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Development of Waste Polystyrene as a binder for emulsion paint formulation II: Effect of different types of Solvent

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Abstract: *In our continuous desire to find suitable methods of recycling waste, expanded polystyrene waste was converted into a paint binder using different solvents (such as gasoline, toluene, xylene, CCl4 and chloroform). Some properties of the binder developed were investigated. Properties like refractive index, density, viscosity, turbidity, melting point, elongation at break and moisture uptake was found to vary from one solvent to another. The binder developed with gasoline, toluene, xylene and chloroform were found to be soluble in water, while the binder developed with CCl_4 was found to be insoluble in water. However, only binder developed with gasoline showed appreciable percentage elongation at break and projects waste polystyrene as a potential binder for emulsion paint formulation.*
Keywords: *waste expanded polystyrene, types of solvent, physical properties, emulsion paint.*

I. Introduction

Solid waste could be defined as non-liquid and non-gaseous products of human activities regarded as being unwanted or useless (Babayemi and Dauda, 2009). Nigeria and other developing countries have increased their populations, industrialization and urbanization which contribute to increasing solid waste generation. Also, in the recent decade industrialization, migration from rural areas, urbanization, uncontrolled consumption and growth were the causes of increasing the waste and consequently the rise of the waste management problems (Kalanatarifard and Yang, 2012). The management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life.

One important category of solid waste that has posed a great challenge to the society and the environment are plastic solid waste, which include predominantly, polystyrene packaging materials and polyethylene carry bags (both being polymeric materials). These wastes present challenges and opportunities to societies regardless of their sustainability awareness and technological advances (El-Salem et al, 2009). Our attention is however focused on polystyrene waste with specific reference to waste expanded polystyrene (EPS).

Waste expanded polystyrene (EPS), though a nuisance to the environment, if adequately managed can enrich the life of the populace. Various options do exist for managing EPS; out of which waste reduction, waste reuse and recycling are the preferred options. In the bid to recycle waste expanded polystyrene into a paint binder for emulsion paint formulation, finding the right solvent for its dissolution is of paramount importance.

Polymer dissolution in solvents is an important area of interest in polymer science and engineering because of its many applications in industry such as microlithology, membrane science, drug delivery and plastic recycling (Beth et al 2003). The dissolution of a polymer into a solvent involves two important processes, namely: solvent diffusion and chain disentanglement. Therefore, an understanding of the dissolution process allows for the optimization of design and processing conditions as well as selection of suitable solvent.

When an uncross-linked amorphous, glassy polymer is in contact with a thermodynamically compatible solvent, the solvent will diffuse into the polymer. Due to plasticization of the polymer by the solvent, a gel-like swollen layer is formed along with two separate interfaces, one between the glassy polymer and the gel and the other gel layer and the solvent. After some time – an induction time, the polymer dissolves. However, there also exist cases where a polymer cracks and no gel layer is formed (Beth et al, 2003). There are several factors that affect the dissolution of polymers, these factor include: the molecular weight of the polymer (Yasin and Ahmed, 2002), the chain chemistry, composition and stoichiometry, the type of penetrating solvent (Yasin and Ahmed, 2002), external parameters such as agitation, and temperature as well as radiation exposure, solubility parameter and vapour pressure (Paik et al, 2008). Solvents with a very high vapour pressure causes severe material change (Fuesers and Zumbuhl, 2008). Thus the physical properties of the solvent could be the determining factor, (Zumbuhl, 2008). It is also known that the degree of swelling, and hence the volume change is dependent on polymer chemistry, the crosslink density and the solvent quality, i.e the affinity between the solvent molecules and the polymer chains.

According to Supaphol et al (2005), the choice of solvent used is one of the main contributors influencing the solution properties such as viscosity, surface tension and conductivity. Thus, our intention here is to examine the effect of five solvents, namely: gasoline, toluene, xylene, carbon tetrachloride and chloroform on the physical properties of polystyrene solution for use as binder in emulsion paint formulation.

II. Materials And Methods

Materials

Waste expanded polystyrene (EPS) were collected around homes and dump sites in jalingo, gasoline was purchased from mai hanchi fuel station, toluene, xylene, CCl_4 and chloroform were reagent grade products from the British Drug House (BDH). EPS was used as collected and gasoline was used as purchased, while toluene, xylene, CCl4, and chloroform were used as received.

