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# Synthesis of Acrylated Alkyd Resins from Castor Oil and Their Performance Evaluation in Environmental Implications for Coating Applications

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**Keywords:**

acrylated alkyd resin; copolymerization; eco-friendly; renewable resources; sustainability.

**ABSTRACT.** This study presents the synthesis of acrylated alkyd resins derived from castor oil for environmentally-friendly coating applications. A novel approach to alkyd resin synthesis was developed and involved free-radical polymerization with acrylic monomers to enhance drying time, chemical resistance, and solubility. The method advantages controlled radical polymerization to optimize the acrylic-to-alkyd ratio and oil length, resulting in improved film properties, including higher crosslink density and faster drying rate compared to traditional methods. The study also focuses on challenges, such as the observed negative impact on certain film characteristics, which include reduced chemical resistance at high levels of acrylic modification. The limitations underscore the importance of balancing acrylic and alkyd phases to achieve optimal performance. Comprehensive physicochemical analyses, which include FTIR and $^1$HNMR, confirm the formation of the hybrid structure, while performance tests reveal significant advantages over conventional solvent-borne alkyds. This work establishes a foundation for advanced coating binders that combine sustainability with enhanced functionality while recognizing the need for further optimization to mitigate limitations at high modification levels.

## INTRODUCTION

Alkyd resins are widely utilized as binders in paint manufacturing. These paints are typically exposed to extreme humidity, UV rays, and temperature changes, particularly when used on ships' superstructure. In addition to the aforementioned, the paint is subject to salt spray from the wind. In these circumstances, the paint exhibits significant chalking, color fading, and gloss loss during the six months in the tropical climate. To improve the resistance of these paints to weather conditions by chemically modifying alkyd resins with acrylic resins, which is an effective way to increase their durability (Ifijen *et al*., 2022).

Altering hyperbranched alkyd resins with polar groups to interact with water is one way to create more ecologically friendly resins (water-borne). Maleic anhydride copolymerization with acrylic monomers has been studied in order to increase the hydrophilicity of conventional alkyd resins (Bao *et al*., 2024; Sair *et al*., 2023; Selim *et al*., 2023); Maleic anhydride has also been grafted into polymers to produce specific interactions between them (Bag *et al*., 2021; Redfearn and Goddard, 2022). By modifying alkyd resins with acrylic monomers, it is possible to combine the weathering and general resistance qualities of acrylic systems with the alkyd's desired application and film-forming capabilities. Additionally, while environmentally friendly feedstocks such as castor oil have been explored, their integration into hybrid systems with tailored acrylic-to-alkyd ratios remains underexplored.

Alkyd resin modification and nondrying oil alkyds by acrylation have been extensively investigated. Solomon proposed acrylate them by either reacting an acid-containing acrylic copolymer with a monoglyceride, then adding polyol and dibasic acid, or by condensation of a preformed addition copolymer with an alkyd, and

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finally condensation to the required acid value and viscosity; the former is referred to as post-acrylate, whereas the latter is dubbed the monoglyceride technique (Arauz-Solís *et al*., 2024). It was reported that attempts to produce methacrylated alkyds through the interaction of an alkyd with a premade acid-containing polymer were faced with challenges because of alkyd gelation. This study addresses these shortcomings by developing a novel synthesis approach for acrylated alkyd resins using controlled radical polymerization techniques. The method optimizes the acrylic-to-alkyd ratio and oil length, striking a balance between rapid drying, enhanced chemical resistance, and environmental sustainability.

## RESEARCH METHODS

### Materials and Instruments

#### *Materials*

Castor oil, Pentaerythritol, glycerol, Methanol, Acetone, Toluene benzene and Carbon tetrachloride from (BDH- Chemicals Limited Poole/ England) Phthalic anhydride, Lead oxide, Lead oxide, Xylene, Tetra hydro furan (THF), propylene glycol, Malic anhydride and Dimethyl Sulfoxide (DMSO) from (Merck – Schumann /Germany). Phenolphthalein, Carbon tetrachloride, ethanol ether (Scarab S.L./Spain) from (HIMEDIA Hi media/India), Acrylic acid, Potassium Iodide, Sodium Thiosulfate, Sodium Chloride, Potassium Hydroxide, and Hydrochloric Acid. Sulfuric acid from (SD fine- CHEM Limited/India). Dimethyl forms amide from (Scarab S.L./Spain). Hydroxide (Water purification company Baghdad). The choice of castor oil and acrylic monomers as key materials in synthesizing acrylated alkyd resins is based on their unique properties, availability, and cost-effectiveness, which align with performance goals and environmental considerations.

#### *Instruments*

Fourier transform infrared spectroscopy (FTIR) spectra were recorded using an FTIR device from (Shimadzu) of the type (8400) in the Chemistry Department at the College of Engineering at Al-Qadisiyah University. The sensitive analytical balance with four levels after zero (Sartorius / BL2105Germany) was used to weigh the sample. Nuclear magnetic resonance spectrum ($^1$H-NMR) spectra were recorded using a solvent (DMSO-d6) by a Bruker Ultra Shield 500 MHz spectrometer (Swiss origin) at the University of Tehran - Iran. The measurement of differential calorimetric thermal analysis (DSC) was made using a differential thermal analysis device (DSC) type (DSC 131 Eva, SETARAM) of (France) origin and at the University of Tehran/ College of Pure Sciences/ Department of Chemistry. Oven drying oven type Hot Air Sterilizer Laboratory Oven/ M6040P/ Germany was used. The Headmen: A thermal heater was used for heating with a temperature of more than 250 °C . of the type Jenkins/ HV65/ England. To measure the viscosity of alkyd resin, use a viscometer and prepare the samples in the Chemistry Department / College of Education at Al-Qadisiyah University, a device from the company of (Brookfield), (P 8500 + RVDV- II) with a voltage (~230 V), (50/60 Hz) frequency, and (30 VA) power. The apparatus was produced in the (U.S.A).

### Synthesis of Alkyd Resin from Castor Oil

Several alkyd resins were prepared by using dehydrated Castor oil in the presence of glycerol, Pentaerythritol, and propylene glycol with maleic anhydride and phthalic anhydride, and the catalyst lead (ii) oxide. The reactions were conducted in a three-necked round-bottom flask equipped with a motorized stirrer, a dean-stark trap equipped with a water-cooled condenser, and nitrogen in a let tube at temperatures between 230 and 2500 °C. Additionally, xylene was used as the zeotropic solvent. There were two stages. In State 1 (Alcoholics): At this stage, the flask was filled with the measured amount of dehydrated palm kernel oil, which was then heated to around 120 °C to eliminate moisture. A heating mantle was used to complete the heating. The determined amount of glycerol was then added, and the temperature was then increased to 230 ºC, as in Table 1. A small sample of the aliquot was obtained after 30 minutes to check if it was soluble in methanol. The reaction mixtures were cooled to about 140 ºC. In State 2 (The esterification process): This stage involved adding the indicated amounts of xylene, maleic anhydride, and phthalic anhydride to the flask, which was heated using a heating mantle. The temperature was progressively increased to around 230 °C and was subsequently maintained between 230 – 250 °C for around three hours. At 30-minute intervals, aliquots were taken out of the reaction mixture to check if the acid value had decreased. The reaction was discontinued as soon as the mixture's acid value reached roughly 10 mg KOH/g (Abed *et al*., 2019; Villada *et al*., 2023).

**Table 1.** Composition of the preparation of resins.

| Raw materials | Weight (g) | Weight (%) |
|---|---|---|
| Castor oil | 25 | 12.047 |
| Phthalic anhydride | 12.5 | 6.023 |
| Maleic anhydride | 12.5 | 6.023 |
| Ethanol | 50 | 4.911 |
| Catalyst (Bo) | 0.5 | 0.25 |
| **Total** | **100.5** | **29.254** |

### Synthesis of Acrylate Alkyd Resin from Castor Oil

Alkyd resin (10 g) and acrylic acid (4 g) were added to the flask along with benzoyl peroxide (0.605 g) as an initiator, as shown in Table 2. The mixture was stirred and heated under reflux at 120 ºC for 3 h in the presence of nitrogen. The polymerization process described in this study minimizes waste by employing a controlled radical polymerization technique, which improves reaction efficiency and reduces by-products (Choe *et al*., 2022).

