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Emulsion Paints from Waste Styrofoam Food Packs

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ABSTRACT

This study developed formulation for paint production using binder obtained from waste Styrofoam food packs using *Eucalyptus* oil. Pulverized waste Styrofoam food packs were dissolved in *Eucalyptus* oil, to form binder. The binder was characterized, and used in the formulation of emulsion paint. The paints were applied on different surfaces: cemented walls, glass, wood, and ceiling board, to determine their dry-to-touch and dry-to-hard properties. Control emulsion paint was also produced using a conventional binder, polyvinyl acetate. Paint properties such as drying times, pH, opacity, tackiness, flexibility, adhesion, resistance to blistering, and chemical resistance, the morphology, functional groups, and the heat stability, were determined. It was observed that the emulsion paints displayed moderate surface drying period in the range of 15 to 23 min for PVA and 18 to 25 min for eucalyptus binder across surfaces. These drying period were compared to the Standard Organization of Nigeria standards for dry-to-touch of 20 minutes. The *Eucalyptus* oil styrofoam binder paint met coating criteria and showed good consistency, smoothness, and homogeneity, pH, viscosity, flexibility, adhesion, opacity, hardness test, tackiness, resistance to blistering, and drying time. It showed good resistance to acidic, alkaline and salt medium compared to the gasoline-based styrofoam binder paint.

Keywords: *Eucalyptus* oil, polyvinyl acetate, styrofoam, waste.

INTRODUCTION

An urgent environmental issue facing Nigeria's cities and rural areas is solid waste management. Nigeria is one of Africa's biggest generators of solid trash, with a population of over 170 million. The nation's solid waste management situation is getting worse every day in spite of a plethora of laws and rules. Only 20–30% of Nigeria's yearly production of over 32 million tons of solid trash is collected [1]. Plastic waste and Styrofoam food packs are the two main sources of the remaining waste goods that are neglected. They are responsible for an astounding 80% [2].

Due to its continuous presence in natural ecosystems and non-biodegradable nature, the dispersion of expanded polystyrene (EPS) debris, often known as Styrofoam, has emerged as a significant environmental concern in recent years [2]. Because animals frequently mistake polystyrene for food, it can harm wildlife and is extremely harmful to the environment. Furthermore, suspension polymerization produces tiny, hard polystyrene beads that might decompose into harmful microparticles in the ocean, perhaps polluting marine food. Polystyrene also contains dangerous chemicals including benzene and styrene. Suspension polymerization produces small, rigid polystyrene beads that might decompose into poisonous microparticles in the ocean, perhaps contaminating the marine food chain and, eventually, human food [1].

A study by Rucore Libraries highlights that polystyrene, a precursor to Styrofoam, is the fifth-largest source of hazardous waste [3]. Polystyrene foam has been found in wind and water, contributing significantly to marine debris. These materials pose severe risks to wildlife, as fragments of broken-down polystyrene can block airways, contaminate food sources, and cause cancer or stomach issues.

Due to the toxicity of Styrofoam to the environment and the improper management of waste in Nigeria, the strategic and ideal solution is valorization which is the transformation of Styrofoam into usable products. This will not just reduce the toxicity of these waste products but will bring a step closer to achieving cleaner cities in view of the coming plastic pollution. There are currently recycling procedures used for trash from Styrofoam products. These procedures include mechanical processing, high-temperature pyrolysis, chemical modification, physical dissolution and melting regeneration. As effective as they all might be, they have their disadvantages. Mechanical processing uses a lot of energy and physical dissolution needs a lot of organic solvents [3]. Carbonizing Styrofoam to create carbon-based materials for a variety of applications is also another effective way of recycling [4]. However, during carbonization, Styrofoam will emit harmful gases into such as toluene and benzene [5]. Hence an effective and eco-friendly approach is needed.

Paints are primarily composed of three key ingredients: pigments, solvent, and binder. The binder system plays a crucial role in determining properties such as abrasion resistance, impact resistance, chemical resistance, adhesion, gloss, hardness, durability, and drying time, although minor modifications to other paint components can also influence these characteristics. The binder, also known as resin, is the main component of paint. It forms continuous film layers and binds the pigments and other ingredients together.

In this study for new paint formulation, Styrofoam food pack (SFP) waste will be utilized as the binder. This approach replaces the alkyd resin commonly used in commercial paints, which is typically derived from crude oil refinement byproducts. One type of polyester resin that was initially used as a paint binder in the 1930s is alkyd resin. Alkyd resins are one of the most appealing platforms for creating a variety of coating formulations because they may be used with a broad range of polymers. It is one of the most widely used resins in the paint and coatings industry due to its broad compatibility, exceptional flexibility, superior gloss, and good water resistance and barrier qualities [6]. Nevertheless, it has a long drying time, poor UV resistance, volatile organic compound, limited chemical resistance, and irritation of the skin and eyes owing to improper handling and ventilation, even though it is compatible and effective. Petroleum products such as polyols and phthalic anhydrides are also present, making it is combustible, which is a characteristic of oil-based paints.

This study aims to explore how Styrofoam waste can be transformed into useful binders for paints. This approach seeks to reduce the environmental issues caused by discarded Styrofoam while identifying a more sustainable and affordable alternative to traditional paint binders.

MATERIALS AND METHODS

The Styrofoam waste was collected from the University of Lagos community. They were prepared by washing the samples with soap, and leaving them out to dry. The Styrofoam food packs were then broken into smaller pieces and dissolved in separately *Eucalyptus* oil and gasoline.

Preparation of the Binder

Weighed samples of the binder; 15 g and 30 g, were dissolved in a fixed volume (100 ml) of *Eucalyptus* oil and gasoline respectively. These weighed samples were placed into 2 beakers, then the measured volume of *Eucalyptus* oil was carefully poured into one of the beakers, and the same was done for gasoline into the other beaker. The mixture was also gently stirred rod or a spoon until the polystyrene began to dissolve.

Characterization of the Binder

Determination of the binder viscosity was done using the method reported in Tawiah et al [7]. The density of the binder was determined following the method reported in Kalu et al [8]. The melting points of each binder were determined using the Stuart SMP40 melting point apparatus, employing the standard capillary tube method. The refractive index of each resin binder was measured using a refractometer, following the procedure reported in Kalu et al [8]. Turbidity of the binders were measured using Labtech Turbidity meter. Utilizing an Intron Tensile machine based on ASTEMD 638, the elongation at break was determined. The binder film, measuring 5 cm in length, 2 cm in width, and 0.2 cm in thickness, was fully loaded with 150 g for each sample and clamped onto a stand. All samples underwent three runs, and the average elongation was calculated as a percentage. To find solubility, 2 milliliters of the resin were mixed with the necessary 20 milliliters of distilled water. The transparency or cloudiness of the samples indicated whether they will be soluble or insoluble in water [7].

