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RESEARCH ARTICLE

EVALUATION OF CARDANOL ACETATE AS A REACTIVE DILUENT FOR ALKYD COATINGS

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Abstract

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Alkyd resins are viscous, tacky materials that are difficult to handle. Most often, these handling problems are overcome by dissolving the resins in organic solvents, which evaporate into the atmosphere as volatile organic compounds (VOC's), giving rise to regulations (in many parts of the world as a way to reduce the environmental impacts). Cashew nut shells are normally burned to provide heat during processing of the nut. This practice ends up in production of dark thick smoke with particulate matter which pollutes the environment profoundly. This is mainly due to the presence of cashew nut shell liquid residue in the shells. Cashew nut shell liquid (CNSL) is not currently utilized in Kenya and the objective of this work was to develop reactive diluents from chemically modified CNSL products and evaluate their compatibility and suitability in alkyd coatings. Cardanol was isolated from decarboxylated CNSL using a combination of physical and chemical methods. The cardanol acetate was synthesized by treating cardanol with acetic anhydride and was also characterized by FT-IR and it showed the presence of the C=O stretch functional group characteristic of the ester and the absence of the OH group that was present in cardanol. Cardanol acetate and neat cardanol were tested as reactive diluents for alkyd resins in coating formulations. Cardanol acetate showed good properties, including low viscosity and good drying performance. Furthermore, a shortening of the drying time of about 25-35 % compared to conventional commercial products.

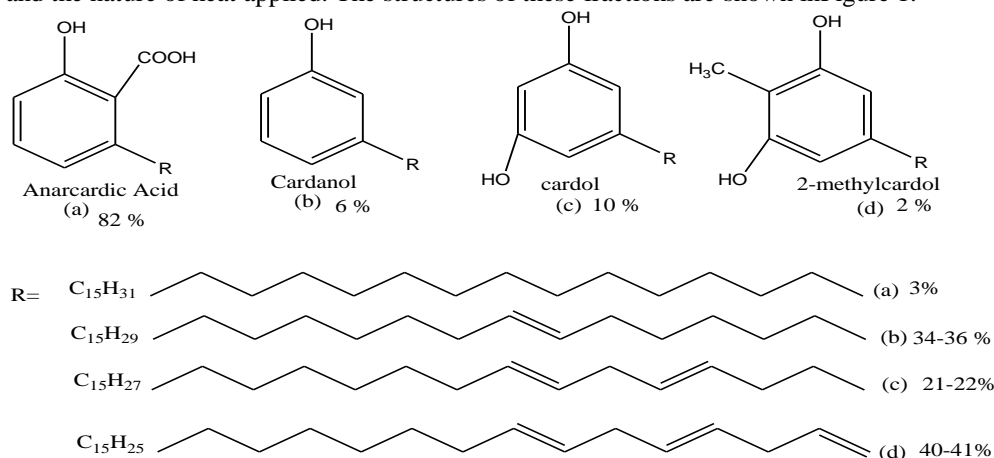
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1.0 INTRODUCTION

Alkyd resins are produced by the condensation of polybasic carboxylic acids with polyhydric alcohols (Wicks et al., 1992). At least one of the alcohols must be trihydric or higher. The most commonly used alkyd polyesters are those produced from phthalic anhydride and glycerol and are modified with unsaturated oils or fatty acids such as oleic or linoleic acids to achieve air drying properties. Alkyd resins are also modified with acrylic, epoxy or silicone compounds (Wicks et al., 1992). Paints based on alkyd resin binders are usually solvent-borne paints, common solvents being white spirit, a mixture of saturated aliphatic and alicyclic C7-C12 hydrocarbons with a content of 15-20% by weight of aromatic C7-C12 hydrocarbons, or xylene. Further important components of alkyd paint are pigments and extenders. The pigment is the substance that gives the paint color. Pigments are derived from natural or synthetic materials that have been ground into fine powders. Extenders are inert pigments used to extend or increase the bulk of a paint. Another important component of alkyd coating comprises the additive catalyst or driers. Driers are metal soaps or coordination compounds which accelerate paint drying, thus shortening the total drying time. Without driers, the drying time of alkyd paints would be over 24 hours. Alkyds can be classified by various criteria. One classification is by oil length based on the ratio of monobasic fatty acid to dibasic acid utilized during

synthesis. The amount of oil is defined as the triglyceride equivalent to the amount of fatty acids in the alkyd. Alkyds with oil lengths greater than 60 are long oil alkyds; those with oil length from 40 to 60, medium oil alkyds, and those with oil lengths less than 40, short oil alkyds (Dieter et al., 1998).

Cashew nut shell liquid (CNSL) is a viscous liquid found in the honeycomb structure of the cashewnut shells having a bitter taste and it is dark brown in color. It is essentially a mixture of 4 phenolic compounds namely anacardic acid, cardanol, cardol and 2-methyl cardol (Francisco et al., 2006). Natural CNSL contains about 90% by weight anacardic acid, a derivative of O-carboxyphenol that readily decarboxylates on heating and converts to cardanol. The remaining 10% of CNSL consists of cardol, a resorcinol that is mainly responsible for the vesicative activity of the CNSL (Cornelius, 1966). De Lima et al.(2008), further stated that the actual composition of CNSL, color and stability depend to some extent on the duration and condition of storage as well as on the method of its production and the nature of heat applied. The structures of these fractions are shown in Figure 1.



CNSL is used in manufacturing cardanol based resins and varnishes, cardanol, foundry resins, brake linings, clutch facing, acid resistant paints, insecticides and fungicides, rubber compounding resins, lacquers and enamels (Kumar et al., 2002). CNSL based resin possess an outstanding resistance to the sulfiding action of mineral oils and high resistance to acids and alkalis (Knop et al., 1979). A number of products based on CNSL are used as antioxidants, stabilizers and demulsifiers for petroleum products. Soluble metal derivatives of CNSL are used to improve the resistance to oxidation and sludge formation of lubricating oils.