**Table 2.** Composition of the preparation of acrylate alkyd resin.

| Alkyd | Acrylic acid |
|---|---|
| 10 (g) | 4 (g) |

### Chemical Properties of Alkyd Resin

#### *Acid Number*

The AOAC technique and standard 969.17 1997 were used to determine the acid value.

#### *Iodine Number*

A 300-mL conical flask with a ground-in stopper was filled with a (0.1 g) sample. Then, 20 mL of carbon tetrachloride was added, and the flask was closed. The sample was then dissolved in an ultrasonic washer machine, 25 mL of Hans' solution was added, and the flask was closed again. After a minute of shaking, it was kept in a dark place at around 20 °C for half an hour. Next, 100 mL of water and 10 mL of 15% potassium iodide were added, and then the flask was closed. After 30 seconds of shaking, the iodine value was determined by titrating with (0.1) mole/L sodium thiosulfate. Additionally, a blank test was also measured to determine the blank level (Isaac *et al*., 2023).

#### *Saponification Number*

The sample was weighed (1 g) and placed into an Erlenmeyer flask. Then, 25 mL of 0.5 N KOH and 4 mL of (ethanol-ether) solvent were added using a pipette to the flask. After refluxing for 30 minutes at 70 °C, the inside of the condensers was rinsed with DI water (about 25 mL), then the solvent was allowed to drain into the Erlenmeyer mask, and the solution was allowed to cool to room temperature. Then, 3 – 5 drops of phenolphthalein indicator were added to the solution with agitation, and 0.5 N HCI (titrant) was added without leveling the burette. Finally, the titrant was added from the burette to the solution until the pale pink color disappeared completely (for at least 30 seconds) without leveling the titrant in the burette (Ogawa *et al*., 2011).

### Physical Properties of Alkyd Resin

#### *Density*

The density was measured using a pycnometer S9611826 (100 ccs) and an analytical scale in accordance with NF EN 1097-6.

#### *Drying*

The aluminum plates were pre-cleaned with ethanol to ensure no contaminants were affecting the result. A ground coating of varying fixed thickness was used to equally coat the resin on the surface of the test plates (Forte, 2022).

#### *Viscosity*

The viscosity was measured at 25 °C using a Brookfield rotary viscometer Ku-2 type RVDV-II P8500, using various spindles and speeds.

#### *Volatility*

Samples of alkyd resin were prepared in watch glasses, and their weight was recorded and then heated for 2 hours at 135 – 140 °C. Three of these samples were then placed in the oven within 30 minutes, and the non-volatile matter was calculated from the difference in the initial and final weight of the watch glasses. The average value of the three results was reported as the percentage of non-volatile matter (Ayoku, 2022).

## RESULTS AND DISCUSSION

### Synthesis and Characterization of Alkyd Resin from Castor Oil with Glycerol (C-G)

To synthesize this alkyd resin, the castor oil, glycerol, malic anhydride, and phthalic anhydride were condensed in the presence of the catalyst lead (ii) oxide at (120 – 240 ºC) for (6 hours) in the presence of $N_2$ as in Figure 1.

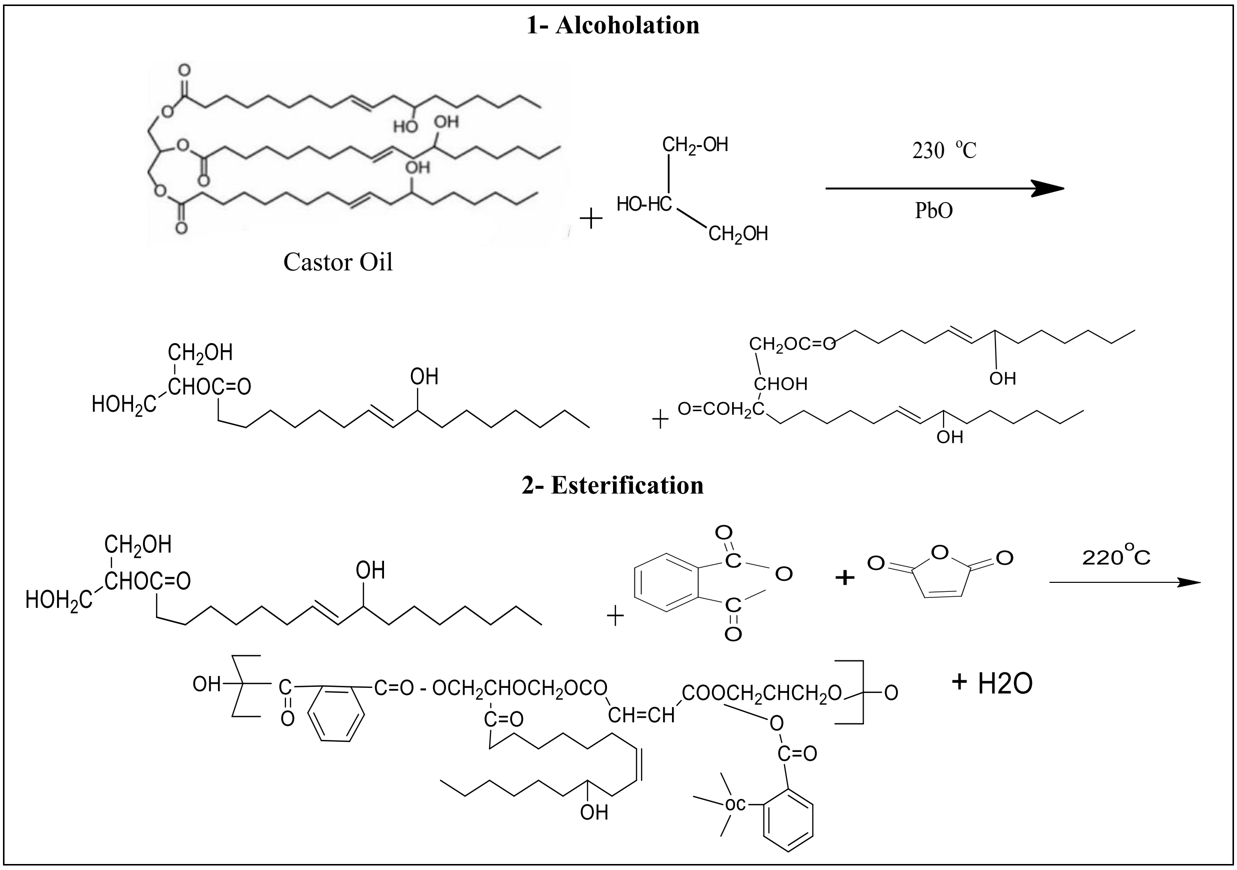

**Figure 1.** Synthesis of alkyd resin castor with glycerol.

### *FTIR Spectrum of Alkyd Resin from Castor Oil with Glycerol (C-G)*

The FTIR spectrum of (CG) in Figure 2 shows the appearance of an absorption band at (3550 cm for (OH) of Carboxylic acid. While the emergence of two distinct bands at the two frequencies (2854, 2923 cm$^{-1}$) is due to the vibration of the stretching of the aliphatic (C–H) bond, also the appearance of the peak at the frequency (1743 cm$^{-1}$) is due to the vibration of the stretching of the bond (C=O) in the ester group. Also, the appearance of the absorption band at (1465 cm$^{-1}$) is shown to the vibration of the aromatic bond (C=C), and the appearance of the absorption band at (1615 cm$^{-1}$) is shown to the vibration of the bond stretching (C=C) of the alkene, as well as the appearance of the band at (1110 cm$^{-1}$) to the (C–O) straining vibration (Pavia *et al*., 2009; Tooba *et al*., 2023).

