



Montmorillonitic clay as a Cost Effective, Eco-Friendly and Sustainable Adsorbent for Physicochemical Treatment of Contaminated Water

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Abstract

The goal of this paper is to use an Egyptian modified clay found in Suez zone, montmorillonitic clay to remove hazardous lead and nickel from water-based contaminated media. The FT-IR instrument was utilized to detect the functional groups on the clay's surface. The specific surface area of the adsorbent was determined to be around 433 m²/g. Iron particles are intercalated between the sheets of montmorillonitic clay, according to XRD patterns. Pb²⁺, and Ni²⁺ had Langmuir monolayer sorption capacities of 40 and 3.75 mg/g, at high concentration of heavy metals (10 mg/L) with high R² of more than 98% and 96%, indicating that, the experimental data are reproducible for both contaminants respectively with R_L values between 0 and 1 which indicate a favorable adsorption of the heavy metals onto the adsorbent. In other hand, Pb²⁺, and Ni²⁺ had Freundlich isotherm represented a chemisorption and cooperative adsorption respectively. Intra-particle diffusion seems to perform a substantial responsibility in the elimination of these two hazardous contaminants, according to kinetic studies. The implications of this research suggest that composite of montmorillonitic clay might be used to cleanse water that contains harmful contaminants, the removal reached 99% and 96% of highly loaded water of both heavy metals Pb²⁺, and Ni²⁺ respectively. According to Langmuir and Freundlich isotherm models the adsorption were favorable for both elements and according to Freundlich isotherm, adsorption process of lead onto montmorillonitic clay indicating normal adsorption process, but a cooperative sorption process for nickel. The treatment process is applied for real industrial wastewater COD is removed by more than 25%, TKN is removed by more than 54%. On other hand, hazardous heavy metals were removed by more than, 74%, 45%, 76%, 44%, 52%, 60%, and 73% for Pb, Cu, Ni, Cd, Mn, Cr and Co ions respectively.

Keywords: Montmorillonitic clay; Sorption Toxic Pollutants; Langmuir and Freundlich Isotherms; Removal of Heavy Metals.

1. Introduction

Because of the fast expansion of industry and urbanization, metalloid and metal hazardous contaminants are commonly disseminated in the human being natural environment [1-4]. Because of the significant repercussions for human health, the occurrence of dangerous poisonous ions of metalloid and metal in the water natural environment is a most important worldwide issue [5-8]. Metal ions like Fe, Zn, Cu, Co, Cr, Mn, and Ni are significant rare elements since they're needed for metabolism in biological systems at small amounts; nevertheless, a big dosage can be damaging to living organisms [9-11]. Poisonous metallic ions such as Pb, Ni, Hg, and metalloids arsenite/arsenate, among others, damage biological purposes and are urgent contaminants of considerable disquiet for the health of human being due to

their elevated poisonousness even so at very minimal doses [12-14].

Many metals and metalloids have also been classified as human carcinogens by the International Agency for Research on Cancer (IARC) and the US Environmental Protection Agency (EPA). More than 500,000 people die each year from lead poisoning, according to the Institute for Health Metrics and Evaluation (IHME). [15, 16]. Nickel can cause a multi-action on human health, such as allergy, cardiovascular and kidney diseases, lung fibrosis reaching cancer as well as nasal cancer. As a result, several research projects are underway to produce appropriate adsorbents for the removal of such harmful contaminants [17-20]. Membrane separation, coagulation, precipitation, electro dialysis, and adsorption, are some of the several

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methods. Because of its cheap cost, simplicity, and great effectiveness, adsorption is only of the extremely often used techniques for treating polluted water from harmful particles [21, 22].

Composite materials have piqued attention in environmental remediation in recent decades, particularly in the treatment technology of wastewater, owing to their efficiency of treatment and the nature of multifunctional techniques [23, 24]. In single and binary systems, bentonite was employed to remove Hg^{+2} and Pb^{+2} from water-based medium, and this work discovered that the molecular structure especially the functional group of the chemical structures shows a significant responsibility in the process of adsorption [25, 26].

