

# Non-Linear Sorption Isotherm and Kinetic Studies of $Pb^{2+}$ on Poly(1-phenylethene-1,2-diyl) Waste Adsorbent

C. W. Dikio<sup>1</sup>, C. Y. Abasi<sup>2\*</sup>, O. Benson<sup>2\*</sup>, D. Wankasi<sup>2</sup>, E. D. Dikio<sup>2</sup>

<sup>1</sup>Applied Chemistry and Nano-science Laboratory, Department of Chemistry, Vaal University of Technology, P. O. Box X021 Vanderbijlpark 1900, South Africa

<sup>2</sup>Department of Chemical Sciences, Niger Delta University, Wilberforce Island, P.M.B. 071, Yenagoa Bayelsa State, Nigeria

\*Corresponding Author

**Abstract:** The sorption of  $Pb^{2+}$  on waste poly(1-phenylethene-1,2-diyl) adsorbent has been investigated. Batch equilibrium and kinetic adsorption experiments were done to determine the effects of concentration and contact time respectively. Data analysis was carried out using the non-linear isotherms and kinetic models. Non-linear isotherm parameters showed high consistency with those of the linear. The rate studies showed that the controlling kinetics was pseudo second order. Chi-squared ( $\chi^2$ ) statistics was also applied for the best fitting model between closely competing correlation values of Langmuir and Freundlich models. Chi-squared ( $\chi^2$ ) statistics showed that Freundlich model described the sorption better than the Langmuir isotherm. The prevalence of Freundlich over Langmuir from correlation and validity tests indicated a multilayer adsorption. Diffusion analysis showed that intraparticle diffusion was not the prevailing mechanism for the adsorption.

**Keywords:** Sorption, non-linear, poly(1-phenylethene-1,2-dial), adsorbent, isotherm, polymer, physisorption.

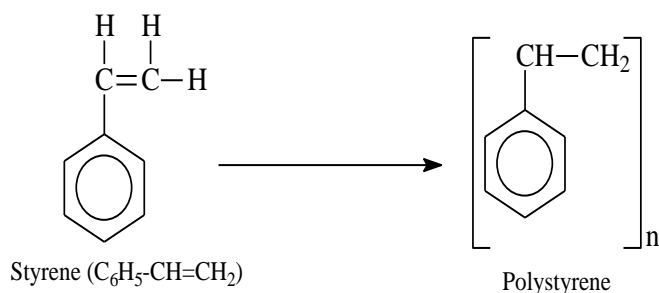
## I. INTRODUCTION

The increasing diversification in industrialization and urbanisation has contributed to the existence of heavy metals such as lead (Pb) in the aqueous environment, with a noticeable threat to living organisms (animals, humans and plants) as a result of their bio-accumulating propensities and toxicity[1]. Some specific sources of  $Pb^{2+}$  in our environment include automobiles, batteries, paints, textile and petroleum industries, etc. [2],[3]. The elimination of these toxic heavy metals from urban and industrial wastes prior to their summary release into the environment has therefore, become essential.

Conventional heavy metal removal techniques such as reverse osmosis, filtration, precipitation, flocculation and ion exchange are very expensive. However, there have been cheaper and more renewable materials used to remove metal ions from wastes. These include biomasses like Seaweed [1], *Medicago sativa* [2], *Manihot esculenta Crantz* [3] and *Nipa palm*[4].

Information on the usage of poly(1-phenylethene-1,2-diyl) waste as adsorbent for removing metals from aqueous solutions is rare, which has brought about this research work.

Poly(1-phenylethene-1,2-diyl), otherwise called thermocol or polystyrene, is a polymeric compound of styrene (Scheme 1).



Scheme 1: Synthesis of polystyrene from the monomer

Poly (1-phenylethene-1, 2-diyl) is a commonly used plastics material, the scale of worldwide use being estimated to be several billion kilograms per year. Uses of polystyrene are in CD and DVD cases, disposable cutleries, smoke detector casings and plastic models. This polymer is also used as insulators and Styrofoam cups [5]. Poly (1-phenylethene-1, 2-diyl) is an abundant pollutant in the environment, often seen along shores and waterways in the low-density cellular form. Some studies have been done on using polystyrene for eliminating iron from wastewater[6], cadmium ion from aqueous solution, and removal of phenolic compounds[7].

