JOURNAL OF ENGINEERING SCIENCES
ЖУРНАЛ ІНЖЕНЕРНИХ НАУК
ЖУРНАЛ ИНЖЕНЕРНЫХ НАУК

Web site: http://jes.sumdu.edu.ua

DOI: 10.21272/jes.2018.5(2).g1 Volume 5, Issue 2 (2018)

UDC 621.3.035.4

Characterization and Degradation of Viton Fuel Hose Exposed to Blended Diesel and Waste Cooking Oil Biodiesel

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Article info:
Paper received: July 7, 2018
The final version of the paper received: October 1, 2018
Paper accepted online: October 5, 2018

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Abstract. Degradation and material incompatibility between biodiesel and fuel system are the major concern associated with the adoption of biodiesel. In this research, effects of different mixture of waste cooking oil biodiesel/diesel blends (B10, B20 and B40) were investigated on the basic fuel properties such as density, kinematic viscosity (KV), flash point (FP), pour point (PP), cloud point (PP), freezing point (FRP) and sulphur content (SC). Viton fuel hose exposed to different fuel of types and their degradation characteristics, total acid number and change in the surface morphology were studied. It was found that density, KV, FP, FRP, CP and PP increased while SC decreased with increasing biodiesel content in the blends. The biodiesel concentration was noticed to affect the properties of elastomers, causing swelling of Viton fuel hose. The exposure of Viton fuel hose to fuel types of increasing biodiesel content led to reductions in tensile strength, harness and compressive strength.

Keywords: degradation, Viton hose, biodiesel, hardness, compressive strength, swelling.

1 Introduction

Increase demands for alternative energy and pollution problem caused by the widespread usage of fossil fuel have stimulated increasingly development of alternative source of energy. Biodiesel has marked a realistic option among other biofuel because of its environmental friendliness, readily available feedstock and technical feasible [1]. Biodiesel synthesized from lipid feedstocks (e. g., waste cooking oil). is considered as potential feedstock because of its biodegradability, higher flash point, lubricity, less exhaust emission, higher cetane, and almost zero sulphur content [2]. The adoption of up to 20 % biodiesel has been implemented in many developed country, but there is practical step towards exploring of higher blends for the future heavy-duty vehicles capable of up to 40 % (B40) [3, 4]. Biodiesel, although a biodegradable and sustainable fuel, often associated with degradation of automotive elastomers and corrosion of automotive parts when exposed to biodiesel [5, 6]. Degradation of automotive rubbers implies irreversible deterioration of the physical and chemical properties [7]. Notable factors that cause degradation are temperature, light, ionizing, radiation, humidity, fluids, bio- organism, mechanical stress and electrical stress [8]. In addition, the corrosiveness and degradation nature of automotive parts have been aggravated by the presence in the molecules in biodiesel [9]. In spite of the numerous advantages of biodiesel over fossil diesel, rubber automotive material is prone to wear and degradation when exposed to biodiesel. Polymers such as elastomers and plastic can degrade because of pure biodiesel contact [10]. As a result of degradation, mechanical properties such as hardness, tensile strength, cracking and chemical disintegration of petroleum products are being affected [10, 11]. Moreover, the degree of degradation of automotive rubber has been attributed to high level of biodiesel contact [12]. The impact of employing high blends of biodiesel has been identified to cause several problems of corrosion, degradation, filter clogging, pour combustion, low performance, and so on by several authors [13, 14]. In addition, insufficient information regarding compatibility of biodiesel and elastomers has been causing set-backs in an automotive industry [12].

