Nigerian Research Journal of Chemical Sciences (ISSN: 2682-6054)
Volume 15, Issue 1, 2026

Development and Characterization of Waste Polystyrene-Derived Oil as a Binder and Solvent for the Formulation of a Non-Volatile Oil Paint

[*1]Akase Emmanuel I., [1]Osemeahon Sunday, [1]Malgwi Daniel W., [2]Maidugu G.S., [3]Ominyi Emmanuel C.

[1]Department of Chemistry, Modibbo Adama University, Yola, Nigeria

[2]Department of Chemistry, College of Education, Waka-Biu, Nigeria

[3]Department of Science Laboratory Technology,
Akanu Ibiam Federal Polytechnic, Unwana-Afikpo, Nigeria

*Corresponding Author: zanalochem2@gmail.com

Accepted: *July 27, 2026* **Published Online***: July 31, 2026*

ABSTRACT

This study investigated the development of a non-volatile oil paint by converting waste polystyrene (PS) plastic into pyrolysis oil, aiming to reduce environmental plastic pollution and eliminate volatile organic compound (VOC) emissions. PS waste collected from dumpsites and electronics shops was cleaned, dried, and pyrolyzed in a fabricated plant comprising a double-heated reactant tank, condenser, and oil collection system. The resulting polystyrene oil (PSO) was characterized for physicochemical properties: turbidity (180 NTU), viscosity (1.6 cP), density (0.84 g/cm³), refractive index (1.41), melting point (182 °C), and pH (6.1). Optimization of the PSO/PS binder revealed a 50:50 ratio as optimal for coating applications. Instrumental analyses: Fourier Transform Infra-Red (FTIR), Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), Thermogravimetric Analysis (TGA), and Differential Thermal Analysis (DTA) identified functional groups, surface morphology, crystallinity, thermal degradation, and energy absorption profiles respectively. A non-volatile paint formulated with this binder and PS oil as solvent exhibited properties within acceptable standards, including pH, density, viscosity, drying time, opacity, blistering resistance, adhesion, and flexibility, making it suitable for interior and exterior decoration. This innovation mitigates VOC-related ozone depletion and global warming while converting plastic waste into valuable products.

Keywords: Paint, binder, solvent, polystyrene, plastic.

INTRODUCTION

For decorative and protective purposes, paint is a colloidal mixture of chemicals that is applied to a substrate to create a thin coating that sticks to the applied subsurface for both ornamental

and protective purposes. The liquid pigment should react rapidly to heat, light, weathering, and chemical changes [1]. The use of paint becomes prominent and significant due to the fact that many objects' surfaces corrode in the air and can be harmed by weathering and wear [2]. Wood and walls deteriorate, and iron corrodes. Many surfaces that are thought to be inadequate without coating do not look visually pleasing. This explains the reason why paint manufacturing and modification is in such a way that cost is reduced by employing available local raw materials [3].

Oil based paints are coatings in which majority of the liquid content in it is a solvent which is not water. These types of paint require a longer duration of drying time. Thin coats are necessary to avoid the problems of sagging and streaking. The dry time in solvent paint is usually longer than that of water-based paint. On application to the surface, it stands out beautifully for a long time before it wears or tears. Scrubbing off of dirt and scuff mark does not affect the paint. The binder in oil paint or coating is made from vegetable oil or polymer-based sources that oxidizes or dries and crosslinks when it is exposed to the air [4].

The aim of this study is to develop and characterize waste polystyrene oil as a binder and solvent for non-volatile oil paint formulation. Normal paints show yellowing and brittleness with aging. To close this gap, a novel paint that uses waste polystyrene plastic was used to produce a non-volatile oil paint that chemically cures, oxidizes and polymerizes with age which give a strong, hard coat that does not yellow nor brittles with aging.

MATERIALS AND METHODS

The waste polystyrene was collected from electrical appliances shops and stores and construction packaging all in the Jimeta Metropolis of Yola, Adamawa State, Nigeria. The PS was cleaned, dried and shredded into smaller particles.

Fabricated pyrolysis batch reactor) was used. Vibroviscometer, model (SV-10), Density bottles, LaMotte smart2digital turbidimeter, Heidolph stirrer No 50111, digital pH meter HI 2211 by Hanna Instruments, LA 164 weighing machine, Optimelt automated melting system, desiccators, and refractometer 700 model.

Pyrolysis of polystyrene

A pyrolyser (batch reactor) was fabricated that operated at a maximum temperature of 700 ^{o}C with water condenser and reactant tank. A galvanized iron cover loading waste PS was put in the furnace and a lead for the feedstock was located in the center of the furnace heating zone.

A thermocouple was attached to the furnace to read the pyrolysis temperature with a heating rate of 10 ^{o}C min^{-1}.

Determination of the physicochemical properties of the pyrolyzed PS oil

Determination of pH

The pH of the PS oil was evaluated using a digital pH meter [5].

Determination of density

The density was determined according to AOAC [6]. A weighing balance was used to weigh a known volume of the PS oil in a density bottle in order to estimate the density of the resin. The mass-volume connection will be used to determine the density (Equation 1). For the sample, three readings were made, and the average value was determined.

$$\text{Density} = \frac{(\text{wt of empty bottle} + \text{sample}) - (\text{wt of empty bottle})}{\text{volume of sample}} \quad (g/cm^3) \qquad (1)$$

Melting point

The melting point of the sample was determined by using Stuart melting point machine (model SMP 10). Three different readings were taken for the sample and the average was calculated. The above property was determined according to standard method [7].

Refractive index

The refractive index of the resin sample was determined using Abbe refractometer [8]. Three different readings were taken for each sample and the average will be calculated and recorded.

Turbidity

The turbidity of the binder was determined by using Labtech Turbidimeter (Model AVL-654). Triplicate readings were obtained and the average value taken [9].

Determination of viscosity and gel time

The viscosity of the resin sample 50 ml of the resin sample was determined using a BROOKFIELD DV-E viscometer, model (LVDE). The gel point of the resin was determined by checking the viscosity of the resin with time until a constant viscosity profile was obtained [10].

Specific gravity

This test was carried out to evaluate the ratio of the density of a substance to the density of the referenced substance [6].

$$\text{Specific gravity} = \frac{w_2 - w_o}{w_1 - w_o} \quad (2)$$

W_1 = Wt of paint + density bottle

W_2 = Wt of H_2O + density bottle

W_o = Wt of empty density

Preparation of polystyrene pyrolysis oil dry film

The method for the preparation of the PS oil dry film was applied according to Osemeahon and Dimas [10]. PS oil (5 ml) was poured into petri dish for casting. The resin was allowed to cure and set for seven days at 30 ℃. The physical properties of the resin were then determined.

Instrumental Analysis of the Pyrolyzed Oil and Formulation of Paint samples

FTIR analysis

The FTIR analysis of the samples was performed using a Perkin-Elmer spectrum 100 FTIR spectrometer interfaced to a spectrum spotlight 400 FTIR microscope. This evaluation will be performed to determine their functional groups and characteristic nature [5].

Scanning Electronic Microscopy

The SEM analysis of the sample was performed to evaluate their morphology and particle size compositions using JEOL JSM 5600 LV Scanning Electronic Microscope [5)]

Differential Thermal Analysis

The DTA was performed to evaluate the morphological, compositional and crystalline information of the resin sample. The DTA curve typically shows an endothermic peak, indicating the energy absorbed during the decomposition of the material. This peak is associated with the breakdown of the polymer chains into smaller molecules including liquid products [6].

X-Ray Diffraction Test

This XRD test was performed to evaluate the phase and crystal structure of the samples by analyzing the diffraction pattern of the samples and obtaining information about the composition of materials as well as the structure or morphology of the molecules in the samples. Perkins-Elmer spectrum Diffractometer was used for this test [8].