A comparative study of poly (1-phenylethene-1, 2-diyl) and poly (methyl 2-methylpropenoate) has been reported[8]. The characterisation with XRD, FTIR, EDX, and SEM was considered for the poly (1-phenylethene-1, 2-diyl) and compared with the poly (methyl 2-methylpropenoate). In addition, the equilibrium and kinetics parameters of lead (II) ions sorption from aqueous solutions using both adsorbents were also reported[8]. However, the isotherms and kinetic analyses considered were linear plots of the experimental data. Herein, we present the non-linear isotherm and kinetic results of the sorption of  $Pb^{2+}$  on waste poly (1-phenylethene-1, 2-diyl) adsorbent, to establish the validity of the linear models.

II. MATERIALS AND METHODS

2.1 Sample preparation

The poly(1-phenylethene-1,2-diyl) waste materials were obtained from waste bins and oven-dried at 30 °C after thorough washing with demineralized water. After grinding, the adsorbent samples were passed through a Wiley mill with 100-mesh screens. The screened particles were rinsed repeatedly with 0.01 M HCl, to get rid of metal contaminants or other debris possibly present in the adsorbent sample before experimental exposure to lead ions. The acid-washed poly(1-phenylethene-1,2-diyl) waste particles were again washed two times with demineralized water to eliminate any acid residue and dried at 30 °C to stable mass.

2.3 Characterization of the polymer sample

The surface features of the poly (1-phenylethene-1, 2-diyl) sample were analysed by FTIR, XRD, EDX and FE-SEM. Infrared spectra (FTIR) were collected with the Perkin-Elmer spectrum 400FTIR/FT-NIR spectrometer in the 400 – 4000 cm<sup>-1</sup> range. The Powder X-ray diffraction (PXRD) patterns were obtained using a Bruker AXSD8 diffractometer operated at 45 kV and 40 mA with monochromatic copper Kα1 radiation wavelength (λ=1.540598) and Kα2 radiation wavelength (λ=1.544426). The surface measurements (SEM and EDX) were determined using a JEOL 7500F Field Emission scanning electron microscope.

2.4 Batch adsorption experiments

2.4.1 Concentration Effect: To determine the effect of concentration, six working solutions of Pb<sup>2+</sup> in the concentration range of 21.8 to 141.5 mg/L as reported[8] were made. The measured working solutions of Pb<sup>2+</sup> (10 mL) were introduced to each test-tube holding 0.2 g of the adsorbent sample and agitated for 1-hour at 29 °C. The adsorbent suspensions were separated by centrifuge for 5 minutes at 2500 rpm and the supernatants collected for metal ion determination.

2.4.2 Time-Dependent Studies: A specific mass of 0.2 g of the adsorbent was put into five clean test-tubes to which 10 mL of standard concentration of Pb<sup>2+</sup> (72.3 mg/L) was added. Each test tube holding the adsorbent-adsorbate mixture was agitated at durations of 5, 10, 20, 40 and 60 minutes respectively at 29 °C and separated by centrifuge for 5 minutes at 2500 rpm as in [8]. The supernatants were collected for metal ion determination.

2.4.3 Metal Analysis: The amounts of lead (Pb) in the supernatants were analysed by Atomic Absorption Spectrophotometry as in [8].

2.4.4 Data Analysis

Different equilibrium isotherms and kinetic models were used to evaluate the data and determine the surface coverage of the adsorbate. The concentration of Pb<sup>2+</sup> adsorbed was calculated using equation 1, [1].

$$q_e = \frac{V}{M}(C_o - C_e) \tag{1}$$

where  $q_e$  is amount of metal adsorbed ( $mg/g$  adsorbent),  $C_e$  is the residual metal ion concentration in solution ( $mg/L$ ),  $C_o$ , is the initial metal ion concentration ( $mg/L$ ),  $V$ , the volume of solution in litres (L) and  $M$ , the dry mass of the adsorbent used ( $g$ ).

Plots for Langmuir isotherms were obtained using equation 2.

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \tag{2}$$

with  $q_e$  as the quantity of Pb<sup>2+</sup> adsorbed in  $mg/g$  of adsorbent,  $K_L$  is the Langmuir equilibrium constant and  $q_m$  is the maximum adsorption capacity. The separation factor  $R_L$ , for the Langmuir adsorption isotherm was calculated using equation 3.

$$R_L = \frac{1}{(1 + K_L C_o)} \tag{3}$$

Where  $C_o$  is the initial Pb<sup>2+</sup> concentration in solution (mg/L), and  $K_L$  is the Langmuir adsorption constant. [9] The magnitude of  $R_L$  indicates the nature of adsorption isotherm; when  $R_L > 1$ , the isotherm is unfavourable; when  $R_L = 1$ , it is linear; when  $0 < R_L < 1$ , it is favourable and when  $R_L = 0$ , it is irreversible.

