

The Use Of Agricultural Waste In Solving Of Environmental Problems In Democratic Republic Of The Congo

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Abstract— The presence of chromium in wastewaters produced from mining industries in Democratic Republic of the Congo is harmful for the environment. As a promising and polishing method for heavy metals removal from wastewaters, adsorption has been used with agricultural waste as low adsorbent. In this study, the use of sugar beet pulp has been investigated for the removal of hexavalent chromium from aqueous in batch adsorption mode. Adsorption experiments were conducted to obtain the optimal conditions combinations for the highest percent removal. Four parameters were studied such as contact time (30–180min), initial chromium concentration (10-50mg/L), pH (2-9) and solid to liquid ratio (0.25 g/100 mL-3 g/100 mL). However, the agitation rate was equal to 100 rpm and the room temperature was considered. The highest percent removals of 90.53% for 10 ppm concentration and 76.34% for 50 ppm concentration were achieved at the following conditions: pH 2, contact time 90 min, S/L ratios of 2 g/100 mL and 3 g/100 mL respectively. Langmuir and Freundlich adsorption isotherms were used for the mathematical description of adsorption equilibrium. Freundlich isotherm fitted well the equilibrium data. The maximum capacity (Q_{max}) from the Langmuir isotherm was found to be 11.299 mg/g. These results indicated that sugar beet pulp can be used as low cost adsorbent for the removal of chromium from mining industries wastewater to avoid environmental problems.

Keywords— Adsorption, Hexavalent chromium, Mining companies, Sugar beet pulp, Wastewater

I. INTRODUCTION

Mining industries in the Democratic Republic of the Congo (D.R.C.) are implied in the extraction of several matters as copper, diamond, tantalum, tin, gold, coltan (from which the extracts of niobium and tantalum are extracted), and produce more than 70% cobalt produced worldwide. These industries put together a set that includes exploration activities and mining of minerals, rare earth and metals. The Greater Katanga region, located in the southeastern part of the D.R.C., contains several copper and cobalt minerals deposits that have been exploited in industry since the last century [1]. The region is the richest in the world in cobalt and the second in copper after Chile. [2] have shown that the two main sources of heavy metals in polluted water are known: natural and man-made. And according to [3], mining pollution and non-ferrous metals are the main containers of heavy metals that have been banned from the environment.

Several mining process industries and concentration mineral processing plants reject wastewater containing a certain amount of heavy metals. The discharges produced contain large amounts of heavy metals in solid, gaseous, and wastewater forms. These metals (such as copper, cobalt, chromium, zinc, lead, iron), volatile organic compounds, suspended solids, acidic and basic compounds, are harmful to the environment.

They affect humans, animals and plants, and can be sources of diseases such as cancer, respiratory insufficiency, eye diseases, and skin irritations, renal insufficiency and gastrointestinal problems [4].

According to [5]-[7], heavy metals have become a serious issue of environment and public health concern due to their toxicities, bioaccumulation in the human body and food chain, carcinogenicities, and mutagenesis in various living organisms. Also, they may also negatively impact by seriously decreasing the tenacity of the organism by enhancing susceptibility to impairment and diseases [8].

In this study, the average values of the metals ubiquitous in liquid effluents are: silver (25.9 times the standard value), arsenic (4.65 times the standard value), copper (11.4 times the standard value), chromium (6.5 times the standard value), iron (52 times the standard value), manganese (71 times the standard value) and zinc (16.83 times the standard value). Chromium, especially the hexavalent chromium Cr(VI) that causes many negative effects to the environment, is considered in this study. Moreover, wastewaters rejected contain low level of chromium but 6.5 times the allowable maximum level. So that they represent an environmental pollution and a risk to the health of humans and animals. Research on the collection of Cr(VI) in polluted water is particularly important because of its high toxicity, carcinogenicity and the harmful effects of mutagenicity on living organisms [9]-[14].

