Thermal Evaluation of an Internal Combustion Engine Lubricated with Mustard Seeds Oil as A Renewable Bio-fluid

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Thermal Evaluation of an Internal Combustion Engine Lubricated with Mustard Seeds Oil as A Renewable Bio-fluid

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Abstract: The bio-renewable oil and fluid such as the plant fluids are in high demand nowadays as a lubricant, cooling oils and motion energy transmission fluids in mechanical or hydraulic systems processes, since they are a natural resource with a high biodegradability compared to commercial mineral fluids. In this work, the thermal performance of the mustard seeds oil is assessed utilizing a rotary pin-on-disc machine at varying rotational speeds of 250, 500, and 750 rpm, with 50 N as a fixed normal load, and 25ºC as a test temperature over the course of 60 minutes. The oil samples' performance was also evaluated using a single-cylinder, four-stroke, cooled by air, directly-injection diesel engine that requires no engine modifications. According to the findings of the research, could be seen a number of beneficial properties of the mustard seed oil as a bio-cooling oil depending on the high value of flash temperature parameter 5.74 as compared to mineral fluids of 5.63 under 250 rpm and 4.33 and 4.08 under 500 rpm, that mean the mustard seed oil has satisfactory thermal performance. The experimental results also reveal that using non-edible mustard seeds oil reduces brake-specific fuel consumption by around 6% and 4% respectively, at a constant engine speed of 2000 rpm and a constant applied load of 5 N.m. In overall, it can be concluded that using of the mustard seeds oil has a promising future as an alternative bio-cooling oil instead of mineral oils in internal combustion engines.

Keywords: Bio-oil; mustard seeds; cooling fluid; IC engine; engine temperatures; wear scars

1. Introduction

The increased awareness of human health deficiencies and negative environmental consequences, as well as sustainable development for future manufacturing processes, contributed to the continuous implementation of bio-renewable cooling fluid, transmission fluid, hydraulic oil, lubricants, and metalworking fluids in most mechanical engineering and industrial applications[1-6]. Bio-based fluids have been shown to facilitate the transition from quickly depleting non-biodegradable petroleum fluids to environmentally sustainable, renewable, and cleaner production[7-14]. In the recent decade, several different forms of vegetable oils, including palm kernel oil, sunflower seed oil, castor oil, and soybean oil, among others, have been explored, and the finding demonstrate that the used vegetable oils have the ability as a mineral oil substitute in wide sectors[15]. In this aspect, Wichmann et al.[16] investigated the ecological characteristics of new glycerol/water-based metalworking fluids. Technical grade glycerol, a biodiesel industry by-product that is renewable, was found to be pure enough for use. Investigations revealed that the application of biocides for fluid preservation was unnecessary if metalworking fluids included 35% biostatic trihydric alcohol glycerol. The water solubility of all fluid components significantly eased the cleaning of metal surfaces simply by washing with water when compared to standard metalworking fluids. Also, Zulkifli et al.[17] compared the wear and friction properties of several trimethylolpropane samples. They discovered that adding up to 3% of a trimethylolpropane ester derived from palm oil to a regular lubricant decreased the maximum wear-scar diameter and decreased the friction coefficient by up to 30%. Trimethylolpropane, when added at a concentration of 7%, also decreases friction by as much as 50%, improving the mechanical efficiency of machine parts.

Yuvarajan and Venkata[7] conducted an experimental investigation on the neat mustard oil methyl ester that had been treated to microwave and ultrasonic irradiation in a single-cylinder of four-stroke diesel engine. It was discovered that mustard oil methyl ester treated with ultrasonication and microwave irradiation had a braking thermal efficiency that was 5.84% higher and a fuel consumption that was 5.14% lower than that of pure mustard oil with methanol. Wan Nik et al.[18] studied the changing in the food-grade oil properties by varying the temperature and shear rate. Many types of oils were considered, including coconut, canola, corn, palm, and sunflower oils. Temperature has a stronger influence on viscosity variation than shear rate. As a result, sunflower and palm oils appeared a stable performance for share rate and temperature. In another study, Wan Nik et al.[19] examined the hydraulic system's effectiveness using palm oil as a hydraulic fluid under different operating conditions such as pressure, speed, and oil ageing. The results indicated that when pump speed increases, the slip coefficient drops and volumetric efficiency improves due to an increase in oil viscosity. Furthermore, Syahrullail et al.[20] used plane strain extrusion experiments and viscoplasticity studies to examine the effects of friction restriction with the use of paraffin mineral-based and palm oil lubricants on the plastic deformation of Aluminum workpieces. When compared to paraffin mineral oil lubricant or the friction-free condition, the results showed that palm olein oil performed well in terms of lubrication. Syahrullail et al.[21] explored the use of palm oils as lubrication in cold operations such as a forward plain strain extrusion method. Palm oil's performance was compared to that of without additives paraffinic mineral oil. At room temperature, investigations were carried out using a flat strain extrusion device and a symmetrical workpiece. The workpiece's material is annealed pure Aluminum. The testing findings demonstrated that palm oil has superior lubricating properties when compared to paraffinic mineral oil and has advantages in lowering extrusion load.

