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Comparative Study of Oil and Gas Products with Manual Formula on a Laboratory Scale in Ensuring Production System Information

Calista Aulia Haqi[1], Maharani Pramesti Aulia Nuha[2], Mulki Maulana Zaydan[3], Nadira Annisa Ryanthika[4], Reo Samtalira Bayu Nugraha[5], Oksil Verinza[6]*
[1,2,3,4,5,6] Oil and Gas Logistics Department, Politeknik Energi dan Mineral AKAMIGAS
Jl. Gaja Mada No. 38 Cepu Blora Jawa Tengah, 58315
*Coresspondence Author: oksil.venriza@esdm.go.id

ABSTRACT

This study explores the enhancement of oil and gas products through laboratory-scale manual formulations to address quality, efficiency, and environmental sustainability challenges. It focuses on biodiesel blends (B10, B30, and B50) and used lubricants treated with citric acid to reduce heavy metal content. The research identifies key functional components in biodiesel that improve combustion efficiency and lower greenhouse gas emissions. Simultaneously, the addition of citric acid in used lubricants aims to reduce metal concentrations, enhancing the potential for recycling and reuse. The results indicate that increasing biodiesel content significantly improves environmental performance and reduces reliance on fossil fuels, though water and sulfur content require strict monitoring to maintain product stability. In used lubricants, the application of citric acid demonstrates varied effectiveness, reducing specific metals like magnesium but increasing others such as calcium and zinc, posing challenges for consistent metal reduction. This study concludes that combining manual formulations and chemical treatments provides valuable insights into optimizing oil and gas products. It emphasizes the need for careful control of component levels to meet quality standards and environmental regulations. The findings suggest that refining the application of citric acid could further enhance its effectiveness in minimizing harmful metal concentrations, supporting sustainable and eco-friendly practices in the oil and gas sector.

Keywords: *Oil and gas, biodiesel, lubricants, citric acid treatment, quality standards.*

Introduction

The oil and gas (O&G) industry plays a pivotal role in global energy supply but faces ongoing challenges in maintaining the quality, consistency, and sustainability of its products. Oil and gas products such as biodiesel, lubricants, and other refined outputs must meet rigorous specifications to ensure operational efficiency, machinery compatibility, and adherence to environmental regulations. **Stricter environmental quality specifications for oil products tend to increase energy consumption and CO2 emissions at refineries, requiring a balance between local and global emissions https://doi.org/10.1016/J.ENERGY.2006.08.008 (masukin doi nya lewat mendeley cite) kalo gak bisa ini link jurnal nya https://www.sciencedirect.com/science/article/abs/pii/S0360544206002416?via%3Dihub** [1]**.** In this context, laboratory-scale evaluations and the application of manual formula methodologies are critical for generating reliable production system information. These evaluations serve as a foundation for ensuring that product quality remains consistent throughout the production and distribution processes. To address these challenges, chemical and physical characterizations are essential, particularly in laboratory environments where manual formula applications provide detailed insights. Analytical methods like Fourier Transform Infrared Spectroscopy (FTIR) and Inductively Coupled Plasma (ICP) are frequently employed for precise monitoring of both organic and inorganic components in O&G products. These methods not only validate product specifications but also offer comparative benchmarks for different formulations and processes, especially when developed on a laboratory scale. Balancing these demands requires an integrated approach that accounts for both environmental and operational efficiency, ensuring the industry's ability to comply with evolving regulations without compromising sustainability goals.

Fourier Transform Infrared Spectroscopy (FTIR) is a key tool for identifying functional groups in chemical compounds, based on molecular "fingerprint" spectra[1]. This technique is particularly effective in analyzing biodiesel blends such as B10, B30, and B50, as it detects critical components like carbonyl (C=O) and aliphatic hydrocarbons (CH_2, CH_3). These insights are essential for determining methyl ester content, which impacts combustion efficiency and greenhouse gas emissions. As a qualitative and quantitative method, FTIR provides a comprehensive approach to ensuring the quality and sustainability of biodiesel-based fuels.

Inductively Coupled Plasma (ICP), on the other hand, is a sophisticated technique for detecting metal elements within samples with high precision. In the oil and gas context, ICP is crucial for assessing heavy metal content in used lubricants, especially after applying chemical agents like citric acid for remediation[2]. Heavy metals can significantly influence lubricant performance and pose environmental hazards if not adequately managed. By integrating ICP analysis, laboratories can optimize regeneration processes and support the recycling and sustainability of oil and gas products[3].

