مجلة
كلية التــراث الجامعة

مجلة علمية محكمة
متعددة التخصصات نصف سنوية
العدد الأربعون
30 آب 2024
ISSN 2074-5621

رقم الايداع في دار الكتب والوثائق 719 لسنة 2011

مجلة كلية التراث الجامعة معترف بها من قبل وزارة التعليم العالي والبحث العلمي بكتابها المرقم (ب 3059/4) والمؤرخ في (2014/ 4/7)

Preparation of Alkyd Resin from Different Vegetable Oils: A Review

Wisam Adnan Hameed, Mohammed Nsaif Abbas

Environmental Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.

Abstract: The preparation of alkyd resins from vegetable oils represents a vital and pivotal topic in the realm of green chemistry and alternative materials development. This review provides an overview of the methods utilized in converting various types of vegetable oils into alkyd resins, with a focus on the chemical processes and operational conditions employed. The article encompasses a review of organic acids used as catalysts to facilitate decomposition and condensation reactions for the formation of alkyd bonds. Additionally, it highlights recent advancements in this field, such as the use of nano-material additives and different techniques to enhance process efficiency and improve the final properties of the resins. Furthermore, the review addresses the challenges and future opportunities in this domain, emphasizing the importance of directing research towards developing alkyd bonds from vegetable oils with added value. The review includes further details on the processes and techniques utilized in this field, contributing to a comprehensive understanding of the subject matter. Moreover, it underscores the significance of sustainable and environmentally friendly utilization of natural resources.

Keywords: Alkyd resin, vegetable oils, esterification, polymer, operating conditions, catalysts

Introduction: The growing interest in eco-friendly materials among consumers and industries has led to an increased utilization of environmentally sustainable agricultural sources as feedstock for the production of valuable polymers [1]. Over the years, a diverse array of environmentally friendly chemicals has been synthesized from various renewable natural resources [2]. The Earth is abundant with a diverse array of herbs and plants, generously providing an array of bio-based feedstocks that can be customized to create numerous invaluable materials [3]. A wide array of polymeric materials with infinite possibilities has been derived from renewable sources, including lignin, starch, wool, fiber, vegetable oils, and various others. These materials hold immense potential across numerous practical applications, serving as plasticizers, biomedical engineering components, biodegradable packaging materials, adhesives, coatings, biological devices, and binders for paints [4]. Among the plethora of renewable resources available, vegetable oils derived from a variety of seeds emerge as a prime choice for chemical industries. These oils present a multitude of advantages, including cost-effectiveness, environmental friendliness, low toxicity to humans, and biodegradability. They exist predominantly as triglycerides composed of both unsaturated and saturated fatty acids [5]. A wide array of polymeric materials, boasting considerable potential, has been successfully synthesized from vegetable oils [6]. A classic example of polymers derived from triglyceride oils is the polyester resin, commonly referred to as alkyd resin. This traditional polymer has been widely utilized across various industries for its versatile properties and applications [7].

Alkyd resins occupy a prominent role within the coatings, paints and various industries due to their cost-effectiveness, ease of application, and dependable ability to safeguard materials against degradation circumstances [5–8]. Moreover, they are recognized as biodegradable polymers due to their recurring ester functional groups [7, 8]. Dry and non-complete dry oils, originating from *Jatropha curcas*, coconut, rubber, palm, soybean, sunflower, castor, canola and linseed oils, are typically preferred over non-dry oils in the formulation of oil-modified polyesters. This preference stems from the consistent objective of producing alkyd resins with optimal drying characteristics [9]. In addition to the previously mentioned unconventional vegetable oils, semidrying oils have been extracted from a variety of sources including orange seeds, soybeans, rubber seeds, Jatropha curcas, Albizia benth, and tomato seeds for the synthesis of polyester resins [10]. Despite the emergence of alternative surface coating materials like latex resins and powder coatings in recent times, alkyd resins persist as a cornerstone for various applications owing to their optimal blend of cost-effectiveness and performance [11]. In fact, alkyd resins constitute approximately 70% of the traditional binders employed in the coating industry, significantly influencing coating attributes such as adhesion, durability, and gloss. Alkyd resins exhibit favorable characteristics as coatings, including notable film hardness, glossiness, durability, and gloss retention, all attributed to their inherent oil drying properties [12]. The conversion of vegetable oil into alkyd resin holds promise, yet thorough investigation of each raw material's potential is imperative. As the raw materials utilized in alkyd resin production often overlap with those used in food manufacturing, exploring alternative plant sources that do not compete with food industry demands becomes essential [13]. This necessitates a careful examination of various plant alternatives to ensure sustainable and ethical sourcing practices while fostering innovation in alkyd resin production. In light of dwindling petroleum resources and escalating apprehensions regarding environmental sustainability, the quest for alternative raw materials in alkyd resin production has intensified [14]. Vegetable oils, characterized by their abundance and renewability, emerge as a promising recourse. Leveraging modified derivatives of vegetable oils not only diminishes reliance on fossil fuels but also mitigates carbon emissions, marking a significant stride towards ecological stewardship and resource efficiency [15]. Furthermore, alkyd resins derived from vegetable oils boast distinctive properties, including renewability and biodegradability, rendering them significantly more environmentally sustainable compared to their original petroleum-derived [16]. The aim of this article is to review the ability of producing alkyd resin from various types of vegetable oil at different operating conditions.

Method and material for Preparing Alkyd Resin from Vegetable Oil:

The process of preparing alkyd resin from vegetable oil involves an orchestrated series of steps aimed at harnessing the natural properties of plant-derived oils to create a versatile and sustainable material. Initially, the vegetable oil undergoes a series of chemical reactions, including esterification and polymerization, facilitated by the addition of catalysts and other additives. This transformation yields a viscous liquid known as alkyd resin, which exhibits a remarkable combination of characteristics, including excellent adhesion, durability, and flexibility [17]. Moreover, alkyd resin derived from vegetable oil offers distinct environmental advantages, such as renewability and biodegradability, making it an attractive alternative to traditional petroleum-based resins. The choice of vegetable oil used in the process can also influence the final properties of the alkyd resin, with oils like soybean, linseed, and sunflower each imparting unique qualities to the end product [18]. Overall, the method for preparing alkyd resin from vegetable oil represents a significant advancement in green chemistry, offering a promising avenue for the development of eco-friendly materials with a wide range of applications.

Raw Materials for Preparation of Alkyd Resin:

The utilization of vegetable oil as a raw material for alkyd resin production aligns the resultant product with its intended applications. Alkyd resins are categorized into three distinct types based on their fatty acid content: Long Oil Alkyd (LOA), Medium Oil Alkyd (MOA), and Short Oil Alkyd (SOA). LOA formulations typically contain approximately 56% fatty acids, rendering them suitable for applications requiring enhanced durability and flexibility. On the other hand, MOA variants encompass fatty acid levels ranging from 46% to 55%, offering a balance between flexibility and drying time. Meanwhile, SOA formulations exhibit lower fatty acid concentrations, typically falling below 35% to 45%, making them ideal for applications necessitating rapid drying and film hardness. This categorization underscores the versatility of alkyd resins derived from vegetable oil, as they can be tailored to meet a diverse array of performance requirements across various industries and applications [19].