Using a four-ball tribometer, Jabal et al.[22] investigated the qualities of rubber seed oil as a pure bio-hydraulic oil and compared them to mineral hydraulic results under varied typical loads. Based on the data, rubber seed oil superior on the hydraulic oil due to it has a lower friction coefficient at varied loads, flash temperature parameter was grater at low loads and wear scar diameter was smaller. In addition, rubber oil reduces wear at low loads and increases wear at high loads, and the oil also has the ability to work as a hydraulic fluid. Furthermore, Syahrullail et al.[23] also demonstrated that palm olein has a relatively low friction coefficient when compared with additive-free paraffinic mineral oil by utilizing a four-ball tribometer to examine the impact of sliding speed on palm olein's anti-friction at speeds ranging from 800 to 1400 rpm while bearing a 40 kg weight.

Bari et al.[24] employed an enhanced friction test that entails injecting fuel externally during engine operation to investigate how the injection mechanism is affected by preheating fuel. The findings indicate that preheating crude palm oil decreased viscosity and facilitated smooth fuel flow, however did not impact the injection system, even at a temperature of 100 °C. In combustion investigations comparing crude palm oil and diesel, crude palm oil produced a 6% greater peak pressure, and a longer burning duration. Jabal et al.[25] employed a four-ball tribometer to test the use of sunflower oil as a lubricant under different loads, and exhaust emissions were measured with a 4-stroke, single-cylinder diesel motor. When compared to petroleum oil samples, sunflower oil shown acceptable antifriction and antiwear properties, under different test conditions, it was more successful in lowering the emissions of hydrocarbons, carbon dioxide (CO_2), and carbon monoxide (CO). Ing et al.[26] employed a four-ball tribometer at temperatures of 55, 65, 75, and 85°C at a sliding speed of 1,200 rpm to evaluate how temperature affects the performance of wear and friction for refined, bleached, and deodorized (RBD) palm stearin without the use of additives like paraffinic mineral oil. The results showed that RBD palm stearin outperformed paraffinic mineral oil in terms of reducing frictional constraints. Golshokouh et al.[27] used a four-ball tribometer to investigate the application of palm fatty acid distillate (PFAD) as an alternate source of mineral lubricant/hydraulic oils at 800, 1000, 1200, 1400, and 1600 rpm. The same tests were carried out with hydraulic oil and an engine. The tests revealed that PFAD has better anti-friction and anti-wear properties than engine and hydraulic mineral oils. Furthermore, PFAD oil had a greater flash temperature than the other test oils. However, PFAD requires a lower viscosity oil than engine oil.

Jabal et al.[28] used a four-ball tribometer to assess and compare the tribological properties of mustard seed oil mixed with commercial mineral oil at volumetric ratios of 22.5 to 90%. The results demonstrate that different mixes of mustard seed oil and mineral oil have higher flash temperature parameter values, lower wear scar width, and lower friction torque, friction coefficient, and wear scar width than mineral oil and plain mustard seed oil. The mustard seed oil mixture at 22.5% shows better anti-wear and anti-friction qualities than oil samples. As a result, mustard seed oil has the potential to serve as a lubricant for mating surfaces. Abdul Fattah et al.[29] used a four-ball tribometer to assess the tribological characteristics of mineral oil combined with rubber seed oil and compare them to commercial lubricants. Rubber seed oil was blended with commercial mineral oil at volumetric ratios ranging from 20 to 80%. The study found that various rubber seed oil/mineral oil mixes have lower coefficients of friction torque than mineral oil. Using a pin-on-disc tester, the mixing ratio, sliding speed, and load values varied from 0 to 20%, 1.3 to 3.8 m/s, and 50 to 100 N. Yashvir et al.[30] evaluated the lubricity of an oil-based Phyllanthus Emblica seed lubricant. The results indicated that adhesive wear occurred during the testing. At low load and high sliding velocity conditions, it has been shown that a 10% blend ratio produces the best results in terms of friction and wear qualities when compared to other lubricant versions and serves as an effective lubricant additive. Jayashri et al.[31] studied the emission and performance characteristics of diesel engines with 10%. 20%, and 30% blends of neem oil as biodiesel. using a single-cylinder, 4-stroke, diesel engine. The results showed that the 10% blend created lower pollutants and outperformed the other mixes and diesel. The braking thermal efficiency exceeds that of diesel, and the emissions of carbon monoxide, hydrocarbons, and nitrogen oxide are 23%, 8.5%, and 22% lower, respectively, than that of diesel.