Another study used cysteine-montmorillonite composites to remove hazardous cations of heavy metal including Zn^{+2} , Co^{+2} , Pb^{+2} , Ni^{+2} , and Hg^{+2} , and the capacity of adsorption in presence of mixture from organic and inorganic ingredients was shown to be greater than that of pure montmorillonitic clay materials [27]. By developing a suitable montmorillonitic clay material, current study might be employed as an effective adsorbent for the treatment of selected synthetic and actual industrial wastewater containing dangerous heavy-metal contaminations.

2. Materials and method

2.1. Materials

Montmorillonitic clay samples provided by Ayash clay Mine at Cairo-Suez district, Egypt, represent Upper Miocene montmorillonitic clays. As a physicochemical adsorbent for the treatment of chosen, synthetic, and actual industrial wastewater, the newly montmorillonitic clay will be employed as a cost-effective, environmentally friendly alternative. The 1 g/l synthetic solutions of Ni^{+2} and Pb^{+2} was prepared for further dilutions. Real industrial wastewater was collected from a metal industry located on the 10th of Ramadan industrial city, the wastewater was acidified to pH below 3 and stored in a refrigerator for further analysis and experimental sequences. Chemicals were used in the study were analytical-grade chemicals obtained from Merck (Germany). Lead chloride $PbCl_2$, hexahydrated nickel chloride, $NiCl_2 \cdot 6H_2O$, HCl, and NaOH. Double distilled water was used for the preparation of the dilutions in all the experiments.

2.2. Methods

Primarily smectite and kaolinite, with some quartz and calcite, are the basic ingredients for montmorillonitic clay. Montmorillonitic clay raw materials were used as an active adsorbate in this research. They were crushed into minor pieces to ensure homogeneous grinding, dried up on the stove at 105 °C for stable weight, and then desiccated for further use. To acquire fine mesh scale particles, ground Montmorillonite was conceded throughout a US Standard Testing Sieve No 100 (150 microns). The Jasco-FTIR-Spectrometer, Japan, was used to measure the absorption

spectra of FT-IR montmorillonitic clay powder in the 350-4000 cm^{-1} range. In the chemical structure of the montmorillonitic clay, this method was used to categorize the functional groups that were present.

Quanta-250 FEG, USA, was used to measure the pore style, surface area, and size of the adsorbent. Scanning electron microscopy with X-ray microanalysis for images and elemental analysis were taken (SEM/EDX) at different magnifications using Quanta-250 FEG, USA. The heavy metal ions concentrations were measured using atomic absorption spectrometer Varian Spectr-AA(220), USA. The synthetic wastewater was tested in a lab environment using lead chloride as a source of Pb^{+2} , and nickel chloride hexahydrate as a source of Ni^{2+} . Desired concentrations of these ions were prepared for different experiments. The pH of solutions was changed to the desired value with HCl and NaOH using a bench pH-meter Jenway 3510.

2.3. Batch experiments

At room temperature (25 °C ±2), the beakers were mixed with a multi-position magnetic stirrer at 200 rpm. The supernatant was filtered throughout the Whatman membrane filters (0.45 μm). The residual metal concentration was measured. The amount of adsorbed metallic ions was calculated as:

$$\text{Adsorption\%} = (C_0 - C_e) \times \frac{100}{C_0} \quad (1)$$

Where C_0 and C_e are the initial and final concentrations of metal ion in (mg/l) The number of metal ions (qt at time t) adsorbed by adsorbent (M) was estimated utilizing the subsequent equivalence:

$$q_t = (C_0 - C_t)V/M \quad (2)$$

C_t is the concentration (mg/l) of metal ion after time t min., V is the volume of initial metal ion in a liter, and M is the adsorbent mass used in gram. The adsorption capacity (q_e) was defined when equilibrium reached:

$$q_e = (C_0 - C_e)V/M \quad (3)$$

2.4. Adsorption Isotherms

Isotherm models evaluate the maximum adsorption capacity of adsorbing materials to the adsorbed substances, which helps in the assessment of the feasibility of the treatment process for a specific application, the required dose of adsorbent, and the selection of the most suitable sorbent for the given case. Langmuir [28] and Freundlich [29] models are the most used isotherm models for describing the isotherm of a single solute.