Formulation of the Paints

Emulsion paint was essentially created in accordance with the method reported [9], which divides the production process into three main stages. The first stage involves adding additives such as dispersants, defoamers, thickeners, anti-skin, driers, wetting agents, stabilizers, pH adjusters, and preservatives. The main goal of this stage is to create an environment that is conducive to particle wetting and dispersion. A mixing tank (1 L) was filled with 185 ml of distilled water, and the overhead stirrers were turned on after 12.7 g of the additives were added. The mixture was agitated for 15 minutes using a high-speed stirrer. In the second stage, also referred to as "mill base," pigments and extenders were distributed in the mills immediately after dispersion. The mill base stage involved increasing the stirrer speed to a very high speed and stirring the mixture for another 15 minutes. To prevent structural deformation under high mechanical forces, binder was not added in the mill base stage. Lastly, binder and the remaining additives from the first stage were mixed with 15 milliliters of water, and the mixture was stirred at a moderate speed for another 15 minutes. By adding thickeners prior to the dispersion stage of the production process, energy losses in the mill were reduced. The formulations are detailed in Table 1 below.

Table 1: Formulation of WSF modified paint

Stage	Reagents	Amount (g)
	Water	185
	Anti-foam	0.2
	Drier	0.2
	Calgon	1.16
First	Genepour	1.16

	Bermocoll	2.5
	Troystan	1.14
	Dispersant	0.2
	Butanol	5
	Ammonia	0.54
	TiO_2	50
	$Al_2(SiO)_3$	11.2
Mill Base	Na_2CO_3	0.58
	Kaolin	2.52
	$CaCO_3$	123
	Binder	200
	Water	5
Letdown	Dispersant	0.2
	Nicofoam	0.2
	Anti-skinning agent	0.2
	TOTAL	500

Characterization of the Paints

A pH meter was used to measure the paint samples' pH. To get the reading, the electrode was dipped into paint samples. After standardizing the electrode's pH with a buffer solution at pH 7, distilled water was used to rinse it. Adhesion test of the emulsion paint was recorded according to ASTM International [10]. The resistance of the paint films to blistering was evaluated by applying an undiluted sample onto a glass panel with the aid of a film applicator, producing a uniform wet film thickness [11]. To evaluate the viscosity of the paint samples, 500 mL of each formulation was measured and analyzed using a Brookfield DV-E Digital Viscometer (Brookfield Engineering, USA) [8,12]. The approach outlined by Tawiah et al [7] was employed to determine the paint samples' opacity test. The paint samples' drying times were assessed [12]. The paint sample's dry test was assessed using the methodology described in Kalu et al [8]. Flexibility test of the emulsion paint was determined by applying the samples to the aluminum panel mix.

Tackiness of the emulsion paint was also determined on the film of each of the paints formulated by hand to find out if the paint is sticky or not. Stickiness of a dried film indicates that the film is tacky. Stability test of the emulsion pain was determined as follows; The paint samples were completely sealed in a container and kept at room temperature (27°C) for 2 months. At the end of this incubation period, the various paint samples were re-examined for any change in viscosity or coagulation of the emulsion paint.

The film composition and morphology of the binder were confirmed by FTIR spectroscopy and SEM. The prepared thin films were examined using the FTIR technique and the morphology by SEM. They were scanned at a resolution of 4 cm-1 with 16 scans over the wavenumber region peaks of IR transmission spectra of 400 –4000 cm-1 using FTIR spectrophotometer (Perkin Elmer, USA)

RESULTS AND DISCUSSION

Characterization of the Binders

The pH values ranged from slightly acidic to moderately alkaline. *Eucalyptus* binder (EB) and gasoline binder (GB) exhibited slightly acidic pH values (6.37 and 6.42), while for the formulated paints, gasoline paint (GP) and *Eucalyptus* paint (EP), were slightly alkaline (8.53 and 8.41). Acidic pH in binders can help minimize premature chemical reactions during storage, improving stability, whereas slightly alkaline paints provide better corrosion protection, particularly on metallic surfaces [8,13]

The moisture content varied across the samples, with gasoline binder showing the highest value at 31.87%, followed by *Eucalyptus* paint, 17.36%, and both gasoline paint) and *eucalyptus* binder at 10.89%. High moisture content in binders can slow down drying and affect the final formation, while moderate moisture in paints can help maintain flow and leveling during application. Low moisture content, as seen in the samples, reduces the risk of microbial growth and improves storage stability [13].

The physicochemical analysis of the binders highlighted significant contrasts between the EB and gasoline-derived binder. The pH values of both binders were slightly acidic (6.37 and 6.42, respectively), which is advantageous for storage stability as it minimizes premature chemical reactions. However, their densities differed, with EPS binder showing 0.82 g/ml compared to 0.78 g/ml for the gasoline binder, suggesting that EB produced a relatively denser film-forming matrix. This difference is important since density often correlates with film compactness and potential durability in coating applications.

Moisture and solid contents further differentiate the two binders. The EPS binder had a lower moisture content (10.89%) and moderately high solid content (17.52%), while the gasoline binder retained significantly more moisture (31.87%) but also exhibited higher solids

(22.86%). The high moisture level in Sample C raises concerns about reduced film stability, incomplete curing, and susceptibility to microbial attack, whereas Sample B's more balanced profile suggests a stable structure with fewer defects. The refractive index readings (78.7 for EPS vs. 75.8 for gasoline binder) support this, indicating better light interaction and potential optical uniformity in EPS formulations.

Viscosity and extended binder-specific properties also reinforced these findings. The EPS binder demonstrated higher viscosity (28 seconds at 24 cm) compared to the gasoline binder (15 seconds at 24 cm), implying superior film-forming ability and resistance to flow under gravity. Additionally, EPS exhibited better thermal stability, higher melting point, and lower water solubility compared to gasoline binder, aligning with reports that polystyrene-based systems resist degradation more effectively [14]. Overall, the results suggest that EPS-derived binder provides a more stable, durable, and environmentally favorable alternative to gasoline binder, making it particularly promising for sustainable paint formulations.

Table 2: Physicochemical analysis of Binders

Properties	*Eucalyptus* Binder	Gasoline Binder
Moisture Content %	35.72	31.87
Solid Content %	17.52	22.86
Refractive Index	78.7	75.8
pH	6.37	6.42
Viscosity @ 24 cm	28 seconds	15 seconds
Density(g/ml)	0.82	0.78
Melting point (^{o}C)	100	120-140
Turbidity (NTU)	120	80
Elongation at break	4%	8-12%
Water Solubility	0.05%	0.02%

Density measures the mass per unit volume of a material and affects coverage, opacity, and solids distribution. *Eucalyptus* paint had the highest density (1.81 g/ml), whereas gasoline paint is 1.71 g/ml. EB at 0.82 g/ml and gasoline binder at 0.78 g/ml was less dense. Higher density in paints suggests higher solid content and better surface coverage, while lower density in binders indicates a lighter, more flowable material that facilitates formulation adjustments [8].

Solid content indicates the proportion of non-volatile matter in the sample. Gasoline binder recorded the highest value (22.86%), followed by EB, 17.52%), Eucalyptus paint, 12.10%, and Gasoline paint, 10.98%. High solid content improves film thickness and opacity, while lower values in paints allow smoother application and leveling. The differences reflect the binder type and formulation strategies [15].

Characterization of the Paints

Table 3 shows the results of Physicochemical characterization of the paints.

