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Optimization of the Processing Parameters of HPKO/MMU Composite, as Co-polymer Binder for a Water-resistant Paint

*1Archibong C.S., 2Fadawa F.G. and 3Bintu Kime
1Department of Industrial Chemistry, Federal University, Wukari, Taraba State, Nigeria
2Nigerian Police Force Command Headquarter, Bompai, Kano State, Nigeria
3Department of Chemistry, Modibbo Adama University, Yola, Adamawa State, Nigeria
*Corresponding Author: archibong@fuwukari.edu.ng

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ABSTRACT

The optimization of the processing parameters for the chemical modification of palm kernel oil triglyceride structure to include hydroxyl groups were studied. This optimized and modified chemical structure now hydroxylated palm kernel oil (HPKO), was blended with monomethylol urea (MMU), a thermoset resin produced from the condensation polymerization of formaldehyde and urea to create a composite HPKO/MMU. Fourier transform infrared (FTIR) spectroscopy was used to verify the presence of chemical interactions between MMU and HPKO. The reduction in the absorption band of the hydroxyl group to around 3360.69 cm^{-1} along with other significant shift observed in the spectra indicated chemical interactions. The composite was further evaluated for rheological properties. Viscosity, refractive index, elongation at break, and turbidity increased with the percentage addition of HPKO until above 50% where the trend changed. Conversely melting point, density, formaldehyde emission, moisture uptake, decreased with continuous addition of HPKO. The copolymerization effectively combined the advantages of MMU species with HPKO while mitigating drawbacks resulting in higher performance polymer with broader application. This research has added flexibility to MMU which was previously rigid and hard, improved water resistance due to the hydrophobic nature of hydroxylated palm kernel oil, and significantly reduced formaldehyde emission from monomethylol urea.

Keywords: Composite, copolymer, hydroxylated palm kernel oil, monomethylol urea, resin, water resistant paint

INTRODUCTION

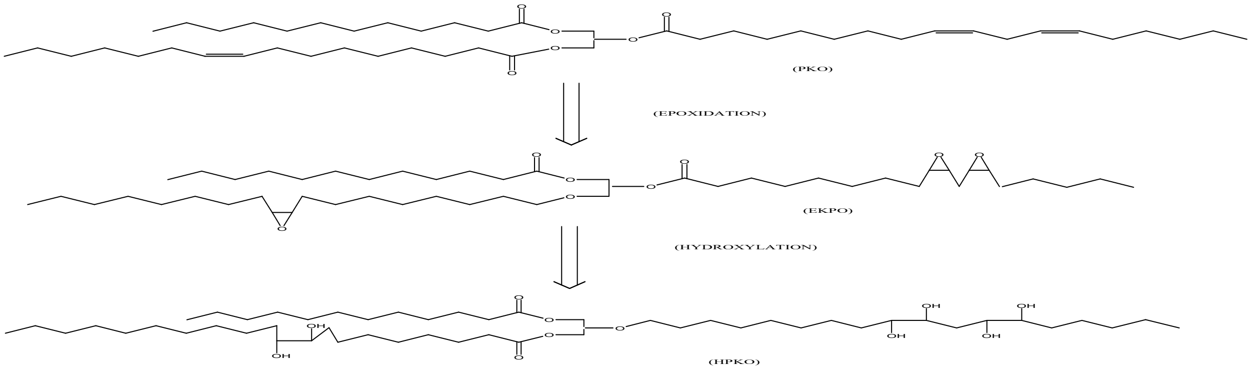
The coating industry has been challenged to the point of being pressured to make production more eco-friendly. Efforts are now tailored towards shifting the prime resource base of the industry (the binder), from fossil (non-renewable) to renewable feed stocks. Among the renewable feed stocks, vegetable oils are the most widely used in the coating industry. They are also considered to be among the most promising raw materials for other purposes, due to their excellent environmental credentials, which include their ready availability, low cost, inherent biodegradability, low toxicity and their versatile applications [1].

The ester groups in the glyceryl part and the double bonds in the carboxylic acid chains are the most significant and promising. These active sites can be used to introduce reactive groups. Hydroxylation, epoxidation, esterification of vegetable oils and their derivatives are given most consideration when it comes to the modification of fatty acid chain [2]. Vegetable oils contain several active sites that are amenable to chemical modification.