2.4.1 Langmuir isotherm:

It depends on maximum adsorption corresponds to a saturated monolayer of adsorbate molecules on the surface of the clay.

The Langmuir isotherm is presented in:

$$q_e = \frac{q_{\max} * K_L C_e}{1 + K_L C_e} \quad (4)$$

Linearized form is:

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{1}{q_m} * C_e \quad (5)$$

$$\text{Slope} = \frac{1}{q_m} \quad (6)$$

$$\text{Intercept} = \frac{1}{q_m K_L} \quad (7)$$

Where q_m and K_L are Langmuir constants related respectively to the sorption capacity, and sorption energy, C_e (mg/l) is the equilibrium concentration and q_e (mg/g) is the adsorption capacity at equilibrium. R_L is the essential characteristic of Langmuir dimensionless constant separation factor or equilibrium parameter which was defined by the following equation.

$$R_L = \frac{1}{1 + K_L * C_0} \quad (8)$$

R_L calculated values from the above equation show the nature of the adsorption process to be either unfavourable ($R_L > 1$), linear when ($R_L = 1$), favourable when ($0 < R_L < 1$), and irreversible when ($R_L = 0$).

2.4.2 Freundlich isotherm:

It involves surface heterogeneity and the exponential distribution of active sites and their energies.

The Freundlich isotherm equation is presented as:

$$q_e = C_e^{\frac{1}{n}} \quad (9)$$

Linearized form is:

$$\ln q_e = \ln K_F + \left(\frac{1}{n}\right) \ln C_e \quad (10)$$

And the ((n)) calculated from the equation:

$$\text{Slope} = \frac{1}{n} \quad (11)$$

And the (K_F) is calculated as the anti-ln of the intercept as:

$$\text{Intercept} = \ln K_F \quad (12)$$

Where q_e (mg/g) is the adsorption capacity at equilibrium, C_e (mg/l) is the concentration of metal ions at equilibrium, K_F is a constant related to the temperature and, n is a characteristic constant.

The real industrial effluent sample was collected from a metal industry on the 10th of Ramadan industrial city, Egypt. It was carefully bottled in a plastic container, acidified to $\text{pH} \leq 3$, and taken to the laboratory for analysis. All water analyses were carried out according to (APHA 2017).

3. Results and discussion

3.1. Characterization of the montmorillonitic clay

As illustrated in Fig. 1, natural montmorillonitic clay samples were analyzed using FT-IR. The IR spectra of the pure clay revealed the typical bands that have been found in other natural bentonite IR spectrums previously published [23]. Several functional groupings have been discovered in the composite of montmorillonite that has been produced. At 3437 cm^{-1} , the stretching shuddering of $-\text{OH}$ generated a dominating peak [30]. Disproportionate and proportionate enlarging pulsations of a $-\text{COOH}$ in the adsorbent fragment are responsible for the appearance of distinct bands at 1632 and 1424 cm^{-1} . Vibrations of $-\text{C-H}$ at 1376 cm^{-1} are responsible for a tiny, strong peak. Si-O-Si stretching vibrations may also be responsible for the 1035 cm^{-1} peak, and $-\text{C-O}-$ stretching vibrations may be responsible for both 900 and 1180 cm^{-1} peaks [30, 31]. FeO vibration peaks are also responsible for the 520 cm^{-1} and 462 cm^{-1} peaks detected [32].

Probably, the hazardous contaminants ions and the reactive sites on the functional groups on the surface of adsorbent interact for a composite of montmorillonite to be able to sorb them. This was validated by investigating the frequencies of vibration of adsorbent primary operational component, ($-\text{COO}-$). Samples recovered following removal of Ni^{+2} and Pb^{+2} metallic ions were analyzed using FT-IR. As for the batch adsorption experiment, it was done at 25°C with an adsorbate concentration of 10 mg/l and adsorbent dosage of 2 g/l ($\text{pH}=4.5$). Ni^{+2} and Pb^{+2} induced FT-IR spectra are shown in Fig. 2.

