

Synthesis of Palm Oil- Modified Polyester (Alkyd Resin)

Ifeoma Perpetua Oragwu, Okolo Azubuike Jeremiah, Obinna Peter Okwuego, Chinyere Emmanuella Okafor.

Department of Pure & Industrial Chemistry, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria.

DOI: <https://doi.org/10.51583/IJLTEMAS.2025.1409000017>

Received: 01 Aug 2025; Accepted: 08 Aug 2025; Published: 29 September

Abstract: Alkyd resin or polyester are polymeric compounds derived by poly-condensation reaction between triglycerides, polyols and phthalic anhydride. Their wide applications in surface-coatings and adhesives had motivated investigations into modification of some renewable, ecofriendly and low cost seed oils as alternatives to the synthetic counterpart. The oil was manually extracted from the seed-mesocarp of palm fruits by cooking, crushing, washing, reheating, decanting and evaporating, to remove excess water molecules from the isolated oil. The percentage yield of the extracted oil was 7.51 ± 0.001 , saponification value (203.57mgKOH/g; iodine value (53.01); specific gravity (0.88 g/ml); etc, were characterized by standard methods. The synthesis of the alkyd resin was carried out under a controlled temperature in a three neck-flask. Physico-chemical analysis of the palm oil modified resin compared well to the commercial grade, in relation to the viscosity, solubility, adhesion, dryness and Fourier Transform Infra-Red tests. Gardner Scale was used to examine the colour, while the refractive index of the oil was determined with Abbe's refractometer.

The impact strength and adhesion resistance of the dry alkyd resin films were determined using tubular impact tester (ASTM D1709/ISO 7765) and Cross hatch tester (ASTM 3359) respectively. Alkyd resin from renewable source, such as palm oil is an innovative approach to mitigating against pollution from thermosetting plastic wastes, and ensure availability of raw materials for

Keywords: Palm seed oil, Alkyd resin; Alcoholysis, Esterification, Characterization.

I. Introduction

Alkyd resin is a macro-molecular polyester, which could be used as film-forming agent in surface coating or adhesive formulations. They are polymerized by condensation reaction between triglycerides or monobasic fatty acids ($C_{18}H_5N$); polyols, such as glycerol ($C_3H_5(OH)_3$) and phthalic anhydride (an aromatic dicarboxylic acid ($CH_4(COOH)_2$)). They are widely used as binders, plasticizers, or compatibilizers in industrial and architectural constructional finishes, such as surface paints, adhesives, varnishes, etc. Many plant seed oils are under-utilized and more researches are required to their utmost industrial application. [1] observed the suitability of castor seed oil which was converted into plasticizer for auto car paint formulation.

Some properties of alkyd resins had made them very effective on wood or metallic materials to enhance their beauties, improve moisture or chemical resistance, durable, flexible, glossy, corrosion resistance, thermal resistance, etc., [2].

Researchers are working hard to synthesize alkyd resin from crude vegetable oils, because, they are biodegradable and not detrimental to health of both flora and fauna. [3] described alkyd resins from fossil fuel as one of the major causes of greenhouse gases, that affect human ecosystem and its inhabitants. They carefully modified some renewable biomass-derived monomers to generate biodegradable alkyd resin, which could decompose when they are no longer useful.

This innovation in modification of thermosetting plastics, such as alkyd resin, will alternatively reduce the over-dependency on fossil fuel products and improve green chemistry, mitigate against pollution and ensure eco-friendly environment.

However, the quality of alkyd resin could be determined based on the oil lengths, which is the percentage of fatty acids composition of the oil, [4]. They reported that long oil length alkyd resins consist of more than 60 % of fatty acids, medium oil alkyd resin consists of 40 – 55 % fatty acids, while short oil alkyd resin has less than 40% of fatty acids. Reports had shown that long alkyd resin are more flexible, has slow drying time and are better for exterior coatings. Short oil alkyd resins are good for metal coatings as primers, because they are harder. However medium oil alkyd resins have intermediate properties of the former. Alkyd resins generally are made up of polyester backbone through polymerization of polyols, acid anhydrides and isophthalic acid or diacids, [5]. [6] and [7] discovered that different seed oils could be blended to achieve a desirable length oil-length in the synthesis of polyester resins. They used melon seed oil and rubber seed oil to blend linseed and soybean seed oil respectively. It is very necessary to impact biodegradation properties into polyesters because these class of organic thermosetting plastics cannot be recycled, reshaped or degrade when they are not useful again, [8] and [16].