Table 3: Physicochemical properties of Paints

Properties	Gasoline Paint (GP)	Eucalyptus Paint (EP)
pH	8.53±0.02	8.41±0.01
Moisture Content %	10.89±0.05	17.36±0.005
Density (g/ml)	1.71±0.01	1.81±0.03
Solid Content %	10.98±0.10	12.10±0.11
Refractive Index	0.3±0.1	0.1±0.05
Viscosity @ 15 cm	69±1 sec	31±2 sec

Refractive index measures how light bends through a material, influencing opacity and gloss. EB and GB had very high refractive indices (78.7 and 75.8), suggesting strong optical activity in the binder phase. In contrast, finished paints had extremely low values (0.3 and 0.1), likely due to dilution with solvents and pigment dispersion. High refractive index in binders may enhance light scattering, improving coverage in the final paint film [16].

Viscosity determines the flow resistance of a liquid, affecting application ease and leveling. Eucalyptus paint was the most viscous (31 sec at 20 cm flow distance), followed by EB, 28 sec at 24 cm), gasoline paint, 69 sec at 15 cm, and gasoline binder, 15 sec at 24 cm. Higher viscosity facilitates thicker film formation and reduces sagging, while lower viscosity improves spreadability but may produce thinner films [7].

Table 4 shows the paint performances.

Table 4: Paint performance properties

Properties	Gasoline Paint	Eucalyptus Paint
Adhesion test	Strong	Moderate
Resistance to blistering	Excellent	Good
Opacity test	Excellent	Moderate
Dry to touch time	25 mins	30 mins
Dry to hard time	120 mins	150 mins
Flexibility test	Good	Excellent
Tackiness	No Tackiness	Slight Tackiness
Stability	Excellent	Moderate

The melting point or Tg indicates thermal behavior and softening of the material. EB softened at ~100 °C, whereas GB softened at ~120–140 °C. Higher thermal resistance in gasoline binders allows better stability under heat, while lower Tg in EB makes it more brittle. These values influence drying behavior and the final film properties of paints [16]. Turbidity measures cloudiness or particle dispersion in a solution. Eucalyptus binder showed higher turbidity (~120 NTU) compared to Gasoline binder, 80 NTU), indicating more suspended particles in EPS suspensions. Finished paints were expected to have lower turbidity due to pigment incorporation and solvent dilution, improving optical clarity [17].

Elongation at break indicates flexibility, expressed as the percentage stretch before failure. Eucalyptus binder had low elongation (~4%), showing brittleness, whereas Gasoline binder exhibited better flexibility (~8–12%). Paints inherit these properties: Eucalyptus paint demonstrates better crack resistance, while Gasoline paint is moderately flexible [18]. Water solubility shows the ability of a material to absorb water, affecting blistering and durability. Eucalyptus binder absorbed slightly more water than Gasoline binder (~0.02%). Low water uptake in gasoline binders contributes to better moisture resistance, while slight water absorption in EPS can influence film porosity [19].

Adhesion determines how well a paint film bonds to a substrate. Gasoline Paint scored 4B, while Eucalyptus Paint scored slightly lower at 3B. Strong adhesion, as observed in GP, indicates durable performance and resistance to peeling under stress, whereas the moderate adhesion in EP suggests that the binder–pigment interaction was less effective. According to Obi et al. [20], higher adhesion ratings correlate with enhanced protective properties, particularly in metal substrates where detachment can accelerate corrosion.

Blistering resistance reflects a paint’s ability to withstand moisture penetration and vapor entrapment. Both paints performed well, with GP showing “No Blistering” and EP exhibiting “Few Blisters.” The superior result in Sample A suggests better film integrity and water repellence, which is typical of gasoline-based formulations. EP’s minor blistering indicates slightly higher water sensitivity, a characteristic reported in natural resin-based paints [21]. Opacity measures the covering ability of paint. Sample A achieved 95% opacity, while EP recorded 88%. A higher opacity means fewer coats are required to achieve uniform coverage, which improves efficiency in application. Gasoline-derived paints, often exhibit superior pigment dispersion, while natural-based paints like EP sometimes suffer from partial transparency due to irregular pigment–binder distribution [22]. Drying behavior is critical for usability and performance. GP reached dry-to-touch in 25 minutes and dry-to-hard in 120 minutes, while EP required 30 minutes and 150 minutes, respectively. Faster drying in Sample A reflects the volatility of gasoline solvents, which promotes quicker evaporation. The slightly delayed curing in EP is consistent with reports on eucalyptus-based resins, which retain moisture longer and thus slow down film formation [23].

Flexibility reflects the paint's ability to withstand deformation without cracking. GP passed a 3 mm mandrel bend, while EP passed a 5 mm bend, showing greater flexibility. Natural resins in EP likely contributed to a more elastic film, which is beneficial in applications where substrates undergo thermal expansion or mechanical stress. Comparable findings were reported by [24], where bio-based paints demonstrated higher elasticity compared to synthetic ones. Tackiness indicates residual stickiness after drying. GP was rated "non-tacky," while EP retained "Slight Tackiness." Non-tacky surfaces, as in Sample A, are advantageous for usability and resistance to dust accumulation. In contrast, the slight tackiness of EP may be due to incomplete curing or higher oil content in the eucalyptus binder, a behavior noted in other plant-based coatings [25]. Paint stability relates to resistance against phase separation, sedimentation, and viscosity changes during storage. GP remained stable after 30 days of observation, while EP showed "Minor Settling." The higher stability of Sample A suggests superior binder compatibility and solvent balance, while Sample D's settling is characteristic of natural-based paints, which may require frequent stirring before use [26].

Energy Dispersive X-ray Spectroscopy (EDS) Analysis

EDS data for GP show that carbon and oxygen dominate, representing the organic binder. Peaks for titanium (Ti), calcium (Ca), and silicon (Si) were also detected, consistent with TiO_2 pigment, calcium carbonate extender, and silica additives. Minor traces of iron (Fe) and zinc (Zn) suggest the use of colored pigments or metallic driers. Interestingly, stronger inorganic signals were found near cracks, confirming the SEM observation that binder tends to separate from pigment-rich regions.

This mixture of organic resin and inorganic fillers is typical of conventional solvent-based coatings. While such fillers improve whiteness, opacity, and hardness, they also reduce flexibility, which helps explain the brittle cracking seen in the microstructure [27,28].

