



EVALUATION OF THE USE OF CARDANOL-FURFURALDEHYDE RESIN TO BOND UNRETTEED PALM FROND FIBER FOR THE PRODUCTION OF PARTICLE BOARDS

¹Salehdeen M.U, ¹Salifu N*, ²Usman S.O*, ²Salihu A.A, ²Adam U.S, ²Audu J. E , ²Okpanachi C.B, ³Buluku G.T

¹*Department of Industrial Chemistry, Faculty of Natural Sciences, Federal University Lokoja, Kogi State, Nigeria*

²*Department of Pure and Industrial Chemistry, Faculty of Natural Sciences, Kogi State University, Anyigba, Kogi State, Nigeria.*

³*Benue State University, Markudi, Benue State, Nigeria.*

Email: salifu.dev@gmail.com

Received 17-11-2025

Accepted 16-12-2025

Published on line 27-12-2025

Abstract

This study investigated the production of particle boards from palm frond fiber using cardanol-furfuraldehyde as a bonding agent. The raw material for cardanol-furfuraldehyde resin of resole type was obtained from technical cashew nut shell liquid, while the furfural was obtained from chemical vendors. The pH, acid value, moisture content, and relative density of the technical cashew nut shell liquid were determined before cardanol extraction. The extracted cardanol was reacted with furfural using an acid as a catalyst to form furfuraldehyde resin. The resin was used to prepare a composite with unretted palm frond fiber after the solubility in various solvents had been examined. Finally, the water floatation test of the composite was analyzed. This study showed that particle board and floating platforms can be obtained from cardanol resin and palm frond fiber.

Keywords: cardanol, furfuraldehyde, resin, palm frond fiber, unretted

Introduction and literature review

Cardanol-furfuraldehyde is a bio-based phenolic resin (also called a novolac resin) created by combining two renewable plant-derived chemicals: cardanol and furfuraldehyde, through a polymerization reaction.

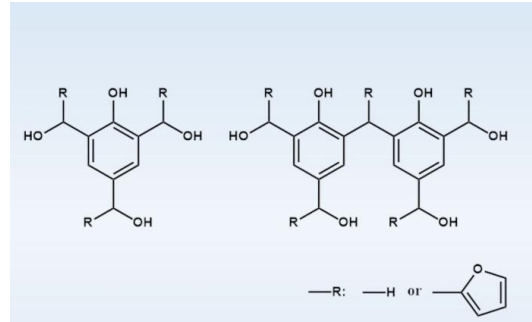


Figure 1: Cardanol-furfural resin

There are two main by-products of cashew: cashew apple and cashew nut shell. Cashew nut shell liquid is present in the cashew nut shell. The cashew apple is an edible fruit rich in vitamin C. It can be dried, canned, and stored, or taken fresh from the tree. It can also be squeezed for fresh juice, which can then be fermented into cashew wine, which is a very popular drink in West Africa. In South America, like Brazil, the apple is used to produce jams and soft alcoholic drinks (De Lima et al 2008). Its juice has been reported to have anti-tumor, antimicrobial, and antioxidant properties. According to (Melo et al 2003).

The cashew nut shell has a thickness of about 0.3cm, inside which is a honeycomb structure made of the cashew nut shell liquid (CNSL). The shell of the nut comprises about 50 % of the weight of the raw nut, the kernel represents 25 % and the remaining 25 % consists of the natural CNSL, a dark reddish brown viscous liquid which is the pericarp fluid of the cashew nut (Maria and Gouvan, 1999).

CNSL is only one of the components of the shell that is mentioned often as having enormous applications in polymer-based industries (Edoga et al, 2008). However, other polymerizable components include the extractives from the shell as well as the cellulose and lignin. CNSL resins have been applied as an adhesive for particle board, cashew cements, and many other applications.

Particle board has been described as generic term for a panel manufactured from ligno cellulosic materials, usually wood, primarily in the form of discrete pieces or particles, as distinguished from fibers, combined with a synthetic resin or other suitable binder and bonded together under heat and pressure in a hot press by a process in which the entire inter particle bond is created by the added binder, and to which other materials have been added during manufacture to improve certain properties [8]. Particleboard is cheaper, denser, and more uniform than conventional wood and plywood and is substituted for them when appearance and strength are less important than cost (Rocket 1997). These particle boards are made when fillers like palm fronds are bound with resins made using cardanol.

Palm fibers belong to the category of fibers/fibrous materials called leaf fibers (hard fibers). Palm fiber is a leaf fiber obtained from the leaves of the dwarf palm (*Chamaerops humilis*), a member of the palm family (palmae). As a natural cellulosic fiber(palm fiber) that is widely distributed and an abundant cellulose and engineering fiber source [9], Palm fiber presents abundant fiber cells with spiral vessel tissues at the cross-section. The chemical composition reveals that palm fiber contains abundant lignin but a smaller amount of cellulose (the content of 28.16 %). Palm fiber exhibits excellent breaking elongation, high moisture regain, distinct yield characteristics, and variability in strength. (Tonghua and Min, 2015) This research aims at producing cardanol resin from technical cashew nut shell liquid and apply it to bond particles of unretted palm fronds.