Thermogravimetric Analysis

Thermogravimetric analysis of the samples will be carried out to measure or evaluate the changes in the sample mass as a function of temperature with high levels of sensitivity, providing insights into the sample's thermal behavior, composition and structure. TGA Thermalgravimetric analyzer (SGT Q600 V20.9 BUILD 20) was used for the analysis [10].

Formulation of Paint using PS oil as a Binder and Solvent

Oil paint samples were formulated following the method as adopted by Morgan [11] with modification while substituting for low density PS oil in place of the solvent toluene. High viscosity PS oil/PS binder was used in place of linseed oil as a binder. This formulation was conducted so as to achieve reproducible and smooth paint samples of a fixed layer.

About 50 g of pigment (TiO_2) was weighed and transferred into a 500ml beaker. A crater was made at the center of the pigment in the beaker using a spatula. Thereafter, 50 ml of PS oil/PS (PSO/PS) binder was measured and then slowly added into the pigment, incorporating carefully by pre-mixing with the spatula and a glass rod stirrer. A stirrer was introduced into the paint mixture which was used to subsequently stir the paint mixture for 25 minutes, gradually and consistently. 20 ml of PS oil was added into each of the paint samples as the solvent. Additives were also added into the mixture and stirred to obtain a homogenous mixture. This gradual and consistent stirring helped to disperse the pigment and the additives evenly and adequately in the vehicle to form a paste/solution. This formulation of the paint formed the parent paint.

The oil paint was formulated with 30, 40, 50, 60, 70, and 80% of the PS oil/PS binder to the pigment composition. Straining and clarification was done to remove coarse particles. Finally, checking and controlling of the physico-chemical properties was done to conform to standards [11].

RESULTS AND DISCUSSION

Table 1 shows the results of the values obtained from the characterization of the properties of PS oil. The waste polystyrene plastic pyrolysis oil was characterized so as to ascertain some of its physicochemical properties such as density, viscosity, turbidity, refractive index, moisture uptake, melting point and gel time.

Table 1: Physicochemical Properties of PS Pyrolysis Oil

S/N	Physicochemical Parameters	Values	Standard	
1	Viscosity (Cp)	1.6	6-15	[12]
2	Density(g/dm^3)	0.84	0.865	[12]
3	Refractive Index	1.41	1.47	[12]
4	Turbidity (NTU)	180	600	[12]
5	Melting point (^{o}C)	182	130	[12]
6	pH	6.1	7-9.5	[13]

Viscosity of PS oil (resin)

From Table 1, the viscosity of the resin has the average value of 1.6 cP. This value is relatively low, indicating that the oil flows easily. This property could have several implications on paints formulation and application, as lower viscosity could make a paint easier to apply. It could spread more evenly and smoothly, resulting in a more uniform coating [14].

A lower viscosity might result in a smoother finish and equally serve as a solvent in oil paint formulation; hence, it is self-solventing. Why a higher viscosity result in a ticker and more textured finished which can also serve as a binder in paint formulation [15]. The viscosity could also influence the drying time of the paint. A lower viscosity might lead to a quick drying time and non-film formation while a higher viscosity might result in extended drying time. It was observed that though PS oil has low viscosity, it has an in-built viscosity that makes the oil polymerizes to a higher viscosity when kept over for some time.

Density of PS oil

The density of a substance is a key parameter that determines its behavior in mixtures and its physical properties. From Table 2, the waste polystyrene oil showed the average density of 0.84 g/dm^3, which is indeed lower than density of water (1 g/dm^3). This suggests that PS oil is less dense than water, which agrees previous works [16, 17]. The density of waste polystyrene oil could influence how it interacts with other substance in a mixture. In a non-volatile oil paint binder, the oil could either float on top or mix well with other components depending on their densities or could also affect the properties of the paint. For example, a lower density could

result in a higher paint that spreads more easily. Conversely, a higher density could result in a heavier paint that provides better coverage [16].

Refractive index of PS oil

The refractive index serves as a power tool in oil analysis, offering valuable information about the molecular composition variations, impurity selection and combustion optimization [18]. From Table 2, the waste PS oil had an average refractive index value of 1.41 at 27 ^{o}C. The value obtained from this work is not far from the ones obtained by other researchers in the coating industry [19] This refractive index is industrially satisfactory for the purpose of this research, the higher the refractive index, gives strength to a greater gloss [20]

Reflectiveness has shown to be a good property of paint and has been reported to have something to do with refractive index. Also, the differences in molecular feature, molecular orientation and state of aggregation of the resin molecules could lead to creation of the scattering of light owing to the continuous and discontinuous in the arrangement of the polymer strand. The cross-linking density gives a higher gloss, hence higher refractive index. The binder plays a role in exhibiting the reflective property of paint (20].

Turbidity of PS oil

The result of waste PS oil (Table 1) had an average turbidity value of 180 NTU. This suggests that the PS oil has a certain level of suspended particles [21]. These impurities can affect the properties of the paint if the oil is used as a binder in paint formulation. High turbidity can lead to a less clear or less glossy finish, and it may also affect the stability of the paint over time. The reason for determining the turbidity of a resin is in order to characterize the optical properties of the binder as it relates to the gloss performance of the paint. Turbidity has to do with light scattering; hence refractive index gives indication of the turbidity [22]. For homogenous clear solution, there are few particles that scatter light. On the other hand, non-homogenous system with a lot of particles, a rise in turbidity is expected. For PS oil of which the colour is light yellow, all the colours of the white light were reflected and refracted. Therefore, the turbidity of this resin is indicative of the gloss performance of the potential non-volatile oil paint that is formulated. The value obtained is within the same values as found by other research studies [23]

Melting point of PS oil

The melting point of the PS oil as shown in Table 1 has an average value of 182 ^{o}C. This melting point of the oil with the value might be as a result of additives initiated during the manufacturing process as well as the degradation suffered during the pyrolysis process.

Use of PS oil as a solvent and a binder

Polystyrene oil when extracted from the PS solid by pyrolysis method, the oil has a very low viscosity of between 1.3 cP to 1.7 cP. At this level of viscosity, the PS oil has the potency to be used as a solvent in the formulation of an oil paint. Most solvents used in the formulation of oil paint have same values or their values fall within the range of standard of viscosity used as solvents in paint formulation. In this particular case, the viscosity of the PS oil is 1.6 cP as shown in Table 1 which shows the physiochemical properties of the PS oil.

The viscosity of solvents used in paint formulation is generally very low, typically ranging from roughly 0.2 cP to 3.0 cP at 28 ^{0}C room temperature, allowing them to effectively reduce the overall viscosity of the paint for proper application. These solvents have a low resistance to flow, which help decrease the high-shear "floor" viscosity of resin solution improving flow and leveling. While the solvent itself has low viscosity, it is chosen for its ability to dissolve resins and affect the overall formulation in specific ways. The solvent ability to dissolve polymers (resin) is often more critical than its base viscosity. A solvent with high solvency allows for high solid context at lower overall paint viscosity. It also increases strong adhesion with surfaces, increases film strength and hardness (24)

Hence, for this PS oil to be used as a binder, the effect of PS solid concentration on the physicochemical properties of PS oil/ polystyrene was carried out. These tests were carried out to ascertain the effects of some of these physicochemical properties particularly the viscosity of the binder. The viscosity of the binder is a primary factor in the formulation of oil paint. The viscosity of the binder was built–up by dissolving known mass of PS into 100 g/dm^3 of PS oil and various physicochemical tests were carried out and the optimized binder sample was selected to be used as binder. The viscosity of the binder used is 7.6 cP as compared to standards [25].

Table 2 shows the effect of PS on PS oil.

