

Original Research Article

Adsorption Isotherm studies of Ni(II), Cu(II) and Zn(II) ions on unmodified and Mercapto-Acetic Acid (MAA) modified Sorghum Hulls.

ABSTRACT

Aims: To compare the efficiency of Sorghum Hull of two different particle sizes, different concentrations modified with mercaptoacetic acid and the effect of each on the heavy metal removal to obtain optimum conditions for sorption process.

Study design: The concentrations of the metal ions were monitored using Atomic Absorption Spectrophotometer (AAS).

Place and Duration of Study: This study was carried out at the Industrial Chemistry laboratory, Department of Pure and Industrial Chemistry, University of Port Harcourt between February and August 2013.

Methodology: The Sorghum Hulls (SH) (*Sorghum bicolor*) obtained from a Brewery, were washed and air dried, crushed to smaller particles and sieved to obtain particle sizes of 106 μm and 250 μm . They were activated by soaking in excess of 0.3M HNO_3 solution for 24h, filtered through a Whatman No.41 filter paper, rinsed with deionised water and air dried for 24h. The air-dried activated Sorghum Hulls were divided into three parts, one part was left unmodified and the other two parts were modified by 0.5M and 1.0M mercaptoacetic acid (HSCH_2COOH). Equilibrium sorption of Ni (II), Cu (II) and Zn (II) were carried out for each adsorbent (106 μm and 250 μm) at pH of 6.0 and temperature of 28 $^\circ\text{C}$ to find the effects of initial concentration on the sorption process by preparing stock solutions of 1000 mg/L of Cu (II), Ni (II) and Zn (II) ions from CuSO_4 , $\text{Ni}(\text{C}_2\text{H}_3\text{O}_2)_2$, and ZnSO_4 respectively. Working concentrations of 10, 20, 30, 40, 50 mg/L were obtained by serial dilutions. The concentrations of these solutions were confirmed using Atomic Absorption Spectrophotometer (AAS). The difference in the metal ion concentration of the solutions before and after sorption gave the amount adsorbed by each adsorbent.

Results: Sorption efficiency followed the trend $\text{Cu}^{2+} > \text{Ni}^{2+} > \text{Zn}^{2+}$ and $\text{Ni}^{2+} > \text{Cu}^{2+} > \text{Zn}^{2+}$ for 106 μm and 250 μm , respectively. This was influenced by factors such as ionic radii, ionic charge, hydration energy, initial metal ion concentration, contact time, adsorbate pH and extent of acid modification. Sorption capacity followed the sequence: 1.0MSH > 0.5MSH > USH. Equilibrium sorption of the three metals on the adsorbents using coefficient of determination (R^2) showed that sorption of Zn^{2+} on 250 μm size and sorption of Ni^{2+} on 106 μm size followed Langmuir isotherm; sorption of Zn^{2+} on 106 μm mesh and sorption of Cu^{2+} on 250 μm size by Freundlich isotherm and sorption of Cu^{2+} on 106 μm size and sorption of Ni^{2+} on 250 μm mesh by Temkin isotherm. Sorption on 1.0MSH gave the highest value of constants: ($q_{\text{max}} = 121.814 \text{ mg/l}$, $K_F = 1.5281 \text{ mg/l}$ and $b_T = 0.245 \text{ kJ/mol}$) and ($q_{\text{max}} = 148.932 \text{ mg/l}$, $K_F = 1.7246 \text{ mg/l}$ and $b_T = 0.262 \text{ kJ/mol}$) for 106 μm and 250 μm size, respectively, for Langmuir, Freundlich and Temkin isotherms respectively.

Conclusion: Therefore, Sorghum Hulls were found to be good adsorbent for Ni, Cu and Zn ions with mercaptoacetic acid modification increasing the sorption capacity.

Key Words: Adsorption, Environment, Isotherm, Metal ions, Modification, Sorghum Hulls

1. INTRODUCTION

Surface chemistry is the study of processes that occur at the interface of two bulk phases. The bulk phases can be of the solid-gas, solid-liquid or liquid-liquid. The bulk phase can be solution or pure compounds. Adsorption is a physical or chemical phenomenon by which the molecules present in a liquid or gas attach to the surface of an adsorbent. It involves separation of a substance from one phase accompanied by its accumulation at the surface of another. Adsorption occurs because of an affinity of the surface for the particular substance. The adsorption phenomenon provides an excellent method of separation of a variety of fluid mixtures particularly at low concentrations and as such it is recognized as an important mass transfer operation [1, 2]. The solid that adsorbs a component is called an adsorbent.