Sugar beet pulp, a product of the agricultural processing industry, has proven to be an effective and efficient way to remove Cr(VI) from wastewaters [15]-[17]. The purpose of this work is to extract Cr(VI) from contaminated water by adsorption using the dried sugar beet pulp as adsorbent for better utilization of environmental problems in the Democratic Republic of the Congo under optimal conditions such as contact time, initial concentration, pH and solid to liquid (S/L) ratio for effective removal of Cr(VI). Also the study of the system equilibrium using Langmuir and Freundlich isotherms, followed by the determination of the maximum adsorption capacity of sugar beet pulp, are investigated.

II. MATERIALS AND METHODS

2.1. Preparation of adsorbent

After sugar extraction, sugar beet pulp was collected as agricultural waste from a factory in Alexandria (Egypt), and this material was subjected to a number of treatments to remove Cr(VI). It was carefully washed with tap water in order to eliminate undesirable solid particles and other remained compound after sugar extraction. The washed material was cut in small parts to increase contact surface, and spread for air drying. Then, it was oven dried at $100\pm 5^{\circ}\text{C}$ for 3 hours. The dried sugar beet pulp was cooled at room temperature for 1 hour and grinded into small particles. After that, it was sieved with vibratory sieves for 20 minutes and the considered particle of powder was $<600\ \mu\text{m}$. Fig. 1 below shows the adsorbent preparation.



Fig. 1. Adsorbent preparation

The obtained dried beet pulp was used for further experiments of adsorption.

2.2. Preparation of Cr(VI) solution

Stock solutions of potassium dichromate $\text{K}_2\text{Cr}_2\text{O}_7$ (1000 ppm Cr(VI)) were prepared by dissolving accurately weighted 2.8282 grams of potassium dichromate in 1 L distilled water and the operation was repeated to obtain 2 L of solution. Then low concentration solutions were prepared by dissolving stock solution to 10, 20, 30, 40 and 50 ppm Cr(VI) working solutions respectively.

2.3. Adsorption experiments

The setup was composed of small bottles of 100 mL volume and a shaker. At a wave length of 540 nm, a UV-visible spectrophotometer with a 1 cm quartz cell was used to measure the absorbance of Cr(VI). The pH-metre was also used to measure pH.

Prior to the experiment, spectrophotometry was used to determine the amount of chromium in low concentration solutions 10-50 ppm Cr(VI) in order to plot the calibration curve. Following the determination of the amount of chromium in the samples and the plot of the calibration curve, the adsorption efficiency onto dried sugar beet pulp was evaluated using different chromium initial concentrations, contact time, pH, and solid to liquid (S/L) ratios. Eqs. (1) and (2) below were used to calculate adsorption efficiency in percent and milligrams of Cr adsorbed per gram of adsorbent.

$$\%R = \left(\frac{C_0 - C_f}{C_0} \right) \times 100 \tag{1}$$

where %R is percent removal, C_0 is initial concentration and C_f concentration after adsorption.

$$q = \frac{V(C_0 - C_f)}{m} \tag{2}$$

where q is adsorption capacity in mg/g, C_0 is initial concentration, C_f concentration after adsorption, m is adsorbent mass in gram and V is volume of wastewater used during the experiment.

Stock solutions of potassium dichromate $K_2Cr_2O_7$ (1000 ppm Cr(VI)) were prepared by dissolving accurately weighted 2.8282 grams of potassium dichromate in 1 L distilled water and the operation was repeated to obtain 2 L of solution. Then low concentration solutions were prepared by dissolving stock solution to 10, 20, 30, 40 and 50 ppm Cr(VI) working solutions respectively.