Table 2: Effects of PS on PS oil

PS Oil (g/dm^3)	PS added (g)	Viscosity (cP)	Film formation
100	0	1.6	Fail
100	10	6.8	Fail
100	15	7.1	Pass
100	20	7.5	Pass
100	25	7.9	Pass
100	30	8.2	Pass

Physiochemical test has shown that PS oil when extracted from PS has low viscosity of between 1.2 cP to 1.7 cP. The test carried out using this PS oil gave a viscosity of 1.6 cP which was tested for the formulation of binder. The performance test of the PS oil did not form any film because of the low viscosity of the oil. The test showed that the oil was wet and created runs. Hence, it was used as a solvent n the formulation of a non-volatile oil paint.

Consequently, the viscosity of the PS oil was built-up by adding known mass of PS (10 g, 15 g, 20 g, 30 g) in separate test volumes of 100 g/dm^3 of PS oil. Various viscosity values were obtained for the different samples. Performance test was carried out on each of the samples and some failed in film formation while some passed the film formation test. This test was carried out for each of the samples and the best sample with physical/chemical parameters and particularly viscosity that meet the standard was chosen to be used as the binder. The binder with the viscosity of 7.5cP was selected.

Instrumental Analysis

The sample resin from waste polystyrene pyrolysis oil was allowed to dry and formed a solid film for five days. The dried film sample was subjected to instrumental analysis including FTIR, XRD, SEM, TGA and DTA.

FTIR analysis of PS pyrolysis oil

The FTIR analysis of the PS oil dry film produced a characteristic spectrum with peaks corresponding to the vibration modes of the polystyrene molecule. Key brands include those associated accordingly as indicated in Figure 1.

In the spectral of polystyrene pyrolysis oil, the peaks at 3841.0, 3824.2, 3802.7 and 3691.9 cm^{-1} could be attributed to O-H stretching vibrates suggesting the presence of awhile or phenols.

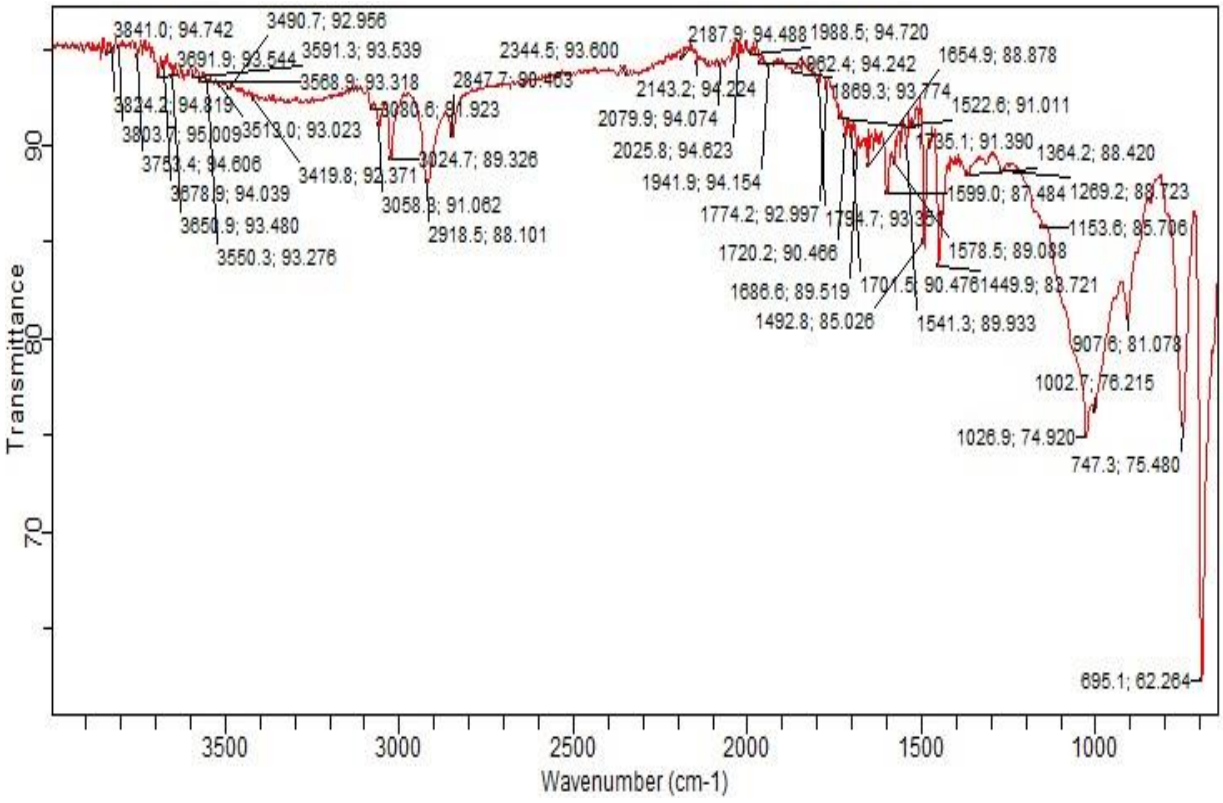


Figure 1: FTIR spectra of PS pyrolysis oil

The peaks at 3058.9, 3024.7, 2918.5 and 2847.7 cm^{-1} are likely due to C-H stretching vibrations, which are characteristic of alkanes, indicating the presence of $-CH_2$ and $-CH_3$ groups typical of polystyrene. The peaks at 2187.9 cm^{-1}, 2079.9 cm^{-1}, 2025.8 cm^{-1} and 1941.9 cm^{-1} can be due to C=O stretching, suggesting the presence of carbonyl groups (possibly due to oxidation during pyrolysis). The peaks at 1774.2 and 1720.2 cm^{-1} could be due to C-H bending vibrations, further supporting the presence of $-CH_2-$ and $-CH_3$ groups [26].

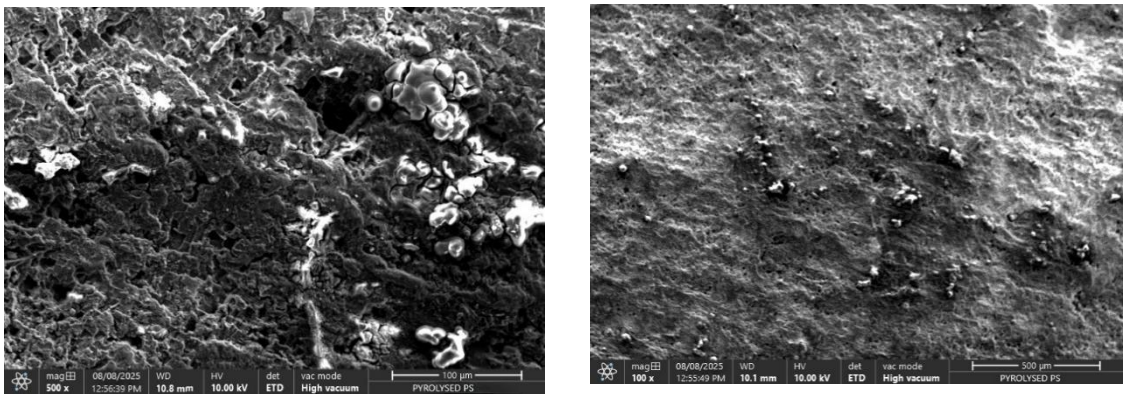
Also, in the finger print region of the spectra, the absorption peak of PS oil is at 1020.9 cm^{-1} to 747.3 cm^{-1} ortho-distributed benzene with which has a very strong absorption peak of the PS pyrolysis oil at 695 cm^{-1} [27].

From Figure 1, the minor changes in the absorption peaks might have been as a result of the effect of temperature during pyrolysis of the PS to obtain the PS oil. The disappearance of some peaks could be due to chemical reactions occurring during pyrolysis [28].