Proponents for the use of adsorption for heavy metal treatment argue that the technique is economical, efficient and it produces high quality wastewater with minimal pollutant concentration [3-5]. Although these adsorbents are efficient to use, their production has been found to be relatively expensive. This therefore increases the research interest in using alternative low cost adsorbents of agricultural origin for metal removal from effluents. Since effectiveness and cost of an adsorbent are important issues, a number of novel adsorbents have been investigated. These includes; bamboo root biomass [6]; cocoa pod husk [7]; sugar beat pulp [8]; egg shell [9]; groundnut shell [10]; bitter leaf [11]; *Citrus limetta* peel [12]; *Ficus religiosa* leaves [13]; *Citrullus lanatus* seed husk [14]; and Brewer's Spent Grain (BSG) [15]. These are natural biopolymers representing unused resources and have the ability to retain relatively high concentration of metal ions in waste water by passive sorption and or complexation based on metal-sequestration and they have high affinity for metals [16, 17]. However, chemical modification process have been used to further increase the sorption capacity since research has shown that chemical modification of lingo-cellulosic materials increases their sorption capacity for heavy metals [18-22].

Sorghum Hull, an agricultural waste product from the alcoholic brewing industry was used to investigate its potential in the sorption of Nickel, Copper and Zinc ions from aqueous solution. Therefore, this work was aimed at comparing the efficiency of the Sorghum Hull of two different particle sizes, different concentrations of modification by mercaptoacetic acid and the effect of each on the heavy metal removal to obtain optimum conditions for sorption process.

2. METHODOLOGY

2.1 Adsorbent Preparation

The Sorghum Hulls (SH) (*sorghum bicolor*) were sourced from consolidated Brewery, Awomanma in Imo State, south east Nigeria. The Sorghum Hulls were washed and air dried in preparation for the adsorption analysis. The air dried Sorghum Hulls were crushed with a manual blender to smaller particles and sieve analysis was performed using a mechanical sieve screen to obtain final sample sizes of 106µm and 250µm. The screened fine Sorghum Hulls powder was further soaked in excess of 0.3M HNO₃ solution for 24 hours. It was then filtered through a Whatman No.41 filter paper and rinsed with deionised water. The rinsed Sorghum Hulls were later air dried for 24h. The treatment of the biomass with 0.3M HNO₃ solution aids the removal of any debris or soluble biomolecules that might interact with metal ions during sorption. This process is called chemical activation of the Sorghum Hulls.

2.2 Preparation of Adsorbate Solutions for Sorption Studies

All glassware and plastic wares were washed with deionized water and rinsed with 0.1M HCl to eliminate errors. All the reagents used were of analytical reagent grade. Stock solutions of 1000 mg/L of Cu (II), Ni (II) and Zn (II) ions were prepared from Copper

tetraoxosulphate (VI) (CuSO_4) 98% assay; Nickel acetate ($\text{Ni}(\text{C}_2\text{H}_3\text{O}_2)_2$) 99% assay and Zinc tetraoxosulphate (VI) (ZnSO_4) 99% assay. Thereafter, serial dilutions were carried out on the stock solutions to obtain working solutions of 10, 20, 30, 40, 50 mg/L of each of the metal ions. The concentrations of these solutions were confirmed using Atomic Absorption Spectrophotometer (AAS) model GBC SCIENTIFIC AVANTA PM AAS A.C.N 005472686 manufactured by GBC Scientific equipment Ltd Australia.

2.3 Chemical Modification of Sorghum Hulls with Mercapto-Acetic Acid (MAA)

The air-dried activated Sorghum Hulls were weighed and divided into three parts. 500g of the first part labeled A was left untreated and called unmodified Sorghum Hulls (USH). 500g of the second part labeled B was acid treated by dissolving it in excess of 0.5M mercaptoacetic acid (HSCH_2COOH) solution, stirred for 30min and left to stand for 24h at 28°C and designated as 0.5M modified Sorghum Hulls (0.5MSH). Another 500g of the third part labeled C was also acid treated by dissolving it in excess of 1.0M mercaptoacetic acid solution, stirred for 30 min and left to stand for 24h at 28°C and called 1.0M modified Sorghum Hulls (1.0MSH). After 24h, the mixtures in the beakers designated as 0.5 MSH and 1.0MSH were filtered off using Whatman No. 41 filter paper and were air dried. The three working adsorbents were stored in air tight plastic containers and labeled USH, 0.5 MSH, and 1.0 MSH for the unmodified, 0.5M modified and 1.0M modified adsorbent respectively

2.4 Effect of Initial Concentration of Adsorbate on Equilibrium Sorption

Equilibrium sorption studies were carried out according to the procedure described by Ho *et al*, [23]. Sorption of Ni (II), Cu (II) and Zn (II) were carried out for each adsorbent (106 μm and 250 μm) at pH of 6.0 and temperature of 28°C . 100 cm^3 of standard solutions of each metal with various concentrations (10, 20, 30, 40 and 50 mg/L) were transferred into 250 cm^3 Erlenmeyer flasks and labeled. Thereafter 0.2g of each adsorbent (106 μm and 250 μm) was weighed into the different flasks and agitated in a shaker for 1h. After the agitation time, the content of each flask was then filtered using Whatman No.41 filter paper and the equilibrium concentration of each metal was determined using Atomic Absorption Spectrophotometer model GBC SCIENTIFIC AVANTA PM AAS A.C.N 005472686 manufactured by GBC Scientific equipment Ltd Australia. The difference in the metal ion concentration of the solutions before and after sorption gave the amount adsorbed by each adsorbent.

