Chapter 16

Biodiesel Compatibility with Elastomers and Steel

Salete Martins Alves, Valdicleide Silva e Mello and
Franklin Kaic Dutra-Pereira

Additional information is available at the end of the chapter

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Abstract

This chapter describes the compatibility of biodiesel with automotive components, such as metallic and polymeric materials. It consists of a survey of literature as well as research results obtained by the authors. Aspects as wear, corrosion, and degradation materials are discussed.

Keywords: biodiesel, biofuel, elastomers, steel, corrosion, lubricity

1. Introduction

The great attention is attributed to biodiesel in recent years, due to its renewable character and sustainable use that can minimize damage to the environment. They can reduce emissions of pollutants gas and particulate materials compared to diesel from petroleum. Also, they have biodegradable and nontoxic character. In order to meet market requirements, in recent years a significant advance in installed capacity of the biodiesel industry was observed. The use of this fuel and its increase in the energetic matrix implies in constant research and development of technology to ensure its safety use. In the Brazilian energy matrix, the biodiesel use is regulated in 7% biodiesel blended with diesel. However, in this year, the biodiesel proportion will increase to 10%. Associated with growth in biodiesel demand, the fuel quality control is a greater concern, because of its natural process of degradation, corrosion or tampering, and consequently of their blends with diesel.

On the other hand, due to the unsaturated molecules present in your chemical composition, some adverse effects were reported by various authors [1–6]. Most of them are focused on the corrosive character because it is more oxidative and causes enhanced corrosion and material

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degradation. However, at low concentrations, no serial problems were reported to parts of the engine.

The correct material selection minimizes the corrosion problem presented by biodiesel. For example, the material used to biodiesel transportation and storage is commonly stainless steel because it has a good corrosion resistance, as well as benefits cost relation. It had been cited that they have an excellent compatibility with corrosive fluids. Some metallic substrates are used in automotive systems like tanks and carbon steel plates (covered or not by zinc), iron-zinc alloys, aluminum-zinc or nickel-zinc, lead, and tin [7–9].

Studies about the biodiesel compatibility with the other kinds of materials are some important, especially because of their injection process in the automotive application. In this step, it gets in contact with different materials such as metallic, ferrous, and even elastomeric.

The chapter describes studies of the biodiesel compatibility with some components of fuel injection system and materials used to storage and transporting of this fuel, focusing on elastomers and metals degradation after biodiesel and diesel contact.

2. Fuel and biofuel compatibility with seals of injection systems of diesel engine

Some studies had shown that when biodiesel was used as fuel in diesel engines, the injection system has been suffering some damages, such as swelling in the elastomeric seals in injection distribution, which may result in leakage of fuel [10].

Swelling results showed an incompatibility between the elastomer and the fuel, which cause a substantial loss of elastomeric properties and thus loss of sealing ability. Faced with this issue, some questions arise associated with the use of blends of biodiesel vehicle: How to evaluate the deterioration of elastomers applied to the injection system of a diesel engine caused by the use of biofuel? How the addition of the biodiesel in diesel influences the mechanical properties loss and swelling of elastomers? How are biodiesel compatibility and their blends with elastomers?

Searching answers for these questions, many authors have exposed the elastomeric materials, which are used in sealing automotive, in contact with fuel. The compatibility methods are described in the following sections of this chapter, as well as the results of degradation and compatibility of some fuels with these stamps.

2.1. Conventional compatibility test

The compatibility evaluation is commonly performed by immersion test, which consists of immersed sample in a suitable solvent, analyzing the damage by swelling by gravimetric analysis. Hasseb et al. studied the degradation of different elastomers in contact with palm biodiesel [9]. After immersion test, they found that some properties such as tensile strength, elongation and toughness were significantly reduced for both the nitrile rubber (NBR) and chloroprene rubber (CR), while minor changes were found to fluoro-VITON. Bessee and Fey assessed the influence of methylic soybean biodiesel blends in the mechanical properties of the elastomer, such as hardness, tensile strength, elongation, and swell [11]. They observed changes for nitrile, nylon 6/6, and high-density polypropylene exhibited in the mechanical properties listed above. On the other hand, this behavior is not observed for VITON. Trakarnpruk and Porntangjitlikit investigated the impact of biodiesel on the properties of six types of elastomers commonly found in fuel systems (NBR, HNBR, NBR/PVC, rubber, acrylic copolymer FKM, and FKM terpolymer). Biodiesel is mixed with diesel to prepare B10 (10% mixed with diesel) [12]. The study showed little impact on properties for the polymer FKM and FKM terpolymer, ensuring consumer confidence in the use of B10 for contact with these polymers.

Michal Dubovsky reviewed the changes in the physical and mechanical properties of rubber mixtures (produced from NBR) immersed in blends of biodiesel-diesel, B10, B50, B75, and B100 at room temperature (23°C) for 3000 h and at 100°C for 500 h [13]. After immersion tests, the greatest degradation of samples exposed to a higher concentration of biodiesel (B100) at 100°C was observed. So rate used the SAE J1748 standard for assessing the compatibility of natural rubber, nylon, and EPDM (monomer ethylene-propylene diene) immersed in high oil biodiesel FFA (high content of free fatty acids) for 500 h at 55 ± 2°C. EPDM and nylon change significantly after immersion tests, but no changes were observed to natural rubber [14].

Lei Zhu studied the NBR compatibility with nine different fuels: diesel, PME, WCOME, PME, (C12:0), (C16:0), (C18:0), (C18:1 M), and (C18:1 E). After 168 h of immersion test at ambient temperature (25°C), the changes in mass, volume, and mechanical properties of NBR samples showed that biodiesel has a higher solvent power than diesel fuel. Mei Sze Loo investigated the effect of fatigue on the nitrile rubber [15]. The elastomers were immersed in the conventional diesel engine for 3 months and palm biodiesel for 10 days, and the same degree of swelling was obtained before the application of uniaxial fatigue loading. The authors through the stretch-N curves found that the swollen rubbers B100 had a shorter life when compared with swollen rubbers diesel [16].

2.2. Compressive immersion and pressurized tests

In order to analyze the changes in shaft seals suffered by fuel contact, some authors conducted tests and simulated that the real conditions of contact in these shaft seals are submitted.

In their investigations, Chai et al. [17] submitted two kinds of rubbers (NBR and CR) to a test tensioned by a set of plates that pressed the seal. The device consisted of four rectangular stainless steel plates with spacer bars between them. The spacer bars are designed to introduce pre-compression on the rubber specimens while they are immersed into biodiesel. Then, the device with rubbers was immersed in different palm biodiesel blends (B0, B25, B75, and B100) for 30 and 90 days, respectively. After the tests, it was found that for the types of rubber used, there was an increase in mass as well as a change in volume when the exposure time is increased from 30 to 90 days, especially when using the higher percentage of biodiesel content (B100). However, it is also noted that the pre-compression stress applied in the test reduced the amount of swelling, as compared to rubber without application of tension. That is, the swelling of NBR and CR increases with increasing biodiesel content and decreases with increasing pre-compressive stress [15].

Chai et al. and Mello [17–19] were performed immersion tests in innovative pressurized fluid device fluid, to simulate and investigate the degradation of a rubber seal in a fuel injection pump. She studied two elastomers NBR and VITON, as a sealing material. Pressurized fluids used were: diesel, biodiesel soybean, sunflower and palm oil, and its mixture with diesel (B5 and B20). The system is available in BR 10 2014 028966 6 patent.

In this study, the elastomeric seals degradation because fuel contact was investigated by testing for static and pressurized immersion. Thus it is possible to identify changes in the seal degradation under compression conditions. Below, schematic drawing device has been described.

The compression was employed using m steel cylinder by applying a preload 2500N, calculated by the required torque to maintain the closed cylinder during the expansion (**Figure 1**). O-rings (NBR and VITON) were compressed within the cylinder. All equipment was subjected to the pressure of fluid 200 bar for 5 h. The pressure amounted to 80% of the less-resistant elastomer pressurized NBR. The fluids used were diesel and biodiesel of soybean, sunflower and palm oil, and its mixture with diesel (B5 and B20).