Experimental Methods

Extraction of CNSL from cashew nutshell

Solvent extraction was employed to recover cashew nutshell liquid (CNSL) from cashew nutshells. The extraction was performed using a Soxhlet apparatus with n-hexane as the extracting solvent. Upon completion of the extraction, the CNSL was distilled using a Dean–Stark setup to recover any solvent trapped within the sample

Decarboxylation of technical cashew nut shell liquid

The extracted CNSL (100 g) was mixed with toluene (150 ml) in a round-bottom flask and refluxed for 3 hours at about 140 oC by using the Dean-Stark apparatus. After cooling, the acid value was determined to ascertain the level of decarboxylation of CNSL (Gandhi et al 2012).

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 minutes. This solution was then extracted with n-hexane (4 x 200 ml). The organic layer was washed with 5 % HCL (100 ml) followed by distilled water (100 ml). Note: these steps were carried out in a separatory funnel.

Activated charcoal (10 g) was added to the organic layer, stirred for 15 minutes, and filtered through filter papers. The filtrate was dried over anhydrous sodium sulfate (45 g), filtered again and concentrated to get pure cardanol (Khumar et al 2012). Note: the washing with n-hexane and distilled water was done severally.

Production of resoles based on pure cardanol:

A given concentration of cardanol (0.7 mole) was reacted with formaldehyde (1 mole) in the presence of sodium hydroxide catalyst (10 % aqueous). The residue obtained was viscous or almost semi-solid. Little ethanol was used to keep the reaction mixture homogeneous. During the reaction, pH was maintained at 8 to 9, and after the reflux was over, water was distilled off under a vacuum. Rishabh (2013).

Methods for the preparation of fillers

Material chosen as filler for the resin was unretted palm frond fiber. It was obtained from Ayingba, the particle size was reduced using hand operated grater, sieved (460 mesh size), and ground further in a bigger grinding machine. The particles so treated were then used in the formulation of compounds using a modified version of (Danladi and Patrick, 2013).

Wetting of fillers with resins or other additives

Following the preparation of the filler was the wetting of the filler. The filler was slightly wetted with the resins and other additives like paraffin oil, ethanol, and then dried.

Compounding of resin with fillers

The measured weight of the filler (50 g) was adequately mixed with a given volume of the resin (50 g). The weight of the filler relative to the volume of the resin was varied to get the optimum value. They were then blended, and 5 g was cast into segments of a mold to complete the final process of cross-linking. The molding was carried out in an oven at a temperature of 145 °C for three hours. The compounding ingredients used were: resin, accelerator, catalyst (stearic acid), filler, and lubricant.

Determination of specific gravity

Specific gravity was determined using a 50 ml pycnometer at 25 °C. The pycnometer was filled with distilled water, dried on the outer side, and the weight recorded. The pycnometer was then oven-dried and filled with natural CNSL, and the weight was measured.

This procedure was repeated for technical CNSL, decarboxylated CNSL, and cardanol (Brian et al, 1989).

Determination of pH

The pH measurement was done using a pH meter. The pH meter was calibrated using buffers 4, 7, and 9, and readings were obtained by inserting the probe of the pH meter into the natural CNSL, and three values were taken. This procedure was repeated for technical and decarboxylated CNSL in triplicate, and an average result was taken for the samples (Akinhanmi and Akintokun, 2008).

Procedure for acid number/value

A given sample of CNSL (1 g) was weighed into a conical flask. 25 ml of diethyl ether and 25 ml of ethanol were mixed, 1 ml of 1 % phenolphthalein was added, and neutralized with 0.1 M KOH solution. The weighed CNSL was then added to the neutralized solvent mixture and shaken well to ensure proper mixing. The solution was then titrated with KOH titrant until pink coloration was obtained, which persisted for 30s. The acid value was then calculated thus;

$$\text{Acid value} = \frac{\text{titrant volume (ml)} \times 5.61}{W}$$

Where w = weight of the fatty oil being examined (g). (Usono et al, 1982).

Test for the solubility of resin

The solubility of the resin was tested using different solvents. The solvents used were n-hexane, methanol, diethyl ether, ethanol, and chloroform. A rod was dipped into the sample and inserted into the test tube containing each of the solvents. Then each test tube was observed for dissolution of the sample in the solvents used.

Water test for plastic

The plastic formed was put in water to check for its density relative to water.

Results and Discussions

Results

Table 1: Percentage composition of CNSL in the shell and the yield of cardanol in CNSL

Sample	Percentage yield (%)
CNSL	32.98
Card.	57.4

KEY:

Card = Cardanol

CNSL= Cashew Nutshell liquid

pH and acid value

Table 2: pH and acid values of the different types of cashew nutshell liquid

Sample	Acid Value (mgKOH/ g sample)	pH value
N-CNSL	145.00	5.37

T-CNSL	48.00	6.22
D-CNSL	16.58	-

KEY:

N-CNSL = Natural Cashew Nutshell Liquid

T-CNSL = Technical Cashew Nutshell Liquid

D-CNSL = Decarboxylated Cashew Nutshell Liquid

Test for the solubility of resin**Table 3: Solubility of resin**

S/N	Solvent	Formed resin
1	N-hexane	+
2	Methanol	+
3	Diethylether	+
4	Chloroform	+
5	Ethanol	+

KEY:

+ Soluble

- Non Soluble

Discussions**Percentage composition of CNSL in the shell and the yield of cardanol in CNSL**

From Table 1, the percentage of CNSL in the CNS is given as 32.98 % and the reference value from literature reviewed was 30-35 % (Kumar et al., 2009).