3. RESULTS AND DISCUSSION

3.1 Effect of Initial Metal Ion Concentration

The percentage of metal ion removed by the adsorbent was based on the initial concentration and equilibrium concentration. This value indicates the sorption efficiency of the adsorption process. The percentage of the metals Cu (II), Ni (II) and Zn (II) removed by the adsorbents was calculated using the relationship:

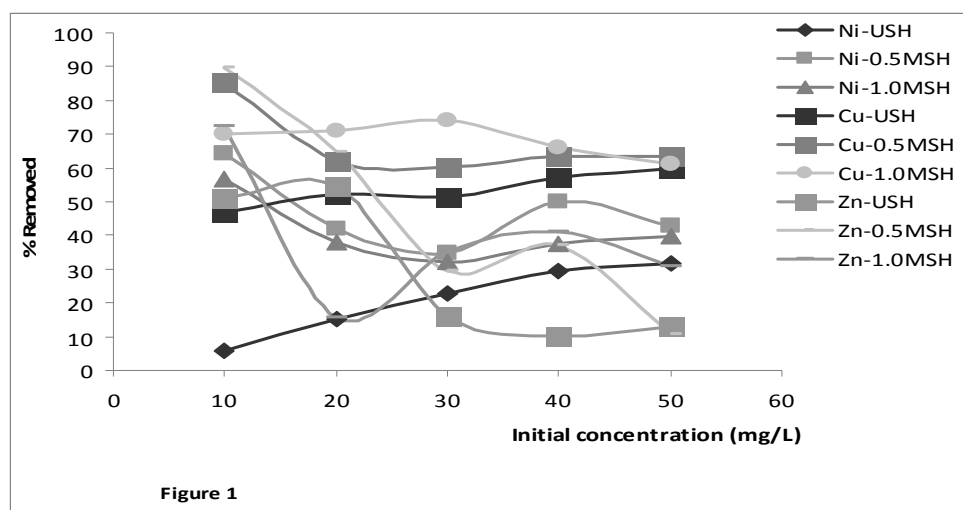
$$R_E = 100 \times (C_i - C_e) / C_i \quad (1)$$

Where R_E is the removal efficiency and C_i and C_e are the initial and equilibrium metal ion concentrations respectively [24]. The results obtained for the percentage removal of the metal ions are shown in the figures below. The variation of percentage removal with initial concentration of the metal ions for the three adsorbents is shown in **Fig 1** for 106 μm particle sizes and **Fig 2** for 250 μm particle sizes. From the results obtained, for 1.0MSH of 106 μm particle size; Ni (II) decreased from 56.89% at 10 mg/L to 39.6% at 50mg/L and for 250 μm particle size, decreased from 68.35% at 10 mg/L to 47.5% at 50 mg/L. Cu (II) on 106 μm particle size decreased from 70.31% at 10 mg/L to 61.23% at 50 mg/L and on 250 μm particle size, decreased from 79.15% at 10 mg/L to 65.39% at 50 mg/L while Zn (II) on 106

122 μm particle size decreased from 72.2% at 10 mg/L to 30.73% at 50 mg/L and on 250 μm
 123 particle size decreased from 77.67% at 10 mg/L to 19.72% at 50 mg/L.

124 For 0.5MSH adsorbent of 106 μm , Ni (II) decreased from 64.08% at 10 mg/L to
 125 43.08% at 50 mg/L and for 250 μm particle size, increased from 17.83% at 10 mg/L to
 126 89.56% at 50 mg/L; Copper on 106 μm particle size decreased from 85.3% at 10 mg/L to
 127 63.44% at 50 mg/L and on 250 μm particle size decreased from 71.04% at 10 mg/L to
 128 66.69% at 50 mg/L while zinc on 106 μm particle size decreased from 89.57% at 10 mg/L to
 129 10.72% at 50 mg/L and on 250 μm particle size decreased from 54.52% at 10 mg/L to
 130 16.13% at 50 mg/L. For USH of 106 μm ; Nickel increased from 5.94% at 10 mg/L to 31.49%
 131 at 50 mg/L and on 250 μm particle size increased from 5.3% at 10 mg/L to 34.71% at 50
 132 mg/L; Copper on 106 μm particle size increased from 46.71% at 10 mg/L to 59.82% at 50
 133 mg/L and on 250 μm particle size increased from 54.44% at 10 mg/L to 60.14% at 50 mg/L
 134 while Zinc on 106 μm particle size decreased from 50.98% at 10 mg/L to 12.8% at 50 mg/L
 135 and on 250 μm particle size decreased from 45.04% at 10 mg/L to 14.5% at 50 mg/L.