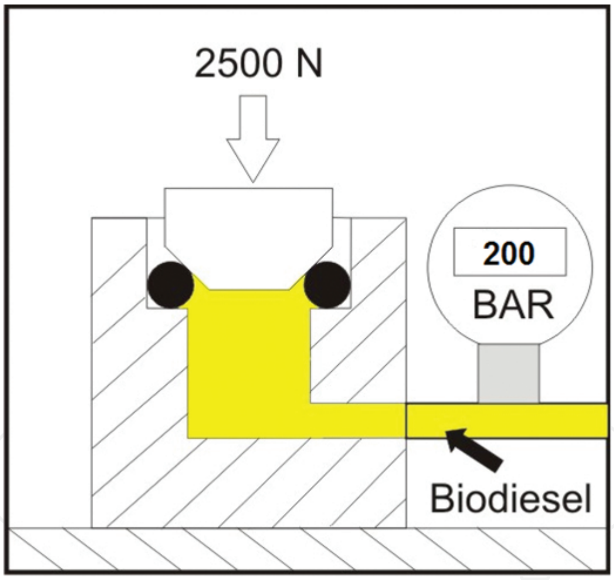


Figure 1. Simulation of the fuel injection system compression.

2.3. Comparative analysis of the compatibility of seals with fuel by the static immersion and pressurized method

Samples of elastomeric seals, NBR (nitrile rubber) and VITON (fluorine-carbon rubber), were studied by two exposure methods in order to verify the influence of the two approaches in the compatibility of the seals with fuel and degradation mechanisms suffered by seals.

In comparison purposes with the norm, the seals were also exposed to the solvent provided in the standard (toluene) with the same temperature ASTM D3616-95, but for 100 h. After the samples were weighed in the precision balance, the samples were weighed before and after the immersion time to determinate the weight loss and were dried in an oven at 108°C for 24 h, and weighed again. The evaluation of the compatibility of the elastomer with the fuel occurs based on the analysis of mechanical properties changes, swelling degree and morphological analysis of the seals after exposure to fluids.

2.3.1. Swelling rate

The **Figure 2** concerns the comparison of elastomers tested, regarding their changes in weight after static immersion (ASTM D3616-95) in soybean, sunflower, and palm biodiesel, and its blends.

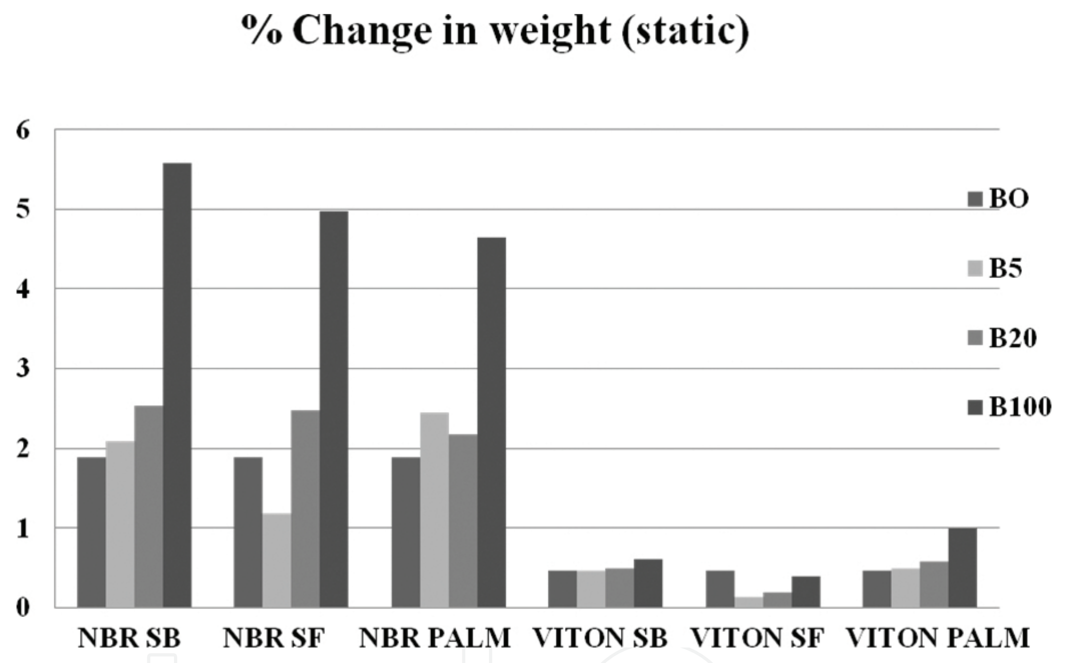


Figure 2. Change in weight of elastomers after static display of biodiesel.

The increase in weight for NBR shows an exponential trend to increased biodiesel concentration for all tested biodiesels. For VITON, moderate increase is observed for all fuels. These results are similar to those found in studies [10].

The nitrile elastomer (NBR) showed significant weight changes in contact with pure biodiesel (B100) due to the swelling ability that increased the absorption of fluid compared to soluble elastomer components. Different biofuels (soybean and palm biodiesel) did not show a big difference in the swelling degree of elastomers. Thus, it can be concluded that differences in the biodiesel composition do not affect in elastomer damage. However, the degree of swelling evaluated for sunflower shows a significant increase due to the moisture content in the biodiesel. **Figure 3** gives the change in the weight of elastomers in contact with pressurized fluids.

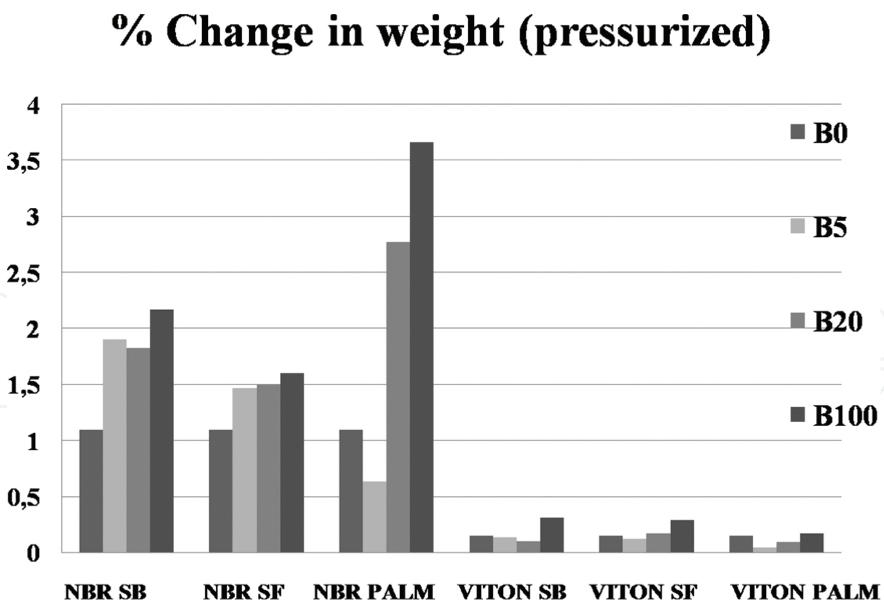


Figure 3. Change in weight of the elastomer after exposure of pressurized biodiesel.

Analogous to static swelling test, the volume change shows the same behavior for the elastomers in the pressure test, even with a time lesser than the static test exposure. Similarly, the VITON elastomer showed substantially constant, this being more compatible with the fuel investigated. This indicates that the pressure contact role should be considered when analyzing systems in which this parameter is present. Based on these results, we found the significant influence of the pressurized contact in the elastomer properties, despite the short-time exposure.

2.3.2. Mechanical properties

The results in the hardness changes for the elastomers are shown in **Figure 4**. For the NBR, the hardness in the condition B0 and B100 (only soybean and sunflower biodiesel) decreases compared to the hardness of the untested material. To contact the palm biodiesel, a reduction in this property for all blends (B0, B5, B20, and B100) occurs. For VITON, significant changes in this property with the use of all biodiesels and their blends are not observed.

The elastomers based on carbon and silica with materials used as fillers may serve to improve the hardness properties, abrasion resistance, tear resistance, and tensile strength. Also, the physical properties of elastomeric materials are determinate by addition of curing agents and accelerators, because they promote cross-linking between polymer chains or backbone.

