UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE EFFECT OF STORAGE TANK MATERIAL AND CONDITION ON BIODIESEL BLEND B10 STABILITY

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A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
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2024

DECLARATION

I declare that this thesis entitled “The Effect of Storage Material and Storage Condition on Biodiesel Blend B10 Stability” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : Satish
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Date : 10 MAY 2024

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature :..
Supervisor Name : DR. NURUL HILWA BINTI MOHD ZINI
Date : 10 MAY 2024

DEDICATION

To my beloved parents and siblings

ABSTRACT

Biodiesel is made from organic materials such as animal fat, plant lipids and waste cooking oil; it is widely used in many applications such as in diesel engine. This is because biodiesel reduces the emissions of carcinogenic compounds compared to petrodiesel. However, the storage stability of biodiesel can be affected by storage tank materials and storage conditions such as extended storage period and different storage environment. On a related note, manual biodiesel storage monitoring system increases risk of human errors, operational cost and expensive. Therefore, this study aimed to investigate the effect of storage material and storage condition, and also foam insulation on biodiesel stability. This study also analysed the potential of IoT technique as a new method to monitor biodiesel stability. Two setups were considered for B10 fuel: a pilot test without storage insulation and an actual test with storage insulation. The pilot test was conducted using three biodiesel storage tank materials with various shapes: stainless steel, high-density polyethylene (HDPE) and glass. The actual test used HDPE and glass for storage material which were insulated with 3D printed foam, together with rockwool as comparison; B10 fuel in the glass storage tank was remotely monitored using IoT. Both setups were monitored in enclosed space (indoor temperature) and outdoor (sun exposure). Based on the pilot test data collected, the results indicated that fuel samples barely degraded in indoor conditions. Properties of fuel in stainless steel tank stored outdoor for 90 days increased by 1.57%, 0.88%, 54.92% and 47.46% in density, kinematic viscosity, water content, and acid value, respectively. Meanwhile, the fuel samples stored outdoor in clear glass tanks showed dramatic increases in density, kinematic viscosity, water content and acid value by 4.35%, 11.23%, 95.08% and 95.41%, respectively, within 90 days of storage. However, the flashpoint decreased by 5.26% with increasing storage duration. Besides that, 3D printed foam as insulation for storage tanks was crucial as the degradation rate dropped for all biodiesel properties when compared to pilot test data. Fuel samples stored in the glass tank with foam insulation increased steadily by 1.69%, 4.67%, 68.85%, and 63.22% for density, kinematic viscosity, water content, and acid value, respectively, after 90 days storage. Furthermore, shapes of storage tank did not have an impact on experimental investigations. CFD simulation was conducted on storage tank insulations which managed to reduce temperature distribution of outdoor exposure (31.3ºC) within the insulator before reaching storage tank wall for rockwool (28.8ºC) and printed foam (29.7ºC). Moreover, RSI value obtained for rockwool and printed which were 1.55 and 1.2, respectively. Meanwhile, IoT monitoring system recorded pH values in the range of 7.02 to 7.22 for indoor glass storage tank; these pH values were also manually validated using pH strips. However, pH values of the outdoor fuel samples dropped from pH 7 to pH 5 indicating increases in acid value within 90 days. From this study, it has been shown that biodiesel stability can be affected by storage material and storage condition; storage tanks made from stainless steel managed to reduce biodiesel degradation and is recommended as a storage tank material for B10, while higher storage temperature and longer storage duration result in biodiesel degradation. Foam insulation is shown to be an effective way to slow down biodiesel degradation. IoT technique is also demonstrated as a reliable new method to monitor biodiesel stability.