Preparation alkyd resin from linseed oil

Linseed oil, derived from the seeds of the flax plant, is categorized as a drying oil due to its ability to polymerize and form a solid film when exposed to air. Within the coating industry, linseed oil serves as a valuable ingredient renowned for enhancing the flexibility of coatings and expediting the drying process of varnishes. Its unique chemical composition, rich in unsaturated fatty acids like linoleic and oleic acid, contributes to its exceptional drying properties, making it a preferred choice for applications where rapid film formation and robust adhesion are paramount [20]. Additionally, linseed oil's versatility extends beyond its role in coatings, finding utility in various other sectors including woodworking, pharmaceuticals, and culinary arts. Its widespread use underscores its significance as a renewable and sustainable resource with multifaceted applications in modern industries [21]. Linseed oil, renowned for its high content of linoleic acids, possesses distinct unsaturated properties that render it resistant to direct reaction with acids. To overcome this limitation, a preliminary alcoholysis step is essential before further chemical processing can take place. This initial alcoholysis facilitates the conversion of linoleic acids into alcohol esters, thereby enabling subsequent reactions with acids to proceed effectively. This strategic approach ensures the successful transformation of linseed oil into alkyd resin, harnessing its unique composition to create a versatile and durable material. By leveraging the distinctive characteristics of linoleic acids through alcoholysis, the resulting alkyd resin exhibits enhanced reactivity and performance, making it an invaluable component in various industrial and commercial applications. This understanding underscores the importance of employing tailored methods to optimize the utilization of natural resources in the synthesis of functional materials, contributing to the advancement of sustainable practices in chemistry and material science [15]. In the synthesis of alkyd resin from linseed oil, a meticulous process unfolds, involving the reaction of the oil with trimethylolpropane and phthalic anhydride under carefully controlled conditions. This reaction occurs at elevated temperatures ranging between 200 to 250 degrees Celsius, extending over a duration of 12 hours. Similarly, the creation of hemp oil-based alkyd resins is a two-stage process, commencing with alcoholysis followed by esterification. Here, trimethylolpropane, in the presence of calcium carbonate catalyst, is combined with linseed oil and subjected to heating at 240 degrees Celsius during the alcoholysis phase. Subsequently, 30 grams or 0.2 mol of xylene phthalic anhydride is introduced to the mixture, lowering the temperature to 140 degrees Celsius. The esterification process ensues at the same temperature, with the reaction continuing until the acid number diminishes to 15 mg KOH/g oil. Notably, observations indicate a direct correlation between the oil content in the alkyd resin and its drying time, as higher oil concentrations yield slower polymerization rates [22]. In addition to the aforementioned studies, further investigations into the synthesis of alkyd resin from linseed oil have

been conducted, focusing on the optimization of reaction conditions and characterization of the resulting product. Initially, the linseed oil was subjected to a reaction with glycerol under controlled conditions, utilizing lead oxide as a catalyst and maintaining a temperature range of 230-250°C [20]. Subsequently, the temperature was reduced as the monoglyceride mixture was dissolved in anhydrous methanol at a ratio of 1:3, reaching a temperature of 180°C. In the subsequent stage, phthalic anhydride and xylene, serving as a solvent, were introduced into the reaction flask, with the temperature elevated to 230-250°C. The progress of the reaction was continuously monitored until the acid value dropped below 10 mg KOH/g, at which point nitrogen was introduced. The obtained linseed alkyd resin exhibited a light yellow coloration, with an acid number of 1 mg KOH/g, a free fatty acids content of 0.503 mg KOH/g, a saponification number of 194 mg KOH/g, a drying time of 144 minutes, and an intrinsic viscosity of 0.0442 [η] [15]. These results underscore the potential of linseed oil as a viable precursor for the production of alkyd resins, highlighting its versatility and promising prospects in the realm of sustainable materials development [22].

Preparation alkyd resin from soybean oil

Soybean oil, renowned for its composition rich in unsaturated fatty acids, presents a versatile raw material with diverse industrial applications. Comprising approximately 85% unsaturated and 15% saturated fatty acids, soybean oil bears resemblance to olive oil in its suitability for direct consumption. Its fatty acid profile predominantly consists of linoleic acid (50%), oleic acid (29%), and linolenic acid (8%). While commonly employed in the food sector, soybean oil extends its utility to various other industries [23]. Beyond culinary uses, it finds application in the production of candles, soaps, varnishes, and paints, owing to its favorable properties and versatile nature. Thus, soybean oil emerges not only as a staple in the food industry but also as a valuable resource for diverse industrial endeavors, showcasing its adaptability and significance in multiple sectors [24]. In the realm of alkyd resin production, meticulous attention to the physical and chemical properties of raw materials is paramount. The specific gravity, refractive index, acid value, iodine value, and saponification value of the substances involved serve as crucial indicators of their suitability for resin synthesis. For instance, a specific gravity of 0.923, refractive index of 1.4718, acid value of 0.341 mg KOH/g, iodine value of 128.4 g Iod/ g, and saponification value of 189.2 mg KOH/g are indicative of the composition and potential performance of the alkyd resin [25]. Moreover, in a comprehensive study conducted, the impact of modifying alkyd resin utilizing soybean oil was systematically evaluated, juxtaposed with the effects observed from utilizing epoxidized soybean oil. This comparative analysis sheds light on the intricate interplay between different modification agents and their implications for the final resin properties, providing valuable insights for optimizing resin formulations and advancing the field of sustainable materials science [23]. An integral component of the experimental protocol was the meticulous deoxygenation of a fraction of the monoglycerides, achieved through the application of an in-situ synthesized peracid. Specifically, soybean oil underwent a stringent purification regimen utilizing performic acid generated on-site, with benzene serving as a solvent. The ensuing reaction involved the amalgamation of soybean oil, glycerol, and a 0.1%CaO catalyst, sustained at a controlled temperature of 220°C for a duration of 3.5 hours, accompanied by the introduction of nitrogen as a refrigerant [26]. The reaction progression was meticulously monitored, halting precisely when the reaction mixture achieved complete dissolution in anhydrous methanol, maintaining a carefully calibrated oil to methanol ratio of 1:3. Subsequently, the reaction mixture was gradually cooled to a controlled temperature of 140°C to ensure optimal conditions for subsequent steps. Upon reaching the desired temperature, the addition of phthalic anhydride and xylene ensued, followed by the commencement of the reaction at 230°C, under the protective atmosphere of nitrogen acting as an inert. This strategic sequence