Trakarnpruk and Porntangjitlikit [12] explain that biodiesel can be absorbed by the polymer that swells and therefore reduces entanglement of the polymer chain. Haseeb et al. [10] suggest an interaction between biodiesel with fillers and curing systems used in the production of elastomers.

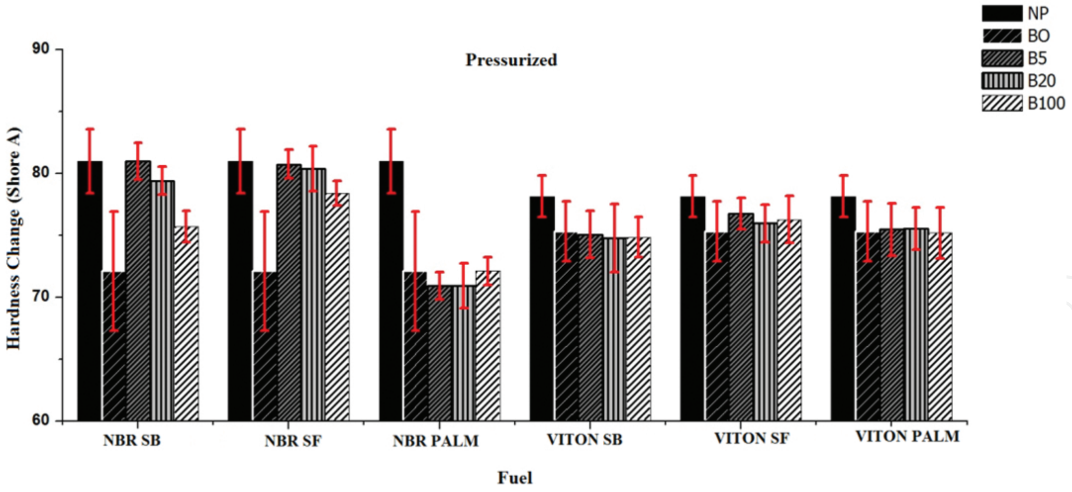


Figure 4. Change in hardness of the elastomers.

According to Haseeb et al. [10], after exposure of different elastomers biodiesel, these cross-linking agents and/or fill appear to react with various components of biodiesel and thus, deteriorate the mechanical properties.

The results of tensile strength tests are shown in **Figure 5**. After the pressure test, there was a greater loss in tensile strength compared to NBR nonpressurized material. Similarly, they observed different behaviors for various fuels, such as palm oil biodiesel, and it, in its pure form, showed a little loss in tensile strength compared to soybean biodiesel, in particular, for the conditions with B20 and B100. This loss was even more pronounced for biodiesel sunflower and all their blends.

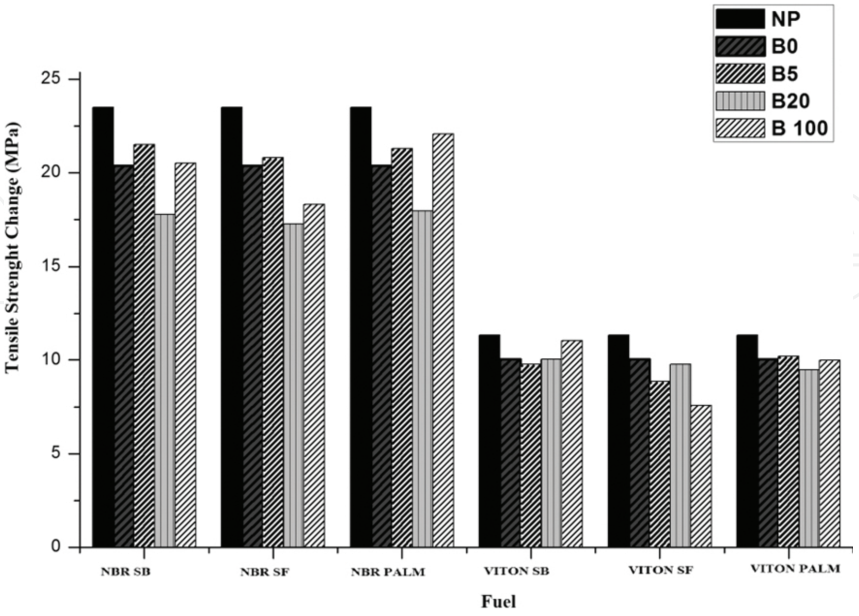


Figure 5. Tensile strength change.

The study concludes that the compatibility of the elastomer with biodiesels showed greater losses in mechanical properties, for investigated elastomers (NBR and VITON), even this displaying lower mechanical properties in conditions not tested.

It also concludes that testing of pressurized biodiesel contact with elastomers showed significant influences on changes in materials, despite the short-time exposure. This demonstrates the importance of pressure in studies of degradation of elastomers.

3. Corrosion caused by biofuel

The damage resulting from corrosive processes includes not only the need to replace metal parts in industries but also environmental problems with improper waste disposal of waste from these processes. Few studies report about corrosion of metallic materials in organic media, although of broad applications.

Biodiesel is a hygroscopic fuel, with greater capacity of water absorption than petroleum diesel. Studies reported by Kovács et al. [4] demonstrated that biodiesel is 30 times more hygroscopic than regular diesel. This feature depends on the feedstock, which favors the oxidation reactions. According to Fazal et al. [20], these reactions change the fuel properties and increase its destructive potential. The water absorbed can act directly on the corrosion of materials; it can cause biodiesel hydrolysis reactions, increasing, therefore, the metal corrosion, and promote microbial growth and, consequently, microbial corrosion.

According to Kovács et al. [4] biodiesel must avoid to its aging and/or oxidation during storage and should not deteriorate of the storage tank materials. Commercial automotive fuels contain additives carefully formulated to meet the stability of the product requirements

Ferrous and nonferrous metal parts after contact with biodiesel corrode through the chemical and electrochemical attack. According to Singh et al. [3], corrosion and wear are caused by contact of metallic materials with biodiesel. However, different materials present different corrosion behaviors in biodiesel. Ferrous alloys have better compatibility with biodiesel than nonferrous alloys. On the other hand, the copper alloys are more susceptible to corrosion than ferrous alloys. The fluorocarbons, a new group of compounds, have a high corrosion resistance.

The use of biodiesel plays considerable economic importance to national and global energy matrix. The corrosion knowledge related to fuel is a relevant issue for investigation, due the damage and cost caused by corrosive processes. Thus, the challenge is to find reliable methods to quantify the biodiesel corrosiveness, materials compatibility, and way to prevent corrosion.

The Brazilian National Agency of Petroleum (ANP) recommends the use of the ASTM D130-04 test standard to evaluate the fuel corrosiveness. This standard consists in the immersion of copper strip (clean and polished) in fuel for 1 h at 37.8°C. After this time, the piece is removed and compared against a color chart. In Refs. [4, 21–23] assess the corrosion of metals by gravimetric techniques such as ASTM G1 rules (2003) and ASTM G31 (2004) and by electrochemical techniques such as potentiodynamic polarization, linear polarization resistance, and electrochemical impedance spectroscopy (EIS).

3.1. Evaluation of corrosion by gravimetric techniques

The immersion tests or gravimetric technique is an almost used method to determinate corrosion rate, corrosion speed, and thickness loss when it is important to investigate the influence of organic or inorganic fluid on metallic materials. ASTM G3172 describes this test (2004) and consists of some steps, such as sample preparation (sanding and polishing), immersion time (hours), pickling (metal immersion in HCl solution 0.2 mol/L for 120 s), and weighing (before and after immersion test).

The degradation of different automotive materials such as copper, brass, aluminum, and cast iron was evaluated by Fazal et al. [23]. These materials were immersed in palm biodiesel and diesel at room temperature for 2880 h. The results showed that biodiesel is more corrosive than diesel, once the corrosion rate of copper (Cu), brass (BS), aluminum (Al), and cast iron (CI) increased when immersed in biodiesel. Also, corrosion rate in biodiesel for the studied materials was: copper (0.39278 mpy), brass (0.209898 mpy), aluminum (0.173055 mpy), and cast iron (0.112232 mpy). Also, the surface damage was analyzed by scanning electron microscopy. They concluded that the corrosion attacks on biodiesel-exposed metal surfaces are greater than diesel. The surface damage of aluminum was less than copper, brass, and cast iron. The corrosion was uniform on the metal surface.