Cardanol is obtained from anacardic acid, through heating process. Each of the fractions in Fig.1 includes four compounds because the composition of the side chain varies with its degree of unsaturation (Kumar et al., 2002). The unique molecular structure of cardanol, especially unsaturation of long hydrocarbon side chain, makes the cross linking easy on polymerization. Structural changes can be effected at the hydroxyl, on the aromatic ring and on the side chain to make tailor made products of high value. In terms of physical properties, cardanol is comparable to nonylphenol. Cardanol is hydrophobic and remains flexible. Its freezing point is below -20 °C, it has a density of 0.930 g/ml and boils at 225 °C under reduced pressure (10 mmHg). Cardanol finds use in the chemical industry in resins, coatings, frictional materials and surfactants used as pigment dispersants for water-based inks. It is used to make phenalkamines, which are used as curing agents for the durable epoxy coatings used on concrete floors. Cardanol based resins possess an outstanding resistance to softening action of mineral oil and high resistance to acids, alkalis, termite and insect resistance (Risfaheri et al., 2009).

Reactive diluents are compounds or mixture of compounds that reduce viscosity of the base resin. They have a relatively high boiling point and remain as part of the coating system after curing (Zabelet al., 1999). Reactive diluents can copolymerize with a base resin thereby reducing the use of solvents which would otherwise result in emission to the environment and pollution of the same. They improve handling and ease of processing in various applications. They are used to optimize performance properties such as impact strength, adhesion, flexibility filler-loading and solvent resistance of a coating system. Reactive diluents are classified into groups which include aliphatic, aromatic and cycloaliphatic. A reactive diluent should have low viscosity, good compatibility with the resin, low volatility (BP >300 °C), non-toxic, low color, economic replacement of solvent and the ability to participate in oxidative cure. Volatile Organic Compounds (VOCs) have been recognized to cause serious problems in air pollution. The three important end effects of volatile organic compounds emissions into the atmosphere are formation of eye irritants, particulates, and toxic oxidants such as ozone. The most critical effects for coatings are ozone and even though ozone is a naturally occurring component of the atmosphere, it is toxic to plants and animals. Also the burning of cashew nut shell produces particulate matter. With the rapid growth of volatile organic

compounds emissions from man-made sources, ozone levels especially in and around cities have exceeded the levels that many plants can withstand and have endangered human health, especially for susceptible individuals. The largest source of man-made VOC emissions is transportation from automotive and truck tail pipe emissions, along with fuel leakage during distribution. The second largest source is coatings. Photochemical reactions in the atmosphere are complex and dependent on many variables in addition to the amount and structure of VOCs, especially the concentrations of various nitrogen oxides. The principle pathways leading to the generation of ozone are by way of hydrogen abstraction from the VOC compounds.

2.0 MATERIALS AND METHODS

2.1 Materials and equipment

The research was conducted in the GK chemistry laboratory in Jomo Kenyatta University of Agriculture Technology (JKUAT). Cashew nut shells were obtained from the Kenya Nut Company in Thika, Kenya. N-hexane, ammonia solution and methanol (all, of General Purpose Reagent grade) and Wij's reagent (Analar) were all obtained from Sigma Aldrich, Germany. Acetic anhydride was obtained from Sigma Aldrich. A screw press mill at the Biomechanical and Environmental Engineering Workshop in JKUAT was used for milling the shells. CNSL was extracted from milled cashew nut shells using n-hexane solvent in conical flasks with a capacity of 3 liters, a rotor vacuum distillation apparatus model Buchirotavapor R 200 with a 1 liter flask was used for evaporation of solvent. Cardanol was isolated using a chemical method employing methanol and ammonium hydroxide. Other equipment used in analyses was a pH meter, Gas Chromatography Mass Spectrometer (GC-MS) and Fourier Transformed Infrared Spectroscopy (FTIR) model 8400.

2.2 Methods

2.2.1 Extraction of cashew nut shell liquid (CNSL)

Milled cashew nut shells (200 g), and n-hexane solvent (600 g) were stirred together in a 2 liter conical flask and allowed to stand overnight. CNSL was extracted twice with n-hexane using a two stage batch extraction process. Fresh solvent was employed for each stage and stirred together to ensure maximum extraction. The clear liquid after settling the tiny particles was decanted while the solvent that remained in the cake was recovered using a simple distillation apparatus. The CNSL rich in solvent was covered using aluminium foils to counter loss of solvent. The CNSL was concentrated using a Buchirotavapor R 200 and the solvent recovered for reuse. The yield of CNSL obtained was then determined.

2.2.2 Decarboxylation of CNSL

CNSL was decarboxylated at 140 °C for 2 hours or until all effervescence ceased.

2.2.2 Isolation of cardanol

Decarboxylated CNSL (100 g) was dissolved in methanol (320 mL), and ammonium hydroxide (25%, 200 mL) was added and stirred for 15 min. This solution was then extracted with n-hexane (4 × 200 mL). The organic layer was washed with 5% HCl (100 mL) followed by distilled water (100 mL). Activated charcoal (10 g) was added to the organic layer, stirred for 10 min, and filtered through filter papers. The filtrate was dried over anhydrous sodium sulfate and concentrated to get pure cardanol (Kumar et al., 2002).

2.2.3 Synthesis of cardanol acetate

The method described by Saeid and Somayeh, 2010 was adopted. Cardanol (31.6 g), acetic anhydride (15.8 g), concentrated sulphuric acid (0.4 g) and acetonitrile (10 ml) were mixed together. The reaction mixture was refluxed at 80 °C in a water bath for 4.5 hrs. After completion of the reaction, the mixture was filtered off. The product was extracted with ethyl acetate and washed with water and finally dried over anhydrous sodium sulphate to obtain pure product.

2.2.4 Characterization of raw CNSL, decarboxylated CNSL, cardanol and cardanol acetate

2.2.4.1 Determination of specific gravity

Specific gravity was determined using a 25 ml pycnometer at 25 °C. The pycnometer was filled with distilled water, dried on the outer side and the weight recorded. This was repeated using two other values and the weight obtained recorded. The pycnometer was then oven dried and filled with raw CNSL and the weight measured. This procedure was repeated in triplicates for decarboxylated CNSL, cardanol and cardanol acetate (Abbott, 1989).

