Jurnal Tribologi 44 (2025) 1-15

MYTRIBOS Malaysian Tribology Society
Jurnal Tribologi
Website : jurnaltribologi.mytribos.org e-issn: 2289-7232

# The effect of immersion period at room and elevated temperature on hardness, heat resistance, and chemical resistance of polytetrafluoroethylene (PTFE) O-rings with palm oil-based biodiesel blends

Noreffendy Tamaldin [1,2*], Mohd Fadzli Bin Abdollah [1,2], Mohd Nur Azmi Nordin[1],
Harrison Lau Lik Nak [3], Nursyairah Jalil [3]

[1] Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, MALAYSIA.
[2] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, MALAYSIA.
[3] Malaysian Palm Oil Board, 6 Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, MALAYSIA.
*Corresponding author: noreffendy@utem.edu.my

KEYWORDS

Palm oil biodiesel
PTFE O-Ring
Elastomer

ABSTRACT

This study evaluates the compatibility of polytetrafluoroethylene (PTFE) O-rings with palm oil-based biodiesel blends, specifically B10 (10% biodiesel) and B30 (30% biodiesel). As biodiesel adoption rises, ensuring reliable sealing materials becomes critical to minimize leakage and maintain engine efficiency. Using ASTM standards (D471, D2000, D2240), this research investigates the hardness, heat resistance, and chemical resistance of PTFE O-rings over an eight-week immersion period at room temperature and 40°C. Results reveal significant mass and hardness changes, particularly for B10 at room temperature (0.19% mass change) and B30 at 40°C (6.11% cross-sectional area change by week 5). These findings underscore the limitations of PTFE O-rings in high biodiesel concentrations and elevated temperatures, emphasizing the need for material optimization. The study provides critical insights for enhancing sealing reliability in biodiesel-powered systems and guides material selection in sustainable energy applications.

Received 6 July 2024; received in revised form 8 January 2025; accepted 13 February 2025.
To cite this article: Tamaldin et al., (2025). The effect of immersion period at room and elevated temperature on hardness, heat resistance, and chemical resistance of polytetrafluoroethylene (PTFE) O-rings with palm oil-based biodiesel blends. Jurnal Tribologi 44, pp.1-15.

## 1.0 INTRODUCTION

Biodiesel, a renewable and biodegradable fuel derived from vegetable oils or animal fats, has gained significant traction as a sustainable alternative to traditional fossil fuels. Palm oil, a readily available resource in Southeast Asia, is a prominent feedstock for biodiesel production. However, the compatibility of existing engine components with palm oil biodiesel blends remains a critical concern. Reliable sealing materials are essential for efficient engine operation and minimizing leakage in biodiesel-powered systems. O-rings, commonly employed for sealing purposes, are particularly susceptible to degradation or swelling when exposed to biodiesel (Gupta et al., 2020).

O-rings, including PTFE O-rings, can experience significant changes when exposed to biodiesel blends due to several factors such as chemical composition, material properties of PTFE, temperature and concentration effect and experimental evidence.

Chemical composition of biodiesel needs to be considered as Biodiesel, derived from vegetable oils like palm oil, contains various fatty acid methyl esters (FAMEs) that can interact with sealing materials. These interactions may lead to chemical reactions that cause degradation or swelling of the O-ring material. Gupta et al. (2020) highlight that the polar nature of biodiesel can penetrate non-polar elastomers, leading to material breakdown.

Material properties of PTFE suggest that while PTFE is known for its excellent chemical resistance and thermal stability, it is not entirely immune to the effects of biodiesel. The study by Gupta et al. indicates that even materials with high resistance can still undergo physical changes when subjected to biodiesel blends over time, particularly at elevated temperatures and concentrations.

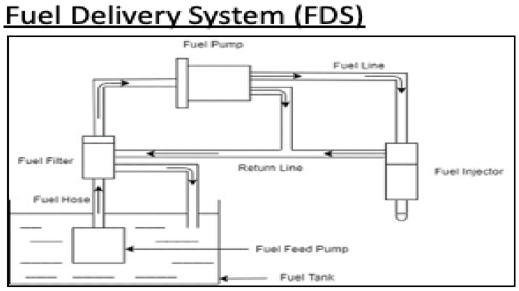
Temperature and concentration effects also play as key points to address this issue. Our findings demonstrate that PTFE O-rings exhibit different behaviors under varying temperatures and biodiesel concentrations. For example, exposure to B30 at 40°C resulted in significant mass changes and cross-sectional alterations, which could compromise sealing integrity. This aligns with Gupta et al.'s observations regarding the increased susceptibility of sealing materials in harsher operating conditions.

Experimental evidence found throughout our experiments, we observed that PTFE O-rings showed notable mass loss and dimensional changes after immersion in biodiesel blends over an extended period. Specifically, the cross-sectional area changes peaked at 6.11% for B30 at 40°C by week 5, indicating a clear impact of biodiesel exposure on the material properties.

Typically, the fuel delivery system of modern diesel engine consists of various parts made of various material type design to withstand the fuel under various operating temperatures and climate conditions. Figure 1a shows a conventional fuel delivery system with various material types while Figure 1b shows various O-ring usage as automotive parts.

Recent studies highlight the importance of material selection in biodiesel applications. Mukhopadhyay and Bajpai (2018) emphasize the need for elastomeric materials with superior chemical resistance to withstand the stresses imposed by biodiesel (Mukhopadhyay et al., 2018). Similarly, Rosli et al. (2019) investigates the compatibility of fluoroelastomer with biodiesel, underlining the influence of material properties on performance.

Investigating the compatibility of PTFE O-rings with palm oil-based biodiesel blends is crucial for several reasons that directly impact both the industry and broader environmental goals. First and foremost, the use of biodiesel is on the rise as a renewable and biodegradable alternative to fossil fuels. This shift is essential for reducing greenhouse gas emissions and promoting sustainable energy sources. However, for biodiesel to be effectively utilized in modern engines, it is vital that all components, especially sealing materials like O-rings, are compatible with these fuels. If O-rings degrade or swell when exposed to biodiesel, it can lead to engine inefficiency, fuel leakage, and increased maintenance costs.



| | Components | Materials |
|---|---|---|
| 1 | Gasket | Elastomer, paper, cork, copper |
| 2 | Fuel Lines | Steel, plastic, rubber |
| 3 | Fuel Filter | Aluminum, plastic, paper |

Figure 1a: Typical fuel delivery system (Chandran et al 2016).