136 Sorption efficiency can be said to be dependent on the type of metal ion and the
 137 nature of adsorbents. This can be used to explain why some of the adsorbents had an
 138 increase in percentage removed as the concentration of metal ion increased while some had
 139 a decrease in sorption efficiency as the initial metal ion concentration increased. From the
 140 results, the chemically modified adsorbents exhibited an increase in their removal efficiency
 141 when compared with the unmodified adsorbent. It is evident that chemically modified
 142 adsorbent exhibits better removal capability than unmodified adsorbent suggesting that
 143 surface modification of the adsorbent generates more adsorption sites on its solid surface
 144 matrix for metal adsorption [25]. The trend in sorption efficiency is $\text{USH} < 1.0\text{MSH} < 0.5\text{MSH}$
 145 and for the metal ions; $\text{Ni}^{2+} < \text{Zn}^{2+} < \text{Cu}^{2+}$. Decreases in percentage adsorbed as initial metal
 146 ion concentration is increased have also been observed by other authors [10, 11, 13, 26].
 147 This was generally attributed to the increase in the effective collision between the metal ions
 148 and the active sites as a result of decrease in the number of available sites at higher
 149 concentration.
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152
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Figure 1: Percentage removed against Initial concentration of metal ion solution for 106 μm

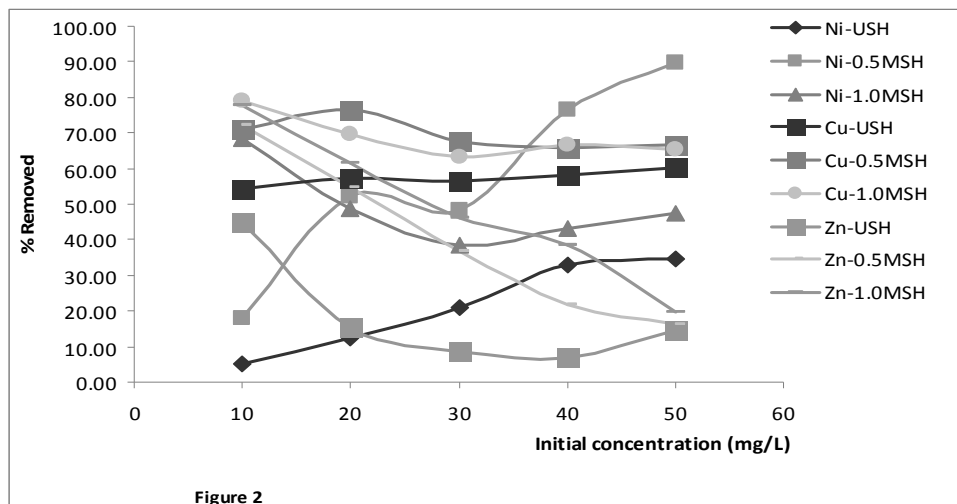


Fig 2: Percentage removed against Initial concentration of metal ion solution for 250µm

3.2 Adsorption Equilibrium Study of Cu (II), Ni (II) and Zn (II)

Adsorption isotherm is a functional expression that correlates the equilibrium distribution of adsorbate between the sorbent and the solution to determine the maximum sorption capacity. It is important to establish the most appropriate correlations for the batch equilibrium data using empirical or theoretical equations as it plays a functional role in predictive modeling procedures for analysis and design of adsorption systems [27-30]. The adsorption equilibrium data was modeled using three sorption isotherms namely the Langmuir, Freundlich and Temkin isotherm models. These isotherms were employed to model the sorption experimental data and to find out that which best fits the equilibrium sorption experimental data.

3.2.1 Langmuir isotherm model

The Langmuir equation is given as [31]:

$$q_e = q_{\max} K_L C_e / (1 + K_L C_e) \quad (2)$$

This linearizes as:

$$1/q_e = (1/q_{\max} K_L)(1/C_e) + 1/q_{\max} \quad (3)$$

Where $q_{\max}$ is maximum adsorption capacity corresponding to monolayer coverage; K_L is the Langmuir isotherm constant. A plot of $1/q_e$ against $1/C_e$ for the Langmuir isotherm is shown in **Fig. 3** for Ni(II), **Fig. 4** for Cu(II) and **Fig. 5** for Zn(II) ions. The linear correlation equations obtained were used to determine the adsorption capacity ($q_{\max}$), the Langmuir isotherm constant (K_L) from the slopes and intercepts and the correlation coefficient (R^2) for the metal ions.

The Langmuir adsorption coefficient (K_L) is related to apparent energy of adsorption and for all the metal ions was high. High values of K_L indicate a steep beginning of the isotherm reflecting high affinity of the sorbent [32]. The maximum sorption capacity ($q_{\max}$) corresponding to monolayer coverage for the metal ions adsorption by 1.0MSH on 106µm and 250µm was also represented. The values of K_L (dm^3g^{-1}) and $q_{\max}$ (mgg^{-1}) are summarized in table 2. The order of $q_{\max}$ for adsorption on 1.0MSH of both particle sizes was $\text{Cu}^{2+} > \text{Ni}^{2+} > \text{Zn}^{2+}$ indicating that Cu^{2+} was most efficiently adsorbed with the highest maximum sorption capacity for both particle sizes. On the whole, the result of the Langmuir isotherm constants show that the adsorbents of 106µm particle size (USH, 0.5MSH and 1.0 MSH) and 250µm particle size (USH, 0.5MSH and 1.0MSH) were both good for the sorption of the metal ions.