Palm kernel oil has a balanced ratio of unsaturated and saturated fatty acids. It has a stable high cooking temperature (high smoking point), longer shelf life, stay longer than other vegetable oils, cholesterol free (even though it is high saturated fat). It is relatively low in cost. The ester linkage and the COOH group of the palm kernel oil can undergo reactions such as hydrolysis, esterification, saponification, amidation, and halogenation, while double bonds can undergo reactions such as oxidative polymerization, hydrogenation, epoxidation, halogenation, and sulphonation [3]

Formaldehyde-based binders are derived from non-renewable petrochemicals and natural gas posing dangerous chemical problems during their manufacture. There is currently no method to degrade formaldehyde at a rate comparable to the current rate of consumption, leading to overflowing landfills, polluted marine waste and unsightly litter [4]. The harmful effects of formaldehyde emission have spurred increased research efforts toward developing formaldehyde-free, environmentally-friendly, safer, biodegradable green alternatives, particularly the sustainable ones based on annual renewable plants [5].

Copolymerization of polymers combines the strength of one polymer specie with another while mitigating their weakness to create a higher performance class of polymer with broader applications. Therefore, chemically linking hydroxylated palm kernel oil with hard and brittle monomethylol urea as this research aims to achieve will introduce flexibility to the monomethylol urea, enhance its water resistance properties due to the hydrophobic nature of the hydroxylated palm kernel oil. This will also reduce formaldehyde emissions from monomethylol urea why in cooperating hydroxylated palm kernel oil and reducing the percentage of monomethylol urea in the mixture.



Scheme 1: Chemical conversion of palm kernel oil to hydroxylated palm kernel oil

MATERIALS AND METHODS

Epoxidation Palm Kernel Oil

Epoxidation was carried out using the method described by Goud *et al.* [6]. Approximately 200 cm^3 of oil was introduced in a 1000 cm^3 three necked flask equipped with a reflux condenser and a thermocouple. The flask was placed on a hot plate with temperature control. Acetic acid and formic acid at a molar ratio of 0.5:1 to the oil and sulphuric acid catalyst 3% weight were added. A hydrogen peroxide as an oxygen carrier of a molar ratio 1.5:1 to the oil was added drop wise into the mixture. The feeding strategy is required in order to avoid overheating the system since epoxidation is an exothermic reaction. The reaction was maintained at uniform state by using a magnetic stirrer which runs at about 1600 rpm under isothermal condition at 50-60 ˚C. The product was cooled and decanted in order to separate the organic-soluble compounds (epoxide oil) from water-soluble compounds. Warm water was used to wash the epoxidized oil (in small aliquots) in order to remove residual contaminants. This procedure was repeated three times.

Hydroxylation of the Epoxidized Palm Kernel Oil

Hydroxylation of the palm kernel oil was carried out using procedure described by Patrovic *et al.* [7]. The reaction was performed in a 1000 cm^3 three necked flask equipped with a reflux condenser and a thermocouple. The flask was placed on a hot plate with temperature control. About 150 cm^3 of the epoxidized oil was hydroxylated using alcohol (methanol and isopropanol) with molar ratio of 4:1 to the oil and water at a molar ratio of 2:1 was mixed with the epoxidized oil and sulphuric acid catalyst in the reactor. The reaction was performed at fixed temperature of 60 °C for 5 hours. Uniformity was maintained by using a magnetic stirrer which runs at about 1600 rpm. The product (polyol) was cooled and decanted in order to separate the organic-soluble compounds from water-soluble compounds. Warm water was used to wash the polyol (in small aliquots) in order to remove residual contaminants. This procedure was repeated three times.

Resin Composition

MMU was prepared using the one step process (OSP) as reported by Archibong and Osemeahon [8] with some modifications. One mole of urea (6.0 g) reacted with one mole of formaldehyde (8.11 ml) 37-41% (w/v), using 0.02 g of sodium dihydrogen phosphate as catalyst. The pH of the solution was adjusted to 13.0 by using 0.1 M H_2SO_4 and 0.5 M NaOH solutions. The solution was heated in a thermostatically controlled water bath at 50 ^{0}C. The reaction was allowed to proceed for 60 min after which the resin was removed and kept at room temperature (30 ^{0}C).

Copolymerization

This was carried out by blending different concentrations (10-70%) of HPKO with MMU. About 10 ml of MMU reacted with 60 ml of HPKO, 20 ml of MMU reacts with 50 ml of HPKO, 30 ml MMU reacts with 40 ml of HPKO.