All experiments were conducted in batch mode at room temperature by agitating (100 rpm) weighed quantities of adsorbent in 100 ml of chromium solutions at the required pH, contact time, initial concentration, and S/L ratio. These experiments were carried out in a variety of small brown bottles with a capacity of 100 ml and each bottle received a predetermined amount of adsorbent. After shaking for appropriate time, the sample was collected and filtered through a Whatman membrane filter paper with a pore size of 0.45×10^{-12} m. The filtrated sample was stocked in 100 mL small brown bottles for further spectrophotometry analysis for the remaining chromium in the solution. The Fig. 2 shows the adsorption process of experiments.

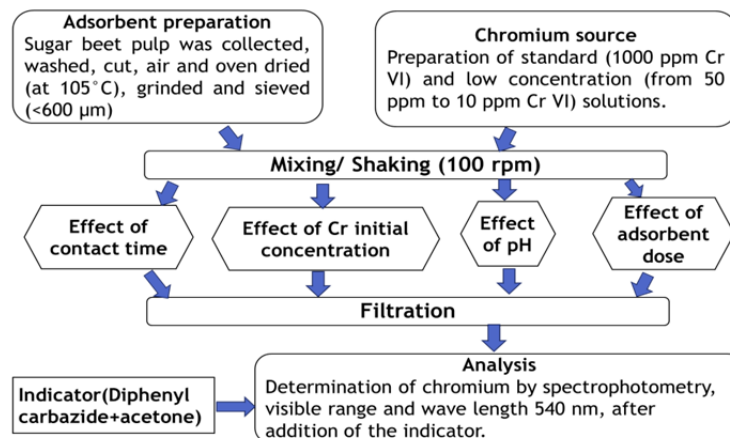


Fig. 2. Chromium adsorption process using sugar beet pulp

Due to the sensitivity of 1,5-diphenyl carbazide (DPC), the indicator was prepared 24 hours before spectrophotometry by dissolving it in acetone at a 5:1 mg of diphenyl per mL of acetone ratio. Experimental measurements have been investigated using the Langmuir and Freundlich isotherm models.

The pH adjustment was done into 400 mL beakers by addition of prepared H_2SO_4 and NaOH for acidic and alkaline ranges respectively, followed by vibration with a magnetic field until the pH is reached. The adsorption process during the test was performed according to Fig. 3 below.

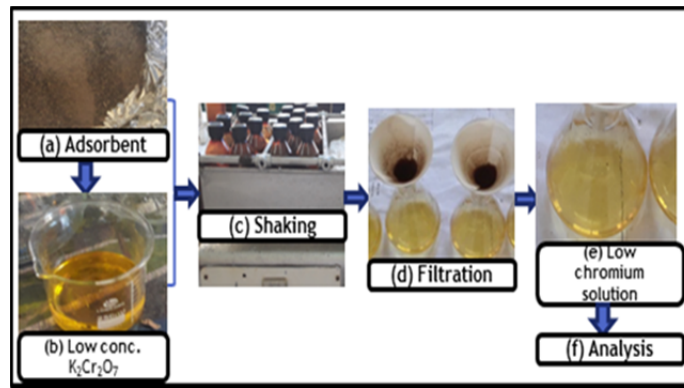


Fig. 3. Chromium removal process

The remaining chromium in the solution was determined using spectrophotometry on the samples. Daily, a stock diphenyl carbazide solution was prepared as indicator. Cr(VI) reacts with DPC to form a reddish violet complex, but no pink color is formed on complexation with 1,5-diphenylcarbazide due to its low sensitivity of Cr(VI) and the low detection range of Cr (VI) in samples.

III. RESULTS AND DISCUSSION

After the analysis by spectrophotometry of low concentration solutions (10-50 ppm Cr(VI)) before bath adsorption process, a calibration curve was obtained with equation $y = 0.317x$ and $R^2=0.9334$, where y is absorbance and x is Cr(VI) concentration in ppm. All of the experiments were carried out in closed 100mL small brown bottles on a shaker at a speed of 100 rpm and with a specific pH. The experiments were carried out at room temperature. When the adsorption time was up, the adsorbent and solution were filtered through Whatman 0.45×10^{-12} m filter paper. After that, the solutions were filtered and analyzed to determine the metal ion concentration..