of steps not only ensured the precise control of reaction parameters but also facilitated the efficient synthesis of the desired alkyd resin from vegetable oil, thereby laying the groundwork for further investigation into its properties and applications in diverse fields [25]. Following the formation of the alkyd resin, a crucial step involved the addition of 5% zinc to expedite the drying process of the resin. The subsequent analysis revealed significant findings regarding the properties of the modified alkyd resin derived from soybean oil. Specifically, the acid value was measured at 7.045 mg KOH/g, the saponification value stood at 228.608 mg KOH/g, and the iodine value was recorded at 35.82 g Iod/100g. In contrast, the examination of the epoxidized soybean oil modified alkyd resin unveiled distinct characteristics, with an acid value of 9.35 mg KOH/g, a saponification value of 260.869 mg KOH/g, and an iodine value of 31.74 g Iod/g. These analytical results provide valuable insights into the composition and performance of the modified alkyd resin, shedding light on its potential applications and informing future research endeavors in the field of materials science and chemistry [26]. In the context of the investigation, it was observed that the acid value of the epoxidized soybean oil modified alkyd resin surpassed that of the soybean oil modified alkyd resin, potentially attributable to the presence of a higher level of structural residue resulting from the epoxidation process. Concurrently, the iodine value of the epoxidized soybean oil modified alkyd resin exhibited a lower measure compared to its unoxidized counterpart. This discrepancy is likely attributed to the reduced proportion of unsaturated fatty acids consequent to the epoxidation process. Furthermore, an elevation in the saponification value of the epoxidized oil modified alkyd resin was noted in comparison to the unoxidized resin, indicating potential alterations in chemical composition resultant from the epoxidation treatment. These observations underscore the intricate interplay between the modification processes and the resultant properties of the alkyd resin, thereby contributing valuable insights into the structural and functional modifications induced by epoxidation in the context of alkyd resin synthesis [23-26].

In their experimental investigation, the synthesis of alkyd resin was conducted using soybean oil and glycerin, with zirconium octate employed as the catalyst. The alcoholysis reaction, involving soybean oil and glycerin, was executed under controlled conditions, excluding the introduction of nitrogen gas while incorporating zirconium octate as the catalyst. The reaction commenced by combining soybean oil, glycerin, and lithium hydroxide, which served as a catalyst, at elevated temperatures ranging between 290-300°C. Subsequently, the reaction mixture was cooled to 180°C, followed by the addition of phthalic acid. Upon the addition of phthalic acid, the temperature was adjusted to 240-250°C to facilitate the subsequent stages of the reaction. This methodical approach ensured the precise control of reaction parameters, leading to the successful synthesis of alkyd resin with tailored properties suitable for various applications [27]. The experimental procedure was further refined through repetition, employing zirconium octate as a catalyst. Notably, during the production of monoglycerides, the temperature was elevated to 290-300°C, omitting the use of nitrogen gas inlet, which was exclusively utilized in the ophthalmic anhydride addition step to facilitate water removal from the reaction. The synthesis of alkyd resin ensued through the alcoholysis process, utilizing lithium hydroxide and zirconium 2-ethyl hexanoate. In a parallel reaction, soybean oil underwent transesterification when subjected to heat alongside glycerol, maintaining a controlled temperature of 250°C. These meticulous adjustments and protocol enhancements underscored the systematic approach taken towards optimizing the alkyd resin synthesis methodology, thereby ensuring reproducibility and efficiency in the experimental outcomes [26-28]. In the quest for efficient and environmentally sustainable methods of synthesizing alkyd resin from vegetable oil, a multifaceted approach has been employed. Initially, lithium hydroxide was introduced as a catalyst, accompanied by a controlled nitrogen inlet, facilitating the formation of monoglycerides in the

presence of zirconium octate. This strategic combination of catalyst and atmospheric conditions enabled the transformation of soybean oil into monoglycerides through controlled heating within the range of 290-300°C, thereby preventing undesired oxidation. Subsequently, the esterification process was initiated through the addition of ophthalmic anhydride, further enhancing the chemical conversion of the monoglycerides into alkyd resin. This meticulously orchestrated sequence of reactions not only showcases the ingenuity of the methodology employed but also underscores the importance of precise control over reaction parameters to achieve optimal results. Such innovative approaches represent significant strides towards the development of sustainable materials and hold great promise for broader applications in the realm of green chemistry and materials science [26]. To mitigate the risk of oil oxidation during the catalytic process, a nitrogen gas inlet was incorporated into the lithium hydroxide catalyst setup. Subsequently, in the second stage of the reaction, zirconium octoate was introduced along with ophthalmic anhydride to facilitate the efficient removal of water byproducts generated during the condensation reaction. This careful control of the reaction environment ensured optimal conditions for the synthesis of alkyd resin from vegetable oil. Monitoring of the reaction progress was achieved by periodically measuring the acid value at various time intervals, allowing for precise control and adjustment of reaction parameters as needed. Through these meticulous steps, the synthesis process was meticulously orchestrated to yield high-quality alkyd resin with desired properties, contributing to the advancement of sustainable materials in the field of polymer chemistry [27, 28]. The reaction was accuratly monitored until the target acid level was attained, signifying the completion of the transformation process. Notably, the utilization of zirconium octoate salt as a base catalyst facilitated the conversion of triglycerides, in conjunction with glycerin, into monoglycerides, particularly under elevated temperatures. The elucidation of the alkyd resin's structure was accomplished through rigorous analysis using Fourier-transform infrared (FT-IR) and proton nuclear magnetic resonance (H-NMR) spectroscopy techniques. These analyses revealed a structural consistency with alkyd resins synthesized employing lithium hydroxide (LiOH) catalysts, thus corroborating the effectiveness of zirconium octoate salt as a viable alternative catalyst in the alkyd resin synthesis process [29].

Preparation alkyd resin from rubber seed oil

Rubber seed oil stands out as a notable example of a dry oil, evident from its notably high iodine number of 139.09 g Iod/100 g sample. This characteristic underscores its suitability for various applications, particularly in the realm of coatings and paints, owing to its propensity for rapid oxidation and subsequent drying. The abundance of double bonds in rubber seed oil, attributed largely to its rich content of unsaturated fatty acids, particularly linoleic acid, plays a pivotal role in facilitating this oxidative process. These unsaturated bonds render the oil highly reactive, thus expediting the polymerization and crosslinking reactions crucial for the formation of durable coatings. Consequently, rubber seed oil emerges as a promising candidate for the development of eco-friendly and sustainable coatings, offering enhanced performance while minimizing environmental impact [5].

The properties exhibited by rubber seed oil align closely with those of alkyd resin products, making it a promising candidate for coating applications. Specifically, alkyd resin derived from rubber seed oil, with an equivalent ratio (R_{ek}) of 1.3, demonstrates an acid number of 7.6068 mg KOH/g sample and a viscosity of 1.1203×10^{-2} poise. These characteristics indicate the potential of rubber seed oil-based alkyd resin as a versatile coating material, offering desirable attributes such as adhesion, durability, and viscosity suitable for various coating applications. Moreover, the use of rubber seed oil contributes to sustainability efforts, as it utilizes a renewable and readily available resource, thereby reducing dependence on fossil

fuels. Overall, the correlation between the properties of rubber seed oil and alkyd resin underscores the feasibility and potential of utilizing this natural oil as a key component in the development of high-performance coatings [30].

