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Nano sized Fe–Al oxide mixed with natural maize cob sorbent for lead remediation

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Abstract
The present work involves the synthesis, characterization and sorption behavior of Fe–Al–MC nanocomposite for the removal of Pb (II) ions from industrial waste water. The sorbent was synthesized by impregnation method. X-ray diffraction (XRD), Energy-dispersive x-ray (EDX) and scanning electron microscopy (SEM) techniques were applied to study the surface structure, compositions and morphology of the materials. Fourier transform infrared technique was used to analyze the effect of surface properties on the adsorption behavior of Pb(II) ions. The optimum effects of the parameters on the adsorption of Pb (II) ions were determined to be, pH = 6, dose = 2 g, contact time = 24 h and agitation speed = 150 rpm and initial Pb (II) ions 10 ppm. Experimentally, the adsorbed amounts of lead ion tend to decrease with increase in pH. Both Langmuir and Freundlich isotherm models fit the equilibrium data well on the adsorbent. Kinetic data correlated well with the pseudo second order kinetic model. Thermodynamic studies resulted in negative ΔG value indicating the spontaneity of the sorption process. The Fe–Al–MC nanocomposite sorbent showed a sorption capacity of 40.00 mg g⁻¹ at pH 6. Therefore, this adsorbent with large sorption capacity and efficiency is a promising adsorbent for the removal of Pb(II) ions from the wastewater.

1. Introduction

Currently, a serious environmental and public concern all over the world is water pollution by heavy metals due to the increased industrialization and urbanization processes [1–3]. Wastewater from industries such as, chemical, battery, metallurgical, leather tanning, and mining, contain many toxic heavy metal ions [4]. These wastewaters with toxic heavy metal ions (e.g., lead, cadmium, etc) are discharged into natural water directly, not only threat the aquatic organisms, but may be enriched by precipitation, adsorption, and harm human health through the food chain [5, 6]. This forms the basis for the increasing researches with a view to remediying their levels in the environment; and also the growing concern by governmental agencies for the regulation of the discharge of these metals into the environment.

Various heavy metal remediation methods are available to minimize the pollutant levels in water and wastewater, including chemical oxidation and reduction, membrane separation, liquid extraction, ion exchange, electrolytic treatment, electroprecipitation, coagulation, flotation, evaporation, hydroxide and sulfide precipitation, crystallization, ultrafiltration, and electrodialysis and they differ in their effectiveness and cost [7, 8]. Among the above remediation methods, adsorption has been considered as one of the best choice methods for water and wastewater remediation due to its high removal efficiency without the production of harmful by-products [9, 10].

Different materials, such as activated carbons [11], clay minerals [12], chelating materials [13], and chitosan/natural zeolites [14] have been investigated to adsorb metal ions from aqueous solutions. In spite of their high up take capacities, the large-scale use of nano sized oxides alone is quite limited because of the difficulties raised in the dispersion of powdered adsorbents and the need of higher costs of regeneration. Therefore, nano-sized
oxides mixed with natural adsorbents have proven to be an efficient and inexpensive option for the adsorption of heavy metals from wastewater [15].

Maize cob is mainly composed of lignocellulose materials (figure 1) having relatively large surface areas that can provide intrinsic adsorptive sites to many substrates and inherently adsorb waste chemicals such as organic pollutants, inorganic pollutants and atmospheric pollutants in water due to columbic interaction and physical adsorption.

Nano sized metal oxides are used as the novel adsorbent to remove heavy metal ions in wastewater due to their higher efficiency (higher surface areas) and faster kinetics (intraparticle diffusion). An efficient sorbent with both high adsorbing capacity and fast rate adsorption should have the following two main characteristics: functional groups and large surface area [16]. Recently, the development of hybrid sorbents will fulfill these two main characteristics for removal of heavy metals from water [17].

As per the knowledge of the author, since no research work has been conducted on the sorption characteristics of nano-sized mixed oxides with natural sorbents for the removal of heavy metals and its easy synthesis, environmentally friendly, easy regeneration after adsorption and having high uptake capacity was aimed to synthesize Fe–Al–MC sorbent, characterize Fe–Al–MC sorbent and to study its lead sorption behavior. This novel sorbent is believed to exhibit superior adsorption efficiency as it possesses high surface areas and with enhanced functional groups on its surface due to the composite nanoadsorbent properties. The sorption kinetics, sorption isotherms, regeneration, influence of solution pH and coexisting ions on Pb(II) ions uptake were investigated. Finally, the outcome of this study may possibly serve as the basis for the remediation of wastewater on an industrial scale. This could bring tremendous impact on the process of water purification and hence play a significant role in the modification of present status of industry and hence influence the economy of the country.