FTIR is utilized to identify functional groups responsible for hazardous metallic ion removal in a composite of adsorbent before adsorption. At 1621 and 1431 cm^{-1} , the FTIR chart of the montmorillonitic clayey materials revealed two $-\text{COO}-$ modes of vibration the irregular $-\text{COO}-$ elongating (vasym) and the symmetric $\text{COO}-$ stretching (sym). A minor shift in the frequency values from 1621 to 1615 cm^{-1} and 1431 to 1425 cm^{-1} was detected after Pb^{+2} and Ni^{+2} metal ion adsorbed. Anticipated to the distinct composite carboxylate groups of chemical environments with specific metallic ions, this result may have been produced.

According to Chiew and coworkers, Pb^{+2} ions are adsorbable to nanocomposite montmorillonite and interact

with oxygen atoms in two neighboring -COOH groups to neutralize their charge and maintain their structure. They also found that the -COOH groups in the adsorbent molecule are the primary sites for ion exchange, with the hydroxyl groups having just a minor role. The present Fe_2O_3 in the materials forms internal sphere complexes with metalloid species, which is clarified by straight removal on the Fe-modified surface of composite since it is trailed by intra-fragment dispersion into the internal portion. Our earlier work validated and described the probable binding process of the composite of Fe-modified sericite montmorillonitic clay [33,34].

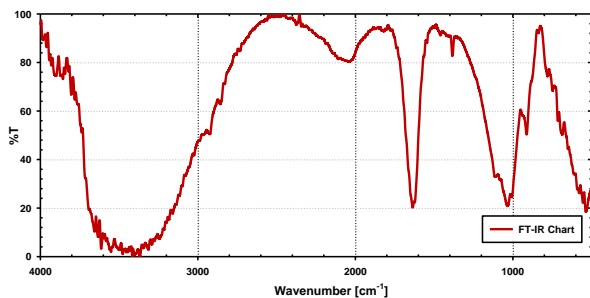


Fig. 1: FTIR spectra of montmorillonitic clay

By using SEM, the original bentonite and composite bead's surface structures were examined, as shown in Fig. 2 [43]. It was apparent from the SEM pictures that the natural bentonite sample was very compact, with layers/flakes as its morphology. As opposed to the composite of montmorillonite whose pictures show microscopic nanoholes, which might have a considerable starring role in the absorption of heavy metal ions from the water. Furthermore, the adsorbent surface was uneven and dissimilar. By using the SEM-EDX technique, Figs. 2,3 the SEM images showed particle size ranged between constituents in the composite bead were identified and shown visually O2, 40, 43.85, C,16.7, Na, 4.54, 4.48, Mg, 1.16, 0.45, Al, 13.8, 10, Si, 26.52, 16.58, Ca, 0.42, 0.27Cl, 3.67, Fe, 11.4, 729.