A comparative study using laboratory-scale manual formulas further enhances the ability to evaluate and optimize these products. By simulating real-world production scenarios, this approach bridges the gap between theoretical standards and practical application. Combining FTIR and ICP techniques provides a holistic methodology, with FTIR focusing on organic functional group characterization and ICP providing quantitative data on inorganic elements. This dual approach supports the development of refined oil and gas products while ensuring they meet quality benchmarks and contribute to production system improvements.

This study specifically aims to conduct a comparative analysis of oil and gas products using manual formulas on a laboratory scale, focusing on biodiesel blends (B10, B30, B50) and used lubricants treated with citric acid. The outcomes are anticipated to validate production system information, support industry standards, and enhance both operational efficiency and environmental sustainability in the oil and gas sector.

Research Methods

In the experiment utilizing Fourier Transform Infrared Spectroscopy (FTIR) and Inductively Coupled Plasma (ICP) methods, each method plays a crucial role in the analysis of the tested materials. Below is an explanation of these methods in the context of this experiment:

The FTIR method is used to analyze the chemical composition of biodiesel in B10, B30, and B50 blends. FTIR identifies chemical compounds based on the infrared spectrum produced by molecular vibrations[5]. This spectrum serves as a molecular "fingerprint" for each compound. The application in this experiment:

- Homogenized biodiesel samples (B10, B30, B50) were analyzed in the wavelength range of 4000–500 cm^{-1}[6].
- FTIR spectrum analysis aims to detect the presence of key functional groups, such as carbonyl (C=O) and aliphatic hydrocarbons (CH_2, CH_3), which indicate the methyl ester content in biodiesel.
- The data obtained helps evaluate biodiesel quality based on the methyl ester concentration, which affects combustion efficiency and greenhouse gas emissions. The procedure adheres to ASTM E168, ensuring accurate acquisition and interpretation of infrared spectra.

The ICP method is used to analyze the heavy metal content in used lubricants, particularly after the addition of citric acid. ICP is an emission spectrometry technique that utilizes high-energy plasma to ionize metal elements in a sample[7]. These ions emit light at specific wavelengths, enabling the identification and quantification of metal elements. Application in this experiment:

- Used lubricants were mixed with 45 grams of citric acid and 55 ml of used lubricant, then heated and filtered.
- The filtrate was analyzed using ICP to detect heavy metals such as Mg, Zn, and Ca.
- The purpose of the analysis is to evaluate the effectiveness of citric acid in reducing heavy metal content and to understand its impact on lubricant regeneration. This analysis complies with ASTM E1479, which standardizes quantitative elemental analysis using emission spectrometry.

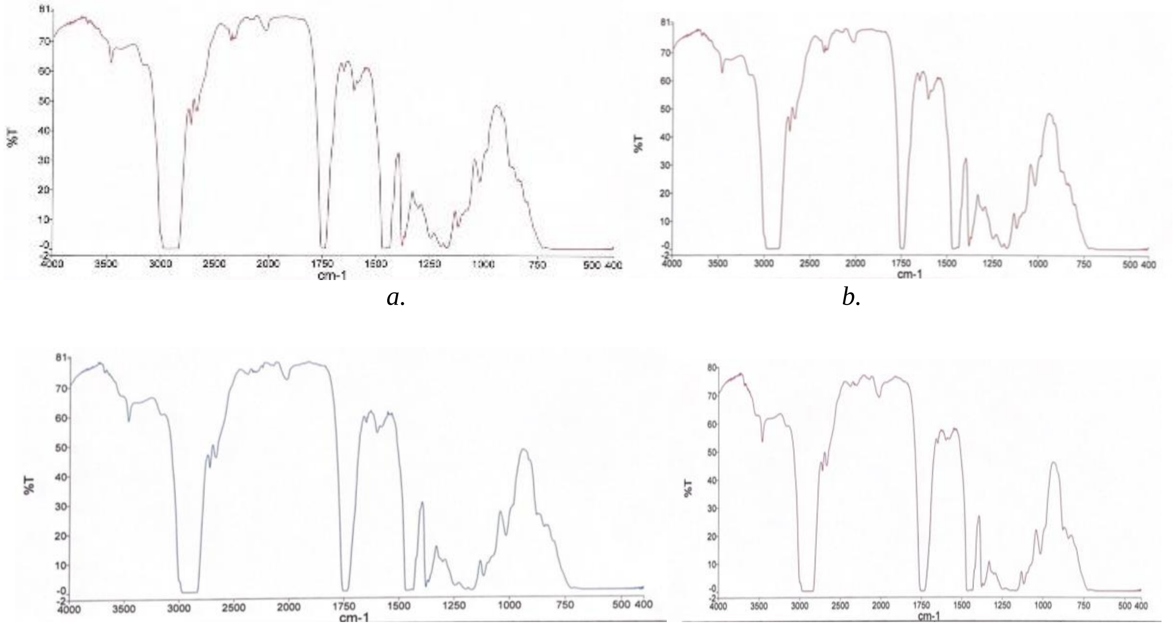
Each analysis was performed with three repetitions to ensure data reliability. Validation of the FTIR results was done by comparing the spectra of known samples with reference standards. For ICP, tests were performed with control blanks and heavy metal standard solutions to ensure linearity and measurement accuracy[8]. In addition, tool calibration was performed before and after testing to minimize systematic errors. The final data were processed to produce interpretations that support the research objectives related to biodiesel quality and effectiveness of used lubricant treatment.

