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Tribological behaviour of RuO_2 in diesel: Benthic-diatom *Navicula* sp. algae biodiesel

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An operating automotive engine generates more friction as well as wears in between their sliding parts when compared to an idle one, and so needs lubrication to lower this particular frictional impact. Biodiesel is surely an alternative renewable source of diesel fuel. The current research will measure the friction and wear characteristics of benthic-diatom *Navicula* sp. algae biodiesel with RuO_2 at various concentrations. The biodiesel was studied at various blends such as B20, B20+50 ppm, and B20+100 ppm. Tests had been carried out at a speed of 1200 rpm at 75 °C under an average load of 40 kg per 1 h. Results revealed that friction and wear decreased with an increase in the concentration of RuO_2 nanoparticles in biodiesel.

[**Keywords**: Algae biodiesel, Four-ball tests, Friction, Ruthenium oxide, SEM/EDX analysis, Wear]

Introduction

The sliding time between two types of contact surfaces, which is often highly dependent on load, velocity, temperature, lubricant, and additive formulation. The design of wear is currently a challenge for mechanical engineers. All objects wear out, mainly due to the frequent operation of motors and machinery and moving parts. Sustained operations can lead to a catastrophic failure of the pistons or liners, which can also cause abrupt and costly engine malfunction[1,2]. The additional weight loss of fuel valve, fuel pump, valve input, exhaust valve as well as engine materials for diesel and biodiesel could be almost equivalent, to comply with an engine study. When the engine was powered by biodiesel compared to diesel, the maximum measure of weight reduction was seen in a compression ring. In determining quality parameters for fuel, lubricity plays an important role. This particular parametric quality is important both to improve machine life and to reduce wear between moving parts. This will further reduce the energy consumption because of reduced friction in the touch aspects of moving parts[3]. The fuel lubricates most engine components such as pumps and injectors. The fuel used on the engine must be well-lubricated[4].

The fuel temperature typically exceeds 60 °C during engine intake, which affects the lubricity of the fuel injected[5]. Also, higher temperatures in fuel pumps as well as in injectors affect the injected fuel's lubricity. Biodiesel provides many technical advantages, such as higher light biodegradability and reduced engine emissions. Biodiesel also provides substantially improved lubricity in engine compared to diesel oil[6]. However, specific negative aspects, such as filter plugging and injection shock, restrict biodiesel usage. In addition to their various technological and environmental advantages, these types of factors minimize the need or use of biodiesel[7]. The carbon oxidation deposition and the corrosive nature of biodiesel also affect the wear and friction of engine parts. Different methods of the tribometer were used for studying friction and wear. Biodiesel's wear and friction properties were improved with an improvement in biodiesel temperature[8]. Although numerous scientific studies have been conducted on the properties of wear and friction, no analysis of biodiesel algae blended with RuO_2 nano additives has been performed until now. Consequently, algae biodiesel has recently attracted attention as an alternative to diesel fuel, and therefore there is a need to assess its tribological performance as an engine fuel[9]. In the present study, the tribological properties of algae biodiesel are tested experimentally using the four-ball tribometer[10].

Materials and Methods

Test procedures

For such an analysis, a four-ball tribo tester has been used, which is a standard test frequently used on the rig by oil companies to ensure with scientific studies as well in the development of new lubricants. The test instrument consists of four balls; three fixed balls are firmly coupled within an oil cup and one rotating ball (Fig. 1). The whole type of oil cup has been practically loaded with the oil, which was being measured. Three balls were charged to the lower part by weights on a load lever, as well as three of the lower balls have been covered to the depth by 3 mm. Currently friction torque has been calculated through the calibrated arm, which would be connected to the friction recording sensor spring. Four new balls have been chosen for each test run as well as cleaned using n-Heptane as well as dried out purely with hot air. To set out the test, the oil cup with steel balls was first carefully washed quickly using toluene after that they were cleaned using tissue before they were properly dried. Instantly afterwards, three steel balls were tightly locked together inside the oil cup. A ball of steel arrived from the collet after it had been put within the unit. Testing the fuel has been drained within the oil cup till the three balls have been poured in full. The testing was conducted out at 300 s, with such a constant rotation speed of 1200 rpm as well as a load of 40 kg. To evaluate their wear scar diameter as well as the SEM / EDX analysis, three of the bottom balls have been obtained during each study[10]. The scanning electron microscopy has been utilized with a precision of 0.01 mm to examine the wear scar.

