Investigation of Bio-Gasoline Oxidation and its Influence on Fuel Supply System Components

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ABSTRACT

This study evaluated the oxidation levels of bio-gasoline fuel and its effects on non-metallic components of fuel supply systems. The experiment was conducted following the SAE J1748 standard, where components of electronic fuel injection systems were soaked in two different fuels, RON92 and E10. The soak lasted 2000 hours at 45 °C to assess the impact of fuel on weight and surface structure changes in non-metal parts. The experimental results indicate that for non-metallic parts exposed to ethanol-blended fuel, significant weight changes were observed compared to those using gasoline. Specifically, the weight of the coarse filter increased from 2.23 mg to 2.27 mg in RON92 and from 2.38 mg to 2.49 mg in E10. Similarly, the fine filter's weight increased from 6.85 mg to 6.88 mg in RON92, while in E10, it rose from 6.91 mg to 6.98 mg. The weight of the fuel level indicator tended to decrease when soaked in both RON92 and E10, with a steeper slope in E10, while the fuel float soaked in E10 decreased in weight by 0.77%, nearly two times higher than that in RON92 (0.33%).

Keywords-ethanol; oxidation; coarse filter; fine filter; fuel level indicator

I. INTRODUCTION

In recent years, biofuels have been considered an effective solution for reducing greenhouse gas emissions but also for enhancing engine performance [1, 2]. Fuel variants, including E10, E15, and E20 are currently being extensively researched with the aim of minimizing pollution as well as optimizing fuel efficiency [3-5]. However, besides the economic and environmental benefits, an important issue that remains unclarified is the compatibility of these biofuels with non-metallic materials used in the fuel supply systems. Materials, such as rubber or plastic, are sensitive to changes in the chemical properties of fuels, especially the oxidation level of biofuel. This is a critical issue since incompatibility can cause damage, reduce performance, and shorten engine lifespan, particularly when using high-percentage ethanol-blended fuels.

Authors in [6] revealed that biodiesel blends increased fuel filter clogging, pressure loss, while reducing filter durability, particularly with karanja oil biodiesel. Mitigation strategies included preheating, larger filter areas, or ethanol blending. In [7], the impact of E20 on polymer materials was examined, with the results demonstrating minimal effects on POM, HDPE, PA6/6, and PA6, but significant degradation in PA66. Authors in [8] observed severe ethanol-induced corrosion in SI engine components, especially with E100, due to oxygen presence. Similarly, in [9], it was found that carbon steel was highly susceptible to E20 corrosion, while aluminum, stainless steel, and copper showed greater resistance. Ethanolamine (0.1 g/L) effectively inhibited carbon steel corrosion for 30 days. Authors in [10] reported that copper corrodes up to 100 times faster than mild steel and aluminum in B100 biodiesel, due to fatty acid interactions. Authors in [11] observed that methanol accelerates corrosion in engine metals, with M100 causing the most severe damage. Furthermore, authors in [12] linked the release of AISI 316 stainless steel ion to biodiesel oxidation, which in turn reduced fuel quality. On the other hand, in [13], minimal corrosion was found in most metals exposed to biodiesel blends, except copper, which corroded unpredictably in different blends.

The novelty of this study lies in its detailed assessment of the impact of ethanol-blended biofuel (E10) on non-metallic materials commonly utilized in fuel supply systems, such as rubber and plastic. Soak tests were conducted on these components in different fuels to analyze changes in weight, size, hardness, and material structure. The findings not only provide a reliable scientific basis for the use of ethanol as a fuel, but also offer valuable insights for the automotive industry, such as developing components with higher compatibility. This contributes to enhancing the durability and long-term performance of engine systems when using biofuels.

II. METHODOLOGY

A. Experimental Method

Biofuels contain a higher oxygen content than fossil fuels, making ethanol fuels more prone to oxidation than RON92 gasoline. E10 fuels have been shown to be compatible with gasoline engines without requiring modifications to component structures or materials. However, increasing the ethanol content in fuel can lead to adverse effects, such as oxidation, aging, or swelling of components.

To assess these effects, the SAE J1748 procedure was proposed for evaluating the compatibility of polymer materials exposed to gasoline containing oxygen-enhancing additives. The key features of this procedure include:

- Soak Temperature: 55 °C
- Soak Time: ≥ 500 hours or until no change in weight is observed.
- Weight Assessment: The weight of the components is measured weekly to record changes. For elastomeric (rubber) parts, the fuel was changed daily for the first three days and then weekly. For plastic parts, the changed happened twice a week.
- Sample Storage: Fuel and components were soaked in glass bottles to ensure a stable test environment.