Several researchers have investigated the degradation natureof elastomers in different types of fuel and its blends [15–20]. Besse and Fay [21] investigated the effect of soya biodiesel-diesel fuel blends on the tensile strength, hardness, elongation and swelling on different polymers. Their results showed that nitrile, nylon 6-6, and high density polypropylene change in physical properties while Teflon, Viton 401-C, and Viton GFLT did not cause a significant change. Alves et al. [18] investigated the effect of biodiesel from palm and soy bean oil on the degradation behaviour and sealing capacity of nitrile rubber (NBR) and fluorocarbon (FKM). They reported a decrease in mass of the NBR for all biodiesel. Trakampruk and Porntangjitlikit [22] studied effect of biodiesels on six kinds of elastomers properties related to fuel systems. The researchers remarked that the biodiesel has negligible impact on the properties of co–polymer FKM, and terpolymer FKM. Haseebet al. [23] compared degradation properties of five types of elastomers (EPDM, NBR, CR, SR and PTFE) in palm biodiesel / diesel fuel. Their results demonstrated that the compatible elastomers in palm biodiesel to be PTFE > SR > NBR > EPDM > CR. Haseebet al. [24] investigated the degradation of various elastomers in palm biodiesel. Their analysis showed that mechanical properties such as tensile strength, elongation and hardness were reduced for both nitrile rubber and polychloroprene while little changes were observed for fluoro-Viton. Nuneset al. [25] determined the effect of biodiesel on nitrile rubber with three kinds of acrylonitrile contents at 28 %, 33 % and 45 %. Their analysis demonstrated that the higher content of acrylonitrile makes the nitrile rubber more resistance to biodiesel degradation. However, none of these studies analyzed degradation of Viton fuel in the spectrum range of blends of waste cooking oil methyl ester and fossil diesel. It is worth knowing that information associated with degradation of the Viton fuel hose system will provide base data information for biodiesel stakeholders in automotive industry. The present work aimed to investigate the degradation characteristic of Viton fuel hose in waste cooking oil biodiesel/diesel fuel blends. This analysis further verified the influence of exposition to the fuel and the changes in the mechanical and degradation properties were also studied.

2 Research Methodology

2.1 Blend preparation and characterization

The biodiesel employed in this work was synthesized in a reactor shown in plate 1. Basic alkaline transesterification was adopted on waste cooking oil (WCO) using oil / methanol molar ratio of 5:99, with 1.1 % potassium hydroxide by weight as the catalyst. The reaction duration and temperature were 78 min and 60 °C respectively. The fossil diesel was procured from Jocceco Filling station, Warri, Delta State, Nigeria. The splash method was adopted to prepare three blends of waste cooking oil methyl ester (WCOME) and fossil diesel (B0) at proportions of B10 (10 %), B20 (20 %) and B40 (40 %) on volume basis. In order to ensure homogeneous mixture, required volume of WCOME and B0 was mixed and agitated as described elsewhere [26–28].

The blend properties of fuel types were analyzed following the ASTM standards. Density was measured in accordance with ASTM D1250 [29] using calibrated glass API gravity hydrometers. Viscosity was determined following ASTM D445 standard [30] using a Model VSTA-2000 Chongqing viscometer (Gallekamp model A345, UK).The Flash point was determined according to the procedures in ASTM methods D56 [31] using a Model 750/AUT Pensky-Martens flash tester (USA, 0.1 °C accuracy). Acid value (AV, mgKOH/g) was determined as indicated in ASTM D664 [32] using an automated titration system (Toledo, USA). Cloud (CP, °C), pour (PP, °C) and freezing points (FP, °C) analyzed were made in accordance with ASTM standards D2500, D97 and D5901 [32] (ASTM, 2007) respectively, using a Model 664 Lawler CP, PP and FP analyzer (USA, 0.1 °C accuracy). Sulphur content was measured in accordance with ASTM D129 [33] using a Horiba sulphur analyzer (Tokyo, Japan).

Schematic set up diagram for transesterification is presented in Figure 1.

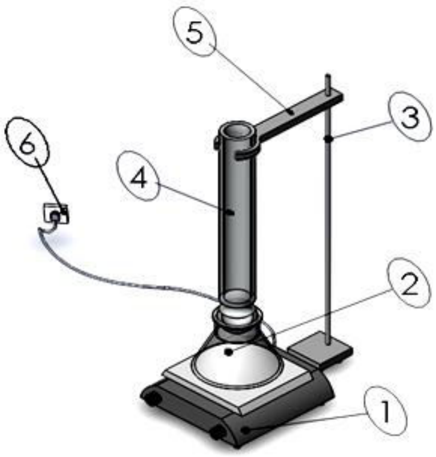


Figure 1 – Schematic set up diagram for transesterification:
1 – heating mantle; 2 – reactor; 3 – tripod stand;
4 – condenser; 5 – clamp; 6 – power source