2.2.4.2 Determination of iodine value

Samples of raw CNSL, decarboxylated CNSL, cardanol and cardanol acetate each weighing 0.51 g were added into separate 250 ml conical flasks and dissolved using 10 mL of chloroform in each case. Chloroform (10 mL) was also added into a conical flask containing no sample. Wij's solution (25 mL) was added into each conical flask containing the sample and an equal volume to the blank. Each flask was shaken vigorously and allowed to stand in the dark for half an hour. The solutions in each flask were diluted with 70 mL of water and 25 mL of 10 % KI solution. Four drops of starch indicator solution was added to each flask and the sample and blank titrated using 0.1N sodium thiosulphate solution to the end point. This procedure was repeated in triplicates for each sample.

2.2.4.3 Determination of acid value

Raw CNSL (1.3 g) was weighted accurately into a 250 mL conical flask. Diethyl ether (25 mL) and ethanol (25 mL) were mixed and introduced into the conical flask and three drops of phenolphthalein indicator added. The solution was shaken so that the fatty acids present in the oil dissolved. This solution was titrated with 0.1N aqueous KOH while shaking. This procedure was repeated for decarboxylated CNSL, Cardanol and cardanol acetate in triplicates.

2.2.4.4 Determination of pH

Measuring of pH was done using a pH meter from Hanna instruments model 211 Microprocessor. The pH meter was calibrated using buffer 4 and 7 and readings were obtained by inserting the probe of the pH meter into raw CNSL and three values were taken. This procedure was repeated for decarboxylated CNSL, cardanol, cardanol acetate and cardanyl methyl ether in triplicates and an average result taken for the samples (Atkins and Julio, 2006).

2.2.4.5 FTIR Analysis

FTIR spectra were obtained using a Shimadzu model 8400 spectrometer. Thin liquid samples were cast on a KBr cubes and ran in FTIR machine and the various peaks recorded (John Coates, 2000).

2.2.4.6 Gas Chromatography-Mass Spectrometer.

GC-MS analysis was carried out using a Finnigan GC 8000 series and interfaced with a voyager EI-mass selective detector, on a RTX-5MS column. Sample (1 mg) was dissolved in 10 mL of dichloromethane, and 1 μ L of this solution was injected into the GC- MS. The temperature was programmed from 50 to 250 $^{\circ}$ C at 10 $^{\circ}$ C/ min and maintained at 250 $^{\circ}$ C for 30 min (Kumar et al., 2002).

2.2.4.7 Determination of viscosity

Capillary viscometer number 3 was mounted on a water bath and the temperature set at 40 $^{\circ}$ C. Distilled water (10 mL) was measured and put into the viscometer using a pipette. The time taken for water to move from the upper mark to the lower mark was recorded. This procedure was repeated for raw CNSL, decarboxylated CNSL, cardanol and cardanol acetate.

2.2.5 Formulation of alkyd coatings with reactive diluent

Table 1 presents the coating formulations for assessing cardanol acetate as reactive diluents. The alkyd resin was diluted with the reactive diluent at weight percentages of 5%, 10%, 15%, 20%, and 25%. Metal driers were added at levels of 1% and 0.6% for lead naphthenate and cobalt octoate respectively. In addition, white spirit was incorporated at weight percentages of 45%, 40%, 35%, 30% and 25%.

Table 1: Composition of clear alkyd coating formulations based on long oil alkyd resin (70% wt solids)

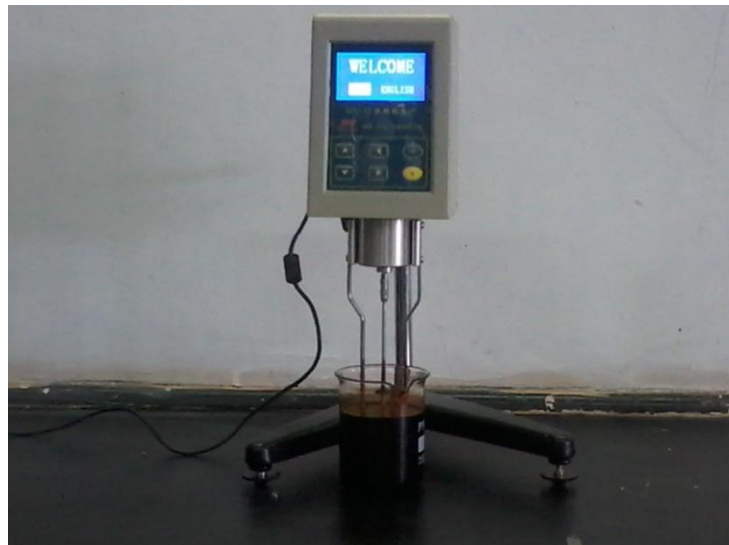
Alkyd resin (70 % wt solid)	White spirit (g)	Lead Naphthenate (32%)	Cobalt octoate (10%)	Reactive diluent (g)
100 g pure resin	45	1 % (3.13 g)	0.6 % (6 g)	5
100 g pure resin	40	1 % (3.13 g)	0.6 % (6 g)	10
100 g pure resin	35	1 % (3.13 g)	0.6 % (6 g)	15
100 g pure resin	30	1 % (3.13 g)	0.6 % (6 g)	20
100 g pure resin	25	1 % (3.13 g)	0.6 % (6 g)	25

2.2.6 Preparation and testing of coatings

Clean metal panels were applied with coatings containing alkyd resin (70 wt% solution in white spirit) and reactive diluents by brushing the prepared formulations onto commercially available steel strips. All experiments were performed in triplicate for each formulation and controls.

2.2.7 Test for viscosity for the formulations

The viscosity was measured by NDJ-5S digital viscometer at room temperature (23 °C). Rotor number one was used at 60 rotations per minute rotating speed (shear rate of 100 mPa.s). Approximately 200 g of samples was prepared in a 200 mL beaker and mixed on roll mill for 30 min.



