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# Integrated Pretreatment of B40 Biodiesel in Steam Power Plants: Operational Mitigation, K3L Implementation, and Professional Ethics

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**Abstract**

*The implementation of a 40% biodiesel blend (B40) in steam power plants presents operational challenges associated with fuel viscosity, hygroscopicity, oxidation stability, and particulate contamination. This study evaluates an integrated pretreatment approach combining additive treatment, ceramic membrane separation, and thermal conditioning to improve B40 fuel quality and mitigate potential operational risks in power generation systems. Experimental tests were conducted by varying the 2-Ethylhexyl nitrate (2-EHN) additive concentration at 200–1100 ppm, applying ceramic membrane filtration with a 0.01 µm pore size at 1–2 bar, and heating B40 to 40–50°C. Fuel quality was evaluated based on viscosity, cetane number, TFr, and particulate concentration, while combustion-related emissions were assessed using a 9-hp diesel engine. The results showed that heating B40 to 50°C reduced viscosity from 4.6 to 3.6 mPa·s, indicating improved fuel-flow characteristics. Additive treatment also substantially reduced measured particulate concentrations, with reductions of 77%, 87%, and 95% for particles ≥4, ≥6, and ≥14 µm, respectively, at 1000 ppm. The cetane number showed a favorable response at selected additive concentrations, particularly within the 400–900 ppm range. Combined additive treatment and thermal conditioning produced improvements in several fuel-quality parameters. At 100% engine load, CO emissions were approximately 250–270 mg/m³, while NOx decreased from approximately 740 to 510 mg/m³ under the tested conditions. From a K3L perspective, the integrated treatment requires controls for chemical handling, pressurized filtration, fuel heating, leakage, fire hazards, and waste management. Overall, the findings indicate that integrated pretreatment has potential to mitigate key B40 operational challenges, although further validation under actual PLTU operating conditions is required.*



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**Keywords: B40 biodiesel; integrated pretreatment; 2-EHN; ceramic membrane; thermal conditioning; K3L; steam power plant**

## INTRODUCTION

Indonesia is pursuing an energy transition that aims to reduce dependence on fossil fuels while increasing the utilization of renewable energy sources. In accordance with Presidential Regulation No. 112 of 2022, Indonesia targets a renewable energy share of 23% in the national energy mix by 2025 and Net Zero Emission (NZE) by 2060 (Peraturan Presiden Republik Indonesia, 2022). This transition is also reflected in the national biodiesel blending policy. Through Decree of the Minister of Energy and Mineral Resources No. 341.K/EK.01/MEM.E/2024, the Indonesian government established a 40% biodiesel blend (B40) in diesel fuel beginning January 1, 2025 (Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, 2024). The policy is intended to strengthen domestic renewable fuel utilization, reduce dependence on petroleum-based diesel, and support national energy security and sustainability.

The increasing biodiesel content in diesel blends, however, introduces changes in fuel physicochemical properties that need to be considered in power generation applications. Biodiesel consists predominantly of fatty acid methyl esters (FAME), whose molecular composition affects properties such as density, viscosity, surface tension, oxidative stability, and combustion characteristics. Higher biodiesel fractions generally result in higher viscosity and density than conventional diesel, which can influence fuel atomization, injection, and combustion performance (Mishra et al., 2021). In a B40 blend, these characteristics become particularly important because the higher FAME content may influence fuel handling and combustion conditions compared with conventional diesel. Experimental studies of biodiesel blends have also reported changes in fuel consumption, engine performance, and emissions as the biodiesel fraction increases (Nghia et al., 2022).

These fuel characteristics are relevant to Steam Power Plants (PLTU), particularly during startup operations in which liquid fuel is commonly used to initiate boiler combustion before the main firing system reaches stable operating conditions. Variations in viscosity, water content, oxidative stability, and fuel cleanliness can affect fuel transfer, atomization, ignition, and combustion stability. Biodiesel is also susceptible to degradation during storage and handling. Research has shown that biodiesel blend stability is affected by biodiesel concentration, storage temperature, humidity, storage duration, and fuel composition (Do Amaral et al., 2020). Furthermore, water contamination can accelerate the loss of storage stability by affecting



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antioxidant performance, while biodiesel oxidation may produce acids and gums that negatively influence fuel performance and equipment durability (Christensen & McCormick, 2023; Masudi et al., 2023).

The presence of water and contaminants is particularly important from an operational and equipment-integrity perspective. Biodiesel storage systems may experience degradation and corrosion because of interactions among fuel properties, water, and metallic materials. A study of palm-based biodiesel storage tanks demonstrated that biodiesel exposure can result in different corrosion behaviors in galvanized steel, carbon steel, and stainless steel, with the potential for localized or generalized corrosion depending on the material and storage conditions (Al-Mulla et al., 2023). In addition, microbiologically influenced corrosion has been identified as a potential concern in diesel blend storage systems, particularly at the fuel–water interface (2024). These conditions indicate that the implementation of B40 cannot be considered solely as a fuel-substitution issue but must also address fuel quality, storage, handling, equipment reliability, and operational safety.