Alves et al.[32] investigated the effects of extreme pressure (EP) and oil basis on tribological behaviour by developing vegetable-based lubricants and adding oxide nanoparticles (ZnO and CuO) as additives. The results revealed that adding nanoparticles to traditional lubricants can greatly improve their tribological qualities. A smoother and more compact tribofilm has developed on the worn surface, accounting for the further reduction in friction and wear. Fatima Leonor et al.[33] examined the tribological properties of synthetic and mineral ester base oils containing copper nanoparticles. Each base oil has a proportion of additive weight ranging from 0.3% to 3.0%. The unacceptability of the extra weights utilized in both situations was one of the most important findings for either antiwear agent or friction modifier. Furthermore, the mineral oil's nano-additive enhanced its antiwear properties and decreased friction at both tested concentrations, particularly at 0.3%wt. Jing Yu et al.[34] examined experimentally how a particle oxidation catalyst (POC) affected a non-road diesel engine's ability to reduce emissions under various operating circumstances. The findings show that during a non-road steady cycle, POC with Pt catalysts and Al2O3 support (POC-3), the optimum overall exhaust purification, particularly for nitrogen oxides (NOx) and particulate matter (PM), is achieved with an asymmetrical channel design with a closed outlet form structure. Furthermore, because to the POC-3's increased exhaust back pressure, the original engine's brake-specific fuel consumption is somewhat lower in all engine operating conditions. Banglin Deng et al.[35] undertook theoretical and experimental research on the primary design and layout parameters that affect the performance of three-way catalysts (TWC) under transient driving circumstances, starting with the refinement and validation of a simplified reaction mechanism. Using boundary conditions acquired from experimental and upstream engine modeling data, this technique was utilized to create a semi-decoupled posttreatment GT-Power model. To guarantee model fidelity, tests were conducted on a real engine. The results showed that the most crucial element influencing pressure loss in a single reactor is cell density. During the first start stage, the reactor's exhaust temperature rapidly drops in the longitudinal direction, despite the reaction rate decreasing in this direction throughout the cycle.

S. Bekal and N. R. Bhat[36] used neat pongamia oil, a blend of pongamia oil and mineral oil (50% V/V), and neat mineral oil as lubricants, and neat pongamia oil, blends of pongamia oil and diesel in proportions of 20, 40, and 100, neat pongamia ester, and blends of pongamia ester and diesel in proportions of 20, 40, and 100 as fuel. NOx, smoke, CO, HC, BSEC, EGT, and friction power were measured for various fuel/lubricant combinations. It was discovered that the engine could be operated without problem utilising the lubricants examined in this work. Furthermore, it was discovered that the greatest results were obtained using neat pongamia as both fuel and lubricant.

Rajendra Uppar et al.[37] assess epoxidised jatropha oil (EJA) enhanced with multi-walled carbon nanotubes (MWCNT) as a bio-lubricant for compression ignition engines. SAE 20W40, EJA, and EJA-MWCNT were used to test engine performance and emission characteristics in a four-stroke diesel engine. The results revealed that EJA with 2 wt% MWCNT reduced friction power by 39.13% compared to SAE 20W40 and brake specific energy consumption by 6.11%, while also cutting hydrocarbon, carbon monoxide and smoke emissions.

Agus Nugroho et al.[38] investigated the development of nanoparticle-enriched palm oil-based biolubricants with the goal of increasing the sustainability and performance of electric vehicle (EV) lubrication systems. The crucial findings show that including nanoparticles like graphene, titanium dioxide, and aluminium oxide into palm oil-based lubricants greatly improves their tribological characteristics. These improvements include a 26.21%-34% decrease in coefficient of friction (COF), a 12.99%-30% reduction in wear, and increased thermal stability. The study discovered that nanoparticle-enriched biolubricants outperformed standard choices in terms of friction and wear at high temperatures and pressures, as evidenced by regression analysis.

T. Stephen et al.[39] conducted an investigation of an IC engine utilizing diesel and five different blends of co-pyrolysis oil with diesel in proportions of 20%, 40%, 50%, and 100%. The trials showed that combining 20% and 50 ppm CeO2 resulted in a 6% gain in thermal efficiency when compared to other blended fuels and diesel, as well as a 30 and 6.2% reduction in CO and HC emissions, respectively.