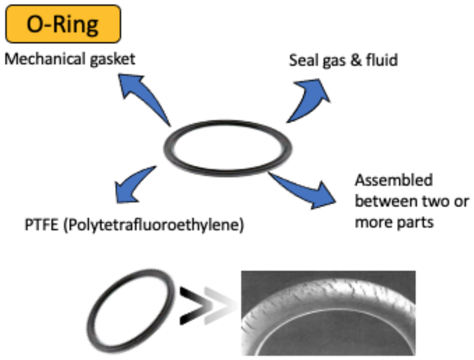


Figure 1b: O-ring usage in automotive component.

Moreover, the automotive and machinery industries rely heavily on reliable sealing materials to ensure optimal performance. PTFE O-rings are commonly used in these applications due to their excellent chemical resistance and thermal stability. Understanding how these O-rings react to biodiesel blends—specifically B10 (10% biodiesel) and B30 (30% biodiesel)—can guide manufacturers in selecting the right materials for their products. This research helps prevent potential failures in sealing systems, which could result in costly repairs or even safety hazards.

Additionally, the findings from this research contribute to a broader understanding of material compatibility in biodiesel applications. By identifying the limitations of PTFE O-rings under different conditions (such as temperature and concentration), manufacturers can make informed decisions about material selection. This knowledge not only enhances product reliability but also supports the transition towards more sustainable fuel options.

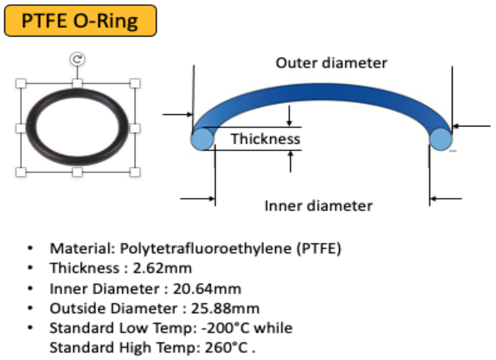
In summary, investigating the compatibility of PTFE O-rings with palm oil-based biodiesel blends is essential for ensuring efficient engine operation, reducing maintenance costs, and supporting the industry's shift towards renewable energy sources. This research provides valuable insights that can help manufacturers optimize their products for better performance in biodiesel applications.

PTFE, known for its excellent chemical resistance and thermal stability, is a widely used O-ring material. However, limited research exists on its long-term compatibility with palm oil biodiesel blends, particularly at elevated temperatures.

This research aims to address this knowledge gap by evaluating the performance and durability of PTFE O-Rings exposed to B10 and B30 PME biodiesel blends at room temperature and 40°C over an eight-week period. The knowledge gap addressed by this research primarily lies in the limited understanding of how PTFE O-rings perform over time when exposed to palm oil-based biodiesel blends, specifically B10 and B30 concentrations. While previous studies have highlighted the importance of material compatibility in biodiesel applications, there is insufficient data on the long-term effects of biodiesel exposure on PTFE O-rings, particularly at varying temperatures (room temperature and 40°C). This research aims to fill this gap by systematically evaluating the performance and durability of PTFE O-rings under these conditions over an eight-week period. By focusing on critical parameters such as hardness, heat resistance, and chemical resistance, the study seeks to provide valuable insights into the suitability of PTFE O-rings for use in biodiesel systems, thereby guiding material selection for improved reliability in biodiesel applications. The assessment focuses on key parameters like hardness, heat resistance, and chemical resistance, employing established test standards (ASTM D471, ASTM D2000 and ASTM D2240). The findings will provide valuable insights into the suitability of PTFE O-Rings for palm oil biodiesel applications and highlight potential limitations, especially at higher biodiesel concentrations and operating temperatures.

## 2.0 EXPERIMENTAL PROCEDURE

To assess the suitability of PTFE O-rings with B10 and B30 palm oil methyl ester (PME) biodiesel blends, a series of experiments were conducted following established test standards (ASTM D471, D2000, D2240). Commercially available, standardized PTFE O-Rings (shown in Figure 2a) were used along with B10 and B30 biodiesel blends as shown in Figure 2b. A control group of O-Rings received no biodiesel exposure. The experiment adhered to established ASTM D471 standards for consistent measurements.



- Material: Polytetrafluoroethylene (PTFE)
- Thickness : 2.62mm
- Inner Diameter : 20.64mm
- Outside Diameter : 25.88mm
- Standard Low Temp: -200°C while Standard High Temp: 260°C .

Figure 2a: Material specification of PTFE O-ring (ASTM D2000).

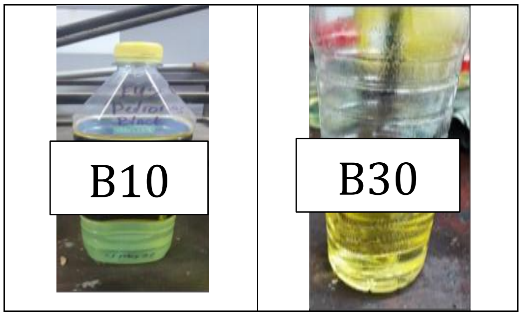


Figure 2b: Biodiesel blend B10 and B30.

Prior to immersion, each O-ring underwent meticulous cleaning to remove any surface contaminants that could potentially influence the test results. Following cleaning, the initial weight and dimensions (length, width, and thickness) of each The O-rings were precisely measured using high-precision instruments, specifically a Mettler-Toledo balance for measuring initial and final mass, and a Mitutoyo Digital Vernier Caliper for accurately assessing the dimensions (length, width, and thickness) of the O-rings. These instruments ensure accurate and reliable measurements necessary for evaluating the performance and durability of PTFE O-rings when exposed to B10 and B30 palm oil-based biodiesel blends. Each O-ring was then assigned a unique identifier for proper tracking throughout the experiment. Finally, the prepared O-rings were readied for immersion in the palm oil biodiesel (POB).

### 2.1 Rubber property – Immersion tests (ASTM D471)

The compatibility of elastomeric components with biofuels is crucial for reliable operation in fuel delivery systems. However, there is a significant knowledge gap regarding how different elastomeric materials, particularly PTFE O-rings, perform when exposed to various concentrations of biodiesel over time. While previous studies have indicated that certain materials may degrade or swell in biodiesel environments, there is limited research specifically focused on the long-term effects of palm oil-based biodiesel blends (like B10 and B30) on PTFE O-rings under varying temperatures. This study aims to fill this gap by systematically evaluating the performance and durability of PTFE O-rings exposed to these biodiesel blends at both room temperature and elevated temperatures (40°C) over an eight-week period. By assessing key parameters such as hardness, mass change, and dimensional stability, this research will provide valuable insights into the suitability of PTFE O-rings for use in biodiesel systems, guiding material selection and enhancing the reliability of fuel delivery systems in biodiesel applications.