FTIR analysis has been used or applied for polystyrene to confirm the presence and purity of polystyrene in a sample. FTIR also reveals the changes in spectrum such as appearance of new peaks or shifts in existing ones indicating degradation process like oxidation or exposure to certain chemicals. It is equally used or applied in quality control in the quality and consistency of PS products. Significantly, is used to follow the ageing process of PS-based materials such as paints or coatings. Lastly, it is used to analyze the surface of polystyrene films or coatings [29].

SEM analysis of polystyrene pyrolysis oil

Figure 2 show the micrograph of the surface morphology of the PS oil dry film. The result showed the orientation of the surface as indicated by the SEM.



×1000.png ×500.png

Figure 2: Scanning Electron microscopy (SEM) image of the polystyrene (PS) oil. The magnification is 1000x and 500. png

The SEM is a valuable technique for analyzing the surface morphology of PS oil films and other materials, particularly when investigating their interaction with oil or other materials. SEM can reveal details about the film's surface texture, pore structures and the distribution of components within the film which is crucial for understanding its properties and performances. SEM can show the formation of honey-like structures in irradiated PS films, the presence of cracks in PS/Schiff base bends or the morphology of PS composites with biochar [30].

However, it can be seen from the micrograph that, the surface is rough and uneven, with a network of cracks and channels. This is likely due to breakdown of the polystyrene chains during pyrolysis. The absence of a smooth, continuous surface is an indicator that the material has undergone pyrolysis. The temperature at which pyrolysis occurs can affect the

morphology of the residue. Higher temperatures typically result in more uniform and smoother surfaces; the presence of other materials or impurities can also affect the morphology of the residue [31].

The result of the micrograph shows that the presence of PS pyrolysis oil tends to the controlled drying process to maintain structural compartments [32]. The topology of the surface shows the sizes of pores and void; though could be minimal, of which may not be unconnected with the air trapped during the process of drying the film [33].

SEM has been employed to study the different film formation from polymer latex particles, observing the coalescence and inter-diffusion of particles to form a continuous film. This SEM micrograph has also been used to visualize how oil interacts with the PS film, revealing the extent of oil penetration and the resulting surface changes. The SEM image has revealed the formation of terrestrial cracks-like patterns in the PS oil film doped with Schiff bases after irradiation [34].

XRD analysis of polystyrene oil

The XRD analysis on PS oil dry film produced a diffraction pattern with sharp, intense peaks that are typical of crystalline materials (Figure 3).

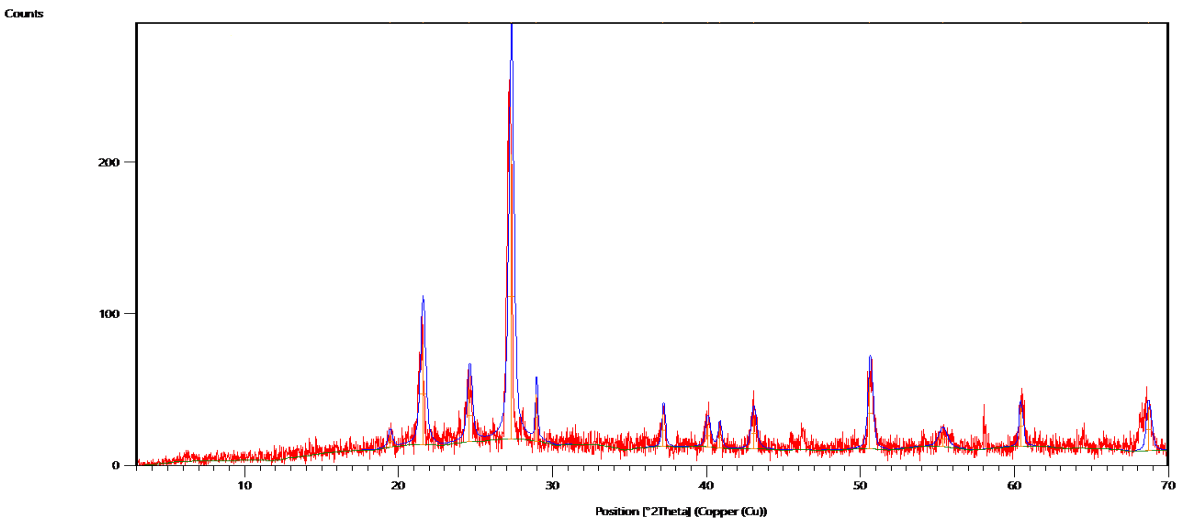


Figure 3: X-ray diffraction pattern of polystyrene oil

The spectrum of the PS oil shows two relatively broad peaks at 21.0^0 and 27.4^0 2 theta. The analysis pattern of the PS oil dry film typically reveals its amorphous nature, meaning it lacks a long-range ordered crystalline structure. These crystalline peaks correspond to the crystalline

packing of polystyrene chain [35]. The diffraction pattern has shown a diffuse and sharp, distinct peaks characteristic of crystalline materials. This is because polystyrene, being a polymer, typically exhibits a random arrangement of its molecular chains [36]. The X-ray diffraction is the method of determining the structure of the diffraction pattern in atom of a substance using X-ray on a material. XRD is used to decide the crystalline or amorphous nature of a material [37]. The spectograph of the XRD diffraction produces a sharp peak which shows that PS oil dry film is crystalline in the atoms and molecules [38]. This goes a long way to speak volume of the fact that the pyrolysis of the polystyrene to obtain the PS oil hence, the matrix of the polystyrene (PS) oil has altered its morphology to a greater degree [39].

PS, especially in its common oil dry film form is known to be amorphous. This means its molecular chains are not arranged in a repeating, crystalline pattern but in a random, disordered manner. This XRD analysis on a material like PS oil dry film produced a diffraction pattern with sharp, intense peaks that are typical of crystalline materials. While the presence of oil as a result of the pyrolysis might influence the surface properties or interactions with other materials or impurities. This has fundamentally altered the amorphous structure of PS itself [39].

TGA analysis of PS pyrolysis oil

TGA is used or applied in formulation and development, to ensure that the film meets specific thermal stability and degradation behaviour. It is used in quality control to ensure that the film meets stability requirements. TGA is also used in material selection to choose the right PS grade and other components for specific applications. Lastly, TGA is used in failure analysis test to investigate the cause of failure in applications where thermal stability is critical [7].

This is a technique used to study the thermal stability and composition of materials by measuring their weight change as a function of the temperature. When applied to polystyrene, particularly in the context of oil-based dry film, TGA reveals information about the material's degradation behavior, including the temperature ranges at which it decomposes and the amounts of volatile components released.

This analysis is crucial for understanding the materials performances under different conditions and for optimizing its use in various applications. TGA measures the weight of a sample as it is heated at a controlled rate. This allows for the identification of various degradation processes such as evaporation of solvents, decomposition of polymers or oxidation of materials [40].