Numerous researchers found that plant (vegetable) oils had acceptable behaviour features and significant potential to become a bio-renewable hydraulic fluid or lubricant that could be used in a variety of industrial applications. However, several challenges must be overcome, such as the level of oxidation of plant oils at high temperatures. The purpose of this study is to experimentally assess the performance of mustard seed oil as an alternate supply of gearbox fluid in a 4-stroke IC engine at various rotational speeds.

2. Methodology

2.1 Rotary pin on disk machine

In recent years, knowing the behaviour of fluids, transmission fluids, and oils in a range of experimental test situations has become increasingly significant. Traditional tribometers and measurement technologies were no longer adequate when new applications emerged, such as automobiles, sophisticated lubricants, novel materials, and composites. Figure 1 shows a rotary pin-on-disk machine built as a modular test system capable of executing fluid testing for tribological evaluation in various test situations. This multifunctional device has test capabilities that go beyond most current industry requirements. A rotary drive regulates the disc rotation in the rotary pin on the disk machine. A friction/loading arm holds the counter specimen, which could be a pin or any other specific geometry. To obtain the appropriate contact stress, a known load is applied to the counter specimen. The pin-on-disk machine is an entirely automated testing method. The Acquire control and data acquisition system allows the operator to select and establish desired test parameters such as oil type, load, temperature, and speed. Table 1 shows the experimental work's operating parameters.

Fig. 1: Rotary pin-on-disk machine.

Table 1. The operation parameters for work experiments.

Normal load (N)	50
Time (sec)	3600
Rotation speed(N) (rpm)	250, 500, 750
Temperature (ºC)	20, 40, 60, 75, 100
Track diameter (D) (mm)	60
Sliding speed (m/sec)	0.942
Sliding distance (m)	3393.3
Wear disk diameter (mm)	160*8 Stainless steel
Specimen pin diameter (mm)	12
Specimen pin length (mm)	25
Pin metal specifications: EIS-52100 chrome-alloy steel. R.WC hardness test: 25 grade Eb and 64-66 hardness	

Where the sliding speed and Sliding distance are calculated using the equations (1 & 2) respectively:

$$\text{Sliding speed (m/sec)} = \pi \times D \times (N/60000) \quad (1)$$

$$\text{Sliding distance (m)} = \pi \times D \times N \times (T/60000) \quad (2)$$

$$\text{Flash temperature } = \frac{\text{Applied load (kg)}}{\text{Wear scar diameter}^{1.4}\text{(mm)}} \quad (3)$$

2.2 Apparatus

The thermal performance of a single-cylinder four-stroke internal combustion engine (Fig. 2) was measured at different speeds and loads, as shown in Table 2. At 3500 rpm, the engine produces the maximum torque and power of 14 N.m and 3.2kW, respectively. The dynamo motor is used to provide different loads to the employed engine. As engine speeds vary, a computerized controller board regulates the applied loads. The engine works on diesel fuel, which has the following specifications: 838.8 kg/m^3 density, 0.8304 specific gravity, 72.8ºC flashpoint, 37.1 American Petroleum Institute (API) gravity, and 10921 kcal/kg. The first test used mineral oil, whereas the second used mustard seed oil instead. Table 2 displays the thermal performance of the internal combustion engine (IC) engine using the previous two fluids under a variety of operating conditions. Two K-type thermocouples installed on the engine's cylinder body and a digital thermometer (TM-946) were utilized to monitor the surface cylinder temperatures of the IC engine.

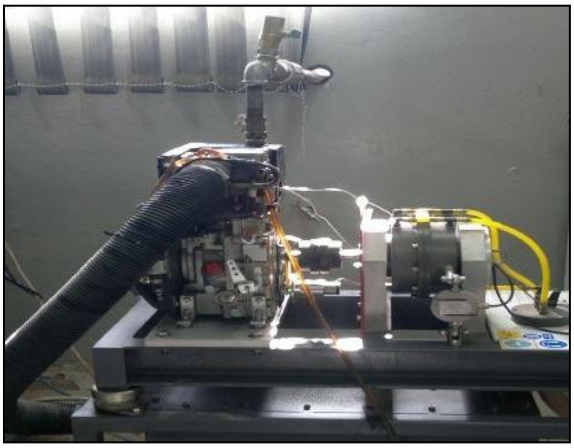

Fig. 2: Single-cylinder four-stroke internal combustion engine.

Table 2. Conditions for internal combustion engine tests.