Figure 1 illustrates the flowchart of the SAE J1748 method.

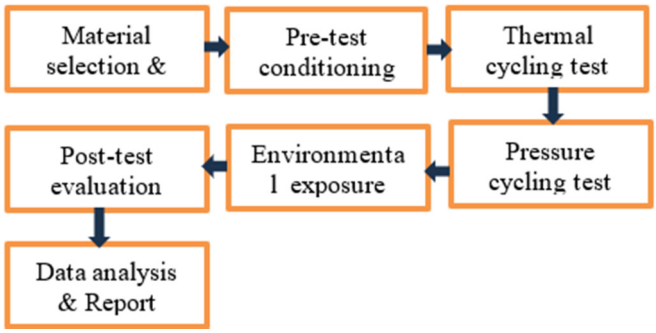


Fig. 1. Flowchart of the SAE J1748 procedure.

B. Experimental Equipment and Research Subjects

A Binder drying oven was utilized, maintaining precise humidity and temperature through an automatic adjustment system, providing high accuracy and reliability. The non-metallic components, after being soaked in ethanol, were dried in this oven under carefully controlled conditions to ensure complete ethanol removal without affecting the material properties. Specifically, a temperature of 45 °C was set for 2000 hours.

The dried components were immediately imaged using Scanning Electron Microscope (SEM) with optimized experimental parameters for high quality and accuracy. Specifically, the imaging mode was set to low vacuum. The accelerating voltage was adjusted between 5 kV and 20 kV to achieve good resolution and minimize surface charging on non-metallic materials. The magnification ranged from 100x to 5000x, to observe the detailed surface structures of the samples. The tilt angle was typically set to 0° or adjusted as needed for surface morphology analysis. Before imaging, the samples were securely mounted on the sample holder using conductive tape and could be coated with a thin layer of gold or carbon to enhance conductivity and reduce image noise.

The experiment was conducted on non-metallic components from the electronic fuel injection system after exposure to two different fuel types: RON92 and E10. The testing process followed a standardized procedure to ensure consistency and reliability of the results.

III. RESULTS AND DISCUSSION

Figure 2 illustrates the weight change of the electric fuel pump's coarse filter element after being soaked in RON92 and E10 at intervals of 500, 1000, and 2000 hours. After 2000 hours, the weight of the element soaked in RON92 increased from 2.23 mg to 2.27 mg, a gain of 0.04 mg (1.79%). Meanwhile, the element soaked in E10 increased from 2.38 mg to 2.49 mg, a gain of 0.11 mg (4.62%). Thus, the weight increase in E10 was 2.58 times higher than in RON92, which can be attributed to the hygroscopic nature of ethanol in E10, which enhances water vapor absorption and promotes by-product accumulation from the surrounding environment.

Additionally, ethanol may chemically interact with the filter material, altering its structure and contributing to increased mass. In contrast, RON92, with its more stable hydrocarbon composition and lack of ethanol, results in lower absorption and minimal material interaction. This finding aligns with [7], where E20 led to changes in polymeric fuel system components, though with varied effects across different material types.

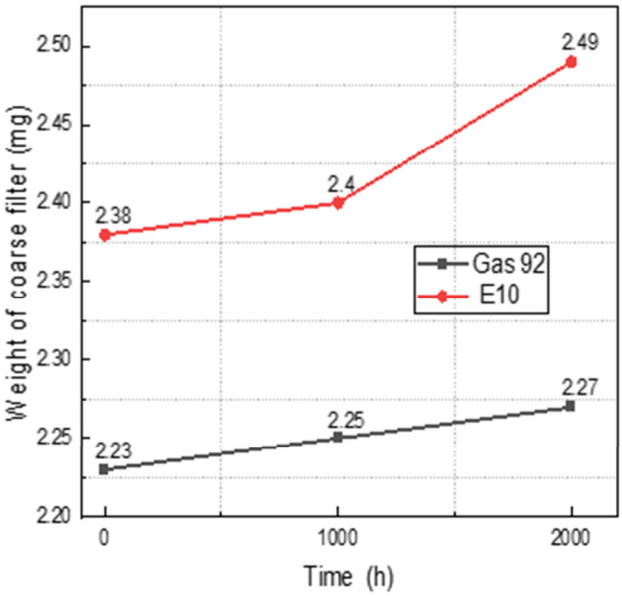


Fig. 2. Weight coarse filter after soaking in RON92 (black line) and E10 (red line).