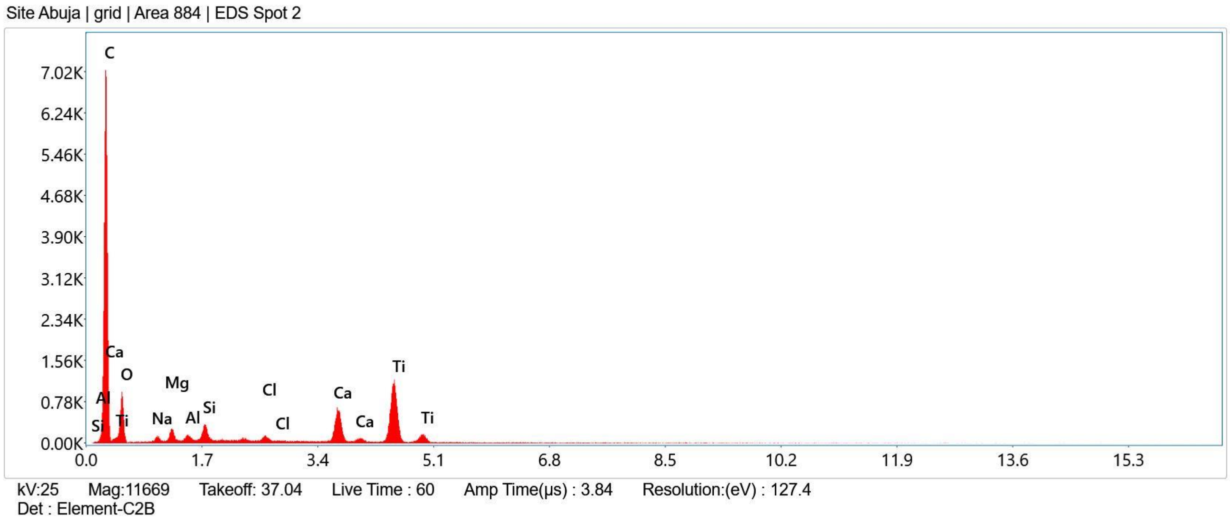

Figure 1: EDS analysis of Gasoline Paint

The EDS spectrum for EP shows that the binder is mainly composed of carbon (~95.5 wt%) and oxygen (~4.0 wt%), confirming its organic nature. Very small signals for Si, S, Cl, K, and Ca were also present, but their concentrations were close to the detection limit. These trace elements are most likely from additives, catalyst residues, or slight contamination during preparation and not from intentional fillers. Compared with conventional paint systems that contain a high number of inorganic pigments or extenders, this result matches expectations for a bio-derived resin [19,29].

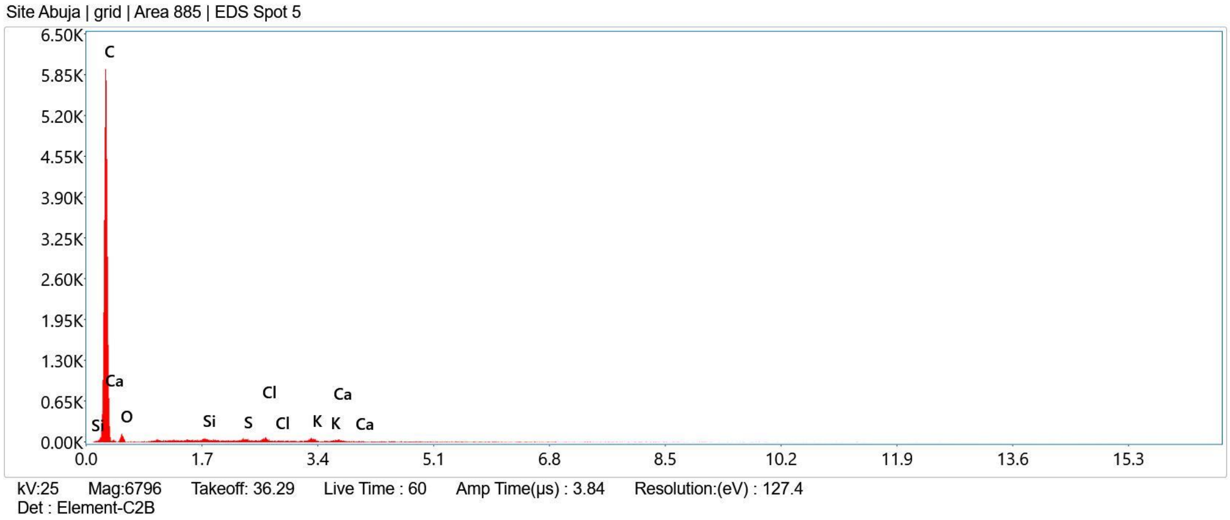

Figure 2: EDS Analysis of Eucalyptus Binder

The EDS spectrum for GB confirmed that carbon was the dominant element, accompanied by oxygen and very small traces of sulfur, chlorine, and silicon. These minor signals are probably linked to impurities, additives, or handling contamination rather than intentional formulation.

The absence of significant inorganic filler peaks supports the SEM finding a relatively smooth binder matrix. Overall, the composition reflects a solvent-processed hydrocarbon system, with film characteristics strongly dependent on binder coalescence and solvent loss [30, 31].

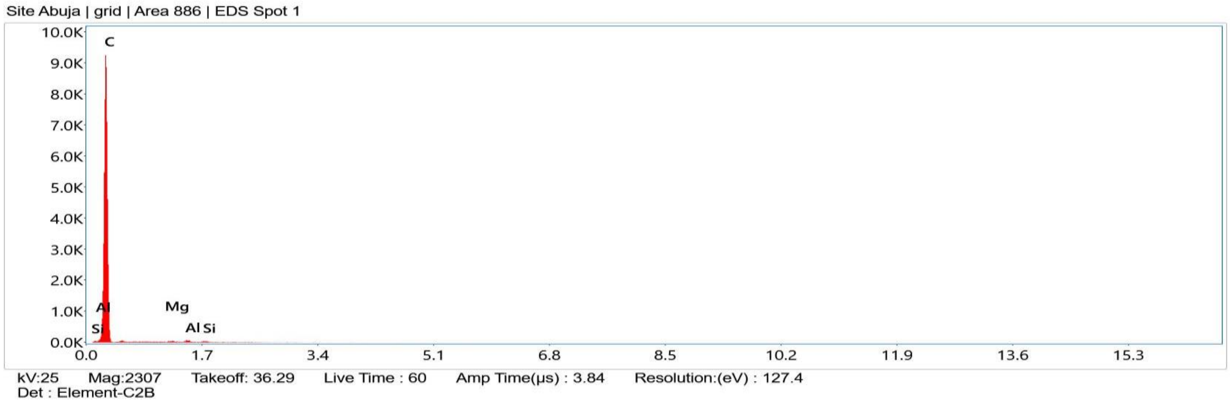

Figure 3: EDS Analysis of Gasoline Binder

The EDS spectrum for EP is dominated by carbon and oxygen, consistent with an organic binder derived from plant material. In contrast with the gasoline-based paint, fewer inorganic signals were detected, although small peaks for potassium (K), magnesium (Mg), and calcium (Ca) were observed, which likely come from natural residues in the eucalyptus resin. Minor amounts of silicon (Si) and titanium (Ti) were also present, suggesting that small amounts of fillers or pigments had been incorporated. The higher oxygen signal compared to GP reflects the oxygen-rich functional groups common in plant polymers, which can enhance adhesion but may also make the film more sensitive to moisture over time.

This elemental profile highlights the greener composition of the eucalyptus binder, with less reliance on inorganic fillers but a greater tendency toward chemical reactivity that may affect long-term stability [32,33].