3.1. Effect of contact time

The experiment was carried out by varying the contact time from 30 to 180 minutes for initial Cr(VI) concentrations in the range of 10 to 50 ppm at pH=5, at 30 minute intervals, and at a S/L ratio of 1/100 g/mL.

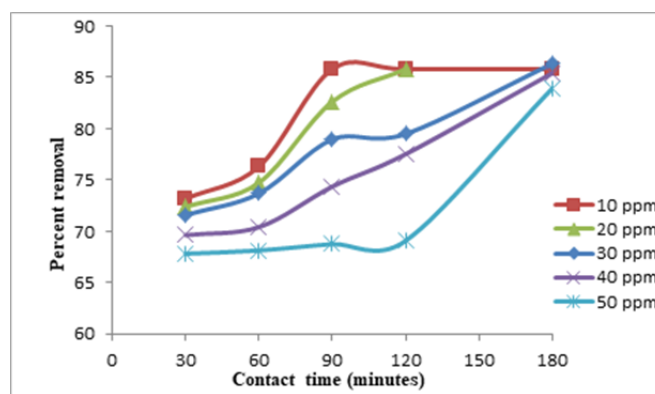


Fig. 4. Effect of contact time on Cr(VI) percent removal (pH: 5, S/L ratio: 1/100 g/mL)

Fig. 4 demonstrates that contact time has a significant influence on the adsorption process, and that adsorption appears to occur in two stages. The first phase involved rapid metal adsorption due to the presence of large vacant sites, with more than 75% and 68% of the adsorption occurring in the first 60 minutes for initial Cr(VI) concentrations of 10 ppm and 50 ppm respectively. The second phase involved reaching a certain percent removal equilibrium, which resulted in Cr(VI) adsorption and curve flattening after 90 minutes for 10 ppm initial concentration and 120 minutes for 20 ppm initial concentration. Furthermore, increasing the contact time had no effect on the percent removal of Cr(VI) at 50 ppm initial concentration until 120 minutes, at which point the percent removal suddenly increases. The reason is that the lower and upper layers no longer have any vacant sites as time passes, causing the repulsion between sugar beet pulp and Cr(VI). As a result, the adsorption equilibrium time for both 10

ppm and 50 ppm initial concentrations was set to 90 minutes. After reaching equilibrium, there was no significant increase in percent removal with increasing contact time for initial concentrations of 10 and 20 ppm only. Results are in good agreement with the results of several earlier researchers [15]-[18].

3.2. Effect of Cr(VI) initial concentration

The Adsorption experiments were carried out with initial Cr concentrations ranging from 10 to 50 mg/L and a fixed pH and S/L ratio of 5 and 1g/100mL respectively. Fig. 5 depicts the effect of initial Cr(VI) concentration on the percent removal using dried sugar beet pulp.

The results show that as the initial Cr(VI) concentration increases, the percentage removal decreases. Fig. 5 shows that for contact times ranging from 30 to 90 minutes and an initial Cr(VI) concentration of 10 ppm, Cr(VI) removal ranges from 73.18 to 85.80 %. When the initial Cr(VI) concentration reaches 50 ppm, the percent removal ranges from 67.82 to 69.08 % for contact times ranging from 30 to 90 minutes.

The explanation is that all adsorbents have a finite number of active sites packed in one place. The initial increase in absorption percentage is rapid. This is because a large number of empty surfaces are available for absorption during the initial phase.