SEM images of the coarse filter mesh before and after soaking in E10 fuel are presented in Figure 3. Post-soaking analysis revealed surface corrosion due to oxidation, pitting and deposits, possibly resulting from reactions with oxygen and acidic components in E10 fuel. This may lead to reduced filtration performance due to clogging or deterioration of the component's durability.

Figure 4 illustrates the effect of E10 on the fine filter element. From 0 to 1000 hours, the weight of the fine filter element soaked in RON92 increased from 6.85 mg to 6.86 mg, a gain of 0.01 mg (0.15%). In contrast, the element soaked in E10 increased from 6.91 mg to 6.94 mg (0.43% gain). The weight increase in E10 was approximately 2.87 times higher than in RON92, indicating that ethanol in E10 had a greater impact on absorption or chemical reactions on the fine filter surface during the early stage. From 1000 to 2000 hours, the weight of the element soaked in RON92 continued to increase, reaching 6.88 mg, an additional gain of 0.02 mg (0.29%), while the E10-soaked element increased more rapidly, reaching 6.98 mg. During this period, the weight increase rate in E10 was approximately twice than that of RON92, demonstrating the ethanol's effect. This is consistent with [6], where it was found that biodiesel blends caused increased pressure loss and clogging in fuel filters, indicating that biofuels in general can influence filtration system performance.

(a)

(b)

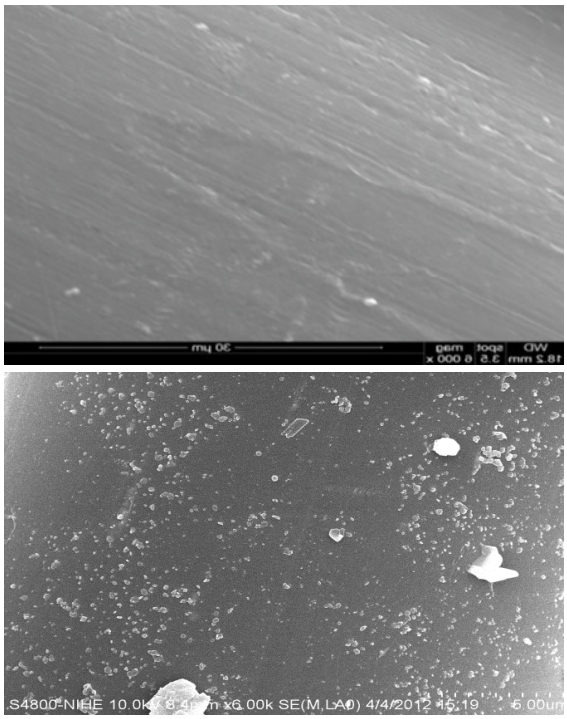


Fig. 3. SEM of the coarse filter mesh (a) before and (b) after soaking in E10 fuel.

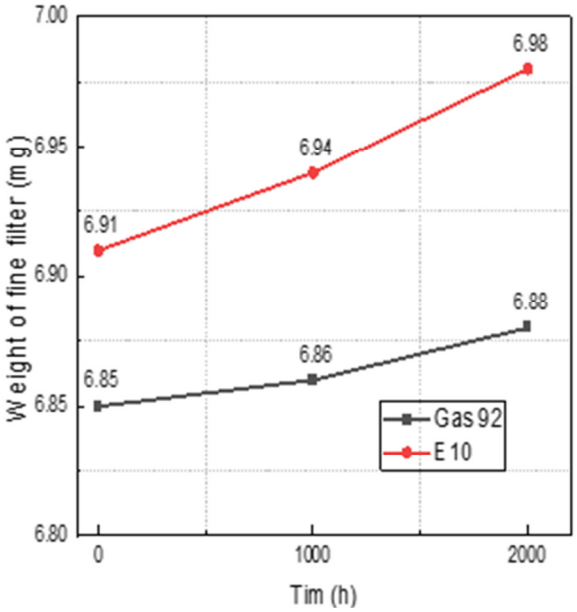
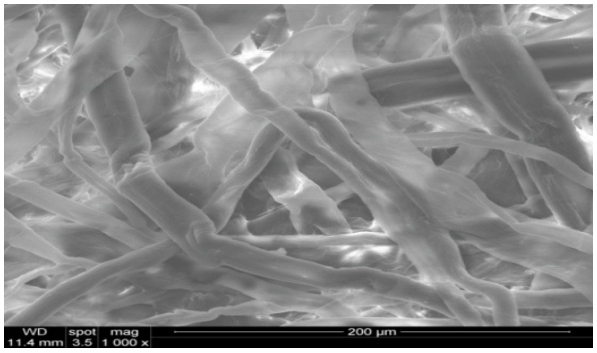


Fig. 4. Weight of fine filter after soaking in RON92 and E10.