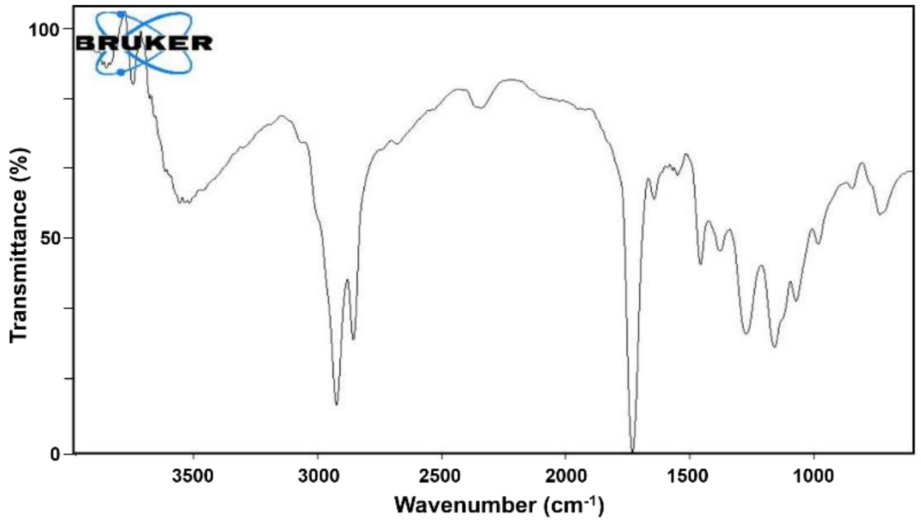

**Figure 2.** The FTIR spectrum of alkyd resin from castor oil with glycerol.

### *¹HNMR Spectrum of Alkyd Resin from Castor Oil with Glycerol (C-G)*

The ¹HNMR spectrum of (C-G) in Figure 3 shows the following chemical shifts: (δ= 0.7 ppm) for ($CH_3$), (δ= 1.2 ppm) for ($CH_2$), (δ= 4.5 ppm) for ($OCH_2$), multiple singles (δ= 8.7 ppm) for Ar-H group, (δ= 15 ppm) for COOH (Glenn *et al*., 2021; Hasnat *et al*., 2024).

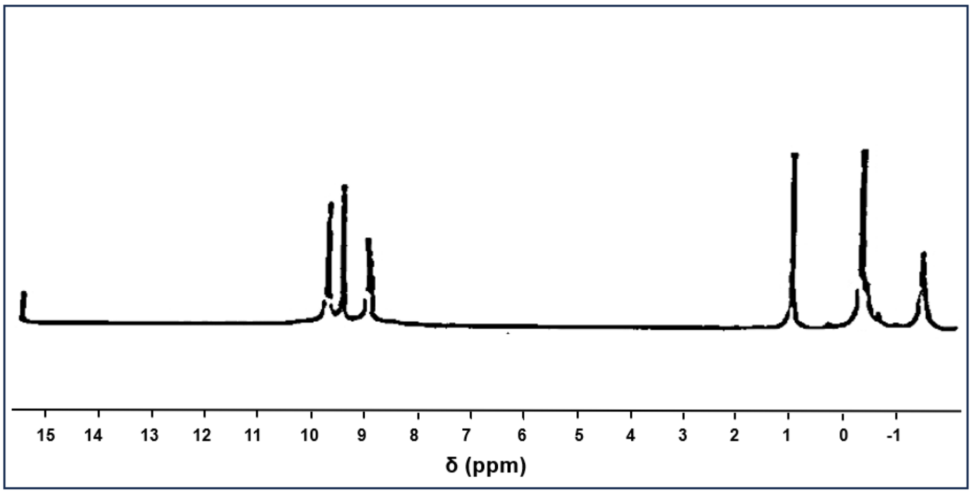

**Figure 3.** ¹HNMR spectrum of alkyd resin castor oil with glycerol.

### Synthesis and Characterization of Alkyd Resin from Castor Oil with Propylene Glycol (C-PR)

As shown in Figure 4, to synthesize this alkyd resin, the castor oil, propylene glycol, malic anhydride, and phthalic anhydride were condensed in the presence of the catalyst lead (ii) oxide at (120 – 240 ºC) for (6 hours) in the presence of $N_2$ (Ma *et al*., 2024).

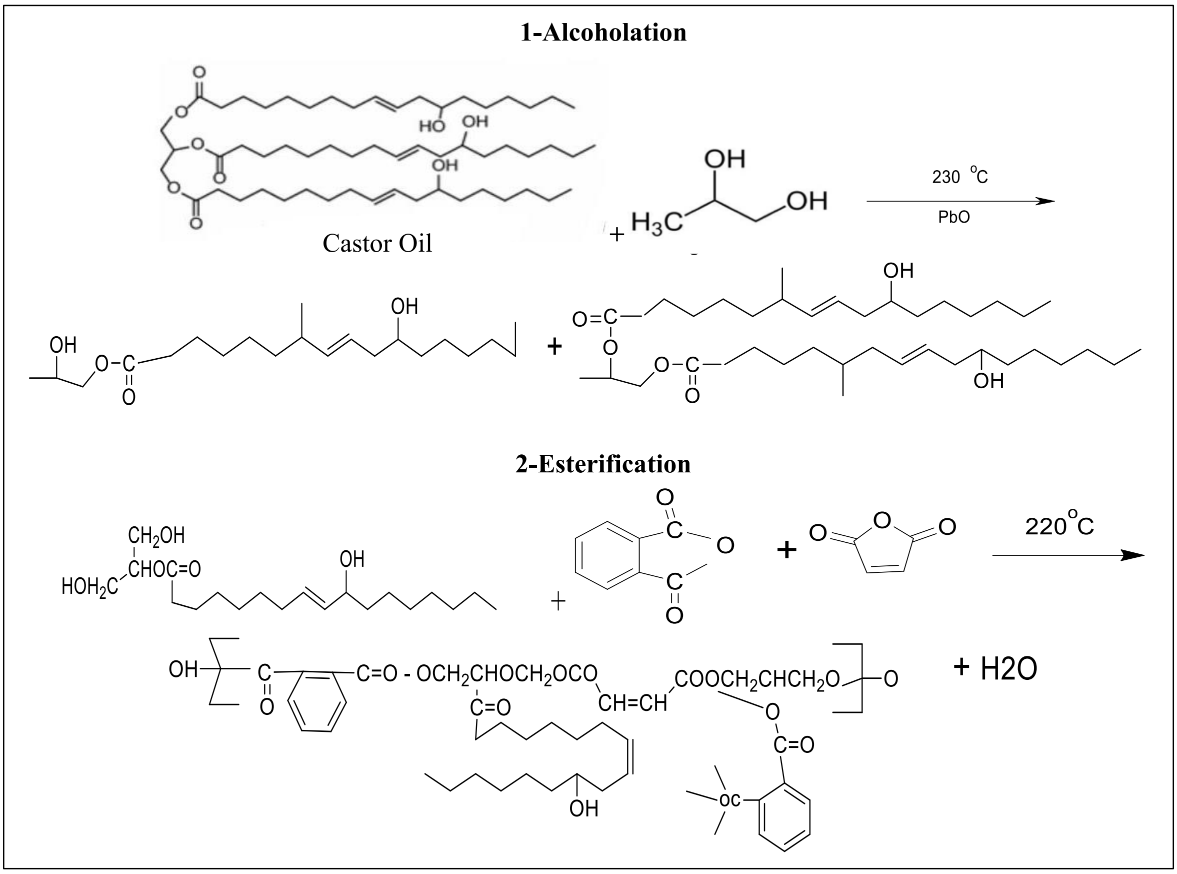

**Figure 4.** Synthesis of alkyd resin castor oil with propylene glycol.

### *FTIR Spectrum of Alkyd Resin from Castor Oil with Propylene Glycol (C-PR)*

The FTIR spectrum of (CPR) in Figure 5 indicates the appearance of the absorption band at (3550 cm for (OH) of Carboxylic acid. While the emergence of two distinct bands at the two frequencies (2854, 2923 cm$^{-1}$) is due to the vibration of the stretching of the aliphatic (C–H) bond, also the appearance of the peak at the frequency (1743 cm$^{-1}$) is due to the vibration of the stretching of the bond (C=O) in the ester group. Also, the appearance of the absorption band at (1465 cm$^{-1}$) shows the vibration of the aromatic bond (C=C), and the appearance of the absorption band at (1615 cm$^{-1}$) shows the vibration of the bond stretching (C=C) of the alkene, as well as the appearance of the band at (1110 cm$^{-1}$) to the (C–O) straining vibration (Chouwdhury *et al.*, 2020; Rajput *et al.*, 2023; Yee, 2022).