Maximum sorption capacity ($q_{\max}$) of the same range as the one obtained from this work have been reported and summarized in table 2. Values of $q_{\max}$ greater than that found in this work have also been reported [28] and summarized in table 2.

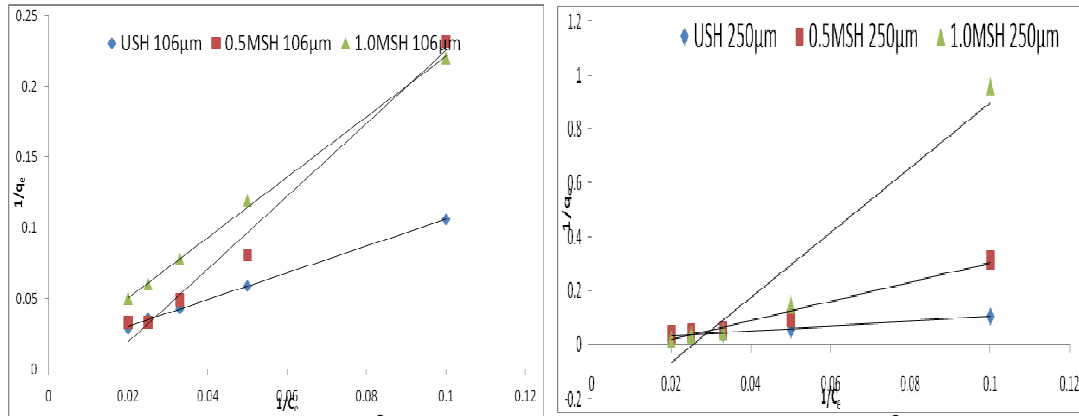


Fig 3: Langmuir isotherm for Ni^{2+} 106µm (a) Langmuir isotherm for Ni^{2+} 250µm (b)

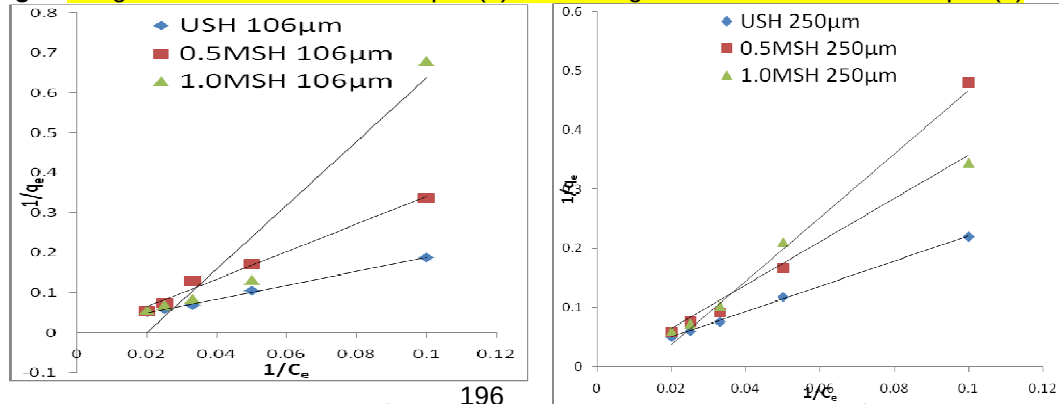


Fig.4: Langmuir isotherm for Cu^{2+} 106µm (a) Langmuir isotherm for Cu^{2+} 250µm (b)

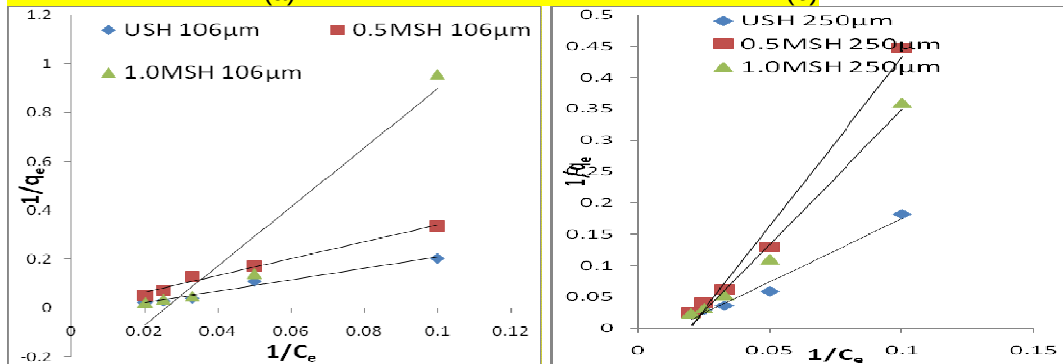


Fig.5: Langmuir isotherm for Zn^{2+} 106µm (a) Langmuir isotherm for Zn^{2+} 250µm (b)