Binder preparation

Known fix weights of waste expanded polystyrene were converted into EPS binder solutions using known volumes of different solvents (gasoline, toluene, xylene, CCl_4, and chloroform).

Determination of viscosity

The method reported by Barminas and Osemeahon (2007) was adopted for the determination of viscosity of EPS binder. A 100ml Phywe made graduated glass microsyringe (Phywe, Gottengen, Germany) was utilized for the measurement. The apparatus was standardized with a 20% (w/v) sucrose solution whose viscosity is 2.0mPa.s at 30^oC. The viscosity of the EPS solution was evaluated with respect to that of the standard sucrose solution at 30^oC. Three different readings were taken for each sample and the average value calculated.

Determination of density, turbidity, melting point, and refractive index.

The properties above were determined according to standard methods (AOAC, 2000). The density of the different binders was determined by taking the weight of a known volume of binder inside a density bottle using metler Model AT400 (GmbH,Greifensee, Switzerland) weighing balance. Three readings were taken for each sample and the average value calculated.

The turbidity of the binders was determined by using Hanna microprocessor meter Model, H193703 (Villafranca Padovana, Italy). The melting point of the different films of samples was determined using Galenkamp melting point apparatus Model, MFB600-010F (Loughborough, UK). The refractive index of each sample was determined with Abbe refractometer (Bellinglam and Stanley, Tunbridge well kent, UK). Three readings were taken for each sample and the average value calculated for each of the parameters above.

Tensile test

Tensile property (elongation at break), was measured using instron testing machine (model 1026). The resin films of dimension 50mm long, 10mm wide and 0.15mm thick was brought to rapture at a clamp rate of 20mm/min and a full load of 20kg. Five runs were made for the sample and the average evaluated and expressed as percentage elongation.

Determination of moisture uptake

The moisture uptake of the resin film was determined gravimetrically. Known weights of the sample were introduced into desiccators containing a saturated solution of sodium chloride .The increase in weight (wet weight) of the sample was monitored until a constant weight was obtained. The difference between the wet weight and dry weight was then recorded as the moisture uptake by the resin. Triplicate determinations were made for each sample and the average value recorded.

Solubility

The solubility of EPS binder in water was obtained by mixing 1ml of the binder with 5ml of distilled water at room temperature (30^oC). The solubility was ascertained by physical observation (Osemeahon and Archibong, 2011).

III. Results And Discussion

Effect of Solvents on waste EPS

Of the five solvents investigated, all the five solvents were found to dissolve expanded polystyrene sufficiently well. Clear solutions of EPS in toluene, xylene, carbon tetrachloride and chloroform were obtained after stirring for 45 minutes while the mixture of EPS in gasoline took a day to become a homogeneous solution. Solvents with strong molecular interaction with polystyrene are good solvents for the polymer. The different properties of the solvents such as boiling point, molecular weight and molecular structure, has an influence on the properties of the polymer solution (Qian et al 2010). Solvents with a very high vapour pressure cause severe material change. The physical properties of solvent are also a determining factor (Zumbbuhl, 2008; Fuesers and Zumbuhl, 2008).

Table 1 shows some properties of the solvents used.

Solvent	MW(g/m)	T_b(°C)	P(g/cm^3)	n(cp)	V_p(mmHg)	d(mPa)$^{1/2}$	X
Gasoline	100-105	40-200	0.7-0.79	0.6		17.0	0.52
Toluene	92.14	110	0.82	0.52	8.7	18.35	0.34
Xylene	106	140	0.85	0.85	00	18.2	0.33
chloroform	119.38	61.20	1.47	0.51	43	19.03	0.35
CCl_4	153.82	76.8	1.57	0.84	30	17.58	0.38

Key: MW= molecular weight, T_b=boiling point, p= density, n= viscosity, V_p= vapour pressure, d= solubility parameter and X= chi parameter.
Source: Pattamaprom et al, 2006.

The chi parameter (X) for polystyrene solution produced from each solvent is carried according to the equation:

$X = (d_s - d_p)^2 \; M_s/RTP_S$ ------------ i (Qian et al, 2010)

Where S = solvent, P = polymer, d = solubility parameter, T = absolute temperature, Ms = solvent molecular weight, R = universal gas constant.