2. Material and methods

2.1. Apparatus and instruments

The laboratory apparatus that were used during the study includes the different sized glass wares (Beaker, Volumetric and Erlenmeyer flasks, Cylinders, Pipettes, Dropper and Funnels), Crucible dish, Filter paper, Mortar & Pestle and Sieve (250 μm). Instruments such as pH meter (MP 220), Vertex 70 FTIR spectrophotometer (Bruker Corporation, Germany), XRD (BRUKER D8 Advanced XRD), SEM (S4800, Hitachi Corporation, Japan) with EDS (JEM-2100, JEOL, Japan), Flame atomic absorption spectrophotometer (Model210/211 VGP), Rotary shaker (Orbital shaker SO1 made in UK), Hot air oven (Contherm260 M and Furnace BIBBY Stuart, UK), were used in various measurements to generate the required analytical data.

2.2. Chemicals

Analytical grade Fe(NO₃)₃·9H₂O (98%, BDH chemicals Ltd, England) and Al(NO₃)₃·9H₂O (95% E. Merck) were used for synthesis of the sorbent. Pb(NO₃)₂ (99% CDH Laboratory reagents), HCl solutions, HNO₃, sodium borohydride and all the reagents were used for the experiments.

2.3. Synthesis of nano-sized oxide/natural sorbent

All chemicals used were of analytical grade. Fe(NO₃)₃·9H₂O (98%, BDH chemicals Ltd., England) and Al (NO₃)₃·9H₂O (95% E. Merck) were used for synthesis of the sorbent. The maize cobs (MC) collected from the local farm were cut into small pieces, washed several times with distilled water and air-dried. Then the substrates were ground to small particles (size < 850 μm) and kept in powdered form in plastic containers for
subsequent use as precursor. The nano sized Fe–Al–MC particles were synthesised by impregnating MC sorbent with Fe₂O₃/Al₂O₃ nitrate aqueous solution having different percentage of mixed oxides and MC adsorbents. Then they obtained product is dried at 110 °C in an oven over night and further calcined at different temperature and stored for further studies [1,2].

2.4. Characterization
The size of the primary crystallite (Dₛ) of the solid-phase was calculated from the XRD diffractogram according to the Debye–Scherrer’s equation:

$$D_s = \frac{0.9\lambda}{\beta \cos \theta}$$

(1)

where, Dₛ is mean crystallite size (nm), λ wavelength of the incident radiation (λ = 0.154 05 nm), β pure diffraction broadening (radians) and θ the Bragg angle (degrees, half-scattering angle). Usually, β was taken as the full width at half maximum of the major diffraction band (FWHM). The XRD, pattern was obtained through a Cu target Kα radiation. FT-IR spectrometer, scanning electron microscope, SEM coupled with energy dispersive x-ray (EDX) were used to determine the morphology, size and composition of the adsorbent.

2.5. Adsorption studies
Adsorption studies were performed by determining different factors that affecting the sorption parameters (solution pH, adsorbent dose, contact time, agitation speed and initial adsorbate concentration). Each parameter influence on the Pb (II) ions adsorption was determined by keeping other parameters at constant and optimized value. Thus the influence of solution pH was carried out by adding 0.1 g of the adsorbent into 250 ml Erlenmeyer flask containing 30 mg L⁻¹ of Pb (II) ions solution by varying pH of the solutions to 2, 4, 6, 8 and 9 and the effect of adsorbent dose was carried out by varying the amount as 0.04, 0.08, 0.16, 0.3, 0.5, 1, 2 and 2.5 g. Following this, the effect of contact time was determined by varying the period as 3, 6, 9, 18, and 24 h and the effect of agitation speed of metal ion adsorption was also determined, by varying the agitation speed as, 100, 150, 200, 250 and 300 rpm. Finally, the effect of initial adsorbate concentration was carried out using different initial metal ion concentrations of 10, 20, 30, 50, and 100 mg L⁻¹. All the above experiments were evaluated by placing different 500 ml Erlenmeyer flasks. During the experiment, the flasks was stoppered and continuously shaken. And then at the end of the adsorption period the solution will be filtered and analyzed for metal ion equilibrium concentration. For all the above parameters percent of adsorption (%) was calculated using the following equation:

$$\text{Percent of adsorption} (%) = \frac{C_o - C_e}{C_o} \times 100\%$$

(2)

where; Cₒ = the initial concentrations (mg/L) and Cₑ = equilibrium concentrations (mg L⁻¹) of the lead ion.