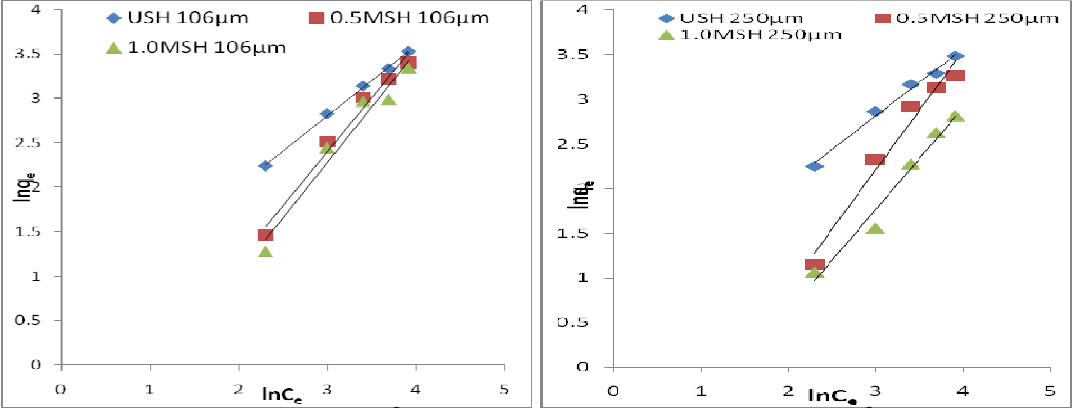
3.2.2. Freundlich isotherm model

The Freundlich isotherm equation is given as [34]:

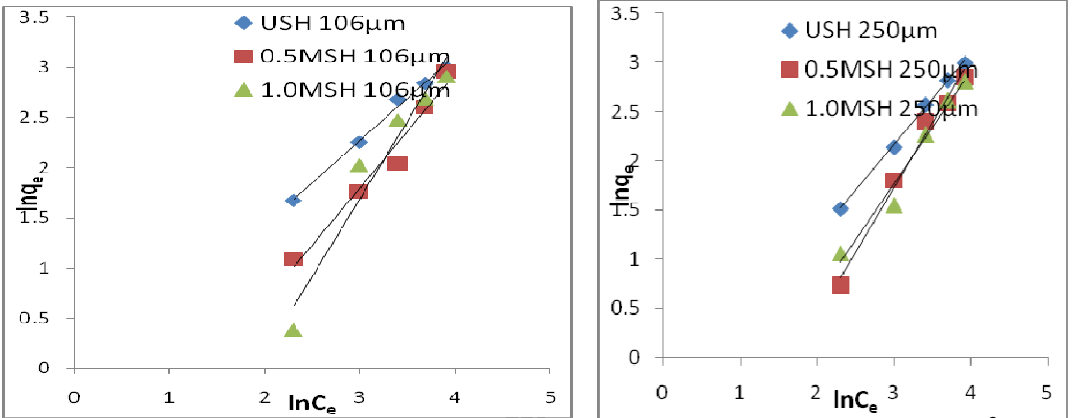
$$\ln q_e = \ln K_F + 1/n \ln C_e \quad (4)$$

where K_F is the Freundlich isotherm constant and $1/n$ is the Freundlich exponent. The Freundlich isotherm plots are shown in Fig 6 for Ni (II), Fig. 7 for Cu (II) and Fig. 8 for Zn (II) ions. By employing the Freundlich model and plotting $\ln q_e$ against $\ln C_e$, linear equations

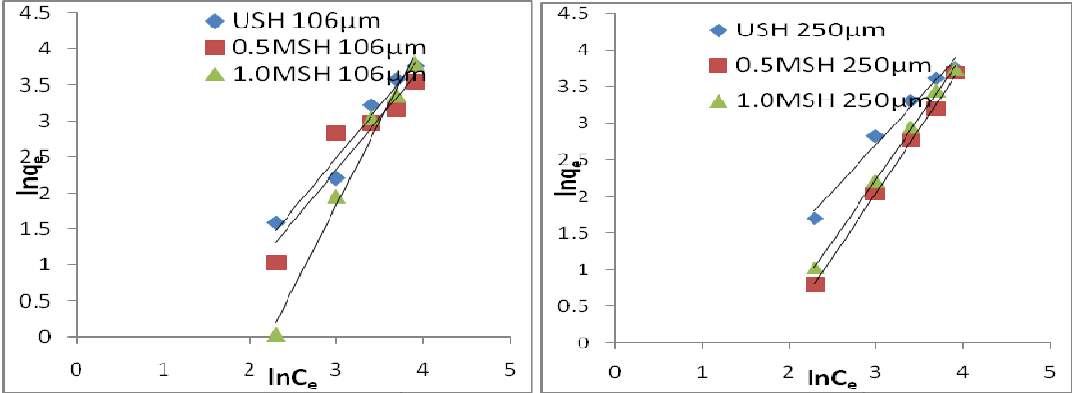
208 were obtained and used to determine the value of n , which determines the suitability of the
 209 adsorbent and the adsorption process, the Freundlich constant (K_F) and the correlation
 210 coefficient R^2 for the metal ions on the three adsorbents. The Freundlich constant for
 211 adsorption of the metals (K_F), n and the R^2 values of the various metal ions for 106 μm and
 212 250 μm are listed in tables 1 and 2, respectively. The highest values of these constants were
 213 obtained for the adsorption of Ni^{2+} . This trend may be attributed to the small ionic radius of
 214 Ni^{2+} leading to its high adsorptivity.