One approach to address these challenges is the implementation of an integrated pretreatment system before B40 is introduced into the fuel delivery and combustion system. Pretreatment can be designed to control critical fuel-quality parameters through a combination of filtration, water removal, contaminant separation, membrane-based purification, thermal conditioning, and, where necessary, the application of suitable fuel additives. The purpose of an integrated approach is not merely to improve a single fuel property but to simultaneously reduce contaminants and conditions that may contribute to clogging, deposit formation, degradation, unstable combustion, and equipment deterioration.

Among the available technologies, membrane-based separation has attracted attention as an alternative to conventional biodiesel purification because it can reduce the use of water and potentially lower energy consumption and wastewater generation. Moreira et al. (2020) demonstrated the application of ceramic membrane technology for biodiesel purification and highlighted its potential to overcome limitations associated with conventional separation processes. Similarly, Ostojčić et al. (2020) reported that membrane filtration can be used as an environmentally friendly approach for reducing contaminants such as glycerol, methanol, and water in crude biodiesel. These findings support the integration of membrane separation into a broader pretreatment strategy, particularly where fuel quality and environmental performance need to be considered simultaneously.

Nevertheless, technical pretreatment alone is insufficient to ensure safe and sustainable


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implementation of B40 in power plant operations. The pretreatment process involves fuel transfer, filtration, heating, chemical or additive handling, pressure-containing equipment, waste management, and maintenance activities, each of which may introduce occupational, environmental, and process-safety risks. Therefore, the design and implementation of integrated pretreatment should incorporate Keselamatan, Kesehatan Kerja, dan Lingkungan (K3L) principles. K3L considerations include hazard identification, risk assessment, appropriate personal protective equipment, control of fuel leakage and spills, safe handling and storage, fire prevention, waste management, environmental protection, and emergency preparedness. The integration of K3L into operation and maintenance activities is consistent with the broader engineering principle that technical decisions should account for safety, health, and environmental consequences rather than focusing exclusively on operational performance.

In addition to K3L, professional ethics provides an important framework for decision-making in the implementation of B40 pretreatment systems. Engineers and technical personnel are responsible not only for achieving operational targets but also for ensuring that decisions prioritize safety, environmental protection, professional integrity, and accountability. Wulandari et al. (2023) demonstrated that the implementation of professional ethics and K3L can be integrated into operation and maintenance activities, while Handika et al. (2024) emphasized that engineering codes of ethics support integrity, professionalism, and responsible decision-making in engineering practice. Consequently, the selection and operation of a B40 pretreatment system should be based on transparent technical considerations, accurate reporting of risks and fuel-quality conditions, compliance with applicable standards and procedures, and prioritization of public, worker, and environmental safety.

Based on these considerations, an integrated approach is required to mitigate the operational impacts associated with B40 biodiesel in Steam Power Plants. Existing studies have extensively discussed biodiesel fuel properties, storage stability, purification technologies, and equipment-related concerns; however, these aspects are often addressed separately. A more comprehensive approach is needed to connect fuel pretreatment with operational reliability, K3L risk control, environmental considerations, and professional ethical responsibilities. Therefore, this paper proposes an integrated pretreatment approach for mitigating the operational impacts of B40 biodiesel in Steam Power Plants by combining fuel-quality control measures with K3L implementation and professional ethics. The discussion focuses on how pretreatment stages can be designed and implemented to improve fuel quality, minimize operational risks, protect equipment and personnel, reduce environmental impacts, and support responsible engineering


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practice in the transition toward higher biodiesel utilization.

## RESEARCH METHODOLOGY

### Integrated Pretreatment Approach

This study employed an integrated pretreatment approach to evaluate the effectiveness of additive treatment, ceramic membrane filtration, and thermal conditioning in improving the quality of B40 biodiesel prior to its utilization in Steam Power Plant (PLTU) startup operations. The pretreatment stages were designed to address several fuel-quality parameters that may influence fuel handling, atomization, combustion performance, and equipment reliability, particularly cetane number, viscosity, total contamination/fuel residue (TFr), and particulate content.

The experimental design consisted of three principal pretreatment treatments: (1) additive treatment, (2) ceramic membrane filtration, and (3) thermal conditioning. The treatments were also evaluated in combination to determine whether the sequential application of pretreatment technologies provided greater improvement than individual treatment. This integrated configuration is consistent with the principle that biodiesel quality is influenced by multiple physicochemical properties and contaminants rather than by a single parameter (Mishra et al., 2021; Masudi et al., 2023).

### Additive Treatment

The additive treatment was conducted by varying the additive concentration added to the B40 fuel. Six additive dosages were evaluated, namely 200, 300, 400, 900, 1000, and 1100 ppm. The selected dosage variations were intended to identify the concentration that provides the most favorable improvement in fuel quality without introducing excessive additive content.

For each dosage, the B40 samples were subjected to repeated measurements during the initial evaluation period. Testing of cetane number, TFr, and viscosity was conducted for three consecutive days and continued during the first week of observation. The repeated measurements were intended to evaluate both the immediate response and short-term stability of the treated B40 fuel.

The selection of these parameters was based on their relevance to fuel performance. Viscosity affects fuel flow and atomization, while cetane number is associated with ignition quality. Contamination and degradation products may also influence fuel-system cleanliness and operational reliability. The use of additives as a fuel-quality improvement strategy has been widely investigated, particularly for improving fuel stability, combustion characteristics, and low-


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temperature properties (Rashedul et al., 2014; Masudi et al., 2023).