Conditions for Internal Combustion Engine Tests	
Test 1	
EnginesSpeed (rpm)	2000
Applied engine Torque (N.m)	1.5, 3, 5
Mineral fluid	CMF
Bio-fluid	MSF
Test 2	
Engine load (N.m)	5
Engine speed (rpm)	1400, 1700, 2000
Mineral fluid	CMF
Bio-fluid	MSF

All The following equations are used for the calculation of the thermal performance characteristics of the internal combustion engine. The expression below shows the calculation of Power generated from the fuel.

$$PF = mf \times CV \quad (4)$$

Brake power

$$BP = 2\pi * N * T/60 * 1000 \quad (5)$$

Brake-specific fuel consumption

$$BSFC = mf\ /BP \quad (6)$$

Brake Thermal efficiency

$$\eta bth = BP/\ mf * C \quad (7)$$

2.3 Description of fluid Samples

Two types of samples were used to make a comprehensive assessment of the performances: the first was a sustainable bio-fluid (mustard seed oil-MSF) and the second was the commercial mineral fluid ATF 900HD (CMF).

3. Results and Discussion

Thermal behaviour characteristics (viscosity-temperature relationship, flash temperature, and thermal performance characteristics for the IC engine) for the mustard seed oil as a renewable bio-lubricant and the mineral fluid oil were investigated thermally, and the results were illustrated in Fig. (2-9) and separately discussed in the following paragraphs.

3.1 Relationship between viscosity and temperature

The viscosity of oils and fluids is an important feature that affects the performance of engines and machines directly or indirectly. The sample's kinetic viscosity was investigated using a rotational viscometer at various temperatures in this study. Figure 3 shows the link between viscosity and temperature acquired from this test. It is clear from this diagram that the temperature and viscosity of both fluid samples have an inverse performance (plant and mineral fluid). At high temperatures, both types of fluids (mustard seed and mineral oil) show a convergence of viscosity values, as seen in the same figure. Furthermore, Fig. 3 reveals that the index of viscosity for the mustard seed oil was higher than the index of viscosity for the mineral fluid[25]. Because it requires more power to circulate and shear high-viscosity oil among moving parts while an engine is running cold, this study supports the idea of utilizing vegetable oil instead of mineral oil as a lubricant. This increases friction work, which reduces braking power and increases fuel consumption. However, at higher operating temperatures, increasing lubricant viscosity is critical for enhancing engine performance and sustaining engine components[1]. Mineral-based fluids, which have lubricating, anti-wear, and friction properties, are frequently used in systems. Petroleum oil undergoes extensive processing for these reasons in order to eliminate undesirable molecules and introduce new substances, including additives, to enhance the oil's functionality. The viscosity and viscosity index are two of these performance indicators. Due to the fact that oil viscosity fluctuates with temperature, it is usually given as a constant temperature., which is typically between 100 and 40ºC. Viscosity is measured with a viscometer. To describe the degree of viscosity change, viscosity index values (units less) are calculated on a scale of 0 to 100. Therefore, zero (0) represents the fluid that has changed the most over a particular temperature, and 100 represents the fluid that has changed the least. All other fluids fall somewhere in the middle of these two extremes.

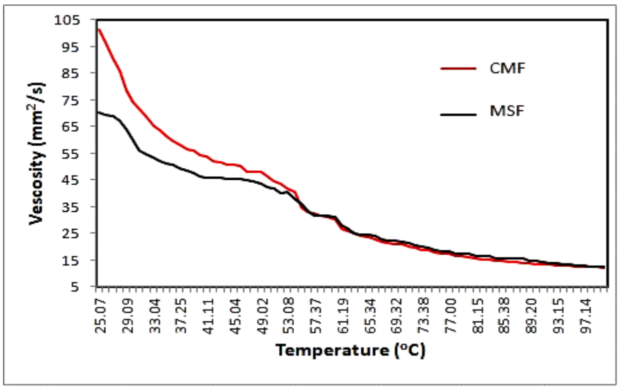

Fig. 3: Viscosity - temperature relationship [25]

3.2 Wear's surface

High-resolution scanning and transmission electron microscopes were used under 100X magnification to evaluate the wear scar zone as illustrated in Fig. 4. The wear scar zone and wear surfaces of the pin put in the oil specimens were circular in form with smooth and metal-concealed edges. Parallel grooves run across the surface, some deeper (dark colored areas) whilst others are shallow (light colored regions). Figure 4 depicts a description of commercial mineral oil (CMF) worn surfaces. Here, the margins are usually ragged, and the wear scars are round. Parallel grooves, most of which are deep (dark-colored region) and some of which are shallow (light-colored region), run parallel to the wear surface. Figure 4 demonstrates that the majority of the grooves are deep, even though the wear scar diameters are less than in pure mustard seed oil (MSF).