215 **Fig. 6:** Freundlich Isotherm for Ni^{2+} 106 μm (a)
 216 Freundlich Isotherm for Ni^{2+} 250 μm (b)
 217



219 **Fig.7:** Freundlich isotherm for Cu^{2+}
 220 106 μm (a)
 221 250 μm (b)



222 **Fig. 8:** Freundlich isotherm for Zn^{2+} 106 μm (a)
 223 Freundlich isotherm for Zn^{2+} 250 μm (b)
 224

From the results obtained, the R^2 values show that Freundlich isotherm is a good model for the metal sorption on the sorghum hull. The rate of adsorption increased in the order $\text{Ni}^{2+} > \text{Cu}^{2+} > \text{Zn}^{2+}$ for all the adsorbents. The values of K_F increased from USH to 1.0 MSH. This suggests that the Freundlich isotherm model could be used to describe the adsorption of these metals by the adsorbents. Also, it is observed that the n values are less than unity. This indicates a stronger bond between the metals and the adsorbents [35]. However, research has shown that the more the n values approximates to unity, the closer the sorption process is represented by the Freundlich isotherm model [36, 37]. The chemical modification of the adsorbents equally enhanced adsorptivity which follows the trend $1.0\text{MSH} > 0.5\text{MSH} > \text{USH}$ for both pore sizes.

3.2.3. Temkin isotherm model

The Temkin equation is given as [38]:

$$q_e = (RT/b_T) \ln K_T + (RT/b_T) \ln C_e \quad (5)$$

Where b_T indicates the adsorption potential of the adsorbent; K_T is the Temkin isotherm constant ($\text{dm}^3 \text{g}^{-1}$); q_e is the sorption capacity at equilibrium (mg g^{-1}); C_e is the equilibrium concentration of adsorbate (mg L^{-1}); R is gas constant and T is absolute temperature. The plots of the Temkin isotherm are shown in **Fig. 9** for Ni(II) , **Fig. 10** for Cu(II) and **Fig. 11** for Zn(II) ions. By employing the Temkin model and plotting q_e against $\ln C_e$, the Temkin isotherm constants K_T , b_T and correlation coefficient (R^2) values were obtained.

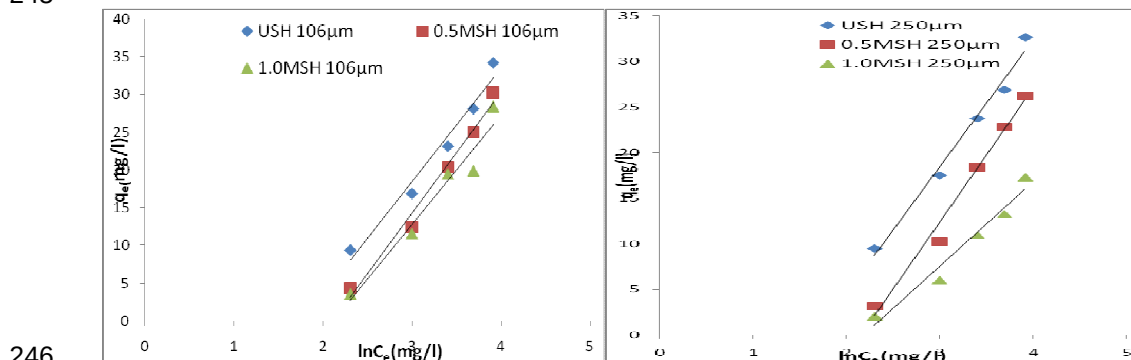


Fig.9: Temkin isotherm for Ni^{2+} 106µm (a) Temkin isotherm for Ni^{2+} 250µm (b)

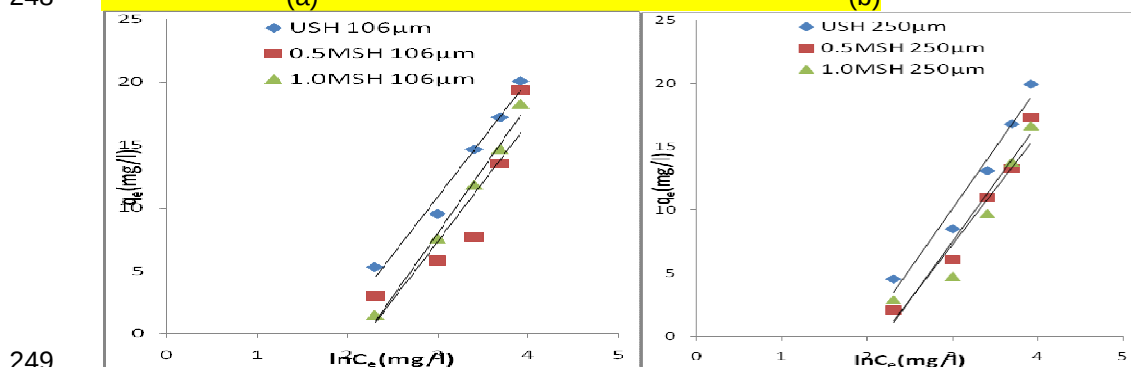


Fig. 10: Temkin isotherm for Cu^{2+} 106µm (a) Temkin isotherm for Cu^{2+} 250µm. (b)