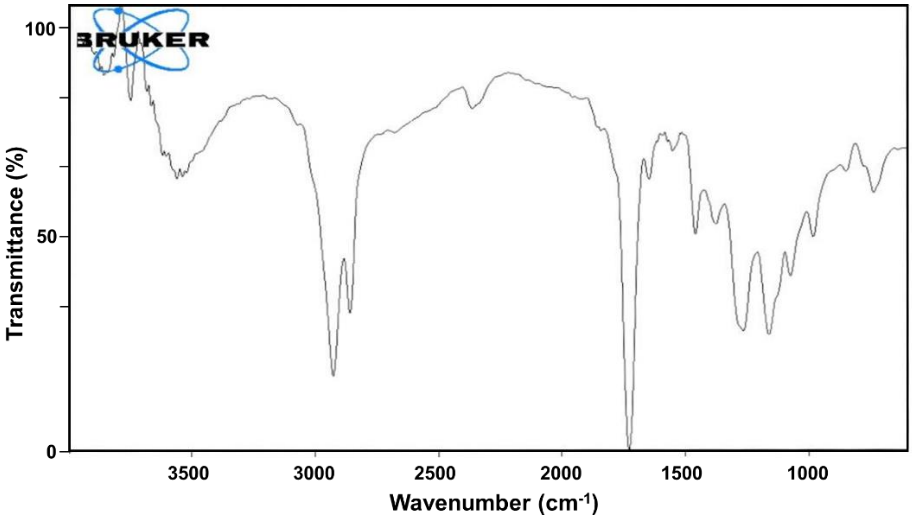

**Figure 5.** FTIR spectrum of alkyd resin from castor oil with propylene glycol.

### Synthesis and characterization of alkyd resin from Castor oil with Pentaerythritol (C-PE)

To synthesize this alkyd resin, the castor oil as in Figure 6, Pentaerythritol, malic anhydride, and phthalic anhydride were condensed in the presence of the catalyst lead (ii) oxide at (120 – 240 ºC) for (6 hours) in the presence of $N_2$ (Poluektova *et al*., 2022).

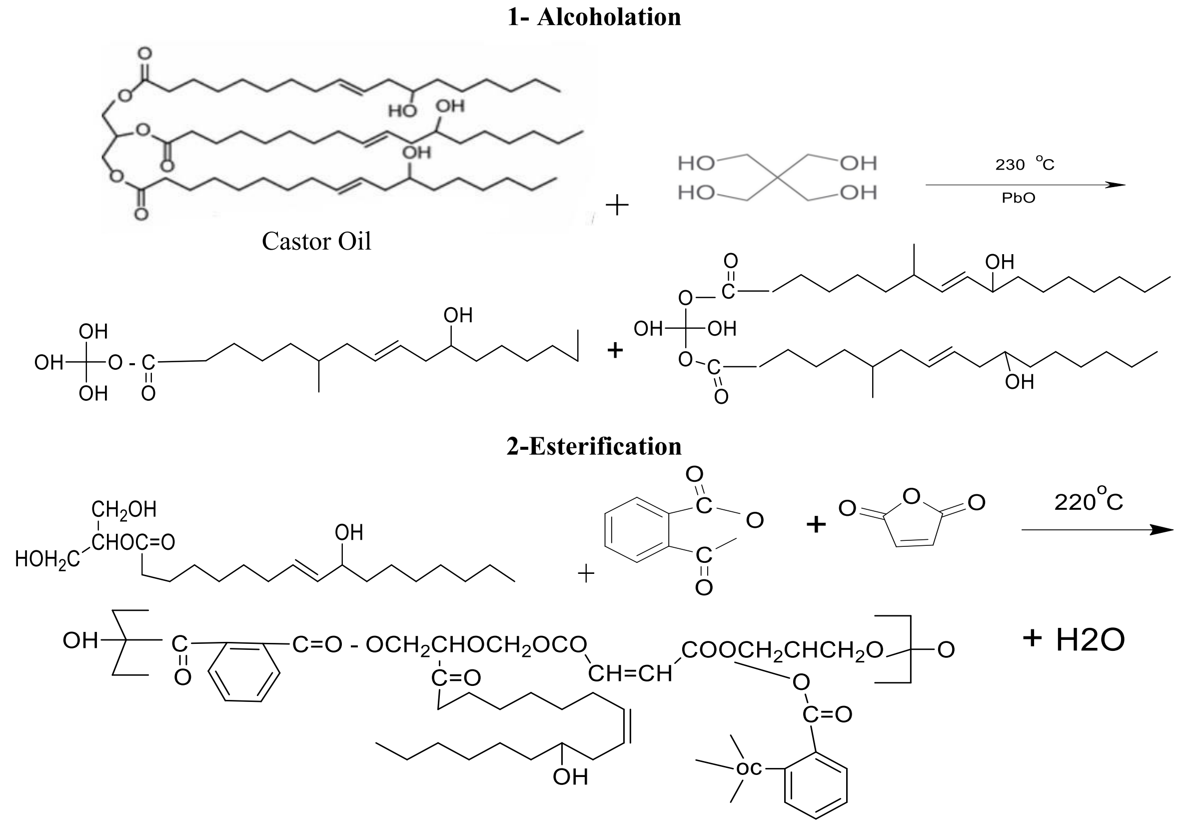

**Figure 6.** Synthesis of alkyd resin castor oil with pentaerythritol.

### *FTIR Spectrum of Alkyd Resin from Castor Oil with Pentaerythritol (C-PE)*

The FTIR spectrum of (CPE) as in Figure 7, indicates the appearance of absorption band at (3550 cm for (OH) of Carboxylic acid. While the emergence of two distinct bands at the two frequencies (2854, 2923Cm$^{-1}$) is due to the vibration of the stretching of the aliphatic (C–H) bond, also the appearance of the peak at the frequency (1743 cm$^{-1}$) is due to the vibration of the stretching of the bond (C=O) in the ester group. Also, the appearance of the absorption band at (1465 cm$^{-1}$) shows the vibration of the aromatic bond (C=C), and the appearance of the absorption band at (1615 Cm$^{-1}$) shows the vibration of the bond stretching (C=C) of the alkene, as well as the appearance of the absorption band at (1110 cm$^{-1}$) to the (C–O) straining vibration (Hadzich *et al*., 2020).

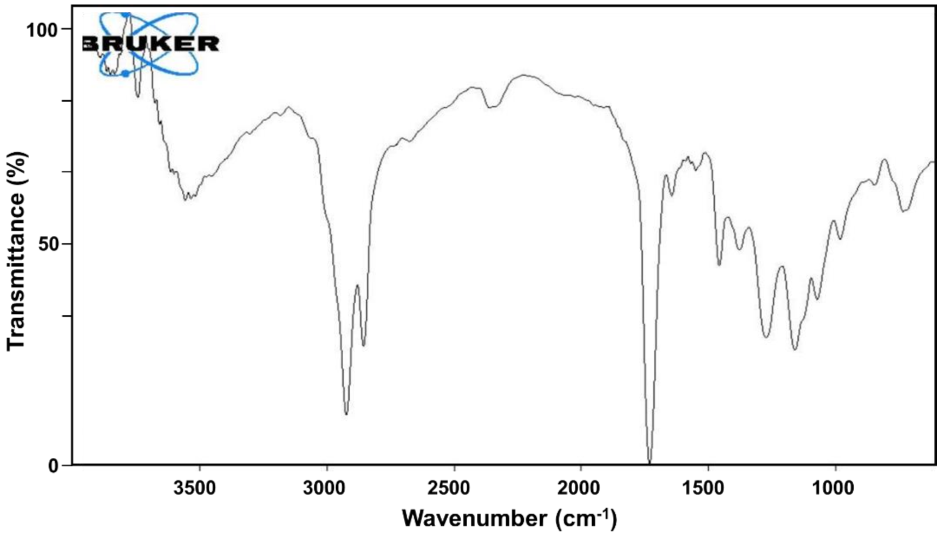

**Figure 7.** The FTIR spectrum of alkyd resin castor oil with pentaerythritol.

***$^1$HNMR spectrum of alkyd resin from Castor oil with Pentaerythritol (C-PE)***

$^1$HNMR Spectrum of (C-PE) as in Figure 8, the following chemical shifts. ($\delta$= 0.7 ppm) for ($CH_3$) group, ($\delta$= 1.2 ppm) for ($CH_2$), ($\delta$= 3.8 ppm) for ($OCH_2$), Multiple singles ($\delta$= 6.2-7.0 ppm) for AR-H group, singles ($\delta$= 12.2-13 ppm) for COOH (Teck, 2020).