The information on the heterogeneity of the adsorbent surface and physisorption was obtained using the Freundlich isotherm in equation 4.

$$q_e = K_F C_e^{1/n} \tag{4}$$

with  $K_F$  as the Freundlich isotherm constant,  $n$  as the adsorption intensity factor and  $C_e$  as the equilibrium concentration (mg/L).

The correlation of the heat of adsorption with the surface coverage of the Pb<sup>2+</sup> on the adsorbent was calculated from the Temkin isotherm from equation 5.

$$q_e = \frac{RT}{b_T} \ln (K_T C_e) \tag{5}$$

with  $K_T$  as the Temkin isotherm constant ( $dm^3/g$ ) and  $b_T$  as the adsorption potential of the adsorbent (J/mol).

The surface coverage of the Pb<sup>2+</sup> on the adsorbent was calculated from equation 6.

$$\theta = 1 - \frac{C_e}{C_o} \tag{6}$$

Where  $\theta$  is the degree of surface coverage

The major adsorption type (that is, monolayer and multilayer adsorption) was evaluated using Sip’s and Redlich-Peterson models in equations 7 and 8 respectively.

$$q_e = \frac{Q_s K_s C_e^{n_s}}{1 + K_s C_e^{n_s}} \tag{7}$$

$$q_e = \frac{k_{RP} C_e}{1 + a_{RP} C_e^g} \tag{8}$$

where  $Q_s$  is the maximum adsorption parameter (mg/g),  $K_s$  is Sips isotherm model constant (L/g) and  $n_s$  is Sips isotherm affinity exponent for homogeneity of the adsorbate-adsorbent system.

with  $K_{RP}$  as Redlich-Peterson isotherm constant (L/g),  $a_{RP}$  as constant (L/mg),  $g$  as Redlich-Peterson exponent,  $C_e$  as the residual concentration of the adsorbate (mg/L), and  $q_e$  as equilibrium adsorbate concentration (mg/g).

### III. RESULTS AND DISCUSSION

#### 3.1 Characterization studies

The characterisation of the polystyrene waste adsorbent has been reported and the characterisation results charts[8] are given in figures 1 to 4. The report identified the presence of C-H stretching vibration corresponding to the aromatic ring of the molecule, C-H symmetric and asymmetric stretching vibrations of  $CH_2$  of the ethylene group, C-C and C-H stretching vibration of the aromatic ring in the plane as the sharp peaks at  $3028\text{ cm}^{-1}$ ,  $2926\text{ cm}^{-1}$ ,  $2856\text{ cm}^{-1}$ ,  $1603\text{ cm}^{-1}$ ,  $1494\text{ cm}^{-1}$  and  $1453\text{ cm}^{-1}$ . Fingerprint bands (Fig. 1) were attributed to C-H, C=C vibrations. The observed higher peaks in the fingerprint regions at  $1603\text{ cm}^{-1}$ ,  $1494\text{ cm}^{-1}$  and  $1453\text{ cm}^{-1}$  were ascribed to the incorporation of the styrene unit[11],[12],[13],[14]. XRD report (Fig. 2) indicated amorphous and semi-crystalline phases of the polystyrene[10]. EDX analysis (Fig. 3) confirmed the presence of C, Al and Ag in addition to hydrogen. The metals Al and Ag might be present as impurities since the pure polymer is organic. SEM micrographs (Fig. 4) revealed a surface with irregular small size particles, indicating a sample of porous nature with a high surface area[15]. Large surface areas in adsorbents facilitate maximum adsorption.

#### 3.2 Equilibrium sorption studies

Percentage sorption of  $Pb^{2+}$  by the poly (1-phenylethene-1, 2-diyl) waste adsorbent at various amounts of the  $Pb^{2+}$  is shown in Fig. 5. The highest percent adsorption of 73.10% occurred when the amount of  $Pb^{2+}$  was 72.3 mg/L. This could be due to more adsorbent pore spaces available to the  $Pb^{2+}$  at lower metal ion concentration. However, the amount adsorbed by the adsorbent decreased as the concentration of  $Pb^{2+}$  increased, by reason of fewer number of vacant adsorption sites. This observation infers that  $Pb^{2+}$  sorption was concentration-dependent.