The temperature influence on biodiesel corrosiveness was studied by [1]. Mild steel coupons were immersed in diesel (B0), blend palm biodiesel and diesel (B50) and palm biodiesel (B100) at 27, 50, and 80°C. They observed that corrosion rate increases with an increase in temperature for all analyzed fuel. This fact can be attributed to fast dissolution of corrosion products. EDS analysis showed the presence of oxygen on coupons surfaces indicating the formation of iron oxides or iron carbide. The metal surface was degraded by subsequent formation of other oxides and their dissolution in fuel. The biodiesel attacks more the metal surface than diesel fuel.

Dutra-Pereira [6], his master thesis, investigated the stainless AISI 316 corrosion when in contact with different biodiesel. These biodiesels were synthesized from vegetable oils (soybean, sunflower, and castor) and methanol/ethanol. The influence of alcohol used in biodiesel formation on corrosion was studied. The experimental procedure followed ASTM G3172 (2004) and time immersion of 2160 h. **Figure 6** shows the mass loss of stainless samples by corrosion related to biodiesel. The nomenclature of biodiesel was adopted considering the precursor oil and alcohol used in transesterification, p.e. soybean methylic (the biodiesel was synthesized from soybean oil and methanol), and B7 is a commercial fuel in Brazil (a mix of 7% of biodiesel and 93% of diesel).

From **Figure 6**, it is possible to verify that the loss mass is a little bigger when ethanol was used in biodiesel synthesis, and it can be justified for two carbons in the carbon chain. Considering the precursor oil, it is noted that soybean biodiesel promotes less mass loss than other biodiesel. The B7 has more mass loss indicating that the mix of diesel and biodiesel increases the corrosiveness of fuel, once diesel doesn't promote corrosion in stainless [22].

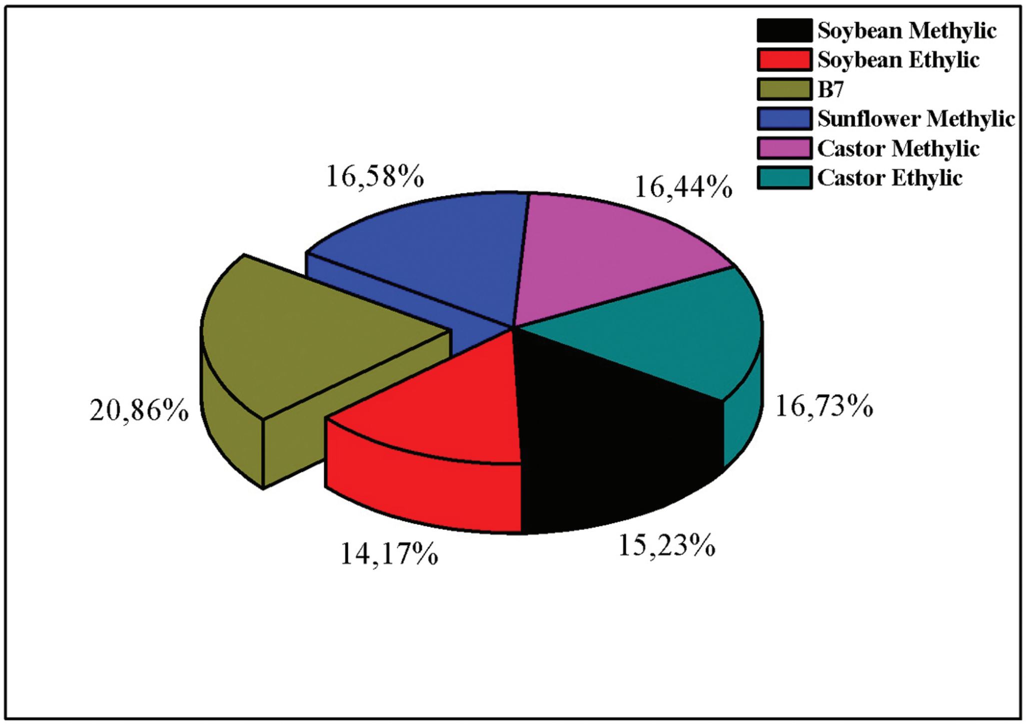


Figure 6. Loss mass due to the corrosion process [6].

The corrosion attack on stainless steel surface was analyzed by Ref. [6] by scanning electronic micrographs (**Figure 7**). Comparing with as-received steel and post-corrosion samples, it is possible to see little damage in surfaces. Basically, the corrosion occurs in pitting form.

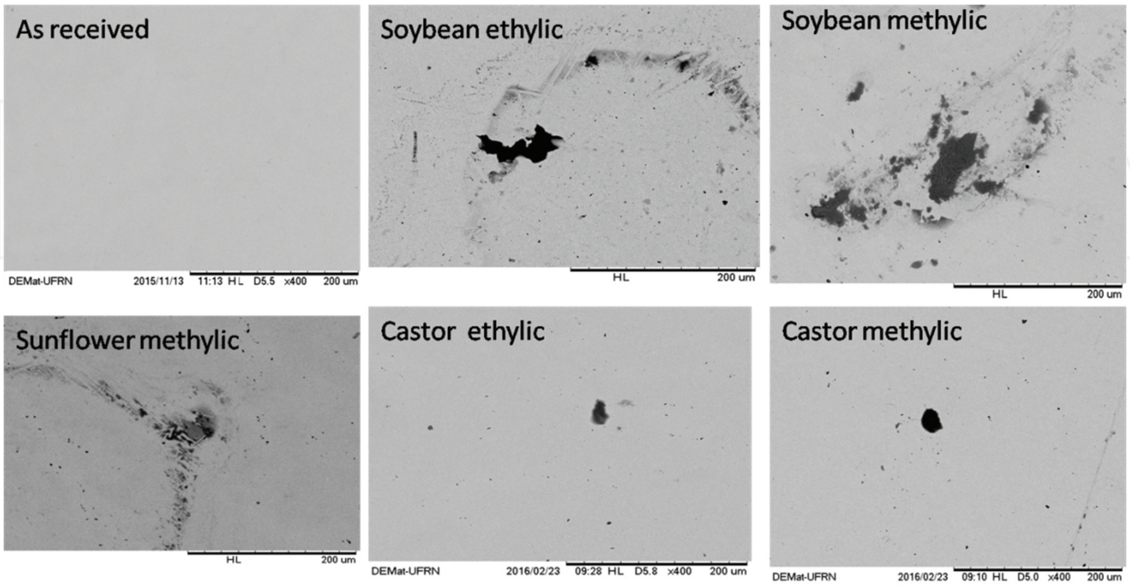


Figure 7. Scanning electronic micrographs of stainless steel after 2160 h of immersion time in biodiesel [6].

In **Figure 8**, it is clear that all biofuels corrode the metal surfaces, and the corrosion rate increases with time immersion. Although soy biodiesel and sunflower have similar molecular structure, the corrosion rate is different, being higher for sunflower biodiesel.