KESAN BAHAN DAN KEADAAN TANGKI SIMPANAN KE ATAS KESTABILAN CAMPURAN BIODIESEL B10

ABSTRAK

Biodiesel diperbuat daripada bahan organik seperti lemak haiwan, lipid tumbuhan dan sisa minyak masak; ia digunakan dalam banyak aplikasi seperti dalam enjin diesel. Ini kerana biodiesel dapat mengurangkan pelepasan sebatian karsinogenik berbanding petrodiesel. Kestabilan penyimpanan biodiesel dipengaruhi oleh bahan tangki simpanan dan keadaan penyimpanan yang berbeza. Selain itu, sistem pemantauan biodiesel secara manual meningkatkan risiko kesilapan manusia, kos operasi dan mahal. Kajian ini bertujuan untuk mengkaji kesan bahan simpanan dan keadaan penyimpanan, dan juga tebatan busa terhadap kestabilan biodiesel. Kajian ini juga menganalisis potensi teknik IoT sebagai kaedah terbaru mengawasi kestabilan biodiesel. Dua persiapan eksperimen diambilkira untuk bahan api B10: ujian perintis tanpa penebat dan ujian sebenar dengan penebat. Ujian perintis dijalankan dengan tiga bahan tangki simpanan biodiesel dengan pelbagai bentuk: keluli tahan karat, polietilena berketumpatan tinggi (HDPE) dan kaca. Ujian sebenar menggunakan HDPE dan kaca untuk bahan simpanan yang ditebat dengan busa bercetak 3D, bersama-sama dengan rockwool sebagai perbandingan; bahan api B10 dalam tangki simpanan kaca dipantau dari atas talian menggunakan IoT. Kedua-dua bahan kajian dipantau dalam ruang tertutup (suhu) dan luar (pendedahan matahari). Keputusan ujian rintis menunjukkan bahawa keputusan sampel minyak hampir sama dalam ruang tertutup. Tangki keluli tahan karat yang disimpan di luar selama 90 hari meningkat sebanyak 1.57%, 0.88%, 54.92% dan 47.46% dalam ketumpatan, kelikatan kinematik, kandungan air dan nilai asid. Sampel yang disimpan di luar dalam tangki kaca jernih menunjukkan peningkatan mendadak dalam ketumpatan, kelikatan kinematik, kandungan air dan nilai asid sebanyak 4.35%, 11.23%, 95.08% dan 95.41%, dalam tempoh 90 hari penyimpanan. Titik kilat berkurangan sebanyak 5.26% dengan peningkatan tempoh penyimpanan. Busa bercetak 3D sebagai penebat untuk tangki simpanan adalah penting kerana kadar degradasi menurun untuk semua sifat biodiesel jika dibandingkan dengan data ujian perintis. Sampel bahan api yang disimpan dalam tangki kaca dengan penebat buih meningkat secara berterusan sebanyak 1.69%, 4.67%, 68.85%, dan 63.22% untuk ketumpatan, kelikatan kinematik, kandungan air dan nilai asid, masing-masing selepas penyimpanan 90 hari. Bentuk tangki simpanan tidak mempunyai kesan ke atas penyiasatan eksperimen. Simulasi CFD dilakukan pada penebat tangki simpanan dan ia berjaya mengurangkan taburan suhu pendedahan luar (31.3ºC) dalam penebat sebelum mencapai dinding tangki simpanan untuk rockwool (28.8ºC) dan busa bercetak (29.7ºC). Nilai RSI diperoleh untuk rockwool dan busa ialah 1.55 dan 1.2. Sistem pemantauan IoT merekodkan nilai pH dalam julat 7.02 hingga 7.22; nilai pH ini juga telah disahkan secara manual menggunakan jalur pH. Nilai pH sampel minyak di luar menurun daripada pH 7 kepada pH 5 menunjukkan peningkatan dalam nilai asid dalam masa 90 hari. Kestabilan biodiesel dipengaruhi oleh bahan simpanan dan keadaan penyimpanan manakala suhu penyimpanan yang lebih tinggi dan tempoh penyimpanan yang lebih lama mengakibatkan degradasi biodiesel. Penebat busa berkesan untuk melambatkan degradasi biodiesel. Teknik IoT juga ditunjukkan sebagai kaedah baharu yang boleh dipercayai untuk memantau kestabilan biodiesel.

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LIST OF ABBREVIATIONS

3D	-	3-dimensional
AN	-	Acid number
ASTM	-	American Society for Testing and Materials
CO_2	-	Carbon dioxide
EPA	-	Environmental Protection Agency
EPS	-	Expanded polystyrene
FA	-	Fatty acid
FAME	-	Fatty acid methyl ester
GHG	-	Greenhouse gas
HDPE	-	High-density polyethylene
IDE	-	Integrated development environment
IoT	-	Internet of Things
KOH	-	Sodium hydroxide
NaOH	-	Potassium hydroxide
OEM	-	Original equipment manufacturer
PU	-	Polyurethane
PV	-	Peroxide value
SoC	-	System on Chip
TBHQ	-	Tert-Butylhydroquinone
UF	-	Formaldehyde
UV	-	Ultraviolet
WCO	-	Waste cooking oil

LIST OF PUBLICATIONS

1. Rao, N.S., Zini, N.H.M., Saadun, M.N.A., Anuar, F.S., 2023. Effect of Storage Tank Material on Biodiesel Stability under Different Environmental Conditions. *Jurnal Tribologi,* vol. 36, pp.32–42.

2. Rao, N.S., Zini, N.H.M., Saadun, M.N.A., Anuar, F.S., 2022. Numerical and Experimental Approaches on Printed Foam Insulation for Biodiesel Storage Tanks. *Proceedings of SAKURA Symposium on Mechanical Science and Engineering, Nagoya, Japan.* pp. 43-44.

3. Rao, N.S., Zini, N.H.M., Saadun, M.N.A., Anuar, F.S., 2022. Analysis of Insulation on Biodiesel Storage Tanks. *Proceedings of Mechanical Engineering Research Day (MERD 2022), Melaka, Malaysia.* pp. 259-260.