Friction evaluation

$$\text{The friction torque} = \mathrm{T} = \frac{\mu\, 3\mathrm{Wr}}{\mathrm{T}\sqrt{6}} \qquad \ldots (1)$$

$$\text{Coefficient of friction} = \mu = \frac{\mathrm{T}\sqrt{6}}{3\mathrm{Wr}} \qquad \ldots (2)$$

Where, W is the applied load and r = 3.6 mm

Flash Temperature parameter

The FTP helps to determine the ratio between wear scar in diameter, it's being used to assess the critical temperature over the lubricant. The formula used to calculate the parameter of flash temperature while loads are decided to enter to wear the diameter of the scar.

$$\Rightarrow \mathrm{FTP} = \mathrm{W}/\mathrm{D}^{1.4} \qquad \ldots (3)$$

Where, W- load act on the ball (kg)
D-Wear scar Diameter of the ball (mm)

Wear evaluation

The wear scar ball diameter has been measured using the electron microscope at a resolution of 0.01 mm (as per ASTM D4172). The ball bearings have been washed with acetone as well as cleared away until the tissue became drier. The scar also was examined, and the ball is put mostly on stage when it was found (platform to position the specimen) with the scar facing upwards. A sufficient magnification lens was chosen as well as the focus was changed until the computer screen displays a clear image. The image was captured and saved by pressing the on-computer capture button. Afterward, the diameter of an image wear scar has been tested using the available software on the computer. Both of these procedures were repeated for one of each test's bolt bearing.

Results and Discussion

Frictional behaviour

The friction behaviour has been inaccurate, with both the time only in the early part of each study. A few seconds later, in such a sampling as a steady-state condition, the whole operation resolved. Fig. 2 & 3 reflects the difference between both the friction coefficient (FC) as well as the frictional torque over the period. Over time, this hits the same stable-state stage. The whole result is because the contact surface has been scratchy initially. A few seconds later, eradication of influential abrasive particles softened the test ball's surface. Unsteady-state FC diesel fuel improves over time, especially in comparison to many other analyzed blended fuels. This particular aspect could be due to the influence of ester in biodiesel that