The research endeavor involved the in situ alcoholic process of rubber seeds, aimed at extracting rubber seed oil methyl ester. Lead (II) oxide and xylene were employed as catalysts in the process. The procedure commenced with the maceration of rubber seed oil methyl ester in methanol for 30 minutes, followed by stirring for an additional 3 hours at room temperature. Subsequently, the mixture underwent vacuum filtration to remove impurities, and the residual substance was subjected to a thorough wash with 200 ml of methanol. This meticulous process was undertaken to ensure the efficient extraction and purification of rubber seed oil methyl ester, laying the groundwork for subsequent analyses and applications in various industrial sectors [31]. The experimental procedure involved the extraction of the residue obtained through Soxhlet filtration using n-hexane, followed by the addition of 100 ml of water to the filtrate. Subsequently, the solution underwent re-extraction with 50 ml of n-hexane three times. The alkyd resin synthesis proceeded in two distinct stages: alcoholysis and esterification. Analysis of the methyl ester derived from rubber seed oil revealed specific gravity of 0.94 kg/m^3, a refractive index of 1.502, an acid value of 13.80 mg KOH/g, an iodine value of 71.69 g Iod/100g, and a saponification value of 293.02 mg KOH/g. Notably, the acid number of the resulting alkyd resin is contingent upon the rate and efficacy of the esterification process, while the iodine value serves as an indicator of the resin's degree of unsaturation, which correlates with the oil's molecular structure and length. These findings underscore the intricate interplay between process parameters and the chemical composition of the starting materials in determining the properties of the synthesized alkyd resin [18]. Drawing upon this data, it is evident that rubber seed oil methyl ester exhibits commendable resistance to various environmental factors, including saltwater, acids, and water. When utilized in the production of alkyd resins, rubber seed oil demonstrates optimal performance, particularly when employed at oil lengths of 35% for short alkyd formulations and 50% for medium alkyd compositions via the alcoholysis method. Moreover, the chemical composition of rubber seed oil is characterized by an iodine value of 139.59 g Iod/100g, indicating its suitability for resin synthesis. Additionally, the measured viscosity stands at 4.905 St, reflecting the fluidity of the oil and its potential impact on resin properties. Furthermore, the free fatty acid content, quantified at 13.87 mg KOH/g, is indicative of the oil's purity and its potential influence on resin characteristics. Finally, the light brown coloration of rubber seed oil suggests its compatibility with various pigmentations and applications within the alkyd resin industry [5, 18, 30].

Preparation alkyd resin from sun flower oil

Sunflower oil (SFO), a vegetable oil refining, is a complex mixture comprising free fatty acids, glycerol, and sterols. It is predominantly composed of long-chain unsaturated fatty acids, particularly oleic acid, sourced primarily from sunflower oil. Harnessing its unique composition, SFO serves as a valuable resource for the modification of alkyd resins, enabling the synthesis of hydroxylated polyester derivatives. This strategic utilization underscores the importance of repurposing industrial by-products in sustainable materials science, emphasizing the transformative potential of waste streams in enhancing the performance and versatility of polymeric materials. The integration of SFO into alkyd resin formulations not only mitigates waste and reduces environmental impact but also fosters the development of novel materials with enhanced functionality and eco-friendliness. By embracing this innovative approach, researchers can pave the way for the advancement of green chemistry practices and the creation of more sustainable solutions for various industrial applications [31].

The analysis of sunflower acid oil (SFO) composition reveals a substantial presence of free fatty acids, constituting 65% w/w, accompanied by triglycerides (15.5% w/w), diglycerides (7.9% w/w), monoglycerides (3.1% w/w), sterols (0.7% w/w), tocopherol (0.2% w/w), and phospholipids (3.2% w/w). Significantly, alkyd resin synthesized from SFO demonstrates a drying time of 225 minutes, with an acid value measuring 14.8 mg KOH/g and a saponification value of 346 mg KOH/g. These comprehensive findings underscore the potential of SFO as a primary raw material for the coating industry. With its diverse composition and favorable attributes, SFO presents an opportunity to develop sustainable, high-performance coatings tailored to various applications. Leveraging the abundant free fatty acids and distinctive chemical profile of SFO opens innovative pathways toward eco-friendly and efficient coating solutions. This emphasizes the importance of exploring natural resources like SFO to drive advancements in the coating industry, aligning with principles of environmental sustainability and resource efficiency [32]. The synthesis of alkyd resin from sunflower oil is a meticulously orchestrated two-stage process that yields a versatile material with tailored properties suitable for diverse industrial applications. In the initial stage, sunflower oil or linoleic acid undergoes alcoholysis to transform into monoglycerides, serving as polyols. This reaction sets the stage for the subsequent esterification process in the second stage, where phthalic anhydride and xylene are introduced. Facilitated by a lead oxide catalyst, these reactions result in the formation of alkyd resin, denoted as SFO. This resin exhibits a viscosity range of 90 to 180 and demonstrates a drying time spanning 17 to 56 minutes. Notably, its saponification value falls within the range of 188 to 196 mg KOH/g, while its iodine number ranges from 136 to 171 g Iod/100g, and its acid number falls between 8.13 and 9.81 mg KOH/g. These precise parameters underscore the tailored nature of alkyd resin SFO, highlighting its potential for various industrial applications. This meticulous synthesis process and the resulting resin's specific characteristics contribute to its suitability for a wide range of industrial uses [15].

Preparation alkyd resin from palm oil

In this study, 100g of palm oil was subjected to a controlled heating process at 60°C to optimize the reaction conditions. Subsequently, the precise quantity of a concentrated strong base (2N NaOH) was meticulously calculated and added to the heated palm oil under constant agitation. This step aimed to neutralize the free fatty acids present in the oil, a critical stage in the synthesis process. The progress of the neutralization reaction was carefully monitored using phenolphthalein indicator, ensuring accuracy and completeness. This methodological approach allows for precise control over the chemical transformation of palm oil into alkyd resin, laying the foundation for further characterization and evaluation of the resulting material's properties [33].

Upon achieving the desired pink hue in the sample mixture, indicating the completion of neutralization, sodium chloride solution was introduced to facilitate the effective salting out or graining out of the soap stock. Subsequently, the resultant mixture underwent transfer into a separating funnel, a pivotal step in the extraction process aimed at achieving phase separation and isolating the desired components. This methodical approach ensures the efficient removal of impurities and undesirable by-products, laying the foundation for subsequent purification and refinement steps. The utilization of sodium chloride solution serves to enhance the efficacy of the salting-out process, enabling the precipitation of soap components for easy separation from the desired product. This carefully orchestrated sequence of steps underscores the meticulous attention to detail inherent in the experimental procedure, culminating in the attainment of high-quality results essential for the advancement of scientific knowledge and understanding in the field [34]. Following a three-hour reaction period, the resulting mixture underwent phase separation, yielding

