



## RESEARCH ARTICLE

# Synthesis and characterization of alkyd resin based on palm fatty acid distillate (PFAD) modified with vegetable oil

Desi Nurandini<sup>1,\*</sup>, Lestari Hetalesi Saputri<sup>2</sup>, Nopi Stiyati Prihatini<sup>3</sup>

<sup>1</sup>Department of Chemical Engineering, Faculty of Engineering, Universitas Lambung Mangkurat, Jl. Jenderal Achmad Yani KM 35,5, Banjarbaru, 70714, Indonesia

<sup>2</sup>Department of Industrial Chemical Engineering Technology, Politeknik LPP Yogyakarta, Jl LPP No 1A, Balapan, Yogyakarta, 55222, Indonesia

<sup>3</sup>Department of Environmental Engineering, Faculty of Engineering, Universitas Lambung Mangkurat, Jl. Jenderal Achmad Yani KM 35,5, Banjarbaru, 70714, Indonesia

Received 28 April 2026; revised 12 May 2026; accepted 25 May 2026



This graphical abstract was generated using AI-based image generation tools for conceptual illustration only.

**OBJECTIVES** Coating industry is currently in urge to produce environmentally friendly products based on considerations of maintaining ecological stability. However, the coating industry, utilizing synthetic alkyd resins, generates substantial emissions of hazardous volatile organic solvent component, while its waste presents degradation challenges. Therefore, innovations are required to coating material from renewable and eco-friendly alkyd resins. Modifying alkyd resins with natural ingredients, such as vegetable oils and fatty acids, potentially enhances their performance as coating material. This research utilizes palm fatty acid distillate (PFAD), a byproduct of palm oil (CPO) processing, as a renewable material for alkyd resin. **METHODS** The use of vegetable oil to modify alkyd resin improves characteristics of the product. Drying-vegetable oil solidifies and hardens through a chemical reaction in which its components cross-link and form a tough, solid film due to oxidation upon exposure to the air. This research aims to study the synthesis process of PFAD-based alkyd resin modified with vegetable oil and investigate the effect of type and composition of modified oil on the characteristics of PFAD-based alkyd resin and its performance as coating material. In this research, PFAD, glycerol, and phthalic anhydride were reacted through a one-

step polyesterification process (fatty acid process) at a temperature of 240°C for 4 hours. Modification was conducted by adding vegetable oil at various compositions (a comparison was carried out using several types of drying oil including candlenut oil, linseed oil, and tung oil). **RESULTS** The alkyd resin product was characterized by determining its acid value, iodine value, and FTIR analysis, alongside evaluating its curing performance (drying speed) in application as a coating material. The best formulation for the characteristics qualified according to the Standar Nasional Indonesia (SNI 06-0504-1989) are alkyd resins with composition of 50% weight linseed oil (AR-LO-50) and composition of 50% weight tung oil (AR-TO-50) modification, i.e. acid value of 4.6 mgKOH/g sample and iodine number of 119.20 gI<sub>2</sub>/100 g for linseed oil, then acid value of 8.31 mgKOH/g sample and iodine number of 102.44 gI<sub>2</sub>/100 g for tung oil. **CONCLUSIONS** The curing test results confirmed that the modified product meets the required 1-day drying time standard.

**KEYWORDS** alkyd resin; coating material; drying oil; PFAD; vegetable oil

## 1. INTRODUCTION

Polymer industry is currently in urge to utilize environmentally friendly raw materials, emphasizing sustainability and biodegradability. Alkyd resin is a polymer product widely used in the paint, coating, and film-forming industries. It is a product of the reaction of polyhydric alcohol, monobasic fatty acid, and polybasic acid (Suhendi et al. 2022). This is due to its excellent properties as a surface coating, including flexibility, strength, durability, and good adhesion (Nurandini et al. 2018). Alkyd resin is obtained through a polyesterification reaction that combines carboxyl and hydroxyl groups (Ikhuoria et al. 2011).

Coating is a process applied to an object or substrate. The goal is to improve the surface properties of the coated object in several ways, such as appearance, resistance to water or corrosion, scratch resistance, and wear. With the presence

\*Correspondence: [desi.nurandini@ulm.ac.id](mailto:desi.nurandini@ulm.ac.id)

of a coating, various machines and equipment used in the production process can withstand various disturbances for a considerable period of time. Problems in industrial coating production include the use of synthetic resins derived from petroleum, and the associated emissions of volatile organic solvent components in coatings, which are potentially hazardous to human health and contribute to global warming and ozone layer depletion (Nosal et al. 2015). Furthermore, recycling issues arise from the disposal of waste from resins, which are long-lasting and therefore difficult to decompose in the environment (Santiasih 2016).

Therefore, innovations are needed to obtain coating materials from renewable alkyd resins to reduce the consumption of synthetic coating. The utilization of vegetable oil to modify alkyd resins provides a good impact on the final product, depending on its intended use (Janesch et al. 2023). Oil can accelerate the drying process in coating application by undergoing oxidation and polymerization in the air to form a durable film (Uzoh et al. 2013). Vegetable oil is a sustainable natural resource and potential material to synthesize biodegradable product. Nurandini et al. (2018) has studied the characteristics of alkyd resin products formed from the polyesterification reaction of glycerol and adipic acid modified with rubber seed oil. Characterization results indicate the influence of the OH/COOH equivalent ratio on the characteristics of alkyd resins. FTIR analysis revealed the presence of ester, hydroxyl, and carboxyl groups.

This study utilized palm fatty acid distillate (PFAD) as well for alkyd resin synthesis. Indonesia is currently the world's largest producer of palm oil (CPO). Palm oil refineries produce palm fatty acid distillate (PFAD) as a by-product of the CPO refining process. If all CPO products in Indonesia were refined domestically, the amount of PFAD produced would be enormous, reaching approximately 1.5 million tons per year (Rochmadi et al. 2017). PFAD is composed of 81.7% free fatty acids (FFA), fat oxidation products, and several compounds such as tocopherols, phytosterols, squalene, and tocotrienols (Purnama et al. 2021). The content of these compounds makes PFAD a potential raw material for the coating industry (Simasatitkul and Arpornwichanop 2017). The FFA contained in PFAD is dominated by palmitic acid or hexadecanoic acid, with a percentage of approximately 46.05–47.45% (Jumaah et al. 2018).