The thought of modifying alkyd resin from renewable seed oil is an innovative approach towards controlling waste alkyd resins and eradicating its detrimental pollution effect to human health and the environment. They suggested that various qualities of resins, such as, adhesiveness, glossiness, dryness, and moisture/chemical resistance properties of alkyd resins could be improved by natural oil modification.

Palm seed oil is a natural source vegetable oil, which is extracted from the mesocarp of the fruit or from the endocarp of the kernel seeds, [9]. The African specie of oil palm tree (*Elaeis guineensis*) is one the most sustainable economic plants, because of

its commercial relevance. The stem and fronds could be used in building houses, bridges or furniture constructions; artistic works such as basket, clothing, hats, mats, etc. The oil could be used in cleansing or skin-beauty products, in food/drug formulations, agricultural mulching, in erosion control; the hard seed shell is good in combustion and road repair. The palm trees are also good in balancing carbon dioxide and oxygen circle around the environment, according to, [10].

The palm seed oil which are the cheapest vegetable oil accounts for about 33 % of the global oils from natural source and the fiber could also be used as pulp, paper or polymer-composites [11] and [12].

The major oils isolated from palm fruit are the palm oil (PO) and palm kernel oil (PKO). [13], recorded that palm oil is rich in triglycerols, vitamin E, carotenes, phytosterols, phospholipids, free fatty acids, gum, etc. Palm oil is considered to be oxidatively stable due to the concentration ratio of saturated and unsaturated fatty acids, such as tocopherols, tocotrienols and carotenoids, [14]. Palmitic or hexadecanoic acid ($\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$) is about 40 % and is the highest fatty acid content in palm oil. Oleic acids, stearic acid, linoleic acids are also in high concentration. It also consist of high percentage of vitamin E and other minerals. Palm oil had been reported to consist of 50 % of saturated fatty acids, 40 % monosaturated fatty acids and 10 % polyunsaturated fatty acids, [14, 15]. The synthesis of alkyd resin from renewable source such as palm oil is an innovative approach towards management of pollution menace from thermosetting plastic wastes.

II. Materials and Method

Materials

The chemicals and reagents used in this synthesis are:

3 ml of 5 M of methanol, 2 ml of xylene (Anal grade), 28 g of phthalic anhydride, 5 g of glycerol, 2 g of lead oxide (catalyst), phenolphthalein indicator, potassium hydroxide, ethanol, cobalt (used as dryer) and 1000 ml of extracted palm oil sample.

Apparatus and equipment used includes: manual grinding machine; Brookfield viscometer, Fourier Transform Infra-Red Spectrometer (FTIR), Abbe's refractometer, Ohaus digital weighing balance, three-neck glass flask, thermometer, stirrer, 500 ml glass beakers, 1000 ml electric heating mantle(220 volts), mortar and pestle, etc.

Extraction of the palm oil

Isolation of palm oil from palm fruit mesocarp

Fully ripped palm fruits were carefully removed from the large fruit bunch using a sharp knife. These fruits were thoroughly washed with clean water, 2 kg of the fruits were cooked until softened. The heat softened fruits were pounded the wooden mortar to separate the seed kernel (endocarp) from the mesocarp. This was allowed to cool, washed again with cold water, allowed to sediment. The mixture was decanted and set to boil. Evaporation process was applied to separate the oil and water molecules. After separation, the oil phase was carefully decanted, heated further to removed excess water, filtered and stored in a clean container for other investigations.

Percentage yield of the palm Oil

This was determined on the extracted palm oil, according to Vogel, (2020) and calculated using the formular below:

$$\text{Percentage Yield (\%)} = \frac{\text{weight of extracted oil}}{\text{weight of dry seed powder}} \times \frac{100}{1}$$

Specific gravity or density of the palm oil

The oil sample was poured into 10mls measuring cylinder previously weighed and recorded as W_1 . The cylinder with oil content was recorded as W_2 . Mass of palm oil samples were the difference between the two. The ratio of the mass per unit volume is the specific density (g/cm^3) and was calculated thus:

$$\text{Specific gravity} = \frac{W_2 - W_1}{V(\text{volume})} \quad \text{NB: } W_2 \text{ is the measuring cylinder with palm oil and } W_1 \text{ is empty cylinder}$$

Determination of Refractive Index of palm oil sample

Abbe's refractometer was used to determine the refractive index of the palm oil at 30 °C. The values were recorded after three determinations.