2.5.1. Adsorption isotherms
The affinity of the adsorbate for an adsorbent was quantified using adsorption isotherms, which are used to describe the amount of adsorbate that can be adsorbed onto an adsorbent at equilibrium and are usually as a function of the liquid phase concentration. For this both Freundlich and Langmuir models were employed to describe the experimental results of metal ion adsorption. Metal ion adsorption isotherms were determined by keeping all parameters at optimized conditions. Initial metal ions concentration was varied from 0.01–6 mg L⁻¹. In separate flask 25 ml of solutions containing different amounts of metal ion concentration was added. After the reaction period, all samples were filtered of and analyzed for the corresponding metal ion concentration.

2.5.2. Thermodynamics of adsorption
Thermodynamics of adsorption gives information whether the processes are spontaneous or not at a given temperature. Therefore, in order to determine the effect of temperature on sorption phenomenon, all predetermined and optimized values of parameters (pH, dosage, contact time, speed of agitation and concentration) were used and the temperature was maintained at 30, 40, 50, and 60 °C.

2.5.3. Desorption of metal ion
Metal ion desorption was studied using metal ion loaded powder sample. The optimized amount of adsorbent loaded powder was added into each flask containing 25 ml of deionized water and 0.1 M NaOH and 0.1 M HCl solutions were used to adjust pH of the solution from 2 to 9. The solutions were agitated at optimized value, filtered and analyzed for metal ion concentration according to the method described previously. The quantity of desorbed metal ion was determined by the amount of metal ion in the solution after each desorption experiment. The regenerated adsorbent was reused to adsorb the metal ions throughout the experiments.
3. Results and discussion

3.1. Synthesis and characterization
In this process, impregnated method was used to synthesize two series of Fe–Al–MC nanosorbent and characterized by using XRD, SEM, EDX and FTIR. The XRD patterns shows hematite peaks (figure 2(a)). Since, most of the crystalline structure was dominated by Fe$_2$O$_3$ than Al$_2$O$_3$ and MC. This could be due to the presence of crystallized alumina ($\gamma$-Al$_2$O$_3$ might present under thermal treatment at 800 °C and $\alpha$-Al$_2$O$_3$ might present under thermal treatment at 1000 °C) [13] and small percentage of MC. Sample with the smallest crystallite size was selected from the obtained XRD result using Debye Scherer’s equation and used for further adsorption studies. Relatively, composite sample (A) calcined at 400 °C has small particle size (22.71 nm) than sample (B) calcined at 600 °C whose crystalline size was 22.86 nm. This is possibly due to little temperature effect; as calcinations temperature increases, the crystal size increases insignificantly. From the XRD peaks for both data $2\theta$ values represented as miller indices (111), (220), (311), (400), (422) and (440) shows all the hematite peaks (figure 2(a)).

It has also been observed from the XRD patterns (figure 2(a)) that there is no significant change in the structure of the sorbent materials at different calcination temperatures of 400 °C and 600 °C. In addition, absence of sharp peaks, confirms more of amorphous nature of the sorbent than crystalline nature.

FT-IR spectra of Fe–Al–MC sorbent before and after adsorption were shown in figure 2(b)). The strong alkyl C–H-stretch bands were observed nearly around 2928 cm$^{-1}$ due to C–H bonds in the CH$_2$ and CH$_3$ groups. The peak at 1386 cm$^{-1}$ before adsorption was due to the CO single bond and the broad band centered at 3417 cm$^{-1}$ after adsorption is caused by the hydroxyl group stretching. It may also be due to OH-stretching frequency of AlO(OH) phase as reported in the earlier work [14]. A band at 1626 cm$^{-1}$ primarily recognized to the bending vibration of hydroxyl groups of hydrated iron oxides (Fe–OH). The band spectrum in the region around 478 cm$^{-1}$ shows the presence of mixed metal oxides with MC bond in specific vibration and the adsorption band at 559 cm$^{-1}$ shows the presence of hematite [13]. From the graph we understand that, the availability of more H$_2$O
molecules during experiment processing shows relatively higher strengths of the peaks after adsorption than before adsorption. While before adsorption, since the adsorbent were calcined there is no more H2O molecules expected. After adsorption new peak appeared at 1410 cm\(^{-1}\) which corresponds to bending vibration of adsorbed lead\(^{15}\) and corresponds to adsorbed water on adsorbents. This is because of replacement reaction carried out in the process (surface hydroxyl groups were replaced by the adsorbed lead). The peak at 559 cm\(^{-1}\) assigned to Fe–O group on Fe–Al–MC may indicated the presence of Fe–Al on the composite\(^{16}\).