2.2 Elastomer preparation

The test was conducted using 10 test coupons 7×100 mm, cut from a Viton fuel hose, as set by ASTM D471 [34]. Two jars per coupon were used for immersion test and the Viton fuel hoses were suspended by stainless safety wire, via 2.5 mm hole in the end of each one, so that they were completely immersed but were not rested on the bottom of the jar.The mass of the automotive rubber types before swelling of the test coupon were subsequently determined using an analytical balance (Contech, India). The temperature was maintained constant during the exposure time for 720 hours, as stipulated by the standard using circulating water bath. The ten time coupons were kept in the dark. The coupons were removed from the vessel and suspended outdoor to enable fuel evaporate, so that other final mass after swelling was then carried out. Finally, the percentage mass changes were calculated by the following equation:

$$\Delta_m = \frac{m_2 - m_1}{m_1} \cdot 100\ \%, \quad (1)$$

where Δ_m – change rate of mass; m_1 – sample mass before immersion; m_2 – sample mass after immersion.

2.3 Mechanical parameters evaluation

The mechanical properties testing of duplicate test elastomers were conducted before and after swelling experiment. Mechanical properties such as hardness testing and compression testing with Rockwell hardness testing machine (Excel B34H, England) and universal tensiometer machine (TM 415, England), situated at the University of Nigeria, Nsukka, respectively.

2.4 Degradation of the fuel types and surface morphology

The changes in the surface morphology of the coupons Viton fuel hose after being exposed to the fuel types were investigated by JCM 100 mini scanning electron microscope (SEM) (Joel, USA) at the Chemical Engineering Department, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.

Moreover, degradation of the different biodiesel / diesel fuel types was assessed before and after using total acid number.

3 Results

3.1 Characterization of waste cooking oil methyl ester and diesel fuel blends

Presented in Figures 2–9 are the variations of basic fuel properties and biodiesel content. Fuel properties of the experimental data were correlated as a function of biodiesel concentration. The effect of biodiesel concentration was investigated on the following key properties: such as density, kinematic viscosity (KV), flash point (FP), acid value, water content, pour point (PP), cloud point (CP), freezing point and sulphur content (SC).

Density increased as the content of WCOME increased in the blends. As the content of WCOME–fossil diesel shifted from 10 % to 40 %, the density of the biodiesel blends advanced from 862.6 to 871.2 kg/m^3 but they are within the specification of EN14214 standard (860–900 kg/m^3). Second-degree equation was found suitable to correlate the variation of densities and WCOME–diesel fuel blends. The coefficient of determinant (R^2) from the density regression model shows that over 99.6 % of the data is captured in the empirical equation. Hammare and Yamin [35] reported that more fuel is injected as the fuel density increase.

The kinematic viscosity (KV) of the WCOME–diesel fuel blends certified the density norms of the ASTM D6751 (1.9–6.0kg/m^3) and EN14214 (3.5–5.0 kg/m^3) specification even though the KV of the WCOME increased as the content of biodiesel in the blends increased. The third-degree model equation was found adequate to correlate the variation of KV and WCOME-diesel fuel blends. Similar observation was also reported by Alptekin and Canacki [36]. The high R^2 (0.978) indicates that over 97.8 % of the data is captured by the empirical equation.

The flash point (FP) increased as the content of WCOME increases in the blends. The increasing trend reveals that the fuels are safe to transport and store. A third-degree polynomial equation was utilized to correlate the variation of FP with biodiesel content at any blend. The R^2 of 0.999 reveals that over 99.9 % of the measured FP was captured by the FP regression equation.

The cloud and pour points values increased as the content of waste cooking oil methyl esters advance in the blends. A second-order degree equation and third-degree equation were developed for the respective cloud point and pour point variation with biodiesel percentage. The high R^2 (0.999) and R^2 (0.995) resulting from the pour point regression model and cloud point polynomial, respectively reveal that not less than 99 % of the experiment data were captured for the cloud and pour points measured.

The freezing point increased from –15 °C to –12 °C as the percentage of biodiesel advanced from B10 to B40. The values of freezing point of WCOME (2 °C) were higher than that of the diesel fuel (–16 °C). The measured freezing points are found to be correlated by the third-degree equation and a high R^2 (0.999) indicates that over 99.9 % of the data are captured by freezing point regression model.

The sulphur content of the WCOME-diesel blends certified the sulphur content norms of the ASTM D6751and EN14214 (0.05 mg) specification, even though the sulphur content of the WCOME decreased as the content of biodiesel in the blends increased. The result is in consistent with the findings of sulphur content of loofa oil ethyl ester blends [37]. Sulphur (IV) oxide is expected to reduce if fossil diesel is fuelled with WCOME blends. The third degree model equation was found adequate to correlate the variation of sulphur content and methyl ester in the blends. The high R^2 (0.9999) indicates that 99.9 % of the experiment was captured by the sulphur content model equation.