The chi parameter X shows the degree of solvent/ polymer compatibility. For values of X of less than 0.5, represents favourable solvents while values higher than 0.5 shows unfavourable polymer-solvent interactions and therefore the solvent is not able to dissolve the polymer (however, there are exceptions). And gasoline is one of such exceptions. It is also a critical theory that, the lower the value of X in a polymer solution system indicates the better solvent for the dissolved polymer (Qian et al, 2010).

All five solvents were able to adequately dissolve EPS because their solubility parameters were close (see table 1) to the solubility parameter of polystyrene (which is about 19.2), and each has a chi-parameter X of less than 0.5 (see table 1). However, carbon tetrachloride and chloroform cannot be used for the processing of EPS as binder for emulsion paint formulation. Reason being their high vapour pressure (see table 1) which can cause severe material change (Zumbuhl, 2008; fuesers and Zumbuhl, 2008) that could affect the film forming ability of the binder developed. For instance, films formed from chloroform gave a higher surface roughness due to high vapour pressure, this agrees with the work of Paik et al (2008).

Effect of Solvent on the density of EPS resin

Usually, the density of a paint resin has a profound influence on factors such as flow, leveling, sagging, pigment dispersion and brushability of paint (Osemeahon, 2011). From figure 1, the density of EPS/CCl4 and EPS/chloroform solutions are much higher than the density of EPS/gasoline, EPS/toluene and that of EPS/xylene solutions. This implies that the density of the solvent used has an effect on the density of resin formed. The observed effect of solvent on the density of resin formed is in agreement with previous studies (Zumbuhl, 2008; feusers and Zumbuhl, 2008 and Qian et al, 2010).

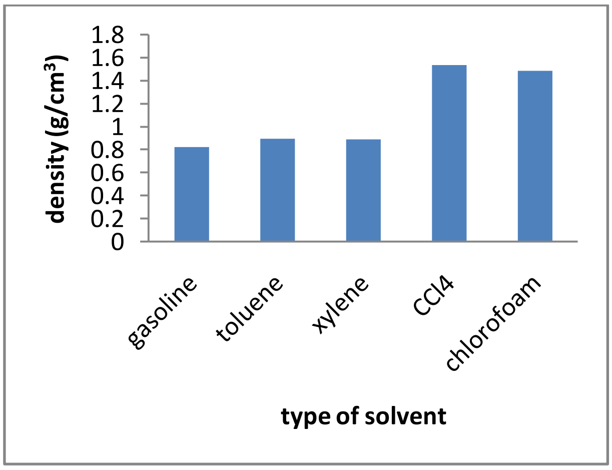


Figure 1: Effect of solvent on the density of EPS resin

Effect of solvent on the turbidity of EPS resin

Turbidity of a resin is an important property in the coating industry, because it relates to the gloss property of the resin. Figure 2, shows the effect of solvent on turbidity of EPS resins. The turbidity of the EPS/gasoline was observed to be much higher than those of ESP/toluene, EPS/xylene, EPS/ CCl4 and EPS/

chloroform. This might be as a result of the composition of gasoline. While other solvents used are made of single chemical substances, gasoline is a mixture of hydrocarbon. Thus the combined properties of each component in the mixture such as boiling point, molecular weight and molecular structure is a contributing factor (Qian et al, 2010). This could also be the reason that EPS/gasoline took a longer time to form a homogeneous solution.