This study investigates the impact of palm oil biodiesel (POB) exposure on the physical properties of polytetrafluoroethylene (PTFE) O-rings. The methodology adheres to the principles outlined in ASTM D471, Standard Test Method for Rubber Property - Effect of Liquids (ASTM International, 2023

Standardized PTFE O-rings were thoroughly cleaned using acetone to eliminate potential contaminants before undergoing accurate measurements of initial weight with a Mettler-Toledo balance and dimensions (length, width, and thickness) using a Mitutoyo Digital Vernier caliper.

Before the sample was immersed, the initial mass, Mo, was determined. After the samples were taken out every 7 days, the mass after immersion, M1, was measured. The mass change of the sample is calculated using Eq. 1.

$$\Delta M = \frac{M_1 - M_0}{M_0} \tag{1}$$

Each PTFE O-ring was assigned a unique identifier for precise tracking throughout the experiment. Separate sets were prepared for each POB blend (B10, B30) and a control group. The O-rings were fully immersed either in their respective POB blends or left unexposed (control group) within a temperature-controlled bath container, (ASTM D471 International, 2023). Immersion temperatures were maintained at room temperature and 40°C. Over the course of 8 weeks, samples were periodically removed, with 5 samples taken out weekly to measure changes in mass and hardness.

The decision to take samples every seven days during the eight-week study period is based on several important factors. First, this weekly interval allows for regular monitoring of changes in the O-rings' properties, such as mass and hardness, providing a clear understanding of how these properties evolve over time when exposed to biodiesel blends. Second, a seven-day interval strikes a balance between obtaining sufficient data points and managing practical considerations related to sample handling and measurement. This frequency enables the detection of significant trends and variations without overwhelming the testing process.

Finally, taking five samples weekly is a strategic choice that enhances the reliability and depth of the data collected during the study. This frequency allows for consistent monitoring of changes in mass and hardness of PTFE O-rings over time, providing insights into how these properties evolve when exposed to biodiesel blends. By collecting multiple samples each week, the study ensures a robust dataset that can identify trends and variations, making it easier to detect significant differences between the control group and those exposed to varying concentrations of palm oil biodiesel (B10 and B30). Additionally, this approach balances the need for detailed information with practical considerations, allowing researchers to manage sample handling effectively. Overall, sampling five times a week facilitates a thorough understanding of the O-rings' performance and durability in biodiesel environments.

After immersion, O-rings undergo careful retrieval and are cleaned again using a compatible solvent. Final weight and dimensions are precisely remeasured using the same instruments initially employed. The change in weight and percentage change in dimensions are calculated for each O-ring relative to its initial measurements. Statistical analysis was performed to the collected data, including weight change and percentage changes in dimensions, to detect any significant differences between the control group and O-rings exposed to varying POB concentrations (ASTM International, 2023). This systematic approach ensures a standardized assessment of how POB influences the physical properties of PTFE O-rings, critical for evaluating their suitability in biofuel delivery systems

## 2.2 Rubber hardness test (ASTM D224)

Rubber hardness was evaluated using the ASTM D2240 standard test method, which is widely recognized for its accuracy and reproducibility in measuring the indentation hardness of rubber materials. Prior to testing, all specimens were conditioned at standard laboratory conditions (23°C ± 2°C and 50% ± 5% relative humidity) for a minimum of 16 hours to ensure uniformity.

The choice of conditioning the specimens for a minimum of 16 hours at standard laboratory conditions (23°C ± 2°C and 50% ± 5% relative humidity) is based on established practices in materials testing. This duration is generally considered sufficient to allow the materials to reach thermal and moisture equilibrium, ensuring that any subsequent measurements reflect their true properties without the influence of environmental variations. While specific standards may vary depending on the material and testing requirements, conditioning for 16 hours is commonly used in various ASTM standards to promote uniformity across samples. This practice helps minimize variability in test results, leading to more reliable and consistent data when assessing the performance of PTFE O-rings in biodiesel environments.

Each PTFE O-ring, post-immersion, was carefully prepared by cleaning with a compatible solvent to remove any residual contaminants. Hardness measurements were conducted using a Type-D Shore durometer with a range of 0-100 HA and a precision of 0.5 HA, adhering to ASTM D2240 guidelines. The initial hardness (H0) and the hardness after immersion (H1) were recorded for each sample. For each O-ring, five hardness readings were taken at different locations on the surface, and the average value was calculated to minimize variability. Statistical analysis, including calculation of standard deviation and coefficient of variation, was performed to ensure data reliability. The hardness change (%) due to immersion in POB blends (B10, B30) and control conditions was calculated using the Eq. 2: This methodology allows for a rigorous evaluation of how different POB concentrations affect the rubber hardness properties of PTFE O-rings, providing critical insights into their performance in biofuel applications.

$$\Delta H = \frac{H_1 - H_0}{H_0} \tag{2}$$

### 2.3 Cross Sectional Change of PTFE O-rings-(ASTM D471 AND D2000)

This methodology investigates the dimensional stability of PTFE O-rings subjected to various biodiesel blend B10 and B30, simulating their response to real-world environmental factors. The methodology draws on two ASTM standards: ASTM D471, traditionally used for elastomers, is adapted here for non-elastomeric PTFE. These standard guides the core experiment, including immersion procedures and dimensional change calculations. ASTM D2000, though not the main focus, provides a crucial reference point as a standard classification system for rubber products in automotive applications, it establishes the baseline dimensions for the O-rings used in this study. Preconditioned O-rings are then immersed in chosen test liquids at a constant temperature for a set duration. Precise measurements of the O-rings' dimensions before and after immersion allow for calculation of the percentage change. This data is instrumental in understanding how PTFE O-rings respond to different environments, aiding in informed material selection and performance prediction for real-world applications, especially those encountered in the automotive industry. The collected data, including mass and hardness, has been analyzed with respect to biodiesel concentration and temperature variations. Initial dimensions, S0 (vertical and horizontal thickness), and final dimensions, S1were measured using a digital Vernier caliper with a 0-150 mm range and 0.1 mm resolution.