two discernible layers. Subsequently, the mixture underwent a thorough washing process with hot water, continuing until the phenolphthalein indicator ceased to exhibit a pink hue, indicating the removal of any acidic impurities. Once fully washed, the oil component was subjected to drying at a temperature of 100°C in an oven until a consistent weight was achieved, signifying complete evaporation of any residual moisture. The neutralized oil was then meticulously weighed to ascertain any loss during the process, while the determination of the free fatty acid content (FFA) provided crucial insights into the quality and composition of the resulting alkyd resin. This meticulous procedure ensures the precise characterization of the alkyd resin derived from vegetable oil, laying the foundation for further analysis and application in various industrial settings [35]. In the experimental procedure, 130g of neutralized oil, in conjunction with a 2% (wt) concentration of NaHSO4 catalyst, was introduced into a round bottom flask, which was subsequently attached to a rotatable evaporator. The setup was then subjected to a temperature of 220°C for a dehydration period lasting 60 minutes. Notably, the dehydration process was executed under vacuum conditions, as outlined in the established protocol. This methodological approach aims to efficiently drive the esterification and polymerization reactions essential for the synthesis of alkyd resin from vegetable oil. By carefully controlling the temperature, catalyst concentration, and duration of dehydration, optimal conditions can be achieved to ensure the successful formation of high-quality alkyd resin. Such meticulous experimental design is fundamental to the advancement of knowledge in the field of sustainable materials chemistry, offering insights into the synthesis and characterization of environmentally friendly polymers [36]. The synthesis of palm oil modified alkyd resin was meticulously conducted utilizing dehydrated palm oil, glycerol, and phthalic anhydride in the presence of PbO and NaOH catalysts. The process was carried out employing state-of-the-art equipment, including a rotatable evaporator equipped with a digital thermometer, a rotatable round bottom flask operated at an agitation speed of 700 rpm, and a water bath coupled with a condenser. This advanced setup ensured precise control over reaction parameters, facilitating the synthesis of high-quality alkyd resin with tailored properties. The utilization of palm oil as a renewable and abundant feedstock underscores the sustainable nature of the synthesis process, aligning with the principles of green chemistry. The resulting palm oil modified alkyd resin holds great promise for various applications in coatings, adhesives, and other industries, offering enhanced performance and reduced environmental impact compared to traditional petroleum-based alternatives [30].

Preparation alkyd resin from canola oil

The preparation of alkyd resin from canola oil and glycerol was carried out in a resin reactor equipped with essential instruments including a thermometer, mechanical stirrer, Dean-Stark apparatus, and nitrogen gas inlet. The reactor was charged with precise amounts of canola oil (110 g), glycerol (38.2 g), phthalic anhydride (59 g), maleic anhydride (1.23 g), and xylene (80 g). A catalyst, calcium acetate, was introduced at a concentration of 0.01% w/w based on the oil content. The temperature was gradually increased to 240°C and maintained until the formation of monoglycerides was confirmed through a methanol test. Subsequently, the temperature was reduced to 120°C, and additional quantities of phthalic anhydride and maleic anhydride were added to the reactor. The reaction mixture was further processed at 220°C for 8–10 hours, ensuring thorough conversion. The reaction was monitored until the acid value decreased below 10 mg KOH/g, indicating the successful synthesis of alkyd resin with desired properties and quality [37].

Preparation alkyd resin from *Delonix Regia* (Flamboyant) Seed oil

In the process on alkyd resin synthesis, several key reagents were employed. Phthalic anhydride, glycerol, hydrochloric acid, marble chips ($CaCO_3$), and an oxygen scavenger (antioxidant) were among the essential components utilized. The synthesis procedure was executed in two distinct stages: alcoholysis and esterification. These stages are integral to the transformation process, facilitating the conversion of the raw materials into the desired alkyd resin product. The alcoholysis stage involves the reaction between phthalic anhydride and glycerol, leading to the formation of monoesters and diesters. Subsequently, during esterification, the monoesters and diesters undergo further reactions with phthalic anhydride to yield the final alkyd resin product. The inclusion of marble chips serves as a catalyst in these reactions, enhancing their efficiency and promoting the desired chemical transformations. Additionally, the oxygen scavenger plays a crucial role in preventing undesired oxidation reactions, ensuring the integrity of the synthesized alkyd resin. This meticulously designed synthesis protocol lays the foundation for further exploration into the properties and applications of the resulting alkyd resin [38]. Following the assembly of the aforementioned experimental setup, the reactor was charged with 50g of the oil sample along with 2g of $CaCO_3$ acting as the catalyst. The temperature was gradually raised to approximately 120°C. Once the desired temperature was reached, 20g of glycerol was introduced into the mixture. Subsequently, the temperature was elevated to a range of 180-190°C and maintained for a duration of 30 minutes, during which vigorous agitation was employed to ensure thorough mixing. This thermal treatment facilitated the transesterification process, resulting in the conversion of triglycerides present in the oil sample into a mixture comprising mono- and diglyceride oils. This pivotal step in the reaction sequence lays the groundwork for subsequent stages of the alkyd resin synthesis process, wherein the modified oil mixture serves as a fundamental precursor [38]. After 30 minutes, the reaction temperature was decreased to 150°C, and 25g of phthalic anhydride was introduced into the mixture. Subsequently, the temperature was raised to 245°C while maintaining continuous stirring to facilitate the polymerization process and enhance the molecular weight of the resin. To mitigate the presence of water, which is a by-product of the reaction, an additional 5g of phthalic anhydride was added to the reaction mixture. This excess phthalic anhydride served the dual purpose of eliminating water and accelerating the reaction rate. To ensure complete removal of water and unreacted acid, the mixture was heated to temperatures exceeding 250°C while under continuous agitation, effectively evaporating any residual moisture and unreacted components from the bulk solution. This meticulously controlled temperature and addition protocol is crucial for achieving the desired chemical structure and properties of the alkyd resin derived from vegetable oil, ensuring optimal performance in various applications [38].

Preparation alkyd resin from yellow oleander (*Thevetia peruviana*) seed oil

Three distinct alkyd resin formulations were synthesized employing a two-stage alcoholysis-polyesterification method [39], with variations in the proportions of phthalic anhydride (PA) and maleic anhydride (MA). Detailed quantities of the ingredients utilized are delineated in the referenced study. The process unfolded in two stages: firstly, the conversion of oil into a monoglyceride precursor through reaction with glycerol, followed by its subsequent reaction with PA and/or MA to produce the alkyd resin. This sequential approach enabled precise control over the resin's composition and properties, offering flexibility in tailoring the resin for specific applications and performance requirements. The meticulous adjustment of ingredient proportions ensured the attainment of desired resin characteristics, such as viscosity, curing behavior, and film-forming properties. The utilization of phthalic anhydride and maleic anhydride in varying ratios imparted distinct chemical functionalities to the resin matrix, influencing its mechanical strength, chemical resistance, and adhesion properties. This methodological framework underscores the systematic and deliberate approach employed in the synthesis of alkyd resins, laying a

solid foundation for further investigation and optimization in the realm of materials science and polymer chemistry [39]. The alcoholysis-polyesterification reaction was conducted in a meticulously controlled environment using a three-necked round-bottom flask outfitted with a precision mechanical stirrer from Heidolph, Germany, alongside a thermometer and a nitrogen gas inlet. A carefully measured mixture comprising 33.6 grams (0.04 mol) of yellow oleander oil, 7.36 grams (0.08 mol) of glycerol, and 0.05 wt% (relative to the oil) of PbO catalyst was heated to 230°C (±5°C) under a nitrogen atmosphere with continuous stirring at a constant speed of 500 rpm for 60 minutes, facilitating the formation of monoglyceride. Confirmation of monoglyceride formation was achieved through a methanol solubility test, wherein a portion of the resin was combined with methanol in a sample vial at ambient temperature, resulting in complete dissolution of the resin and the formation of a clear liquid. Subsequently, the reaction mixture was cooled to 120°C, followed by the addition of 0.12 mol of acid anhydride in finely divided form and an excess of 1.98 grams of glycerol (27%). The reaction temperature was then raised to 210°C (±5°C), and heating was continued until the acid value of the mixture fell within the desired range of 20–30 mg KOH/g. Assessment of the acid value was conducted by sampling aliquots of the reaction mixture at various time intervals, ensuring precise control and monitoring of the reaction progression [40].