USH	0.997	0.993	0.978	0.999	0.998	0.963
0.5MSH	0.987	0.967	0.823	0.983	0.973	0.962
1.0MSH	0.939	0.941	0.990	0.970	0.986	0.907
Zn(II) ions						
USH	0.965	0.965	0.901	0.981	0.981	0.979
0.5MSH	0.987	0.899	0.865	0.982	0.998	0.840
1.0MSH	0.940	0.998	0.883	0.985	0.982	0.892

287 Table 2: Comparison of biosorption capacities of Sorghum Hulls and some
288 adsorbents reported in literature

Adsorbents Reported in Literature									
Metal ion	Adsorbent	q _{max} mg/g	Ref.	Metal ion	Adsorbent	q _{max}	K _L	Ref.	
Pb ²⁺	Barley Straw	23.20	33	Cu ²⁺	Sorghum Hull (106µm)	121.814	2.0x10 ⁻³	This Study	
	Modified Luffa Cylindrical fiber	13.68	29		Sorghum Hull (250µm)	148.000	1.9x10 ⁻³	This Study	
		46.00	34		Sorghum Hull (106µm)	90.909	1.21x10 ⁻²	This Study	
Ni ²⁺	Salvinia Plant Biomass	44.05	34	Ni ²⁺	Sorghum Hull (250µm)	83.333	1.29x10 ⁻²	This Study	
		61.72	34		Sorghum Hull (106µm)	15.781	1.43x10 ⁻²	This Study	
Cr ³⁺	Neem and Mango Dust	58.82	34	Zn ²⁺	Sorghum Hull (250µm)	12.500	1.86x10 ⁻²	This Study	
Cr ⁶⁺		37.73	34						
FREUNDLICH CONSTANTS									
Metal ion	Adsorbent	n	K _F mg/g	Ref.	Metal ion	Adsorbent	n	K _F mg/g	Ref.
Cu ²⁺	Sorghum Hull (106µm)	0.919	0.7827	This study	Cu ²⁺	Sorghum Hull	1.014	0.5337	This study
Ni ²⁺		1.0025	1.5281	This study	Ni ²⁺	Hull	1.018	1.7246	This study
Zn ²⁺		0.6887	0.1557	This study	Zn ²⁺	(250µm)	0.7746	0.3113	This study
TEMKIN CONSTANTS									
Metal ion	Adsorbent	b _T kJ/mol	K _T	Ref.	Metal ion	Adsorbent	b _T kJ/mol	K _T	Ref.
Cu ²⁺	Sorghum Hull (106µm)	0.2455	0.1102	This study	Cu ²⁺	Sorghum Hull (250µm)	0.2620	0.1125	This study
Ni ²⁺		0.1562	0.1212	This study	Ni ²⁺		0.1689	0.1024	This study
Zn ²⁺		0.9718	0.0853	This study	Zn ²⁺		0.1053	0.0891	This study

289
290 For sorption with 106µm at 1.0 MSH, the Langmuir isotherm seems to give the best
291 fit and hence the best representation of the sorption process of Ni (II) ion; the Freundlich
292 isotherm best describes the sorption of Zn (II) ion while the sorption of Cu (II) ion is best
293 described by the Temkin isotherm. For sorption on 250µm at 1.0 MSH, the Langmuir
294 isotherm best describes the sorption of Zn (II) ion; Freundlich best describes the sorption of
295 Cu (II) ion while the Temkin isotherm best describes the sorption of Ni (II) ion. From the data
296 obtained, all the adsorbents had high R² value indicating that they can be used as low cost
297 adsorbents for the removal of the metal ions (Ni²⁺, Cu²⁺ and Zn²⁺) from their aqueous
298 solutions. Also, results with the isotherms indicate that the isotherm models can be used to
299 assess the potential of sorghum hull as low cost adsorbent.

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301

302 4. CONCLUSION

303 This result obtained from this work showed that the sorption of the heavy metals
304 onto the Sorghum Hull adsorbent was feasible. The sorption process was dependent on

initial concentration and adsorbent modification. Percent adsorbed decreased with increase in initial concentration and modified adsorbent gave better sorption capacity. These results will help in the selection of appropriate conditions for the efficient use of the adsorbent in the treatment of industrial effluents for the removal of heavy metals. The conditions that yield maximum sorption efficiency for the heavy metals can be adopted and modified for the design of batch/semi-continuous adsorbents for use in various small scale industries in tertiary waste water treatment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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