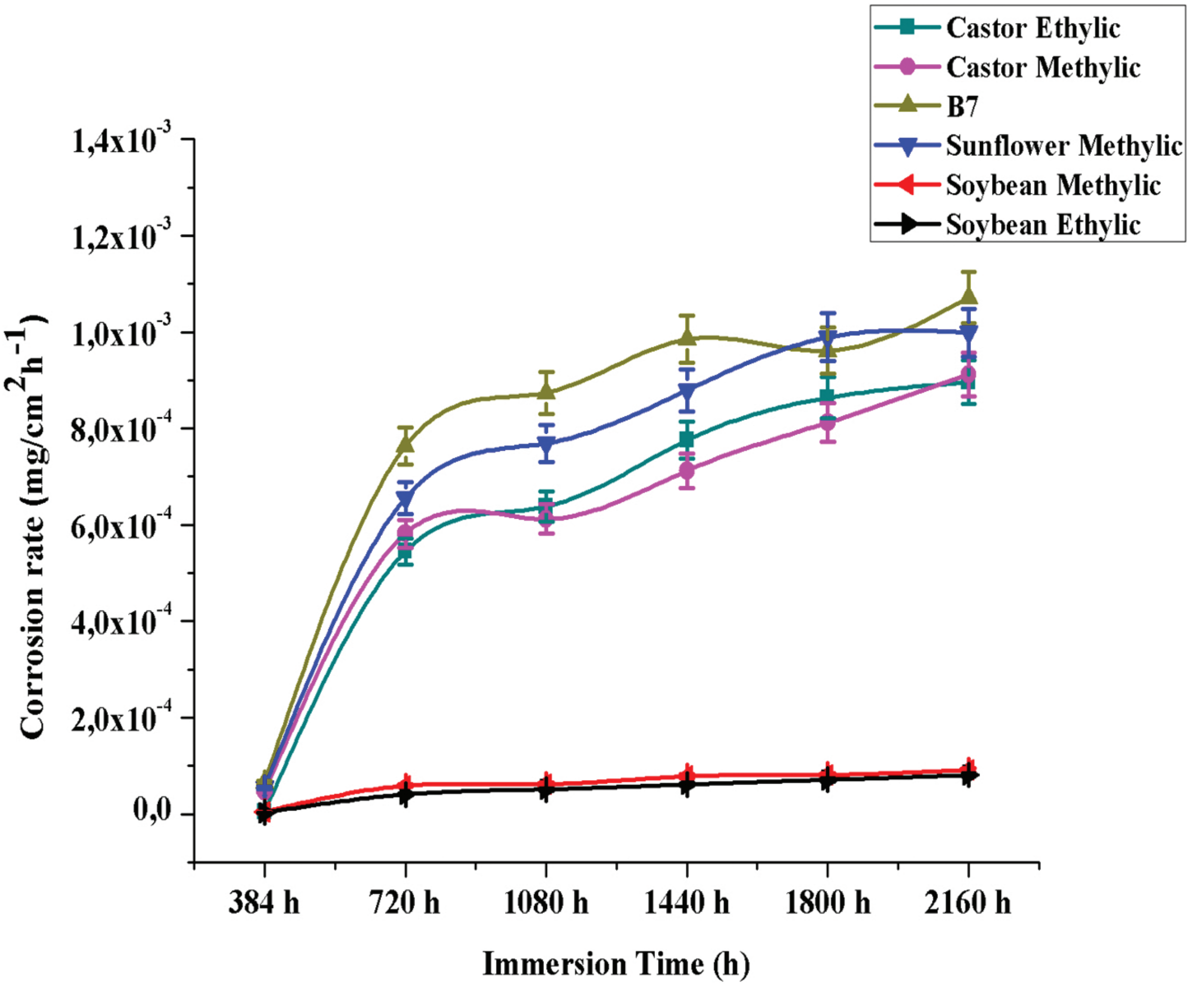


Figure 8. Corrosion rate in function of immersion time [6].

According to Fazal et al. [24], some factors influence the biodiesel corrosiveness: (i) biodiesel composition (ester and its polarity, unsaturated components, presence of oxygen, and contaminants), (ii) environment (temperature, air, light, moisture, and exposure to different metals), and nature of components (auto-oxidation, hygroscopic nature, microbial growth, and affinity of exposed metal).

The corrosion involves chemical and electrochemical reactions, which can accelerate the metal wear and promote corrosion. However, there are few studies in the literature about corrosion of automotive materials in contact with biodiesel [20, 22, 25].

As mentioned before, there are no specific techniques to analyze corrosive aspects of contact between biodiesel and metallic materials. Thus, it is important to study new methods that can evaluate the biodiesel corrosiveness, such as electrochemical techniques.

3.2. Evaluation of corrosion by electrochemical methods

As mentioned before, the most common method to assess the biodiesel corrosiveness in literature is gravimetric by immersion tests. However, this approach is only qualitative and did not characterize the trend and mechanism of corrosion of metals in contact with fluids. Also, it is important to consider that, usually, the metals corrosion is described as an electrochemical mechanism. Based on this, some electrochemical techniques and results are presented in this topic.

According to Aquino [2], the evaluation of nonaqueous fluid, as biodiesel, through electrochemical techniques is a challenge because of the high resistivity (or low conductivity) of media making difficult the determination of quantitative parameters of corrosion. The most usual electrochemical techniques are potentiodynamic polarization and electrochemical impedance spectroscopy (EIS).

Electrochemical impedance spectroscopy (EIS) is a nondestructive technique and consists "in a transient method where an excitation is applied to the system and the response (as a function of frequency) is observed" [26]. In corrosion studies, the diagram more used to analyze the information from EIS test is the Nyquist diagram (**Figure 9**), where the real part of impedance is plotted on the x-axis and the imaginary part in the y-axis of a chart. In this plot, the y-axis is negative, and each point on the Nyquist plot is the impedance Z at one frequency. The Nyquist diagram is useful to recognize the process type.

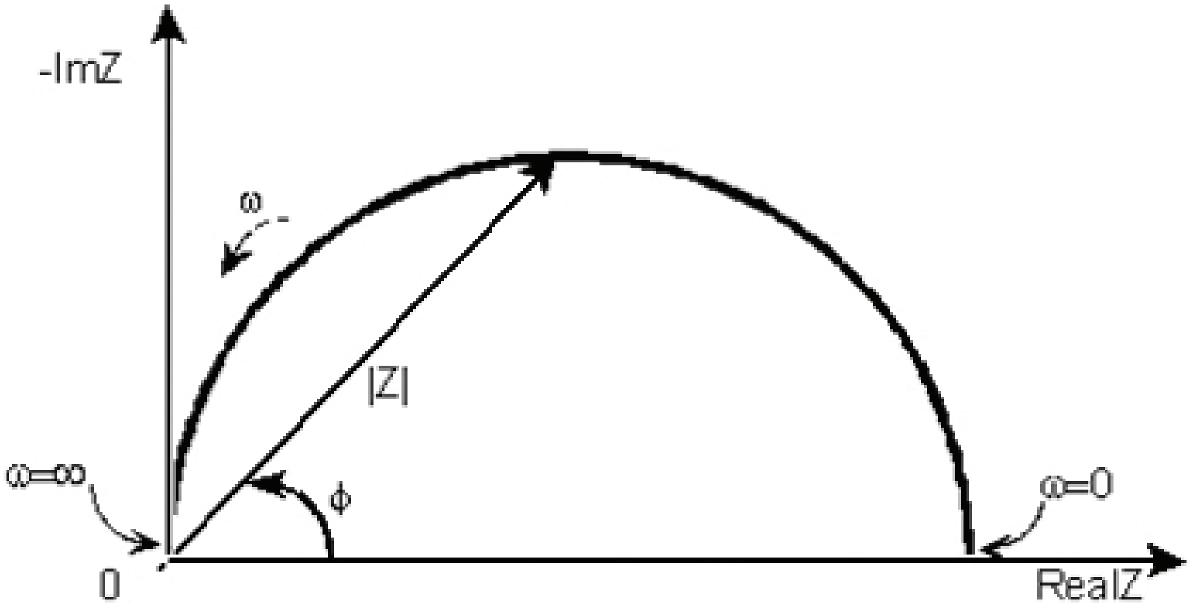


Figure 9. An example of Nyquist plot.

The potentiodynamic polarization is a technique that obtains polarization curve and scanned the electrode potential continuously. This curve (**Figure 10**) gives some important characteristics of the electrochemical behavior of metal in contact with fluids, like biodiesel.