This interaction also accounted for the mechanism of surface modification of Fe–Al with MC. The IR spectrum of the Fe–Al–MC sorbent before and after adsorption indicates distinct changes in the absorption intensities of CO stretch in acids, and OH stretch in alcohols suggesting that such ionizable functional groups on the adsorbent surface were able to bind with the metal ions.

SEM images with different magnifications and different areas of the sorbent system were shown in figure 2(c)). It was observed that Fe–Al–MC sorbent exhibit variation in surface morphologies. It indicates that the nano-materials have more porous nature. The presences of all the elements were confirmed by EDX analysis (figure (d)). The percentage composition of Fe was found to be higher than other elements. This variation indicates that the heterogeneity of the nano sorbent system.

### 3.2. Adsorption mechanism

The adsorption mechanisms of Pb\(^{2+}\) ions onto the Fe–Al–MC were investigated as the schematic representation (figure 3):

From the schematic representation for the adsorption mechanisms of Pb\(^{2+}\) ions onto the Fe–Al–MC adsorbent it is possible to understand that the adsorption mechanisms are dependent on the degree of adsorbate-adsorbent interaction and the adsorbate-solvent interactions. This point view was supported researches reported by\(^{17}\). Therefore, it shows the adsorbate has positive charge and the adsorbent has the negative charge on the surface and the adsorption process enhances greatly.

#### 3.3. Effect of pH

The effect of solution pH on the adsorption of Pb(II) ions is demonstrated in the figure 6. The Pb(II) ions removal was evidently dependent on solution pH with relatively greatest adsorption occurring under the conditions of increased solution pH in Fe–Al–MC adsorbent and decreased with decreased solution pH (figure 4(a)). As the pH of the solution was decreased, H\(^+\) ions competes with Pb\(^{2+}\) ions for the functional groups present on the adsorbent at acidic condition thus lowering the adsorption capacity of the adsorbent\(^{18}\). Generally, to maximize the removal of heavy metals by the adsorbents, knowledge of an optimum pH is important. In addition to this, an increase in pH was found to increase the adsorption efficiency, although to avoid the precipitation of Pb, the pH of the solution was raised only to a maximum value of 6 in this study\(^{19}\).
3.4. Effect of adsorbent dose
Initially the adsorption process was increases, but at higher adsorbent dose it become slow this is because at lower adsorbent dose the adsorbate is more easily accessible whereas, at higher adsorbent dose there is a very high supercritical adsorption onto the adsorbent surfaces that produces a lower solute concentration than when adsorbent dose is low (figure 4(b)). In line with this, at higher adsorbent dose, the availability of high energy sites decreases with large fraction of lower energy sites being occupied, resulting in lower adsorption capacity but, at the low adsorbent dose, all types of sites are entirely exposed and the adsorption on the surface is saturated faster showing a higher adsorption capacity ($q_e$) [20].

3.5. Effect of speed of agitation
The adsorption efficiency of the adsorbent used in this study was found to increase as the agitation speed increased from 100 to 150 rpm (97.1% to 99%) (figure 4(c)). This is owing to the fact that increasing agitation speed could improve the diffusion of solute towards the adsorbent surface. But, beyond this agitation speed the adsorption efficiency decreased because of more agitation speed causes more desorption of Pb(II) ions from the adsorption site in agreement with the work done by [13, 21].