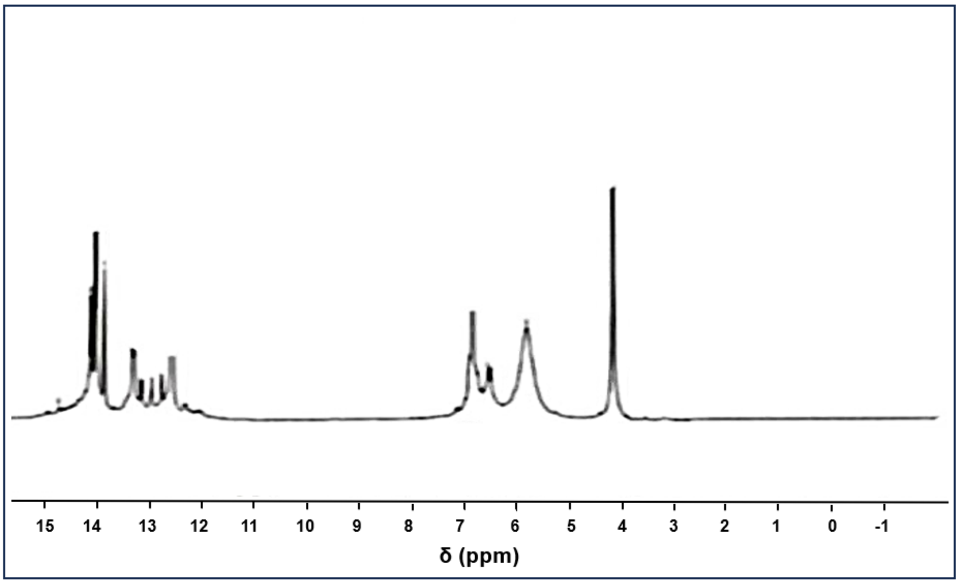

**Figure 8.** $^1$HNMR spectrum of alkyd resin castor oil with pentaerythritol.

**Chemical Properties of Alkyd Resin**

***Acid Value***

It is useful to determine the acid value by assessing the number of milligrams of potassium hydroxide KOH needed to neutralize one gram of the model (the prepared resin), representing the number of carboxylic acid groups in chemical compounds such as fatty acids. An increase in this value is an indication of the occurrence of rancidity of the fatty substance, as there is an allowable limit for the amount of free fatty acids present in the triglycerides (oil). This characteristic is important in evaluating the quality of oil seeds at the time of extraction. Under the proper humidity and temperature circumstances, the enzyme (lipase) found in these seeds breaks down into triglycerides (oils). Therefore, to keep oil seeds from going bad and to lower the amount of fatty acids they produce, it is critical to store them properly. When manufacturing resins, alkyd-free fatty acids are rapidly inactivated in alcoholic reactions; the damaged vegetable oil is unsuitable for the manufacture of alkyd resins (Burande and Dhakite, 2020).

**Table 3.** The values of acid in the prepared alkyd resins from castor oil.

| Alkyl resins | Acid value (mg KOH $g^{-1}$) |
|---|---|
| C-G | 9.6 |
| C-PR | 9.5 |
| C-PE | 9.7 |

This test was applied to all alkyd resin prepared by taking 0.2 g of it, putting it in 5 mL of methanol, and then rinsing it with potassium hydroxide solution using phenolphthalein as an index to obtain the neutral point when the color changed. It was observed from the results displayed in Table 3 that changes occurred between each resin prepared according to the type of oil used and its storage period. The acid value of the prepared resin increases with the increase in the chain fatty acid length of which the vegetable oil is composed. The acid value of alkyd resin from castor oil is low due to the short chain of fatty castor oil, which has (18) a carbon atom. The variations in the physical, chemical, or mechanical properties of the prepared resins were analyzed and linked to two independent variables. First, the type of oil and the specific oil used in synthesizing the resin likely influenced its polymerization process, molecular structure, or chemical composition. Dissimilar oils may introduce distinct functional groups, fatty acid profiles, or reactivity patterns that affect the resin's final properties. Second, depends on the storage period, and over time, resins can undergo changes due to oxidation, polymer degradation, or crosslinking processes. The duration of storage may lead to measurable changes in properties such as viscosity, mechanical strength, or chemical stability.

### *Iodine Number*

It is the number of grams of iodine needed to saturate the double bonds present in 100 g of fat. Since the iodine number of saturated fatty acids is zero, this feature can be used to gauge the degree of unsaturation (double bonds) in unsaturated fatty acids. Since the iodine number is regarded as one of the constants of oils, it is also used to identify adulterated vegetable oils. A high percentage of unsaturated fatty acids is indicated by a high iodine number. A low iodine value signifies that the fatty acids are saturated (Orozco *et al*., 2021).

The results of the iodine numbers were listed for the alkyd resins prepared in Table 4. Castor oil contains double bonds in its composition, and as was said previously, the iodine number measures the degree of unsaturation (double bonds). It is noted from the results that alkyd resins from castor oil showed the lowest value of iodine number because of the short chain of castor oil (C18) and the presence of unsaturation in small quantities in the chain.

**Table 4.** The iodine number values for the prepared alkyd resin.

| Alkyd resins | Iodine number (g$I_2$/100 g) |
|---|---|
| C-G | 123 |
| C-PR | 121 |
| C-PE | 126 |

### *Saponification Number*

It is the quantity of potassium hydroxide milligrams needed to spoon one gram of oil or fat. The saponification number (value) is used to know the length of the fatty acid chain in glycerides, as the value of saponification is inversely proportional to the length of the fatty acid chain (the lower the saponification value, the longer the chain fatty acid and vice versa) because it has the lowest relative number of functional (effective) carboxyl groups per unit mass of fat Balancing with short-chain fatty acids; and b) estimating the approximate molecular weight of the fat (particularly mixed poly glycerides), also, and the saponification number is one of the important constants for the identification of some oils (Senra *et al*., 2022). The results were observed in Table 5. The length of the fatty acid chain has an inverse relationship with the saponification number, as well as having relatively fewer carboxyl functional groups (active) in balance with the short chain of fatty acids; therefore, the saponification value of alkyd resins from castor oil is high.

**Table 5.** The saponification numbers of the prepared alkyd resins.

| Alkyd resins | Saponification number (mg KOH $g^{-1}$) |
|---|---|
| C-G | 223 |
| C-PR | 221 |
| C-PE | 228 |

## Physical Properties of Alkyd Resin

### *Density*

The density of the prepared alkyd resins was determined in accordance with the standard NF EN 1097-6 by using a pycnometer in accordance with specification S96118226. The test was applied by taking a quantity of the prepared resin and placing it in the Pycnometer, calculating the weight of the resin with the Pycnometer, and then finding the difference in weight between the Pycnometer when it was filled and when it was empty according to the volume Pycnometer (25 mL).

The observed results for the resins prepared are shown in Table 6. As the length of the fatty acid chain increased, the density of alkyd resins decreased, and vice versa, because it has the lowest related of active carboxyl groups. It is noted that the alkyd resins prepared from castor oil showed a higher density than the alkyd because of the length of the fatty acid chain the oils are composed of which is inversely proportional to the density of alkyd resin.

**Table 6.** The density values for the prepared alkyd resins from castor oil.

| **Alkyd resins** | **Density (g/cm$^3$)** |
|---|---|
| C-G | 0.88 |
| C-PR | 0.86 |
| C-PE | 0.89 |

### *Drying Time*

Because the production of alkyd resins does not affect the unsaturation of the fatty acid chains, the film formation mechanism of these alkyds is identical to that of oils. Since alkyds have a higher molecular weight than oil, the crosslink needed to form a film is less, which causes faster drying rate to happen more frequently than with the corresponding oil.

On drying, semi-drying oils discolor less than the highly conjugated drying oils. Considering the aforementioned point, semi-drying oils can be used in alkyds by resin formulators to improve color and speed of drying. For such alkyds, oil lengths of 50 – 60% are typically utilized; however, it is important to keep in mind that higher oil lengths result in faster drying rates. They also negatively impact the film’s durability, color, and gloss retention.