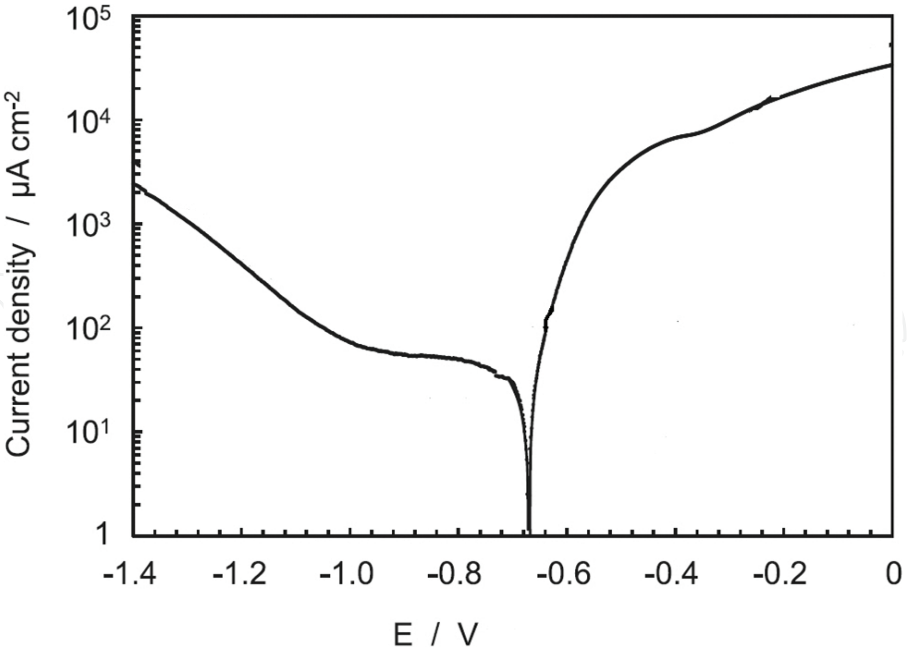


Figure 10. Typical polarization curve.

Few works are found in literature about the use of the electrochemical technique to evaluate corrosiveness of biofuel. In Diaz-Ballote [27] studied the corrosive biodiesel effect on aluminum by conventional electrochemical techniques. They verified that the corrosion current density and free corrosion potential depend on the purity of the biodiesel. Also, the biodiesel quality was determined by the provided electrochemical data.

As corrosion of steel equipment in biodiesel factory is a major problem, Torres et al. [5] analyzed AISI 316L steel corrosion in a biodiesel plant using electrical resistance probes at strategic points in the process. This procedure was developed to monitor the corrosion.

The biodiesel corrosiveness was studied by Aquino [2] and also gravimetric and electrochemical techniques. The electrochemical characterization was performed by electrochemical impedance spectroscopy (EIS) in order to evaluate the corrosion behavior of metal in biodiesel, without the addition of supporting electrolyte. The results of electrochemical characterization by EIS indicated that it could be used as an interesting tool to evaluate the biodiesel quality as well as corrosion behavior of metal in biodiesel, but the EIS for this purpose must be investigated more.

Dutra-Pereira [6] studied the corrosion of stainless steel AISI 304 in biodiesel using two electrochemical techniques: potentiodynamic polarization and electrochemical impedance spectroscopy. The experimental setup is shown in **Figure 11**. The potentiodynamic polarization curves were obtained with a scanning velocity of 1 mV s^{-1}, with the curves was possible to know the corrosion potential. EIS diagrams were achieved in frequency interval from 100 kHz to 0.004 Hz with 0.01 V of amplitude.

According to Dutra-Pereira [6], the results of electrochemical tests demonstrated that the stainless steels are incompatible with the biofuels because they oxidize in the presence of the organic medium. The diagrams of Nyquist allowed observing well-defined capacitive arcs, presenting behavior second order. The values of Rp (polarization resistance) prove that the immersion test changes the metal properties. The Rp value is a good number to compare fuel corrosiveness, less Rp means high corrosion rate. Also, polarization curves showed that occurred the passivation breaking, allowing the metals dissolution, such as chromium. This fact is evidenced by high potential values.

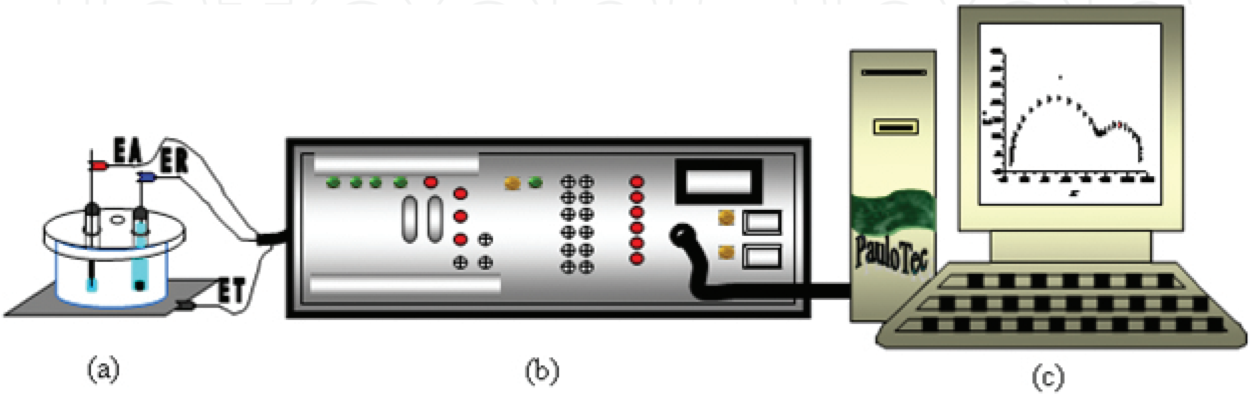


Figure 11. Experimental setup to analyze corrosion in biodiesel (a) electrochemical cell, (b) potentiostat/galvanostat, (c) microcomputer with AUTOLAB software (GPES-4 and FRA) [6].

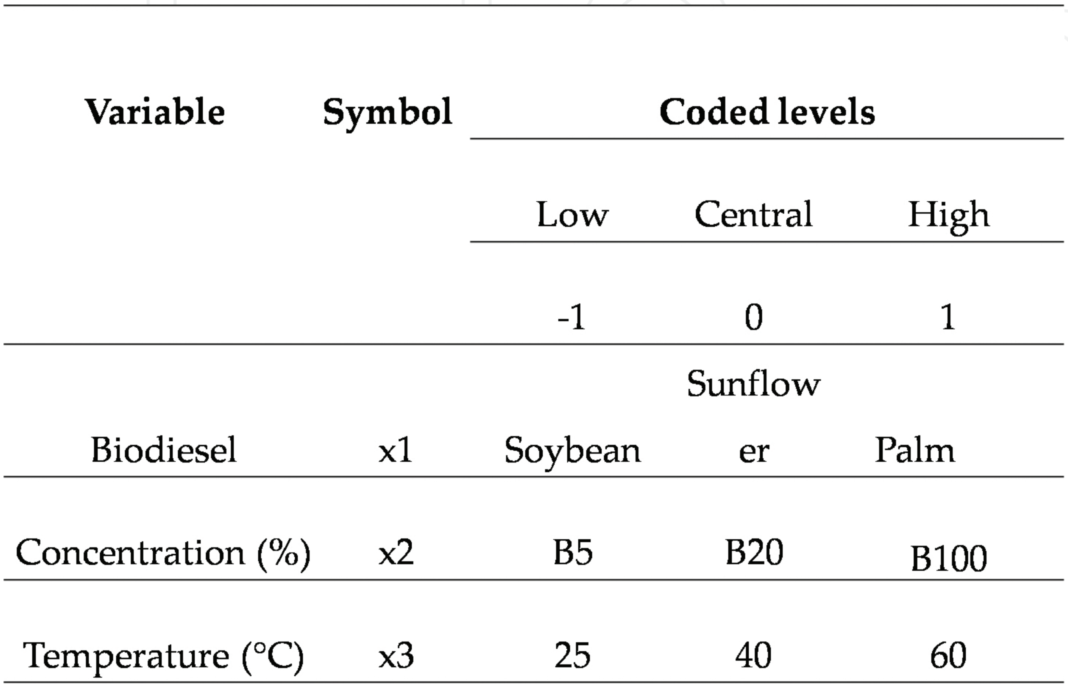
4. Biodiesel lubricity

The diesel engines require the fuel to have lubricating properties, avoiding the direct contact between pieces in movement. Biodiesel presents superior lubricity than diesel, becoming an alternative to replace the diesel.

In their studies, Mello [18] evaluated the effect of the low-sulfur diesel (LSD) and high-sulfur diesel (HSD) on diesel lubricity. Also, they studied the biodiesel addition in diesel. A lower lubricity was detected for diesel with low-sulfur than with high-sulfur content. For blends from soybean and sunflower biodiesel, the wear scar diameters (WSD) were lower showing greater lubricity.