One advantage of using PFAD as a raw material is its renewable nature and abundant availability. Another material used is glycerol. Glycerol, also a by-product of biodiesel production from crude palm oil (CPO), along with PFAD and phthalic anhydride, is used to enhance its utility value for alkyd resin synthesis. The reaction between PFAD (fatty acid), glycerol, and phthalic anhydride is esterification, which occurs between carboxyl group (–COOH) and hydroxyl group (–OH). The overall reaction in alkyd resin synthesis based on PFAD can be written in Figure 1 (Rochmadi et al. 2017).

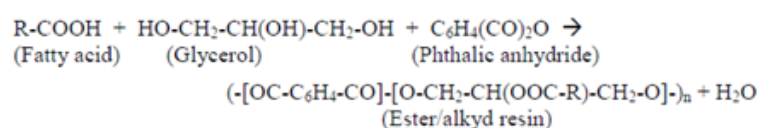


FIGURE 1. Esterification reaction in the synthesis of alkyd resin based on PFAD.

Research on PFAD-based alkyd resins has not been widely conducted. Rochmadi et al. (2017) have investigated PFAD-based alkyd resins and styrene as coatings, but the results of curing tests showed that the alkyd resin product could not self-dry or self-cure at room temperature. This is due to a low iodine number of PFAD-based alkyd resin product (ranges from 2 to 20 g Iodine/100g sample), which is caused by PFAD being a non-drying material that still contains a high amount of saturated fatty acids, and therefore this alkyd resin product is not suitable to be used as coating material. The acid value of alkyd resin product did not meet standards as well. PFAD/glycerol ratio gives acid value in the range of up to 50 (mg KOH/g sample), which significantly exceeds the required specification. This occurs because the functional group –COOH in PFAD have lower reactivity, leading to an incomplete esterification process and a subsequent excess of –COOH or higher acid value.

In this research, innovation was carried out by modifying PFAD combined with vegetable oil in order to improve the characteristics of alkyd resin products. Aigbodion et al. (2003) have studied that vegetable oil-based alkyd resin has a lower volatile organic solvent component (1–1.5%) than synthetic alkyd resin (around 10%). Oils classified as drying oils consist of many double bonds, which will increase the iodine value of the alkyd resin and accelerate the drying process when it expands or forms a film due to oxidation by air. Furthermore, amino resin additives were used as well in this research to accelerate the curing time which had not been achieved in previous studies (Rochmadi et al. 2017). Amino resin is a thermosetting compound with high chemical stability that functions as a cross-linking agent that binds molecules into a hard three-dimensional structure. In addition to its fast drying ability, amino resin has strong adhesion, high thermal stability, resistance to acids and bases, and is not easily damaged or dissolved in common solvents. These excellent characteristics make amino resin a suitable additive for coating material applications (Athariqa et al. 2022). Thus, the utilization of PFAD modified with vegetable oils (linseed oil, tung oil, and candlenut oil) for synthesis of alkyd resin by fatty acid process is a novel development in this research, aimed at overcoming the performance issues found in previous studies.

## 2. RESEARCH METHODOLOGY

### 2.1 Materials

The materials used in this research are palm fatty acid distillate (PFAD), glycerol, phthalic anhydride, various of vegetable oils (candlenut oil, linseed oil, and tung oil), and xylene as solvent. Other chemicals used are amino resin as additive, as well as chemical reagents for analyzing and characterizing alkyd resins, such as NaOH, ethanol, Wijs reagent, carbon tetrachloride, potassium iodide, and sodium thiosulfate which are Merck chemicals.

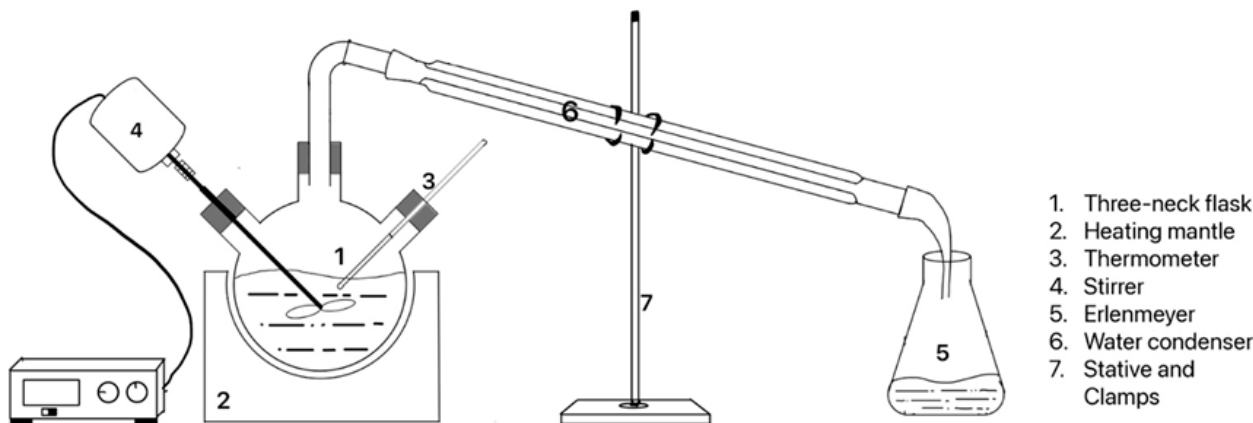


FIGURE 2. Experimental unit for synthesis of alkyd resin by fatty acid method.