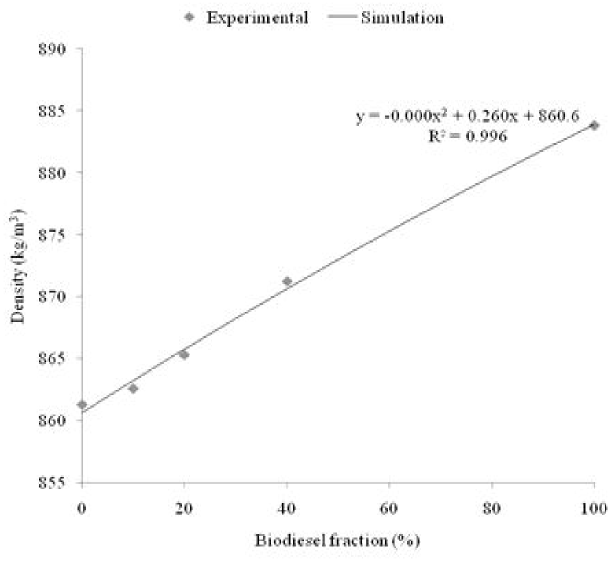


Figure 2 – Variation of density with biodiesel fraction

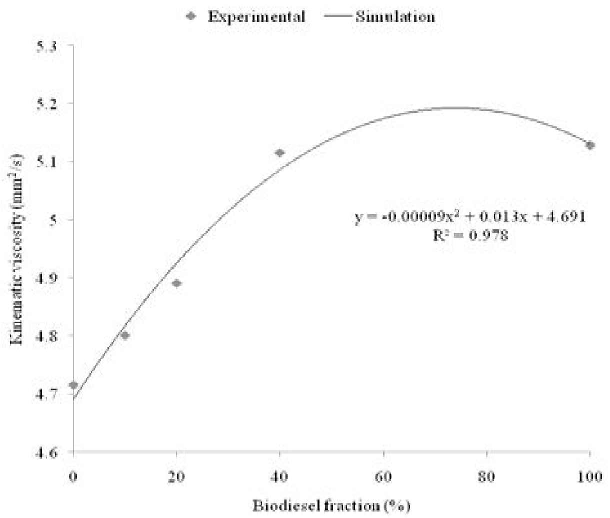


Figure 3 – Variation of kinematic viscosity with biodiesel fraction

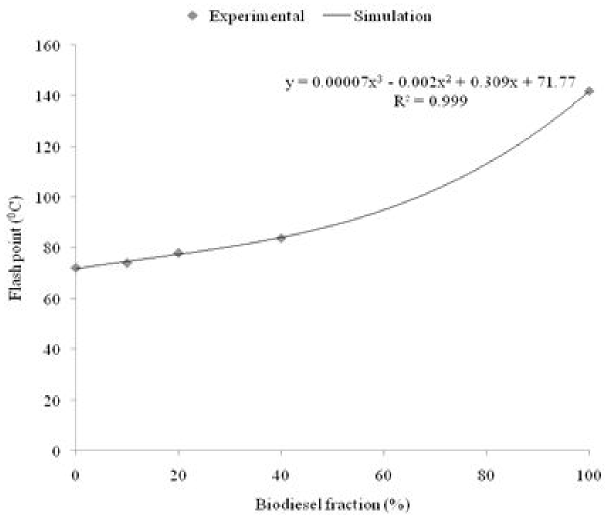


Figure 4 – Variation of flash point with biodiesel fraction

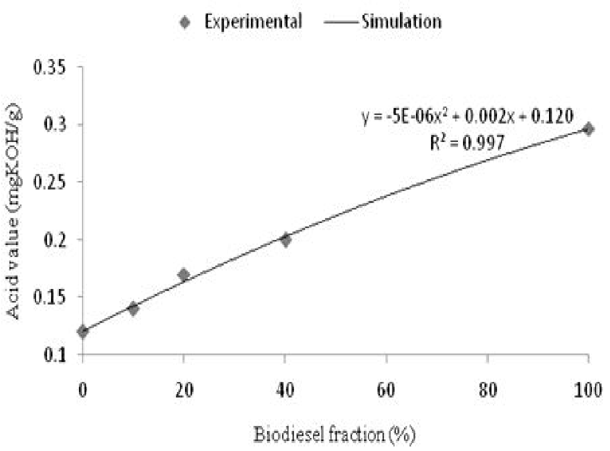


Figure 5 – Variation of acid value with biodiesel fraction

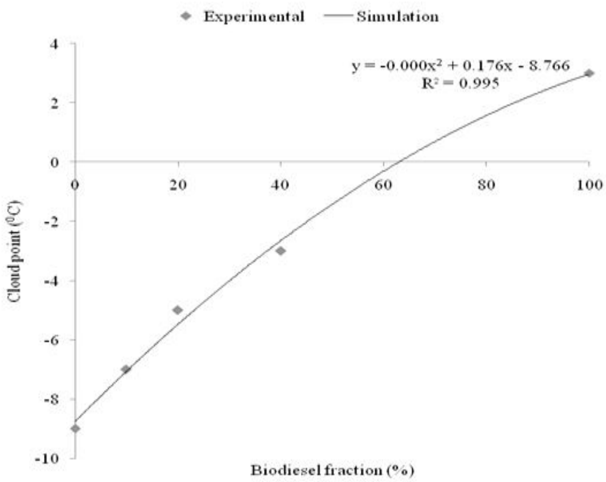


Figure 6 – Variation of cloud point with biodiesel fraction

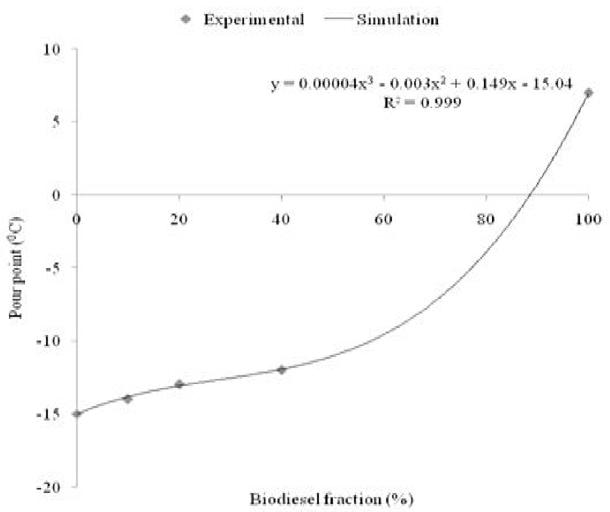


Figure 7 – Variation of pour point with biodiesel fraction

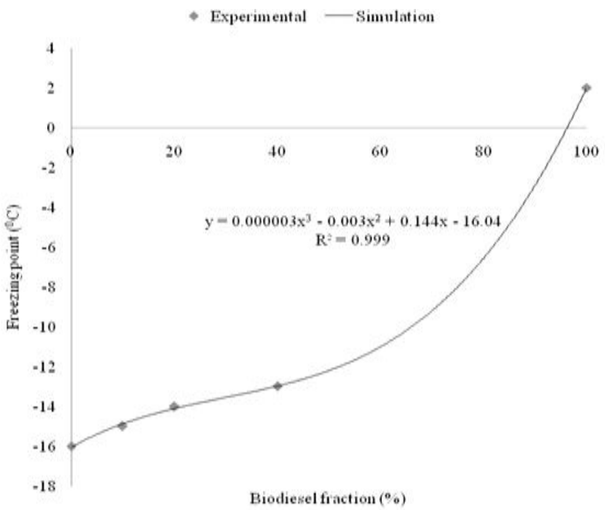


Figure 8 – Variation of freezing point with biodiesel fraction

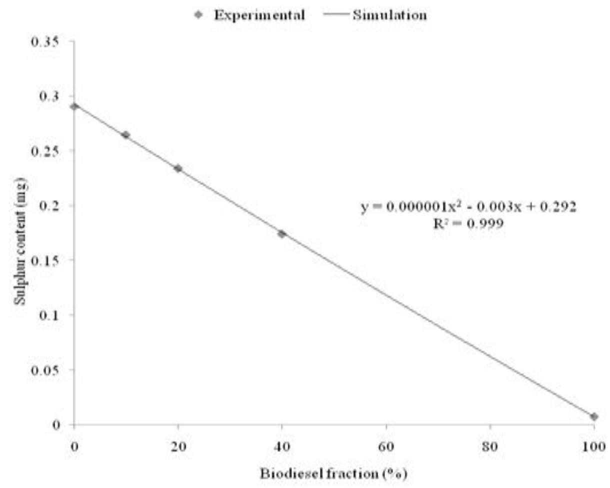


Figure 9 – Variation of sulphur content with biodiesel fraction

3.2 Mass change rate and mechanical properties of Viton fuel hose

To obtain a detailed overview on degradation potential of diesel fuel (B0), waste cooking oil biodiesel/diesel fuel blends(B10, B20, and B40) and waste cooking oil biodiesel (B100),percentage change in mass, change in hardness, change in compressive strength and tensile strength were determined. Figure 10 shows mass change of Viton fuel hose after being exposed to B0, B100 and its blends at 35 °C for 720 hours. As