Determination of Gel Time

Gel time was determined by gel-time meter. The temperature was set to 121 °C in a gel time meter and filled with liquid paraffin. The heating system and stirrer were switched on. About 10 g of the sample was weighed in a test tube and placed vertically in hot paraffin bath using wooden holder. Resin level in the tube was taken such that it was within hot bath. A glass rod was placed in the test tube and locked to the spindle drive with magnetic couple. The spindle was rotated. When the top spindle rotates, the magnetic coupling and bottom fin also started rotating along with glass rod. When the resin started solidifying, rotation of glass rod was resisted, which in turn stopped rotation of the bottom fin. Upper fin, still rotating freely, came into contact with static one, and the time was noted from the stopwatch. The gel-time was determined.

Determination of Melting Point

To determine the effect of melting point on monomethylol urea (MMU) and that of the composite, a melting point differential macrophase separation technique was developed. In this technique, MMU was introduced into a porcelain dish. The dish with its content was transferred into an oven set at 120 ^{o}C for curing. The mixture was removed periodically from the oven and stirred until the mixture gelled and finally solidified. The temperature was then raised to 150 ^{o}C and left for 5 min then the sample was removed and cooled for observation. The experiment was repeated three times.

Determination of Viscosity

Viscosity was determined by adopting Ganeshram *et al.* [9] method, using Brookfield viscometer. Spindle number was selected and the speed of motor was set. The temperature of the solution was measured using temperature probe. The spring cap was removed and the spindle was fixed. It was immersed up to the mark in the resin and the motor switched on. Spindle rotates inside the solution and produces shear, which gives value of viscosity. This was conducted at a temperature of 25 °C.

Determination of Turbidity

The turbidity of the samples was determined by using Supertek digital turbidity meter (Model 033G). Each sample was subjected to three readings and the average taken

Determination of Density

The density of the resins was determined by taking the weight of a known volume of resin inside a density bottle using Pioneer (Model PA64) weighing balance. Three readings were taken for each sample and average value calculated.

Determination of Refractive Index

The refractive index was measured using Abbe refractometer which measured the extent to which light is bent when it moves from air into the sample. Each sample was subjected to three readings and the average taken.

Determination of Moisture Uptake

The moisture uptake of the resin films was determined gravimetrically, according to the method described by Archibong *et al.* [10]. Known weight of the samples was introduced into desiccators containing a saturated solution of sodium chloride. The increase in weight (wet weight) of the sample was monitored until a constant weight was obtained. The difference between the wet weight and dry weight of the sample was recorded as the moisture uptake by the resin. Triplicate determinations was made for each sample and the average value recorded.

Determination of Elongation at Break

The elongation at break was determined using inston tensile testing machine (Model 1026). Resin films of dimension 50 mm long, 10 mm wide and 0.15 mm thick was brought to rupture at a clamp rate of 20 mm/min and a full load of 20 kg. Three runs were carried for each sample and the average elongation evaluated and expressed as the percentage increase in length.

Determination of Formaldehyde Emission using UV-Spectrophotometer

To determine any possible absorbance by formaldehyde, deionized water was used as the blank. The cuvette was rinsed several times with tap water followed by deionized water. It was then filled with deionized water, and placed in the holder, and the spectrophotometer was blanked at 563 nm. The sample was put into another cuvette and the absorbance was noted at the same wavelength of 563 nm, with the concentration recorded

Determination of Water Solubility

The solubility of MMU was determined by mixing 1 ml of the resin with 5 ml of distilled water at room temperature (30 ^{0}C). The degree of solubility was evaluated visually and the result recorded.

RESULTS AND DISCUSSION

The spectra of A (MMU), B (HPKO). C (MMU/HPKO) is presented in Figure 1.