The percentage yield of cardanol was calculated and was determined to be 57.4 %. Thus, this method of isolation is advisably used within the laboratory for research purposes and shouldn't be applied in the industries.

Economically, the feasibility of this method is inappropriate because the atom economy of the process is very low, considering the cost of reagents used and the heat supply, which must be put in place in the industrial setting. The economy of this process can, however, be enhanced by recovering most of the reagents used during the process.

In view of Green Chemistry, the process is not environmentally friendly considering the use of toxic reagents such as toluene, ammonia etc. It also involves the use of solvents that generate by-products unless there is proper management of the by-products to avoid waste generation.

From Table 2 above, the pH of the CNSL moved from being slightly acidic (5.37) to being slightly basic. The acid value also reduced from 48.00 in Technical CNSL to 16.58 after decarboxylation. This suggests the conversion of anacardic acid to cardanol.

pH and acid values of the different types of cashew nutshell liquid

The pH value shows that the raw CNSL was acidic due to the fact that the anacardic acid content in the liquid was very dominant; however, heating the raw CNSL decomposed the anacardic acid into cardanol and carbon dioxide (Equation 1). The pH for the technical CNSL was found to be 6.22, as reported by Akinhanmi et al., (2008).

Some of the properties obtained in this report show a slight deviation from those reported; this may be due to differences in the species of the cashew nut, the environment in which they are grown, and the methods of extraction of oils before characterization.

Solubility is a chemical property referring to the ability of a given substance, the solute, to dissolve in a solvent. It is measured in terms of the maximum amount of solute dissolved in a solvent at equilibrium. The

resulting solution is called a saturated solution. The result obtained in Table 2 shows that the resin was soluble in all the solvents used, which was confirmed from the literature (Rishabh 2013). The trifunctionality of the phenol is retained while the reactivity at one or two positions in the benzene ring is reduced due to the long side chain. This is favorable to the formation of oil-soluble resins similar in properties to those derived from substituted phenol with the added advantage of internal plasticization, higher solubility in aromatic and aliphatic solvents, as well as better resistance to water, acid, and alkalies (Rishabh, 2013).

Cardanol-furfuraldehyde molding technology is a highly established one, with cardanol-furfuraldehyde being the base material for its production. It was not a wild guess to have thought that cardanol, the structure of which has a similar reactive site as phenol, could undergo similar reactions. Therefore, this is strong evidence that this project has achieved its set goal.

The possibility of obtaining particle board and floating platforms from cardanol resin and palm frond fiber has been confirmed by carrying out this research. Further research work should be carried out so as to determine other performance and characteristics of the product, such as impact resistance, fire resistance, corrosion resistance, flexibility, and gloss of the cross-linked resin, as well as determine if the cross-linked resin can be used to bind other organic fillers.

For further study and research on this project, I suggest advanced study to isolate and quantify other components of the cashew nut shell, especially lignin and also furfural, to determine the possible application of their respective components in industry for the production of resins, fine and heavy chemicals, solvents, and other materials of economic importance.

Conclusions

This study successfully demonstrated the feasibility of producing particle boards from palm frond fiber bonded with cardanol-furfuraldehyde resin derived from technical cashew nut shell liquid. The extraction process yielded 32.98% CNSL from cashew nutshells, with cardanol isolation achieving a 57.4% yield. Chemical

characterization confirmed successful decarboxylation of anacardic acid to cardanol, as evidenced by the reduction in acid value from 48.00 mg KOH/g to 16.58 mg KOH/g and the pH shift from acidic (5.37) to near-neutral (6.22) conditions.

The synthesized cardanol-furfuraldehyde resin exhibited favorable solubility characteristics in various organic solvents and demonstrated effective bonding properties when compounded with unretted palm frond fiber. Water flotation tests confirmed the composite's structural integrity and potential application in particle board manufacturing and floating platforms.

While the laboratory-scale isolation method proved effective for research purposes, economic and environmental considerations suggest that industrial-scale implementation would require optimization, including solvent recovery systems and alternative green chemistry approaches to reduce the use of toxic reagents. Future research should focus on evaluating additional performance characteristics such as impact resistance, fire resistance, corrosion resistance, and mechanical properties of the composites. Furthermore, an investigation into the utilization of other cashew nutshell components, particularly lignin and furfural, could expand the industrial applications of this renewable resource in resin production and fine chemical manufacturing.

This work establishes a foundation for valorizing agricultural waste materials—cashew nutshells and palm fronds—into value-added composite materials, contributing to sustainable material development and waste management strategies.

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