Estimation of Saponification Value

5 g of palm oil sample was weighed into a 250 ml conical flask. A 50 ml pipette of alcoholic KOH was added into the flask and refluxed for 30 minutes. 0.5 M HCl was added to the mixture after cooling. Phenolphthalein indicator was used to dictate the colour change. Blank determination was carried out with same procedure and the value calculated thus:

$$\text{Saponification Value} = \frac{28.05(B-S)}{\text{Weight of Oil}}$$

Where B is volume (ml) of 0.5 M HCl required to titrate blank; S is volume (ml) of 0.5M HCl required to titrate the oil sample.

Oil Colour using Gardner Scale

20 ml of the palm oil was filled into the glass cuvette and placed in compartment of the Gardner Scale. The oil colour was observed, according to (0.5 ASTM Color) standard.

Determination of Acid Value (ASTM D664)

The indicator used was phenolphthalein. 7.00 g of the crude oil sample was weighed into 250 ml conical flask and 50 ml of 1 M alcohol added. Few drops of the indicator was added into 0.14 M sodium hydroxide solution, and agitated vigorously until a permanent pink colour appeared after few minutes.

Percentage free fatty acid was expressed as oleic acid, and was calculated thus:

$$\text{Acid Value} = (V_{eq} - b_{eq})N \frac{56.1 \text{ g/mol}}{\text{Oil Weight(g)}}$$

Where: V_{eq} is volume of titrand at equivalent point? b_{eq} is titrant at equivalent point, while; 56.1 g/mol. is molecular weight of NaOH.

NB: NaOH is the titrant and Crude oil is the titrand

$$N = \frac{1000 \times \frac{W_{KHP}}{204.23}}{V_{eq}}$$

Where: W_{KHP} is mass (g) of potassium hydrogen phthalate (KHP) in 50 ml of standard solution.

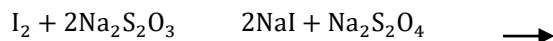
V_{eq} is the volume of titrant (ml) consumed by 50 ml KHP standard solution at the equivalent point, and 204.23 g/mol. is the molecular weight of KHP.

Determination of Iodine Value using Wijs method

The amount of unsaturated fatty acids was determined by calculating the iodine value. Iodine was slowly absorbed by the oil, while it was rapidly taken up by Wijs solution. The Wijs solution is a solution of iodine monochloride (ICl) dissolved in glacial acetic acid and carbon tetrachloride, as shown in the equation 1 below. The unsaturated bonds present took up the iodine to saturate the double bonds and the remaining unabsorbed iodine is then titrated by using sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_4$).



Equation 1. Reaction for iodine value determination



The iodine value was calculated using the formula: $\text{Iodine value} = \frac{(B-S) \times M \times 12.69 \times 100}{W(\text{Weight of oil})}$

Where: B is blank titre of sodium thiosulphate solution (amt. of oil present). S is volume of standard sodium thiosulphate solution required; M is molarity of sodium thiosulphate solution ($\text{Na}_2\text{S}_2\text{O}_3$). W= weight of oil samples and 12.69 is a conversion factor.

Synthesis of Alkyd resins

100 ml of palm oil was heated at 80 °C in a three necked round bottomed flasks to reduce water molecules or moistures. After this, the oil was subjected to the process of modification into alkyd resin and this was carried out in two stages:

Alcoholysis Stage:

10 g of the palm oil was transferred into the three necked flask, 5 g of glycerol was added to it and 0.2 g of lead oxide was used as catalyst to form the monoglyceride. The heat was maintained at 230°C for 1 hour for a complete reaction. The solubility of 1 ml of the heated mixture in 3 ml of methanol showed that alcoholysis reaction is complete and a monoglyceride was formed. The mixture was allowed to cool to 140°C, before the esterification process.

Esterification Stage

3.0 g of phthalic anhydride and 2 ml of xylene, were added to monoglyceride sample mixtures and heated to 230°C for 4 hrs to remove water molecules. The acidity values of the sample was determined at 30 min intervals until the stable pH drop was achieved. This polymerization process was inhibited by dipping the reaction system in cold water. The alkyd resin formed was allowed to cool down before subjecting it to further properties tests.

Physico-chemical characterization of the alkyd resin**Determination of viscosity**

Brookfield Viscometer was used to determine the viscosity of the alkyd resins at 30 °C. After rinsing the cup with organic solvent (acetone) and allowed to dry, small quantity of the resin was transferred into the viscometer with micro pipette to fill the mark. A stopwatch was set before releasing of the sample. The time taken for the resin to flow from the point of origin to the calibrated mark was recorded and multiplied by a constant factor (0.2483m²/s)

Solubility of the alkyd resin sample

The solubility of the modified palm oil was tested in different solvents, by dropping 1 g of the resin into glass beaker containing 5 ml of these solvents; xylene, benzene, toluene, acetone, ethanol and methanol.

