, and BT68 25, respectively. Clearly, increasing the biodiesel content in blends leads to an increase in density. This difference can be attributed to the distinct chemical composition of the two fuels. Thus, an increase in the proportion of diesel may lead to a decrease in the density of the blend due to the specific properties of the blend components.

Flash point. The evolution of the flash point according to the percentage of BT68 is illustrated in Fig. 8. The flash point is the minimum temperature at which a fuel generates enough vapour to create a flammable combination with the surrounding air [11]. The flash point was calculated by equation (2) below:

$$\kappa \cdot \mathrm{T_{BT68}} + \kappa' \cdot \mathrm{T_{DF}} \tag{2}$$

Where κ and κ′ represent the percentages of Tiska 68 oil biodiesel and pure diesel respectively, TBT68 and TDF represent the flash points of Tiska 68 oil biodiesel (212°C) and pure diesel (58°C) respectively. It has been observed that higher blending percentages result in higher flash points. According to EN 14214, the observed values exceed the minimum limits set by current standards for blends, which vary from 30% to 100% and from 51% to 100%. To ensure proper operation of compression-ignition engines, this study recommends the use of blends comprising at least 30% or 51% biodiesel and pure diesel.

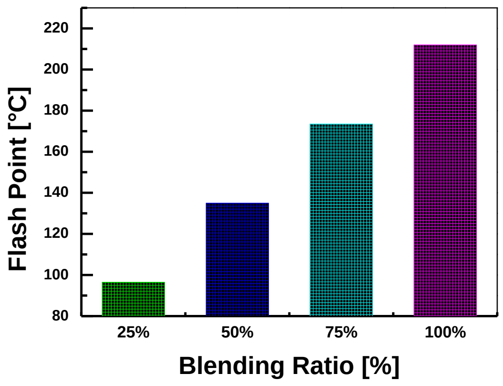

Fig. 8. Flash point of BT68 and pure diesel blends versus blend percentage

3.2. Engine tests results

NO_x emissions. Due to combustion temperature, equivalence ratio, oxygen overabundance and prolonged combustion, NO_x emissions occur within the engine [29]. Figure 9 shows the variability of NO_x emissions as a function of load for each test fuel sample. Overall, NO_x emissions in the fuels tested fell as engine weight increased. Increasing load slightly increased NO_x emissions for each biodiesel sample examined. The increase in NO_x emissions is due to higher loads having a higher combustion temperature than lower loads [29]. The increased load resulted in a noticeable increase in diesel emissions. In all cases of engine loading, BWCO 15 had a lower NO_x emission concentration than all the samples examined. Six blends, BT68_45, BT68_30, BT68_30, BWCO 30, BWCO 45 and BWCO 15, had NO_x concentrations of 19.17, 20, 28.68, 35.75, 51.39 and 69.7% respectively, which is below the DF.

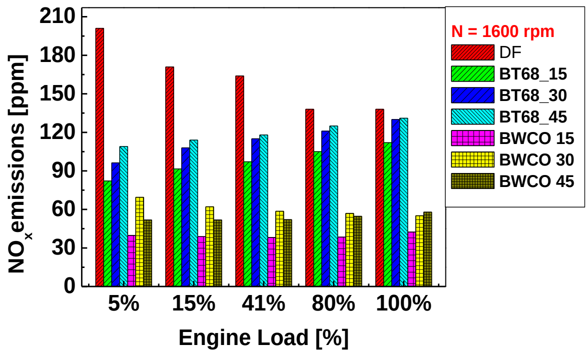

Fig. 9. NO_x emissions for different biodiesel/diesel blends at different loads

CO emissions. The increase in CO emissions is mainly due to partial combustion caused by a lack of oxygen, a reduced combustion temperature or an air-fuel mixture that is too lean or too rich [29, 55]. Figure 10 shows the fluctuation in CO emissions for each fuel type tested in relation to load.