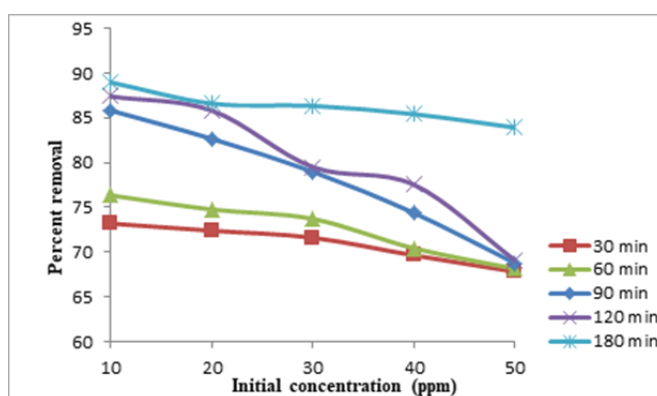


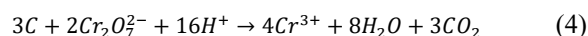
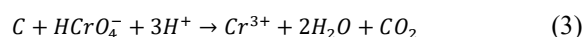
Fig. 5. Effect of initial concentration on Cr(VI) percent removal (pH: 5, S/L ratio: 1/100 g/mL)

According to (1), another reason for the reduction in percentage emissions is the greater increase in the value of denominator (C_0) than the value of ($C_0 - C_e$), as stated also by [19].

At low initial Cr(VI) concentrations, the adsorbent's available surface area for Cr(VI) adsorption ratio at specific time was large. The effect of initial concentration has almost insignificant effect at 180 minutes contact time. However, as the initial Cr(VI) concentration in the solution increases, the ratio of adsorbent surface area to available Cr(VI) concentration decreases, and thus percentage adsorption decreases slightly after 30 and 60 minutes only. The decrease of initial Cr(VI) concentration was most significant at 90 and 120 minutes contact time. Moreover, the formation of a barrier around the adsorbent molecular surface by the adsorbed Cr(VI) molecule occurred after the saturation of the adsorbent surfaces.

In addition, due to the gradient of concentration of adsorbed species, there is a driving force created during the process. As the initial concentration increases, the diving power becomes higher which includes an increase in adsorption capacity. Also, the increase in concentration initially involved an increase in the friction between the adsorbent and Cr (VI) types, resulting in an improvement in the driving force to overcome all the mass resistance between solid and liquid phases.

Moreover, the increase of initial concentration involves the decrease of percent removal due to the fact that the carbon present in the sorbents was not sufficient to maintain the reaction equilibrium as shown in Eqs. (3) and (4) below:



3.3. Effect of pH

The effect of solution pH on 10 and 50 ppm Cr(VI) ions adsorption was investigated using sugar beet pulp adsorbent and conducted at different pH values (ranging from 2.0 to 9.0). The pH adjustment was done with the addition of either 0.1 M NaOH or 0.1 M H₂SO₄. The results are presented in Fig. 6.

Fig. 6 show that the percent removal of Cr(VI) decreased with pH increase. It is apparent that with increase in pH from 2 to 10, adsorption of Cr(VI) onto sugar beet pulp decreases from 88.95% to 71.60% for 10 ppm Cr(VI) initial concentration and from 69.71% to 65.93% for 50 ppm Cr(VI) initial concentration. The effects of pH decrease were more significant for initial concentrations of 10 ppm Cr(VI) and almost insignificant for initial concentrations of 50 ppm Cr(VI). The results are in accordance with previous study [14], [15] confirming the strong dependence of Cr(VI) ions in solution on the pH of solution. The maximum pH value for adsorption capacity and the efficiency of Cr(VI) ion removal was 2.

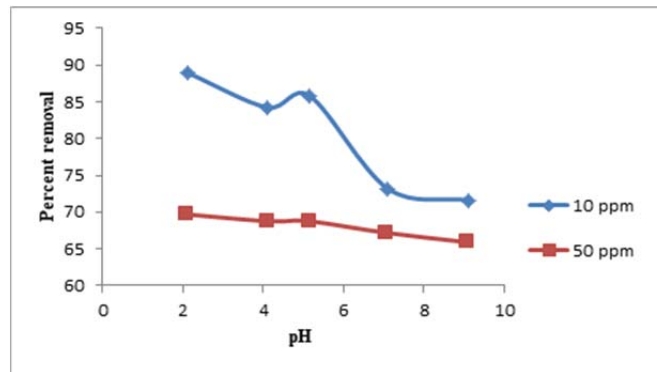
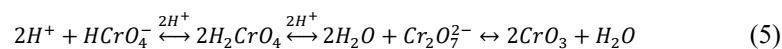