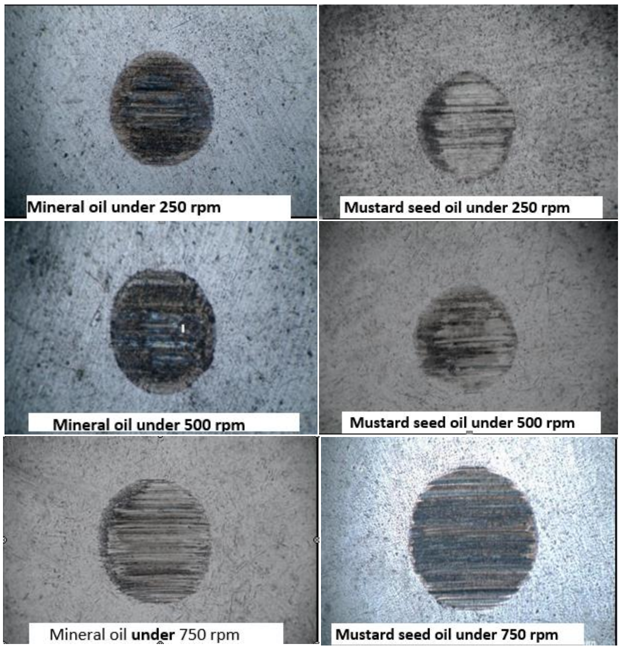

Fig. 4: Wear surface descriptions for the oil samples under different rotation speeds

3.3 Flash temperature

The flash temperature, also known as the flash temperature parameter (FTP), is one of the most significant properties to calculate for fluids since it represents the fluid's ability to sustain operational conditions or tests before collapsing[23]. A high flash value creates the impression of fluid efficiency in various operating settings. The flash temperature values were computed and displayed clearly in Fig. 5 based on the diameters of the wear area results under various rotational speeds and using equation No. 3.

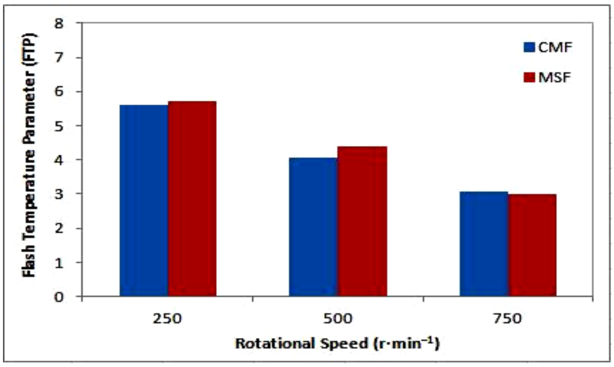

Fig. 5: Flash temperature's parameter for the fluid sample.

This figure shows that increasing the rotational speed reduces the values of the flash temperature for the mustard and mineral fluids and that the performance of the mustard and mineral fluids was comparable at most speeds (5.74 and 5.63 for the mustard and mineral fluid respectively under 250 rpm and 3.04 and 3.07 for the vegetable and mineral fluid respectively under 750 rpm). Furthermore, it was discovered that under high rotational speeds, vegetable fluid (mustard) performed better than the mineral fluid sample.

3.4 Thermal performance characteristics of IC engine

Figures 6 and 7 depicted the engine temperatures at a constant engine speed of 2000 rpm and a constant applied engine load of 5 Nm, respectively, for the thermal performance characteristics of the lubricating oils utilized and their influence on the IC engine performance. The CFM lubricating oil contributed to the reduction in engine temperature for both test situations, as shown by the findings. The physical basis for this improvement is that the CFM oil lubricant has a sufficient viscosity in comparison to MSF, which influenced the engine temperature experimentally. As a result, the high friction of the engine parts contributed to a reduction in temperature, and the engine was eventually cooled.

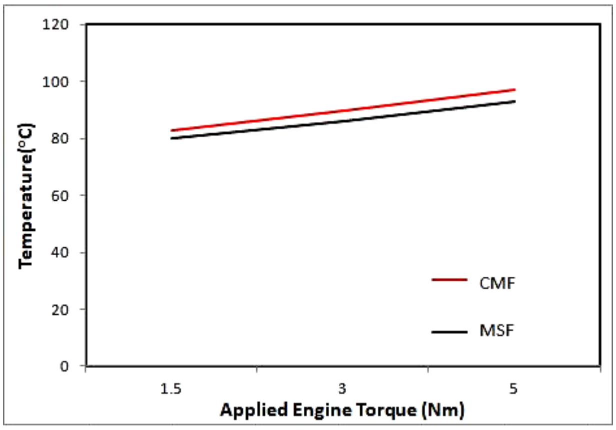

Fig. 6: Engine temperature at 2000 rpm for different loads.