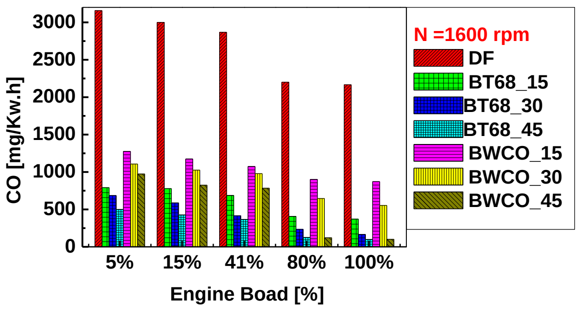

Fig. 10. CO emissions for different biodiesel/diesel blends at different loads

The test results clearly demonstrate that increasing the engine load for all the fuels examined contributed to lower CO emissions. When the engine is at low load, its temperature within the cylinder decreases compared to a higher load, leading to faulty combustion and higher CO [45]. Under all load conditions, pure diesel had higher CO emissions than the other blends examined, with the exception of BWCO30, which showed a slight increase. This is justified by the fact that conventional diesel generates higher CO emissions than biodiesels and their combinations, due to its chemical composition and combustion process. Conventional diesel has a higher carbon content and lower oxygen content than biodiesel. During combustion, partial oxidation of carbon occurs, producing more carbon monoxide (CO). Biodiesels, on the other hand, have a chemical structure that encourages more complete combustion, thereby reducing CO emissions. BT68_45, BT68_30 and BT68_15 diesel-biodiesel blends produce CO emissions that are 82%, 75.12% and 70.45% lower than those of DF, respectively, both at no load and at full load. The BT68_45 diesel-biodiesel blend, both at no load and at full engine load, produced CO emissions some 82% lower than the DF. The presence of sufficient oxygen in the mixtures stimulated CO oxidation, thereby reducing emissions. Under nominal load conditions, higher cylinder temperatures also contribute to lower CO [30].

Exhaust gas temperature (EGT). The EGT provides information on combustion efficiency inside the combustion chamber. The variation of EGT with load for all fuel samples tested is shown in Fig. 11. It was observed that EGT increased with increasing load for all fuel samples tested. This could be explained by the fact that diesel engines burn more fuel to create the extra energy needed to handle higher load conditions [55]. For DF BT68_15, BT 68_30, BT68_45, BWCO 15, BWCO 30, and BWCO 45, EGT values at no load were found to be 130, 170, 167, 172, 157, 83 and 104^{o}C respectively, while at full load, these values were increased to 156, 208, 209, 208, 157, 127and 152^{o}C respectively. All blends have lower exhaust temperatures than diesel at any braking power due to their lower calorific value and higher oxygen content, which improves combustion inside the engine chamber. The addition of 15% 1-pentanol by volume to the diesel-biodiesel blend had the lowest EGT value for every engine load condition. The EGT for higher alcohol-biodiesel-diesel blends is lower than for D100, due to higher viscosity and higher latent heat of vaporization [40].

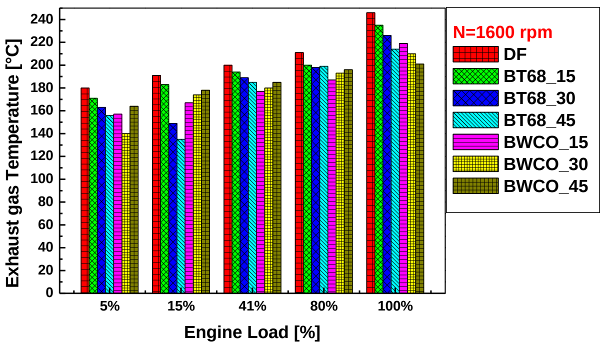

Fig. 11. Exhaust gas temperature for different biodiesel/diesel blends at different loads

Brake specific fuel consumption (BSFC). The brake specific fuel consumption parameter is crucial, as it determines how much energy the fuel produces to generate one unit of engine power [29]. Figure 12 shows how brake specific fuel consumption varies with engine load for various fuel blends. It was immediately apparent that the BSFC values for each fuel studied decreased with increasing engine load. This can be explained by the increased load, which results in higher cylinder temperatures and improved fuel combustion efficiency [29, 54]. The BSFC of DF was found to be lower than that of all blends, whatever the load condition. The BSFC values for BT 68_30, BT 68_45, BWO_30, BTWO_45, BTWO_15 and BT68_15 blends were 9.06%, 7.32%, and 6.26%, 6.26% and 4.24% higher than the DF values, respectively, when the engine was at 5% load.