2.2.8 Test for drying time

Drying time study was evaluated by adopting ASTM standard (D 5895-03) method using a Quadracycle electronic drying time recorder DT 5040 (supplied by Gardco of USA). The coatings (2mls) were applied to glass panels using a bird film applicator and a circular dry time recorder was immediately placed on the wet film. The drying time was observed.

2.2.9 Test for Adhesion of coating film to the metal surface

Adhesion test study was evaluated by adopting ASTM standard (D 3359-09e2) method. Cross-cut tape test was undertaken to assess the adhesion of coatings on the metal. After curing the coating by air-drying for 10 days, panels were held firmly and then six cross-cuts, 1 mm apart, were made manually on the coated surface. The detached flakes or ribbons of coating were removed from the surface with a soft brush. A strip of fiber-reinforced cellulose acetate pressure-sensitive tape was then placed over the surface of the metal panel. The tape was manually smoothed, and pressure was applied using a rubber eraser to ensure good contact between the tape and the coating film. After 1 minute of application, the tape was removed from the coated surface by rapidly pulling it off, back upon itself, at an angle as close to 180° as possible. The grid area was inspected for removal of coating from the panel surface using an illuminated magnifier. The rate of adhesion was averaged for six panels of each group based on the code given in the standard for classification.

RESULTS

Table 2: Characteristics of Raw CNSL, decarboxylated CNSL and cardanol

Parameter	Raw CNSL	Decarboxylated CNSL	Cardanol
Specific gravity @ 25 °C, g/ cm ³	0.99	0.96	0.95
Viscosity @ 40 °C, mPa.s	52.36	46.56	45.31
Acid value, g/100 g KOH	12.64	1.73	1.18
Iodine value, g/100 g	231.5	231.2	232.0
pH @ 25 °C	3.07	6.02	6.16
Moisture content (%)	0.55	Negligible	Negligible

Table 3: Comparison of the characteristics of cardanol acetate and neat cardanol

Parameter	Cardanol acetate	Cardanol
Specific gravity @25 °C, g/cm ³	0.96	0.93
Viscosity @ 40 °C, mPa.s	42.06	45.31
Iodine value, g/100 g	232.4	232.0
Moisture content (%)	Negligible	Negligible
pH @25 °C	6.23	6.16

