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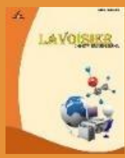

# Evaluation Of The Performance Of Fatty Acid Methyl Ester (Fame) As An Alternative Solvent In Alkyd Resin-Based Paints

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**Abstract**

The use of conventional solvents in the oil paint industry often causes emissions of volatile organic compounds (VOCs) and toxicity, so this study aims to evaluate the potential of Fatty Acid Methyl Ester (FAME) as an alternative solvent for the solvent-based paint industry. FAME is synthesised from vegetable oil through a transesterification reaction, then formulated into alkyd resin-based paints with varying binder content (40%, 50%, and 60%) to be compared with acetone solvent. The paint performance evaluation includes tests on drying time, gloss level, hiding power, and Whiteness and Yellowness Index. The results show that FAME-based paints have a much higher gloss level (10–26 GU) than acetone (3–6 GU) because their slower evaporation rate provides optimal levelling time, though this results in much longer drying time, namely 780–819 minutes. In addition, FAME has been proven to produce better covering power and a lower Yellowness Index (1.39–4.15) than acetone (4.09–5.74). This superiority is influenced by the nature of FAME, which minimises damage to the polymer binder and uniformly disperses pigments, preventing agglomeration. Overall, FAME has great potential as a sustainable paint solvent that can improve optical and physical properties, although its formulation still requires optimisation to accelerate drying.



## 1. Introduction

Solvent selection in the oil paint industry is a fundamental aspect that determines the quality, safety, and sustainability of the paint production and application process. For decades, petroleum-based solvents such as toluene, xylene, and white spirit have been the industry standard due to their ability to dissolve resins and accelerate paint drying. However, these conventional solvents have significant negative impacts, such as high toxicity, emissions of volatile organic compounds (VOCs) that are harmful to the environment and worker health, and the risk of damage

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to the substrate and paint film due to swelling and leaching of critical components (Biribicchi et al., 2024; Ghobakhloo et al., 2023). In the context of tightening environmental regulations and market demand for environmentally friendly products, the need for safer, more sustainable alternative solvents is becoming increasingly urgent.

Fatty Acid Methyl Esters (FAME), commonly known as the main component of biodiesel, have emerged as a promising alternative solvent for oil and solvent-based paint applications. FAME offers several fundamental advantages: derived from renewable sources (vegetable oil or waste oil), biodegradable, low toxicity, and capable of significantly reducing VOC emissions(Biribicchi et al., 2024; Zaratti et al., 2024). In addition, the modifiable chemical structure of FAME (chain length, degree of unsaturation, and functional groups) allows adjustment of solvent properties to meet the needs of paint formulations, both as the main solvent and as an active reactant in the polymerisation process (Nameer et al., 2019). This potential positions FAME as a strategic solution in the paint industry's transition to a greener, more sustainable future.

To reduce Volatile Organic Compound (VOC) emissions and minimise negative impacts on the ecosystem, several studies have developed bio-solvents derived from renewable materials, such as vegetable oils, fatty acids, and cellulose (Biribicchi et al., 2024; Hunek & Franus, 2025). Another renewable solvent is ethyl lactate, also known as a lactate ester, synthesised by esterification of lactic acid with biomass-derived ethanol. This compound is a biodegradable, non-toxic solvent with excellent solubility. Due to its high safety, ethyl lactate is currently widely applied in various industrial sectors, including the food and pharmaceutical industries, as a coating (Devale & Mahajan, 2024; Pereira et al., 2011) However, the potential of ethyl lactate as an alternative solvent in the paint industry has not been comprehensively discussed. Another potential bio-solvent for application in solvent-based paints is d-limonene. As a natural compound commonly extracted from citrus fruit peel waste, such as oranges and lemons, d-limonene has been utilised in the synthesis of bio-based epoxy paints. D-limonene in epoxy matrices has been shown to provide superior thermal and mechanical strength characteristics compared to conventional petroleum-derived epoxy resins (Bonamigo Moreira et al., 2022) The solvent n-butanol, synthesised from starch raw materials via fermentation with the bacterium Clostridium acetobutylicum, shows great potential as a future solvent for the coatings (such as varnishes, resins, and waxes) and paint industries. In its application, n-butanol plays an important role in facilitating the formation of a uniform, stable film. This characteristic directly contributes significantly to improving the final quality and overall durability of the paint (Gallo-garcía et al., 2024; Reetz & König, 2021; Sun et al., 2022).