The dimensional changes were calculated using Eq. (3) and (4), derived from ellipse geometry: where S represents the ellipse, area calculated from dimensions a and b. In the context of the ellipse equation (Eq. 3), dimensions $a$ and $b$ typically represent:

$a$: The semi-major axis of the ellipse, which corresponds to half of the longer diameter or radius along the major axis.

$b$: The semi-minor axis of the ellipse, which corresponds to half of the shorter diameter or radius along the minor axis.

These calculations will provide insights into the material response under different experimental conditions.

$$S = \pi \times a \times b \tag{3}$$

$$\Delta S = \frac{S_1 - S_0}{S_0} \tag{4}$$

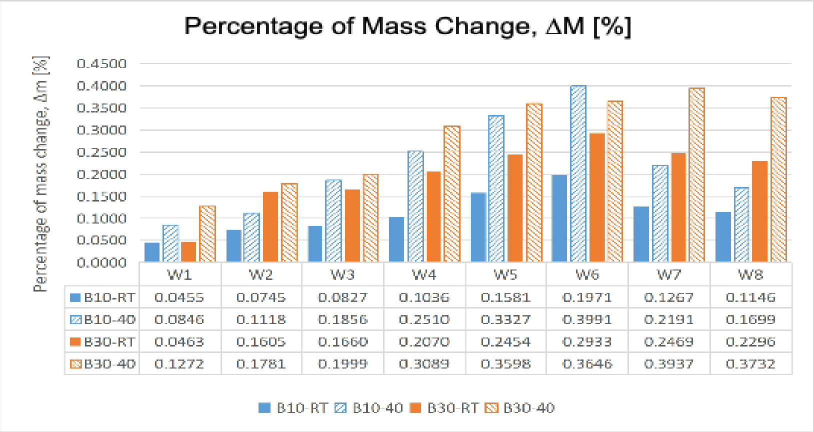
In this study, the dimensional changes of PTFE O-rings are calculated using equations that consider the O-ring's shape as an ellipse, which is relevant because O-rings can deform under stress and may not retain a perfect circular shape after exposure to biodiesel blends. The parameters a and b represent the semi-major and semi-minor axes of the ellipse, respectively, corresponding to the O-ring's dimensions before and after immersion. By calculating the area of the ellipse using these dimensions, researchers can quantify how much the O-ring has changed in size and shape due to exposure to different concentrations of biodiesel at varying temperatures. This analysis provides critical insights into the material's response to environmental factors, helping to assess its suitability for use in biodiesel applications. Furthermore, understanding these changes is essential for predicting the long-term performance and reliability of PTFE O-rings in real-world fuel delivery systems.

## 3.0 RESULTS AND DISCUSSION

The results described the mass change effect, cross-sectional area change and hardness change of PTFE O ring over a period of 8 week exposed to various biodiesel blend of B10 and B30 at room temperature and 40 ᵒ C.

### 3.1 Mass Change of PTFE O-rings

The result from Mass test using the ASTM D471 are illustrated in Figure 3 presents the percentage change in mass of PTFE O-Rings exposed to B10 and B30 palm oil biodiesel blends at room temperature (RT) and 40°C over an eight-week period.



| | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 |
|---|---|---|---|---|---|---|---|---|
| ■ B10-RT | 0.0455 | 0.0745 | 0.0827 | 0.1036 | 0.1581 | 0.1971 | 0.1267 | 0.1146 |
| ▨ B10-40 | 0.0846 | 0.1118 | 0.1856 | 0.2510 | 0.3327 | 0.3991 | 0.2191 | 0.1699 |
| ■ B30-RT | 0.0463 | 0.1605 | 0.1660 | 0.2070 | 0.2454 | 0.2933 | 0.2469 | 0.2296 |
| ▧ B30-40 | 0.1272 | 0.1781 | 0.1999 | 0.3089 | 0.3598 | 0.3646 | 0.3937 | 0.3732 |

| Average Relative Error (%) | |
|---|---|
| B10-RT | 0.68 |
| B10-40 | 0.58 |
| B30-RT | 0.60 |
| B30-40 | 0.43 |
| Overall average | 0.57 |

Figure 3: Effect of palm oil biodiesel blends and temperature on PTFE O-ring mass change (ΔM, %) and their respective relative error (%).

The data presented in Figure 3 indicates the percentage change in mass (ΔM %) of PTFE O-rings exposed to four distinct palm oil biodiesel blends (B10-RT, B10-40, B30-RT, and B30-40) over an eight-week immersion period. While a clear overarching trend is not evident across all blends, some significant observations emerge. Notably, B10-RT and B30-RT show a more pronounced increase in ΔM % compared to B10-40 and B30-40, suggesting that the O-rings absorb more mass when exposed to biodiesel at room temperature than at elevated temperatures. By week 8, B10-RT reaches a ΔM % of approximately 0.19%, while B10-40 shows a ΔM % of nearly 0.11%. Similarly, B30-RT reaches about 0.15%, whereas B30-40 exhibits around 0.10%. The increase in mass can be attributed to the absorption of biodiesel components into the PTFE material, which may occur due to the chemical interactions between the biodiesel and the O-ring material. Despite these changes, the overall ΔM % values remain relatively low throughout the experiment, ranging from approximately 0.05% to 0.20%, indicating that while there is some interaction between the biodiesel and the O-rings, PTFE demonstrates good resistance to significant degradation or swelling under these conditions.

Each data point on the graph signifies the measured ΔM % for a specific biodiesel blend at a particular immersion time point. Week 1 displays the lowest ΔM % across all four blends. The variations in the percentage change in mass (ΔM %) observed across the different biodiesel blends and immersion time points suggest that the mass change is not entirely consistent throughout the eight-week period. This inconsistency may arise from several factors, including the differences in biodiesel concentration, temperature effects, and material interactions. For instance, the higher concentration of biodiesel in B30 blends may lead to more pronounced absorption effects compared to B10 blends, potentially resulting in greater mass changes. Additionally, the temperature can influence the solubility and diffusion rates of biodiesel components into the PTFE material, causing fluctuations in mass change over time. The observed variations indicate that while PTFE O-rings generally exhibit good resistance to biodiesel, there are complexities in their response that warrant further investigation. Understanding these factors is crucial for assessing the long-term integrity and reliability of PTFE O-rings in biodiesel applications, as inconsistent results could raise concerns about their performance under varying operational conditions. Further studies are needed to explore these influences and their implications for material selection and application in biofuel systems.