3.6. Effect of initial Pb(II) ions concentration
The removal efficiency of the Pb(II) ions by the Fe–Al–MC adsorbent was decreased from 99.20% at 10 mg L$^{-1}$ to 92% at 150 mg L$^{-1}$ as shown in the (figure 4(d)). The adsorption efficiency was found to decrease at low concentrations of Pb(II) ions because of the ratio of the initial number of moles of solutes to the available surface area of adsorbent is large and subsequently the fractional adsorption becomes independent of initial concentration and consequently higher adsorption yields were obtained. No matter how at higher concentration, most of the adsorption sites could be occupied by Pb(II) ions and the available sites of adsorption would become fewer, hence the percentage removal of Pb(II) ions which depends upon the initial concentration could decreases. This is in line with studies that have shown that removal efficiency of heavy metal is concentration dependent and there exist decreasing trend if increase initial concentration [22].
3.7. Adsorption isotherm

Both Langmuir and Freundlich models \([23, 24]\) were employed to explore the results of Pb (II) ion adsorption. The linearized Langmuir and Freundlich plots are given in figures 5(a) and (b) respectively. The slopes and intercepts of the linearized Freundlich and Langmuir plots were used to calculate the adsorption constants (table 2). From table 2, the higher correlation coefficients of Langmuir isotherm indicate that this model fits the adsorption data better than the Freundlich model.

Linear equation used to calculate Langmuir adsorption model is expressed as

\[
\frac{C_e}{q_e} = \frac{1}{bQ_o} + \frac{C_e}{Q_o} \ldots
\]

The plot of \(C_e/q_e\) versus \(C_e\) yields a straight line with a slope, intercept, \(Q_o\), and \(b\) values of 0.025, 0.045, 40.00 and 0.56 respectively for Fe–Al–MC adsorbent (figure 5(a)). A dimensionless equilibrium parameter (\(R_L\)) value for all concentration is calculated by using the equation expressed as

\[
R_L = \frac{1}{1 + bC_o} \ldots
\]

and found to be 0.056 which is between 0 and 1 and confirms the feasibility of the isotherm \([25]\).

The Freundlich equation is an empirical expression that encompasses the heterogeneity of the surface and the exponential distribution of sites and their energies. The linearized form of the equation is:

\[
\log q_e = \log K_f + \frac{1}{n} \log C_e \ldots
\]

and the plot of \(\log q_e\) versus \(\log C_e\) yields a straight line with a slope 0.197 and an intercept of 0.002. The value of \(1/n\) was found between 0 and 1 and equal to 0.197 (table 1). The \(n\) value was (5.07) which is lay between 1 and 10, which shows adsorption of Pb \(^{2+}\) ions onto adsorbent surface was easily carried out \([26]\).

In this study, the values of correlation coefficient \(R^2\) for Fe–Al–MC adsorbent system were found to be \(= 0.997\) and 0.995 for Langmuir and Freundlich model respectively, which confirms that both Langmuir and Freundlich models have the good representation of experimental data for the sorption isotherms of Pb (II) ions.

3.8. Kinetics of adsorption

On this study, the flow of the graph was almost similar to that of contact time except very insignificant modification were seen on the percent of adsorption, because it was done after optimization of agitation speed and initial metal ions concentration (figure 6(a)). The kinetic curves obtained for the adsorption of Pb (II) ions from aqueous solutions onto the adsorbent (nanoparticle mixed with MC adsorbent) systems are shown (figure 6(a)). The theoretical results of equilibrium capability for Fe–Al–MC adsorbent system are found to be

![Figure 5. Langmuir (a) and Freundlich (b) adsorption isotherms of Pb\(^{2+}\) ions by Fe-Al-MC adsorbent at pH = 6.](image-url)
2.17 mg g$^{-1}$, which shows that the first-order-kinetic model was not much correlated because it differs from the experimental values. That mean it represents the initial stages where rapid adsorption occurs well but cannot be applied for the entire adsorption process. In contrast to this, pseudo second-order reaction rate model provides high correlation value ($R^2 \approx 0.998$ in Fe–Al–MC). Therefore, the study indicated that the pseudo-second order model better represents the metal ions adsorption kinetics, suggesting that more of the adsorption process might be follows chemisorption. The first order rate constant $k_1$ and equilibrium adsorption density $q_e$ were determined from the slopes and intercepts of Pseudo-first order model \[
\log(qe - qt) = -0.108x + 0.337
\] (figure 6(a)) and the value of $q_e$ and $k_2$ determined from the slopes and intercepts of Pseudo-second order model, $t/ qt$ versus $t$ (figure 6(b)). The kinetic parameters obtained from the models are given in table 2.

| Model                     | $k$     | $q_e$ (mg g$^{-1}$) | $R^2$ |
|---------------------------|---------|---------------------|-------|
| Pseudo-first order        | 0.249   | 2.17                | 0.989 |
| Pseudo-second order       | 0.578   | 7.35                | 0.998 |