### 2.1.1 Procedures

The equipment of alkyd resin synthesis is shown in Figure 2, which consists of three-neck flask as a batch reactor, provided with a mechanical stirrer, mantle heater, and condenser. PFAD, glycerol, and phthalic anhydride were charged into the three-neck flask with a predetermined mole ratio composition (PFAD : glycerol : phthalic anhydride = 0,6 : 1 : 1), along with 10 mL of xylene solvent. Modifications were conducted by adding vegetable oil with various compositions, i.e. 40% and 50% by weight (comparison by using several types of drying oils: linseed oil, tung oil, and candlenut oil). The mole ratio of reactant and weight percentage of oil were determined based on the best results from previous preliminary experiments. The mixture of reactants was heated to a reaction temperature of 240°C. The temperature was held constant during 4-hour reaction (Rochmadi et al. 2017). Some resultant water (as byproduct) was separated into a collector/separator flask. In the end of the reaction, the mixture was cooled to room temperature. Furthermore, the alkyd resin products were characterized, including acid number, iodine number, and FTIR analysis. In addition, a curing test (drying time speed) was carried out on the alkyd resin applied as a coating material.

### 2.2 Instrument and data analysis

The acid value was determined by titration. A sample of 20 grams of alkyd resin was weighed into a flask and dissolved in 50 mL of 95% neutral alcohol. The solution was then titrated with 0.1 N KOH standard alcoholic solution using PP indicator. The acid value is calculated with Equation 1.

$$\text{Acid Value} = \frac{V \text{ KOH (mL)} \times N \text{ KOH} \times 56.1}{\text{weight of sample (g)}} \quad (1)$$

Iodine number was determined by Wijs reagent method. This method requires a blank solution, and the titrant is Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> solution. Iodine number is calculated with Equation 2 below:

$$\text{Iodine number} = \frac{(B - C) \times N \times 12.69}{W} \quad (2)$$

where B = volume of titrant used for alkyd resin sample (mL), C = volume of titrant used for blank solution (mL), N = normality of Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> solution, W = weight of alkyd resin sample (gram), and 12.69 = factor from iodine molecular weight.

Fourier Transform Infra-Red analysis was performed to determine the functional groups present in alkyd resin. The observed wavelengths were 400-4000 cm<sup>-1</sup>.

The curing test was conducted by mixing alkyd resin with solvent at various compositions (10%-40% weight), then was added with amino resin (Melamine Formaldehyde) at specified % weight ratio (from alkyd resin/amino resin 70/30 to 50/50). The mixture was applied to surface of metal plate at specified dimension to form a thin film. Several samples were prepared and left at room temperature, then the curing time was observed.

## 3. RESULTS AND DISCUSSION

Acid value and iodine number are key parameters for controlling alkyd resin quality. Alkyd resin synthesized based on Palm Fatty Acid Distillate (PFAD) has not met the standard specifications in terms of low iodine number because PFAD is a non-drying material that still contains a lot of saturated fatty acids. Therefore, this research modified alkyd resin by adding several type of drying oils (candlenut, linseed, and tung oil) to enhance its characteristics, specifically the iodine number. The results of acid value and iodine number analyses on alkyd resin product based on PFAD modified with various oils compared with unmodified (non-oil) alkyd resin are presented in Figure 3 and Figure 4 below.

### 3.1 Acid value of alkyd resin

Based on Figure 3, acid value analysis on the alkyd resin from PFAD modified with linseed oil and tung oil showed better result compared to acid value of the unmodified PFAD-based alkyd resin. It is observed that higher percentage of modified oil in alkyd resin composition results in a significant decrease of its acid value. The general standard for the acid value in drying alkyd resin based on SNI 06-0504-1989 is maximum of 20 mgKOH/g sample (BSN, 1989) and it will be even better if the acid value can reach a value of <10 mgKOH/g

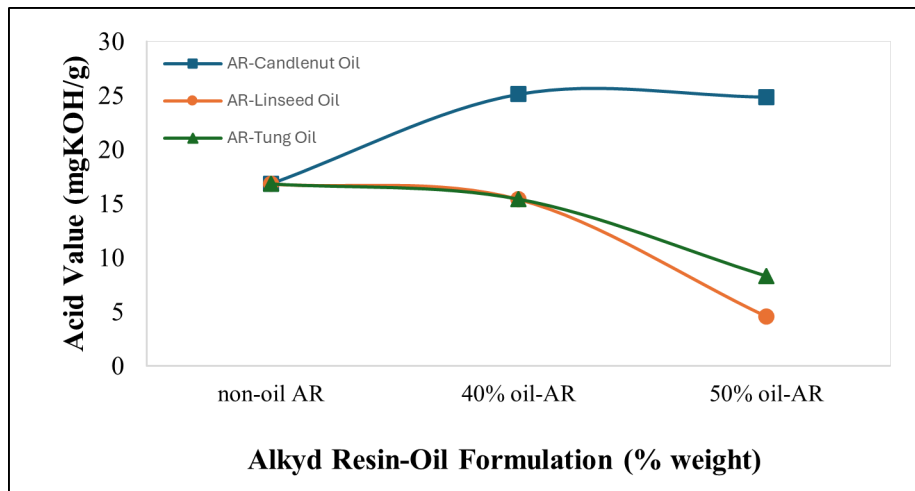


FIGURE 3. Acid value of PFAD-based alkyd resin modified with various oils.

sample. The use of linseed oil and tung oil with a composition of 50% by weight succeeded in obtaining alkyd resin products with acid value of 4.60 and 8.31 mgKOH/g sample.

The acid value of unmodified PFAD based-alkyd resin is 16.83 mgKOH/g. After being modified with vegetable oil, the acid value of alkyd resin decreased. The addition of drying oil facilitates a more complete esterification reaction, thereby reducing the amount of unreacted free acid groups ( $-\text{COOH}$ ). High temperatures during the reaction damage the oil structure by breaking the bonds in the triglycerides, some of which yield glycerol, thereby potentially increasing the hydroxyl content. The hydroxyl groups ( $-\text{OH}$ ) react with excess carboxyl groups ( $-\text{COOH}$ ), resulting in a reduction of the residual  $-\text{COOH}$  concentration or lower acid value

The acid value of linseed oil-modified alkyd resin decreased to 15.42 mgKOH/g (40%) and 4.60 mgKOH/g (50%). A study by Iseri-Caglar et al. (2014) supports the use of linseed oil to improve the adhesion and durability of alkyd resin. Meanwhile, the acid value of tung oil-modified alkyd resin decreased to 19.85 mgKOH/g (40%) and 8.31 mgKOH/g (50%). Research by Xu et al. (2017) states that utilization of tung oil for alkyd resin produced superior mechanical properties and good chemical resistance. Modification of alkyd resin with candlenut oil showed unqualified results of the standard. The acid value of candlenut oil-modified alkyd resin are

25.14 mgKOH/g (40%) and 24.83 mgKOH/g (50%), The higher acid value is due to remaining carboxylic groups from the incomplete esterification reaction. This increase in acid value is common in alkyd resins made from oils rich in free fatty acids.