Sorption capacity at the adsorbent surface was assessed using isotherms such as Langmuir, Freundlich and Temkin. The adsorption data obtained were subsequently fitted into the afore mentioned isotherms. The linear sorption parameters of plots of Langmuir, Freundlich and Temkin isotherm models for the adsorption of  $Pb^{2+}$  by the adsorbent have been reported and confirmed their application to the data[8]. Slopes and intercepts were used to determine the isotherm parameters (Table 1). The linear plots all gave coefficients of determination ( $R^2$ ) of more than 0.9, with that of the Langmuir approaching unity. The linear correlation coefficient,  $R^2$  of 0.999 for the Langmuir isotherm indicated a monolayer formation; which implies that

chemisorption also occurred alongside the physisorption. From the linear Langmuir plot, the sorption capacity of the adsorbent was determined to be 90.09 mg/g.

The  $R^2$  value of 0.9958 for the Freundlich isotherm also indicated the existence of heterogeneous surfaces due to multilayers arising from physisorption processes. The magnitude of the linear adsorption intensity parameter,  $n$ , for the Freundlich isotherm is 1.0155 (Table 1), indicating positive adsorption[16],[17]. When  $n$  is in the range of 1 and 10, the value indicates a positive adsorption. The intensity factor,  $n$ , in this study is within range, therefore, the adsorbent is applicable.

Table 1: Linear isotherm parameters of  $Pb^{2+}$  sorption by poly(1-phenylethene-1,2-diyl) waste sample

Isotherm	Parameter		
Langmuir	$q_{max}$ (mg/g)	$K_L$ (L/g)	$R^2$
	90.09	0.00147	0.999
Freundlich	$K_F$ (mg/g)	$N$	$R^2$
	0.1526	1.0155	0.9958
Temkin	$B$	$K_T$	$R^2$
	2.328	0.1959	0.9381

The validity of the linear isotherm parameters was tested using the non-linear equations of the isotherms. The values of the non-linear isotherm parameters showed high consistency with the linear values (Table 2); for instance, the linear and non-linear parameters for the Temkin isotherm are almost the same.

Table 2: Non-linear isotherm parameters of  $Pb^{2+}$  sorption by poly(1-phenylethene-1,2-diyl) waste sample

Isotherm	Parameter			
Langmuir	$q_{max}$ (mg/g)	$K_L$ (L/g)	$\chi^2$	$R^2$
	69.3954	0.0021	0.04592	0.9919
Freundlich	$K_F$ (mg/g)	$n$	$\chi^2$	$R^2$
	0.1526	1.0344	0.03843	0.9912
Temkin	$B$	$k_T$ (J/mol)	$R^2$	
	2.3289	0.1960	0.9381	
Redlich-Peterson	$K_{RP}$	$a_{RP}$	$G$	$R^2$
	-0.8911	1.0437	0.9954	0.9913
Sip's	$Q_s$	$K_s$	$n_s$	$R^2$
	0.7054	0.0895	0.9667	0.9912

Redlich-Peterson and Sip's models were applied to ascertain the best fitting isotherm between the Langmuir and the Freundlich models using Equations 9 and 10 respectively. Table 2 shows the non-linear parameters obtained from the afore mentioned equations. The plots of their relationship are shown in Fig. 6. Redlich-Peterson equation translates to Langmuir equation when  $g = 1$  only but is Freundlich when  $g = 1$  and  $a_{RP}C_e \gg 1$ . From the value in the table, the product,  $a_{RP}C_e$  far exceeds 1 for each of the residual adsorbate

concentrations, hence it is deduced that the Freundlich adsorption isotherm fits better, which indicates that physisorption predominates. From the Sip's isotherm, the equation tends to Langmuir when  $n_s = 1$  and is Freundlich when  $k_s$  slants towards zero. With the  $k_s$  value of 0.0895 and  $n_s$  value of 0.9667 ( $< 1$ ), the Sip's equation also reduces to the Freundlich confirming physisorption as the dominant process. A prevalence validity test between the Langmuir and Freundlich models was done using chi-squared ( $\chi^2$ ) test [18]. Comparatively, the Freundlich model was observed to have a lower value than the Langmuir, making it a better model for the adsorption. The prevalence of the Freundlich model indicates that physisorption was prevalent.

The surface coverage of  $Pb^{2+}$  on the polymer is 0.73 as shown in Table 3. This value indicates a high degree of adsorption, as 73% of the pore spaces of the poly (1-phenylethene-1, 2-diyl) surface were covered by the  $Pb^{2+}$ .

Table 3: Equilibrium parameters of  $Pb^{2+}$  sorption by polymer sample.