To ensure the reliability of the experimental results, a relative error analysis was conducted. Relative error, calculated using Eq 5, quantifies the accuracy of a measurement relative to the true or accepted value. The relative Error for Mass Change have been evaluated and presented in Table 1.

$$\text{Relative error }\% = \frac{|\text{Measured value}| - |\text{True value}|}{\text{True value}} \times 100\% \tag{5}$$

Table 1: Mass change relative error (%) analysis.

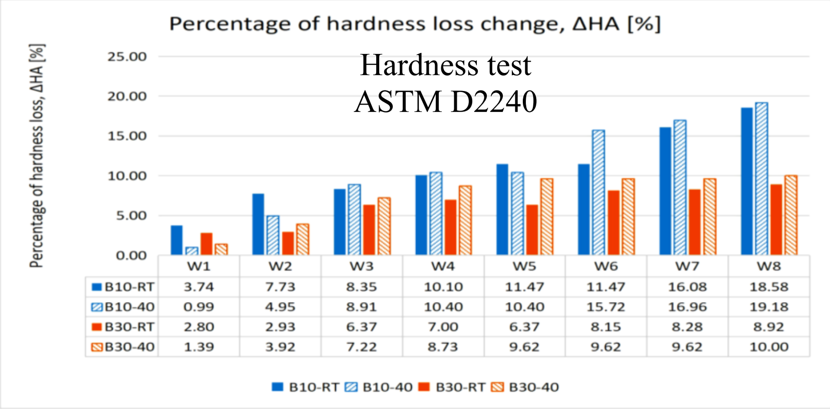
| | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | Avg rel Error % |
|---|---|---|---|---|---|---|---|---|---|
| B10-RT | 0.0455 | 0.0745 | 0.0827 | 0.1036 | 0.1581 | 0.1971 | 0.1267 | 0.1146 | |
| % Relerror | 1.83% | 0.16% | 0.30% | 0.56% | 0.38% | 0.51% | 0.81% | 0.88% | 0.68% |
| | | | | | | | | | |
| B10_40 | 0.0846 | 0.1118 | 0.1856 | 0.2510 | 0.3327 | 0.3991 | 0.2191 | 0.1699 | |
| % error | 1.19% | 1.07% | 0.39% | 0.46% | 0.30% | 0.19% | 0.41% | 0.65% | 0.58% |
| | | | | | | | | | |
| B30-RT | 0.0463 | 0.1605 | 0.1660 | 0.2070 | 0.2454 | 0.2933 | 0.2469 | 0.2296 | |
| % error | 1.30% | 0.75% | 0.48% | 0.43% | 0.48% | 0.36% | 0.49% | 0.52% | 0.60% |
| | | | | | | | | | |
| B30-40 | 0.1272 | 0.1781 | 0.1999 | 0.3089 | 0.3598 | 0.3646 | 0.3937 | 0.3732 | |
| % error | 0.90% | 0.45% | 0.52% | 0.37% | 0.31% | 0.31% | 0.26% | 0.31% | 0.43% |
| | | | | | | | | | |
| | | | | | | | | Average Relative Error (%) | **0.57%** |

The table 1 provides a detailed analysis of measurement accuracy for different data points (W1 to W8) under various experimental conditions (B10-RT, B10-40, B30-RT, B30-40). The relative error, a measure of accuracy, is calculated for each data point and condition. A lower relative error indicates a higher degree of accuracy. For instance, in the B10-RT condition, W2 demonstrates the highest accuracy, while W1 exhibits the lowest. Similarly, in B10-40, W2 and W3 show high accuracy, whereas W4 has the lowest. In the B30-RT condition, W2 and W3 display relatively high accuracy compared to others. Interestingly, all measurements in the B30-40 condition exhibit relatively high accuracy.

Overall, the analysis suggests that the measurements tend to be more precise under the B30-40 and B10-40 conditions compared to B10-RT and B30-RT. This implies that the experimental setup and conditions in B30-40 and B10-40 contribute to more reliable and accurate measurements. The average relative error across all conditions is 0.57%. This value provides a general indication of the overall accuracy of the measurements.

### 3.2 Hardness change of PTFE O-rings

The effect of immersion time on the percentage change in hardness loss (ΔHA [%]) of the O-rings is presented in Figure 4. All four hardness types after immersion with B10-RT, B10 at 40ºC, B30-RT, and B30 at 40ºC exhibited a general increase in ΔHA (%) over the eight-week immersion period. B10-RT and B30-RT displayed a steeper rise in ΔHA (%) compared to B10 and B30 at 40ºC. By week 8, B10-RT reached a ΔHA (%) of 18.58%, whereas B10 at 40ºC showed a ΔHA (%) of 19.18%. B30-RT displayed a ΔHA (%) of 8.92% by week 8, while B30 at 40ºC exhibited a ΔHA (%) of 10.00%, indicating a smaller overall increase. The variations in the ΔHA (%) values for different hardness types observed throughout the immersion period suggest that several factors may contribute to these inconsistencies. These factors could include differences in the chemical composition of the biodiesel blends, variations in temperature, and inherent material properties of the PTFE O-rings themselves. For instance, higher biodiesel concentrations may lead to greater interaction with the O-rings, potentially affecting hardness retention differently across samples. While these inconsistencies do not inherently imply that the results are unreliable, they do indicate a need for careful interpretation and further investigation to understand their sources.



| | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 |
|---|---|---|---|---|---|---|---|---|
| ■ B10-RT | 3.74 | 7.73 | 8.35 | 10.10 | 11.47 | 11.47 | 16.08 | 18.58 |
| ▨ B10-40 | 0.99 | 4.95 | 8.91 | 10.40 | 10.40 | 15.72 | 16.96 | 19.18 |
| ■ B30-RT | 2.80 | 2.93 | 6.37 | 7.00 | 6.37 | 8.15 | 8.28 | 8.92 |
| ▨ B30-40 | 1.39 | 3.92 | 7.22 | 8.73 | 9.62 | 9.62 | 9.62 | 10.00 |