can be observed in Figure 10, mass change of Viton fuel hose exposed to the fuel types increased as the biodiesel content increased. Coronado et al. [11] attributed the phenomenon to the solvent absorption and relaxation of polymer chain. Haseeb et al. [24] further attributed the increase in mass change to the interaction of ester present in the biodiesel with elastomer through dipole-dipole interaction, causing swelling.

Presented in Figures 11–13 are the variations of change in hardness, compressive strength and tensile strength, respectively at 35 °C for 720 hours. Figure 11 depicts the hardness change of Viton hose exposed to different fuel types. This indicates increasing biodiesel concentration; consequently decreased the hardness change of Viton hose. As can be observed in Figure 11, the hardness change of Viton hose in B10, B20, B40 and B100 is lower than that of B0.This can be attributed to dissolution of linkage agents between the polymeric chains, resulting in a reduction of hardness of Viton hose exposed to high concentration of biodiesel [11]. This observation is consistent with the report of Sellden [38]. Percentage change in hardness quadratically decreased with increasing biodiesel content. Owing to this variation, a second degree model equation was found adequate to correlate the variation of change in hardness versus WCOME-diesel fuel blends. The high R^2 (0.993) indicates that 99.3 % of the experiment was captured by the change in hardness model equation for Viton fuel hose.

The variation between percentage change in compressive strength and biodiesel fraction is presented in Figure 12. The change in compressive strength of Viton fuel hose decreased with increasing biodiesel content in the blend. The adopted compressive strength model equation has high R^2 (0.982) indicates that 98.2 % of the compressive strength measured was captured by the compressive strength regression equation for Viton fuel hose.

Presented in Figure 13 is the relationship between tensile strength and biodiesel/diesel fuel types. As noticed in Figure 13, the percentage change in tensile strength for Viton fuel hose decreased with increasing biodiesel content in the blends. The reduction in tensile strength of the Viton exposed to higher biodiesel content was attributed to the higher loss of cross-linkage between polymeric chains [16, 18]. The second degree model equation was found adequate to correlate the variation of tensile strength Viton fuel hose with WCOME-diesel fuel blends. The high R^2 (0.993) indicates that 99.3 % of the experiment was captured by the tensile strength model equation for Viton fuel hose.