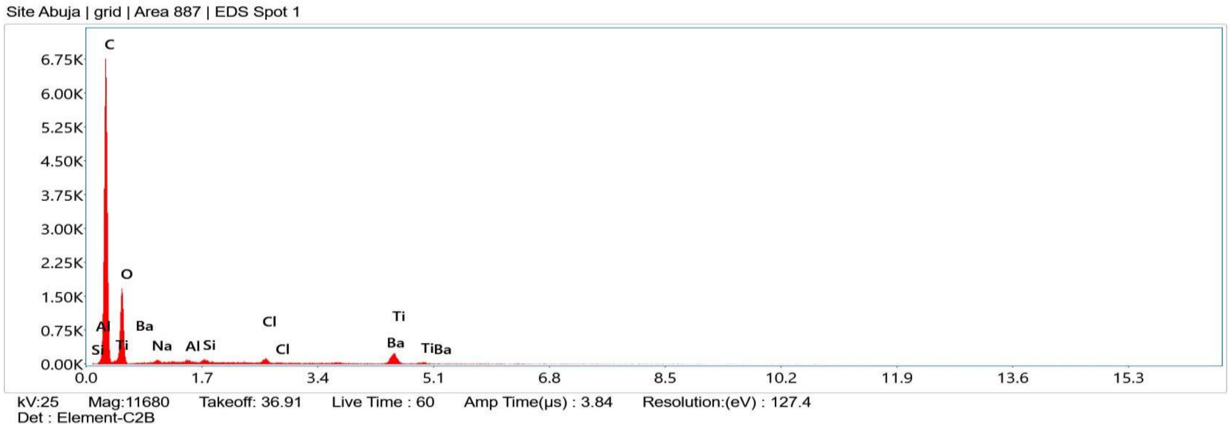

Figure 4: EDS Analysis of Eucalyptus Paint

Scanning Electron Microscopy (SEM) Analysis

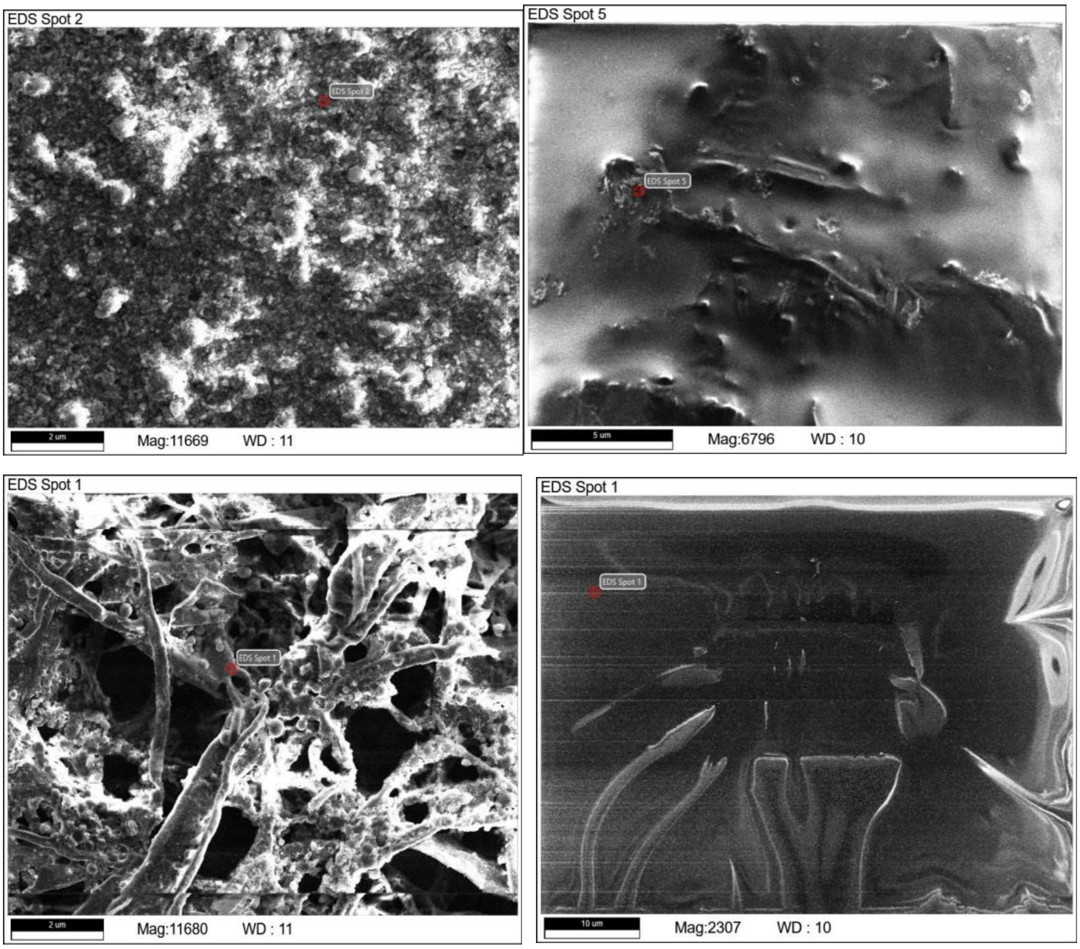

Figure 5: SEM Analysis of Samples A, B, D, and C, respectively

Gasoline Paint**:** At 11,669× magnification with a 2 µm scale, the surface appears uneven and granular, with clusters of bright particles embedded in a darker binder matrix. These brighter areas likely represent pigment or extender particles, consistent with paint formulations. The clustering of particles, with irregular shapes and variable sizes, suggests pigment agglomeration, possibly due to aging or incomplete dispersion during preparation. Such features can act as weak points under stress, increasing the likelihood of microcracks. While this distribution enhances opacity due to high-refractive-index pigments, voids around agglomerates may reduce the barrier performance of the film.

Eucalyptus Binder: At 6,796× magnification with a 5 µm scale, the eucalyptus binder shows a smooth, continuous film-like morphology with shallow pits and flow-like streaks. The absence of distinct particles indicates that the binder matrix is homogeneous and predominantly organic. The shallow depressions may result from solvent evaporation or entrapped volatiles during curing, which can serve as stress concentration points under thermal or mechanical loads. Overall, uniformity suggests effective film formation, though eliminating surface imperfections would further improve durability.

Gasoline Binder: At 2,307× magnification with a 10 µm scale, the gasoline binder surface appears smooth and film-like, with large flowing streaks and wave-like patterns across the micrograph. Unlike particulate-rich surfaces, the binder here forms a continuous layer without distinct pigment clusters, which is consistent with its role as a matrix material. The streaked appearance likely results from flow orientation during application or curing, while the few shallow depressions may be due to trapped air or solvent evaporation. The overall uniformity suggests that the binder can spread evenly to form a protective film.