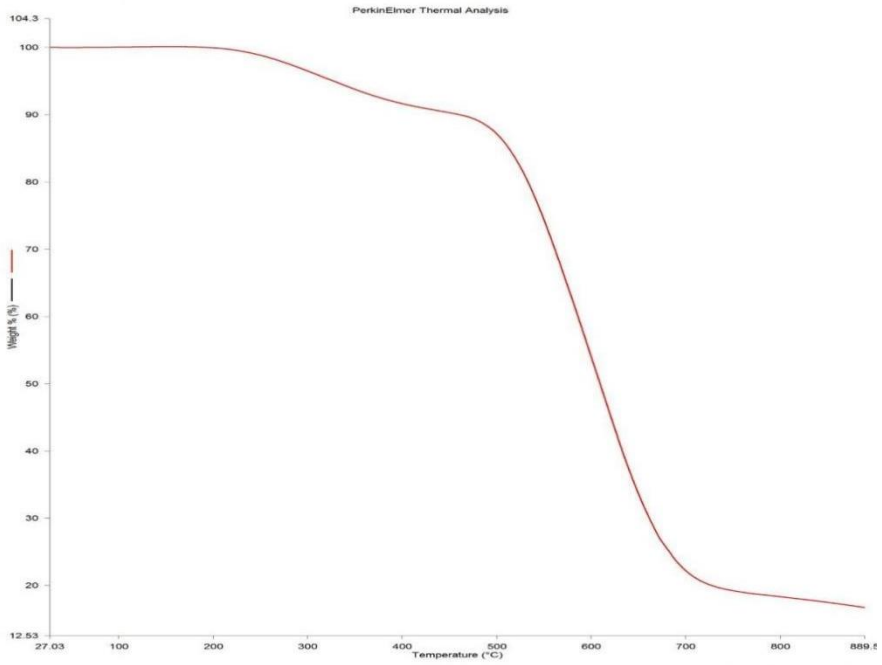


Figure 4: Thermogravimetric analysis of PS oil dry film.

The TGA thermogram, shows the thermal behaviour of the material as it is heated. The X-axis shows the temperature (^{o}C) and the Y-axis shows the weight at percentage remaining (%) of the sample. As the temperature increases, the weight percentage of the sample decreases due to thermal degradation. The PS pyrolysis oil curve shows a relatively sharp decrease in weight starting around 400 ^{0}C. This indicates that PS undergoes rapid degradation at this temperature [41].

The exact degradation temperatures and weight loss profiles can vary depending on the specific types of polymers and the heating rates used in the TGA experiment. The presence of impurities can also affect the degradation behavior. PS is a thermoplastic polymer, meaning it softens and melts when heated. TGA is used to study its thermal degradation behaviour including the temperature at which it starts to decompose and the rate at which it degrades [42]. TGA is used or applied in formulation and development, to ensure that the film meets specific thermal stability and degradation behavior. It is used in quality control to ensure that the film meets specific stability requirements. TGA is also used in material selection to choose the right PS grade and other components for specific applications. Lastly, TGA is used in failure analysis test to investigate the cause of failure in applications where thermal stability is critical [7].

DTA analysis of polystyrene pyrolysis oil

The DTA curve for PS pyrolysis oil provides valuable information about the thermal behaviour of PS during pyrolysis including its decomposition temperature, the energy required for the process and the potential for maximizing liquid oil production.

The DTA curve for polystyrene pyrolysis oil (Figure 5) shows an endothermic peak indicating the energy absorbed during the decomposition of PS.

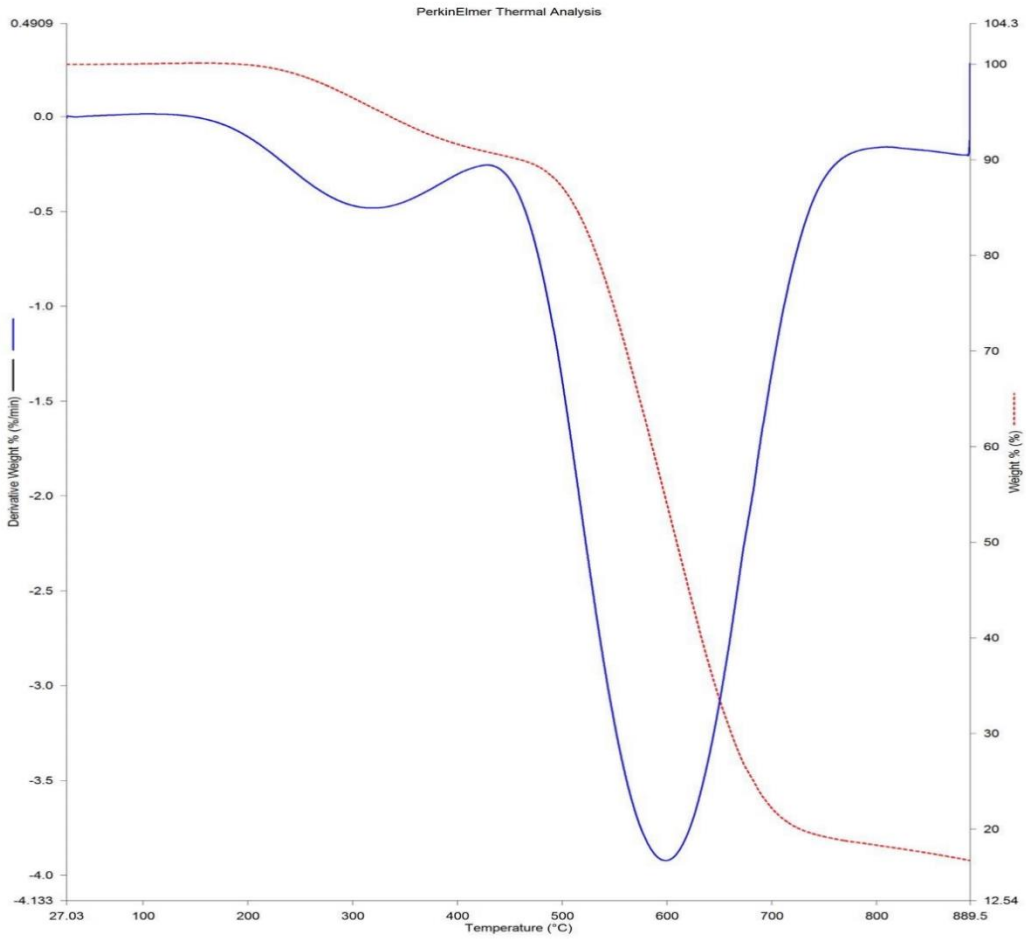


Figure 5: DTA of PS pyrolysis oil

The DTA curve for polystyrene pyrolysis oil typically shows an endothermic peak, indicating the energy absorbed during the decomposition of PS. This peak is associated with the breakdown of the polymer chains into smaller molecules including liquid products. The DTA incorporates TGA hence heat is used for the decomposition of the polystyrene plastic [43]. The onset temperatures of the endothermic peak indicate the temperature at which the PS begins to

decompose which is at 400 ℃. The peak temperature represents the point where the decomposition rate is highest which is at 800 ℃. The offset temperature marks the end of the decomposition process which is at 600 ℃. As the pyrolysis temperature increased, the decomposition rate generally increases. Leading to a more pronounced endothermic peak, however, at very high temperatures, the formation of char (solid residue) may also increase, potentially affecting the shape and intensity of the DTA curve [44].

The DTA curve is related to the yields of different products (liquid, gas and chair) obtained from PS pyrolysis. The temperature at which the endothermic peak reached corresponds to the optimal temperature for maximizing liquid oil yield. The DTA curve also can be related to the composition of the pyrolysis oil. For example, the proportion of aromatic compounds in the oil can increase with temperature which is reflected in the DTA carve [45].

In summary, the DTA curve for PS pyrolysis oil provides valuable information about the thermal behaviour of PS during pyrolysis, including its decomposition temperature, the energy required for the process and the potential for maximizing liquid oil production. Further increase in temperature from 460 ℃ up to 680 ℃ showed only 4-5% sample weight loss, completing the degradation of plastic with some residue [46].

Paint Formulation

The physicochemical parameters of paint samples made from PSO/PS binders were observed. The results showed that the basic properties increased encouragingly. The non-volatile oil paints using PSO/PS binders were successfully formulated. PPD20 was formulated and used as the parent paint from which other paint samples were optimized and characterized to ascertain their physicochemical parameters. The physicochemical parameters of the paint qualities obtained were as shown in the Table 3.