### 3.2 Iodine number of alkyd resin

The iodine number represents the degree of double bond  $\text{C}=\text{C}$  unsaturation, serving as an indirect indicator of the potency to be drying oil. Figure 4 indicates that modifying the PFAD-based alkyd resin with 50% linseed oil and 50% tung oil significantly improved the iodine number. Iodine number of modified resin exceeds the minimum standard requirement for drying oil alkyd resins ( $100 \text{ g I}_2/100 \text{ g sample}$ ), in contrast to the unmodified PFAD-based alkyd resin ( $21.15 \text{ g I}_2/100 \text{ g sample}$ ).

Linseed oil has iodine number of  $110.99 \text{ g I}_2/100 \text{ g}$  based on the test results. This value is considered high because of its content of unsaturated fatty acids, such as linolenic acid. After being modified into alkyd resin with 40% and 50%, the iodine number becomes  $80.86 \text{ g I}_2/100 \text{ g}$  and  $119.20 \text{ g I}_2/100 \text{ g}$ , respectively. The decrease in the iodine number (at 40% oil composition) indicates that most of the double bonds have reacted, while at 50% oil content, a higher unsaturated content remains, in accordance with the needs for coating appli-

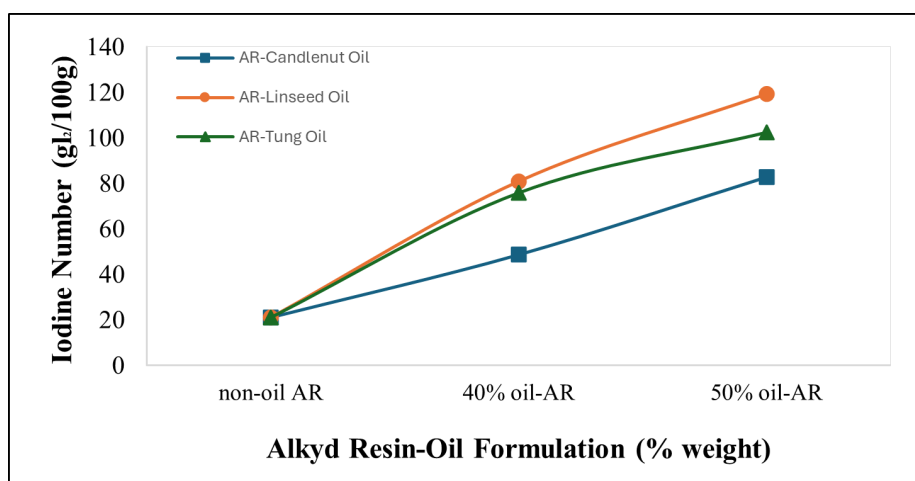


FIGURE 4. Iodine number of PFAD-based alkyd resin modified with various oils.

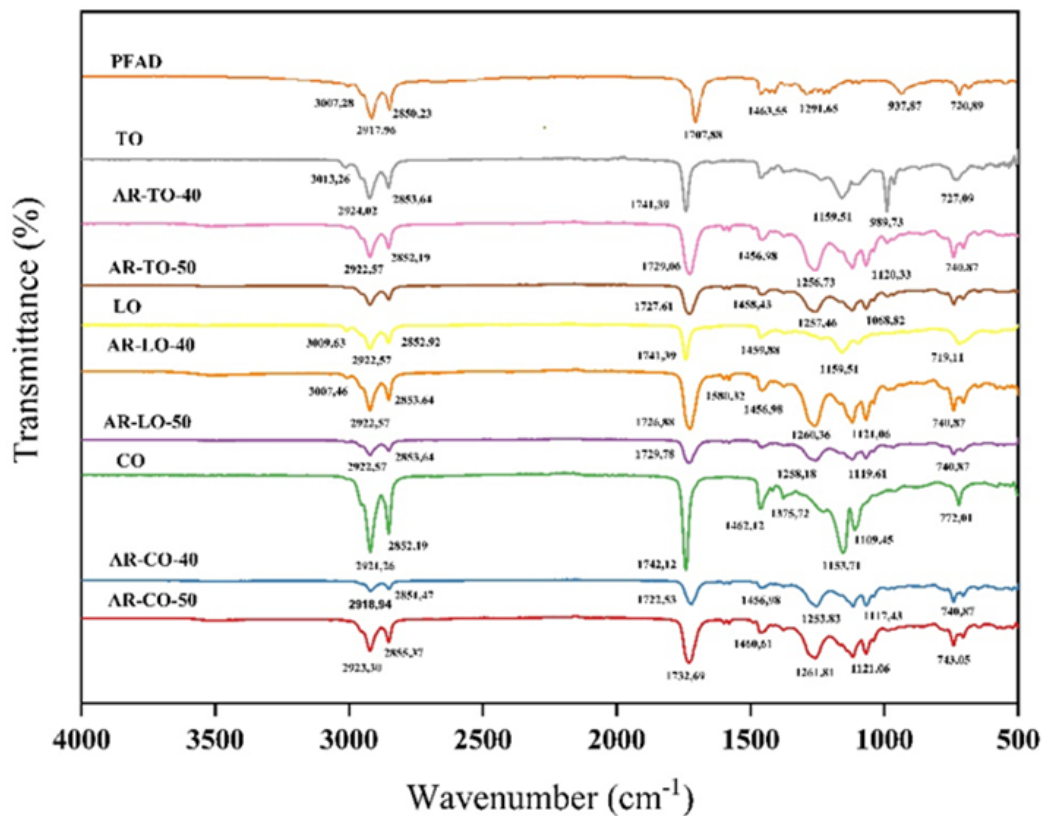


FIGURE 5. FTIR spectra of PFAD-based alkyd resin modified with vegetable oil.

cations that require of fast drying.