Among the various solvent alternatives, Fatty Acid Methyl Esters (FAME) remain the best option for development as a renewable solvent for the solvent-based paint industry. This is because FAME production technology is currently ready for industrial-scale production compared to other bio-based solvents. Hence, the paint industry benefits more, as it does not need to incur investment costs to develop new bio-based solvents. In addition, raw materials (e.g., palm oil, castor oil, soybean oil) are abundant, and their renewable nature makes FAME an attractive solvent candidate (Salehpour & Dubé, 2008; Zaratti et al., 2024). However, implementing FAME as a solvent in solvent-based paint formulations still requires in-depth research. Crucial questions arise regarding the

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compatibility of FAME with various types of resins used in paints (such as alkyd, acrylic, epoxy, phenolic and petroleum resins), the impact of FAME on the physical and chemical properties of the resulting paint film (e.g., hardness, gloss, abrasion resistance, chemical resistance, and colour stability), and the storage stability of paint formulations containing FAME. Therefore, this study aims to explore the potential use of FAME as an alternative solvent in the solvent-based paint industry. The research will focus on evaluating the solubility of FAME in various paintalkyd resins, analysing the physical properties and performance of paints formulated with FAME, and comparing them with conventional paint formulations containing VOCs.

## 2. Materials and Methods

### 2.1 Material

The materials used in this study consist of two main groups, namely materials for the synthesis of Fatty Acid Methyl Ester (FAME) and paint formulation materials. In the synthesis of FAME, the main raw material is commercial vegetable oil produced by PT. Wilmar Cahaya Indonesia Tbk. This oil was chosen because it has a Free Fatty Acid (FFA) specification of less than 0.2% which is very important to minimize the saponification reaction during the transesterification process. This process also uses methanol and Potassium Hydroxide (KOH) catalyst obtained from a local distributor. Furthermore, in the paint formulation stage, the main resin used as a binder matrix, which includes alkyd medium oil. To enhance the coating performance, a number of functional additives from local suppliers were added. These additives include dryers (cobalt naphthenate and manganese naphthenate), dispersing agents, anti-slip and leveling agents, antifoam, and solvent-based thickeners. Finally, Titanium Dioxide ($TiO_2$) pigment KRONOS 2450 brand from Behrindotama Buana was used to provide maximum paint coverage.

### 2.2 Method

#### 2.2.1 Synthesis of Fatty Acid Methyl Ester

The production process of Fatty Acid Methyl Ester (FAME) from commercial vegetable oil is carried out systematically in three main stages: raw material preparation, transesterification, and purification. In the initial stage, vegetable oil with a Free Fatty Acid (FFA) specification of 0.2% by weight is prepared. The transesterification reaction is carried out in a reactor consisting of a three-necked round-bottom flask with a capacity of 250 mL, equipped with a reflux condenser to prevent solvent evaporation. As an initial step, 250 g of oil is heated slowly to a constant operating temperature of 60°C. After the temperature is reached, Potassium Hydroxide (KOH) catalyst is added at a concentration of 1% by weight of the oil, along with the methanol reactant at a molar ratio of 10:1 (methanol to oil). To ensure optimal and homogeneous reaction, the mixture is stirred continuously with a magnetic stirrer at 400 rpm for 1 hour. In the purification stage, the mixture is placed in a separating funnel to separate the FAME phase from by-products such as glycerol, excess methanol, water, and various other impurities. This raw FAME product is then washed with warm water to dissolve the remaining methanol. In the final stage, the FAME is evaporated at 100 °C to remove the remaining water, yielding a high-purity final product.