Test on drying process

The drying process was monitored in terms of time to set-to-touch, surface-dry and hard dry. The alkyd resins from palm oil was dissolved in xylene mixed with drying agents (cobalt naphthanate). This was applied on clear glass panels and allowed to dry at room temperature.

Determination of chemical resistance according to (ASTM D 543 standard)

Glass panels with alkyd resin film on one end were coated with wax in order to prevent migration of film from the open end. The panels were then dipped into water, 3 % (V/V) Dil. HCl, and 1 % (W/V) NaOH, respectively. The change in appearance at the interval of 30 mins were noted by recording the first noticeable attack on the glass panels.

Impact strength

The impact strength of the dry alkyd resin films was determined using tubular impact tester according to ASTM D1709/ISO 7765

Adhesion Test (ASTM 3359)

Cross hatch tester was used to test the adhesion of the dried films. A scope tape was imprinted onto the film and peeled off quickly at 180° angle. The peeled off grid of areas on the tape were observed by a magnifier.

Pendulum hardness

This was done using pendulum hardness tester, to determine the viscoelastic behavior of the alkyd resins.

viii. Fourier Transform Infra-Red Spectrometer (FTIR) Test

FTIR spectrometer was used to identify the bond formations, qualitative compositions of the crude palm oil and modified alkyd resin sample. Standard interpretation according to the peaks of different absorption spectrum were taken to identify the bonds, organic and inorganic compositions of the alkyd resin samples.

III. Results and Discussion**Results on the Characterization Tests on Palm Oil (PO)**

The values of three determinations on the percentage yield of palm oil as stated on Table 1, is 21.51 ±0.001%. The yield shows that palm oil is a good raw material for many commercial purposes and in conformity to the yield of most vegetable oils, [14] and [15]. The slight decrease in the yield could be attributed to the specie of palm fruits used and method of oil extraction.[16], suggested that vegetable oils with considerable percentage yields are suitable for commercial production of toiletries, cosmetics, and other skin- care products.

The saponification values of the oil was 203.57 mg KOH. [17], concluded that bio-resins from with high saponification values are better than those with low values. They researched on many seed oils and discovered that, saponification values of soy beans (191.50 mg KOH) and breadfruits seed oil (161.30 mg KOH/g) compared well to our research sample palm seed oils. They concluded that seed oils with high saponification values can undergo alkaline hydrolysis to produce glycerol and soap.

The iodine value for the sample palm oil (PO) gave 53.01 as stated in Table 1. Some reports had shown that oils with low iodine values could be as a result of high concentration of saturated fatty acids, [18]. They suggested that, oils having iodine values more than “130” are drying oils; those between “115 – 130” are semi-drying oils; but those below “115” are non-drying oils. High iodine value means high concentration of unsaturation more double bonded carbon atoms C=C according to, [19] and [20]. They concluded that, double bonds are reactive sites for epoxidation of bio-resins. Rancidity and shelf-life of seed oils could be predicted by their iodine value.

The result of the specific gravity (0.888 g/ml) is given in Table 1. Researchers have recorded the specific gravity of palm seed oil to range between 0.888 to 0.931 g/ml. [21] and [22], emphasized that, the differences could be due to the method of processing or extraction of the oil.

The acid value of the palm oil sample is 2.86 mg KOH/g, which is within the range of most vegetable oils. [23]; [22];[19] and [25] reported on acid values of other seed oils, such as mango seed oil (3.31 mg KOH/g), hemp seed oil (2.15 mg KOH/g), and soya bean oil (1.05 mg KOH/g). [25], concluded, that the high acid value of mango seed oil (3.31 mg KOH/g) indicates that, it has high concentration of free fatty acids and carboxylic acid groups.

Researches had shown that, the lower the acid value, the lower the concentration of free fatty acids, reduced carboxylic acids molecules and lower the rate of rancidity of the oil, [26].