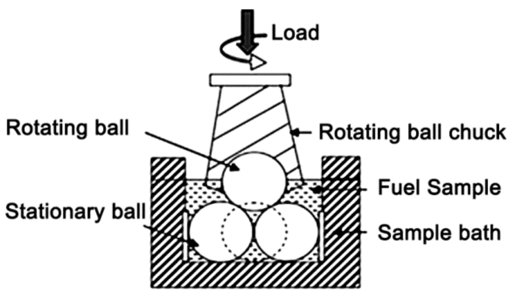


Fig. 1 — Schematic diagram of four ball Tribometer

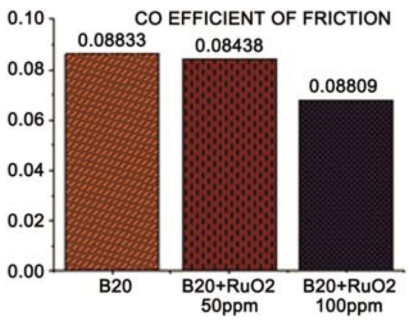


Fig. 2 — Friction coefficient

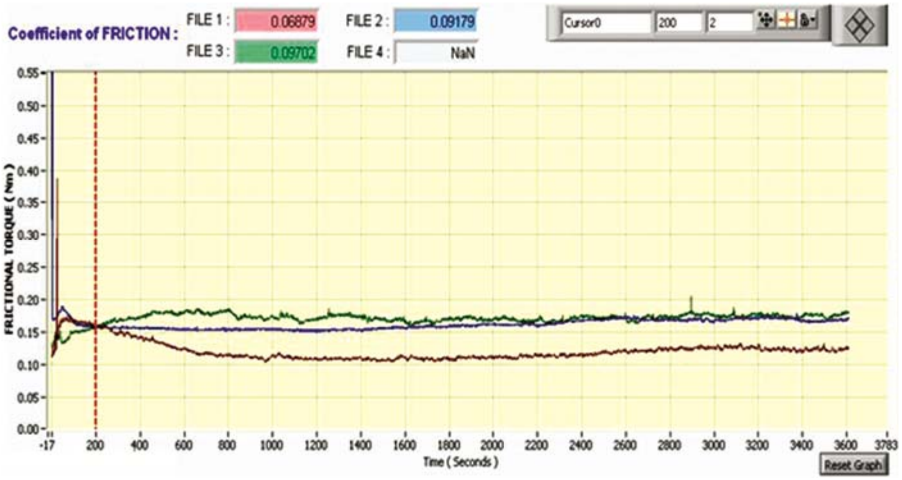


Fig. 3 — Frictional torque

will prove an enhancement in the shelter's safety performance as contrasted to diesel hydrocarbons. Unsteady-state FC B2+100 ppm is the lowest of the reported fuel and seems to be nearly linear but reduce with a shorter period. The absorption of RuO_2 ester molecules in biodiesel could be attributed to this outcome. These substances may function as surface contact surfactants[8].

Wear behaviour

Figure 4 shows the impacts of multiple fuel blends with various loads to wear scar diameter. A significant WSD typically indicates extreme wear[11]. This diameter increased with increasing wear load that could be because perhaps the tribological fuel properties resulting from oxidation were weakened by a change in pressure upon this metal contact area. The elimination of metallic soap film produced at full load. It may be causing such particular degradation. However, the average WSD for the biodiesel fuel is more than RuO_2 blended fuel and steadily reduces because of increasing RuO_2 quantity[12]. This particular increasing trend is similar around all the blends other than the B20+100 ppm. In this particular blend, the WSD lowers considerably. A further increasing amount of RuO_2 amount minimizes the diameter partially. This particular finding has been typically presented by the increase in the number of ester groups that also generates the formability to bind on the particles[13].

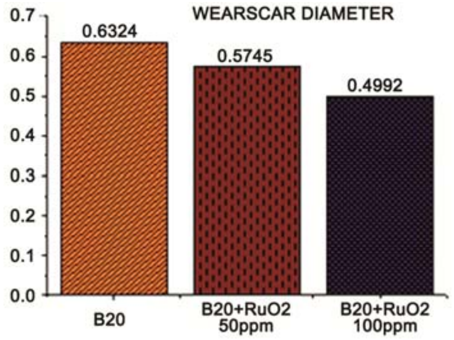


Fig. 4 — Wear Scar Diameter in mm

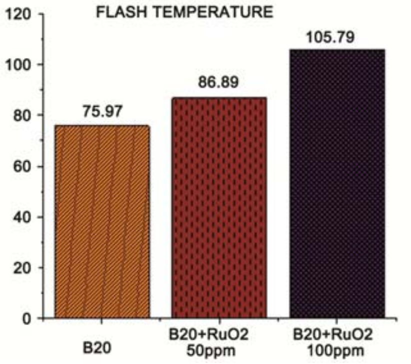


Fig. 5 — Flash temperature (°C)

Flash temperature parameter

It is also the temperature beyond which lubricating films are usually made to enhance lubricity. Larger FTP values indicate efficient lubricating performance as well as a lower probability of film break - down by lubricants[14]. The impact on FTP on various loads of different concentrations of biodiesel mixed with diesel fuel is represented in Figure 5. The FTP value of each fuel improves through wear reduction. The reality may well indicates this outcome that the increase in load as well improves the WSD on the worn surface, and FTP is inversely proportion linked to WSD[15]. Also, FTP is slowly enhancing the use of the same development with such an increase in biodiesel concentrations with RuO_2 compared to B20. B20+100 ppm are better than all of the other fuel samples, where B20 was attributed as the minimum FTP value.