Another parameter that affects the lubricity is the temperature. Wadumesthrige et al. [28] observed that the lubricity decreases with increasing temperature between 20 and 70°C, for blends of 2% of biodiesel in LSD. However, for high temperature (80–90°C), lubricity increases. The positive effect on lubricity at high temperatures is due to the increased molecular motion of polar components, allowing their better distribution on the metal sometimes positively or sometimes negatively.

The influence of temperature, concentration, and oil precursor type (using in biodiesel synthesis) was investigated by Mello [18]. The researcher used Box-Behnken statistical tool as a method to evaluate these variables and their combination on biodiesel lubricity. In her experimental design were assessed the input parameters: the type of the biodiesel (soybean, sunflower and palm), the concentration (5, 20, and 100%), and the temperature of contact (25, 40, and 60°C). The analyzed output parameters were the percentage of film formation, the coefficient of friction, and wear scar diameter (WSD) of the ball, and these output parameters were obtained by tribometer HFRR. Levels and factors used as test parameters are shown in **Figure 12**, with their real and coded values.



Variable	Symbol	Coded levels		
		Low	Central	High
		-1	0	1
Biodiesel	x1	Soybean	Sunflower	Palm
Concentration (%)	x2	B5	B20	B100
Temperature (°C)	x3	25	40	60

Figure 12. Provision levels and actual and coded factors [18].

The trend to the coefficient of friction, in function of variables, is shown in **Figure 13**. In the contour surface generated for the fuel, the lower results of coefficient of friction for higher concentration levels were observed, as proposed in the literature. This fact occurs due to the oxygen present in the ester molecule and the presence of carboxylic acids which improve the lubricity. In fuels, higher coefficients of friction were observed for sunflower biodiesel, probably due to the moisture present in this fuel. According to Fazal et al. [29], the high moisture absorption seems to act as a factor that potentiates the corrosiveness of biodiesel.

In addition, it is possible to observe the decrease in coefficient of friction at high-temperature level; at the higher temperature, molecular motion for polar components increases enough, enabling these to be more evenly distributed on the metal surfaces and, therefore, enhancing lubricity. Also, the chemical adsorption of polar compounds on the metal surface is greater at high temperatures.

The response surface generated for WSD (**Figure 14**) confirms the influence of concentration and moisture of biodiesel in the lubricity. Small WSD values were found for all fuels in the upper level of concentration, as observed in friction coefficient and higher WSD values to sunflower biofuel due to the most moisture level.

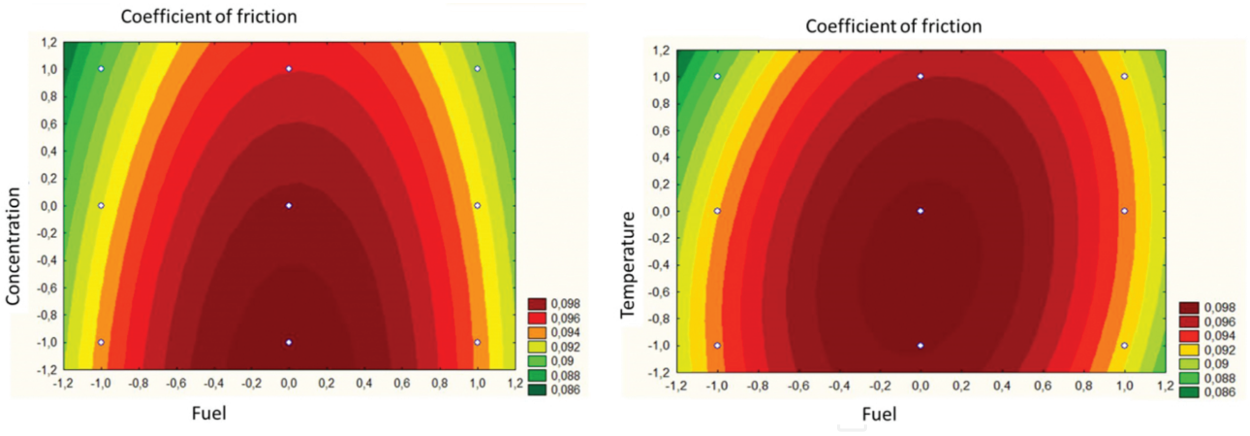


Figure 13. The coefficient of friction response [18].

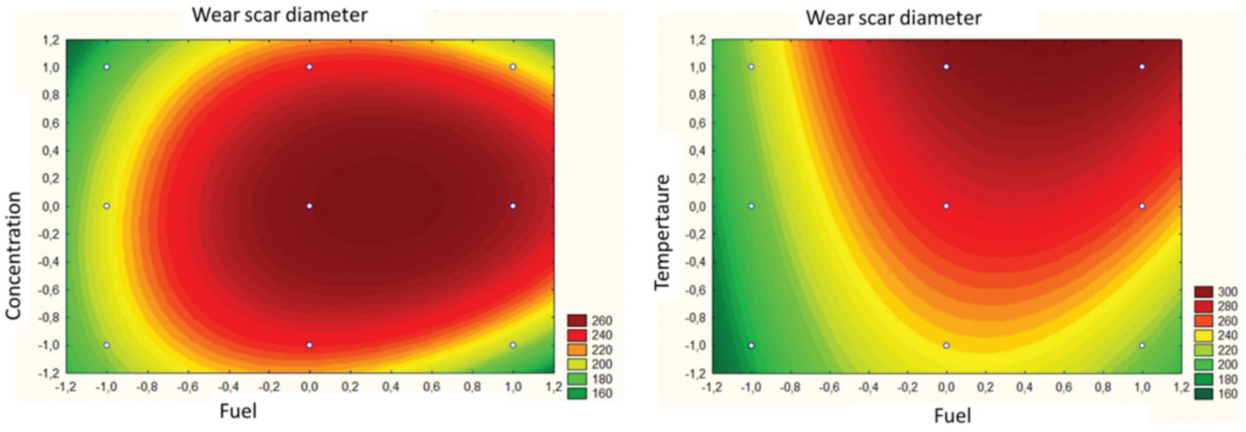


Figure 14. Wear scar diameter response [18].

The effect of fuel temperature observed in WSD confirms the results obtained by Wadumesthrige et al. [28], and better lubricity ability was noted for fuel at high temperatures. **Figure 14** shows that lubricity increases at the upper-level fuel temperature.

Figure 15 presents the response surface generated for a percentage of film formation. It is possible to verify that high rate of film formation is reached for the concentration levels above of center and high point. The biodiesel lubricity is due to the presence of a polarity-imparting heteroatom, the oxygen, and the presence of a carbonyl moiety. The influence of fuel temperature on percentage of film formation presents a more uniform response surface, showing that the percentage of the film has its optimum performance for analyzed temperature. For these variables, there is not a significant influence on the concentration in the lubricity of the higher to an intermediate point. However, there is a negative impact of the synergism by lowest levels of temperature and concentration. This synergism may compromise the lubrication system. It is a definite point because the working temperature of the engine is high than studied in this work.

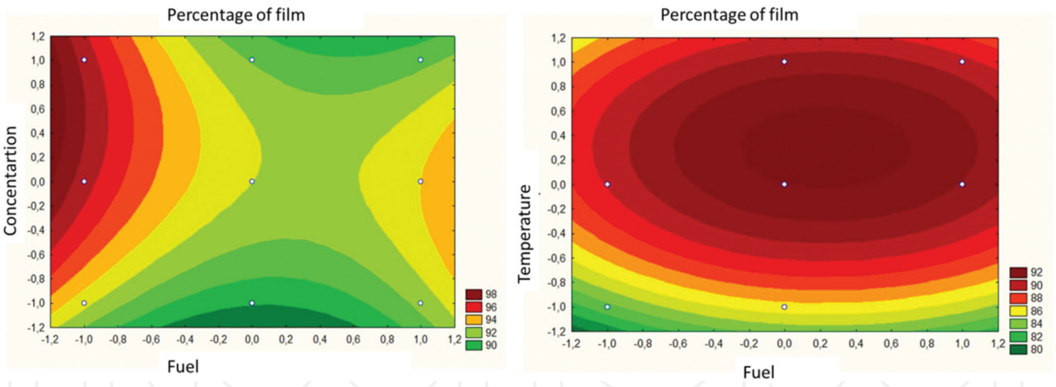


Figure 15. Percentage of film response [18].