**Ceramic Membrane Filtration**

Ceramic membrane filtration was applied as a physical pretreatment to reduce particulate contaminants in B40 fuel. A ceramic membrane with a nominal pore size of 0.01 µm and a flux capacity of approximately 1,200 L/h was used. The membrane system consisted of a 15-L chamber connected to a pumping system.

The B40 sample was introduced into the membrane chamber and circulated through the ceramic membrane at a pressure of approximately 1–2 bar. The filtration process was conducted under controlled operating conditions to maintain consistency among samples.

The performance of the membrane treatment was evaluated based on changes in cetane number, TFr, and suspended particulate concentration. In addition to untreated B40, membrane filtration was also performed on B40 samples that had previously received additive treatment at the selected concentrations. This configuration was used to determine whether membrane filtration provided an additional improvement in fuel quality following additive treatment.

Membrane-based purification has been reported as a potential alternative to conventional biodiesel purification because it can reduce contaminants while potentially minimizing water consumption and wastewater generation. Ceramic membranes are particularly relevant because of their mechanical and chemical stability under appropriate operating conditions (Moreira et al., 2020; Ostojčić et al., 2020).

**Thermal Conditioning**

Thermal conditioning was subsequently applied to evaluate the effect of controlled heating on the physical properties of B40. The B40 sample was placed in a storage chamber and transferred using a pump to a heating tube. The fuel was heated to a controlled temperature range of 40–50°C before being directed to the fuel supply/injection system for subsequent quality evaluation.


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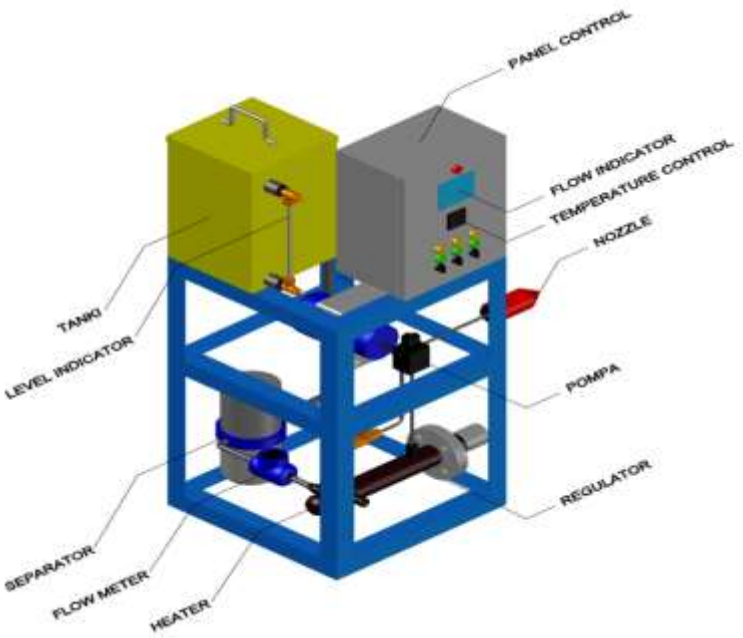



Figure 1. B40 testing apparatus with heating process

Thermal treatment was performed on both untreated B40 and B40 samples that had previously received additive treatment. The additive concentrations evaluated in the thermal-conditioning stage corresponded to the concentrations used in the additive-treatment experiment: 200, 300, 400, 900, 1000, and 1100 ppm.

Following thermal conditioning, the samples were analyzed for viscosity, TFr, and cetane number. Additional measurements of microscopic and suspended particulate content were conducted to evaluate whether heating affected the physical quality and cleanliness of the treated B40.

The use of controlled heating was considered particularly relevant because biodiesel viscosity is generally higher than that of conventional diesel and can influence fuel flow and atomization. Thermal conditioning can therefore be considered a complementary treatment for improving fuel handling characteristics, particularly when the fuel is required to pass through pumps, filters, and injection systems (Mishra et al., 2021).

**Integrated Pretreatment Sequence**

The results from the individual treatments were subsequently compared to establish the most effective integrated pretreatment configuration. The proposed treatment sequence was:

B40 → Additive Treatment → Ceramic Membrane Filtration → Thermal Conditioning →



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Quality Testing

The sequence was designed to combine different mechanisms of fuel conditioning. Additives were used to modify selected fuel properties, membrane filtration was used to reduce particulate and suspended contaminants, and thermal conditioning was applied to improve fuel-flow characteristics through controlled reduction of viscosity.

The effectiveness of the integrated pretreatment was evaluated by comparing the measured fuel-quality parameters before and after treatment. The principal evaluation parameters were cetane number, viscosity, TFr, and particulate concentration. The treatment producing the most favorable overall fuel-quality profile was identified as the preferred pretreatment configuration.

**K3L Implementation**

The implementation of the integrated pretreatment system was also evaluated from the perspective of Keselamatan, Kesehatan Kerja, dan Lingkungan (K3L). Each treatment stage involves potential hazards associated with fuel handling, pressurized flow, heating, chemical/additive exposure, leakage, fire, and waste generation. Therefore, hazard identification and risk control were incorporated into the experimental procedure.