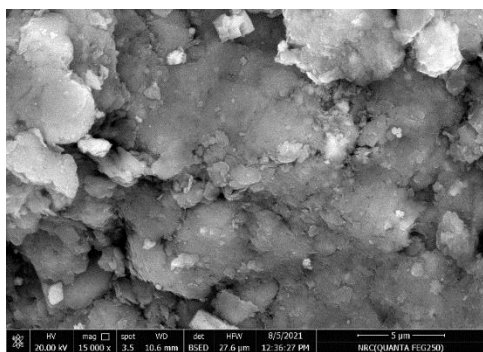


Fig. 2: SEM image for the montmorillonitic clay

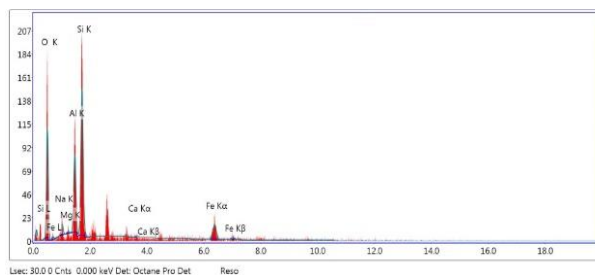


Fig. 3: EDX of the montmorillonitic clay

3.2. Batch adsorption experiments

3.2.1. Effect of pH

The impact of solution pH on the removal of lead and nickel was studied in the batch way at start pH ranges of 2 to 7, using sorbate concentrations of 10 mg/l, individually, a dose of 5 g/l of the montmorillonitic clay and stirring for 3 hours were applied. These hazardous contaminants were removed at a certain proportion depending on the starting pH. pH was raised from 2 to 7 to remove Pb and Ni from the polluted media, as shown by the graph (Fig. 4). Overall, this is due to -COOH groups or reactive spots on the adsorbent being extra negative at elevated pH levels since in turn increases the electrostatic interaction in the middle of metallic ion and adsorbent molecules. Lead and nickel, on the other hand, showed relatively modest absorption (99% and 96%, respectively) underneath this pH or under extra acidic pH circumstances. H^+ ions may participate with Pb^{+2} and Ni^{+2} cations for the same reactive spots [35].

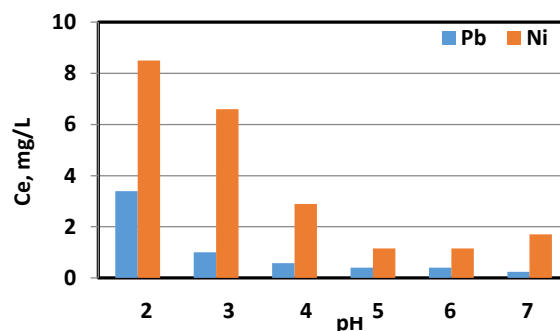


Fig. 4: Effect of pH on removal of heavy metals

3.2.2. Effect of sorbent dose

This was done by varying the amount of montmorillonitic clay powder from 0.1 to 10 grams per liter while keeping the following constants: pH, 5-6, contact time, 3 hours, and solution volume 100 ml, 10 mg/l concentration of the metal individually, all at (25 °C). With increasing montmorillonitic clay content, the proportion of Pb^{+2} and Ni^{+2} eliminated from the clay increases from 0.01 to 1 see Fig. 5. The absorption of metallic ions decreases as montmorillonitic clay increases. This is due to an increase in

the number of clay particles that have larger surface areas suitable for metal ion attachment as the adsorbent dosage is increased for Pb^{+2} and Ni^{+2} .

At lower adsorbent loading, metal ions are saturating the attachment sites on the montmorillonitic clay particles. The greater individual uptakes under certain situations can be explained in this way Metal ions, which were limited due to montmorillonitic clay's growth, could no longer reach these regions. Additionally, increasing the dose of adsorbent results in increase in exchangeable sites or surface area quality as well as an improvement of heavy metal removal.

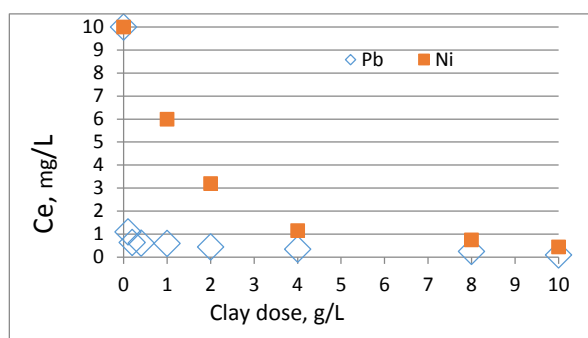


Fig. 5: Effect of montmorillonitic clay dose on the removal of heavy metals

3.2.3. Contact time

Different durations of contact time from 5 to 360 minutes were examined under ideal circumstances to ascertain the impact of time on the removal of Pb^{+2} and Ni^{+2} by montmorillonitic clay powder as presented in Fig. 6. Under the following circumstances: optimum pH value of 5 -6 for each metal, a preliminary load of 10 mg/l, a solution volume of 100 ml, a shaking velocity of 200 rpm, adsorbent dose of 0.2 g/l for lead, and 4 g/l in case of nickel, and room temperature (25 °C), the experiments were carried out under these optimum conditions. It was determined that the adsorption of Pb^{+2} and Ni^{+2} by montmorillonitic clay powder was affected by time at intervals ranging from 5 to 360 minutes for reaching absorption – desorption equilibrium. Based on the data shown in this graph, the removal efficiency increased with increasing dwell time.