The iodine number analysis on tung oil showed a very high value, i.e. 163.06 g  $I_2$ /100 g, which reflects the content of eleostearic acid with three double bonds. After being modified into alkyd resin with 40% and 50%, the iodine number decreased to 75.85 g  $I_2$ /100 g (40%) and 102.44 g  $I_2$ /100 g (50%). This significant decrease indicates the high reactivity of the unsaturated groups of tung oil during the esterification process. This iodine number content makes tung oil ideal for producing fast-drying alkyd resin.

The analysis on candlenut oil resulted an iodine number value of 55.21 g  $I_2$ /100 g, which is relatively low because the content of saturated fatty acids is more dominant than unsaturated fats. After being modified into alkyd resin with 40% and 50% candlenut oil, the iodine number decreased to 48.71 g  $I_2$ /100 g (40%) and 44.78 g  $I_2$ /100 g (50%). This decrease was caused by the esterification reaction which removed most of the double bonds in the oil. Candlenut oil produces alkyd resin with good moisture resistance, although its iodine number is lower than other oils.

Based on the test results, it can be concluded that the addition of vegetable oils from linseed oil and tung oil to alkyd resin synthesized from PFAD successfully improved the quality of the alkyd resin product, especially in terms of acid value and iodine value. The addition of these oils resulted in significant variation in results, depending on the type and percentage of oil used. After the addition of oil, almost all alkyd resins modified with 40-50% oil met the maximum acid value standard of 20 mgKOH/g sample. For iodine value, alkyd resins using 50% linseed oil (119.20 g  $I_2$ /100 g) and 50% tung oil (102.44 g  $I_2$ /100 g) met the minimum standard of 100 g  $I_2$ /100 g. The addition of candlenut oil, although increasing the io-

dine value, still did not meet the standard because the value was still below 100 g  $I_2$ /100 g.

Overall, PFAD based-alkyd resin modified with 50% linseed oil and 50% tung oil are the best formulation because it meets both standards. According to Standar Nasional Indonesia (SNI 06-0504-1989), alkyd resin has a maximum acid number standard of 20 mgKOH/gram. and iodine number (>100 g  $I_2$ /100 g). The longer the oil (oil length) in the alkyd resin can increase the iodine value because more unsaturated bonds are added. The combination with this oil provides a positive contribution to the characteristics of the alkyd resin so that it has the potential to be developed with further research on the synthesis of PFAD-based alkyd resin modified with vegetable oil to produce coating material products with better characteristics and can be applied in coating and paint industrial applications.

### 3.3 FTIR analysis

FTIR spectra is used to analyze the chemical structure changes during alkyd resin synthesis, based on the differences in spectra at various compositions. The analysis as shown in Figure 5 is performed to compare the spectra of PFAD and vegetable oil before reaction with those of the alkyd resin product, as well as to identify peak changes.

Based on Figure 5, the FTIR spectrum of PFAD shows several main peaks, including a carbonyl (C=O) peak at 1707.88  $cm^{-1}$ , indicating the presence of carboxylic acid groups from free fatty acids, a hydroxyl (O-H) peak at 3007.28  $cm^{-1}$ , indicating the presence of polar compounds such as water or free glycerol, and aliphatic C-H stretching peaks at 2917.96  $cm^{-1}$  and 2850.23  $cm^{-1}$ , reflecting saturated hydrocarbon chains.

In addition, a C–O peak at  $1233.70\text{ cm}^{-1}$  indicates slight natural esterification in PFAD. Afterwards, FTIR spectrum of vegetable oils before esterification reflects the basic structure of triglycerides, which is generally characterized by ester groups (C=O) at wavenumbers around  $1740\text{ cm}^{-1}$ , aliphatic  $-\text{CH}_2-$  and  $-\text{CH}_3$  group vibrations in the range of  $2920\text{--}2850\text{ cm}^{-1}$ , and C–O ester bonds around  $1150\text{--}1100\text{ cm}^{-1}$ . However, because each oil has a different fatty acid composition, its FTIR spectral pattern also has its own characteristics. Tung oil (TO) has a high content of eleostearic acid, a fatty acid with three conjugated double bonds, which causes the appearance of distinctive bands at wavenumbers  $3013\text{ cm}^{-1}$  (=C–H alkene) and  $989\text{ cm}^{-1}$ , which represent out-of-plane deformation vibrations of the double bonds (Li et al. 2016). This uniqueness distinguishes tung oil from the other two oils. In addition, TO also displays a strong band at  $1741\text{ cm}^{-1}$  for the C=O ester group and  $2924$  and  $2853\text{ cm}^{-1}$  for the aliphatic group. In contrast, candlenut oil (CO), which is dominated by oleic and linoleic acids, has a simpler spectrum without the presence of conjugated double bonds (Shintawati et al. 2022). The C=O band is visible at  $1742\text{ cm}^{-1}$ , while the  $-\text{CH}_2-$  and  $-\text{CH}_3$  vibrations appear at  $2921$  and  $2852\text{ cm}^{-1}$ . Other signals at  $1153$  and  $1109\text{ cm}^{-1}$  indicate the presence of the C–O group from the ester. Similar characteristics are also found in linseed oil (LO), but with the addition of a small band at  $3009\text{ cm}^{-1}$  indicating the presence of unconjugated double bonds from linolenic acid, which is more dominant in this oil. This indicates that LO is between TO and CO in terms of fatty acid chain unsaturation.

After the esterification, Figure 5 shows that spectral changes in all oils confirmed the success of the alkyd resin formation reaction. One of the most significant changes was a shift in the carbonyl group (C=O) stretching band from approximately  $1741\text{--}1742\text{ cm}^{-1}$  to approximately  $1726\text{--}1732\text{ cm}^{-1}$ , depending on the oil type and composition. This shift indicates the formation of a new ester bond between the hydroxyl group of the triglyceride and the anhydride group of the phthalic anhydride. This shift to lower wavenumbers is consistent with literature reports by Sahoo et al. (2015) and Mahendran et al. (2012), which suggest that esterification forms a more polarized bond due to the aromatic structure of the phthalate affecting the carbonyl vibrations.