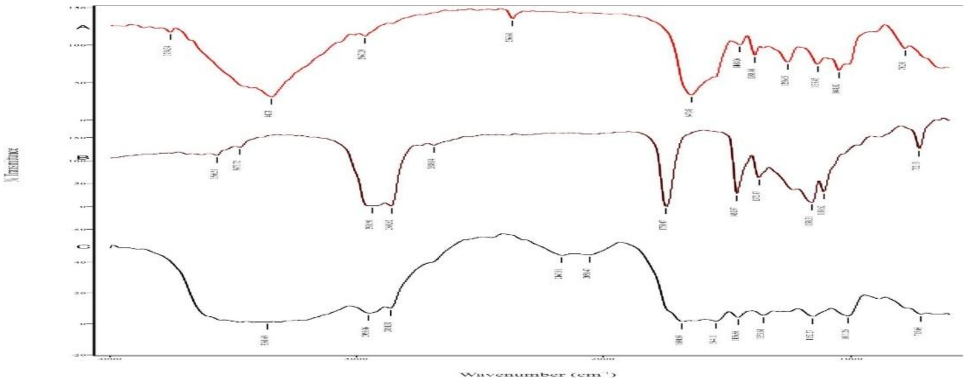


Figure 1: FTIR Spectra of A=MMU, B=HPKO, C=MMU/HPKO

The FT-IR spectra of A (MMU) shows the appearance of a sharp band in the region 3754.34 cm^{-1} and another broad band at 3344.73 cm^{-1} frequency indicating the presence of (-OH-) on the monomethylol urea. The appearance of stretching bands at 2967.29 cm^{-1} and 2369.61 cm^{-1} indicates the presence N-H.; The peak at 1647.43 cm^{-1} is due to C=O of urea, while the bands at 1448.06 cm^{-1} and 1388.84 cm^{-1} are due to C-H of methylene bridge. The bands at 1256.55 cm^{-1} through 1048.02 cm^{-1} was due to characteristic C-O-C ether linkage stretching [11].

In the FT-IR spectrum of B (HPKO), the broad band stretching at 3566.51 cm^{-1} and 3473.72 cm^{-1} are due to – OH group present in the HPKO. The dual band sharp transmitted at 2936.91 cm^{-1} and 2850.82 cm^{-1} produced by stretching of the C-H group of alkane in the spectrum of HPKO can be remarkably distinguished. The peak at 1750.07 cm^{-1} indicates C=O stretching vibrations of the saturated ester present in the oil [12]. In addition, the region of 1460.97 cm^{-1} and 1372.87 cm^{-1} of the IR spectrum show two bands that correspond to the bending vibration of C-H of alkane. The peak at 1158.31 cm^{-1} is due to C-O stretching mode of carboxylic acid [13].

In the MMU/HPKO spectra, the O-H peak at 3754.34cm^{-1} in MMU now appeared at a lower frequency band of 3360.69 cm^{-1}. This may be due to the hydrogen bonded hydroxyl groups that contribute to the complex vibrational stretches associated with free inter- and intra-molecular bound hydroxyl groups [14]. Also the frequency bands of C=O, N-H, CH_2, C=C, C-O-C, C-H in MMU and HPKO all shifted to different bands in the MMU/HPKO composite, thereby indicating chemical reactions actually took place between MMU and HPKO.

Effect of HPKO concentration on the Gel time of MMU/HPKO

The graph of HPKO concentration on the gel time of MMU/HPKO is as shown in Figure 2.

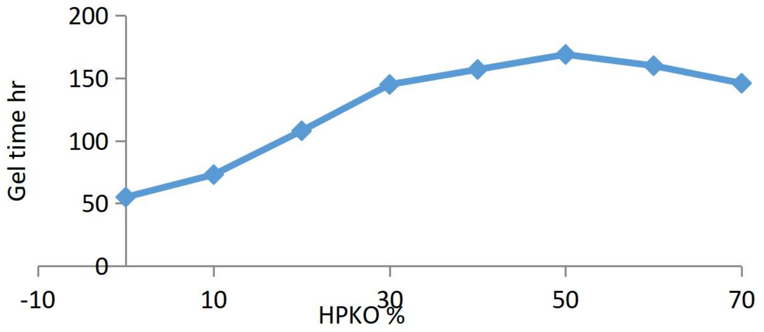


Figure 2: Effect of HPKO concentration on the Gel time of MMU/HPKO

Addition of HPKO results to the gel time rise of MMU/HPKO. This may arise from the fact that the structure of oils contain fatty acids with carbon–carbon double bonds that can act as sites for chemical coupling, which in turn creates a strong polymer cross linkages. This observable pattern could also be explained in terms of increase in molecular weight and cross-linking density which culminated to increase in viscosity and high viscosity results to increase gel time [15]. After 50% addition phase inversion and dissociation might have sets in and this explains the slight decrease in the gel time.

Gelation is commences by the initial formation of a material of an infinite molecular weight and gives an indication of the conditions of the process-ability of the material. Prior to gelation, the system is soluble, but after gelation, both soluble and insoluble materials are present. As gelation is approached, viscosity increased dramatically and the molecular weight goes to infinite. The reaction between monomers leads to the formation of network, hence gelation. Both molecular weight and poly-dispersity increase until one single macromolecule is formed. At this point, the behavior of the system changes from liquid-like to rubber- like thus the reactive system becomes a gel [16].

Effect of HPKO concentration on the Melting point of MMU/HPKO

The graph of the effect of HPKO concentration on the melting point of MMU/HPKO is as seen in Figure 3.