Fig. 6. Effect of pH on Cr(VI) percent removal (Time: 90 minutes, S/L ratio: 1/100 g/mL)

The acidity and core of the solutions can affect the adsorbent surface properties as well as the specification of the metal ion. This is due on the one hand to the fact that the hydrogen ion is a highly competitive adsorbate and on the other hand to the chemical specification of metal ions as a function of solution pH. Metal ion adsorption is affected by both the nature of the adsorbent surface and the species distribution of the metal ions in the aqueous solution [20].

At acidic pH ranges (pH<6), chromium ions various forms are existing such as $Cr_2O_7^{2-}$, $HCrO_4^-$, $Cr_3O_{10}^{2-}$, $Cr_4O_{13}^{2-}$, the predominant species of Cr(VI) are $Cr_2O_7^{2-}$ and $HCrO_4^-$ [20]. Moreover, $HCrO_4^-$ ions forms of Cr(VI) are easily adsorbed in acidic pH environment (pH≈2) due to the reduction of Cr(VI) to Cr(III). The following reaction mechanism for adsorption of Cr(VI) at different pH was proposed according to the following (5) [22]:



Moreover, when the pH is ranged between 2 and 3 values, there is attraction between adsorbent surface (positive charge) and the $HCrO_4^-$ or $Cr_2O_7^{2-}$ ions (negative charges) improving the increase in Cr(VI) absorption percent removal [23]. On another hand, at acidic pH, the reduction of Cr (VI) to Cr (III) increases the percent removal of adsorption onto sugar beet pulp, due to the high presence of H^+ ions in the solution and high redox potential (around 1.3V in standard condition) as shown in the reaction below:



As seen in Eqs. (6) and (7), water and Cr(III) ions are products. At low pH, there is the mechanism of reduction of Cr^{6+} to Cr^{3+} in 3 steps:

- The bind between anionic Cr(VI) species and the positively charged group H^+ present in the solution;
- The reduction of Cr(VI) to Cr(III) by electron donor group;
- The electrostatic repulsion between the adsorbent surface and Cr(III) formed, followed by Cr(III) precipitation.

The process of replacement of trivalent chromium ions (small size) by ions charged positively on the adsorbent surface leads to the liberation of sites and attraction between adsorbent surfaces and $HCrO_4^-$ or $Cr_2O_7^{2-}$ [23]. Adsorption onto rice straw, banana pith, bacterium biomass, pyrolysis corn cobs activated carbon which were used as adsorbents confirmed the increase in Cr(VI) adsorption with decreasing solution pH [24]-[26].

In addition, [22] established that Cr(VI) exists as $HCrO_4^-$ and $Cr_2O_7^{2-}$ species at $pH < 6.0$ and CrO_4^{2-} at $pH > 6.0$. So that, at high pH value, there is ions competition between the anions CrO_4^{2-} and hydroxyl ions (OH^-) (which is predominant) for adsorption onto the adsorbent surface. The adsorbent surface become rapidly deprotonated, and adsorb first OH^- then Cr(VI) ions in small quantity due to lack of available sites. The percent removal in adsorption of Cr(VI) is therefore decreased.

For both 10 ppm and 50 ppm initial concentrations, adsorption of Cr(VI) decreases on increasing pH from 2 to 9 and $pH \approx 2$ was found optimum.

3.4. Effect of S/L ratio

The effect of S/L ratio on 10 and 50 ppm Cr(VI) ions adsorption was investigated using sugar beet pulp adsorbent and conducted at $pH=2$ and 90 minutes contact time.