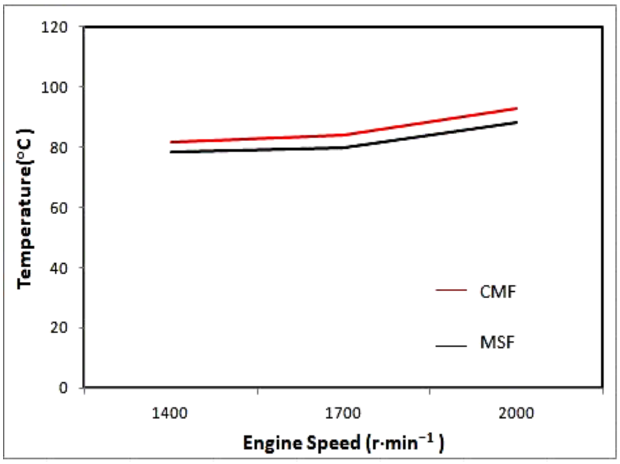

Fig. 7: Engine temperatures under 5 N.m for different engine speed.

Figure 8 depicts the IC engine's brake-specific consumption of fuel (bsfc) at a constant engine speed (2000 rpm). According to the results of the tests, increasing the engine's applied load increased the engine's loud bangs, which eventually increased brake power losses and brake-specific fuel consumption. While the bsfc of an IC engine under constant applied load (5 N.m) decreases from higher values at lower engine speeds, it hits a minimum and subsequently rises as engine speed rises, as seen in Fig. 9. The physical rationale for this scenario is that the engine's low speed results in a longer cycle time, which results in higher heat loss (fuel consumption goes up). Furthermore, increased brake-specific fuel consumption at high engine speeds is caused by higher friction losses, and CFM oil lubricant contributed to improving the bsfc in both test situations since it had a sufficient viscosity compared to the MSF oil lubricant employed. According to previous Fig. 8 and 9, utilizing MSF oil lubricant instead of mineral oil reduced brake-specific fuel consumption by around 6 and 4 percent in the employed internal combustion engine.

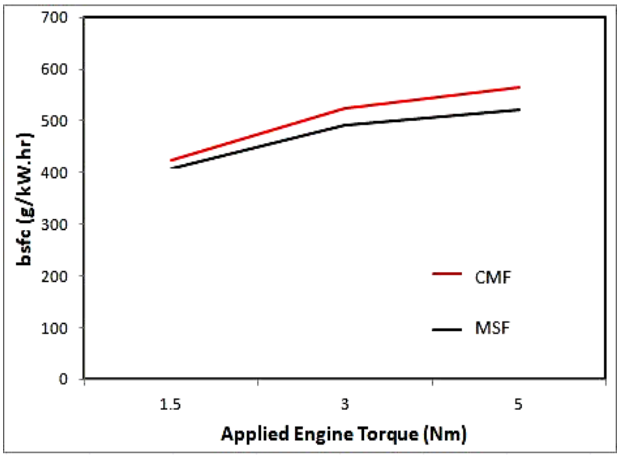

Fig. 8: The (bsfc) of engine under 2000 rpm for different applied loads.

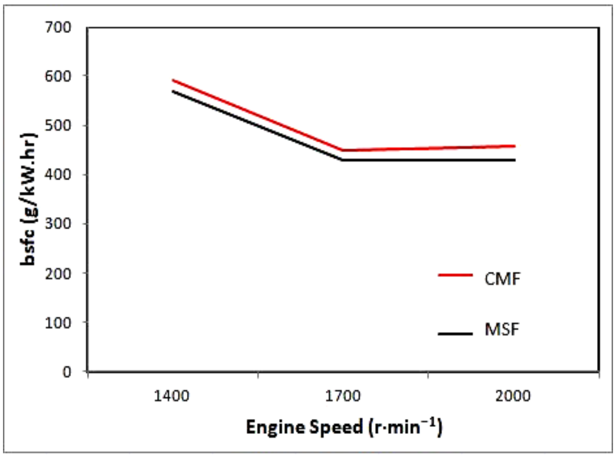

Fig. 9: The engine's (bsfc) under 5 N.m for different speeds of engine.