SEM/EDX analysis

This filtering process is a robust technique of observing the puck-used surfaces while changing their direction, to measure the size of wear debris in blended fuels. Although fuel has to be clean and clear for optimization by filter paper just after the transesterification check, the filter debris is considered for the analysis using the SEM / EDX process. Particles of diesel fuel are generally higher than fuel found in blended fuels. The overall size of the surfaces worn from the metal ball slightly decrease as biodiesel blends increase. The particle measurement of filter wreckage is enlarged wide than, 20 µm which also will provide the adhesive wear rate from the fuel characteristics breaking down of the formation. It presents the SEM micrograph area surrounding static balls wear scar worn surfaces under a pressure load of 40 kg of various fuel blends. The basic surface framework thus reveals that the metal surfaces from of the worn surfaces forbidden the rotating ball is a sliding path. SEM / EDX analyses of surfaces worn by steel balls show the SEM micrographs of the area around the scar-worn surfaces of static ball samples under a load of 40 kg of different test fuels (Fig. 6 & Fig 7). The surface deformation is simply severe for B20; besides that, the wear scar decreases with the concentration of

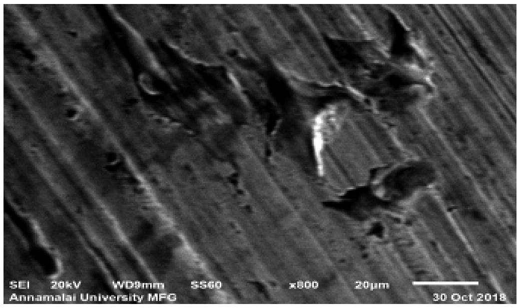
B20+50 ppm RuO_2 Ball 1 B20+50 ppm RuO_2 Ball 2

B20+50 ppm RuO_2Ball 3 B 20+100 ppm RuO_2 Ball 1

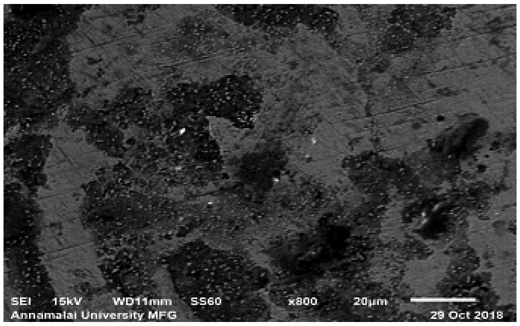
B20+100 ppm RuO_2Ball 2 B20+100 ppm RuO_2Ball 3

B20 Ball 1 B20 Ball 2

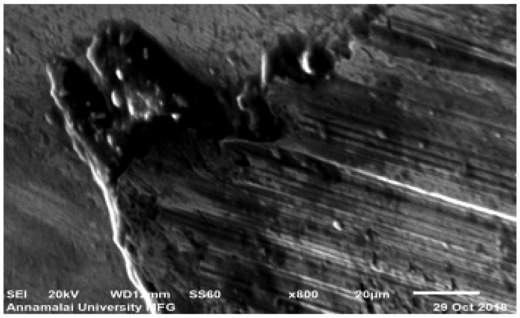
Fig. 6 — a) B20+50 ppm RuO_2 Ball 1, b) B20+50 ppm RuO_2 Ball 2, c) B20+50 ppm RuO_2 Ball 3, d) B20+100 ppm RuO_2 Ball 1, e) B20+100 ppm RuO_2 Ball 2, f) 11- B20+100 ppm RuO_2 Ball 3, g) B20 Ball 1, and h) B20 Ball 2



B20 +50 ppm RuO_2



B20 +100 ppm RuO_2



B20

Fig. 7 — Sample SEM image for: a) B20+50 ppm RuO_2, b) B20 +100 ppm RuO_2, and c) B20

RuO_2 as biodiesel increases. The surface morphology shows that throughout the sliding direction of a spinning sphere, surfaces of metals from the worn surfaces are excluded. The surface degradation with all fuel types is much more than 20 um, and therefore indicates adhesive wear.

Conclusion

Both wear and friction decrease with the support of the increase of RuO_2 proportion in B20. In comparison to RuO_2 blends, B20 revealed a high frictional coefficient during run-in time and stable-state conditions below 40 kg load conditions. RuO_2 blends showed a lower average volume of FC than B20, as well as other blends did. RuO_2, therefore, provides improved lubrication performance compared with other mixtures. RuO_2 blends have lower worn scar surfaces relative to B20 blends. In conclusion, these findings and results indicate that while in terms of friction and wear, RuO_2 shows the most favourable as well as better lubricating efficiency. Hence, this blend could be used to improve the life of the engine in automobiles.

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Conflict of Interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Author Contributions

JA: Preparation of materials and methods and performed experiments. TE: Provided essential input to result and discussion of the research.

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