5. Final considerations

The biodiesel use is consolidated in some countries like Brazil. Thus, it is essential to research in technologies to produce this fuel and to minimize the damage during its use in a diesel engine. In this issue, investigation about compatibility between biodiesel and materials engine is crucial to avoid premature wear and maintenance in this engine.

As addressed in this chapter, development of methodologies that described better or simulated the real contacts between biofuel and different materials is mentioned, as per example device that represents the biodiesel in contact with the elastomer of the injection system.

The corrosion has demonstrated a big challenge to biodiesel use because of its nature that attacks some metals of diesel automobiles. In this context to know, the corrosion behavior of metal in biodiesel is necessary, and thus, electrochemical techniques appear a promissory method to evaluate corrosion mechanism and quantify biodiesel corrosiveness.

Another important aspect of biodiesel is its lubricity that decreases the wear in the injection system, besides it can restore lubricity of low-sulfur diesel. Thus, it is possible to conclude that with some research to adequate the diesel engine to biodiesel and to understand better its characteristics, the biofuel is suitable to replace diesel fuel.

Author details

Salete Martins Alves[1*], Valdicleide Silva e Mello[2] and Franklin Kaic Dutra-Pereira[2]

*Address all correspondence to: saletealves@ect.ufrn.br

1 School of Sciences and Technology, Federal University of Rio Grande do Norte, Natal, Brazil

2 Federal University of Rio Grande do Norte-UFRN, Natal, RN, Brazil

References

[1] Fazal, M. A.; Haseeb, A. S. M. A.; Masjuki, H. H. Effect of temperature on the corrosion behaviour of mild steel upon exposure to palm biodiesel. Energy. 2011;36:3328–3334.

[2] Aquino, I. P. Evaluation of biodiesel corrosiveness by gravimetric and electrochemical techniques. Doctor thesis—Escola Politécnica da Universidade de São Paulo. São Paulo SP. 243 p. 2012 (in portuguese)

[3] Singh, B.; Sharma, Y. C. A.; Korstad, J. A critical review on corrosion of compression ignition (CI) engine parts by biodiesel and biodiesel blends and its inhibition. Renewable and Sustainable Energy Reviews. 2012;16:3401–3408.

[4] Kovács, A.; Tóth, J.; Isaák, G.; Keresztényi, I. Aspects of storage and corrosion characteristics of biodiesel. Fuel Processing Technology. 2015;134;59–64.

[5] Torres, C. E. D. A. S.; Costa, C. G. F.; Pereira, A. P.; De Castro, M. D. M. R.; Lins, V. D. F. C. Corrosion failure analysis in a biodiesel plant using electrical resistance probes. Engineering Failure Analysis. 2016;66:365–372.

[6] Dutra-Pereira, F. K. Evaluation of corrosive action of different biodiesels on the stainless steel AISI 316 using electrochemical methods and planning statistical. [Dissertation] [Masters degree in Engineering Mechanics]. Federal University of Rio Grande do Norte, UFRN. Natal, RN. 160 p. 2016 (in Portuguese).

[7] Ambrozin, A. R. P.; Monteiro, M. R.; Kuri, S. E. Metallic corrosion related to mineral fuels and biofuels utilization. Quimica Nova. 2009;32(7):1910–1916.(in portuguese)

[8] Susuki, C. Comparative Study of alternatives to development, design and manufacturing of fuel tank for passagers car into General Motors of Brazil. Master These (Master in Automotive Engineering)—Escola Politécnica da Universidade Estadual de São Paulo, São Paulo, SP. 136 p. 2007. (in portuguese)

[9] Haseeb, A. S. M. A.; Jum, T. S.; Fazal, M. A. Degradation of physical properties of different elastomers upon exposure to palm biodiesel. Energy. 2011;36:1814–1819.

[10] Haseeb, A. S. M. A.; Fazal, M. A. Jahihul, M. F. Masjuki, H.H. Compatiblity of automotive materials in biodiesel: a review. Fuel. 2010;90:922–931.

[11] Bessee, G. B.; Fey, J. P. Society of automotive engineering, Technical Paper No. 971690. 1997.

[12] Trakarnpruk, W.; Porntangjitlikit, S. Palm oil biodiesel synthesized with potassium loaded calcined hydrotalcite and effect of biodiesel blend on elastomer properties. Renewable Energy. 2008;33:1558–1563.

[13] Dubovsky, M.; Bozek, M.; Olsovsky, M. Degradation of aviation sealing materials in rapeseed biodiesel. Journal of Applied Polymer Science. 2015; 132 (28);42254

[14] Sorate, K. A.; Bhale, P. V.; Dhaolakiya, B. Z. A material compatibility study of automotive elastomers with high FFA based Biodiesel. Energy Procedia. 2015;75:105–110.

[15] Loo, M. S.; Le Camb, J. B.; Andriyana, A.; Robin, E.; Afifi, A. M. Fatigue of swollen elastomers. International Journal of Fatigue. 2015;74:132–141.

[16] Zhu, L.; Cheung, C. S.; Zhang, W. G.; Huang, Z. Compatibility of different biodiesel composition with acrylonitrilebutadiene rubber (NBR). Fuel. 2015;158:288–292.

[17] Chai, A. B.; Andriyana, A.; Verron, E.; Johan, M. R.; Haseeb, A. S. M. A. Development of a compression test device for investigating interaction between diffusion of biodiesel and large deformation in rubber. Polymer Testing. 2011;30:867–875.

[18] Mello, V. S. Study of physical-chemical biodiesel properties and its influence in deterioration of elastomers of injection system of diesel engine. [Dissertation] [Masters degree in Engineering Mechanics]. Federal University of Rio Grande do Norte, UFRN. Natal, RN. 102 p. 2013 (in Portuguese).

[19] Alves, S. M.; Mello, V. S.; Medeiros, J.S. Palm and soybean biodiesel compatibility with fuel system elastomers. Tribology International. 2013;65:74–80.

[20] Fazal, M. A.; Haseeb, A. S. M. A.; Masjuki, H. H. Comparative corrosion characteristics of petroleum diesel and palm biodiesel for automotive materials. Fuel Processing Technology. 2010;91:1308–1315.

[21] Wang, W., Jenkisn, P. E.; Ren, Z. Electrochemical corrosion of carbon stell exposed to biodiesel/simulated seawater mixture. Corrosion Science. 2015;57:215–219.

[22] Gallina, A. L.; Stroparo, E. C.; Cunha, M. T.; Rodrigues, P. R. P. A. The corrosion of austenitic 304 stainless steel in biodiesel. Revista Escola de Minas. 2010;63(1):71–75 (in portugese).

[23] Fazal, M. A.; Haseeb, A. S. M. A.; Masjuki, H. H. Degradation of automotive materials in palm biodiesel. Energy. 2012;40:76–83.

[24] Fazal, M. A.; Haseeb, A. S. M. A.; Masjuki, H. H. A critical review on the tribological compatibility of automotive materials in palm biodiesel. Energy Conversion and Management. 2014;79:180–186.

[25] Chew, K. V.; Haseeb, A. S. M. A.; Masiuki, H. H.; Fazal, M. A.; Gupta, M. Corrosion of magnesium and aluminum in palm biodiesel: a comparative evaluation. Energy. 2013: 57; 478–483.

[26] Fayyad, E. M.; Almaadeed, M. A.; Jones, A.; Abdullah, A. M. Evaluation techniques for the corrosion resistance of self-healing coatings. International Journal of Electrochemical Science. 2014;9:4989–5011.

[27] Diaz-Ballote, L.; López-Sansores, J. F.; López-Maldonado, L.; Mesias-Garfias, L. F. Corrosion behavior of aluminum exposed to a biodiesel. Electrochemistry Communications. 2009;11:41–44.

[28] Wadumesthrige, K.; Ara, M.; Salley, O.S.; Simon, K.Y. Investigation of lubricity characteristics of biodiesel in petroleum and synthetic fuel. Energy & Fuels. 2009;23:2229–22344.

[29] Fazal, M. A; Hasseb, A. S. M. A; Masjuki, H. H. Biodiesel feasibility study: an evaluation of material compatibility; performance; emission and engine durability. Renewable and Sustainable Energy Reviews. 2011;15:1314–1324.