Surface coverage $\theta$	Separation factor $S_f$	Sorption coefficient $K_d$	Adsorption capacity mg/g
0.730	0.678	0.374	69.3954

To determine whether the sorption is positive or negative, the separation term  $S_f$  was applied to the data using equation 3. The separation factor ( $S_f=0.678$ ) shown in Table 3 lies between 0 and 1, which indicated that the sorption of  $Pb^{2+}$  onto the poly (1-phenylethene-1, 2-diyl) was favourable.

The effectiveness of the poly (1-phenylethene-1, 2-diyl) for  $Pb^{2+}$  removal from bulk solution was evaluated from the partition coefficient,  $K_d$  as given in Table 3. The value of  $K_d(0.374)$  is indicative of the polymer as a good adsorbent with a few cycles of sorption application for  $Pb^{2+}$  in solution.

### 3.3 Adsorption kinetics and diffusion

The variation of time dependent removal of  $Pb^{2+}$  is shown in Fig. 7. A saturation concentration of 75% of  $Pb^{2+}$  was removed in 10 minutes and remained constant afterwards [19]. The reasonably short contact time for equilibrium indicates fast adsorption for  $Pb^{2+}$  by the adsorbent. However, the saturation of pore spaces after equilibrium made further adsorption difficult.

The adsorption rate of the metal ions on the adsorbent was estimated using the non-linear pseudo-first-order and the pseudo-second order models using equations 9 and 10 respectively.

$$q_t = q_e(1 - e^{-k_1 t}) \quad (9)$$

$$q_e = \frac{q_e^2 k_2 t}{1 + k_2 q_e t} \quad (10)$$

The plots of  $q_t$  against  $t$  for the afore mentioned equations are given in Fig. 8. The plot for the pseudo-second-order model correlated well with that the experimental data. This implies

that the prevalent kinetic mechanism was the pseudo-second order rate model. The non-linear pseudo-first order and pseudo-second order kinetic parameters are given in Table 4. The rate-limiting mechanism was determined using Weber-Morris intraparticle diffusion model [20] given by equation 11.

$$q_t = k_{id} t^{0.5} \quad (11)$$

With  $q_t$  as the quantity adsorbed at time  $t$ ,  $k_{id}$  as the intraparticle diffusion constant, and  $t$  as the time in minutes. When intraparticle diffusion is the prevalent mechanism, the line of the plot is straight and the intercept is zero [21]. The plot as presented in Fig. 9 shows that, there are many stages of the line, therefore, Weber-Morris intraparticle diffusion is not the controlling rate model for the adsorption. Though the initial stage has a straight line that indicates intraparticle diffusion, the multiple stages indicate that other forms of diffusion are present in the process [22]. The parameters are also given in Table 4.

Table 4: Kinetic and Diffusion parameters of  $Pb^{2+}$  sorption by polymer sample

Type	Parameter	Value
Pseudo -first order	$q_e$ (mg/g)	2.7494
	$K_1$	0.5842
	$R^2$	0.8087
	$\chi^2$	0.001404
Pseudo -second order	$q_e$ (mg/g)	2.7934
	$K_2$	0.9939
	$R^2$	0.9819
	$\chi^2$	0.0001135
Intraparticle diffusion	$K_{id}$	2.9164
	$R^2$	0.0471

## IV. CONCLUSION

The studies carried out recorded an initial rapid uptake of  $Pb^{2+}$  by the poly-(1-phenylethene-1,2-diyl) waste adsorbent which could be explained as diffusion controlled. Applying non-linear models for both the equilibrium and kinetic studies showed a high consistency with those of the linear parameters. The predominant adsorption process from the models applied, was indicated as physisorption mechanism. The kinetic and diffusion studies revealed that the controlling kinetics was pseudo-second order and no controlling diffusion respectively. The polymer is, therefore, an effective adsorbent with a high degree of efficiency for the elimination of  $Pb^{2+}$  from aqueous solutions. The results obtained from this study provide useful data for the application of poly-(1-phenylethene-1,2-diyl) as a possible filtration technology material, which is environmentally friendly and effective for eliminating and recovering heavy metals from aqueous media. This material can be used as a cheaper alternative, to replace most of the conventional and high cost treatment methods presently in use.

## ACKNOWLEDGEMENT

This work was supported by a research grant from the Research Directorate of the Vaal University of Technology, Vanderbijlpark, South Africa.