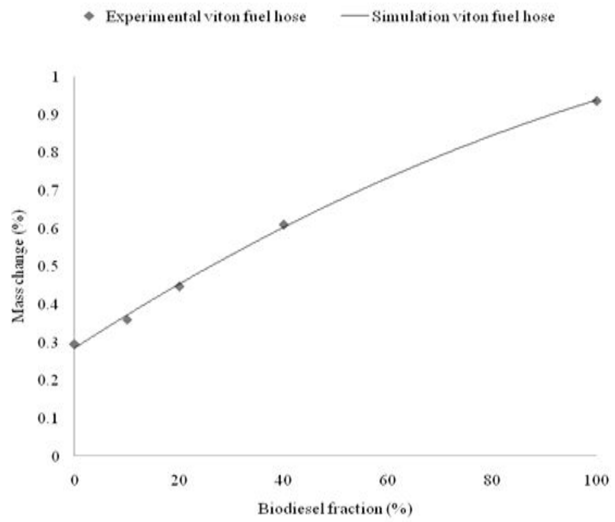


Figure 10 – Relative change in mass of Viton fuel hose with biodiesel fraction

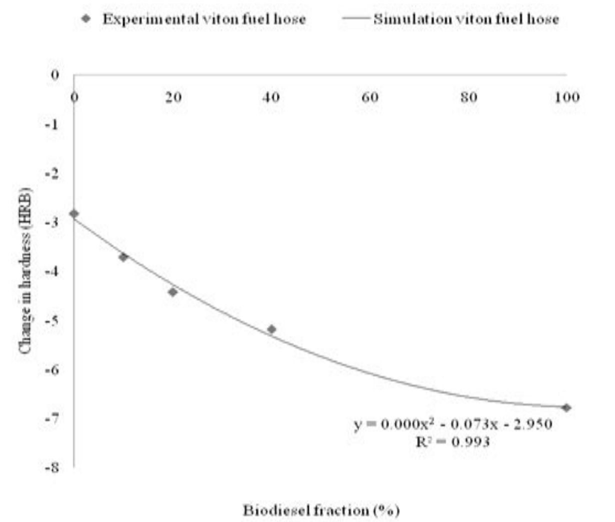


Figure 11 – Variation of hardness test on Viton fuel hose with biodiesel fraction

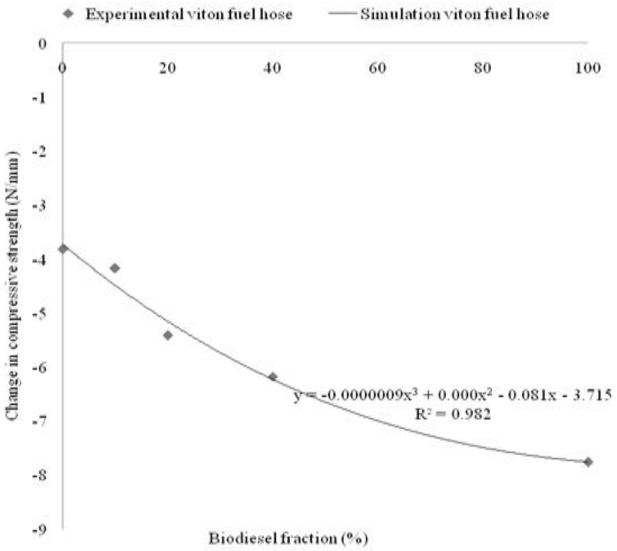


Figure 12 – Variation of Viton fuel hose compressive strength with biodiesel

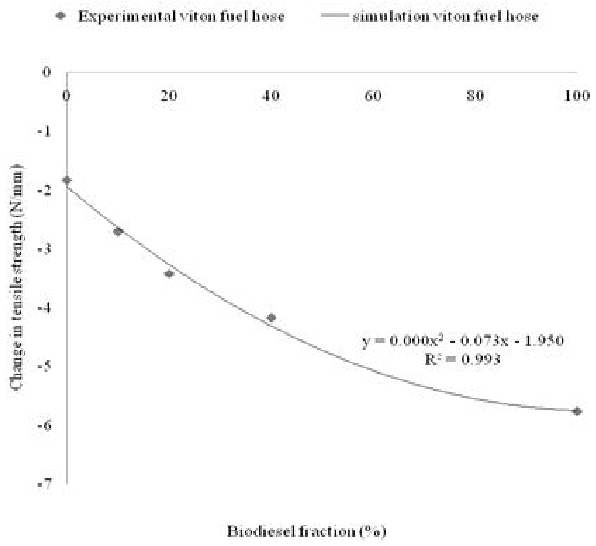


Figure 13 – Variation of Viton fuel hose tensile strength with biodiesel fraction

3.3 Acidity change of different fuel and surface morphology of Viton fuel hose

Figure 14 depicts fuel acidity change after Viton fuel hose has been exposed to biodiesel/diesel fuel blends. As can be observed, blends B10, B20, B40 and B100 showed remarkable change in acidity to diesel fuel. These results are in consistent with earlier reports by other researchers [11, 24]. Their results indicated that biodiesel is more prone to oxidation than fossil diesel.

Presented in Figure 15 is the surface morphology of Viton fuel hose (VFH) before and after exposed to different fuel types. Deterioration of VFH is accentuated when the biodiesel content increased in the fuel types. This is evident by more pits and crack observed in VFH in biodiesel and its blends compared to diesel fuel. Hence, this study recommends the use of low biodiesel content to be blended with diesel exposed to VFH.