For additive treatment, appropriate personal protective equipment (PPE), controlled chemical handling, proper labeling, and prevention of spills were applied. For membrane filtration, attention was given to pump pressure, hose and chamber integrity, leakage prevention, and safe depressurization before maintenance. During thermal conditioning, temperature control, insulation of hot surfaces, prevention of fuel leakage, and fire-risk control were considered.

Environmental aspects were addressed through proper management of residual B40, used filtration materials, additive residues, and other waste generated during the experiment. These measures were intended to ensure that improvement in fuel quality did not compromise worker safety or environmental protection. The integration of K3L into technical operations is consistent with the broader principle that engineering processes should consider safety, health, and environmental consequences as part of operational decision-making (Wulandari et al., 2023).

**Professional Ethics**

Professional ethics was incorporated into the experimental and implementation framework to ensure that technical decisions were based on accurate measurements, transparency, accountability, and compliance with applicable procedures and standards. All



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experimental results were recorded according to the actual measurement conditions, including additive concentration, membrane pressure, heating temperature, and treatment sequence.

The selection of the recommended pretreatment configuration was based on measurable fuel-quality improvements rather than solely on operational assumptions. Potential limitations, risks, and adverse effects of each treatment were also considered before determining the preferred configuration.

This approach reflects the responsibility of engineering professionals to prioritize safety, environmental protection, technical integrity, and accountability when making decisions that may affect equipment, workers, and the wider environment. The integration of professional ethics into engineering practice is therefore considered complementary to K3L implementation in the application of B40 pretreatment technology (Handika et al., 2024).

**Data Evaluation**

The performance of each pretreatment was evaluated by comparing the measured values of cetane number, viscosity, TFr, and particulate concentration between untreated and treated B40 samples. The results were assessed based on the direction and magnitude of changes in each parameter.

For the additive treatment, the comparison was performed across the six additive concentrations. For membrane treatment, untreated B40 was compared with membrane-treated B40 and B40 that underwent combined additive–membrane treatment. For thermal conditioning, untreated and additive-treated B40 samples were compared before and after heating at 40–50°C.

The final evaluation considered both technical effectiveness and implementation feasibility. Therefore, the preferred pretreatment configuration was determined not only by its ability to improve fuel-quality parameters but also by its operational safety, environmental considerations, and compliance with professional responsibilities.

**RESEARCH RESULTS**

**Characteristics of B40 Tar and Potential Operational Impacts**

The EDX analysis of B40 tar identified several inorganic compounds that may contribute to the formation and persistence of deposits. Among the detected compounds, $SiO_2$ had the highest concentration at 6.95 mass%, followed by $Fe_2O_3$ at 4.82 mass%, $Al_2O_3$ at 3.44 mass%, $SO_3$ at 1.75 mass%, CaO at 3.00 mass%, and MgO at 0.641 mass%. These findings indicate that the combustion residue contains both mineral and metal-derived components that may contribute to the physical


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characteristics of the deposited material.

$SiO_2$ may contribute to the formation of a rigid or glassy inorganic fraction in the residue, while $Al_2O_3$ and other inorganic compounds can contribute to the physical persistence of deposits. The presence of $Fe_2O_3$ is also relevant because metallic species can participate in fuel oxidation and deposit-forming processes. Previous studies have shown that biodiesel oxidation can increase fuel viscosity and promote the formation of deposits, while metal contamination and thermal exposure can influence oxidation pathways (Longanesi et al., 2022). Biodiesel-related deposits can subsequently affect fuel-injection characteristics and combustion performance (Hidayat & Sugiarto, 2020).

Therefore, the EDX results provide an important indication that the operational impact of B40 should not be evaluated solely through bulk fuel properties such as viscosity and cetane number. Deposit-forming contaminants also need to be considered because accumulation in fuel-system and combustion components may reduce operational reliability.

Table 1. Main Compounds Forming Sticky Structure on B40

| No. | Compound | Content (mass%) | Potential Role |
|---|---|---|---|
| 1 | SiO2 | 6.95 | Main former of the glass phase, supporting the viscoelastic amorphous structure |
| 2 | Al2O3 | 3.44 | Viscosity enhancer, increasing the thickness of the residue |
| 3 | Fe2O3 | 4.82 | Oxidation catalyst, accelerating the formation of a sticky carbon or tar film |
| 4 | SO3 | 1.75 | Reactant in the formation of sticky sulfate esters |
| 5 | CaO, MgO | 3.00, 0.641 | Calcium/magnesium soap forming agent from residual FAME (biodiesel fat), which can become a semi-solid layer |

The presence of these compounds strengthens the rationale for pretreatment. In particular, particulate and suspended contaminants should be controlled before B40 enters the fuel supply and combustion system. This is consistent with the role of filtration and purification as preventive measures for reducing contaminants that may contribute to deposits and fuel-system problems (Ostojčić et al., 2020; Moreira et al., 2020).


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**Effect of Additive Addition**

The additive treatment produced different viscosity responses depending on additive concentration and temperature. At room temperature, the addition of the additive resulted in an increase in B40 viscosity after three days of observation. The increase tended to become more pronounced as the additive dosage increased. However, the viscosity values at 200 and 1100 ppm were relatively similar, indicating that increasing the additive concentration did not produce a proportional change in viscosity across the tested range.