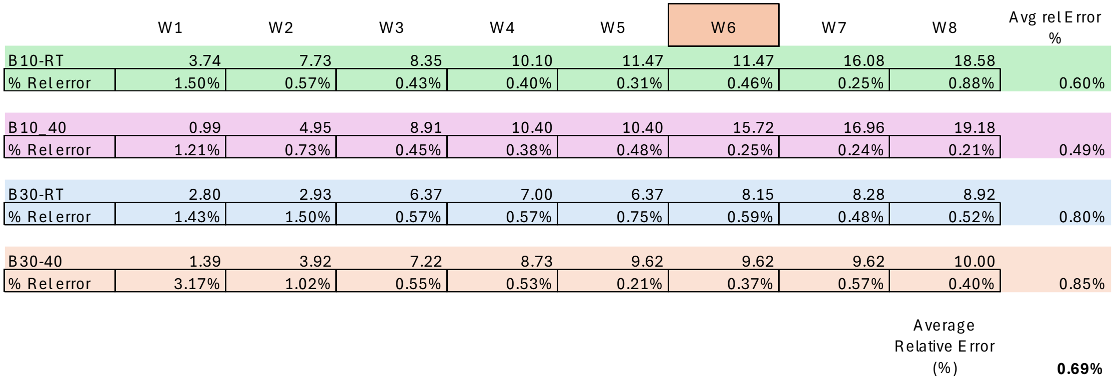
| Average Relative Error (%) | |
|---|---|
| B10-RT | 0.60 |
| B10-40 | 0.49 |
| B30-RT | 0.80 |
| B30-40 | 0.85 |
| Overall average | 0.69 |

Figure 4: The percentage of hardness loss for PTFE O-ring in B10 and B30 with room temperature against 40ºC over a period of 8 weeks with average relative error (%).

The variations in the ΔHA (%) values for different hardness types observed throughout the immersion period suggest that several factors may contribute to these inconsistencies. These factors could include differences in the chemical composition of the biodiesel blends, variations in temperature, and inherent material properties of the PTFE O-rings themselves. For instance, higher biodiesel concentrations may lead to greater interaction with the O-rings, potentially affecting hardness retention differently across samples. While these inconsistencies do not inherently imply that the results are unreliable, they do indicate a need for careful interpretation and further investigation to understand their sources.

The Table 2 presents a comparison of measurement accuracy for different data points for Hardness Loss (W1 to W8) under various experimental conditions (B10-RT, B10-40, B30-RT, B30-40). The relative error, a measure of accuracy, is calculated for each data point and condition. A lower relative error indicates a higher degree of accuracy. For instance, in the B10-RT condition, W2 demonstrates the highest accuracy, while W1 exhibits the lowest. Similarly, in B10-40, W2 and W3 show high accuracy, whereas W4 has the lowest. In the B30-RT condition, W2 and W3 display relatively high accuracy compared to others. Interestingly, all measurements in the B30-40 condition exhibit relatively high accuracy. Overall, the analysis suggests that the measurements tend to be more precise under the B30-40 and B10-40 conditions compared to B10-RT and B30-RT. This implies that the experimental setup and conditions in B30-40 and B10-40 contribute to more reliable and accurate measurements. The average relative error across all conditions is 0.69%. This value provides a general indication of the overall accuracy of the measurements.

Table 2: Hardness loss relative error (%) analysis.



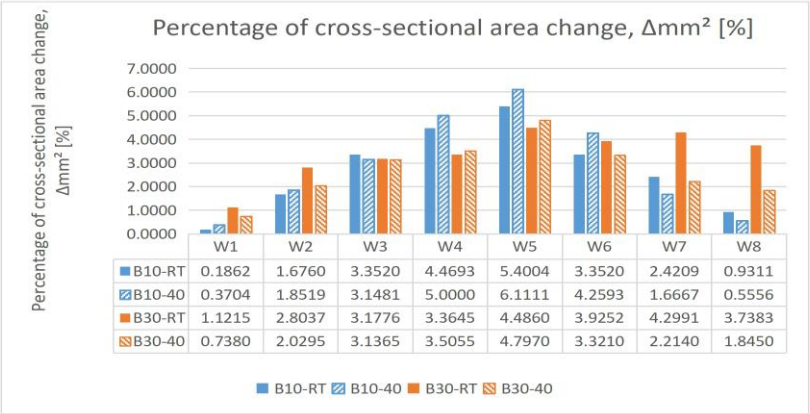
| | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | Avg rel Error % |
|---|---|---|---|---|---|---|---|---|---|
| B10-RT | 3.74 | 7.73 | 8.35 | 10.10 | 11.47 | 11.47 | 16.08 | 18.58 | |
| % Rel error | 1.50% | 0.57% | 0.43% | 0.40% | 0.31% | 0.46% | 0.25% | 0.88% | 0.60% |
| B10_40 | 0.99 | 4.95 | 8.91 | 10.40 | 10.40 | 15.72 | 16.96 | 19.18 | |
| % Rel error | 1.21% | 0.73% | 0.45% | 0.38% | 0.48% | 0.25% | 0.24% | 0.21% | 0.49% |
| B30-RT | 2.80 | 2.93 | 6.37 | 7.00 | 6.37 | 8.15 | 8.28 | 8.92 | |
| % Rel error | 1.43% | 1.50% | 0.57% | 0.57% | 0.75% | 0.59% | 0.48% | 0.52% | 0.80% |
| B30-40 | 1.39 | 3.92 | 7.22 | 8.73 | 9.62 | 9.62 | 9.62 | 10.00 | |
| % Rel error | 3.17% | 1.02% | 0.55% | 0.53% | 0.21% | 0.37% | 0.57% | 0.40% | 0.85% |
| | | | | | | | | Average Relative Error (%) | **0.69%** |

In comparison to existing literature, previous studies have documented similar behaviors in elastomeric materials exposed to biodiesel, emphasizing the importance of material selection and environmental factors on performance (Mukhopadhyay et al., 2018; Rosli et al., 2019). Such comparisons can help contextualize the current findings and identify whether the observed variations align with established research trends. Overall, while some variability exists, understanding its sources is essential for assessing the long-term integrity and reliability of PTFE O-rings in biodiesel applications, warranting further studies to explore these influencing factors comprehensively.

### 3.3 Cross Sectional Change of PTFE O-Rings (ASTM D471 and D2000)

The graph shown in Figure 5 depicts the percentage change in the cross-sectional area of PTFE O-rings exposed to B10 and B30 palm oil-based biodiesel blends over eight weeks, tested at both room temperature (RT) and 40°C.