## Disclosure Statement

The authors have no conflict of interest

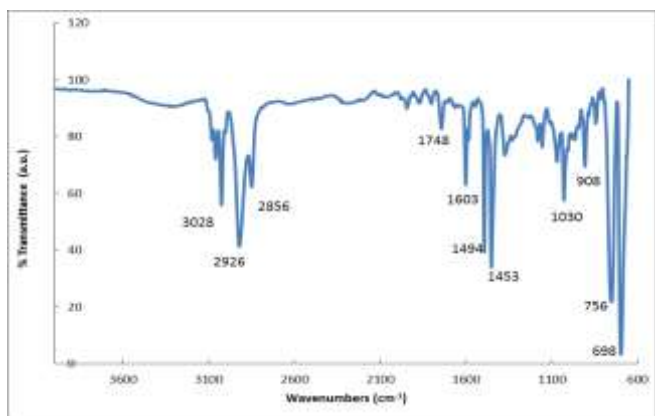


Fig. 1: Fourier Transform Infrared (FTIR) Spectrum of the polymer sample.

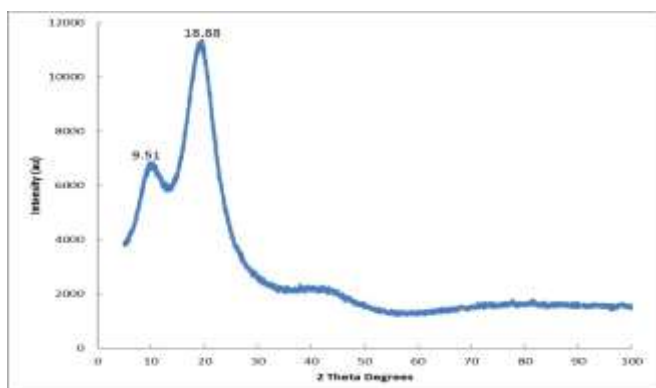


Fig. 2: X-ray diffractogram (XRD) of the polymer sample.

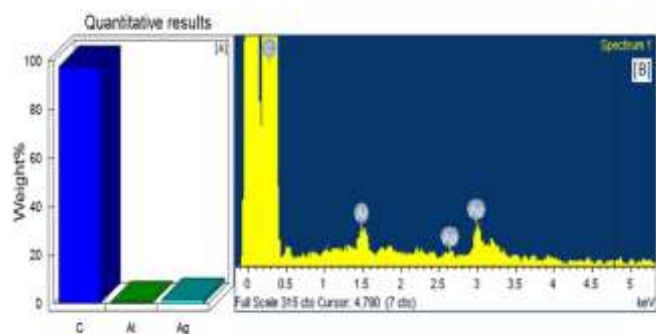


Fig. 3: Energy Dispersive X-ray (EDX) of polymer sample (a) quantitative result and (b) spectrum.

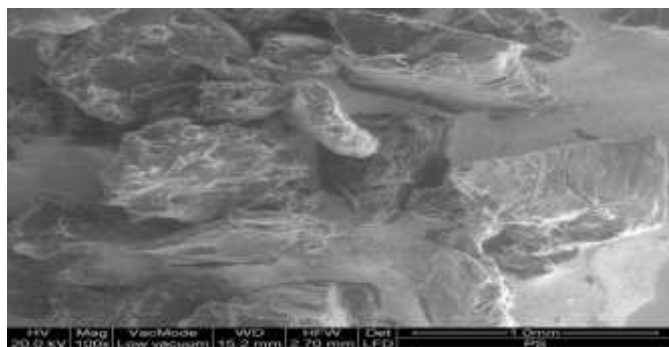


Fig. 4: Scanning Electron Microscope (SEM) image of the polymer sample.

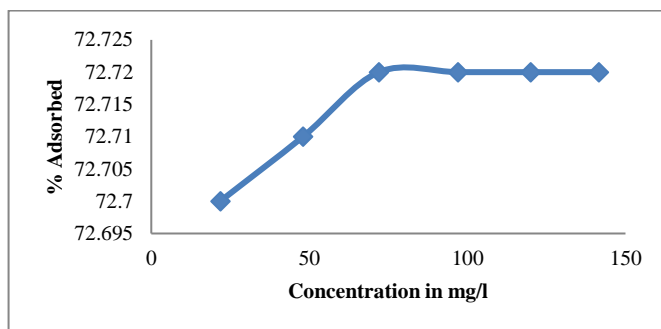


Fig. 5: Effect of initial concentration of  $Pb^{2+}$  on the sorption by the polystyrene