SEM images of the fine filter mesh before and after soaking in E10 fuel are presented in Figure 5. Before soaking (Figure 5(a)), the surface structure was observed smoothy, with no signs of deformation or degradation. After soaking (Figure 5(b)) swelling or deformation of the material was detected, possibly due to interaction with ethanol in E10. As ethanol can dissolve some additives in the material, changes in mechanical properties and filtration capacity can occur.

(a)



(b)

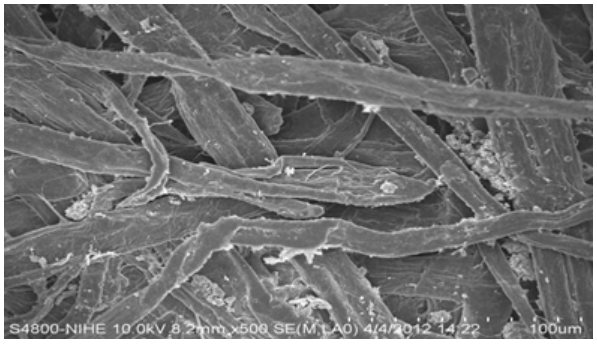


Fig. 5. SEM of the fine filter element of the electric fuel pump (a) before and (b) after soaking in E10 fuel.

Figure 6 illustrates the effect of fuel on the weight of the electric fuel pump fuel level indicator over time. A weight reduction of the electric fuel pump fuel level indicator was observed after soaking in both fuels. Specifically, in the first 1000 hours of soaking, the component in RON92 decreased in weight by 0.56%. In contrast, the soaked part in E10 fuel, was reduced by 1.27%.

In the second half of the experiment (1000-2000 hours), the slope of the graph steepened, indicating a significant reduction in weight. The weight of the fuel level indicator soaked in RON92 decreased further by 1.69%, while the part soaked in E10 had a final weight of 3.73 mg, with a total loss of 0.21 mg (5.34%). Thus, the weight loss in E10 was approximately three times greater than in RON92 after 2000 hours, revealing that E10 fuel exhibited a more significant impact on the electric fuel pump fuel level indicator than RON92 gasoline.

The SEM images of the fuel level indicator before and after soaking in E10 fuel are depicted in Figure 7. The microstructure of the fuel level indicator after soaking in E10 fuel developed microscopic cracks, a roughened surface, and blistering. These surface alterations suggest that oxidative and acidic components in E10 fuel contribute to the aging and weakening of the polymer structure. Specifically, ethanol's oxygen content and trace acids can cause swelling or disrupt polymer bonds, resulting in dimensional changes and reduced mechanical durability of the fuel level indicator.

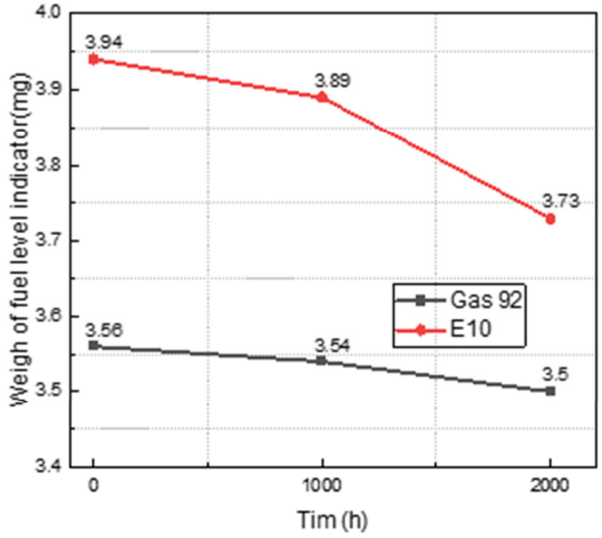
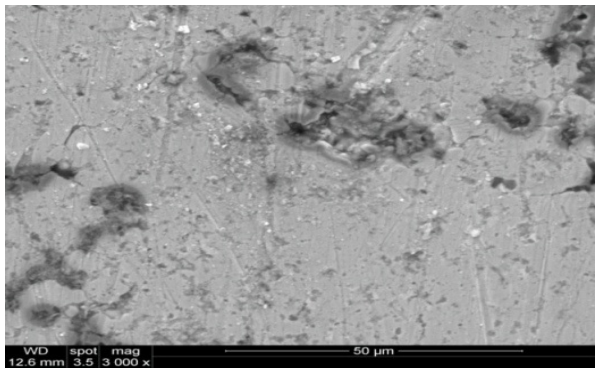


Fig. 6. Weight of fuel level indicator after soaking in RON92 and E10.