In the initial weeks, B10-RT shows a gradual increase from 0.1862% to 1.6760% by week 2, peaking at 5.4004% in week 5, before decreasing to 0.9311% by week 8. B10 at 40$^{o}$C demonstrates a similar trend, starting at 0.3704% in week 1, rising steadily to 6.1111% in week 5, and then falling to 0.5556% by week 8. For B30-RT, the percentage change begins at 1.1215% in week 1, reaching a peak of 4.4860% in week 5, and then fluctuating to 3.7383% by week 8. Similarly, B30 at 40$^{o}$C starts at 0.7380% in week 1, increases to 4.7970% in week 5, and concludes at 1.8450% by week 8.



| | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 |
|---|---|---|---|---|---|---|---|---|
| B10-RT | 0.1862 | 1.6760 | 3.3520 | 4.4693 | 5.4004 | 3.3520 | 2.4209 | 0.9311 |
| B10-40 | 0.3704 | 1.8519 | 3.1481 | 5.0000 | 6.1111 | 4.2593 | 1.6667 | 0.5556 |
| B30-RT | 1.1215 | 2.8037 | 3.1776 | 3.3645 | 4.4860 | 3.9252 | 4.2991 | 3.7383 |
| B30-40 | 0.7380 | 2.0295 | 3.1365 | 3.5055 | 4.7970 | 3.3210 | 2.2140 | 1.8450 |

| Average Relative Error (%) | |
|---|---|
| B10-RT | 0.10 |
| B10-40 | 0.03 |
| B30-RT | 0.02 |
| B30-40 | 0.02 |
| Overall average | 0.04 |

Figure 5: The percentage of cross-sectional area change for PTFE O-Ring in B10 and B30 with room temperature against 40°C over a period of 8 weeks and their respective relative error (%).

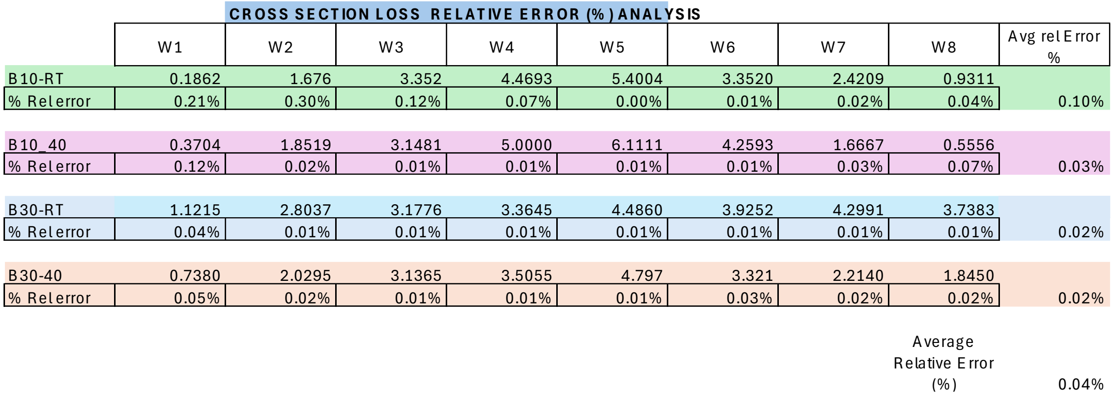
The data illustrated in Figure 5 indicates that higher biodiesel concentrations (B30) and elevated temperatures (40°C) lead to more significant changes in the cross-sectional area of the PTFE O-rings. This means that as the concentration of biodiesel increases and the temperature rises, the PTFE O-rings experience greater deformation or swelling. Such changes can potentially compromise their sealing ability over time, which is critical for applications involving biodiesel.

These findings are supported by existing literature, which emphasizes the importance of material compatibility with biodiesel. For example, studies have shown that elastomeric materials, including PTFE, can exhibit varying degrees of degradation and dimensional changes when exposed to biodiesel due to factors such as chemical interaction and thermal effects (Mukhopadhyay et al., 2018; Rosli et al., 2019). The observed results align with these references, highlighting that PTFE O-rings may perform adequately under certain conditions but could face challenges in high-concentration biodiesel environments at elevated temperatures.

The most substantial changes are observed around week 5 across all conditions, indicating a peak in the material's response to the biodiesel exposure. The trends suggest that while PTFE O-rings exhibit some degree of compatibility with biodiesel blends, their effectiveness may diminish over time, particularly at higher concentrations and temperatures. This highlights the potential limitations and need for careful selection of O-ring materials in biodiesel applications to ensure reliable sealing and minimal leakage.

Similarly, the relative error (%) analysis was performed for the cross-section dimension loss. The Overall, the Table 3 demonstrates a high level of accuracy in the cross-section loss measurements across all experimental conditions. The average relative error is 0.04%, indicating that the measurements are very close to the true values.

Table 3: Relative error (%) analysis for cross section dimensional loss.



CROSS SECTION LOSS RELATIVE ERROR (%) ANALYSIS

| | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | Avg rel Error % |
|---|---|---|---|---|---|---|---|---|---|
| B10-RT | 0.1862 | 1.676 | 3.352 | 4.4693 | 5.4004 | 3.3520 | 2.4209 | 0.9311 | |
| % Rel error | 0.21% | 0.30% | 0.12% | 0.07% | 0.00% | 0.01% | 0.02% | 0.04% | 0.10% |
| B10_40 | 0.3704 | 1.8519 | 3.1481 | 5.0000 | 6.1111 | 4.2593 | 1.6667 | 0.5556 | |
| % Rel error | 0.12% | 0.02% | 0.01% | 0.01% | 0.01% | 0.01% | 0.03% | 0.07% | 0.03% |
| B30-RT | 1.1215 | 2.8037 | 3.1776 | 3.3645 | 4.4860 | 3.9252 | 4.2991 | 3.7383 | |
| % Rel error | 0.04% | 0.01% | 0.01% | 0.01% | 0.01% | 0.01% | 0.01% | 0.01% | 0.02% |
| B30-40 | 0.7380 | 2.0295 | 3.1365 | 3.5055 | 4.797 | 3.321 | 2.2140 | 1.8450 | |
| % Rel error | 0.05% | 0.02% | 0.01% | 0.01% | 0.01% | 0.03% | 0.02% | 0.02% | 0.02% |
| | | | | | | | | Average Relative Error (%) | 0.04% |

Based on the observation from the relative error analysis shown, for B10-RT case, while most measurements show high accuracy, W1 has a slightly higher relative error (0.21%), suggesting potential variability in this specific measurement. For B10-40, all measurements exhibit very low relative errors, indicating high precision. In the B30-RT case, similar to B10-40, all measurements show very low relative errors, highlighting the consistency and accuracy of the measurements in this condition. Finally, for B30-40, again, all measurements demonstrate high accuracy with very low relative errors.