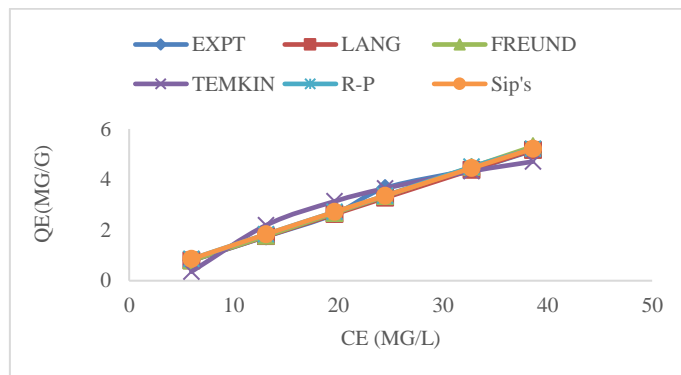


Fig. 6: Isotherm plots for the sorption of  $Pb^{2+}$  by the polystyrene

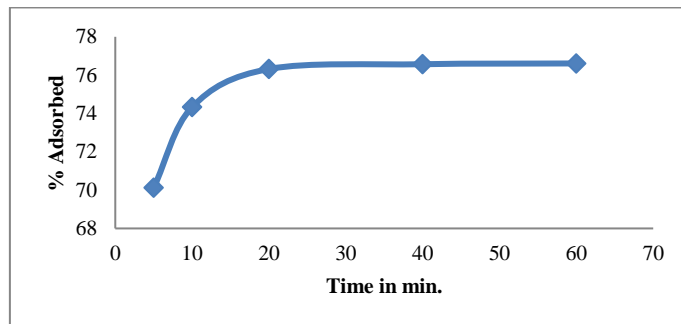


Fig. 7: Effect of contact time on the sorption of  $Pb^{2+}$  by the polystyrene

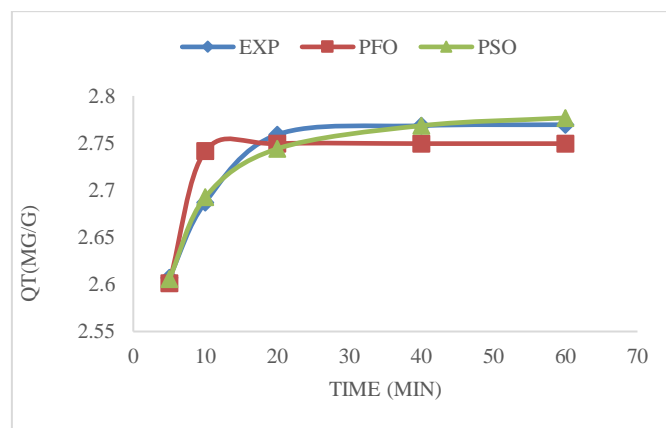


Fig. 8: Kinetic plot for the adsorption of  $Pb^{2+}$  by the polystyrene

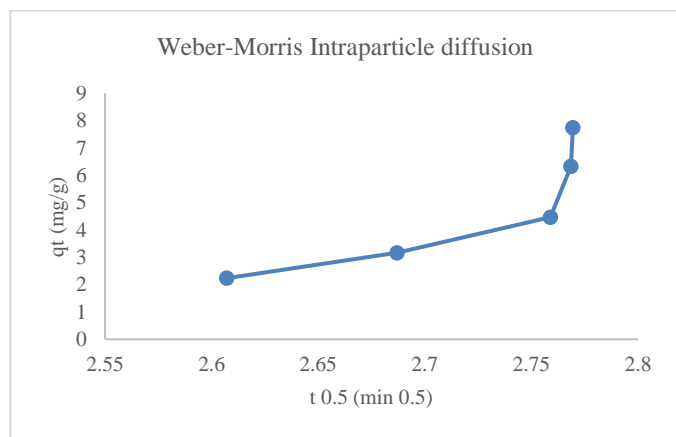


Fig. 9: Weber-Morris Intraparticle diffusion plot for the adsorption of  $Pb^{2+}$  by the polystyrene