Eucalyptus Paint: At 11,680× magnification with a 2 µm scale, the eucalyptus paint reveals a fibrous, porous microstructure interwoven with particulate clusters. EDS showed a composition dominated by carbon (≈75.81 wt%) and oxygen (≈22.92 wt%), with trace elements including Na, Si, Ti, and Ba

The fibrous nature is characteristic of lignocellulosic materials, while the particulates are likely pigments or additives. This structure enhances breathability and flexibility but may reduce barrier protection due to the presence of voids. When comparing all four samples, the differences between the gasoline-based and eucalyptus-derived materials become clear. The gasoline paint had a rough, grainy appearance with clusters of pigment particles within the binder, suggesting incomplete dispersion. While this improves opacity, it may create weak spots that encourage cracking. The gasoline binder, in contrast, formed a smooth, film-like surface with noticeable streaks and flow marks. EDS confirmed it was almost entirely carbon, which is typical of hydrocarbon binders. Its uniformity indicates strong coverage, though the streaks and shallow depressions may reduce durability under stress. The eucalyptus binder also produced a mostly continuous film with occasional shallow pits that likely came from solvent loss during curing. This shows good film formation overall, though refinement in processing could reduce surface flaws. Finally, the eucalyptus paint displayed a porous fibrous network with particles attached to the fibers, a structure consistent with lignocellulosic origins. EDS revealed high levels of carbon and oxygen with traces of inorganic elements, reflecting its natural composition combined with additives. Overall, the gasoline-based coatings produced smoother and more uniform films with stronger barrier potential, while the eucalyptus-based samples demonstrated eco-friendly features and fiber reinforcement but higher porosity, which may weaken their protective performance unless optimized.

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The FTIR spectrum of GP shows a broad absorption band at approximately 3329 cm^{-1}, which corresponds to O–H stretching vibrations, typically associated with alcohols, phenols, or absorbed moisture. This broad band suggests the presence of hydrogen-bonded hydroxyl groups within the paint matrix. A distinct peak is also observed at 1633 cm^{-1}, which is characteristic of C=C stretching in aromatic rings or possibly C=O stretching vibrations from carbonyl groups. These features are commonly linked with organic binder components in paint formulations, such as aromatic hydrocarbons or oxygen-containing additives.

In addition, the strong absorption in the region below 1200 cm^{-1} can be attributed to C–O stretching vibrations and bending modes of aliphatic C–H groups, confirming the predominance of organic functionalities in the gasoline paint. Such spectral patterns are consistent with petroleum-derived binders, where hydrocarbon backbones dominate, accompanied by minor oxygenated groups from additives or partial oxidation. The combination of hydroxyl, carbonyl/aromatic, and aliphatic peaks suggests that the gasoline paint contains a mixture of hydrocarbon chains and polar functional groups, which together influence its adhesion and film-forming properties. This aligns with recent studies where FTIR analysis has been used to identify functional groups in petroleum-based coatings and assess their aging or modification [34.35].

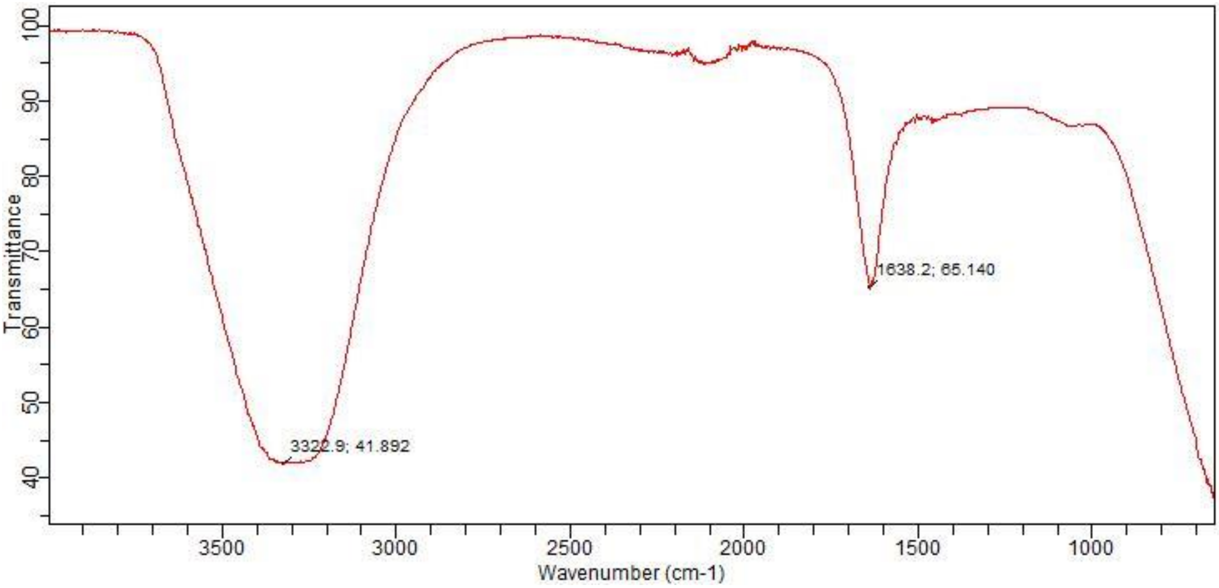

Figure 6: FTIR Analysis of Gasoline Paint

The FTIR spectrum of the eucalyptus binder shows several important peaks that confirm its organic nature. A broad absorption at 3516 cm^{-1} indicates the presence of hydroxyl (–OH) groups, which are common in bio-based resins. Peaks around 3082–3026 cm⁻¹ correspond to aromatic C–H stretching, indicating the presence of aromatic structures in the binder. The strong signals at 2924 cm⁻¹ and 2857 cm⁻¹ are assigned to aliphatic $–CH_2$ and $–CH_3$ stretching, which are typical of polymer backbones.

A strong absorption between 1740–1670 cm⁻¹ points to carbonyl (C=O) groups, likely from ester or carboxyl functionalities in the binder. Additional bands at 1600–1500 cm⁻¹ confirm aromatic ring vibrations, while the region near 1450–1375 cm⁻¹ is linked to bending of methyl and methylene groups. In the 1250–1050 cm⁻¹ range, clear peaks due to C–O stretching confirm the presence of esters or alcohol derivatives, which are typical for natural binders. Finally, peaks below 1000 cm⁻¹ correspond to out-of-plane aromatic C–H bending, further supporting the presence of aromatic structures Overall, the spectrum confirms that the eucalyptus binder contains a mixture of aliphatic chains, hydroxyl groups, aromatic structures, and carbonyl/ester functionalities, which is consistent with the chemical profile of bio-based resins.