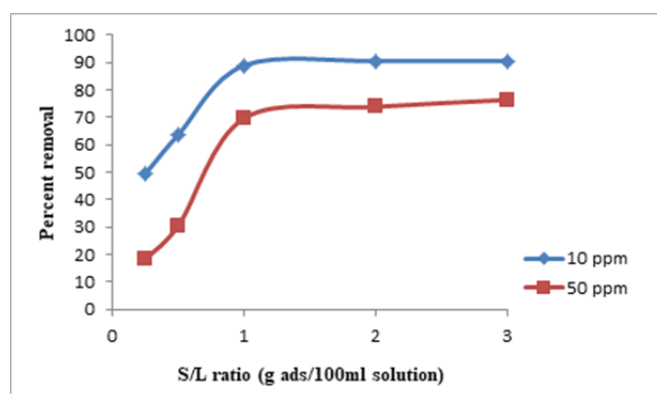


Fig. 7. Effect of S/L ratio on Cr(VI) percent removal ($pH: 2$, Time: 90 minutes)

It is observed from the Fig. 7 that percentage adsorption increases from 49.52% to 90.53% on increasing S/L ratio from 0.25 g/100 mL to 3g/100mL for 10 ppm Cr(VI) initial concentration; and from 18.29% to 76.34% for 50 ppm Cr(VI) initial concentration.

It is assumed that on increasing S/L ratio the availability of exchangeable active sites or the surface area for adsorption onto adsorbent, resulting in increased Cr(VI) adsorption. In addition, the maximum percent removals of 90.53% and 76.34 % were observed at S/L ratios of 2 g/100 mL and 3 g/100 mL respectively.

This suggests that as the amount of adsorbent increased so that the number of sites available for adsorption, resulting in a large area of solid left unsaturated, and Cr(VI) adsorption remained available. On another hand, when the S/L ratio was beyond the optimum value, the percent removal was no longer increased due to achieving the equilibrium state. The results are in accordance with those reported by previous researchers [15], [16]. As a result, the amount of Cr(VI) adsorption increases as the S/L ratio increases but not indefinitely, and a S/L ratio of 1g/100mL is recommended for high Cr(VI) removal.

3.5. Adsorption isotherms

Langmuir and Freundlich isotherms were used to describe the experimental adsorption data considering the studied model and equilibrium isotherm model equations given above. The correlation coefficient (R^2) of the profile which represents the obtained data was used as indication of affinity between equilibrium concentration and adsorption capacity. An equation was also created by analyzing and representing accurately the results obtained for design purposes. The adsorption data can be interpreted using a number of relationships that describe the distribution of Cr(VI) ions between liquid and solid phases. Adsorption isotherm studies were performed with Cr(VI) concentrations ranging from 10 to 50 ppm, at room temperature, $pH=5.2$, with 180 minutes contact time, and a S/L ratio of 1g/100mL. The equilibrium relationship of a single solution system can be expressed as a mathematical (8) below.

$$q_{eq} = f(C_{eq}, T) \tag{8}$$

where C_{eq} is the equilibrium concentration of the adsorbate, q_{eq} is the amount absorbed in the state of equilibrium, and T is the temperature.

3.5.1. Langmuir model.

Equation (9) describes the Langmuir linear form equation:

$$\frac{C_e}{q_e} = \frac{C_e}{q_{max}} + \frac{1}{K_L q_{max}} \tag{9}$$

q_{max} and K_L are calculated through the interference of the Langmuir plot of C_e/q_e vs C_e by calculation of the slope.

3.5.2. Freundlich model.

The Freundlich isotherm states that at different concentrations, there is no consistency in the relationship ratio between the amount of absorbed species onto the adsorbent and the solute concentration. However, it is assumed that the absorber has a different level, which means that the binding sites are not the same. Equation. (10) below highlight the Freundlich adsorption:

$$q_e = K_f C_e^{1/n} \tag{10}$$

where C_e is the equilibrium concentration of the adsorbate (mg/L), q_e is the equilibrium capacity (mg/g), K_f and $1/n$ are Freundlich constants.