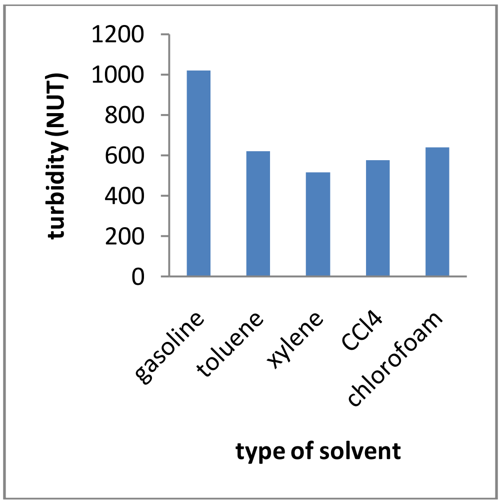


Figure 2: Effect of solvent on the turbidity of EPS resin

Effect of solvent on the refractive index of EPS resin

Typical binders of oil or acrylic (refractive index 1.4), tend to scatter maximum amount of light and posses excellent hiding power. Figure 3; show the refractive index profile on the effect of solvent on the refractive index of EPS resin. Observing the refractive indexes, it could be seen that the refractive index of EPS/gasoline and EPS/toluene falls within the right range and agrees with previous work (Hlaing & Oo,2012; Uthman, 2012). Thus gasoline and toluene could be considered as options when choosing solvents to convert EPS to paint binder for emulsion paint formulation.

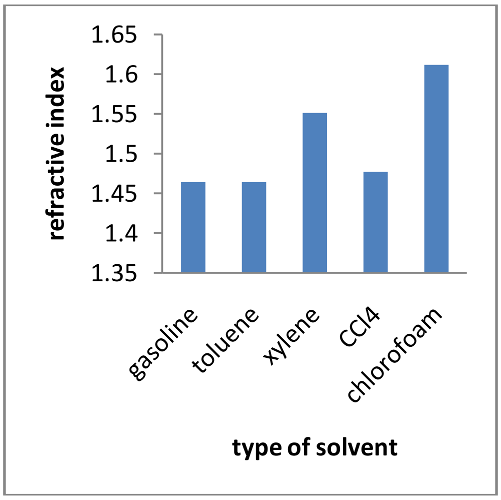
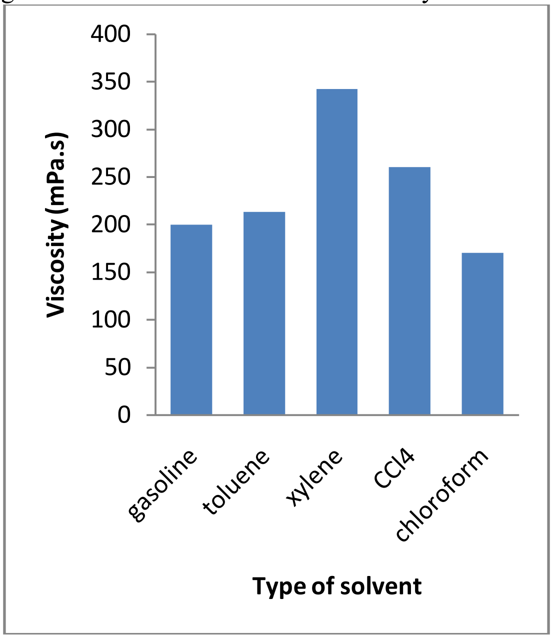


Figure 3: Effect of solvent on the refractive index of EPS resin

Effect of Solvent on the Viscosity of EPS resin

Viscosity is traditionally regarded as one of the most important material properties; the viscosity of the binder is also an important factor to the coating industry. This is because the viscosity of the binder controls many of the processing and application properties such as flow rate, leveling and sagging, thermal and mechanical properties, dry time of paint film and adhesion of the coating to the substrate (Osemeahon and Archibong, 2011). Figure 4; shows the effect of the solvent on the viscosity of EPS resins, clearly, the viscosity of the solvent does have an effect on the viscosity of the EPS solution. This is in agreement with the works of Zumbuhl (2008) and Feusers and Zumbuhl (2008).However, the viscosity of EPS with gasiline and toluene as the solvent agrees with the works of Hlaing et al (2012).

Figure 4: Effect of solvent on the viscosity of EPS resin



Effect of solvent on elongation at break of EPS resin

The mechanical properties of a resin system are used to compare formulations and determine the suitability for an application. Generally, paint resins need to be hard and rubbery. Figure 5; shows the effect of solvent on elongation at break of EPS resin. It was observed that the elongation at break for EPS/Toluene. EPS/Xylene, EPS/CCl4 and EPS/Chlorofoam were low; while that of EPS/Gasoline was relatively higher. This could be due to the elastic nature of EPS/Gasoline resin which enabled it to attain high strain level before breaking. For the other resins, due to their brittleness, they break at low strain. This implies that for preparing a paint binder from waste polystyrene, the solvent of choice should be gasoline.