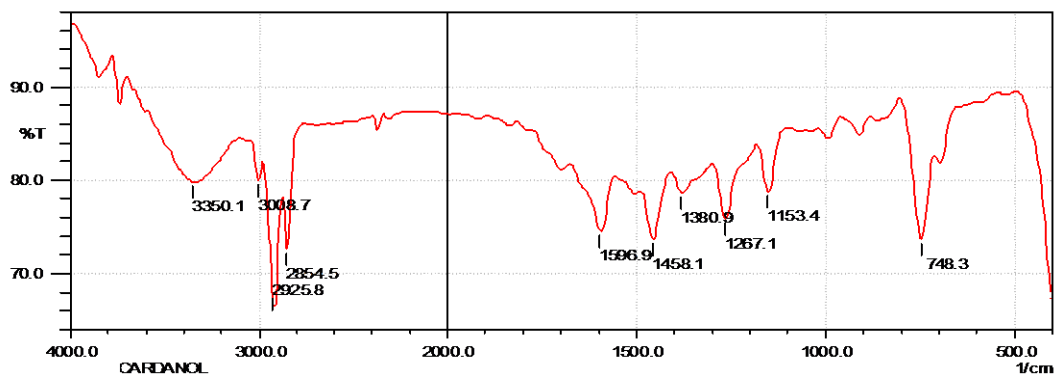


Figure 2: FTIR Spectrum of cardanol

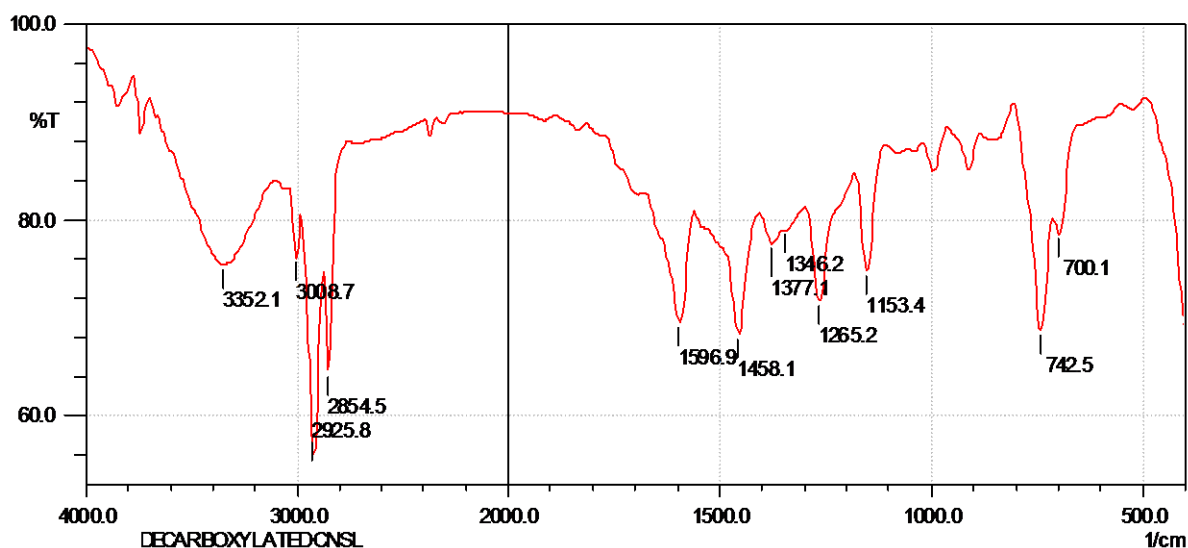


Figure 3: FTIR Spectrum of decarboxylated CNSL

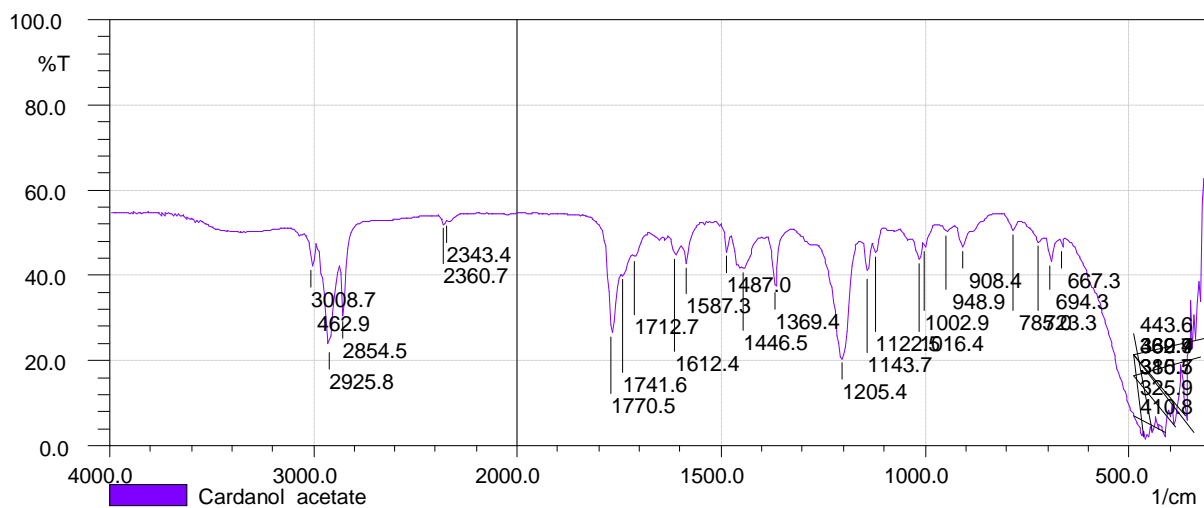


Figure 4: FTIR Spectrum of cardanol acetate

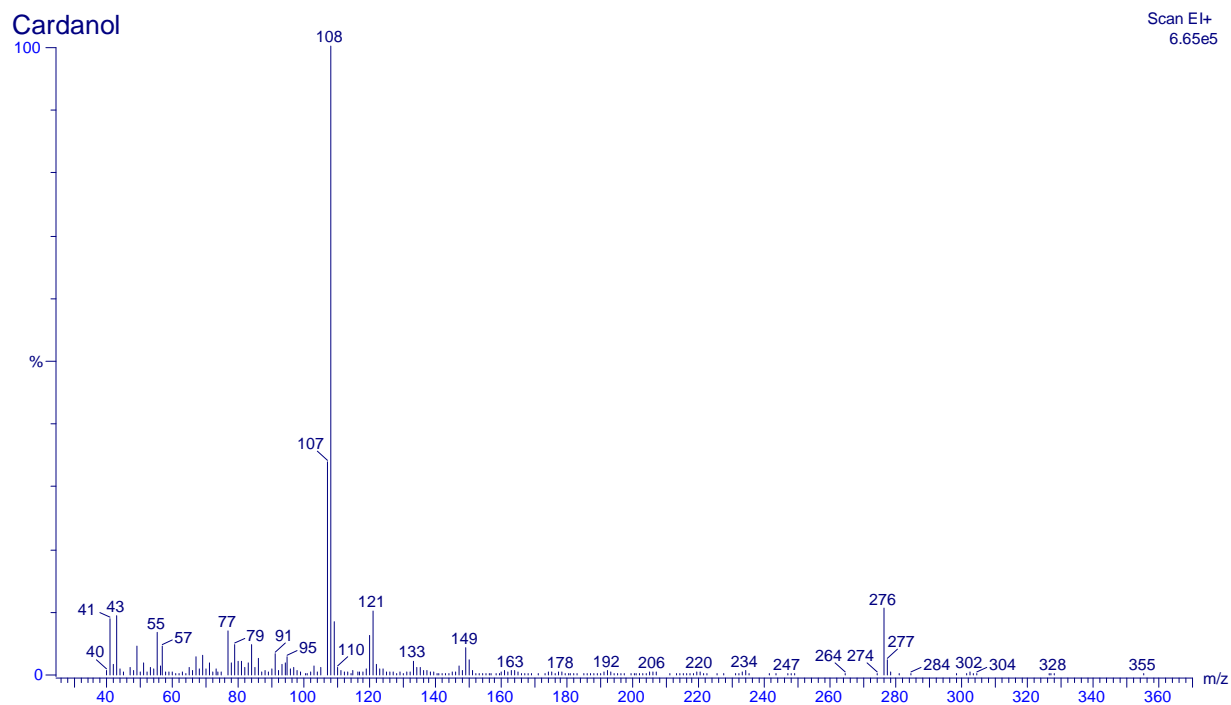
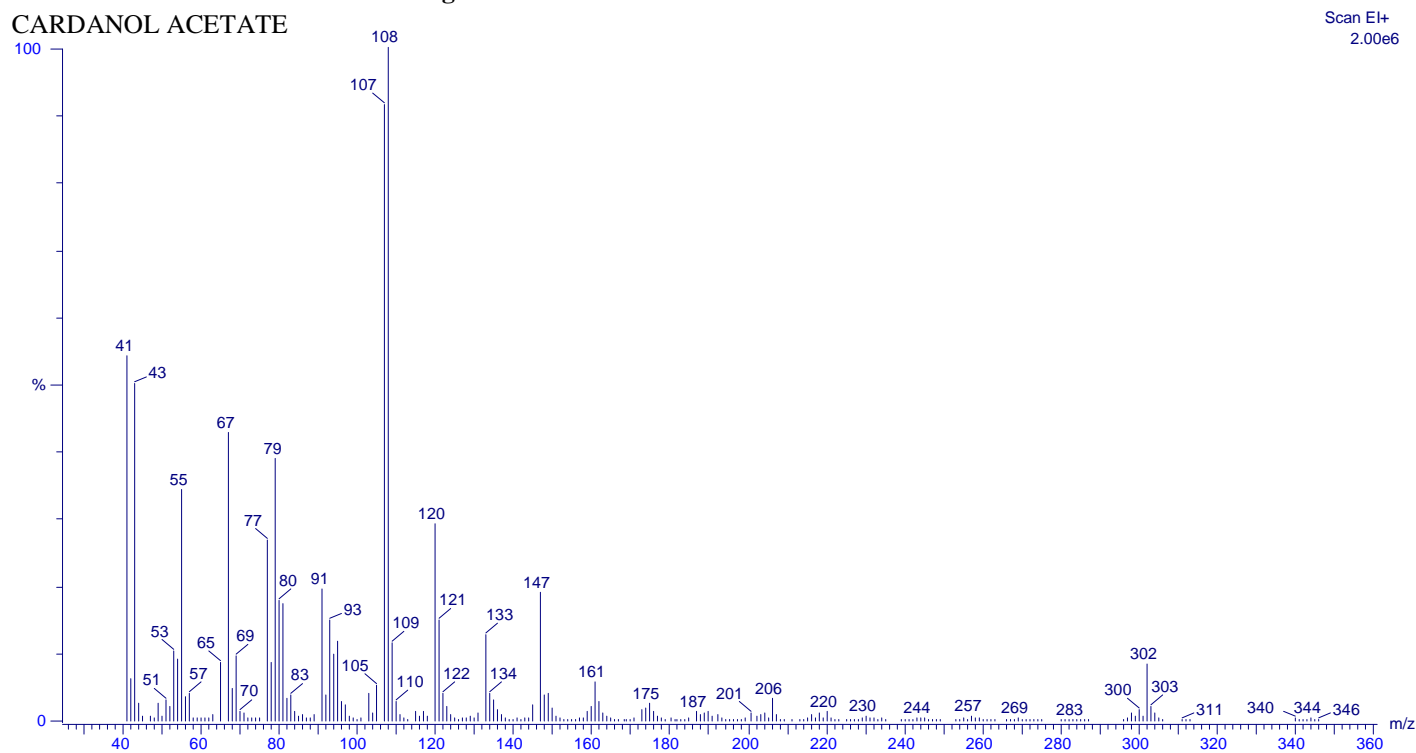
**Figure 5:GC MS Profile for cardanol****Figure 6:GC MS Profile for cardanol acetate**