4. Rao, N.S., Zini, N.H.M., Saadun, M.N.A., Anuar, F.S., 2022. Biodiesel Storage Stability: Evaluation and Monitoring Advancements. *Proceedings of the 7th International Conference and Exhibition on Sustainable Energy and Advanced Materials (ICE-SEAM 2021), Melaka, Malaysia*. https://doi.org/10.1007/978-981-19-3179-6_43

LIST OF SYMBOLS

ρ - Density

V - Volume

M - Mass

C - Concentration

% - Percent

CHAPTER 1

INTRODUCTION

1.1 Background

Initially, diesel engines were designed by Rudolf Diesel in the 1980s to run on various fuels such as kerosene and coal dust with a complex injection system. Then, he made a conventional diesel engine that used 100% peanut-based oil which gave him a breakthrough during Paris Exhibition in 1900 (Adipah, 2018). However, poor quality fuel spray was caused by the viscosity of the vegetable oil, and thus, engines were damaged as a result of this. Scientists then continuously conducted experiments to improve the quality of the vegetable oils, which are now commercially known as biodiesel (Ogunkunle and Ahmed, 2019).

A biodiesel blend is a mix of ethyl esters or methyl derived from various renewable sources such as vegetable oil, recycled cooking oil, and animal fat. These esters, known as oxygenated organic compounds, are compatible to be used in compression ignition engines due to their key properties comparable with existing diesel fuel. Biodiesel properties offer a carbon-neutral cycle due to its net-zero carbon impact on the environment (Nguyen et al., 2020). Biodiesel is considered carbon-neutral because the sources of biodiesels are from feedstocks, such as palm oil trees which absorb carbon dioxide (CO_2) as they grew. CO_2 absorption by the raw materials balances the CO_2 formed during the making and burning of biodiesel (Mishra and Goswami, 2018).

Biofuel can be divided into two categories: (1) biodiesel and (2) bioethanol. Biodiesel is renewable and obtained from animals, plants, microorganisms, and organic wastes. The organic materials for biodiesel are extracted from rapeseed, palm, soybean and sunflower meanwhile bioethanol is produced from sugar beet, potatoes, maize, and wheat. (Noraini et al., 2014). Biodiesel is widely used for numerous purposes such as transportation fuel, energy generation, cooking, lubrication and paint removal. This fuel causes less damage to the environment as it is non-toxic, biodegradable, grown locally, and has fewer greenhouse gas (GHG) emissions (Abed et al., 2019). On the other hand, petroleum diesel is high in toxic, clogs engines and expensive.

There are several processes involved to extract the biodiesel fuel, which are transesterification, pyrolysis, micro emulsification and blending (Rajalingam et al., 2016). In the transesterification process, crude methyl esters and glycerine are separated from the vegetable oil. Then, they are further refined, which turns methyl esters of biodiesel and glycerine into a variety of products such as soaps and shampoo. There are specific blends for biodiesel that will be made according to the usage. Some examples include B100 which contains 100% biodiesel and B20 that contains 80% petrodiesel with 20% biodiesel (Nair, 2015). Most of the current engines can run on B100 but modification needs to be done on the engines in the aspects of cold starting, engine timing, rubber seals and oil change to avoid future performance and maintenance complications. The rubber seal also has to be replaced as this fuel reacts with the seals and the timing of the diesel engines has to be tuned by two or three degrees by considering the number of cetane of the respective fuels to maintain the performance of the engine (Xue et al., 2011).

Biodiesel has a shelf life of around three years in stable storage conditions. Many researchers have tested the fuel with various storage materials in different surroundings to obtain the best storage tank for this fuel. In addition, the materials used were mild steel, stainless steel, plastic, glass and copper. (Bouaid et al., 2007; Hu et al., 2012; Pattamaprom et al., 2012; Shahabuddin et al., 2012; Komariah et al., 2017; Prasad et al., 2018; Komariah et al., 2019). Oxidation, water level, bacteria contamination, kinematic viscosity, acid level, density, temperature and humidity level are the main factors that have to be monitored throughout the storage period (Shahabuddin et al., 2012; Komariah et al., 2017; Prasad et al., 2018). In this aspect, a country climate is also the main issue to be taken into account; for biodiesel storage, the extreme climate during transportation can affect biodiesel quality. For example, biodiesel fuel tends to freeze in an icy climate at around -1°C and increases in viscosity during higher temperature storage compared to fossil fuels (M.A. Hazrat et.al., 2020). An ideal storage tank can maintain or increase the shelf life of biodiesel fuel without any problem.

1.2 Problem statement

Biodiesel is derived from animal fat, vegetable oil and waste cooking oils (Datta et al., 2019). As it is biodegradable, biodiesel is susceptible to microbial contamination and oxidation. If it is not stored correctly, biodiesel can be exposed to atmospheric oxygen and moisture which can result in biodiesel to become unstable due to its chemical structure degrading over time. Apart from that, long term storage stability of biodiesel is not as good as conventional petrodiesel storage because of its degradable properties (Thompson et al., 2013). Properties such as water content, kinematic viscosity, density, and acid value tend to increase over longer storage time in most cases.

Oxidation is a process that will increase fuel acidity level and corrodes the fuel system. Therefore, the time taken for oxidation or degradation of biodiesel in the storage shall be prolonged or completely diminished if possible. However, current study shows that the oxidation process cannot be avoided (Erdmann et al., 2019). Other than that, higher water content in the biodiesel is observed during the pyrolysis process. This indirectly increases fuel degradation. Thus, a proper storage of biodiesel is very crucial to prevent fuel storage