Table 1: The Results of Characteristic Properties of Palm Oil (PO)

Parameter	Palm Oil
Percentage yield (%)	21.51 ±0.001
Saponification value (mgKOH/g)	213.750
Acid value (mgKOH/g)	2.860
Iodine value(Wijs)	53.010
Peroxide value	1.500
Density(g/ml)	0.888
Free fatty acid (%)	3.710
Colour(Gardner scale)	16.00

NB: % = Percentage; g/ml = gram per millilitre; mg KOH/g = milligram Potassium Hydroxide per gram.

Table 2: Properties of Palm Oil Alkyd Resins as Compared to Commercial Grade.

Physico-chemical Properties	Palm Oil Alkyd Resin	Commercial Alkyd Resin
Colour (Gardener scale)	17	11
Viscosity @ 25 °c	384cp	457cp
Gloss level	fair	standard
Drying time (hrs): set-to-touch, surface-dry hard dry	 5.3 5 – 7	 3-4 5
Chemical resistance: 1% HCl 2% NaOH Cold water Hot water	 fair poor excellent good	 fair poor excellent good
Solubility: Xylene Benzene Methanol	 fair fair good	 fair fair good

Table 2 represents the results of some physico-chemical analysis carried out on the palm oil modified alkyd resin sample as compared to the commercial grade. The palm oil modified resin exhibited the viscosity of 384cP, while the commercial grade was 457cP at the temperature of 25 °C. We therefore, suggested that, most bio-alkyd resins exhibit comparable lower viscosity value

than synthetic ones. They confirmed that bio-resins having up to 100cP to 1000cP are suitable for surface coatings, gluing, bonding, etc, because of their higher molecular weight.

The result of Gardner scale colour test, showed the values of 17 and 11 for palm oil alkyd resin (POAR) and commercial alkyd resin (CAR) respectively. The higher concentration of fatty acids in POAR could be attributed to the darker colour of the alkyd resin, while, the commercial grade showed faint yellow colour. They demonstrated that POAR has better hiding capacity than the commercial resin (CAR), which is more suitable for colour reflections.

The drying times of POAR were generally higher than that of CAR. This could be as a result of some additives or amount of fatty acid concentrations in the different oil samples. The results on the research alkyd resin also showed good chemical resistance and solubility properties compared to the commercial grade, as displayed on Table 2.

Result of FT-IR (Fourier Transform Infrared) on the Raw Palm Oil

The results of the FTIR spectra of the crude palm oil are represented in Fig.3. The spectra showed a long stretching absorption at 3600cm^{-1} , which corresponds to the hydroxyl (OH) groups of the unsaturated fatty acid the oil. The sharp peak of carboxyl group ($\text{C}=\text{O}$) is indicated at 1747cm^{-1} . The symmetric straight chain of $-\text{CH}_2-$ stretch of an aliphatic compound is found at the absorption band 2854cm^{-1} . Alkene group ($\text{CH}=\text{CH}$) is attributed to band 3000cm^{-1} . The spectra/peaks from the FTIR analysis revealed all the properties of palm oil. [27], studied the FTIR and GC-MS absorption of palm oil and palm kernel seed oil in other to monitor the suitable one for laundry soap making. They observed absorption peaks of methylene group at $723, 2855, 2922\text{ cm}^{-1}$ and 1744 cm^{-3} for carbonyl group spectra and concluded the oil with higher level of unsaturated fatty acids.