There are two types of drying: physical drying and chemical drying. Chemically dried are alkyd resins. These resins are characterized by the fact that they dry quickly due to the fact that most of the chains of the fatty acid included in the composition of these oils are unsaturated, which makes them have the ability to interact with air oxygen; that is, the drying process occurs as a result of the occurrence of the oxidation and polymerization processes of the alkyd resin, and the auto-oxidation mechanism is a complex process (Chardon *et al*., 2021). There is more than one type of intermediate that can be formed, and the double bonds in fatty acids or vegetable oils may be conjugated or unconjugated, and the form of the double bonds has effects in drawing crosslinking (Arauz- Solís *et al*., 2024; Ma *et al*., 2021), which is formed in the polymerization process, and in general, the auto-oxidation process is divided into five stages They are 1) initiation, 2) hydroperoxide formation, 3) hydro peroxide dissociation, 4) crosslinking, and 5) dissolution.

As listed in Table 7, the difference in the drying time between each prepared alkyd resin depended on the length of the fatty acid chain composed of the alkyd resin. Hence, the drying time of alkyd resins prepared from castor oil is less dry due to the location of the double bonds on which the drying process (oxidation) takes place. The number of double carbon atoms is of particular importance because it distinguishes the centers transverse entanglement. It also depends on the type of vegetable oil used. Among the oils used in the production of dried resins, castor oil is preferred due to the removal of water from it. The thickness of the aluminum plate on which the model is placed. If the thickness of the plate is 120 µm, it requires more time to dry. Balance with the aluminum plate, whose thickness is 30 µm. The dried was used (solvent) in order to speed up the drying process because, without the drier, the process would be very slow. The amounts of driers should be kept to the lowest possible level because they not only stimulate drying but also stimulate the reaction after drying, which causes brittleness, splitting, and color change.

**Table 7.** The drying time values for the prepared resins from castor oil.

| Alkyd resins | Drying time (min.) |
|---|---|
| C-G | 25 |
| C-PR | 33 |
| C-PE | 20 |

### *Viscosity*

The polymer solutions are distinguished by a unique characteristic from the solutions of other materials by being more viscous. Since the viscosity of the solution is a measure of the volume and the molecular weight of the polymer, it can be considered an important technique in characterizing polymers. The important factors affecting viscosity are pressure and temperature. Pressure has little effect on viscosity; however, when the pressure exceeds 68 bar, the effect of viscosity appears. The viscosity of liquids decreases when the temperature increases. When the temperature of the liquid increases, the distances between the molecules increase, so the friction between them decreases, and then the viscosity decreases (Abed *et al*., 2019; Zhao *et al*., 2022). It is observed that for all kinds of oils used in production of resin in prevous studies, the viscosity of alkyd resins rises during the reaction. Additionally, it is observed that the viscosity gradually increases through the first three reaction hours. After that, the viscosity increases significantly in the esterification reaction between monoglycerides and phthalic anhydride or maleic anhydride. After 5 or 6 hours, the reaction finishes, and the alkyd resin is very viscous, i.e., the polymeric chains are in the form of a gelatinous substance. According to this test, using a viscometer (RVDV-II + P 8500), with a voltage of (230 V~), a frequency of (50/60), and a power of (30) VA.

It was observed from the results in Table 8 that the viscosity of alkyd resins differs according to the vegetable oils they are composed of. It is noted that the viscosity is high for short-chain resins prepared from castor oil, and the viscosity value decreases in long-chain fatty acid resins due to the presence of the double bonds associated with the chains of fatty acids.

**Table 8.** The viscosity values of the prepared alkyd resin resins from castor oil.

| Alkyd resins | Viscosity (CP) | Temperature | Number of spindles | Speed of viscosity |
|---|---|---|---|---|
| C-G | 1050 | 25 | 63 | 60 |
| C-PR | 1604 | 25 | 63 | 60 |
| **C-PE** | **High viscosity** | **25** | **63** | **60** |

### *Volatility*

This test was applied by calculating the weight difference in the percent of the prepared alkyd resin samples before and after drying in the oven at a temperature of 140 °C for two hours. The results of the volatility value of the prepared alkyd resins are noted in Table 9. Because castor oil contains a short chain of fatty acids, the alkyd resins made from it exhibit the lowest volatility value when comparing the volatility values of each manufactured resin. However, the long chain of alkyd resins, which contains double bonds that may interact with oxygen, caused them to volatilize rapidly, resulting in a high volatility value (Gaş, 2024).

.**Table 9.** The volatility values of the prepared alkyd resins from castor oil.

| Alkyd resins | Volatile percent (%) |
|---|---|
| C-G | 76 |
| C-PR | 74 |
| C-PE | 78 |

### *Chemical Resistance*

The prepared alkyd resins were tested for resistance to some chemicals, and the results indicated in Table 10 indicated that each resin had a different level of chemical resistance. It is noted that the resins prepared from castor oil are resistant, i.e., insoluble in water, because the resins are a component from a series of unsaturated fatty acids; that is, these chemical molecules are non-polar, while water is a polar solvent. Additionally, since tetrahydrofuran (THF) is a non-polar organic solvent, all previous resins are resistant to it.

**Table 10.** Shows the chemical resistance values of the prepared alkyd resins from castor oil.

| Alkyd resins | Dist. $H_2O$ | HCl | $H_2SO_4$ | KOH | NaCl | THF |
|---|---|---|---|---|---|---|
| C + G | + | + | + | - | + | + |
| C + PR | + | + | + | - | + | + |
| C + PE | + | + | + | - | + | + |

*(-) denotes non-resistant alkyd resins (melted)*
*(+) denotes the insoluble resistant alkyd resin*

Also, it should be noted that the resins prepared from castor oil are resistant to sodium hydroxide, sodium chloride, sulfuric acid, and hydrochloric acid. While these resins are non-resistant (soluble) in the KOH, the reason for this is that alkyd resins are made from a variety of vegetable oils depending on their composition and level of solvent resistance.

***Solubility***

The solubility of alkyd resins was measured qualitatively in some common organic solvents, which is summarized in Table 11. The solubility was measured by taking (0.01 g) of the synthesized resin samples and dissolving them in (2 mL) of different solvents. The solvents used were DMF, Acetone, Toluene, and Xylene as polar aprotic solvents, as well as non-polar solvents like Benzene and $CHCl_3$, as well as other solvents including Methanol, Ethanol, and Kerosene. It increases the reaction rate, i.e., the formation rate of polyester. This is due to the hydrogen bonding between the oxygen atom of the carboxyl ester group (O–Carboxyl ester) and the solvent. In addition, the (acid-base) interaction between the solvent and the polyester (alkyd resin) prevents proton dissociation. In addition, among the factors affecting solubility (temperature, stirring, and surface area), it is noted, also, through Table 11, that resins prepared from castor oil are dissolved in these solvents, and the solvents molecules attack the chain and dissolve these resins easily.

**Table 11.** The solubility of alkyd resins from castor oil.

| Alkyd resins | Solvent | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | DMF | Acetone | Toluene | Xylene | Benzene | DMSO | Methanol | Ethanol |
| C + G | + | + | + | + | + | + | + | + |
| C + PR | + | + | + | + | + | + | + | + |
| C + PE | + | + | + | + | + | + | + | + |

*+ Soluble at room temperature*

**Synthesis and Characterization of Acrylated Alkyd Resin from Castor Oil**

The acrylated alkyds were synthesized by the polymerization reaction of the alkyd resin, as in Figure 9. The alkyds were added into a flask of 100 mL and heated for three hours at 120 °C under reflux in the presence of an initiator, benzoyl peroxide, and in the presence of $N_2$.