When the B40 samples were heated to 40°C, the viscosity response changed. The sample treated with 900 ppm exhibited relatively stable viscosity compared with the samples treated with 300 and 1000 ppm, which showed greater increases. This result indicates that the effect of additive dosage cannot be evaluated independently of temperature.

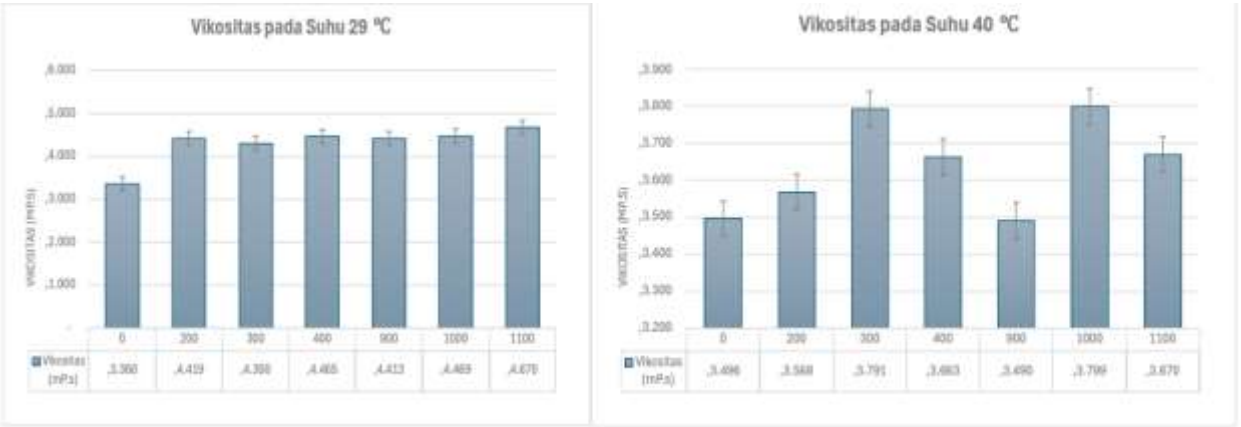



Figure 2. Effect of Additive Dose on Viscosity

The observed temperature dependence is consistent with the general relationship between biodiesel composition, temperature, and viscosity. Biodiesel viscosity is strongly influenced by FAME composition and temperature, with temperature changes producing substantial changes in fuel viscosity (Huang et al., 2020). Consequently, the additive treatment should not be considered solely as a means of reducing viscosity. Rather, its effectiveness needs to be evaluated together with the thermal-conditioning stage.

From an operational perspective, this finding supports the integrated pretreatment concept. Additive treatment may improve selected fuel characteristics, but excessive or unsuitable dosage may not necessarily result in better fuel properties. Therefore, the optimum dosage should be determined from a combination of fuel-quality parameters rather than from a


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single measurement.

**Effect of Additive Treatment on Particulate Content**

The addition of the additive produced a substantial reduction in measured particulate concentration. The initial B40 sample contained 28,666 counts/mL for particles ≥4 µm, 26,531 counts/mL for particles ≥6 µm, and 15,860 counts/mL for particles ≥14 µm.

After the addition of 1000 ppm additive, the corresponding particle concentrations decreased to 6,562, 3,550, and 801 counts/mL, respectively. These changes correspond to reductions of 77%, 87%, and 95%.

Table 2. Particulate Testing of B40 dose 1000 ppm

| Particle Size (um) | B40 Particle | With Additive (1000 ppm) | Reduction | % Reduction |
|---|---|---|---|---|
| >= 4 | 28666 | 6562 | 22104 | 77% |
| >= 6 | 26531 | 3550 | 22981 | 87% |
| >= 14 | 15860 | 801 | 15059 | 95% |

The largest reduction occurred in particles ≥14 µm, reaching 95%. This result demonstrates that the additive treatment was associated with a substantial reduction in the measured particulate concentration under the experimental conditions.

However, the mechanism responsible for this reduction should be interpreted cautiously. The present data demonstrate the change in particle counts but do not independently establish whether the additive chemically removed particles, promoted particle agglomeration, altered particle dispersion, or influenced the measurement characteristics of the fuel. Therefore, further particle characterization would be required to establish the dominant mechanism.

The result is nevertheless important for operational mitigation because particulate contamination is directly relevant to fuel-system cleanliness. Deposit formation and particulate-related contamination can affect injector and fuel-system performance, particularly when deposits alter fuel flow and spray characteristics (Hidayat & Sugiarto, 2020).

**Effect of Additives on Cetane Number**

2-Ethylhexyl nitrate with a concentration above 50% has an impact on increasing the cetane number value of the B40 content. Doses above 900 ppm have a significant impact on



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changes in cetane and TFr numbers. The addition of additives at concentrations of 400 ppm and 900 ppm provides the best results with the highest cetane numbers.

The significant increase in the cetane number in B40 with the addition of additives of 400 to 900 ppm is caused by several chemical factors that synergize with each other. One of the main factors is the occurrence of isomerization to the cis form, such as in methyl oleate compounds. The cis isomer has double bonds that are more reactive to initial oxidation, thereby shortening the ignition delay. In addition, the increase in saturated methyl ester content, such as methyl palmitate and methyl stearate, also improves combustion characteristics because these saturated compounds are easier to burn and produce smoother and more stable combustion.