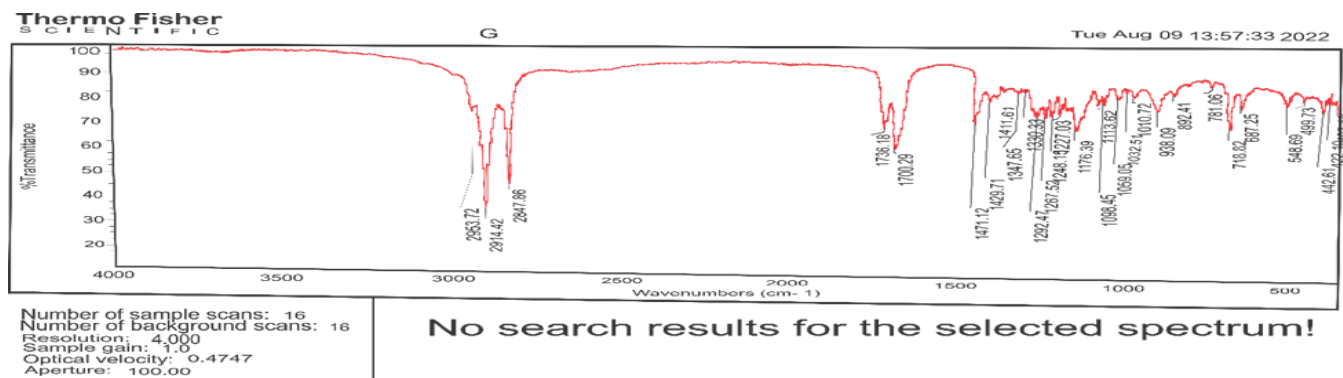


Figure 3: FITR absorption of Raw Palm Oil

Result of FTIR Analysis of Palm Oil Modified Alkyd Resin

The results of FITR analysis carried out on the sample alkyd resin, as displayed in Figure 4, revealed the straight ester chain at 1738.64cm^{-1} and aromatic ($\text{C}=\text{C}$) ring at 1730.09cm^{-1} . The presence of $\text{O}=\text{C}-\text{O}-\text{C}$ also exhibits the characteristics ester band at 1125.62cm^{-1} and the absorption band at 3008.99cm^{-1} , which is characteristic of alkene groups. This $\text{O}=\text{C}-\text{O}-\text{C}$ group and ester ring band of 1730.09 cm^{-3} was not observed in FTIR of crude oil. The appearance of ring ester band at 1730.09cm^{-1} therefore confirms modification of palm oil from the reactions between monoglyceride and phthalic anhydride,[28, 29]. The result shows that quality alkyd resin could be synthesized from agro-materials such as palm oil modification.[30]

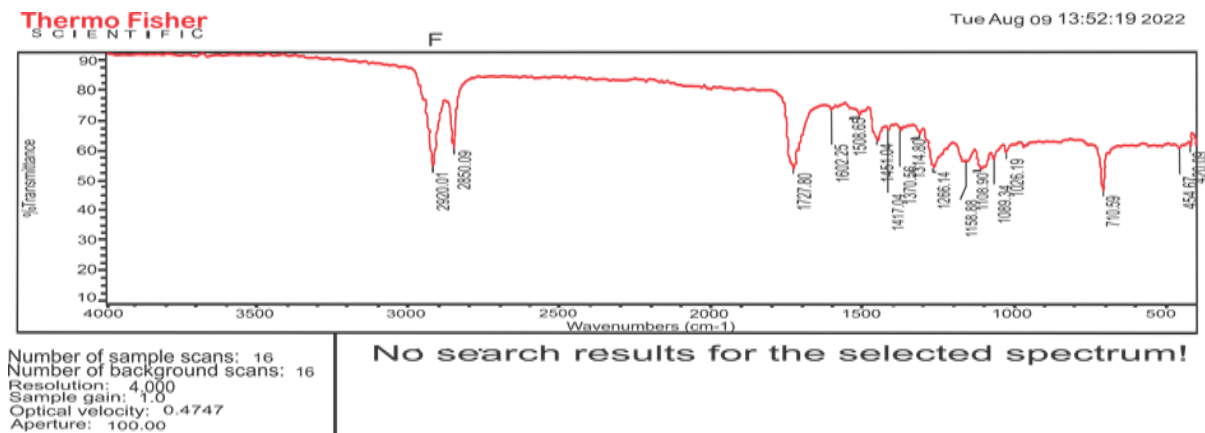


Figure 4: FTIR Spectra of Alkyd Resin from Palm Oil.

IV. Conclusion

Alkyd resin is an inevitable raw material that could be prepared by modification of vegetable and are extensively used by surface-coating, or adhesive industries. These polyesters from modified seed or vegetable oils are renewable, cheap, eco-friendly, always available, and easy to process than the synthetic types. Some of the FTIR analysis revealed bonds of ester-formation on the research palm oil resin in contrast to the spectrum discovered from the crude palm oil molecular chain. Our sample alkyd resin showed longer drying time than the commercial, which could be due to the higher concentration of fatty acids in the palm oil. This may be the reason for the better hiding property of our research alkyd resin. The chemical structure and functional groups of both the palm oil and the alkyd resin are confirmed with FTIR absorption spectrum. The physico-chemical test results of the palm oil alkyd resin compared very well to the commercial grade, therefore, surface coating industries may investigate further in using palm oil for quality alkyd resin. This is an innovative approach to the application of green chemistry in mitigating against pollution from thermosetting plastic wastes.