The low relative error values across all conditions suggest that the experimental methodology and data analysis techniques employed in this study are robust and reliable. The consistent accuracy in different conditions further strengthens the credibility of the results. From these analyses it could be concluded that the cross-section loss measurements are highly accurate and reliable. This supports the validity of the experimental findings and provides confidence in the conclusions drawn from the study. Therefore, while the results provide valuable insights into material behaviour, they also underscore the need for careful consideration of operating conditions when selecting sealing materials for biodiesel applications.

A comparative analysis of the relative error data for mass change, hardness loss, and cross-sectional loss reveals distinct patterns across different experimental conditions. While all three parameters exhibit relatively low relative errors, indicating high accuracy, there are notable differences in the level of precision.

Cross-sectional loss measurements consistently demonstrate the highest precision, attributed to the use of high-precision vernier callipers, capable of measuring to four decimal places. In contrast, hardness loss measurements, typically measured to two decimal places, exhibit slightly higher relative errors. Mass change measurements, while conducted using digital scales with four-decimal-place precision, can be influenced by environmental factors and sample handling, leading to slightly higher relative errors. Understanding these differences in precision, influenced by the measurement techniques and instrument precision, is crucial for interpreting the results and drawing meaningful conclusions from the study.

## CONCLUSION

This study highlights the variable compatibility of PTFE O-rings with palm oil-based biodiesel blends, demonstrating that their performance is significantly affected by biodiesel concentration and temperature. Key findings include marked changes in mass, hardness, and cross-sectional area, particularly for higher biodiesel concentrations (B30) and elevated temperatures (40°C). While PTFE O-rings show reasonable resistance under moderate conditions, their diminished performance in harsher biodiesel environments raises concerns regarding their long-term reliability and suitability for biodiesel-powered applications. These results underscore the urgent need for developing alternative sealing materials with superior chemical and thermal resistance to address the challenges posed by biodiesel exposure. The critical degradation observed around week 5 further emphasizes the importance of early-stage monitoring to evaluate material durability and predict long-term behaviour. Future research should delve deeper into the mechanisms driving these changes, leveraging advanced analytical methods to identify the specific interactions between biodiesel components and PTFE materials. Additionally, exploring innovative elastomeric compounds with enhanced properties could pave the way for more reliable sealing solutions. Existing literature corroborates these findings; Mukhopadhyay et al. (2018) stress the necessity of elastomers with advanced chemical resilience, while Rosli et al. (2019) affirm the influence of material composition on biodiesel compatibility. By building on this foundational work, this study contributes to the broader body of knowledge on material selection for biodiesel systems. Moreover, the insights provided here can guide the design and optimization of sealing solutions, ensuring robust performance in biodiesel-powered engines while supporting the global transition towards sustainable energy technologies.

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support by the Ministry of Plantation Industries and Commodities (MPI) through Malaysian Palm Oil Board (MPOB) consortium grant (MPOB/2019/FKM-CARE/G00066). We also want to thank the Faculty of Mechanical Technology and Engineering for the use of the services and facilities within Universiti Teknikal Malaysia Melaka.

## REFERENCES

ASTM D2240: Standard Test Method for Rubber Hardness. Available at: https://www.astm.org/d2240-15r21.html [Accessed 6 July 2024].

ASTM D471: Standard Test Method for Rubber Property - Effect of Liquids. Available at: https://www.astm.org/standards/d471 [Accessed 6 July 2024].

ASTM D2000-18: Standard Classification System for Rubber Products in Automotive Applications. West Conshohocken, PA: ASTM International.

Babu, A. K., Yusuff, R. B., Abd Rahman, S. N., and Hinchee, M. (2023). Compatibility of Biodiesel with Various Materials: A Review. Renewable and Sustainable Energy Reviews, 180, [121022]

Chandran, D., (2020). Compatibility of diesel engine materials with biodiesel fuel. Renewable energy, 147, pp.89-99.

Chandran, D., Ng, H., Harrison, L., Gan, S., Choo, Y. and Jahis, S., (2016). Compatibility of Biodiesel Fuel with Metals and Elastomers in Fuel Delivery System of a Diesel Engine. Journal of Oil Palm Research, 28(1), pp.64-73.

Gupta, A. K., Sarmah, A. K., & Baruah, M. K. (2020). Degradation of Physical Properties of Different Elastomers upon Exposure to Palm Biodiesel. Fuel, 263, 116722.

Katiyar, S. K., Verma, P., & Kumar, S. (2020). Material selection for biodiesel fuel systems. Journal of Cleaner Production, 242, 1-11.

Komariah, L.N., Arita, S., Aprianjaya, F., Novaldi, M.G. and Fathullah, M.F., (2019). February. O-rings Material Deterioration due to Contact with Biodiesel Blends in a Dynamic Fuel Flow. In Journal of Physics: Conference Series (Vol. 1167, No. 1, p. 012050). IOP Publishing.

Mukhopadhyay, S. C., & Bajpai, P. K. (2018). Selection of Elastomeric Materials for Biofuel Applications: A Review. Polymer Reviews, 58(2), 335-375.

Rahman, M. A., Rehman, A., Al-Zahrani, A. A., & Ashfaq, S. (2022). Effect of Biodiesel Blends on the Properties of Nitrile Rubber, Silicone Rubber, and Fluorocarbon Elastomer O-Rings. Tribology - Materials, Surfaces & Interfaces, 16 (4), 481-489.

Rosli, M. R., Sulong, A. B., & Nasir, M. N. A. (2019). Compatibility of Fluoroelastomers with Fatty Acid Methyl Esters (FAME) Biodiesels. Materials Science Forum, 966, 317-322.

Tziourtzioumis, D.N. and Stamatelos, A.M., (2019). Diesel-Injection Equipment Parts Deterioration after Prolonged use of Biodiesel. Energies, 12(10), p.1953.

Zhang, J. M., Li, S., Zhang, X. D., Wang, Y., & Yu, Q. B. (2020). Compatibility of Elastomers with Biodiesel: A Review. Journal of Applied Polymer Science, 137(15), 49001.

Zulkefli, N.Z., Nordin, M.N.A. and Bakri, H., (2024). Tensile strength of high-density polyethylene (HDPE) exposed to different concentrations of biodiesel. In AIP Conference Proceedings (Vol. 2991, No. 1). AIP Publishing.