Preparation alkyd resin from *Ximenia americana* (Wild Olive) oil

The study commenced with the collection of seeds from the *Ximenia americana* (Wild Olive) plant, sourced from Yola, Adamawa State, Nigeria. Upon collection, meticulous care was taken to shell the seeds through a cracking process to extract the embryos. Subsequently, these embryos underwent a thorough sun-drying process spanning two weeks until achieving an optimal state for further processing. Following the drying phase, the embryos were meticulously milled into granular form to facilitate subsequent extraction procedures. Oil extraction from the seeds was carried out utilizing petroleum ether (40-60°C) employing the soxhlet extraction method, ensuring efficient recovery of the desired compounds. This meticulously executed process sets the foundation for subsequent analyses and investigations into the properties and potential applications of the extracted oil, contributing valuable insights to the broader field of botanical research and sustainable resource utilization [41].

Following the extraction process, a portion of the obtained extract underwent a meticulous separation procedure to remove any traces of petroleum ether, achieved through evaporation in a rotary evaporator, resulting in the isolation of the pure oil. Subsequently, the comprehensive analysis of the physicochemical attributes of the *Ximenia americana* seed oil was conducted utilizing the rigorous protocols outlined by the American Oils Chemists Society Methods. This methodical approach ensured the accurate assessment of key characteristics such as viscosity, density, acidity, and moisture content, providing valuable insights into the composition and quality of the extracted oil. By adhering to established standards and methodologies, the experimental procedure maintained a high level of precision and reliability, essential for generating robust data sets essential for further research and application in various industries, including pharmaceuticals, cosmetics, and food processing [42]. The preparation of monoglyceride involved a meticulous process initiated by heating a mixture comprising oil, glycerol, and a small quantity of CaO catalyst in a 2-liter three-necked round-bottom flask. This flask was equipped with a Dean and Stark apparatus, ensuring efficient monitoring and extraction of water formed during the reaction. The reaction mixture was subjected to heating via a heating mantle, reaching a temperature of 200°C, and maintained at this level for a duration of 2 hours. Subsequently, a small aliquot of the reaction mixture was extracted and tested for solubility in methanol. The solubility test served as a critical indicator of monoglyceride formation, confirming the successful progression of the reaction. This meticulous approach not only

facilitated the synthesis of monoglyceride but also ensured the precise monitoring of reaction parameters, contributing to the overall efficacy and reproducibility of the process [41, 42]. During the second phase, the process transitioned with a decrease in temperature to approximately 180°C. At this point, a precise amount of phthalic anhydride was introduced into the reaction mixture, followed by the addition of xylene, constituting 10% of the total weight charged. The purpose of xylene addition was to facilitate the removal of water resulting from esterification, achieved through the formation of an azeotrope. As the reaction progressed, the temperature was gradually raised to a range between 230°C and 250°C. Throughout the reaction, samples were intermittently withdrawn from the mixture every 30 minutes to monitor changes in acid value and the evolution of water volume. The reaction was deemed complete once the acid value reached approximately 10 mg KOH/g, at which point the alkyd resin was allowed to cool. This meticulous control of temperature and periodic assessment of reaction parameters ensured the attainment of desired resin characteristics with precision and reproducibility [43].

Preparation alkyd resin from *Jatropha Curcas* oil

In a meticulous synthesis process, three-neck round bottom flasks were meticulously equipped with a mechanical stirrer, a thermometer, and a nitrogen gas inlet. A precisely measured amount of 32.68 g (0.04 mol) of *Jatropha Curcas* oil, alongside 7.36 g (0.08 mol) of glycerol, and 0.05 weight percent of PbO (relative to the oil) were meticulously charged into the flasks under continuous stirring. This mixture underwent a gradual heating process, steadily reaching temperatures between 225 and 230 °C over a duration of 45 to 60 minutes until the formation of monoglyceride was achieved, as confirmed by solubility testing in methanol (resin:methanol = 1:3 v/v) at ambient temperature. Subsequently, the reaction mixture was meticulously cooled to 125 °C, whereupon 0.12 moles of acid anhydride, in a finely powdered form, were precisely introduced along with 1.98 grams of excess glycerol (27%). The reaction temperature was then meticulously raised to 230 °C until the acid value fell within the targeted range of 20 to 30 mg KOH/g [43].

Preparation alkyd resin from tobacco seed oil

As part of the thesis research, the synthesis of alkyd resin was conducted in the laboratory, focusing on the creation of a 70% oil length tobacco penta-alkyd through the alcoholysis or monoglyceride process. The formulation employed in the synthesis included alkali-refined tobacco oil (70.00% by weight), pentaerythritol (10.54% by weight), cis-1,2,3,6-tetrahydrophthalic anhydride (22.48 w%), and a catalyst, lithium hydroxide (0.01 w%). The calculation was based on achieving a 100% resin yield, with a minor release of water (3.02 w%) during the reaction. Initially, a mixture comprising alkali-refined tobacco oil, pentaerythritol, and lithium hydroxide was prepared and heated to 250 °C for a duration of 3 to 4 hours, ensuring the conversion of triglycerides into monoglycerides. This meticulous process is crucial for the successful synthesis of alkyd resin with desired properties, contributing to the advancement of sustainable materials in various industrial applications. Following the formation of monoglycerides, the next step involved the addition of phthalic anhydride and xylene solvent to the reaction mixture, with the temperature carefully controlled at 210-215 °C for approximately 6 hours. Throughout the process, the advancement of the reaction was meticulously tracked by assessing the acid value17 of samples taken from the reaction mixture at consistent intervals. As the reaction proceeded, a noticeable decrease in the acid value was observed, indicating the progression of the poly esterification reaction. The reaction was allowed to continue until reaching an acid value below 10, signifying the completion of the desired chemical transformation. This methodological approach ensured precise control over the synthesis

process, enabling the production of alkyd resin with the desired properties and quality suitable for various applications in coatings, adhesives, and other industrial sectors [44].

Conclusions: The utilization of vegetable oils in alkyd resin production represents a significant stride toward bolstering sustainability within the chemical industry. Extensive research underscores the renewable and abundant nature of these oils, diminishing reliance on non-renewable petroleum resources and fostering environmental equilibrium. Moreover, alkyd resins derived from vegetable oils exhibit distinctive attributes, including renewability and biodegradability, positioning them as an eco-conscious substitute for petroleum-derived counterparts. Empirical evidence further demonstrates the efficacy of these resins across various applications, such as paints and coatings, boasting commendable mechanical and chemical properties. Nonetheless, there exists an imperative for continued research and development, particularly in refining conversion processes and optimizing product characteristics. Future investigations can explore novel technologies to augment resin efficiency and quality, alongside devising strategies for their more efficient and sustainable utilization. By embracing advancements in technology and materials rooted in vegetable oils for alkyd resin production, both industry professionals and researchers can actively contribute to bolstering environmental sustainability and fostering ecological balance.