Reference

1. Ifeoma Perpetua Oragwu, Joseph Onyebuchi Nwadiogbu, Azubuike Jeremaih Okolo, Chika Enujekwute, Genevieve Adinnu.(2023) Alkyd Resin Synthesis from Mango Seed Oil (*Mangifer Indica*, *Anacardiceae*). American Journal of Polymer Science and Technology. 9, No. 4, 2023, pp. 55-62. doi: 10.11648/j.ajpst.20230904.12
2. Ifeoma Perpetua Oragwu^{1*}, Chigozie Nwankpa², Azubuike Jeremiah Okolo¹, Chinyere Emmanuella Okafor (2024) 'Comparative Studies on Alkyd Resins from Palm (*Elaeis guineensis*) Oil and Mango(*Mangifera*) Seed-Oil. Open Journal of Polymer Chemistry, 14, 199-213. <https://www.scirp.org/journal/ojpchem>.
3. Konda Reddy Kunduru; Shady Farah; Krishanu Ghosal; and Merna Shaheen-Mualim (2023). Renewable Polyol-based Biodegradable Polyesters as Greener Plastics for Ind. Applications, Chemical Engineering Journal, 459(1), 141211 <https://doi.org/10.1016/j.cej.2022.141211>.
4. Oragwu, I. P., (2013). Automotive (Car Paint), From Local Raw Material, Castor-seed Oil (*Ricinius Communis*) As Plasticizer," American Journal of Engineering Research, vol. 2 (11), page 272- 275. Dio. 30.0847/211272275; www.ajer.org
5. Joris Hulsbosch^a, Laurens Claes^a, Dries Jonckheere^a, Dirk Mestach^b and Dirk E. De Vos (2018). Synthesis and characterization of alkyd resins with glutamic acid-based monomers. Advanced Royal Sciences Journal. 8, 8220-8227. DOI: 10.1039/C8RA00060C
6. Isaac Ogbennaya Igwe, Ifeoma Perpetua Oragwu and Chinedu Nwapa (2024). Analysis of Sustainable Polyester Tiles of Domestic Waste. Journal of Polymer Science and Technology 8(1) ;14-22, Polymer Research Centre, ISSN: 255-1917.
7. Elabor; I. O. Bakare; E. U. Ikhuoria; F. E. Okieimen; A. I. Aigbodon (2023). Synthesis and Characterization of Alkyd Resins from Rubber Seed/Soybean Oil Blends, Nigerian Journal of Technology, 42 (3): DOI: <https://doi.org/10.4314/njt.v42i3.4>.
8. Ikhuoria Hilary Ifijen; Nyaknno Udokpoh; Gregory E Onaiwu ;Esther Ikhuoria(2022). Coating Properties of Alkyd Resin, Epoxy Resins and Polyurethane Based Nanocomposites: A Review. Momona Ethiopian Journal of Science 14 (1):2220-184
9. Murphy, D.J., Goggin, K. & Paterson, R.R.M. (2021). Oil palm in the 2020s and beyond: challenges and solutions. CABI Agric Biosci 2, (39).
10. Khanh Phan; Tuyen Truong; Yong Wang; Bhesh Bhandari(2024). Impact of Carbon Dioxide Nanobubbles on Crystallising Properties of Palm Oil. Food and Bioprocess Technology 17(11):4290-4302.
11. Jaya, Prasanth Rajakal, Jason Zhao Hong Hawang, Mimi H. Hassim, Vinesh Andiappan, Qian Thong Tan, and Denny, K S. Ng (2023). Intergration and Optimization of Palm Oil Sector with Multiple- Industries to Achieve Circular Economy. Journal of Sustainable and Consumption, 40, (8), 318-336.
12. Elizabeth Tobi Adewale, Katayat Yemisi, Belewu and Opeyemi Eytayo(2024).Seasonal Price Variation Analysis of Palm Oil Case Study of Nigeria Springer Nature, 4(116).
13. Annamaria Mancini, Esther Imperlini, Ersilia Nigro, Concetta Montagnese, Aurora Daniele Stefania Orrù, and Pasqualina Buono (2015). Biological and Nutritional Properties of Palm Oil and Palmitic Acid: Effects on Health, Molecules 20, 17339-17361.
14. Tong Si, Xiaoyng Wang, Yuhao, Zhou, Wei, Xie, Haiyan Yuan, Yuefu, Wang and Yuming, Sun (2022). Seed Yield and Quality Responses of Oilseed Crops to Stimulated Nitrogen Deposition: Ameta-analysis of Field Studies, GCB-Bioenergy vol., 14(18), 959-971.
15. Aka B.L., Nwadiogbu, J.O., Oragwu, I.P., Igwe, D.O., A. S.C., Eberendu, K.O., Nlemchukwu, and B. N. C. (2025). Acetylation and Characterization of African Star Apple Kernels for preparation of Crude Oil Sorption Active Material: Physicochemical Properties, FTIR Spectroscopy, and Surface Morphology Analysis, Human Daxue Xuebao/ Journal Human University Natural Sciences. vol. 62(05), 54-66.
16. Chirico, Maria Vincena^a, Nikolas Galli^b, Monia Santini^a, Maria Cristina Rulli (2024). Deforestation and greenhouse gas emissions could arise when replacing palm oil with other vegetable oils, Science of The Total Environment, 914,(1) 169-486.
17. Oragwu and Ugwu (2021). Essential Oils from Lemon Peel (*Citrus Lumion*) Application in skin-care lotion. American Chemical Science Journal, 30(9): 30-38.