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### 2.2.2 Formulation and Mixing of Solvent-Based Paints

The solvent-based paint formulation in this study was designed in accordance with the Indonesian National Standard (SNI) 06-4827-1998, which specifies the requirements for ready-to-use oil-based paint mixtures. The paint production formulation complies with SNI to meet national coating industry standardisation criteria. The solvent-based paint production process uses Fatty Acid Methyl Ester (FAME) and acetone as comparators, divided into two main process stages: the preparation of the binder phase and the preparation of the paint material. The first stage, namely the preparation of the binder material, begins with mixing the alkyd medium oil resin at a total proportion of 72% w/w with a drying agent, a combination of cobalt naphthenate and manganese naphthenate, at 5% w/w to catalyse the oxidative polymerisation reaction during application. Next, 23% by weight of FAME solvent or acetone was added to the mixture, and the mixture was stirred at 300 rpm with constant temperature control at 35–40°C for 30 minutes until homogeneous.

The second stage is the preparation of the paint material, which aims to form a protective film layer and provide covering power or opacity. This process involves dispersing titanium dioxide ($TiO_2$), the main pigment, in a FAME solvent or acetone, along with various other additives. These additives include a dispersing agent to prevent particle agglomeration, an anti-slip and levelling agent to smooth the surface, an antifoam to prevent the formation of air bubbles, and a solvent-based thickener. All components are mixed in a mixer at 300 rpm for 30 minutes, according to the composition listed in Table 1. After each binder component and paint material is completed, the binder is then mixed into the pigment material. This final mixing composition varies with 40%, 50%, and 60% w/w of the total paint weight. The homogenization process is carried out at 300 rpm for 15 minutes. The same formulation method is also replicated using acetone solvent.

**Table 1. Composition of pigment ingredients**

| No | Components | Composition (%) |
|---|---|---|
| 1 | $TiO_2$ | 47 |
| 2 | FAME | 41 |
| 3 | Dispersing Agent | 3 |
| 4 | Anti Slip and Levelling | 3 |
| 5 | Anti Foam | 3 |
| 6 | Thickenner | 3 |

### 2.2.3 Characterization of Solvent-Based Paints

The FAME and acetone solvent-based paint products that have been made are then characterized to evaluate the quality and performance of the coating. Physical and optical testing includes determining the hiding power using

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the BYK Byko-charts instrument according to ISO 6504, measuring the whiteness and yellowness index, and analyzing the gloss level referring to ASTM D523.

**Drying time:** A paint film is considered "dry to the touch" if, when lightly touched with a fingertip, no paint adheres to the skin, indicating that the film surface has dried sufficiently for light contact without causing surface damage. This test is performed under controlled environmental conditions to ensure accuracy and consistency of results. Record the time it takes for the paint to be able to be touched without sticking to the skin.

**Gloss:** Gloss testing is performed based on ASTM D 523 standard, which measures the degree of specular reflection of light from the surface of a paint film. The principle of this test involves reflecting light at a certain angle onto a glass plate surface that has been coated with a film, then comparing it with the reflection of light from a standard black glass surface with a reference gloss value. The measurement results are expressed in Gloss Units (GU), which indicate how shiny or reflective the surface is. This gloss value serves as an indicator of the visual and aesthetic quality of the paint layer.

**Opacity and Hiding Power:** Checkered card (BYK/byko) was weighed before paint application. The paint was applied using a brush until the entire checkered pattern was completely covered, then the card was reweighed. Covering power was calculated in g/cm² based on the difference in mass before and after application and the known surface area of the card.