Conversely, the addition of additives at a concentration of 300 ppm actually shows a decrease in the cetane number. This happens because the additive level is too high and not balanced with other fuel compositions, especially when the dominance of methyl ricinoleate compounds becomes too large. In this condition, heavy compounds and trans isomers such as methyl elaidate also appear, which have a more stable structure but are less reactive in initial combustion. Trans isomers tend to prolong ignition delay, thus harming combustion performance.

The addition of additives in excessive amounts, specifically exceeding 1000 ppm, causes the opposite effect on the cetane number. Additive overformulation causes chemical imbalance in the fuel and triggers the accumulation of heavy compounds, especially long alkanes with a number of carbon atoms of more than 30, which are difficult to burn. In addition, the increase in viscosity due to high additive concentrations disrupts the process of fuel spraying (atomization) in the combustion chamber, so that combustion becomes uneven and less efficient.

Table 3. Additive Dose on Cetane Number (CET) Impact

| Additive Dose | Chemical Impact | CET Impact |
|---|---|---|
| 400-900 ppm | Dominant cis isomer, optimal saturated FAME | High CET |
| 300 ppm | Dominant additive, increased trans isomer | Low CET |
| >1000 ppm | Heavy compounds appear, overformulation | CET drops back |

**Pretreatment with Heating**

Heating in B40 pretreatment can help increase the solubility of biodiesel with diesel, so



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that the mixture becomes more homogeneous. Heating can lower the viscosity of the B40 blend. From the results of the B40 heating process without additive treatment, it was found that there was a decrease in the viscosity number, where the initial B40 condition without heating had a value of 4.6 m.PA.s; after the heating process to 50 C the viscosity value decreased by 1 point to 3.6 m.PA.s which directs to the substantial diesel. The TFr value experienced an increase from the initial condition of -35.9 C to -4.6 C. The Cetane number value experienced an increase from 46 to 59.2 which indicates that there has been a reduction in particulates present in B40.

**Pretreatment with a Combination of Heating and Additive**

The combination of additives and heating on B40 fuel can provide several positive effects, such as improving engine performance, reducing exhaust emissions, and overcoming potential problems that may arise due to the use of biodiesel. From the experimental results of combining the two processes, it was found that there was an increase in TFr and Cetane number values, and suspended particles experienced a fairly significant decrease. The TFr value experienced a significant increase from the 200 ppm to 1000 ppm dose, but experienced a decrease at the 1100 ppm dose. The Cetane value in the combined pretreatment results produced a cetane number value that increased 2-4 times. With the combination process, an additive dose of 200-400 ppm can be used, but of course it needs to be studied regarding the energy requirement process in the heating process.

**Effect of Pre-treatment on Combustion Emissions**

Emission testing was conducted using B40 fuel without pretreatment and with pretreatment on a diesel engine with a capacity of 9 Hp. Testing is carried out in 3 gradual variations, namely with no load, 50 N loading, and 100 N loading.

At No Load O2 Levels, the highest O2 values appeared in all types of fuel, ranging from 18.0 to 18.4%. This reflects incomplete combustion, because at no load conditions where the formation of the air-fuel mixture is less than optimal, the combustion chamber temperature and pressure are low. When the O2 Level was at 100% Load, it was the lowest value in all conditions, which was around 15.3 to 15.6%. In the No Load process, the CO2 value was low, ranging from 1.9 to 2.0%. After the load was increased to 100% Load, CO2 reached its highest value: 4.0 to 5.1%, with an increasing trend when additives were added. At full load (100%), the addition of additives from 200 to 1000 ppm consistently increased CO2 levels, from around 4.2% to 5.1%. This indicates that additives support an increase in combustion efficiency.


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At No Load, the highest CO appeared in this condition, with pure B40 reaching almost 800 mg/m3. 100% Load produced the lowest CO achieved in all conditions, around 250 to 270 mg/m3, indicating the most perfect combustion. The addition of additives from 200 to 1000 ppm shows a gradual downward trend in CO, especially at 50% and 100% loads.