After 15 minutes, equilibrium is attained. Montmorillonite may have undergone two phases of adsorption of metallic ions. A high amount of adsorption was first observed due to the sizeable quantity of active sites on the adsorbent surface that was accessible for attaching with the metallic ions at first. This amount of absorption is affected by the ratio at which the reactive point of adsorbate is conveyed from the surface to internal locations for the particles of adsorbent. The adsorption process achieved equilibrium when the number of accessible sites that were difficult to occupy owing to repulsion forces during the adsorption of metallic ions into the surface of the adsorbent and the major process decreased.

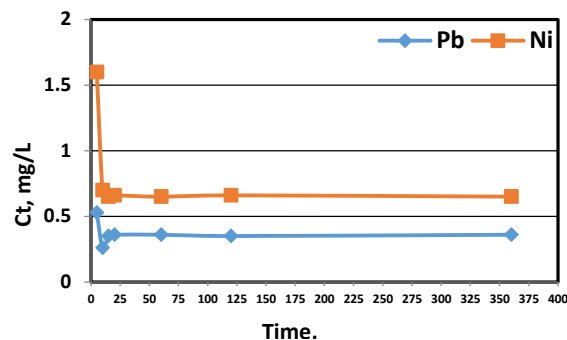


Fig. 6: Effect of contact time on the removal of heavy metals reaching equilibrium

3.2.4. Initial Concentration of Metal Ions

While maintaining constant parameters such as pH of 5 -6 for each metal, time, 15 min. and dosage of each metal 10 mg/l, adsorbent dose of 0.2 g/l for lead, and 4 g/l in case of nickel with solution volume of 100 ml, shaking velocity of 200 rpm, and room temperature of 25 °C, the effect of changing the preliminary metallic-ion load on the exclusion of metals ions by Montmorillonite powder was examined over a range from (2–20 mg/l). Fig. 7 shows the impact of different prior metallic ion loading of Pb^{+2} and Ni^{+2} on the removal effectiveness of Montmorillonite powder. Depending on the main load of metallic ions, adsorption capabilities were determined (q_e). Since an amount of adsorbent can only hold a specific amount of adsorbate, the main load of metallic ions is important.

Metal ion mass transition barriers between the liquid and solid phases are thought to be overcome by increasing primary metal loads. Due to the limited capacity of the montmorillonitic clay surface's adsorption sites, additional metal ion binding is expected to occur as the load increases. An important component of investigating both the selective and non-precise adsorption of pollutants by an adsorptive raw material is the effect of ionic strength.

Through electrostatic attraction, the hazardous ions are attracted to the surface of the adsorbent, where they form outer-sphere complexes. Contrariwise, pollutant-specific adsorption was achieved by direct binding between pollutant and adsorption surface, which culminated in the formation of an internal domain of complexes containing reactive functional groups in the domain of the selected material.

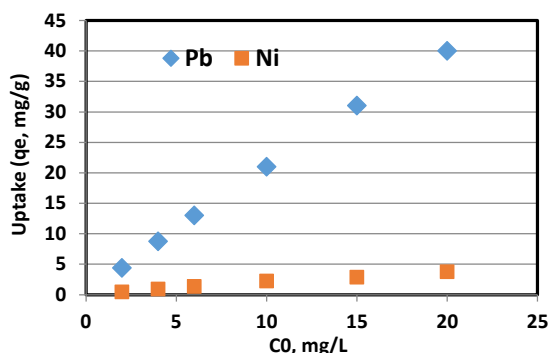


Fig. 7: Effect of initial concentration on heavy metal uptake

3.3. Adsorption isotherm

Montmorillonitic clay were used to study the concentration-dependent sorption of Ni^{+2} , and Pb^{+2} . Initial concentrations ranged from 2-20 mg/l for Ni^{+2} and also for Pb^{+2} . In these studies, the initial pH of the liquids was kept at values of 5-6 and the final pH value was around 6, the clay dose, 0.2 g/l for lead and 4 g/l for nickel and the contact time, 15 minutes for both elements. The relation between the concentration of the solute in the aqueous phase and the amount of solute adsorbed is presented by the adsorption isotherm equation which describes the adsorption process. The Langmuir and the Freundlich adsorption isotherm equations have been successfully applied to the adsorption processes.