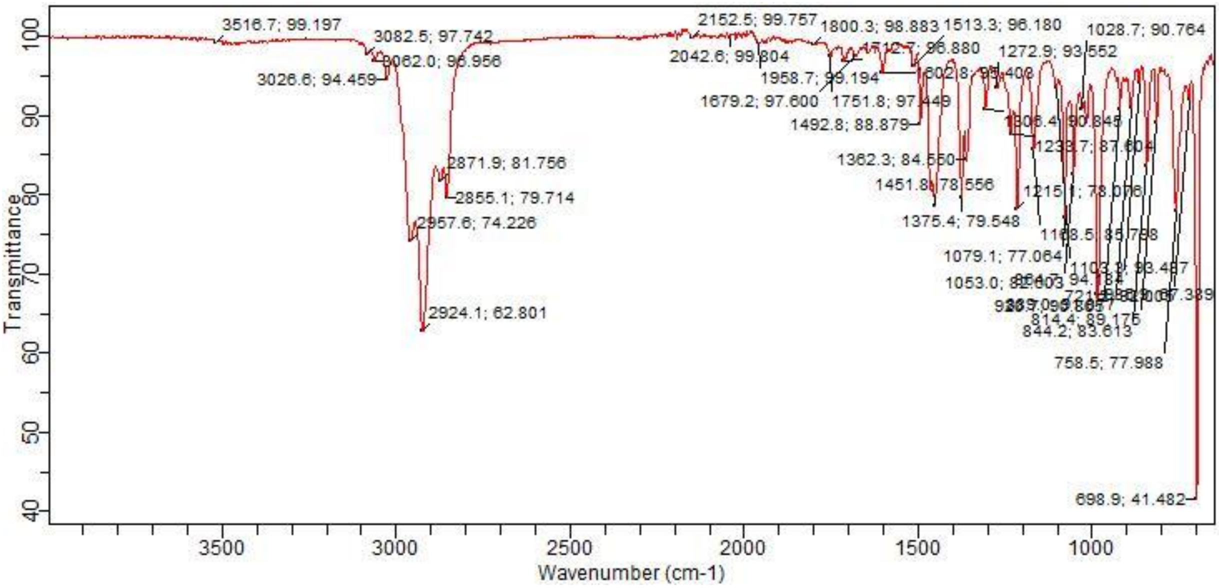

Figure 7: FTIR Analysis of Eucalyptus Binder

The FTIR spectrum for GB mainly shows features typical of hydrocarbon materials. The strongest signals appear in the 2950–2850 cm⁻¹ region, which correspond to C–H stretching from methyl and methylene groups, indicating the binder is dominated by aliphatic chains. There are only weak signals in the 2700–2200 cm⁻¹ region that could be from minor unsaturated species or simply spectral overtones — these are small and should be treated cautiously. Importantly, the spectrum lacks a clear peak around 1700 cm⁻¹, so there is no obvious evidence for carbonyl groups (esters, ketones, or carboxylic acids). That absence implies the binder is not rich in polar oxygenated functionalities and is instead largely non-polar/hydrocarbon in nature.

The fingerprint region (1200–700 cm⁻¹) shows several small bands, but nothing that strongly contradicts the interpretation of a mainly aliphatic resin. Taken together, the FTIR suggests Sample C behaves like a petroleum-derived or hydrocarbon resin binders a material that would be expected to give good hydrophobicity but may have limited sites for strong polar bonding to pigments or substrates unless chemically modified.

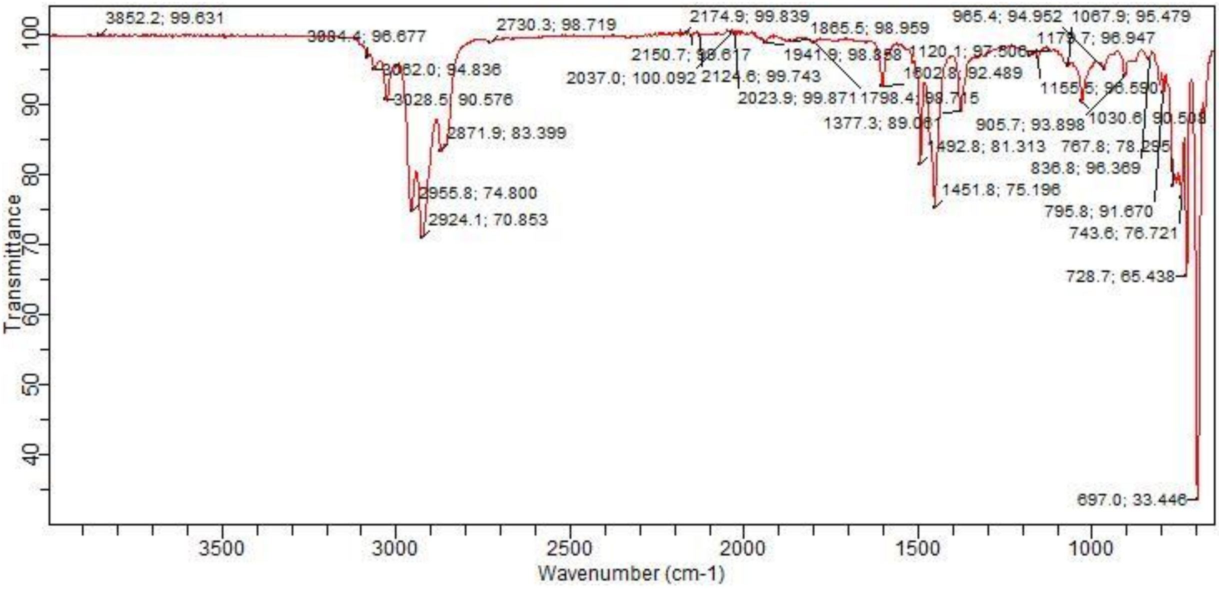

Figure 8: FTIR Analysis of Gasoline Binder

The FTIR spectrum of EP reveals a broad absorption band at approximately 3391 cm⁻¹, which is attributed to O–H stretching vibrations. This is characteristic of hydroxyl groups present in lignocellulosic materials such as cellulose, hemicellulose, and residual lignin from Eucalyptus globulus. Distinct peaks are also seen around 2922 cm⁻¹ and 2853 cm⁻¹, corresponding to C–H stretching vibrations of aliphatic $-CH_2$ and $-CH_3$ groups, confirming the organic backbone of the coating matrix.

A notable absorption near 1732 cm⁻¹ suggests the presence of C=O stretching vibrations, which are typically linked with carbonyl or ester groups in plant-derived polymers. Additional bands at 1603 cm⁻¹ and 1513 cm⁻¹ can be assigned to aromatic C=C stretching, further confirming contributions from lignin-derived structures. The region between 1237–1028 cm⁻¹ displays strong peaks related to C–O stretching vibrations in alcohols, ethers, and polysaccharides, highlighting the influence of cellulose and hemicellulose components. The presence of hydroxyl, carbonyl, and aromatic functionalities suggest that the eucalyptus paint is composed of a complex mixture of lignocellulosic compounds and additives. Such chemical features are consistent with plant-based coatings, where natural polymers contribute both to film formation and functionality. Similar spectral patterns have been reported in recent studies analyzing eucalyptus extracts and bio-based coatings, confirming the role of oxygenated functional groups in determining their performance [36,37].