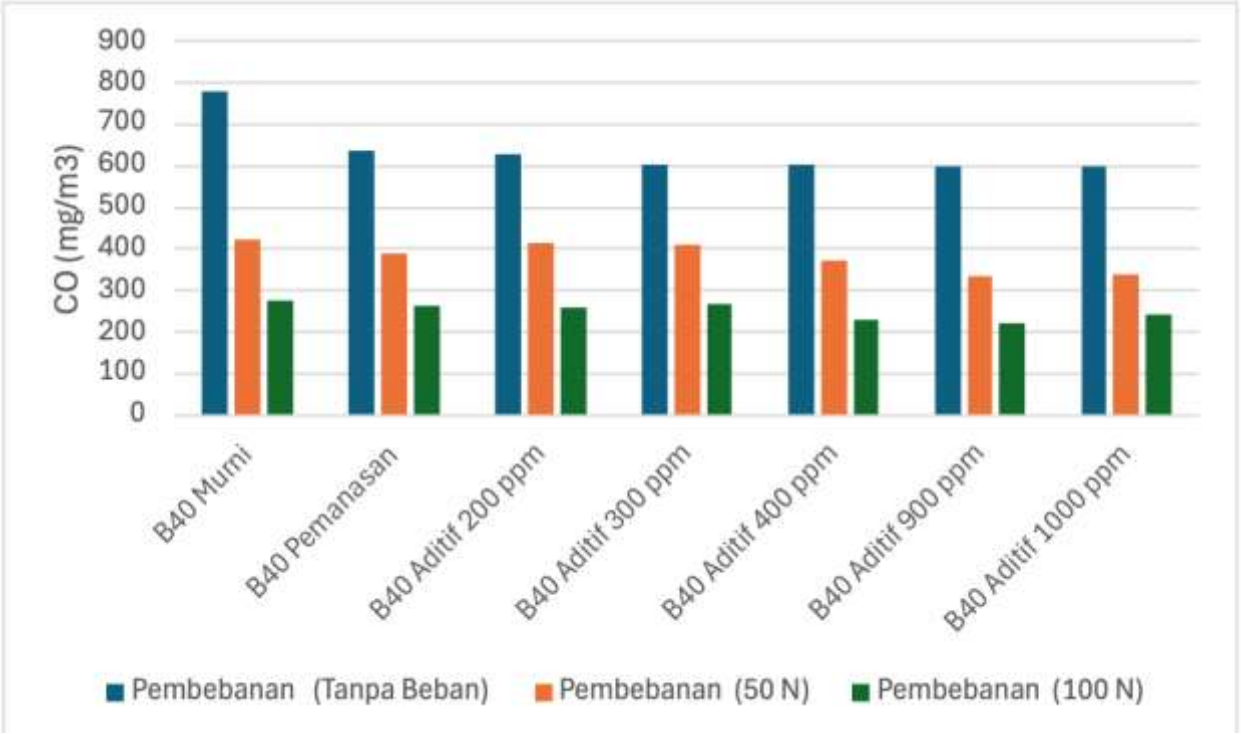



Figure 3. Effect of Additives on CO Value without load and with load

In the testing process without Load, NOx Emissions were the lowest, stable in the range of 160 to 170 mg/m3. At 100% Load, NOx Emissions were the highest, especially in pure B40 and heating (>740 mg/m3). This is a direct effect of the highest temperature and pressure in the combustion chamber. However, the addition of additives shows a downward trend in NOx emissions: From ~740 mg/m3 (without additives) to ~510 mg/m3 (1000 ppm additive).


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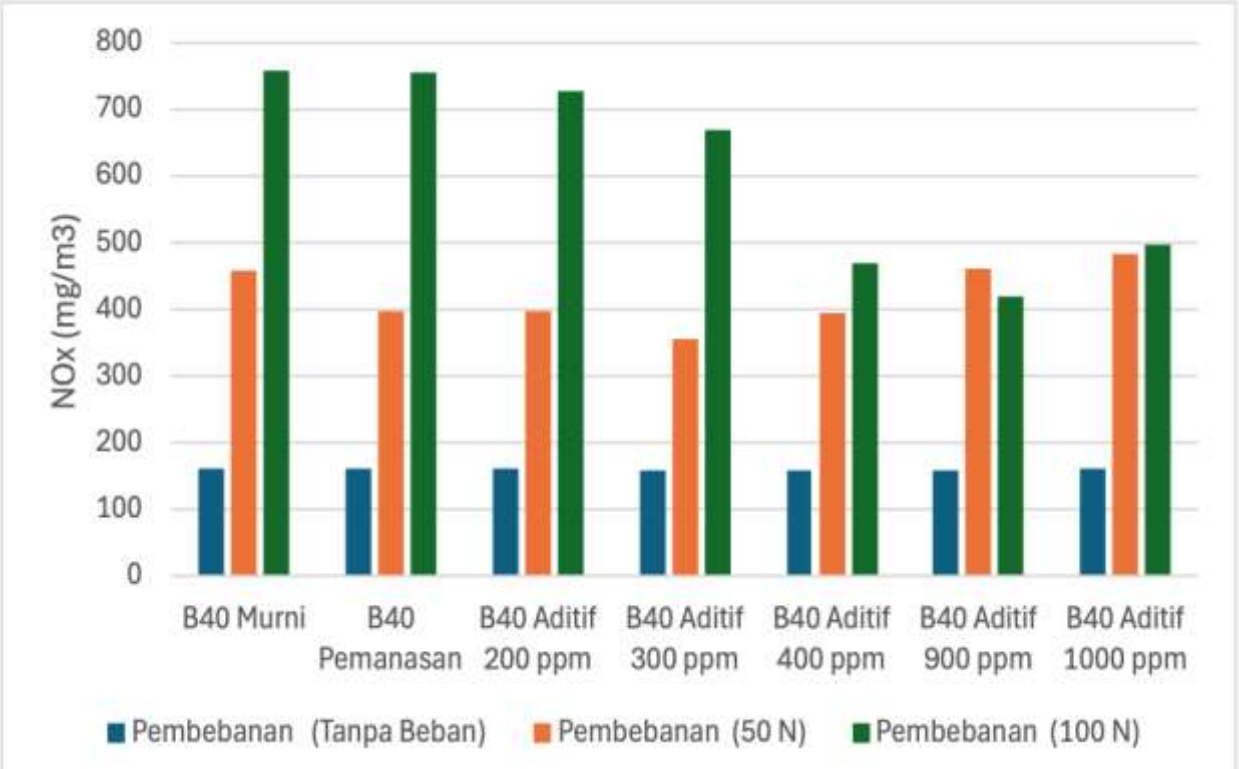



Figure 4. Effect of Additives on NOx Value without load and with load

**K3L and Professional Ethics Implications**

The technical findings also have implications for K3L implementation. The reduction of fuel viscosity through heating, for example, must be balanced against the hazards associated with heating combustible fuel. Similarly, additive treatment requires controlled chemical handling, while membrane filtration introduces pressure-related hazards and requires proper inspection of pumps, chambers, connections, and seals.