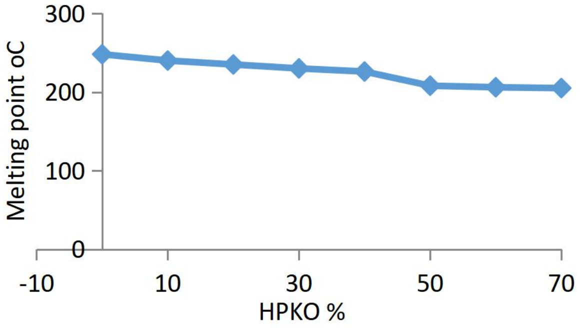


Figure 3: Effect of HPKO concentration on the Melting point of MMU/HPKO

The melting point decline as the HPKO concentration increased. The decline in melting point of the compound indicates domination of plasticising action of vegetable oil over its coupling effect, hence a decline in melting point [17]. It is also seen that up to a certain concentration of HPKO in the composite, the melting point shows an increasing trend. The increase in the melting point of the composite might be a manifestation of increasing cross-link density, thereby, confirming the findings by Kamba *et al.*[18] that vegetable oil acts as a coupling agent causing increase in cross-link density and it also involves in the physicochemical bonding with the MMU interfaces.

Thermal property, molecular weight, degree of cross linking and the level of rigidity of the polymer is related to its melting point. The melting point of a compound increases with its molar mass, intermolecular van der waals interactions and also the intrinsic structures that affect the rigidity. In the case of coating industry, the melting point of a binder is related to its thermal resistance as well as to the brittleness.

Effect of HPKO concentration on the Viscosity of MMU/HPKO

The plot of the effect of HPKO concentration on the viscosity of MMU/HPKO is represented in Figure 4.

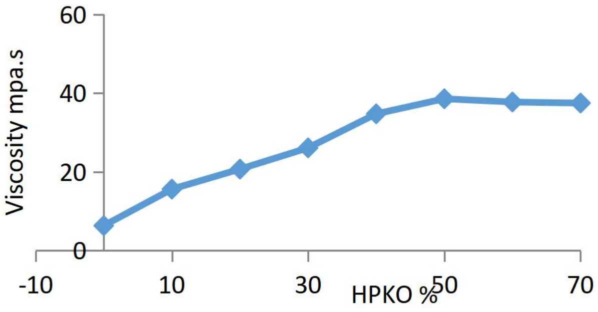


Figure 4: Effect of HPKO concentration on the Viscosity of MMU/HPKO

The viscosity increases with increased percentage addition of HPKO, but at above 50% inclusion of HPKO, the viscosity then decreases. The probable reason for the increased viscosity could be a reflection of incremental intermolecular interactions between the MMU monomer and the palm kernel oil carboxylic acids, for they are made of groups that can instigate the creation of large amount of hydrogen bonds between hydroxyl and ester group. Destruction of these hydrogen bonds and their entanglement at higher HPKO concentration may have been the reason for the decline observed at above 50% inclusion [19]. This apparent increase in the viscosity may also have been contributed by the formation of higher crosslinking density of the polymeric matrix due to increasing curing of MMU and HPKO.

Because the viscosity of the binder controls many of the processing and application characteristics such as flow rates, leveling and sagging, thermal and mechanical properties, dry rate of paint film and adhesion of the coating to the substrate their importance cannot be down played [20].

Effect of HPKO concentration on the Turbidity of MMU/HPKO

The graph of the effect of HPKO concentration on the turbidity of MMU/HPKO is as shown in Figure 5.

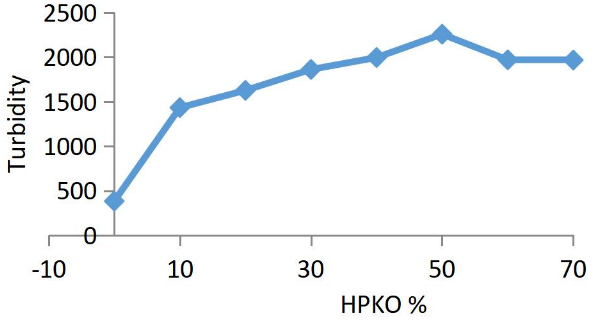


Figure 5: Effect of HPKO concentration on the Turbidity of MMU/HPKO

The turbidity of MMU is seen to rise at the onset with increasing HPKO concentration and at about 50% HPKO inclusion it starts to decline. The increase could be the result of growth of large polymer aggregates due to several inter-polymer interactions occurring fast as a result of the availability of bonding sites, and tendency towards sedimentation with HPKO increases [21]. The polymer chains might have experience a strong frustration in chain packing in the interfacial region due to the formation of large loops at high HPKO addition and inability of the longest chains to be incorporated in the crystalline structure, resulting in the decreasing turbidity [22].