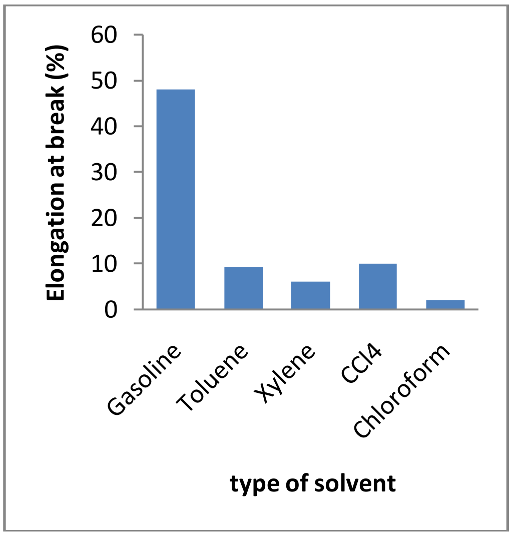


Figure 5: Effect of Solvent on Elongation at Break of EPS Films

Effect of solvent on moisture uptake of EPS resin

The permeability and water uptake of films affects its performance, because they can promote the film degradation and / or damage the substrate (Yuri et al, 2007). Water also deteriorates thermochemical properties and adhesion, it induces chemical degradation of the network and also generates stress because of swelling. Figure 6, shows the effect of solvent on water uptake of films. For all the films , it was observed that, the water uptake is minimal (less than 10%). This implies there will be little or no fear of film degradation, especially if the solvent used is gasoline.

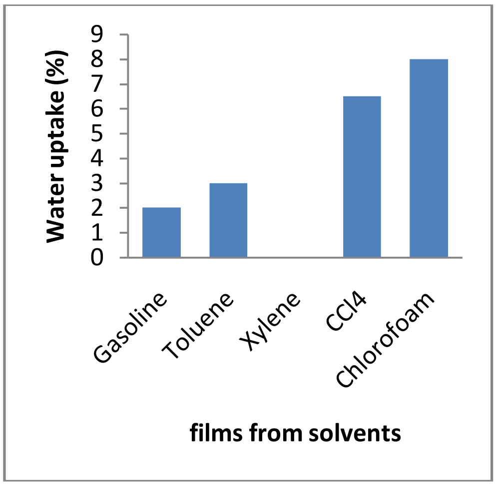


Figure 6: Effect of solvent on water uptake of EPS films

IV. Conclusion

The aim of this study was to investigate the potential of developing an emulsion paint binder from waste expanded polystyrene. The effect of different solvents on the physical properties of the EPS binder showed that, even though all the solvents could adequately dissolve waste EPS, the solvent that gives the EPS binder properties suitable for emulsion paint formulation is gasoline; because binder formed with gasoline as a solvent had properties comparable to the properties of other paint binders.

Table 3: Comparison of some physical properties of EPS resin with other paint resins

Type of Resin	Refractive index	Density (g/cm3)	Melting point (oC)	Viscosity (mPa.s)	Moisture uptake(%)	Elongation at break(%)	Literature
This study	1.454	0.82	164	200	2	48	Current study
Alkyd Resin and Palm oil Blend	ND	0.95	ND	5000	ND	ND	Itoua et al,2012
Low Refractive Index Polymer Cladding Resin	1.363	ND	ND	ND	ND	ND	Yoon et al, 2010
Alkyd Resin from Castor oil	1.474	ND	ND	4	ND	ND	Hlaing & Oo, 2012
Polyvinyl acetate from Vinyl acetate	1.40	1.25	ND	0.43	ND	ND	Uthman, 2012
Polymethyl Siloxane Toughened Epoxy Resins	ND	ND	ND	ND	ND	21.83	Whidad & Emad, 2009
Elastomeric Acrylic Resin	ND	ND	ND	ND	ND	68	Procopio et al, 2012
Polymethyl mathacrylate Resin	1.49	1.16	160	ND	ND	ND	Im et al, 2009

Polyvinyl Chloride Resin	ND	ND	ND	ND	ND	56	Unar et al, 2010
Polyesteamide Resin from Seed oil	ND	ND	0.95	ND	ND	ND	Stephen et al, 2012

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