The selection of a pretreatment configuration should therefore not be based solely on the highest cetane number or lowest particulate concentration. The energy requirement of heating, chemical exposure associated with additives, pressure-related hazards, waste generated by filtration, and potential fuel leakage must also be considered.

This consideration is particularly relevant because biodiesel storage and handling can involve material-compatibility and corrosion issues. Studies of palm-based biodiesel storage systems have demonstrated that different tank materials can exhibit different corrosion behavior during biodiesel exposure (Komariah et al., 2023). Water contamination can also affect biodiesel



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storage stability and the performance of antioxidant systems (Christensen & McCormick, 2023).

From a professional-ethics perspective, the recommended treatment should therefore be based on transparent experimental evidence rather than selecting a treatment simply because it produces the largest numerical improvement. Measurement results, limitations, uncertainty, and potential operational risks should be reported accurately. Engineering decisions should prioritize worker safety, environmental protection, equipment integrity, and long-term reliability alongside technical performance.

Accordingly, the integrated pretreatment concept can be represented as:

B40 → Additive Conditioning → Physical Filtration → Thermal Conditioning → Quality Verification → Safe and Responsible Application

This framework links the technical objective of improving B40 quality with the broader objectives of K3L and professional engineering responsibility.

**Implications for Steam Power Plant Application**

Although the emission experiment was conducted on a 9-hp diesel engine rather than a commercial-scale PLTU, the results provide preliminary evidence regarding the potential of pretreatment to modify fuel quality and combustion behavior. Direct extrapolation to PLTU operation should therefore be avoided.

For PLTU startup applications, the most relevant findings are the reduction in viscosity following heating, the improvement in cetane number at selected additive concentrations, and the reduction in particulate concentration following additive treatment. These changes may potentially improve fuel handling, ignition, and cleanliness of the fuel-delivery system.

However, before implementation at plant scale, further validation is required under actual PLTU operating conditions. The validation should include long-duration fuel-storage tests, injector and burner inspection, filter differential pressure, fuel-system compatibility, particulate accumulation, emissions, energy consumption of the heating system, and operational safety.

Therefore, the present results should be interpreted as a basis for developing an integrated B40 pretreatment strategy rather than as definitive evidence that the proposed treatment is already optimized for commercial PLTU operation.

## CONCLUSION

The implementation of B40 as part of Indonesia's energy-transition strategy provides an opportunity to reduce dependence on fossil-based diesel while supporting renewable energy



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utilization. However, the higher biodiesel content introduces fuel-quality and operational considerations, particularly related to viscosity, particulate contamination, ignition quality, and fuel stability. The experimental results indicate that these characteristics require appropriate pretreatment before B40 is applied to fuel systems associated with Steam Power Plant (PLTU) operations.

The results demonstrate that an integrated pretreatment approach combining additive treatment, ceramic membrane filtration, and thermal conditioning can improve several key B40 fuel-quality parameters. Additive treatment at selected concentrations reduced measured particulate concentrations and improved the cetane number, while thermal conditioning at 50°C reduced viscosity from 4.6 to 3.6 mPa·s. The combination of additive treatment and heating also produced favorable changes in cetane number, TFr, and suspended particulate content. These findings indicate that the treatments can complement one another by addressing different fuel-quality characteristics rather than relying on a single pretreatment method.

The findings also demonstrate that pretreatment optimization should consider operational and environmental factors in addition to fuel-quality improvement. Higher additive concentrations did not consistently provide better results, while thermal conditioning introduces additional energy requirements and safety considerations. Therefore, the most appropriate pretreatment configuration should be selected based on the balance between fuel-quality improvement, energy consumption, equipment reliability, and operational feasibility.

From a K3L perspective, the implementation of B40 pretreatment requires appropriate controls for chemical handling, pressurized filtration, fuel heating, leakage, fire hazards, and management of fuel and filtration waste. Professional ethics should likewise be integrated into technical decision-making through accurate measurement, transparent reporting, compliance with applicable procedures and standards, and responsible consideration of worker and environmental safety. Thus, the implementation of integrated pretreatment should be regarded not only as a technical solution for improving B40 fuel quality but also as part of responsible and safe engineering practice.

Overall, the study indicates that integrated pretreatment has potential to mitigate several operational challenges associated with B40 utilization. However, because the combustion-emission evaluation was conducted using a 9-hp diesel engine rather than a full-scale PLTU, the results should be considered preliminary for power-plant application. Further research under actual PLTU operating conditions is required to validate long-term fuel stability, burner and injector performance, particulate accumulation, emissions, energy requirements, and K3L


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performance before large-scale implementation.

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