3.9. Selectivity of metal adsorption
The selectivity in the adsorption of metal ions in the presence of chloride solutions of copper and cobalt onto Fe–Al–MC sorbent was affected by the anions present in aqueous solution. The amount of Pb (II) ion adsorbed on to Fe–Al–MC sorbent system was relatively lower at high concentration of chloride solutions of copper and cobalt based on the results of selectivity experiment. Nevertheless, the adsorbent is still efficient in removing Pb (II) ions from aqueous system (figure 7). Thus; the results of selected Fe–Al–MC sorbent could selectively adsorb Pb (II) ions from aqueous solutions. Clearly, the existence of these classes of ions has no significant effect on the adsorbent which exhibited high adsorption selectivity toward Pb(II) ion used in wastewater.

3.10. Thermodynamics of adsorption
The values of $\Delta H^0$ and $\Delta S^0$ were presented table 3. The percentage of adsorption of metal ions increases with increase in temperature (figure 8(a)). The negative values of $\Delta G^0$ and the positive values of $\Delta H^0$ indicates the metal ion adsorption process was spontaneous and an exothermic respectively (table 3).
3.11. Desorption of lead
The metal desorbability can be defined as the ratio of the desorbed metal ions over the total adsorbed metal ions by the adsorbent. Therefore, the desorbability can be used to indicate the degree of metal ions desorption from the adsorptive materials [27]. Desorption experiments were carried out using deionized water as an eluent. According to the results of the desorption study (figure 8(b)), the amount of desorbed metal ions from the Fe–Al–MC adsorbent was found to vary from 10% at pH 2 to 65% at pH of 9. From this it is possible to conclude that, desorption process increases with increasing pH values. Regeneration of the adsorbent after adsorption experiment is crucial in industrial practice for metal removal from waste water [27]. By doing so, the regeneration of adsorbent used was possible, because of the adsorbed metal ion was desorbed again.

3.12. Comparison of the method with others
In comparison it is possible to observe the analytical performance of the Nano sorbent Fe–Al–MC with the other conventional sorbent system. The comparative data statistics about various sorbent systems is presented in table 4. The result shows that the adsorption capacity obtained by Fe–Al–MC adsorbent was comparable to those

| Adsorbent  | T (K) | ΔG (KJ mol\(^{-1}\)) | ΔH (KJ mol\(^{-1}\)) | ΔS (J mol\(^{-1}\)k) |
|------------|-------|----------------------|----------------------|----------------------|
| Fe–Al–MC   | 303   | −2.402               | +47.905              | +166.03              |
|            | 313   | −4.062               |                      |                      |
|            | 333   | −7.382               |                      |                      |
presented by other methods and has relatively high adsorption capacity (40 mg g⁻¹, approximately 96%) when compared to [28–32]. Nevertheless, the proposed method is simpler than other methods. For instance, there is no necessitate employing any complexing and/or chelating agent and the adsorbent is steady with a recycling period superior to chelating agent without major loss in its amounts and metal recovery property. The results of this study could provide for future attention on the synthesis of adsorbents with environmentally friendly and relatively better performance capacity for heavy metal ions removal from aqueous solutions.

4. Conclusion

This work was aimed to evaluate the sorption efficiency of Fe–Al–MC sorbent developed from a chemical and local agricultural waste (Maize cob powder) for a toxic Pb(II) ions removal for wastewater remediation. The XRD result indicates that the Fe–Al–MC sorbent was nanocrystalline. The SEM and EDX results showed that the surface morphologies and elemental compositions of the synthesized materials and heterogeneous nature of the sorbent. According to the batch study, the Pb (II) ions removal was found to be highly pH dependent whereas, maximum removal of the Pb (II) ions occurred at nearly neutral solution pH. Chemisorption process is the prevailing mechanism between the adsorbent and the adsorbate in pseudo-second order model which fitted best with the experimental data revealing the reusability and desorption repetition fulfilling the vital criteria for superior adsorbents. Both Freundlich and Langmuir isotherm models were used and from them the latter showing a better fit to the experimental data. Thermodynamic studies resulted in negative ΔG value indicating the spontaneity of the sorption process. The Fe–Al–MC nanocomposite sorbent showed a sorption capacity of 40.00 mg g⁻¹ at pH 6. The sorption efficiency of the Fe–Al–MC sorbent was found to be 40 mg g⁻¹. Therefore, Fe–Al–MC adsorbent with large sorption capacity and efficiency is a promising and potential adsorbent for the removal of Pb(II) ions from the wastewater.

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