When there is a homogeneity and few particles, there is usually less light scattering; hence, higher scattering is observed when we have a non-homogenous system with a lot of particles. Turbidity of the binder is usually performed in order to characterize the optical properties of the binder as related to gloss property. The refractive index gives an indication of the turbidity. Light interaction with a colloidal system is its turbidity. Turbidity of the system can be used as an indication of the level of interchain cross-linking [23].

Effect of HPKO concentration on the Density of MMU/HPKO

The effect of HPKO concentration on the density of MMU/HPKO is presented in Figure 6.

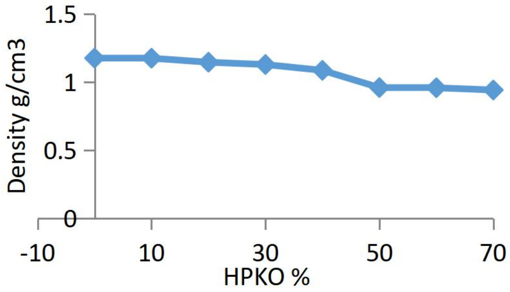


Figure 6: Effect of HPKO concentration on the Density of MMU/HPKO

The density decreases with increasing inclusion of HPKO. Physical properties of polymer depend on chain length and content of soft and hard segments. The initial decline could be due to the inherent flexible structure of carboxylic acid chains, which is not susceptible to form compact crosslinked structure compared to the stiffer MMU repeat units [24]. It can also be the result of differences in the molecular features and morphology which influenced the packing nature of resin molecules as the concentration of HPKO increases. The decrease observed from 0 to 70% HPKO loading could be due to increasing amount of soft segment [25]. Unreactive saturated components like cryptic acid and lauric acid pendant chains in HPKO enhance the flexibility and degree of freedom for movements of the molecular chains in the monomethylol urea network and hence a reduction in the degree of crystallinity and molecular weight.

Density measurements are very significant for the identification and characterization of different substances and an important factor that affects the production cost and profitability of the manufacturing process [26]. Density of a paint binder in the coating industry has an in depth influence on properties such as levelling, sagging, pigment dispersion, brush-ability of paint and flow.

Effect of HPKO concentration on the Refractive index of MMU/HPKO

The plot of the effect of HPKO on the Refractive index of MMU/HPKO is as presented in figure 7.

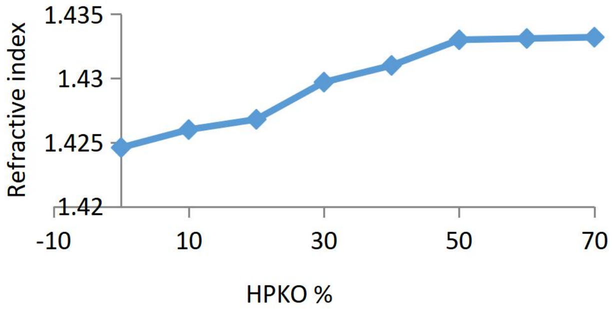


Figure 7: Effect of HPKO concentration on the Refractive index of MMU/HPKO

The refractive index increases with increasing HPKO percentage inclusion until it got to a point where the continuous addition appeared to have no effect on the refractive index. It became apparently clear from the results that, as the molecular weight of the polymer increases due to hydrogen bond interactions and the coupling effect of the HPKO it resulted in an increasing crosslinking density, the refractive index increases in value in reflection of the polymer molecular weight increase. By inspection, it is observed that in the low molecular weight region these values show an unmistakable upward trend with increasing molecular weight. The influence of molecular weight on refractive index may entirely be an end group/pendant group effect because as the proportion of repeat units to end groups increases, the refractive index increment approaches higher values [27]. The point where inclusion of HPKO appeared to be of no effect in the refractive index may be attributed to a possible fall in crosslinking density as a result of polymer degradation with increasing HPKO concentration.

Gloss is a measure of the ability of coated surface to reflect light. Reflection of light from surfaces can be classified according to the diffuse component or the specular component. The diffuse component results from light penetration to the surface, undergoing multiple reflections and refractions, and then re-emerging again at the surface.

Effect of HPKO concentration on the Moisture uptake of MMU/HPKO

The graph of the effect of percentage concentration of HPKO on the moisture uptake of MMU/HPKO is shown in Figure 8.