Table 3: Physical and performance test of paint samples

Physical Tests	Sample PPD 20
In-Can Appearance	White
PH (@28 ^{0}C)	8.85
Density (g/cm-3)	1.268
Viscosity (Poise)	18.8

Performance	
Opacity (Hiding Power)	P
Washability	P
Water Drop Test	P
Drying Time (minutes)	
Drying to Touch	55
Hard Dry	100
Adhesion	Good
Thickness	P
Resistance to blistering	P
Stability	Good
P=Pass F=Fail	

In-can appearance

The non-volatile oil paint made from PS/PSO binders were homogenous, viscous and with a brilliant white colour in appearance. Aesthetically, it has an attractive white colour.

Plate 1: In-can appearance of the Paint

pH of paint

Table 4 shows the pH values for the paint samples of 7.57, 7.68, 8.85, 9.22, and 9.73 respectively that were obtained at 28 ℃. The result is indicative that the paints are of close range in terms of their alkalinity. Within this pH range, the paint qualities are not susceptible to serious bacterial growth, corrosion of metal surfaces and the degradation of wall when applied on them [47]. The pH values of sample paint produced also fell within the acceptable

standard range of 7.0 to 9.0 prescribed by the Standard organization of Nigeria (SON) [48]. pH speeds up the rate of hydrolysis of resin. One of the factors affecting the functionality of paint biocides is the pH, thus requires adjustment of the type of biocide [49].

Viscosity

Table 4 shows the results of the viscosity measurement of the paints. It is obvious that the PS/PSO binder had effect on the viscosities of the formulated paints. The use of proper quality and quantity of the binder is critical to the quality finishing of the coating. Excessive viscosity can cause orange peel; whereas a very low viscosity can create a film that will be too wet and create runs [47]. From the data obtained, the viscosity of PS/PSO was 16.5 cP. P5 had a higher viscosity than the other paint samples.

Density

The result of the analysis of the paint samples indicated the specific gravity of 1.253, 1.267, 1.271, 1.277, 1.283 respectively. From the result it becomes clear that the void fraction percentage of the PS/PSO binder are slightly high. The void content influenced the weight reduction per unit volume of the binders. Ndibe et al [50] reported having a specific gravity value of 1.26 for the blend of natural rubber and polyvinyl acetate. The major influence of density decreases in weight percentage of the substance [51]. The values obtained were close to 1.30 to 1.40 rang set as the acceptable by the Standard Organization of Nigeria [48].

Opacity (Hiding Power)

As shown in the table 4, the paint formulated with PS/PSO binders gave a good hiding power after two coatings and indicated as passed. The hiding power of the pigment titanium dioxide shows an even coverage of all the patches on the surface in the chart after two coatings were completely hidden from view. The hiding power of the paints fell within the standard specified by the Standard organization of Nigeria (SON). Both paints formulated from PS/PSO binder passed opacity test.

Drying Time

Table 4. gave the result of the drying time of the formulated paint samples using PS/PSO binder. The duration of the drying time of 48, 53, 65, 76 and 85 minutes for P1, P2, P3, P4, P5 respectively. Gel time is one of the important factors commonly employed for the resin classification in order to determine their performance in bonding [52]. According to Mirski et

al [53], gel time of the binder impacts on the drying time of the paint. The long drying time displayed by paint is attributed to the good quality of the coating. The Standard Organization of Nigeria prescribes a maximum drying time of 210 minutes for an oil paint [50]. The finding fell within the specified range of this standard.

Adhesion

Table 4 shows the result that the paint which used PS/PSO binder for formulation passed adhesion test. All the samples of the paint passed adhesion test. Polystyrene is known to offer unique performance to surface coatings such as high abrasion resistance, superior durability, elastomeric parameters, good chemical resistance, tensile strength, high extensibility at low temperature and properties that are simple to modify [54]. These qualities of polystyrene lend strength to its good adhesion quality of the coating.

Tackiness

The paint samples were sticky to the hand, and as such, they all passed the stickiness test as indicated in Table 4. Paints with good tackiness and hardness parameters results from high viscosity of the binders.

Resistance to blistering

Table 4 indicated that all the paint samples formulated from PS/PSO binder passed blistering test. The result for water drops test was positive for paints formulated from this binder. There was absence of crack as the water were dropped on the surfaces where distilled water flowed on the surface of the dried paint films coated on glass surface.

Chemical resistance of paint samples

One of the most desirable qualities of a good coating film is the capability of the paint film to withstand chemical attack. High cross-linked density network decreases the chemical attack or resistance on their exposure to chemical environment [55]. The results (Table 4) for the effect of the films of chemical attack on paint samples on different chemical media. The three media considered were salt, acid and an alkaline salt. The paint films were unaffected in salt medium for all the paint samples. At the same time, all the paint samples formulated using PS/PSO binders were not affected in the acidic medium. Similarly, all the paint samples were not affected in the alkaline medium.

On the whole, from the overall assessment of all the paint samples formulated from PS/PSO binder, the better binder from the physicochemical assessment of their parameters in terms of density, viscosity, drying time, chemical resistance, P3 paint generally performed better.

Table 4 compares the physicochemical properties of paint samples formulated from different concentrations of PS/PSO binder.

Table 4. Physical and performance properties of different grades of PSO Paints

Sample	Physical test				Performance test							Chemical Resistance Test		
	Appearance	pH (@28 ^{0}C)	Density (g/cm^{-3})	Viscosity (Poise)	Opacity	Washability	Water Drop Test	Drying time (Min)		Blistering	Stability	0.1M HCl	0.1M NaOH	0.1M NaCl
								Touch	Hard					
PSO10	White	9.88	1.216	10.8	P	P	P	48	75	P	Good	U	U	U
PSO15	White	9.08	1.260	11.5	P	P	P	53	97	P	Good	U	U	U
PSO20	White	8.85	1.338	13.8	P	P	P	65	105	P	Good	U	U	U
PSO25	White	8.22	1.345	15.6	P	P	P	76	115	P	Good	U	U	U
PSO30	White	7.43	1.354	16.5	P	P	P	85	126	P	Good	U	U	
STD (SON)		7-9.5	1.3-1.4	6.0-15.0	P	P	P	20	120	P	Good	U	U	U

Key: P=Pass, F=Fail, B=Blister, U=Unaffected, AB=Blister after some time, STD=Standard, SON=Standard Organization of Nigeria

The result shows that all the paint samples formulated passed density, pH, viscosity, opacity, water drop test, drying time, tackiness, resistance to blistering, stability, chemical tests and compete favorably with commercial paint as it meets prescribed standards set by the Standard Organization of Nigeria.

Table 4. shows the result of the measurement of pH at ambient temperature. pH of the paints decreased with increase in concentration of the binder. The pH of paint samples adjusted from 9.23 to 7.86 as the binder concentration decreases from 10 to 30%. This change in pH is expected in that the proportioning of various ingredients for all the paint samples was based on a fixed mass. The major influence of volume of the paint was the solvent and binder. So as the concentration of the binder increases, the volume of the pigment present in the paint matrix decreases while the mass of the whole set up remains constant. As such, the concentration of hydroxide ion falls whereas the concentration of hydrogen ion in the structure rises. This account for the decreases in pH as the percentage concentration of the binder was in the increase. Optimally, the concentration of 20% concentration feasibly is the concentration at which the pH works best in view of the specification of the Standards Organization of Nigeria. Generally, all the paint samples had pH values that are acceptable to the SON.