**Whiteness Index and Yellowness Index:** The color variation of each sample was measured using a colorimeter (Linshang Colorimeter L172). The color parameters L* (which describes the brightness level of the sample), a* (along the x-axis from red (+) to green (-)), and b* (along the y-axis from yellow (+) to blue (-)) were evaluated, along with the total color difference between the standard color and the sample ( **ΔE** ). The whiteness index (WI) and yellowness index (YI) were then calculated using Equations (1) and (2), as follows (Bielska et al., 2022) :

$$WI = 100 - ((100 - L^*)^2 - a^2 - b^2)^{0,5}) \qquad \text{Eq.1}$$

$$YI = 142.86b\,.\,L^{-1} \qquad \text{Eq.2}$$

## 3. Results and Discussions

### 3.1 Gloss dan Drying Time

The difference in solvent type between FAME and acetone significantly affects the gloss level of the resulting paint layer, as presented in Table 2. This confirms the crucial role of solvent characteristics in shaping the film-forming mechanism and determining the final gloss aesthetics. The gloss characteristics of paint with acetone solvent decreased drastically, with values ranging from only 3–6 GU, much lower than those of FAME-based paint, which can reach 10–26 GU. This phenomenon is closely related to acetone's high volatility, due to its low boiling point, which leads to rapid evaporation. This characteristic

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is confirmed by the relatively short drying time of acetone-based paint, which ranges from 20 to 83 minutes. The excessively rapid evaporation rate when using acetone as the sole solvent shortens the paint's flow and levelling time on the substrate surface. As a result, the coating layer does not have sufficient time to form a homogeneous and even surface. Furthermore, in humid environments, rapid evaporation triggers the blushing phenomenon, resulting in a rough surface topography and significantly reducing gloss (Poós & Varju, 2024; Stoye & Freitag, 2008).

**Table 2.** Gloss of FAME and Acetone Solvent Based Paints

| Solvent Type | Binder Content (%) | Gloss Value (GU) | Drying Time (Minute) |
|---|---|---|---|
| FAME | 40 | 10 | 819 |
| | 50 | 22 | 806 |
| | 60 | 26 | 782 |
| Aseton | 40 | 3 | 83 |
| | 50 | 4 | 71 |
| | 60 | 6 | 63 |

This condition contrasts with FAME-based paints, which have a much slower evaporation rate and drying time that is greatly influenced by the type of binder applied. This low volatility rate essentially prolongs the flow and levelling phase, providing sufficient time for the coating layer to form a flat surface and, in turn, increasing gloss. However, FAME-based paint formulations using alkyd resins do not show a significant increase in gloss when compared to commercial paints. This limitation is triggered by several factors, including the excessively long drying time. The prolonged wet-to-dry transition phase increases the paint surface's susceptibility to airborne contaminants, such as fine dust particles, which directly degrade the surface film quality (Héritier, 2022). Furthermore, this phenomenon is closely related to the drying mechanism of the alkyd binder itself, which is highly dependent on oxidative polymerisation reactions (molecular cross-linking through exposure to air oxygen) (Soucek et al., 2012; Van Gorkum & Bouwman, 2005).

The oxidative drying mechanism requires a balanced flow duration: sufficient time for surface levelling but not excessive, as this is the key to achieving optimal film layer quality and gloss level. In reality, the drying process of the alkyd matrix with FAME solvents takes much longer than with acetone solvents, namely 780-819 minutes. This indicates that in FAME solvent-based paints, the drying process of the alkyd binder is actually hampered by the retention of the FAME solvent itself. The FAME evaporation rate is too slow, resulting in the solvent being retained longer in the paint layer. This condition

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directly affects the kinetics of interactions between alkyd polymer chains in the crucial phase of final drying and the formation of a cross-linking network. As a result, the polymerisation process is suboptimal and inhibits the formation of a truly dense, dry, and smooth surface morphology at the microscopic scale (Hennessy & Münch, 2014; Mossige et al., 2020). In addition, the binder or resin content in solvent-based paints greatly determines the final gloss level. When a sufficient amount of binder is added, it optimally fills all the gaps between pigment particles. This results in a continuous, extremely smooth surface layer free of pores and microscopic irregularities. This perfectly flat surface is essential for achieving uniform specular reflection, enabling the paint to reach its maximum high-gloss level.