(a)



(b)

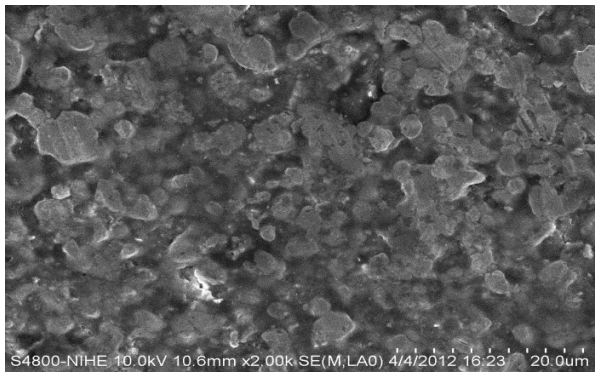


Fig. 7. SEM of the fuel level indicator of an electric fuel pump (a) before and (b) after soaking in E10 fuel.

Furthermore, Figure 8 presents the effect of fuel on the weight of the gasoline float. It is evident that the slope of the E10-soaked part was steeper than that of the RON92-soaked part. This indicated that the weight of the gasoline float decreased in both fuels, but at a higher rate in E10. After the first 1000 hours of soaking, the weight of the part soaked in RON92 gasoline decreased from 36.28 mg to 36.24 mg, a loss of 0.04 mg (0.11%). In contrast, the weight of the part soaked in E10 decreased from 36.88 mg to 36.78 mg, a loss of 0.1 mg (0.27%). At 2000 hours, the weight of the part soaked in

RON92 gasoline further decreased to 36.16 mg, a total loss of 0.33%. Meanwhile, the weight of the part soaked in E10 dropped to 36.61 mg, a total loss of 0.27 mg (0.73%). This difference can be related to the presence of ethanol in E10, which is weakly acidic and facilitates chemical reactions that weaken the plastic's molecular bonds, leading to weight loss.

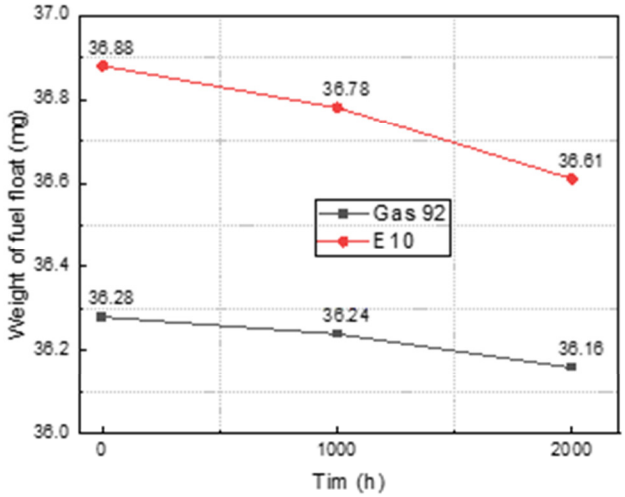


Fig. 8. Weight of fuel float after soaking in RON92 and E10.

IV. CONCLUSION

This study provided a comprehensive assessment of the compatibility of non-metallic fuel system components in electronic fuel injection engines with ethanol-blended biofuel (E10) through a 2000-hour soaking test at 45 °C. The results demonstrated that ethanol-blended fuel exhibited a significant impact on the material properties of these components, primarily due to ethanol's hygroscopic nature, oxidation potential, and chemical interactions. The key findings included:

- Coarse Filter: The weight of the component was 2.58 times higher than in RON92.
- Fine Filter: The weight increased by 1.01% in E10, compared to 0.44% in RON92, with a rate of increase nearly twice as high in the 1000-2000 hour period.
- Fuel Level Indicator: The weight loss in E10 was approximately three times greater than in RON92, demonstrating ethanol's corrosive effect.
- Fuel float: A weight reduction of 0.73% in E10, compared to 0.33% in RON92, was observed.

The novelty of this research lied in its detailed analysis of material property changes in non-metallic fuel system components, particularly through weight, size, hardness, and microstructural evaluations. Unlike prior studies having been focused on metal corrosion or filter clogging, this work provided empirical data on plastic and rubber degradation due to ethanol exposure. The findings indicated that E10 biofuel contributed to material swelling, surface oxidation, and degradation, potentially reducing fuel system performance and durability. Routine maintenance, including sealing inspections, fuel float and rubber membrane checks, and fuel filter cleaning, is essential to mitigate these effects. Manufacturers should explore alternative materials with enhanced ethanol resistance to ensure component longevity.

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