The gradual increase in density as the concentration of the binder increases as depicted in Table 4. The density of the samples rose from 1.216 to 1.354 g/cm^3, as the concentration of the binder rose from 10 to 30%. Density is the physical parameter that demonstrates the ratio of mass to volumes of a material. There was a slight difference in the densities of the different grades of the paint samples of which is not unconnected with the distribution of the void space in the material. The result of scanning electron microscope in Figure 2 showed that the distribution of void space in the PS dry film. This account for the slight difference in the densities of all the grades of the binder and paints. It is a crucial property for the identification of a substance. The density here shows the distribution of void spaces in a material [56]. The density is measured to know the amount of void space variation with concentration of the binder. The density of the property such as the dispersion and the stability of the pigment can be used to determine the critical pigment volume concentration, spreading capacity and consistency of the paint [20]. The densities of all the paints were not far from the range set by the Standard Organization of Nigeria which is 1.3 to 1.4 gcm^{-3}.

Table 4 indicates the results of the data of the viscosity parameter obtained for all grades of paints formulated using PS/PSO binder. Generally, the viscosity of the paints rose

from 10.7 to 16.5 cP. This shared a direct proportion with an increase in the concentration of the binder of which increased from 10 to 30%. This is not unconnected with the result of the nature of the binder from waste polystyrene plastic material of which FTIR, XRD analyses showed similar but not identical data. It is interesting to note that the slight difference run from binder to the finished products. The viscosity of an oil paint is an important property as it affects the constancy, the flow and use. The paint samples show good flow and simplicity of application which can be ascribed to their viscosities of binders used in the formulation [50]. The pattern of the change in the viscosity with concentration was also in tandem with the work of Bergerbink and Billstein [57]. Viscosity influences flow rate of paint as well as the leveling and sagging, thermal and mechanical parameters, moreover, the adherence of paint to the substrate. It is interesting to see that this important parameter increases with increasing concentration in the paint. Good enough, the viscosity obtained from these grades of oil paint meets the standard of 6 to 15 Cp set by Standard Organization of Nigeria.

As shown in Table 4, all the paint samples passed the opacity test. This was probably because the quantity of the extender and pigment in all the samples were kept constant while the concentrations of the binder were varied. This indicates the ability of the paint to disguise or hide the colour of the substrate to which it is coated [1]. It is a function of the numerical measurement of the refractive index of which is the ability of the pigment to turn the direction of the incident light. We use pass (P) and fail (F) to describe our assessment of the opacity performance. Pass was assigned when the coating effectively hid the underlying substrate, whereas it fails, if the paint did not effectively hide the surface of the substrate. Mohart chart for all the samples also passed the test.

From Table 4, the drying time steeply increases with increase in the concentration of the PS/PSO binder. It is remarkable to note that the highest concentration of PPD30 had the highest drying time of 47 minutes, 85 minutes of dry to touch and 126 minutes hard dry. Of course, the increase in the percentage concentration of the binder in the paint reduces the drying time in minutes. The shorter the drying time, the better the quality of the resin [58]. Idris and Rashan [59] also reported having a drying time of 25 minutes using PVA as a binder. On the whole, the drying time of the paint is a function the environmental factors such as temperature and humidity. The Standard Organization of Nigeria prescribes 20 minutes and dry to touch and 120 minutes for hard dry. PPD20 was within the set standard.

All the formulated paints exhibited good tackiness and hardness resulting from the increase in the cross-linking degree of the polystyrene chain in the paint. As shown in Table 4, all the samples of the paint were tacky to touch as such all of them passed the test. The examination of all the paints formulated and kept for a span of one month shows that all the grades of the coating maintained their unchanging profiles of even constitution. No separation whatsoever was noticed. All the samples had good stability and passed the test.

Table 4 indicates the results obtained from chemical media for all the paint samples. In sodium chloride and acid media, all the paint samples formulated using PS/PSO as binder were resistant to blistering. Similarly, in the alkaline medium, all the paint samples passed the test. On the whole, it is most obvious that, at higher percentage concentration of the PS/PSO binder, the chemical resistivity was more pronounced than at lower percentage concentration. However, at higher concentration of the binders the oil paint yielded more resistance. This is in tandem with the previous observations [1, 47]. The quantity and quality of the binder has a crucial effect on the overall performance of the coating. PPD30 has better chemical resistance due to high cross-linked density of network which decreases the chemical during the process of exposure to the chemical surroundings [55]. Optimally, the concentration of PPD20 feasibly is the best concentration at which the pH works best in view of the specification of the Standard Organization of Nigeria.

CONCLUSION

In this study, waste polystyrene plastic was successfully pyrolyzed in the absence of oxygen to obtain PS pyrolysis oil to form the binder and solvent in the coating industry for the first time. A binder was developed with the effect of PS solid on PS oil showing their film forming ability which is the primary property of a binder. The low viscosity of the PS oil determined the solvent capability of the oil. When PS is decomposed in the absence of oxygen, there is polymer dissociation at this stage and the PS become monomers, hence, they have low molecular weight and therefore, it was used as a solvent in the formulation of non-volatile paint.

The objectives of the study were achieved: the results obtained were compared with other results of binders and solvents obtained and compared with standards. The paint has no volatile organic compounds in it. It also has high melting point which a good property that it can withstand very high tropical temperatures.

RECOMMENDATIONS

It is recommended that another solvent should in the formulation of the paint. Also, another waste plastic material should be used as a binder in paint formulation.

REFERENCES

[1] Ibrahim, M.A., Al-Mulla, E.A. & Al-Saady R.K. (2022). Formulation and evaluation of eco-friendly paint. *Journal of Coatings Technology and Research*. 19(1), 245-255.

[2] Ahmad F., Khan M.A. & Ansari M.M. (2019). Corrosion protection of metals using organic coatings. *Progress in Organic Coatings*. 126, 88-98.

[3] Kalu A.E., Okafor V.N. & Eze I.O. (2023). Utilization of local raw materials for cost-effective paint production in Nigeria. *Nigerian Journal of Technology*. 42(1), 112-120.

[4] Ignatyev I.A., Thielemans W. & Vander Beke B. (2014). Recycling of polymers: A review. *Chem Sus Chem*. **7**(6), 1579-1593.

[5] Vilas V.R., Satish S. & Patil S. (2000). Standard methods for polymer characterization. *Polymer Testing.* 91 (5),567-578.

[6] AOAC International. (2000). Official methods of analysis of AOAC International. 17th ed.

[7] Yelwa J.M., Osemeahon S.A. & Nkafamiya I.I. (2017). Development of paint binder from styrenated malenized rapeseed oil. *Journal of Applied Polymer Science*. 134(40), 45374.

[8] Oluranti O.O., Ogunleye O.O. & Akinwunmi O.O. (2011). Physico-chemical characterization of resins from modified castor oil**.** *International Journal of Scientific & Engineering Research*. 2(10), 1-7.

[9] Osemeahon S.A. & Archibong E.J. (2011). Turbidity measurement of polymer resins. *Journal of Polymer Science.* 45(3), 234-241.

[10] Osemeahon S.A. & Dimas B.B. (2014). Formulation of paint from a polystyrene hybrid resin**.** *Journal of Chemical Engineering and Materials Science.* 5(2), 12-22.

[11] Morgan D.L. (2011). Paint and coating testing manual: 15th edition of the Gardner-Sward handbook. ASTM International.

[12] Osemeahon S.A., Yelwa J.M. & Nkafamiya I.I. (2013). Standard values for resin properties in coating applications. *Journal of Applied Polymer Science*. 128(5), 3456-3465.

[13] Standards Organisation of Nigeria (SON). (2008). Standard for paint specifications.

[14] Soundrajan P., Kumar R. & Singh P. (2024). Viscosity effects in paint application. *Journal of Coatings Technology*. 21(2), 189-201.

[15] Soumaya J., Fathi A. & Mohamed M. (2020). Viscosity and drying time relationship in oil paints. *Polymer International*. 69(8), 723-732.