### 3.2 Opacity and Hiding Power

Hiding power is an essential indicator that determines the visual quality and efficiency of paint application. The ability of a paint layer to completely cover the substrate surface is crucial because it directly affects material savings, processing time efficiency, and reduced production costs (Ibrahim, et al., 2022a; Ibrahim, et al., 2022b). From an optical perspective, this covering power parameter shows a strong correlation with opacity, namely the coating film's ability to scatter light. This scattering performance is highly dependent on the physicochemical properties of the constituent pigments, including pigment type, particle size, concentration, refractive index, and the homogeneity of the pigment dispersion in the binder matrix (Diebold, 2019; Karakaş et al., 2015; Koleske, 1995). In this study, the evaluation of hiding power was conducted using a categorical scoring system. The "Pass" criterion is met if the paint film completely hides the substrate's base colour. Conversely, the "Failed" criterion is assigned if the original substrate colour remains visually apparent after paint application, as shown in Table 3 (Ibrahim, et al., 2022a).

Table 3 shows that the opacity of paint using an alkyd binder meets paint specifications at a film thickness of 120 µm. Binders such as alkyds create a dense, homogeneous film layer that effectively spreads and locks pigments. This allows the paint to better cover the surface's base colour, even with just one or two layers. Conversely, low-quality binders can cause problems such as poor pigment dispersion, porous films, and ultimately, less than optimal coverage (Wicks et al., 2006). Therefore, selecting paint with the appropriate type of binder is crucial for optimal painting results. The hiding power of alkyd-based paints ranges from 0.14 to 0.19 g/cm$^2$, but in terms of quality, paints with FAME solvents have better hiding power. The incompatibility between the binder and the $TiO_2$ pigment causes this. Binders and pigments are two crucial components in paint formulations. Both components work together to produce a homogeneous layer that perfectly covers the surface. However, in some cases, the binder was unable to "wet" the pigment particles and spread them evenly, resulting in pigment agglomeration. Pigment agglomeration reduces the paint's ability to cover the surface because it prevents even light distribution. On the other hand,

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agglomeration results in the formation of small, uncovered gaps, allowing the base colour of the surface to remain visible and making the painting results appear patchy (Agbo et al., 2018; Järnström et al., 2010).

**Table 3.** Opacity and Hiding Power of FAME and Acetone Solvent-Based Paints

| Solvent Type | Binder Content (%) | Opacity | Hiding Power ($g/cm^2$) |
|---|---|---|---|
| FAME | 40 | Pass | 0.019 |
| | 50 | Pass | 0.018 |
| | 60 | Pass | 0.016 |
| Aseton | 40 | Pass | 0.014 |
| | 50 | Pass | 0.015 |
| | 60 | Pass | 0.018 |

### 3.3 Whiteness Index and Yellowness Index

In the coating and paint industry, the Whiteness Index and Yellowness Index are two essential parameters for evaluating a product's visual quality. These two parameters provide a precise quantitative measure of the brightness of white and the intensity of yellow in the material's visual appearance. In this study, measurements of these two indices were conducted to analyse the effects of variations in binder type and binder content, as well as the colour impact of the solvent. The evaluation of these optical characteristics is based on the CIE colour system, using L*, a*, b*, and ΔE, as well as the whiteness and yellowness indices. The L* value represents the brightness of the paint film. Meanwhile, the a* value indicates the greenish or reddish spectrum, and the b* value represents the bluish or yellowish spectrum shift in the tested film (Bielska et al., 2022; Kaczmarek-Szczepańska et al., 2022).