References

45. La Nasa, J., Degano, I., Modugno, F., & Colombini, M.P. (2015). Industrial alkyd resins: characterization of pentaerythritol and phthalic acid esters using integrated mass spectrometry. *Rapid communications in mass spectrometry : RCM*, *29*(3), 225–237. https://doi.org/10.1002/rcm.7099
46. Denis, M., Le Borgne, D., Sonnier, R., Caillol, S., Totee, C., & Negrell, C. (2022). Phosphorus Modified Cardanol: A Greener Route to Reduce VolaTile Organic Compounds and Impart Flame Retardant Properties to Alkyd Resin Coatings. *Molecules (Basel, Switzerland)*, *27*(15), 4880. https://doi.org/10.3390/molecules27154880
47. Erol, T., Özaltun, D.H., Çavuşoğlu, F.C., Acar, I., & Güçlü, G. (2024). The effect of linseed oil/canola oil blend on the coating and thermal properties of waste PET-based alkyd resins. *Anais da Academia Brasileira de Ciencias*, *96*(1), e20230859. https://doi.org/10.1590/0001-3765202420230859
48. Hadzich, A., Flores, S., Masucci, A.E., Gomez, E.D., & Groß, G.A. (2023). NMR and GPC Analysis of Alkyd Resins: Influence of Synthesis Method, Vegetable Oil and Polyol Content. *Polymers*, *15*(9), 1993. https://doi.org/10.3390/polym15091993
49. Otabor, G.O., Ifijen, I.H., Mohammed, F.U., Aigbodion, A.I., & Ikhuoria, E.U. (2019). Alkyd resin from rubber seed oil/linseed oil blend: A comparative study of the physiochemical properties. *Heliyon*, *5*(5), e01621. https://doi.org/10.1016/j.heliyon.2019.e01621
50. Honzíček, J. (2019). Curing of Air-Drying Paints: A Critical Review. *Industrial & Engineering Chemistry Research*, *58*(28), 12485–12505. https://doi.org/10.1021/acs.iecr.9b02567
51. Honzíček, J., Matušková, E., Voneš, Š., & Vinklárek, J. (2021). Helmet Phthalocyaninato Iron Complex as a Primary Drier for Alkyd Paints. *Materials (Basel, Switzerland)*, *14*(5), 1220. https://doi.org/10.3390/ma14051220
52. Ouyang, S., Xie, Y., Fu, W., Ding, Y., & Shen, L. (2021). Preparation of autoxidative water-reducible alkyd resins from waste polyethylene terephthalate. *Royal Society open science*, *8*(6), 202375. https://doi.org/10.1098/rsos.202375
53. Arı, H.H., & Çınaroğlu, S. (2011). A new approach to preservation of some organs using alkyd resin. *Research in veterinary science*, *90*(1), 16–19. https://doi.org/10.1016/j.rvsc.2010.05.017

54. Janesch, J., Gusenbauer, C., Mautner, A., Gindl-Altmutter, W., & Hansmann, C. (2021). Efficient Wood Hydrophobization Exploiting Natural Roughness Using Minimum Amounts of Surfactant-Free Plant Oil Emulsions. *ACS omega*, *6*(34), 22202–22212. https://doi.org/10.1021/acsomega.1c02885
55. Yong, M.Y., Ang, D.T.C., & Sarih, N.M. (2019). Novel natural rubber-based epoxy coating. *Progress in Organic Coatings*, *135*, 105–113. https://doi.org/10.1016/j.porgcoat.2019.05.040
56. Selim, M.S., El-Safty, S.A., Shenashen, M.A., Higazy, S.A., Hashem, A.I. (2022). Vegetable Oil-Based Biodegradable Alkyd Materials for Eco-friendly Coating Applications. In: Ali, G.A.M., Makhlouf, A.S.H. (eds) Handbook of Biodegradable Materials. Springer, Cham. https://doi.org/10.1007/978-3-030-83783-9_55-1
57. Silva, J.A.C., Grilo, L.M., Gandini, A., & Lacerda, T.M. (2021). The Prospering of Macromolecular Materials Based on Plant Oils within the Blooming Field of Polymers from Renewable Resources. *Polymers*, *13*(11), 1722. https://doi.org/10.3390/polym13111722
58. Elfadel, R.G., Refat, H.M., El-Wahab, H.A., Salem, S.S., Owda, M.E., & Abdel Reheim, M.A.M. (2023). Preparation of new surface coating based on modified oil-based polymers blended with ZnO and CuZnO NPs for steel protection. *Scientific Reports*, *13*(1), 7268. https://doi.org/10.1038/s41598-023-34085-z
59. Dizman, C., & Cerrahoğlu, K.E. (2022). Alkyd resins produced from bio-based resources for more sustainable and environmentally friendly coating applications. *Turkish Journal of Chemistry*, *47*(1), 1–23. https://doi.org/10.55730/1300-0527.3511
60. Truchet, D.M., Ardusso, M.G., Forero-López, A.D., Rimondino, G.N., Buzzi, N.S., Malanca, F., Spetter, C.V., & Fernández-Severini, M.D. (2022). Tracking synthetic microdebris contamination in a highly urbanized estuary through crabs as sentinel species: An ecological trait-based approach. *The Science of the total environment*, *837*, 155631. https://doi.org/10.1016/j.scitotenv.2022.155631
61. Nurchi, C., Buonvino, S., Arciero, I., & Melino, S. (2023). Sustainable Vegetable Oil-Based Biomaterials: Synthesis and Biomedical Applications. *International Journal of Molecular Sciences*, *24*(3), 2153. https://doi.org/10.3390/ijms24032153
62. Amelia, O., Sailah, I., Kartika, I.A., Suparno, O., & Bindar, Y. (2021). Eco-friendly Alkyd Resins Based on Vegetable Oil: Review. *Jurnal Rekayasa Proses*, *15*(1), 1. https://doi.org/10.22146/jrekpros.64143
63. Hussain, C.M., Verma, C., Aslam, J., Aslam, R., & Zehra S. (2023). Corrosion protective coatings. *Elsevier EBooks*, 283–321. https://doi.org/10.1016/b978-0-323-95185-2.00021-6
64. Singh, P., Rana, A., Karak, N., Kumar, I., Rana, S., & Kumar, P. (2023). Sustainable smart anti-corrosion coating materials derived from vegetable oil derivatives: a review. *RSC advances*, *13*(6), 3910–3941. https://doi.org/10.1039/d2ra07825b
65. İşeri-Çağlar, D., Baştürk, E., Oktay, B., & Kahraman, M.V. (2014). Preparation and evaluation of linseed oil based alkyd paints. *Progress in Organic Coatings*, *77*(1), 81–86. https://doi.org/10.1016/j.porgcoat.2013.08.005
66. Nosal, H., Nowicki, J., Warzała, M., Semeniuk, I., & Sabura, E. (2016). Synthesis and characterization of alkyd resins based on Camelina sativa oil, glycerol and selected epoxidized vegetable oils as functional modifiers. *Progress in Organic Coatings*, *101*, 553–568. https://doi.org/10.1016/j.porgcoat.2016.10.003
67. Chukwuebuka, A.S., Samuel, E.O., Asadu, C.O., Onoghwarite, O.E., Celestine, O., & Ezema, C.A. (2022). Optimal analysis of the effects of process conditions on the yield of alkyd resins from castor

and soybean seed oils using response surface methodology. *Chemical Engineering Journal Advances*, *9*, 100217. https://doi.org/10.1016/j.ceja.2021.100217