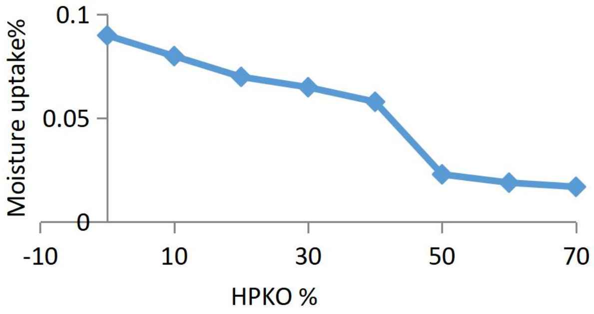


Figure 8: Effect of HPKO concentration on the Moisture uptake of MMU/HPKO

There is a gradual lowering of the moisture uptake decline with gradual addition of HPKO. MMU polymers are by nature highly hydrophilic, but when HPKO are typically included, they introduced hydrophobicity to the polymer matrices, hence boosting reinforcement and matrix adhesion and thus decreases it hydrophilicity.

The decline could be credited to the increasing quantity of soft/flexible and hydrophobic hydroxylated palm kernel oil component to fade off the rigid and compact nature of MMU polymer, as well as implanting a water proof resistance of HPKO to the composite. Increasing interactions of HPKO with MMU due to availability of enough hydrogen boning sites could also leads to a lower composite swelling ratio, which is an indication of not only high crosslinking density but also a lower absorbability of the network in the solvent in this case water [24]. The low moisture uptake recorded in the MMU/HPKO composites could also be explained in terms of the reduction of MMU loading in the presence of the hydrophobic palm kernel oil.

Water-borne coatings are susceptible to durability issues pertaining poor water resistance. The functional groups on polymers or copolymer resins that are used can undergo hydrogen or ionic bonding, unless the hydrophilic character is balanced with that of the hydrophobic, the coating will either be water sensitive or the formulation will not have colloidal stability. Hydrophobic components in the binder give the best combination of improving water resistance of water-borne coating [28, 29].

Effect of HPKO concentration on the Elongation at break of MMU/HPKO

The plot of the effect of concentration of HPKO on the elongation at break of MMU/HPKO is shown in Figure 9.

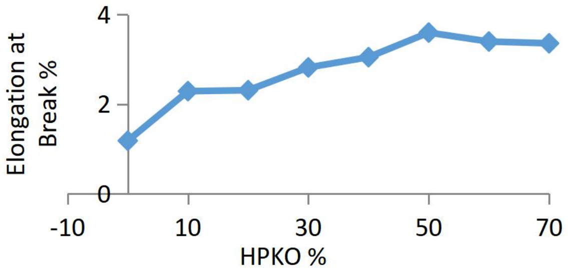


Figure 9: Effect of HPKO concentration on the Elongation at break of MMU/HPKO

The elongation rises steadily with increasing HPKO inclusion. Research has shown that plasticizers lower tensile strength of film but increase percentage elongation as depicted above where the incorporation of HPKO brings about the depressions of tensile strengths due to the plasticizing effects and thus increases the elongation at break [30]. Elongation at break measures the ductility of the material. In as much as a high concentration of HPKO could often permits fast crosslinking process in the composite, this could also bring about the formation structural defects in the composite network such as dangling chains that are not elastic active, this could perhaps attempt to explain the reason for the decline noticed above 50% HPKO addition. Also the increase in elongation at break could be due to increase in molecular mobility emanating from the specific interactions between MMU and the flexible hydroxylated palm kernel oil. The decrease in cross-link density induces increase in elongation at break with increase in HPKO content not beyond 50%, for beyond this value polymer degradation must have set in.

Elongation gives a picture of how much the material will withstand stretch before breaking. The rigid nature of thermosetting resins creates mechanical and structural limitations for wide applications. Elongation at break can be a tool to determine the adhesion between phases, because of its sensitivity for load transfer between phases [31].

Effect of HPKO concentration on the Formaldehyde emission of MMU/HPKO

The graph of the effect of HPKO concentration on the formaldehyde emission of MMU/HPKO is depicted in Figure 10.