### REFERENCES

- [1] Chu, K.H. and M.A. Hashim, Desorption of Copper from Polyvinyl Alcohol-Immobilized Seaweed Biomass. *Acta Biotechnol.*, 2001. **21**, (295–306).
- [2] Gardea-Torresdey, J.L., et al., Phytoremediation of hazardous cadmium, chromium, lead and zinc ions by biomass of *Medicago sativa* (Alfalfa) *J. Hazard. Mater.*, 1998 **57**: p. 29–39.
- [3] Horsfall, M., A.I. Spiff, and A.A. Abia, Studies on the influence of mercapto acetic acid(MAA) Modification on cassava( *Manihot esculenta cranz*) waste biomass on the adsorption of  $Cu^{2+}$  and  $Cd^{2+}$  from aqueous solution. *Bull. Korean Chem. Soc.*, 2004. **25**: p. 969-976.
- [4] Wankasi, D., Kinetics of phytosorption of heavy metals using unmodified and modified biomass *Nipa palm* (*Nypa fruticans wurmb*), in Department of Chemistry. 2004, University of Port Harcourt: Port Harcourt.
- [5] Wankasi, D., M. Horsfall Jnr, and A.I. Spiff, Desorption of  $Pb^{2+}$  and  $Cu^{2+}$  from *Nipa palm* (*Nypa fruticans Wurmb*) biomass. *Afri. J. Biotechnol.*, 2005. **4**: p. 923–927,.
- [6] Osuagwu, J.C., N.L. Nwakwasi, and A.N. Nwachukwu, Iron removal in waste water using expanded polystyrene as an artificial media. *Nigerian Journal of Technology*, 2018. **37**(3).
- [7] Zhang, K., et al., A low-cost crosslinked polystyrene derived from environmental wastes for adsorption of phenolic compounds from aqueous solution. *Journal of Molecular Liquids*, 2020. **314**: p. 113641.
- [8] Wankasi, D. and E.D. Dikio, Comparative Study of Polystyrene and Polymethylmethacrylate Wastes as Adsorbents for Sorption of  $Pb^{2+}$  from Aqueous Solution. *Asian Journal of Chemistry*, 2014. **26**(24): p. 8295-8302.
- [9] Poots, V.J.P., G. McKay, and J.J. Healy, Removal of basic dye from effluent using wood as adsorbent. *Journal of the water Pollution Control Federation*, 1978. **50**(5): p. 926-935.
- [10] Shah, M.R., M. Zulfqar, and Z.S. Khan. Inorganic-Organic Nano Composite Hybrid Membrane Based on Titania and Polystyrene for High Temperature PEM Fuel Cell. in 4th International Conference on Energy, Environment and Sustainable Development 2016 (EESD 2016). 2016.
- [11] Ratvijitvech, T., et al., The effect of molecular weight on the porosity of hypercrosslinked polystyrene. *Polymer Chemistry*, 2015. **6**(41): p. 7280-7285.
- [12] Li, X., et al., A formaldehyde carbonyl groups-modified self-crosslinked polystyrene resin: Synthesis, adsorption and separation properties. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 2016. **500**: p. 1-9.
- [13] Tawansi, A., A. El-Khodary, and A.E. Youssef, Evolution of the Physical Properties of  $FeCl_3$  Filled Polystyrene Films. *International Journal of Polymeric Materials and Polymeric Biomaterials*, 2005. **54**(7): p. 557-574.
- [14] Maragatham, K., S. Muruganand, and N. Manikandan, XRD, FTIR and the Optical Studies of Pure Polystyrene Film. *International Journal on Recent and Innovation Trends in Computing and Communication*, 2014. **2**(5): p. 1148–1151.
- [15] Wankasi, D., Adsorption: A guide to experimental data analysis. 2013. Ano publication company, Nigeria.
- [16] Kadirvelu, K. and C. Namasivayam, Agricultural by-products as metal adsorbents: sorption of lead(II) from aqueous solutions onto coir-pith carbon. *Environ. Technol.*, 2000 **21**: p. 1091-1097.
- [17] Kumar, K.V., Comments on “ Adsorption of acid dye onto organobentonite”. *J. Hazard. Mater.*, 2006. **137**(1): p. 638-639.
- [18] Tran, H., et al., Mistakes and inconsistencies regarding adsorption of contaminants from aqueous solutions: A critical review. *Water Research*, 2017. **120**: p. 88-116.
- [19] Akshay, S. and J. Main, Effect of contact time on adsorption of nitrates and phosphates. *Int J Adv Tech Eng Sci*, 2014. **2**(07): p. 117-122.
- [20] Weber, W.J. and J.C. Morris, Kinetics of adsorption carbon from solutions. *Journal Sanitary Engineering Division Proceedings. American Society of Civil Engineers*, 1963. **89**, p. 31-60, .
- [21] Wang, J. and X. Guoa, Adsorption kinetic models: Physical meanings, applications, and solving methods. *Journal of Hazardous Materials*, 2020. **390**(122156): p. 1 - 19.
- [22] Tang, B., et al., Preparation and Adsorption Properties of Soybean Dreg/ Hydrocalumite Composites. *ACS Omega* 2021. **6**: p. 27491–27500.