Referring to Table 4, it can be seen that the colour transformation of the paint film surface is strongly influenced by the type of solvent and the binder content. The addition of FAME solvents or acetone significantly affects colour changes. Overall, FAME solvent-based paints display a lower Yellowness Index than acetone solvent-based paints. For example, FAME solvent-based paints with 50% alkyd binder produce a Yellowness Index of 3.16. Conversely, with identical types and binder content, the use of acetone solvent results in a higher Yellowness Index of 4.78. This trend consistently occurs in tests of acetone solvents with various binder variations. The increase in the Yellowness Index in the acetone solvent system is due to its strong solvency for various types of resins, which can affect the structure and stability of the binder polymer in the paint. This condition indirectly accelerates the oxidative degradation process, which

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ultimately results in changes in the optical characteristics of the yellow paint film layer (Choi et al., 2014; Desrats, 2013).

**Table 4.** Whiteness Index and Yellowness Index of FAME and Acetone Solvent-Based Paints

| Solvent Type | Binder Content (%) | L* | a* | b* | ΔE | Whiteness Index (WI) | Yellowness Index (YI) |
|---|---|---|---|---|---|---|---|
| **FAME** | 40 | 93.58 | -1.03 | 0.91 | 1.86 | 93.43 | 1.39 |
| | 50 | 92.23 | -1.21 | 2.04 | 2.98 | 91.88 | 3.16 |
| | 60 | 91.93 | -1.07 | 2.67 | 3.58 | 91.43 | 4.15 |
| **Aseton** | 40 | 94.23 | -1.20 | 2.70 | 3.85 | 93.52 | 4.09 |
| | 50 | 93.94 | -1.27 | 3.14 | 4.17 | 93.06 | 4.78 |
| | 60 | 93.29 | -1.35 | 3.75 | 4.64 | 92.20 | 5.74 |

The use of acetone in paint formulations does not directly trigger the oxidation process. However, acetone dissolves protective layers and antioxidant additives incorporated into the paint components. The loss of this protection indirectly makes the paint film much more susceptible to oxidation. As a result, the risk of paint discolouration, including yellowing, will increase over time (Desrats, 2013; Kim et al., 2013). This characteristic contrasts sharply with the use of FAME-based solvents. FAME is classified as a solvent with a less strong dissolving power, and has a polarity level ranging from low to non-polar. Due to its milder nature, FAME solvents only have a very minimal impact on the integrity of the polymer structure in the binder. Furthermore, the molecular structure of FAME solvents, with a long ester chain, combined with their slow evaporation rate, provides a mechanical advantage. This combination of properties provides an adequate time lag for the polymer to recover and regain stability. This process is very effective at preventing and slowing oxidation in the polymer structure, thereby minimising the occurrence of paint discolouration or yellowing.

## 5. Conclusions

Fatty Acid Methyl Esters (FAME) have great potential as an alternative to conventional solvents in the paint industry. Based on performance evaluations, FAME-based paints offer significantly greater advantages than acetone across a range of physical and optical properties. In terms of colour quality, FAME paints produce a lower Yellowness Index, namely 1.39 to 4.15, compared to acetone, which ranges from 4.09 to 5.74. This proves that FAME is safer to apply because it can minimise polymer damage and suppress oxidative degradation. In addition, the FAME formulation provides superior hiding power by dispersing pigments uniformly, thereby preventing agglomeration in the paint layer. In other visual aspects, FAME can achieve a gloss level of 10 to 26 GU, far exceeding acetone, which is only

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in the range of 3 to 6 GU. This high-gloss achievement is supported by FAME's slower evaporation rate, providing an ideal surface levelling duration. However, the main challenge of using FAME is its very long drying time, which takes around 780 to 819 minutes. The low volatility of this solvent risks triggering dust adhesion to the wet paint layer and can inhibit the rate of oxidative polymerisation of the binder. Overall, FAME is a very promising solution for achieving a sustainable paint industry, though it still requires future formulation refinements to optimise the drying process.

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