The appearance of a new band at approximately  $1580\text{--}1585\text{ cm}^{-1}$ , which is absent in the pure oil, is another indicator of the success of the reaction. These bands are identified as stretching of the aromatic rings (C=C) of the phthalate structure into the resin structure. The intensity of these bands is generally higher in 50% resin than in 40%, this indicates that a higher oil ratio increases interaction with phthalates, accelerating the esterification process.

The most profound changes of FTIR spectra in Figure 5 are also observed in the C–O–C ester region, around  $1260\text{--}1120\text{ cm}^{-1}$ . These bands become sharper and more intense in the resin, indicating that the number of ester bonds increases significantly after the reaction. In TO and LO, these bands are particularly strong in AR-TO-50 and AR-LO-50, indicating that the 50% resin produces a more dominant polyester structure. In CO, the increase also occurs, but not as sharply as in LO or TO, likely due to the longer carbon chain length and fewer unsaturated bonds, resulting in lower cross-linking.

In addition to the formation of new groups, it is also important to note that the characteristic oil bands such as  $2922$  and  $2852\text{ cm}^{-1}$  (aliphatic C–H) and the  $\text{CH}_2$  deformation band at  $740\text{--}705\text{ cm}^{-1}$ , still appear in all resins. This indicates that not all of the oil has reacted completely, and some fatty acid chains remain in the final resin structure. However, this presence is not detrimental, as these components can function to provide flexibility in the alkyd resin structure.

A comparison of alkyd resins combined with oil showed that the 50% composition produced a resin with stronger and sharper FTIR characteristics, particularly in the C=O, C–O, and aromatic bands. Therefore, adding more oil increases the potential for an esterification reaction due to a higher concentration of carboxyl and hydroxyl groups, which are generated by the cleavage of oil triglyceride bonds at high temperatures during the reaction. In AR-TO-50, these peaks are very prominent, indicating that tung oil is highly reactive despite its conjugated double structure, which is typically difficult to react with in conventional esterification reactions (Li et al. 2016). However, the success of this reaction indicates that esterification proceeded very well, despite the absence of prior epoxidation.

In AR-LO-50, the absorption results showed the most orderly and symmetrical ester structure, with more separated and cleaner peaks. This findings align with the work of Hadzich et al. (2023) regarding linseed oil as strong candidate for alkyd resins because its linolenic fatty acid structure supports the formation of stable and fast-drying resins (drying oils). Meanwhile, the resin from candlenut oil (AR-CO-50) also demonstrated successful esterification, but with slightly lower C=O and C–O band intensities. This may be due to the imbalanced ratio of saturated to unsaturated fatty acids in candlenut oil, or a lower purity level than TO and LO.

According to recent study by Zubair et al. (2023), oil-based resins with a high unsaturated bond content and strong aromatic structure have potential as replacements for petroleum-based resins. LO-50 resin is considered the most balanced in terms of ester bond formation, chemical stability, and rapid curing potential, while TO-50 excels in advanced reactivity and the possibility of further modification (e.g., for epoxy applications).

### 3.4 Curing test of alkyd resin

Curing tests were conducted on alkyd resin products with variations in solvent composition and amino resin additive ratios which had a significant effect on the drying time of the coating layer. Table 1, 2, and 3 present the results of the curing test.

Iodine number indicates number of double bonds in the oil used to make alkyd resin. These double bonds are important in the drying process because they contribute to the oxidative polymerization reaction. Oils with high iodine numbers, such as tung oil ( $102.44\text{ g I}_2/100\text{ g}$ ) and linseed oil ( $119.20\text{ g I}_2/100\text{ g}$ ), produced alkyd resins that were more reactive to air oxygen, resulting in faster drying times. Conversely, candlenut oil with a low iodine number ( $48.71\text{ g I}_2/100\text{ g}$ ) took longer time to dry, even at high solvent concentrations. At 20% and 40% solvent, alkyd resins containing 50% tung oil or linseed oil can dry in 1 day for alkyd resin:amino resin ratios of 60:40 and 50:50, respectively. This indicates that the

**TABLE 1.** Curing test for alkyd resin product with 10% solvent formula.

AAR Ratio (%w/w) (Alkyd :Amino)	Curing Time					
	Candlenut Oil ((%w/w)		Linseed Oil (%w/w)		Tung Oil (%w/w)	
	40%	50%	40%	50%	40%	50%
70:30	remained liquid	remained liquid	remained liquid	10 days	3 days	3 days
60:40	remained liquid	10 days	10 days	10 days	1 day	3 days
50:50	1 day	10 days	10 days	1 day	1 day	3 days

**TABLE 2.** Curing test for alkyd resin product with 20% solvent formula.

AAR Ratio (%w/w) (Alkyd :Amino)	Curing Time					
	Candlenut Oil ((%w/w)		Linseed Oil (%w/w)		Tung Oil (%w/w)	
	40%	50%	40%	50%	40%	50%
70:30	8 days	10 days	9 days	remained liquid	3 days	2 days
60:40	8 days	10 days	9 days	remained liquid	3 days	2 days
50:50	1 day	10 days	1 day	2 days	1 day	2 days

**TABLE 3.** Curing test for alkyd resin product with 40% solvent formula.

AAR Ratio (%w/w) (Alkyd :Amino)	Curing Time					
	Candlenut Oil ((%w/w)		Linseed Oil (%w/w)		Tung Oil (%w/w)	
	40%	50%	40%	50%	40%	50%
70:30	1 day	9 days	1 day	remained liquid	1 day	1 day
60:40	1 day	4 days	1 day	5 days	1 day	1 day
50:50	1 day	4 days	1 day	1 day	1 day	1 day

high content of eleostearic acid (a fatty acid with three double bonds) accelerates the oxidation reaction. Meanwhile, in the modified product with candlenut oil, the coating did not dry in 10% solvent because the low iodine value was insufficient to trigger effective oxidative polymerization.