The use of these two methods provides a comprehensive approach. FTIR focuses on the characterization of organic components in biodiesel, ensuring that methyl ester content complies with quality standards[5]. ICP analyzes heavy metals in used lubricants, providing quantitative information to support the sustainability of the lubricant recycling process. By leveraging these methods, the experiment aims to ensure that the tested materials meet the required quality specifications, support operational efficiency, and minimize environmental impact.

Results and Discussion

Evaluation of Biodiesel with Fourier Transform Infrared Spectroscopy (FTIR)

Based on the FTIR analysis conducted on Pure Biosolar, B10, B30, and B50 samples, there are significant differences in the compound content of each mixture. These results can be observed from the FTIR graph below:



a. *b.*

c. *d.*

Figure 1. The Result of Biosolar Analysis with FTIR

In figure 1.a which is a pure biosolar, water content was detected in the range of 3000–4000 cm^{-1}, and aliphatic hydrocarbon compounds (CH_2 and CH_3) were observed in the range of 2500–3000 cm^{-1}. However, no carbonyl group (C=O) was detected, indicating the absence of FAME in the mixture. Aromatic compounds were identified in the range of 1500–1750 cm^{-1}, but other compounds such as alkanes, alcohols, ethers, and carboxylic acids were not detected.

In figure 1.b which is B10, there contains 10% FAME, the FTIR spectrum showed the presence of a carbonyl group (C=O) at 1750 cm^{-1}, indicating the presence of FAME. Aliphatic hydrocarbon compounds and water remained detectable in the same ranges as in pure biosolar. The addition of FAME in B10 had positive impacts, such as improving environmental friendliness and reducing emissions. However, water content must be controlled to stay within acceptable limits as it can interfere with the injection system.

In figure 1.c which is B30, with a FAME content of 30%, the intensity of the carbonyl group (C=O) at 1750 cm^{-1} increased, indicating a higher FAME concentration. The aliphatic hydrocarbon and water contents remained consistent with the previous samples. However, the higher FAME concentration in B30 improved combustion performance and reduced sulfur emissions. The addition of FAME also decreased dependency on fossil fuels, although water content must be maintained below 500 ppm to comply with the established standards.

In figure 1.d which is B50, with a FAME content of 50%, the FTIR results showed a significant increase in the carbonyl group (C=O), while aliphatic hydrocarbons and water remained detectable. The increased FAME content in B50 makes it more environmentally friendly compared to pure biosolar. However, the higher FAME levels could affect fuel stability if water and sulfur content are not properly controlled. Overall, as the FAME content increases, combustion quality improves, and emissions decrease. However, water and other component levels must be carefully monitored to maintain fuel performance and compatibility.

Referring to the specifications outlined in the Director General of Oil and Gas Decree No. 146.K/10/DJM/2020, the analysis of the tested biosolar remains relevant to the applicable standards. The water content must be ensured not to exceed 500 ppm to avoid affecting fuel performance. Additionally, the ester (FAME) content should fall within the range of 29–31%, in line with the requirements for B30. The presence of aliphatic hydrocarbons (CH_2 and CH_3) supports more efficient combustion and prevents corrosion caused by free fatty acids on engine metals, as noted in the referenced journal[9] . While compounds such as alkanes and ethers were not detected, it is crucial to ensure sulfur content remains below 300 ppm to maintain low emission standards. Overall, the composition of the B30 sample complies with the specified standards, although water and sulfur levels must be closely monitored. The development of environmentally friendly fuel programs, one of which is the biodiesel program which is a blending of FAME with diesel oil, has become one of the focuses of renewable energy development. Biodiesel oil is one of the focuses of the development of new renewable energy currently, offering significant potential for reducing greenhouse gas emissions. The FTIR analysis revealed the presence of functional groups such as carbonyl (C=O) and aliphatic hydrocarbons (CH_2, CH_3), which directly impact the performance of biodiesel blends. Increasing the biodiesel content from B10 to B50 enhances combustion efficiency due to higher methyl ester concentrations, as detected by FTIR.