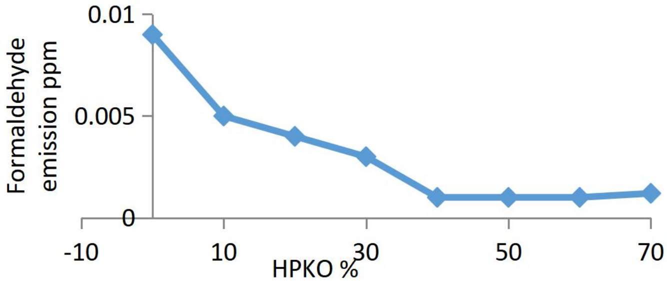


Figure 10: Effect of HPKO concentration on the Formaldehyde emission of MMU/HPKO

Hydrolysis of cured urea resins is responsible for formaldehyde emission leading to sick building syndrome [32]. High emissions of formaldehyde from latex paint was reported by Salthalmmer *et al.* [33]. The formaldehyde emission shows decreasing tendency with increasing concentration of HPKO concentration, which was very obvious at 40% content. This could be due to the deceleration of curing process which influence change of methylene-ether bridges and various active sites in triglyceride structures like the double bond, the ester group, the allylic carbons, and the carbons α to the ester group. Consequently, the decreasing of methylene-ether bridges causes the reduction of formaldehyde emission [34]). It could also be due to the reduction in stress during cure which reduces emission as a result of improved flexibility brought about by the introduction of HPKO to MMU, since a reduced density results in high flexibility and increased ability to absorb but less ability dissipate energy [35].

Because of the health implications of formaldehyde emission on humans and its environs, it is a matter of survival to determine it emission during MMU synthesis and application. The present result shows that formaldehyde emission is even below the acceptable level of (0.10 ppm).

The effect HPKO concentration on the solubility in water of MMU/HPKO copolymer is presented in Table 1.

Table 1. Effect of HPKO concentration on the solubility in water of MMU/HPKO resin

HPKO concentration (%)	Solubility
0	Soluble
10	Soluble
20	Soluble
30	Soluble
40	Soluble
50	Soluble
60	Insoluble
70	Insoluble

As seen from the table (0 -50) % HPKO concentration, the composite is soluble in water because the hydrophilic nature of MMU dominates, at this point the copolymer is in a hydrophilic state, with MMU having higher influence. This allows it to stay in aqueous solution, but when HPKO concentration starts increasing it leads to the formation of globule-like conformation that most often becomes insoluble in water [24]. Also, the effect of interchain repulsions due to increasing HPKO inclusion may allow hydrophobes to take part at least to some extent in intramolecular associations.

Table 2: Comparison of some Physical Properties of MMU/HPKO Film with Films from other Paints Binders

Type of resin	Physical property							
	Viscosity (mpa.s)	Refractive Index	Density (g/cm^3)	Melting point (^{0}C)	Moisture uptake (%)	Elongation at break (%)	Formaldehyde emission (ppm)	Literature
MMU/HPKO	**38.5**	**1.4331**	**0.96113**	**1208**	**0.023**	**0.23**	**0.02**	**This present work**
TMU/PS	19.70	1.425	1.0990	262	1.01	425	0.0233	[36]
Polyvinyl acetate	0.40	1.40	1.25	ND	ND	ND	ND	[37]
Palmoil/Alkyd	499	ND	0.929	ND	ND	ND	ND	[38]
Commercial UF	451	ND	1278	ND	2	ND	ND	[39]
Polyvinyl butyral	9-16	1.485	ND	ND	0.3	110	ND	[40]
Acrylic/Methylcrilic ester	2500	ND	1.03	ND	ND	ND	ND	[41]
Innovative UF	365	ND	ND	ND	0.25	ND	0.07	[42]
MU/NR	248	1.3411	0.641	255	1.341	350.43	0.058	[26]
UF/PE	32.60	1.432	1.3362	130	0.0080	250.0	0.0142	[20]
Alkyd from cater oil resin	4	1.474	ND	ND	ND	ND	ND	[43]

ND: Not Determined

CONCLUSION

In this work, monomethylol urea of the urea formaldehyde family was successfully produced with the lowest formaldehyde emission value using the one step process. The synthesized monomethylol urea chemical structure was subjected to modification using various percentage compositions of hydroxylated palm kernel oil to mitigate the disadvantageous characteristics of the methylol urea family which include poor water resistance, brittleness and hardness and formaldehyde emission. Their morphological and mechanical properties were subjected to analysis, with the intent of the possibilities of using these modified monomethylol urea and its composite resins as a paint binder, comparable to the conventional binders. The monomethylol urea blended with hydroxylated palm kernel oil and exhibited robust rheological and mechanical properties compared to the pure thermosetting resin. At 50% content, the blends presented enhanced properties in their viscosity, gel time, moisture uptake, elongation at break, refractive index and melting point, thereby providing an overall improvement on the monomethylol resin. The rheological and mechanical properties of the modified monomethylol urea resins resulted in increase in their paint binder’s values. These advantages seen in this work will be useful for future applications of the paint binders taking into account their relative low cost and availability of the hydroxylated palm kernel oil added and the simplicity in the production process.

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