Table 3: Comparison of the influence of neat cardanol and cardanol acetate used as reactive diluent on the viscosity of alkyd resin

	0 % Control	5 %	10 %	15 %	20 %	25 %
Viscosity at 25 °C (MPa.s) Neat cardanol	2170	930	620	380	350	320
Viscosity at 25 °C (MPa.s) Cardanol acetate	2170	810	540	330	320	300

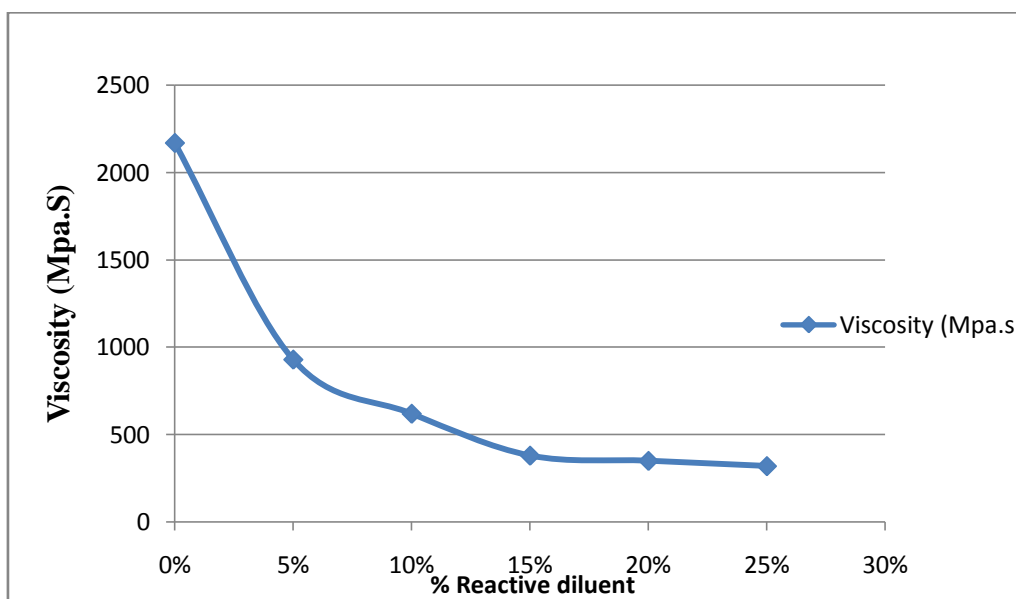
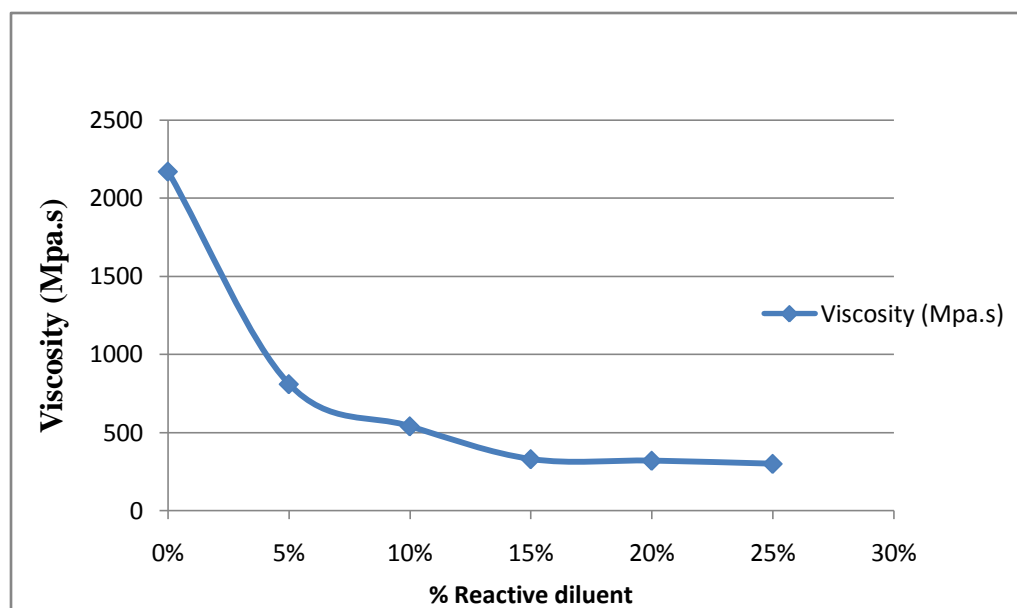
**Figure 7: Viscosity profile of long alkyd solution as a function of reactive diluent (Cardanol acetate)****Figure 8: Viscosity profile of long alkyd solution as a function of reactive diluent (Neat cardanol)**