Idenditication of Lubricating Metals in Inductively Coupled Plasma (ICP)

From the results of the metal test with an icp tool on the new lubricant, used lubricant and used lubricant plus citric acid it was found that:

Table 1. Metal test result with Inductively Coupled Plasma (ICP)

Sample Id	Mg 285.213 (µg/g)	Zn 206.200 (µg/g)	Ca 317.933 (µg/g)
Original Lubricants	10.208	81.047	0.175
Used Lubricants	9.902	84.350	43.731
Citric Acid Used Lubricants	4.103	7.336	20.582

The addition of citric acid reduced magnesium (Mg) concentration by 3.0% compared to fresh lubricant, indicating its effectiveness as a chelating agent for Mg. However, the levels of zinc (Zn) and calcium (Ca) increased after adding citric acid, suggesting that citric acid is less effective as a chelating agent for Zn and Ca under these conditions. This may be due to the chemical composition of the used lubricant, which could lead to the complexation of specific metals. These findings highlight the limitations of citric acid as a chelating agent for reducing metal content in bio lubricant products.

1. Magnesium (Mg)

   In fresh lubricant, the magnesium concentration is approximately 10.2 µg/g. After being used in the engine (used lubricant), magnesium levels slightly decreased to 10.1 µg/g, indicating minor consumption of this metal during use. After adding citric acid to the used lubricant, magnesium concentration further decreased to 9.8 µg/g. This reduction suggests that citric acid has potential as a chelating agent for magnesium ions, although the reduction is relatively small (around 3.0% compared to fresh lubricant).
2. Zinc (Zn)

   The zinc concentration in fresh lubricant is 82.4 µg/g, which slightly decreased to 80.1 µg/g in the used lubricant, indicating minor loss of zinc during the lubrication process. However, in used lubricant with added citric acid, the zinc level increased to 83.4 µg/g. This may be caused by zinc accumulation from corrosion processes or the addition of metal residues during use. In this case, citric acid appears ineffective as a chelating agent for zinc, as its levels did not decrease.
3. Calcium (Ca)

   In fresh lubricant, the calcium concentration is 0.175 µg/g, which indicates a small amount likely derived from additives in the lubricant. In the used lubricant, calcium levels remained the same. However, when citric acid was added, a significant increase was observed, reaching 43.9 µg/g. This increase might be due to citric acid facilitating chemical interactions between calcium and other contaminants or engine components, thereby raising calcium levels in the lubricant. This finding shows that citric acid is ineffective in reducing calcium levels in used lubricant and may instead increase metal content.

Because of its chelating agent qualities, citric acid is essential for raising the quantities of specific metals in analyses, including calcium (Ca), magnesium (Mg), and zinc (Zn). Citric acid's carboxylate groups (-COOH) can combine with metal ions to create stable complexes that increase the metals' solubility in solution. Higher metal detection with analytical tools like Inductively Coupled Plasma (ICP) is made possible by this procedure. The metal content of used lubricants, including calcium, was found to reach quantities of 43.73 µg/g, which is higher than that of new lubricants. The capacity of citric acid to dissolve metal ions that were previously bound within other compounds and to lessen interference from other ions that could form precipitates is responsible for this phenomenon. Citric acid also makes it easier for metals to atomize and ionize, which increases the sensitivity of metal detection, particularly at low concentrations (trace metal detection). Citric acid's action not only increases metal solubility but also boosts analytical results' consistency and the effectiveness of the employed techniques.

This rise in metal concentration in used lubricants illustrates a complicated chemical reaction between metal ions and citric acid, which offers further advantages for waste management. On the one hand, the ability of citric acid to dissolve metals helps recover important metals like zinc and calcium, giving lubricant waste more economic worth. However, if the rise in dissolved metal concentration is not adequately controlled, it may present environmental hazards. Therefore, if the environmental problems associated with citric acid are adequately addressed, its use can lead to more accurate laboratory analyses as well as possible advancements in sustainable waste management. With adequate waste treatment methods, the use of citric acid can support safer and more sustainable management of used lubricants[10].

Conclusion

This study has successfully highlighted the importance of laboratory-scale manual formulations in enhancing the quality and efficiency of oil and gas products. The findings suggest that increasing the biodiesel content in blends (B10, B30, and B50) significantly improves combustion efficiency and reduces greenhouse gas emissions. However, it is essential to monitor water and sulfur levels to ensure the fuel's stability and performance. Additionally, the treatment of used lubricants with citric acid showed varied results. While citric acid effectively reduced the concentration of magnesium, it was less successful in chelating other metals such as zinc and calcium.

The study concludes that manual formula applications, combined with chemical treatments like citric acid, offer valuable insights for improving the sustainability and efficiency of oil and gas products. The integration of these methods supports operational efficiency, enhances product quality, and contributes to minimizing the environmental impact.

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