18. Jumat Salimon, Bashar Mudhaffar, and Nadis Salih(2012). Saponification of Jatropha Curcas Seed Oil: Optimized by D-Optimal Design. *International Journal of Chemical Engineering*, 2012(1), 1-6.
19. Toshisada, S., Kazuki, S., Kazuhiro, F., and Takeshi K., (2021).Iodine value of Tung biodiesel fuel using wijs method is significantly lower than calculated value. *Journal of Wood Science*, 67(55), 998.
20. Nathan, W.M.(2013). Development of hemp oil based bioresins for biocomposites. A Dissertation submitted for the award of Doctor of philosophy. Centre of excellence in engineered fibre composites. Faculty of engineering and surveying University of Queensland, Australia.
21. Wool, R.P. and Sun, X. S. (2005). *Bio-based Polymers & Composites*. Elsevier Academic Press,Walth. Chap. 1-5.
22. Uzoh C.F, Onukwuli O.D, Odera R.S, Okey-Onyesolu C.F. (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.
23. Nursyazana, B.T. and Nazri, M.D. (2014). Production of bio-resin from Palm oil. Unpublished thesis submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Chemical Engineering Faculty of Chemical & Natural Resources Engineering. Malaysia Pahang
24. Oragwu Ifeoma P.*, Okolo Azubike, J., Emmanuel Ifeanyi V., Okoli Precious O., Osuagwu Collins C., Onyia, Okwudili E., Usiakpebru, Austin A., and Okechukwu James O.(2021). Phytochemical and Proximate Composition of Cucumber (*Cucumis Sativus*) Seed Oil *International Journal of Research and Scientific Innovation (IJRSI) | 8(02)*. Pp, 244-250 www.rsisinternational.org.
25. Ifeoma P. Oragwu, Joseph Nwadiogbu, Enejekwute Chika, Genevieve O. Adinnu. (2023). Alkyd Resin Synthesis from Mango Seed Oil (*Mangifer Indica*, Anacardiceae). *American Journal of Polymer Science and Technology*, 9(4), 55-62.
26. Dike, M. C. and M.E. Asuquo (2012). Proximate, phytochemical and mineral compositions of seeds of *Allanblackia floribunda*, *Garcinia kila* and *Poga oleosa* from Nigerian rainforest. *Afr. J. Biotech.* 11 (50): 11096-11098.
27. Elisha, E., Idisis, Y., Timor, U. & Addad, M. (2010). Typology of intimate partner homicide: Personal, interpersonal and environmental characteristics of men who murdered their female intimate partner. *International Journal of Offender Therapy and Comparative Criminology*, 54 (4), 494-516
28. Jacob, A.G., Musa, I., and Ogbesejana, A. B. (2024). Extraction, FTIR and GC-MS Characterization for Laundry Soap Production, *Scientia Africana*, 23(3):185-195
29. Peter Obinna Okwuego, Chigbo Adaobi, Franklin Okpala and Ifeoma Perpetua Oragwu(2025). Spectral Characterization of Polyvinyl Acetate and Its Modified Mercury Complex, Exploring It's Structure and Applications. 6(4), 51-63. *Research Journal of Pure Science and Technology (RJPST)*. DIO 10.56201/RJPST; www.iiardjournal.org
30. Okerie Micheal J., Nwadiogbu Joseph O., Oragwu Ifeoma P., Aka Beatrice L.(2025). Adsorption of Lead Ions from Waste-Water Using Raw and Nano- Composite Agro Waste *Spondias Mombin*, *Scholar International Journal of Chemistry and Material Sciences*, vol.8(3), 1-14, <https://dio.org/10.36348/sijcms.2025.v08i3.00X>; <http://saudijournals.com>