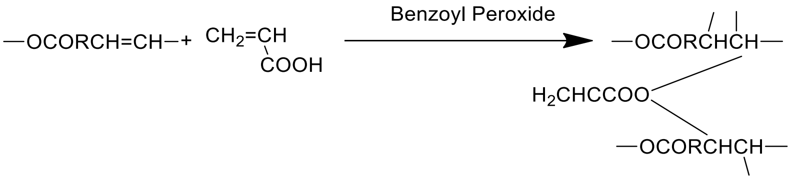

**Figure 9.** Synthesis of acrylated alkyd resin.

***FTIR Spectrum of Acrylated Alkyd Resin from Castor oil (C-G-A)***

The FTIR spectrum of (C-G-A) in Figure 10 indicates the appearance of an absorption band at (3300 $cm^{-1}$) for ─OH of carboxylic acid. While the emergence of two distinct bands at the two frequencies (2854, 2923 $cm^{-1}$) is due to the vibration of the stretching of the aliphatic (C–H) bond, also the appearance of the peak at the frequency (1750 $cm^{-1}$) is due to the vibration of the stretching of the bond (C=O) in the ester group and peak at the frequency (1680 $cm^{-1}$) is due to the vibration of the stretching of the bond (C=O) in carboxylic group. The appearance of the band at frequency (1465 $cm^{-1}$) is due to the vibration of the aromatic bond (C=C), and the appearance of the band at frequency (1615 $cm^{-1}$) is due to the vibration of the bond stretching (C=C) of the alkene. In addition, the appearance of the band at the frequency (1110 $cm^{-1}$) corresponds to the (C–O) straining vibration. The band at 2135.62 $cm^{-1}$ is due to the carboxylic acid group (RCOOH), indicated by stretching at CO, and the bands at 1321.513 cm-1 and 1397.105 $cm^{-1}$ represent the methyl group ($CH_3$). Both resins and acrylate resins have unsaturated compounds, which is evidence that they can dry at any suitable time. Additionally, the final resins exhibit properties such as rapid air drying and high chemical resistance, potentially extending the lifespan of coated surfaces. This longevity reduces the frequency of recoating, contributing to material and energy savings over the product's lifecycle (Choe *et al*., 2022; Das *et al*., 2021).

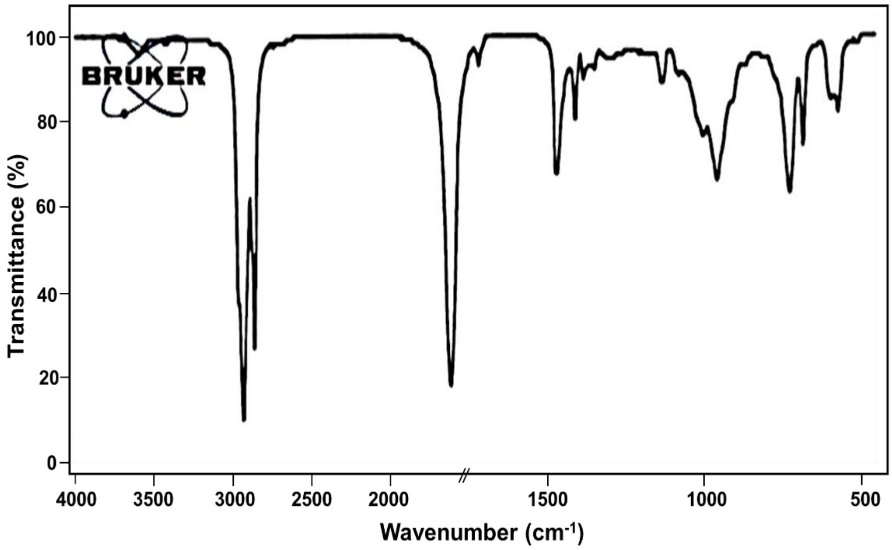

**Figure 10.** FTIR spectrum of acrylated alkyd resin from castor oil with glycerol.

### *FTIR Spectra of Acrylated Alkyd Resin from Castor Oil (C-PR-A)*

The FTIR spectrum of (C-PR-A), as shown in Figure 11, indicates an absorption band at (3300 cm$^{-1}$) for ─OH of carboxylic acid. While the emergence of two distinct bands at the two frequencies (2854, 2923 cm$^{-1}$) is due to the vibration of the stretching of the aliphatic (C–H) bond, also the appearance of the peak at the frequency (1750 cm$^{-1}$) is due to the vibration of the stretching of the bond (C=O) in the ester group and peak at the frequency (1680 cm$^{-1}$) is due to the vibration of the stretching of the bond (C=O) in carboxylic group. The appearance of the band at frequency (1465 cm$^{-1}$) is due to the vibration of the aromatic bond (C=C). The appearance of the band at frequency (1615 cm$^{-1}$) is due to the vibration of the bond stretching (C=C) of the alkene, as well as the appearance of the band at frequency (1110 cm$^{-1}$) to the (C–O) straining vibration. The peak at 2135.62 cm$^{-1}$ is due to the carboxylic acid group (RCOOH), indicated by stretching at CO and the peaks at bands of 1321.513 cm$^{-1}$ and 1397.105 cm$^{-1}$ methyl group ($CH_3$). Both resins and acrylate resins have unsaturated compounds, which is evidence that both of them can dry at any suitable time (Das *et al*., 2021).

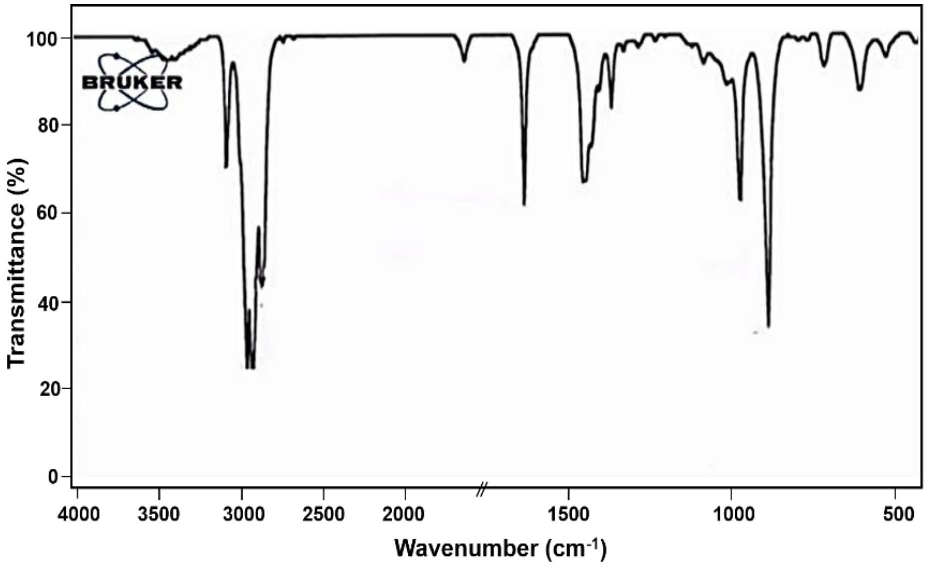

**Figure 11.** FTIR spectrum of acrylated alkyd resin from castor oil with propylene glycol.

### $^{1}$*HNMR Spectra of Acrylated Alkyd Resin from Castor Oil (C-PR-A)*

$^{1}$HNMR spectrum of (C-PR-A) in Figure 12 assigns the following chemical shifts: singles (δ= 0.4 ppm) for methyl group, singles (δ= 1.2-1.7 ppm) for ($CH_2$), singles (δ= 7 ppm) for Ar-H group, singles (δ= 3.4 ppm) for $OCH_2$, singles (δ=14.2 ppm) for COOH. The peak at δ= 10.2 ppm indicated the presence of an alcohol group (RCHOH) (Wang, 2013).