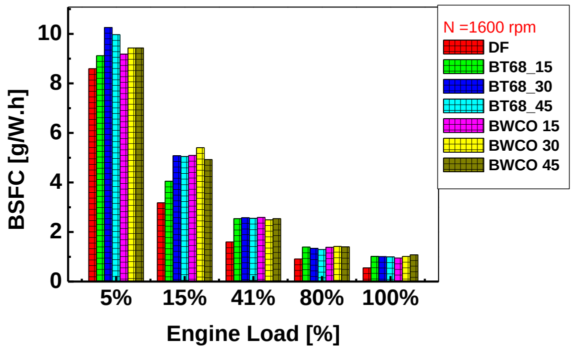

Fig. 12. Brake specific fuel consumption for different biodiesel/diesel blends at different loads

4. Conclusion and perspectives

This research details the complete technique required to obtain a synthetic fuel from a used lubricating oil Tiska 68. Initially, the article focuses on the major physico-chemical characteristics of synthetic fuel. In the liquid phase, kinematic densities and viscosities. The transformation of this oil generates compounds whose physical characteristics comply with ASTM D6751 and EN 14214 standards and constraints for sales biodiesel.

Test results were obtained using a test bench powered by a single-cylinder diesel engine. The DC dynamometer was operated at a speed of 1600 rpm for a variety of loads, from engine brake to total. A comparison was made between actual fuel consumption and specific NO_x and CO emissions for each blend of biodiesel and conventional diesel. The following observations can be made based on the graphs:

- It is possible to use BT68 biodiesel without significantly increasing the resistance to fuel movement in the device, or disturbing injection, atomization and combustion conditions. However, incorporating additives into BT68 biodiesel would help to reduce its viscosity.
- When the engine runs on conventional diesel, more significant CO emissions are observed.
- A decrease in NO_x emissions is observed when the engine runs on conventional diesel at high engine loads. However, an increase in NO_x emissions is also observed when the engine is fuelled with blends of BT68 and DF under the same conditions.
- Exhaust gas temperature increased with increasing load for all fuel samples tested.
- The BSFC values for each fuel studied decreased with increasing engine load. And that the BSFC of DF was lower than that of all blends, whatever the load condition.

In this research, a DC generator is used as a brake. However, its performance is rather modest compared with the Kipor 178FWX diesel engine, thus limiting the tests carried out. In addition, the engine loads change, with the exception of the total load. Above 3000 rpm, the engine can generate more than 4 kW, and the generator can produce more than 2.25 kW. For this reason, a speed of 1600 rpm was chosen, although this is low compared with a fast diesel engine.

The aim of this project is to prove that BT68 synthetic fuel can power the Kipor 178FWX diesel engine. Improvements can be made by carrying out tests on a test bench, collecting information at low and high frequencies. This will enable detailed analysis of unburnt hydrocarbon and NOx emissions at nominal and critical engine speeds, as well as examining how fuel temperature influences engine performance and emissions.

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Nomenclature

BSFC	brake specific fuel consumption
BT68	Tiska 68 Waste Oil Biodiesel
BT68_15	15% synthetic fuel from tiska68 + 85% diesel
BT68_30	30% synthetic fuel from tiska68 + 70% diesel
BT68_45	45% synthetic fuel from tiska68 + 65% diesel
BWCO15	15% synthetic biodiesel from used household oil + 85% diesel
BWCO30	30% synthetic biodiesel from used household oil + 70% diesel
BWCO45	45% synthetic biodiesel from used household oil + 65% diesel
DC	direct current
DF	diesel fuel
WCO	waste cooking oil

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