The brake thermal efficiency (ɳ b.th) of the IC engine is dependent on the brake power generated and the engine's fuel consumption rate, according to prior experimental data. Increases in friction losses induce declines in brake thermal efficiency at high speeds. Using CFM oil lubricant gave a rise in brake thermal efficiency due to its adequate viscosity compared to MSF lubricating oil, as demonstrated in Fig. 10 and 11.

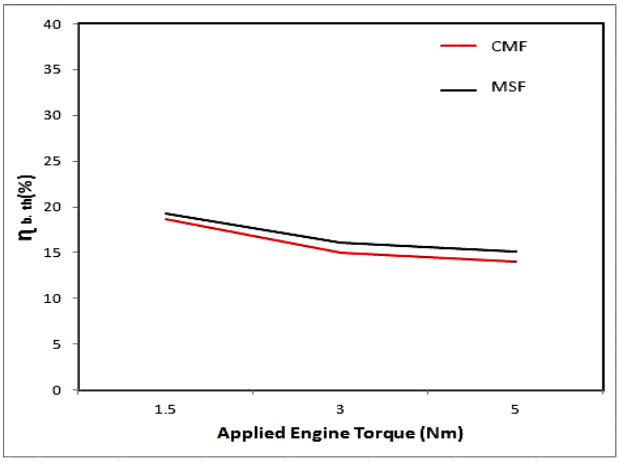

Fig. 10: Brake thermal efficiency under 2000 rev/min for different applied loads.

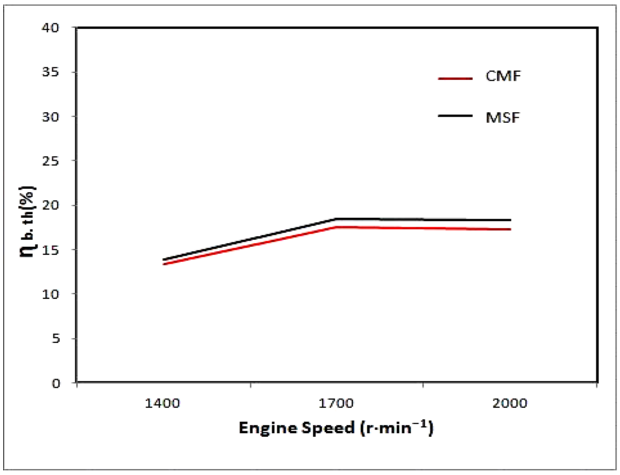

Fig. 11: Brake thermal efficiency under 5 N.m for different engine speeds.

4. Conclusions

The following conclusions can be drawn from the internal combustion engine's performance evaluation:

1- In terms of viscosity and flash temperature, non-edible mustard seed oil performs well as an alternative renewable working fluid. The mustard seed oil has a greater viscosity index than the mineral fluid. This supports the use of vegetable oil as a lubricant in engines rather than mineral oil, because operating a cold engine with high-viscosity oil requires more work to circulate and shear it between rotating components. This increases friction effort, lowering braking power and increasing fuel consumption.

2- Because non-edible mustard seed oil has better viscosity at low and high temperatures in contrast to mineral oil, using it as an engine lubricant rather than mineral oil increases engine cooling, decreases brake-specific consumption of fuel, and increases the IC engine's braking power thermal efficiency.

3- Non-edible mustard seed oil lubricant contributed to improving brake-specific fuel consumption since it had a sufficient viscosity compared to the mineral oil lubricant employed. Utilizing non-edible mustard seed oil instead of mineral oil reduced brake-specific fuel consumption by around 6 and 4 percent in the employed internal combustion engine.

4- Finally, using non-edible mustard seed oil gave a rise in brake thermal efficiency compared to using mineral lubricating oil.

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Nomenclature

ɳb	brake thermal efficiency
µ	Coefficients of friction
API	American Petroleum Institute
b.p	Brake power of the engine (kW).
bsfc	Brake-specific fuel consumption of the engine (g/kW.hr)
CMF	commercial mineral oil
CO	carbon monoxide
CO2	carbon dioxide
Cv	Fuel calorific value (10921kcal/kg).
F	Force of friction (N)
I.p	Indicated power of the engine (kW).
IC	internal combustion engine
m.f	Consumption of fuel (g/s)
MSF	mustard seed oil
N	Apply loads(N)
N	Speed of the engine (rpm).
P	Power generated by the fuel (kW).
PFAD	palm fatty acid distillate
RBD	refined, bleached, and deodorized
T	Torque of the engine (N.m).
tb	The required time to empty the fuel burette (s).
Vf	Fuel volume (8 ×10-6 m3).
W	Applied loads(kg)
WSD	Scar wear diameter (mm)
Pf	Fuel density (kg/ m^3).

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