[16] Khatha S., Weerachai P. & Somchai S. (2021). Density analysis of polystyrene pyrolysis oil. *Journal of Material Cycles and Waste Management*. 23(5), 1789-1798.

[17] Weerachai P., Khatha S. & Somchai S. (2022). Density and composition of polystyrene pyrolysis oil. *Waste and Biomass Valorizat*ion. 13(2),789-798.

[18] Donald J., Smith K. & Williams P. (2013). Refractive index analysis in characterization. *Processing Technology*. 112:78-85.

[19] Osemeahon S.A. & Barminas J.T. (2007). The performance of methylol urea on the modification of polystyrene: A resin for surface coating. *Leonardo Journal of Sciences*. 6(10), 67-78.

[20] Akinterinwa A., Adebayo O. & Ogunleye O. (2015). Refractive index as a determinant of gloss in paint formulations. *Nigerian Journal of Chemical Research*. 20(1), 45-53.

[21] Ruktai S., Pongsa P. & Chaiyaporn P. (2020). Turbidity analysis in oil characterization. *Journal of Analytical and Applied Pyrolysis*, 275, 117-126.

[22] Oladipo A., Adeleke J. & Ogunleye A. (2013). Turbidity and gloss performance in coatings. *Journal of Coating Technology*. 10(3), 234-245.

[23] Edgar T. & Lopes J. (2023). Turbidity effects on gloss performance in coatings. *Progress in Organic Coatings*, 175, 107-115.

[24] Sonntag P., Müller J. & Schmidt H. (2019). Solvent properties in paint formulations. *Progress in Organic Coatings*, 128, 78-89.

[25] Caesar G., Mwangi J. & Omari A. (2024). Viscosity optimization of polystyrene-based binders for coating applications**.** *International Journal of Polymer Science*. 2024, 1-12.

[26] Al-Sagheer F., Ahmed M. & Al-Hassan R. (2020). FTIR analysis of polystyrene pyrolysis products. *Polymer Degradation and Stability*. 178, 109-118.

[27] Onwudili J.A., Insura N. & Williams P.T. (2009). Composition of products from the pyrolysis of polyethylene and polystyrene in a closed batch reactor. *Journal of Analytical and Applied Pyrolysis*. 86(2), 293-303.

[28] Xue Y., Li J. & Lu H. (2015). Pyrolysis of polystyrene: FTIR monitoring. *Journal of Analytical and Applied Pyrolysis*. 114, 23-30.

[29] Ward A., Smith R. & Johnson T. (2006). FTIR analysis of polystyrene films. *Applied Spectroscopy*. 60(5), 523-530.

[30] Zhang Y., Li X. Liu T. (2014). SEM analysis of irradiated PS films**.** *Journal of Polymer Science Part B: Polymer Physics.* 52(12), 823-832.

[31] Li X., Zhang Y. & Liu T. (2020). Morphological changes in polystyrene during pyrolysis. *Journal of Analytical and Applied Pyrolysis*. 149, 104-113.

[32] Osemeahon S.A., Dimas B.B. & Barminas J.T. (2024). SEM analysis of polystyrene-based films. *Polymer Engineering and Science.* 64(1), 123-134.

[33] Gutierrez-Velasquez J., Gonzalez M. & Rodriguez E. (2022). SEM analysis of polymer films: Pore structure and void formation**.** *Journal of Microscopy*. 285(3), 567-578.

[34] Zhang Y., Li X. & Liu T. (2016). Morphological studies of PS composites. *Polymer Composites*. 37(5), 1456-1465.

[35] Akbari S., Mahmood A. & Ahmad I. (2020). Characterization of polystyrene waste through XRD analysis. *Journal of Polymer Research.* 27(8), 234-245.

[36] Akbar S., Mahmood A. & Ahmad I. (2020). XRD analysis of polystyrene materials. *Polymer Bulletin.* 77(6), 3123-3135.

[37] Marimaran R., Kalaiselvam S. & Sridhar R. (2017). XRD characterization of polymer materials. *Materials Today: Proceedings*. **4**(8), 8456-8463.

[38] Pulungan R., Siregar M. & Nasution F. (2019). XRD analysis of amorphous and crystalline polymers. *Journal of Polymer Engineering*. 39(7), 645-656.

[39] Turner J. (2020). Morphology changes in polystyrene during pyrolysis. *Polymer Degradation and Stability*. 175, 109-118.

[40] Liu Y., Qian J. & Wang J. (2017).TGA analysis of polymer degradation. *Thermochimica Acta*. 650, 89-98.

[41] Bhadra S., Singha N.R. & Khastgir D. (2020). Thermal degradation of polystyrene: A TGA study. *Journal of Applied Polymer Science*. 137(15), 485-496.

[42] Jawaid M., Mansour A. & Khalil H. (2021). TGA studies on thermoplastic polymers. *Polymer Testing.* 95, 107-118.

[43] Undri A., Rosi L. & Frediani M. (2021). Pyrolysis of polystyrene in a batch reactor: DTA analysis. *Journal of Analytical and Applied Pyrolysis*. 92(1), 89-96.

[44] Ukei H., Hirose T. & Kitajima T. (2007). DTA study of polymer decomposition**.** *Journal of Applied Polymer Science.* 76(8), 1234-1245.

[45] Undri A., Rosi L. & Frediani M. (2014). Product yields in PS pyrolysis: DTA correlation. *Waste Management*. 34(8), 1456-1463.

[46] Tae J., Kim Y. & Lee J .(2004). Pyrolysis of polystyrene: DTA analysis. *Journal of Thermal Analysis and Calorimetry*. 78(3), 899-910.

[47] Abdrusalam A. & Maiwada M.S. (2015). Evaluation of paint properties from modified acrylic emulsion. *Journal of Coatings Technology and Research*. 12(3), 567-575.

[48] NIS (Nigerian Industrial Standard). (2008). Standard for decorative paint coatings. 2008.

[49] Carter D. (2016). pH optimization in paint biocides. Coatings Technology Handbook. 4th ed. 345-358.

[50] Ndibe O.C., Onukwuli O.D. & Ude C.N. (2016). Evaluation of paint properties from modified acrylic emulsion. *Progress in Organic Coatings*. 151, 106090.

[51] Obiukwu O., Uche E. & Okonkwo J. (2016). Density and weight reduction in paint formulations. *Journal of Chemical Engineering*. 23(4), 89-97.

[52] Goncalves M., Silva R. & Pereira T. (2018). Gel time influence on drying time in paint formulations. *Coatings*. 8(4), 134-145.

[53] Mirski R., Barcik J. & Derda M. (2020). Gel time and drying time correlation in coatings. *European Journal of Wood Products*. 78(5), 1023-1032

[54] Cristiana M., Silva R. & Pereira T. (2018). Polystyrene properties in surface coatings. *Polymer Engineering and Science*. 58(7), 1123-1135.

[55] Motawie A.M., El-Sayed E. & Badr M.M. (2010). Utilization of agricultural wastes in the synthesis of polymeric resins. *Journal of Applied Polymer Science***.** 117(4), 2207-2212.

[56] Ferdou S., Bouchard P. & Dufresne A. (2014). Density and void fraction analysis in polymer composites. *Composites Science and Technology*. 100, 45-52.

[57] Bergerbink R. & Billstein J. (2022). Viscosity-concentration relationships in polymer solutions. *Journal of Rheology*. 66**(**3), 567-578.

[58] Elba M., Santos R. & Oliveira M. (2018). Drying time optimization in resin-based paints. *Journal of Coatings Technology*. 15(2), 234-245.

[59] Idris A. & Rashan M. (2017). PVA as a binder in water-based paints. *Polymer Bulletin*. 74(6), 2123-2138.