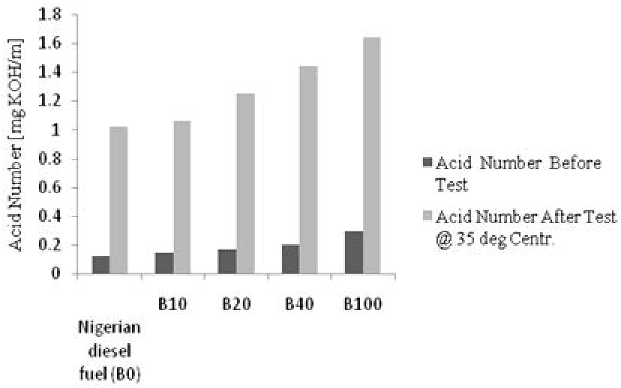
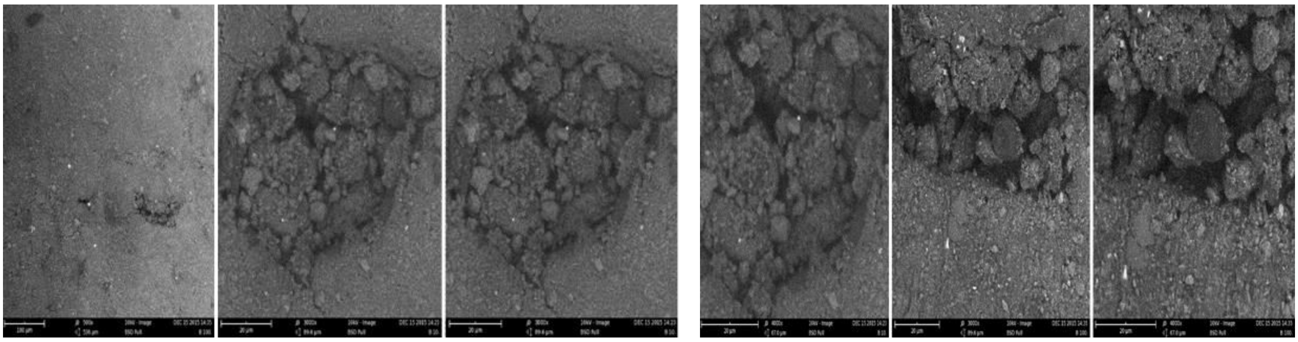


Figure 14 – Acid number of the different fuels prior and after the immersion tests



a b c d e f

Figure 15 – SEM micrographs of Viton hose surface and after exposed to diesel (B0), B10, B20, B40, B100 blends at 35 °C for 720 hours: a, d – Viton hose before; b, e – Viton hose / B0; c, f – Viton hose / B10

4 Conclusions

The following conclusions can be deduced from results obtained from blend characterization of diesel and waste cooking oil biodiesel and its effecton degradation of Viton hose system. Blend density, kinematic viscosity, flash point, cold flow properties, freezing point increases while sulphur content decreases with increasing biodiesel percentage. The density and cloud point variations with biodiesel fraction in the blends follow second degree equation, while those of kinematic viscosity, flash point, pour point, freezing point and sulphur content are found to be well fitted by third degree regression equation. Mass change increased while hardness, compressive strength and tensile strength of Viton fuel decreased with increasing content of biodiesel in the blends.

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Характеристика та деградація паливного шлангу, що піддається випливу суміші дизельного палива з відпрацьованими відходами

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Анотація. Деградація та несумісність біодизеля з паливною системою є головною проблемою, пов’язаною із застосуванням першого. У цьому дослідженні були досліджені основні властивості палива, такі як щільність, кінематична в’язкість, точка займання, вміст сірки тощо у результаті змішування біодизеля / дизельного палива (зокрема, B10, B20 і B40) з відходами. Паливні шланги, що піддаються впливу різних типів палива та їх характеристик деградації, загальної кількості кислот та зміни морфології поверхні. Знайдено вищезазначені параметри, значення яких збільшуються від зменшення вмісту сірки при збільшенні вмісту біодизельного палива у суміші. Зазначено, що концентрація біодизелю впливає на властивості еластомерів, що призводить до випинання паливного шлангу. Встановлено, що експлуатація шлангів для палива з підвищеним вмістом біодизельного палива призводить до зменшення міцності на розрив, жорсткості та міцності при стисканні.

Ключові слова: деградація, паливний шланг, біодизель, твердість, міцність на стискання, випинання.