Table 4: Pencil hardness and adhesion test on alkyd resin– neat cardanol mixture (after 10 days)

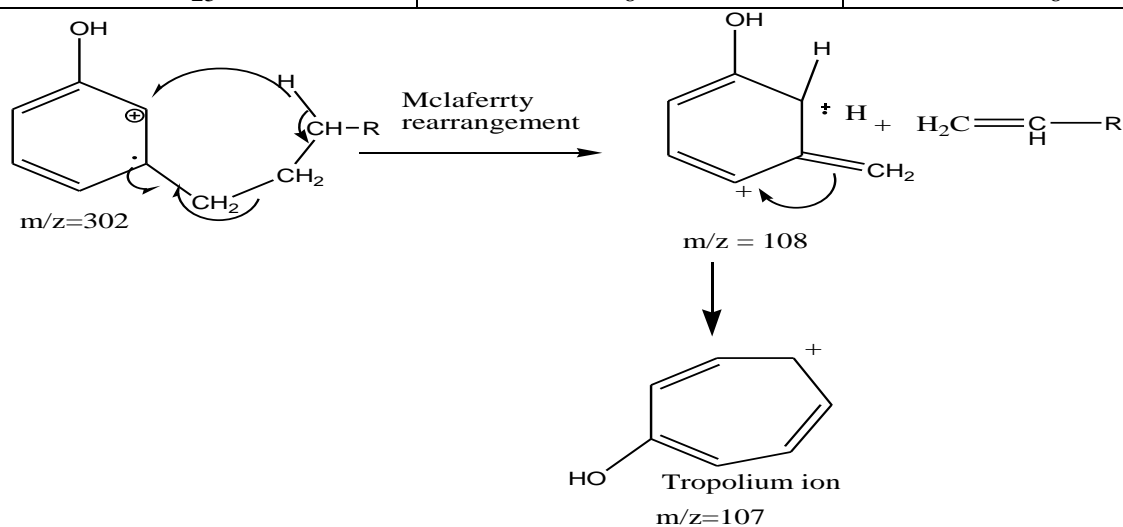
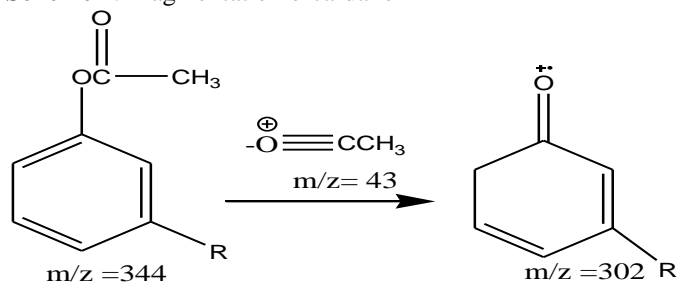
Neat cardanol	0 % Control	5 %	10 %	15 %	20 %	25 %
Pencil Hardness (Scratch/Gauge)	5H	4H	4H	4H	4H	4H
Adhesion	5B	5B	4B	4B	4B	4B

Table 5: Pencil hardness and adhesion test on alkyd resin- cardanolacetate mixture (after 10 days)

Cardanol Acetate	0 % Control	5 %	10 %	15 %	20 %	25 %
Pencil Hardness (Scratch/Gauge)	5H	4H	4H	4H	4H	4H
Adhesion	5B	5B	4B	4B	4B	4B

Table 6: Drying times of alkyd coating formulations blended with reactive diluents

	Alkyd/ neat cardanol (h)	Alkyd/ cardanol acetate (h)
Control	6	6
5	7	7
10	7	7
15	7	7
20	8	8
25	8	8

**Scheme 1: Fragmentation of cardanol****Scheme 2: Fragmentation of cardanol acetate**

3.0 Discussion

3.1 Characteristics of Raw CNSL, decarboxylated CNSL and cardanol

Raw CNSL has a high relative density because it has anarcadic acid as the major fraction; there is intermolecular attraction between the electronegative oxygen atom and the partially positive hydrogen atom of the phenol core as a result the molecules are closely packed together. Decrease in specific gravity in decarboxylated CNSL is due to the elimination of hydrogen bond during decarboxylation. (Table 2). There is no significant difference in the iodine values. This is because iodine value is a measure of the amount of unsaturation in given oil and unsaturation of the samples due to the side chain was the same for raw CNSL, decarboxylated CNSL and cardanol (Table 2). The iodine values of more than 140 in the fractions showed that they are drying oils. There is a variation in the viscosity values. Raw CNSL has anarcadic acid as the major fraction with the $-\text{COOH}$ group in the ortho position of the phenol core and therefore there is strong dipole-dipole attraction between the partially positive charged hydrogen atom and the strong electronegative oxygen atom (Table 2). There is the effect of intramolecular hydrogen bonding which results in the molecule being held together.