Acid value indicates the amount of free fatty acids remaining in the resin. Free fatty acids can inhibit curing because they are hydrophilic and tend to absorb moisture from the air. Alkyd resins with a high acid value, such as 40% candlenut oil (25.14 mg KOH/g), exhibited longer curing times, especially at low solvent concentrations. Conversely, tung oil with a low acid value (8.31 mgKOH/g) exhibited faster curing results. At 20% solvent and a 50:50 ratio, candlenut oil required 1 day to cure, but only at higher alkyd resin concentrations, indicating that the excess free fatty acids limited the curing reaction. At 50% linseed oil and 40% solvent, the relatively low acid number (4.60 mgKOH/g) allowed curing times of 1 day for most alkyd-amino ratios.

Amino resin as a curing agent reacted with the active groups in alkyd resin, such as hydroxyl and carboxyl groups. Amino resin specifications used in this research is melamine-formaldehyde (MF). It is a type of thermosetting material and crosslinker produced by reacting an amine with an aldehyde (Erol and Acar 2024). Its key characteristics include high heat resistance, hardness, and excellent resistance to scratches and moisture (Yun et al. 2020). The addition of amino resin accelerates drying time, especially at a 50:50 ratio. This is due to the high number of reactive groups in the amino resin,

which support the cross-linking reaction with the alkyd resin. Amino resin increases mixture viscosity and creates cross-links between alkyd resin components, resulting in a denser, thicker film (Torlakoglu and Guclu 2009). Meanwhile, the unsaturated fatty acids in PFAD increase film flexibility and evenness. Increasing the PFAD ratio improves interaction with the amino resin, promoting even thicker film formation. This aligns with previous research by Rafiemanzelat and Shirini (2022), which demonstrates that the modified fatty acid reduced drying time and increased the gel content of alkyd resin. At 50:50 alkyd:amino ratio, almost all combinations of alkyd resin with linseed oil and tung oil dried within 1 day (this even applies to alkyd resin from candlenut oil, despite its low iodine value), indicating that increasing the proportion of amino resin facilitates the formation of a stable coating layer. At a 70:30 ratio, the mixture dried slowly or even failed entirely, as the amino resin concentration was insufficient to catalyze the curing reaction.

Solvent (xylene) helps to dissolve the alkyd resin and amino resin, creating a thinner and more even coating layer, thus accelerating drying time. Higher solvent concentrations (40%) showed the best results in curing time because the viscosity of the coating mixture was lower, facilitating the formation of a uniform film. Solvent 10%: At low concentrations, coating mixtures tend to have high viscosity, requiring longer drying times. Even with oils with high iodine numbers, such as linseed oil, drying times can still reach 3-5 days. Solvent 40%: At high concentrations, drying times were acceler-

ated to 1 day for most combinations, especially with linseed oil and tung oil. This was because the coating layer was thinner and allows oxygen to more easily penetrate the layer to initiate the curing reaction.

It can be concluded that the fastest drying time (1 day) was achieved with combinations of tung oil (40% and 50%) with 20% or 40% solvent, at alkyd:amino ratios of 60:40 and 50:50, respectively. Linseed oil (50%) with 40% solvent, at an alkyd:amino ratio of 50:50, respectively. Candlenut oil had a longer drying time or even no drying at all with low solvent (10%) due to its low iodine number and high acid value. The addition of amino resin up to a ratio of 50:50 and 40% solvent gave the best results to accelerate drying, especially for PFAD-based resins modified with linseed oil and tung oil.

#### 4. CONCLUSIONS

The alkyd resin with composition of 50% weight linseed oil and 50% weight tung oil modification is the best formulation for the characteristics qualified according to the Standar Nasional Indonesia (SNI 06-0504-1989), i.e. maximum acid value of 20 mgKOH/gram, as well as iodine number >100 g I<sub>2</sub>/100 g. The acid value of alkyd resin by modification with 50% linseed oil (AR-LO-50) and 50% tung oil (AR-TO-50) were 4.60 and 8.31 mgKOH/g sample, meanwhile the iodine number were 119.20 g I<sub>2</sub>/100 g (AR-LO-50) and 102.44 g I<sub>2</sub>/100 g (AR-TO-50). Based on the intensity and sharpness of the FTIR peaks, AR-LO-50 and AR-TO-50 can be considered the best structurally alkyd resins as well. The curing test results confirmed that the modified product complies with the required 1-day drying time standard for the best alkyd resin formulation as follows: candlenut oil 40% with 40% solvent and amino resin 50% weight; linseed oil 40-50% with 10-40% solvent and amino resin 30-50% weight; tung oil 40-50% with 10-40% solvent and amino resin 30-50% weight.

The modification of PFAD with vegetable oil conducted in this research provides a positive contribution to enhance the characteristics of alkyd resin product. Therefore, it is potential to be more developed with further research on the synthesis of PFAD-based alkyd resin modified with vegetable oil to produce coating material products with better characteristics and can be applied in the coating and paint industry.

#### 5. ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the Directorate of Research and Community Service (Direktorat Penelitian dan Pengabdian kepada Masyarakat – DPPM), Ministry of Higher Education, Science, and Technology (Kemendikristek), for providing research funding through the 2025 PDP Research Scheme under the contract number: 075/C3/DT.05.00/PL/2025.

#### REFERENCES

Aigbodion AI, Okieimen FE, Obazee EO, Bakare IO. 2003. Utilisation of maleinized rubber seed oil and its alkyd resin as binders in water-borne coatings. *Progress in Organic Coatings*. 46(2003):28–31. doi:10.1016/S0300-9440(02)0181-9.

Athariqa D, Oktapia SM, Dermawan D. 2022. Urea-formaldehid konsentrat sebagai bahan baku resin.

Rekayasa Hijau: Jurnal Teknologi Ramah Lingkungan. 6(1):11–21. doi:<https://doi.org/10.26760/jrh.v6i1.11-21>.

Erol T, Acar I. 2024. Ketone modification of alkyd synthesized from waste PET as a sustainable option: A Comparative study of coating and thermal properties of alkyd-melamine-ketone resin systems. *Polymer Engineering & Science*. 64(11):5259–5288. doi:<https://doi.org/10.1002/pen.26935>.