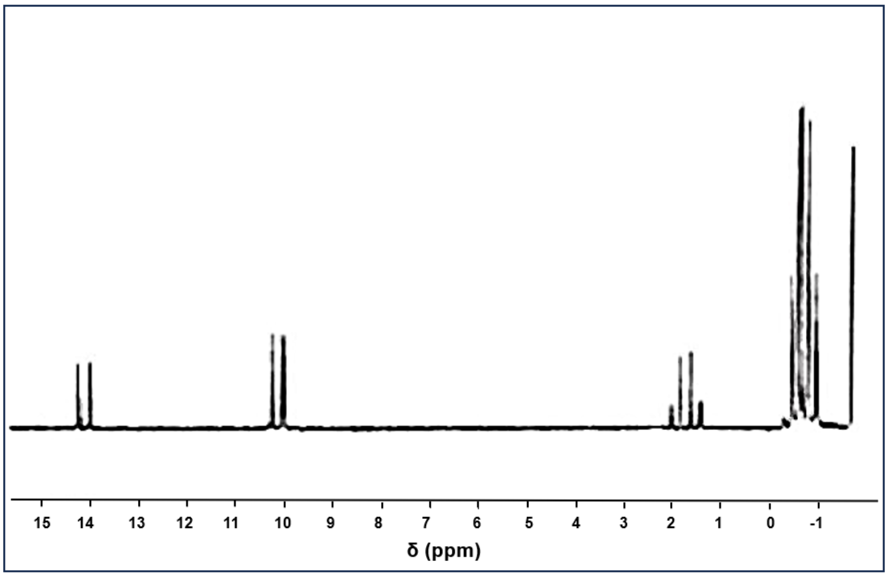

**Figure 12.** $^{1}$HNMR spectra of acrylated alkyd resin from castor oil with propylene glycol.

### *FTIR Spectra of Acrylated Alkyd Resin from Castor Oil (C-PE-A)*

The FTIR spectrum of (C-PE-A) in Figure 13 indicates the appearance of an absorption band at (3300 cm$^{-1}$) for (OH) of Carboxylic acid. While the emergence of two distinct bands at the two frequencies (2854, 2923 cm$^{-1}$) is due to the vibration of the stretching of the aliphatic (C–H) bond, also the appearance of the peak at the frequency (1700 cm$^{-1}$) is due to the vibration of the stretching of the bond (C=O) in the ester group and peak at the frequency (1680 cm$^{-1}$) is due to the vibration of the stretching of the bond (C=O) in carboxylic group. Also, the appearance of the band at frequency (1465 cm$^{-1}$) is due to the vibration of the aromatic bond (C=C), as well as the appearance of the band at frequency (1110 cm$^{-1}$) to the (C–O) straining vibration. The band at 2135.62 cm$^{-1}$ is due to the carboxylic acid group (RCOOH) indicated stretching at CO, also at bands of 1321.513 cm$^{-1}$ and 1397.105 cm$^{-1}$ methyl group ($CH_3$). Both resins and acrylate resins have unsaturated compounds, proving that they can dry at any suitable time (Glenn *et al*., 2023).

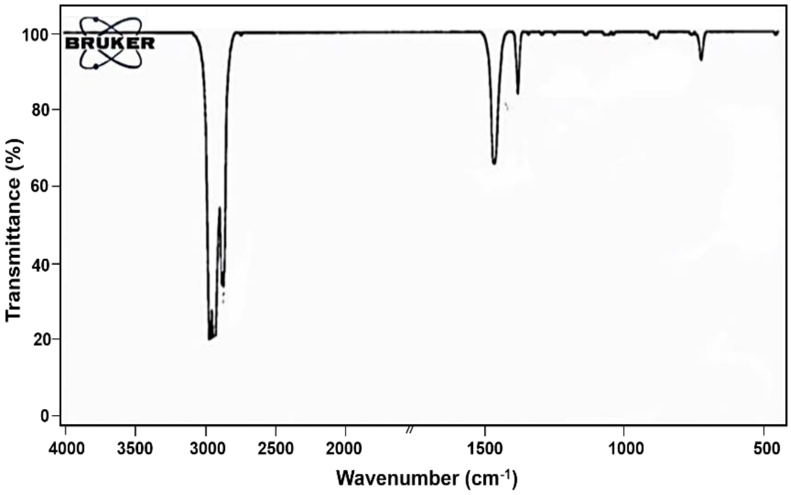

**Figure 13.** FTIR spectrum of acrylated alkyd resin from castor oil with pentaerythritol.

## Physiochemical Properties of Acrylated Resin

### *Drying Time*

After the application of the resins, the steel panel used to measure the drying time of the resins was maintained vertically. According to the data in Table 12, the acrylated alkyds had a lower drying time than the unacrylated alkyds. The molecular weight of acrylic monomers is known to increase, and as molecular weight increases, fewer crosslinks are needed to produce a cohesive film or to reach the drying stage. As the drier presence increases, the drying period of the thicker films can dramatically accelerate the oxygen uptake at the methylene group or at the double bond (Meng and Latta, 2005). It was shown that phthalic and maleic anhydride, along with a specific amount of modification that results in the resin crosslinking, are responsible for the acrylate alkyd resin's capacity to air dry. Phthalic and maleic anhydride concentrations increase through condensation polymerization, producing a comparatively longer chain length and greater crosslinked dense resin. The resin develops a self-curing propensity as it gets denser, more viscous, and more compact.

**Table 12.** The drying time values for the prepared acrylate alkyd resins.

| Alkyd resins | Drying time (min.) |
|---|---|
| C-G-A | 40 |
| C-PR-A | 50 |
| C-PE-A | 39 |

### *Solubility*

The high solubility of the acrylate alkyd resin in different types of solvents has been proven. DMF, acetone, toluene, xylene, benzene, methanol, and ethanol are among the solvents that were used. As the distance between the resin's molecular chains increases, so do the solvent molecules. As solvent molecules fill the space made available by chain movements, they "invaded" the spaces between long chains with a pendant side group of resin. Short-range attractive forces are created when movements bring two chains close together, which restricts chain movement and leads to the formation of a viscous system. Solvents are added to address the problem of high-viscosity resin, which hinders the substrate's wettability. Better resistance to xylene, ethanol, and methanol was shown by the acrylated resins, as in Table 13. Further comparative analysis could include the life cycle assessment (LCA) of the developed resins against traditional formulations. Preliminary findings suggest that the described process reduces overall emissions by utilizing bio-based components and limiting the use of high-VOC solvents, consistent with the principles of green chemistry (Carretti and Dei, 2004).

**Table 13.** The acrylate alkyd resins solubility.

| Acylated | Solvent | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Alkyd resins | DMF | Acetone | Toluene | Xylene | Benzene | DMSO | Methanol | Ethanol |
| C + G + A | + | + | + | - | + | + | - | - |
| C + PR + A | + | + | + | - | + | + | - | - |
| C + PE + A | + | + | + | - | + | + | - | - |

*+ Soluble at room temperature /- Insoluble at room temperature*

### *Chemical Resistance*

Table 14 shows that the acrylated alkyds have higher resistance than the unmodified alkyds to acid, and alkali had noted the same observations about acrylated alkyd resin. The researchers attributed the addition of acrylic polymers, which are known to provide superior alkali and acid resistances, to the increased resistance to these substances. Our results also show that the alkali and acid resistance decreased when the amount of maleic and phthalic anhydrides increased. This could be because the copolymer composition's proportion of acrylic monomer has decreased (Carretti and Dei, 2004).

**Table 14.** The chemical resistance of acrylate alkyd resins.

| Acylated Alkyd resins | Distilled $H_2O$ | HCl | $H_2SO_4$ | KOH | NaCl | THF |
|---|---|---|---|---|---|---|
| C + G + A | + | + | + | - | + | + |
| C + PR + A | + | + | + | - | + | + |
| C +PE + A | + | + | + | - | + | + |

*(+) denotes the insoluble resistant alkyd resin*

## CONCLUSION

Acrylated-alkyd resins were synthesized in the presence of castor oil-based alkyd resin through free-radical polymerization of acrylic monomers. This study demonstrates a novel synthesis approach by utilizing castor oil, an environmentally friendly and renewable resource, in conjunction with acrylic monomers to enhance the performance properties of alkyd resins. Incorporating acrylic phases into the alkyd backbone improved drying times, increased chemical resistance, and higher solubility in various solvents. Characterization techniques, including FTIR and $^1$HNMR spectroscopy, confirmed the successful synthesis and hybrid structure of the acrylated resins. The study highlights the eco-friendly nature of the resins by leveraging sustainable raw materials and reducing reliance on volatile organic compounds (VOCs), contributing to environmentally conscious coating applications. The use of controlled radical polymerization techniques enabled the production of resins with superior film characteristics, such as enhanced crosslink density and reduced drying time. In addition, the work underscores the significance of optimizing the acrylic-to-alkyd ratio and oil length in determining the final properties of the hybrid resins. By bridging the gap between traditional alkyd formulations and modern performance requirements, this research advances the development of sustainable and high-performance coating binders. The findings provide a comprehensive framework for future studies exploring eco-friendly and efficient synthesis methods aligning with the manuscript's overarching goal of addressing environmental and industrial challenges in resin production.

## CONFLICT OF INTEREST

There is no conflict of interest in this article.

## AUTHOR CONTRIBUTION

NBH: Manuscript Drafting, Supervision, Manuscript Review and Editing; DJA: Conceptualization, Methodology, Software; Data Analysis.

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