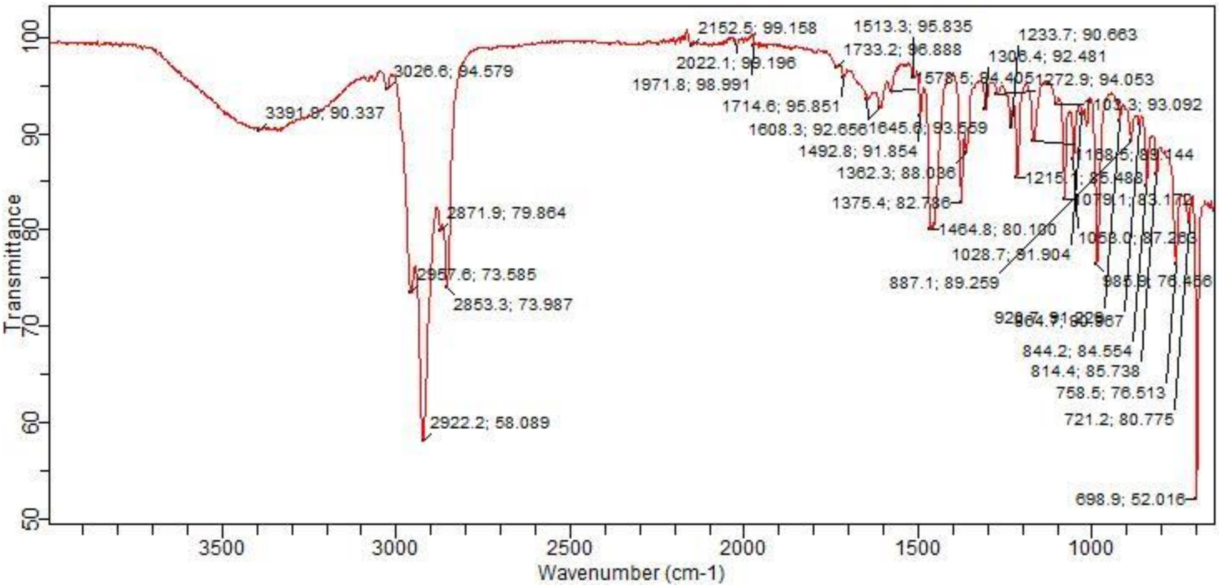

Figure 9: FTIR Analysis of Eucalyptus Paint

The physicochemical properties of the paints revealed that both formulations were alkaline, with pH values of 8.53 for the gasoline paint and 8.41 for the eucalyptus paint. Alkalinity in paints is advantageous as it enhances corrosion resistance on metallic substrates and reduces the risk of microbial growth in storage [8]. In terms of density, both paints exhibited high values (1.71 g/ml for GP and 1.81 g/ml for EP, which suggests compact film formation and potentially strong barrier properties. However, Sample D's slightly higher density indicates a more tightly packed matrix, which could contribute to better durability.

Differences became more apparent when comparing solid content, moisture content, and refractive index. Sample A showed lower solid content (10.98%) than EP (12.10%), suggesting that the eucalyptus paint contained more active material per volume and may form a thicker protective film. On the other hand, moisture content was higher in EP (17.36%) than in GP (10.89%), indicating that the eucalyptus-based system retained more water, which could slow curing or affect long-term stability. The refractive index values (0.3 for Sample A and 0.1 for EP) imply slight variations in optical clarity, though both fall within ranges that support adequate opacity when pigments are introduced.

Performance evaluations further distinguished the two formulations. The adhesion rating was slightly better in GP (4B) than in EP (3B), indicating that the gasoline paint formed a stronger bond with the substrate. However, eucalyptus paint outperformed gasoline paint in flexibility (5 mm vs. 3 mm mandrel bend), meaning it can withstand greater deformation without cracking—an advantage for substrates prone to expansion or movement. Resistance to blistering was excellent for GP, with no blistering observed, while EP showed few blisters, likely due to higher water sensitivity. Drying times were faster in Sample A, aided by volatile solvents, while EP required longer to cure. Despite these drawbacks, the eucalyptus paint offered notable eco-friendly benefits and demonstrated good performance across key parameters, showing promise as a sustainable alternative to gasoline-based systems [24,26].

The combined SEM, EDS, and FTIR analyses give a clear picture of the differences between the gasoline-based and eucalyptus-based coatings. In the gasoline paint, the micrograph revealed a grainy surface with clusters of pigment particles dispersed in the binder. Although this particle arrangement enhances opacity, the agglomeration indicates poor dispersion, which may create weak spots where cracks or moisture penetration could develop. By contrast, the gasoline binder appeared smooth and film-like, marked by flow streaks typical of petroleum-derived resins. The EDS spectrum confirmed its hydrocarbon nature, showing it to be almost entirely carbon. This uniformity points to strong film-forming ability, although the minor streaks and depressions could become points of weakness over time.

The eucalyptus-derived materials showed features that reflect their bio-based origin. The eucalyptus binder was mostly smooth but with occasional shallow pits, likely caused by volatile loss during curing. This suggests that while the binder spreads evenly, these imperfections might reduce its durability. The eucalyptus paint, however, displayed a fibrous and porous structure with particles attached to the fibers. The EDS analysis showed it was mainly composed of carbon and oxygen, with traces of other inorganic elements such as sodium, titanium, and barium. This is consistent with lignocellulosic coatings where natural fibers provide reinforcement, but the porosity could make the coating more permeable to water or other degrading agents.

The FTIR results supported these microstructural observations. The gasoline-based samples were dominated by hydrocarbon signals. GB showed strong C–H stretching along with minor O–H and aromatic features, suggesting small amounts of polar components. EB, on the other hand, lacked a carbonyl peak near 1700 cm^{-1} and showed strong aliphatic C–H bands, confirming its non-polar, hydrocarbon-rich nature. This explains why such binders are good at repelling water but interact poorly with pigments or substrates without chemical modification [34,35]. The eucalyptus-based samples presented more oxygenated functionalities. Sample B showed O–H, C=O, and C–O peaks linked to esters and alcohol derivatives, while Sample D showed O–H, aromatic C=C, and polysaccharide bands typical of cellulose, hemicellulose, and lignin. These oxygen-rich groups enhance adhesion but also increase water uptake, a pattern also observed in bio-based coatings reported in the literature [36,37].

When compared with earlier studies, the results fit within known trends. Gasoline-derived binders, such as GB, behave like other petroleum resins in forming continuous, hydrophobic films with strong aliphatic features and minimal oxygenated groups [34,35,38]. The pigment clustering in Sample A also matches reports of dispersion challenges in hydrocarbon-based paints, which researchers often address using dispersants or advanced milling methods [35]. On the other hand, the eucalyptus-based systems showed fibrous and porous morphologies along with oxygenated FTIR peaks, consistent with prior studies of eucalyptus-derived coatings. Similarly, literature reported porous fiber networks with abundant hydroxyl and carbonyl functionalities, which help with bonding but increase moisture sensitivity [36-38].

Overall, the present findings reinforce the trade-off widely noted in recent research: petroleum-based coatings offer smooth, hydrophobic films with good barrier properties, while eucalyptus-based coatings provide renewable and chemically versatile options, but need formulation improvements to reduce porosity and enhance water resistance.

CONCLUSION

This study shows that Styrofoam waste can be turned into useful paint binders, offering both environmental and practical benefits. The gasoline paint had a granular surface with pigment clusters, while the gasoline binder formed a smooth film mostly made up of hydrocarbons, which explains its good coverage and hydrophobicity. On the other hand, the eucalyptus binder and paint showed fibrous and porous structures rich in oxygenated groups, matching what other studies on bio-based coatings have reported. These natural features improve adhesion but also make the films more porous and less resistant to moisture. Overall, turning Styrofoam into binders supports green chemistry principles and helps achieve the Sustainable Development Goals (SDGs) by reducing plastic waste (SDG 12) and supporting climate-friendly practices (SDG 13). However, more work is needed to improve pigment dispersion in gasoline-based systems and to reduce porosity in eucalyptus-based coatings.

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