From equation (5), and their plots (Figs. 8,9), the charts of Langmuir isotherm showed a high correlation for both heavy metals, Pb^{+2} and Ni^{+2} , more than 0.98 and 0.96 respectively, that meant the experimental data are reproducible, lead showed more correlation than a nickel.

From equation (8), the R_L -values for the adsorption process of both heavy metals with montmorillonitic clay have values between 0 and 1, indicating the adsorption process is favourable (Tables 1,2).

Table 1: Langmuir constants for the sorption of Pb^{+2} onto montmorillonitic clay

Slope	Intercept	qm	KL	RL	R ²
0.0122	0.0524	81.96	4.295	0.012-0.1	0.9857

Table 2: Langmuir constants for the sorption of Ni^{+2} onto montmorillonitic clay

Slope	Intercept	qm	KL	RL	R ²
0.2304	0.2834	4.34	1.23	0.04-0.29	0.9655

From equation (10) and their plots (Figs. 10,11), the charts of Freundlich isotherm showed a high correlation for both heavy metals, Pb^{+2} and Ni^{+2} , more than 0.99 and 0.95 respectively that meant the experimental data are reproducible, lead showed more correlation than a nickel. On the other hand, the n- value for the adsorption process of lead onto montmorillonitic clay has a positive value, more than 1, indicating a normal adsorption process, but a cooperative sorption process is presented by adsorption of nickel ions, where the value of n is less than 1 (Tables 3,4).

Table 3: Freundlich constants for the sorption of Pb^{+2} onto the montmorillonitic clay

slope	intercept	n	KF	R ²
0.78	2.6696	1.282051	14.43419	0.995

Table 4: Freundlich constants for the sorption of Ni^{+2} onto the montmorillonitic clay