3.2 Comparison of Physicochemical Characteristics of cardanol acetate and cardanol

There is a significance difference in the viscosity values of cardanol acetate and cardanol (Table 3). Cardanol acetate has a low viscosity than neat cardanol because of the architecture of the molecule. The substituents in the phenyl core orient themselves in such a way that the molecules do not interact as they flow down the capillary tube. There is reduced shear rate and as a result the shear strain increases and the molecule flows easily as compared to cardanol acetate. In cardanol, there is molecular interaction which results into the entanglement of the long aliphatic chain and the viscosity is reduced. There is no significance difference in the iodine values of neat cardanol cardanol acetate as shown in Table 3. This shows that acetylation of cardanol with acetic anhydride does not affect the unsaturation of the side chain. There is a significance difference in the density values of cardanol acetate and neat cardanol (Table 3); this is because acetylation increases the molecular weight of the phenyl backbone. There is no significance difference in the moisture content of neat cardanol and cardanol acetate as shown in Table 1.

3.3 Identification of cardanol Using FTIR

The peak of absorption that appeared at frequency of 3350.1 cm^{-1} indicated the presence of OH group of phenolic compounds (Fig. 2). The peaks that appeared at frequency of 3008.7 cm^{-1} indicated the presence of C-H symmetrical stretch of the aromatic compounds (Fig. 2). The peak that appeared at frequency 2925.8 cm^{-1} indicated the presence of methylene C-H symmetrical stretch of the long aliphatic chain (Fig. 2). The Spectra that appeared at 1265.2 cm^{-1} area indicated C-O symmetrical stretch of the phenolic compounds (Fig. 2). The absorption peak that appeared at the 1596.9 cm^{-1} frequency indicated presence of C=C of the long aliphatic chain, while the peak that appeared in the 1458.1 cm^{-1} frequency indicated the C=C symmetrical stretch of the aromatic chains.

3.4 Identification of cardanol acetate using FTIR

The peak of absorption that appeared at frequency of 3008.7 cm^{-1} indicated the presence of C-H symmetrical stretch of branch chains of the aromatic compounds (Fig. 4). The peak that appeared at frequency 2925.8 cm^{-1} indicated the presence of methylene C-H symmetrical stretch of the long aliphatic chain (Fig. 4). The peak that appeared at frequency 1770.5 cm^{-1} indicated the presence of C=O stretch for an ester (Fig. 4). The peak that appeared at 1205.4 cm^{-1} area indicated C-O symmetrical stretch characteristic of an ester (Fig. 4). The absorption peak that appeared in the 1587.3 cm^{-1} frequency indicated C=C bending bonds of the long aliphatic chain, while the peak that appeared in the 1446.1 cm^{-1} frequency indicated the C=C stretch of the aromatic chains.

3.5 Interpretation of GC MS profile for cardanol

The base peak at $m/z = 108$ of the spectra can be rationalized in accordance with the main characteristic of alkyl benzene as derived from the molecular ions and is attributed through the β cleavage of the aliphatic chain as shown in Fig. 5. There is the McLafferty rearrangement due to the long aliphatic chain attached to the benzyl ring. The Peak at $m/z = 302$ and 304 correspond to the molecular weights of the two fractions of cardanol as shown in scheme 1.

3.6 Interpretation of GC MS profile for cardanol acetate

The base peak at $m/z = 108$ of spectra can be rationalized in accordance with the main characteristic of alkyl benzene as derived from the molecular ions and is attributed through the β cleavage of the aliphatic chain as shown

in Figure 6. The peak at $m/z = 302$ is attributed due to the cleavage of COCH_3 $m/z = 43$ group from molecular ion as shown in scheme 2. The Peak at $m/z = 340, 344$ and 346 correspond to the molecular ions of the three fractions of cardanol acetate. Scheme 2 shows the fragmentation pattern.

3.7 Viscosity of reactive diluent–alkyd formulations

The formulations were prepared in the presence of metal catalyst at weight percentages of 5 %, 10%, 15 %, 20%, and 25 % reactive diluent. Figure 7 shows the viscosity change of the formulations as a function of reactive diluent (cardanol acetate). Viscosity decreases with increasing cardanol acetate concentration, particularly at low shear rates. Figure 8 shows viscosity behavior of formulations diluted with neat cardanol at the same percentages. Similar trends were observed, but substantially lower decreases in viscosity were obtained, as neat cardanol is a much higher viscosity additive than cardanol acetate

3.8 Drying performance of reactive diluent–alkyd formulations

The dry time results for alkyd resin with cardanol acetate and neat cardanol formulations (0%, 5 %, 15 %, 20%, and 25%) including metal driers are provided in Table 6. In all the cases, cardanol acetate formulations exhibited significantly reduced dry times in comparison to the neat cardanol formulations. Most notably, extremely low set-to-touch times were observed for 10% and 15 % reactive diluent formulations for both formulations, demonstrating fast curing properties of the cardanol acetate as a reactive diluent. Dry times increased dramatically with increasing reactive diluent concentration.

3.9 Pencil Hardness and adhesion for Neat cardanol and cardanol acetate –alkyd films

Pencil hardness results are shown in Table 4 and 5 for neat cardanol and cardanol acetate respectively. Addition of reactive diluents with the metal driers resulted in films with improved pencil hardness compared to the controls. All films were relatively soft, based on the pencil hardness tests, and all films displayed increased hardness with reactive diluent. Adhesion was good in both reactive diluent and control films, and this could be attributed to the double bonds that form strong polymer networks in the coating. Crosslink density versus time, is improved in all reactive diluent–alkyd mixtures relative to controls. These results validate that the reactive diluent plays a role in increasing chemical cross-linking between alkyds and is incorporated throughout the polymer network of the dried alkyd films.

Conclusion

Herein, we report the synthesis of a new reactive diluent, cardanol acetate which was characterized via GC-MS and FTIR. The characteristics of cardanol acetate differed from those of cardanol by a small margin. The resulting alkyd–reactive diluent formulations exhibited low viscosities and extremely low drying times. Their films yielded superior hardness and fast oxidative curing. The results indicate the potential utility of this compound to achieve lower VOC formulations with equivalent performance properties.

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