68. 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*(50), 17625–17632. https://doi.org/10.1021/acssuschemeng.3c04346
69. Kyenge, B., Anhwange, B., Ageh, J.T. & Igbum, G.O. (2012). Comparative analysis of soybean seed oil modified alkyd resin and epoxidized soybean seed oil modified alkyd resin, *International Journal of Modern Organic Chemistry*, *1* (2), 66–71.
70. Navas, M.B., Lick, I.D., Bolla, P.A., Casella, M.L., & Ruggera, J.F. (2018). Transesterification of soybean and castor oil with methanol and butanol using heterogeneous basic catalysts to obtain biodiesel. *Chemical Engineering Science*, *187*, 444–454. https://doi.org/10.1016/j.ces.2018.04.068
71. Selim, M.S., Shenashen, M.A., Elmarakbi, A., EL-Saeed, Ashraf M., Selim, M.M., & El-Safty, S.A. (2017). Sunflower oil-based hyperbranched alkyd/spherical ZnO nanocomposite modeling for mechanical and anticorrosive applications. *RSC Advances*, *7*(35), 21796–21808. https://doi.org/10.1039/c7ra01343d
72. Elba, M.E., Elsayed, & Ashery, R.E. (2018). Synthesis and characterization of alkyd resin based on soybean oil and glycerin using zirconium octoate as catalyst. *International Journal of Chemistry and Technology*, *2*(1), 34–43. https://doi.org/10.32571/ijct.347670
73. Faisal, A.M., & Atiya G.A. (2023). Preparation and Characterization of Alkyd Resin Polymer of Vegetable Oil under the Influence of a Catalyst and a Kinetic Study of Its Polymerization. *History of Medicine*, *9*(1), 1615–1620. https://doi.org/10.17720/2409-5834.v9.1.2023.200
74. Uzoh, C.F., Obele, M.C., Umennabuife, U.M., & Onukwuli, O.D. (2019). Synthesis of rubber seed oil waterborne alkyd resin from glucitol. *Journal of Coatings Technology and Research*, *16*(6), 1727–1735. https://doi.org/10.1007/s11998-019-00235-0
75. Ikhuoria, E.U., Maliki, M., Okieimen, F.E., Aigbodion, A.I., Obaze, E.O., & Bakare, I. O. (2007). Synthesis and characterisation of chlorinated rubber seed oil alkyd resins. *Progress in Organic Coatings*, *59*(2), 134–137. https://doi.org/10.1016/j.porgcoat.2007.02.001
76. Mutar, M.A. & Abdul Hassan, N.M. (2017). Synthesis and Characterization of New Alkyd Resins (Short, Medium and Long) Based on Sunflower Oil and Linoleic Acid as Binder for Paints. *International Journal of Chemical & Petrochemical Technology* (*IJCPT*), *7*(1), 1-16
77. Islam, M.R., Hosen Beg, M.D., & Jamari, S.S. (2014). Alkyd Based Resin from Non-drying Oil. *Procedia Engineering*, *90*, 78–88. https://doi.org/10.1016/j.proeng.2014.11.818.
78. Indrawaty, D.S., & Amalia, R. (2022). Formulation of Alkyd Resin from Palm Oil and Tuna Fish Oil:Effect of Acid Value and Non-Volatile Content as Surface Coating. *Journal of Vocational Studies on Applied Research*, *4*(2), 74-79. http://dx.doi.org/10.14710/jvsar.v4i2.16624
79. Stavila, E., Yuliati, F., Adharis, A., Laksmono, J.A., & Iqbal, M. (2023). Recent advances in synthesis of polymers based on palm oil and its fatty acids. *RSC advances*, *13*(22), 14747–14775. https://doi.org/10.1039/d3ra01913f
80. Chiplunkar, P.P., Shinde, V.V., & Pratap, A.P. (2016). Synthesis and Application of Palm Fatty Acid Distillate Based Alkyd Resin in Liquid Detergent. *Journal of Surfactants and Detergents*, *20*(1), 137–149. https://doi.org/10.1007/s11743-016-1905-9
81. Nimbalkar, R.V., & Athawale, V.D. (2010). Synthesis and Characterization of Canola Oil Alkyd Resins Based on Novel Acrylic Monomer (ATBS). *Journal of the American Oil Chemists' Society*, *87*(8), 947–954. https://doi.org/10.1007/s11746-010-1573-2

82. Ezugwu, M.U., Obidiegwu, M.U., Ezugwu, C.H., Dasofunjo, K., & Berinyuy, E.B. (2019). Synthesis and characterization of alkyd resin from *Delonix Regia* (Flamboyant) seeds. *Journal of Polymer Science & Applications 3*, *1*(2), 12 pages.
83. Bora, M.M., Gogoi, P., Deka, D.C., & Kakati, D.K. (2014). Synthesis and characterization of yellow oleander (*Thevetia peruviana*) seed oil-based alkyd resin. *Industrial Crops and Products*, *52*, 721–728. https://doi.org/10.1016/j.indcrop.2013.11.012
84. Isaac, I.O., Willie I.E., & Idio N.S. (2023). Preparation and physicochemical characterization of emulsion alkyd resins from cottonseed, *Hura crepitans* L. seed and palm kernel oils. *International Journal of Frontline Research in Chemistry and Pharmacy*, *2*(1), 005-013. https://doi.org/10.56355/ijfrcp.2023.2.1.0052
85. Oladipo, G.O., Eromosele, I.C., & Folarin, O.M. (2013). Formation and Characterization of Paint Based on Alkyd Resin Derivative of *Ximenia americana* (Wild Olive) Seed Oil. *Environment and Natural Resources Research*, *3*(3). https://doi.org/10.5539/enrr.v3n3p52
86. Kalu, K.M., Emmanuel, M., Chinedu, E.K., Saa-Aondo M., Yelwa, J.M., Kenneth, R., Haruna, N.A., & Shehu, Z. (2024). Current State of Alkyd Resin Synthesis and Characterization, Extracted from Vegetable Oils. *Asian Journal of Current Research*, *9*(2), 1–16. https://doi.org/10.56557/ajocr/2024/v9i28548
87. Mustapha A.O., Oladele S.G., Adisa S.F., & Afolabi Y.T. (2022). A Response Surface Methodology to Optimize the Vield of Alkyd Resin from Jatropha (*Jatropha Curcas*) and Sesame (*Sesamum İndicum*) Seed Oils Using $CaCO_3$ as Catalyst. *Turkish Journal of Science and Technology*, *17*(2), 475–488. https://doi.org/10.55525/tjst.1090577
88. Mukhtar, A., Ullah, H., & Mukhtar, H. (2007). Fatty Acid Composition of Tobacco Seed Oil and Synthesis of Alkyd Resin. *Chinese Journal of Chemistry*, *25*(5), 705–708. https://doi.org/10.1002/cjoc.200790132