slope	intercept	n	KF	R ²
1.758	-0.8786	0.568828	0.415364	0.9549

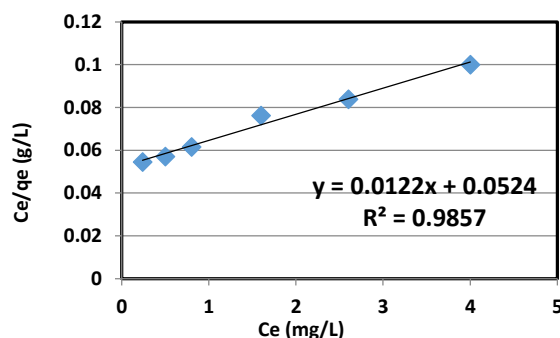


Fig. 8: Langmuir isotherm of Lead

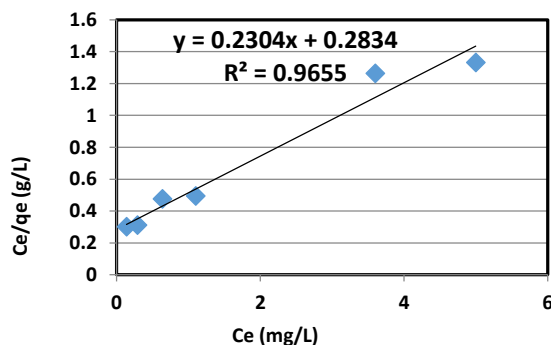


Fig. 9: Langmuir isotherm of Nickel

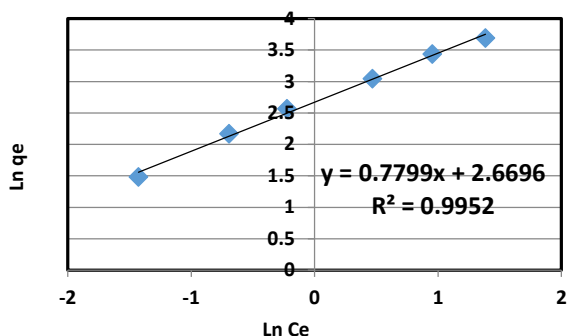


Fig. 10: Freundlich isotherm of Lead

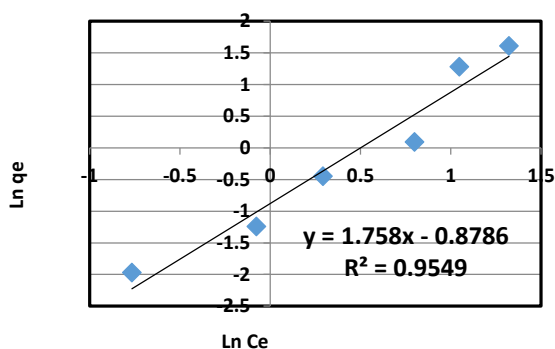


Fig. 11: Freundlich isotherm of Nickel

3.4. Application

Real industrial wastewater was collected from a metal industry located at 10th of Ramadan industrial city; the wastewater analysis is illustrated in Table 5. 1 g/l of montmorillonitic clay was added to the wastewater and stirred for one hour and the treated effluent is subjected to filtration for further analysis, Table 5.

Table 5: Physicochemical characterization of industrial wastewater before and after treatment

parameter	unit	Raw Wastewater	Treated effluent	% Removal
pH	-	6	6.3	-
COD	mg/L	59	44	25.42
TDS	mg/L	640	675	-6
TKN	mg/L	44	20	54.55
TP	mg/L	25	25	0
Pb	mg/L	0.635	0.162	74.49
Cu	mg/L	0.488	0.267	45.29
Ni	mg/L	0.253	0.059	76.68
Cd	mg/L	2.413	1.343	44.34
Mn	mg/L	3.921	1.876	52.16
Cr	mg/L	0.536	0.212	60.45
Co	mg/L	0.21	0.056	73.33

From Table 5, TDS was not exceeding for high ranges, only 6% rise during the experiment, due to the

montmorillonitic clay salts effect, it meant that the montmorillonitic clay was safe and eco-friendly. But COD is removed by more than 25%, TKN was removed by more than 54%. On the other hand, hazardous heavy metals were removed by more than, 74%, 45%, 76.68%, 44%, 52%, 60%, and 73% for Pb, Cu, Ni, Cd, Mn, Cr, and Co ions respectively. The results recorded above in Table 5 proved the effectiveness of the montmorillonitic clay in low concentration (1 g/l) in purifying the real industrial wastewater from different pollutants in varying proportions.

Conclusion

Montmorillonite composite including iron oxide montmorillonitic clay montmorillonite was effectively produced and utilized to remove hazardous contaminants from aqueous solutions Ni²⁺, and Pb²⁺. Images taken using a scanning electron microscope demonstrate that the composite of montmorillonite has mixed surfaces and mini pores on their surface. According to EDX analysis, the primary elements in the adsorbent sample are C of about 70%, Si of about 11.26%, Fe of about 9.18%, Al of about 2.95%, and Ca of about 5.12%. According to the obtained data from the BET technique, the composite of montmorillonite has a surface area of 433 m²/g. Ni²⁺ and Pb²⁺ was removed more efficiently with the composite of montmorillonite at higher pH values.

It was observed that the Langmuir monolayer adsorption capacities for the elements of Pb²⁺, and Ni²⁺ were 40 mg/g, and 3.75 mg/g individually, for the composite of montmorillonite. In addition, intra-particle diffusion is important in the elimination of these two hazardous ions. The montmorillonitic clay composite of montmorillonite is environmentally benign, cost-effective, and sustainable according to the researchers, TDS was not exceeding for high ranges, only 6% rise during the experiment, due to the montmorillonitic clay salts effect, it meant that the montmorillonitic clay was safe and eco-friendly. Ni²⁺ and Pb²⁺ and a mixture of heavy metals and other organic pollutants were removed from real industrial wastewater using these composites of montmorillonitic clay.

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