Hadzich A, Flores S, Masucci AE, Gomez ED, Grob GA. 2023. NMR and GPC Analysis of alkyd resins : influence of synthesis method, vegetable oil and polyol content. *Polymers*. 15(1993):1–14. doi:<https://www.mdpi.com/2073-4360/15/9/1993>.

Ikhuoria EU, Okieimen FE, Obazee EO, Erhabor T. 2011. Synthesis and characterization of styrenated rubber seed oil alkyd. *African Journal of Biotechnology*. 10(10):1913–1918. doi:10.5897/AJB10.681.

Janesch J, Bacher M, Padhi S, Rosenau T, Gindl-altmutter W, Hansmann C. 2023. Biobased alkyd resins from plant oil and furan-2,5-dicarboxylic acid. *ACS Sustainable Chemistry & Engineering*. 11:17625–17632. doi:<https://doi.org/10.1021/acssuschemeng.3c04346>.

Jumaah MA, Yusoff MFM, Salimon J. 2018. Physicochemical properties and analysis of Malaysian palm fatty acid distilled. *AIP Conference Proceedings*. 1940:1–6. doi:10.1063/1.5028007.

Li M, Zhang J, Xin J, Huang K, Li S, Wang M, Xia J. 2016. Design of green zinc-based thermal stabilizers derived from tung oil fatty acid and study of thermal stabilization for PVC. *Journal of Applied Polymer Science*. 44679:1–11. doi:10.1002/app.44679.

Mahendran AR, Aust N, Wuzella G, Kandelbauer A. 2012. Synthesis and characterization of a bio-based resin from linseed oil. *Macromo Symp*. 311:18–27. doi:10.1002/masy.201000134.

Nosal H, Nowicki J, Warzała M, Nowakowska-bogdan E, Zarebska M. 2015. Synthesis and characterization of alkyd resins based on camelina sativa oil and polyglycerol. *Progress in Organic Coatings*. 86:59–70. doi:10.1016/j.porgcoat.2015.04.009.

Nurandini D, Rochmadi R, Murachman B. 2018. Karakterisasi alkyd resin dari gliserol dan asam adipat yang dimodifikasi dengan minyak biji karet sebagai komponen surface coating yang ramah lingkungan. *Geosapta*. 4(2):139–142. doi:<http://dx.doi.org/10.20527/jg.v4i2.5170>.

Purnama KO, Setyaningsih DWI, Hambali E, Taniwiryono D. 2021. The opportunities of palm fatty acid distillate from palm oil industry in production of mono-diglyceride. *Perspektif*. 20(1):11–25. doi:<http://dx.doi.org/10.21082/psp.v20n1.2021.11-25>.

Rafiemanzelat F, Shirini Z. 2022. High solid alkyd resin coatings based on soya beans fatty acid with improved coating performance; The beneficial effects of fatty acid functionalized carbon nanotubes on their water-proofing and biodegradability. *Research Square*:1–28. doi:<https://doi.org/10.21203/rs.3.rs-1518045/v1License>.

Rochmadi R, Budhijanto B, Fahrurrozi M. 2017. Investigation on palm fatty acid distillate (PFAD) based alkyd resin and styrene as a coating material. *Materials Science Forum*. 901(July):173–181. doi:10.4028/www.scientific.net/MSF.901.173.

- Sahoo SK, Mohanty S, Nayak SK. 2015. Toughened bio-based epoxy blend network modified with transesterified epoxidized soybean oil: Synthesis and characterization. *RSC Advances*. 5(15069):13674–13691. doi:[10.1039/c5ra90007g](https://doi.org/10.1039/c5ra90007g).
- Santiasih I. 2016. A Review: The Secondary particulate matter from painting. *Purifikasi*. 16(1):54–66. <https://purifikasi.id/index.php/purifikasi/article/download/37/35/>.
- Shintawati, Widodo Y, Ermaya D. 2022. Yield and quality improvement of candlenut oil by microwave assisted extraction (MAE) methods. *IOP Conference Series: Earth and Environmental Science*. 1012:1–7. doi:[10.1088/1755-1315/1012/1/012024](https://doi.org/10.1088/1755-1315/1012/1/012024).
- Simasatitkul L, Arpornwichanop A. 2017. Economic evaluation of biodiesel production from palm fatty acid distillate using a reactive distillation. *Energy Procedia*. 105:237–243. doi:[10.1016/j.egypro.2017.03.308](https://doi.org/10.1016/j.egypro.2017.03.308).
- Suhendi E, Heriyanto H, Asyuni NF, Shahila IK. 2022. Synthesis of alkyd resin through alcoholysis-polyesterification process from used cooking oil pretreatment using alkaline activated natural bayah zeolite. *World Chemical Engineering Journal*. 6(2):57–65. doi:<http://dx.doi.org/10.62870/wcej.v6i2.17882>.
- Torlakoglu A, Guclu G. 2009. Alkyd – amino resins based on waste PET for coating applications. *Waste Management*. 29:350–354. doi:[10.1016/j.wasman.2008.02.018](https://doi.org/10.1016/j.wasman.2008.02.018).
- Uzoh CF, Onukwuli OD, Odera RS, Okey-Onyesolu CF. 2013. Synthesis and characterization of palm oil based air drying alkyd resin for surface coating. *Research Journal in Engineering and Applied Sciences*. 2(3):187–191.
- Yun X, Xin-yi Y, Dun-hong G, Yong-bo D, Liang S. 2020. Preparation and characterization of waterborne alkyd-amino baking coatings based on waste polyethylene terephthalate. *Royal Society Open Science*. 7(1-10):191447. doi:[10.1098/rsos.191447/554013/rsos.191447.pdf](https://doi.org/10.1098/rsos.191447/554013/rsos.191447.pdf).
- Zubair MF, Ibrahim SO, Stephen K, Hamid AA, Ibukun OJ, Atolani O. 2023. Synthesis and chemical characterization of alkyd resins using maleic and phthalic anhydrides and seed oil of luffa aegyptiaca. *Journal of The Turkish Chemical Society*. 10(3):689–702. doi:<https://doi.org/10.18596/jotcsa.1256237>.