The linear form of (10) is the following (11):

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \tag{11}$$

The detailed results of adsorption isotherms are shown in Figs. 8 and 9 below.

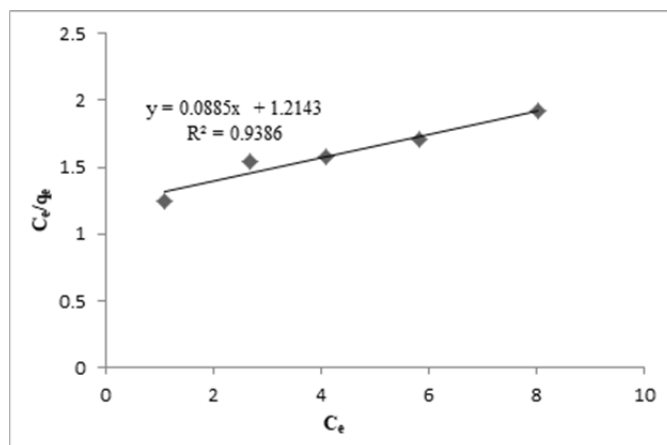


Fig. 8. Linearized Langmuir isotherm for adsorption of Cr(VI) ions onto Sugar beet pulp

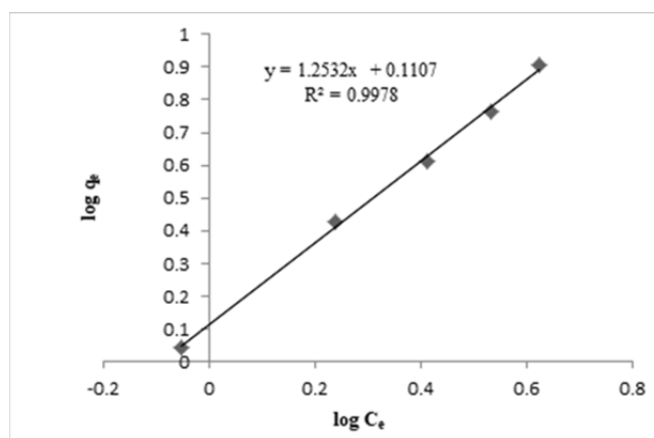


Fig. 9. Freundlich isotherm for adsorption of Cr(VI) ions onto Sugar beet pulp

Adsorption isotherm studies were performed with Cr(VI) concentrations ranging from 10 to 50 ppm, at room temperature, pH=5.2, with 180 minutes contact time, and a S/L ratio of 1g/100mL.

The table 1 below summarizes the Langmuir and Freundlich constants and correlation coefficients.

TABLE I. LANGMUIR AND FREUNDLICH CONSTANTS FOR Cr(VI) IONS ADSORPTION ONTO SUGAR BEET PULP

Langmuir			Freundlich		
$Q_{max}(mg/g)$	K_L (L/mg)	R^2	K_F	N	R^2
11.299435	0.0728815	0.9386	1.29032764	0.79795723	0.9978

Table (1) highlight the results of correlation coefficient and other coefficients values obtained from the Freundlich and Langmuir isotherms. According to the results obtained, the adsorption pattern for Cr(VI) onto sugar beet pulp follows both the Freundlich isotherm ($R^2=0.9978$) and the Langmuir isotherm ($R^2=0.9386$).

According to [28], the adsorption system that obeys both the Freundlich and Langmuir isotherms indicates that the solute forms a homogeneous monolayer on the adsorbent surface. As seen in the above results, Cr(VI) adsorption onto sugar beet pulp obeyed both the Freundlich and Langmuir isotherms, indicating that Cr(VI) formed a monolayer on the adsorbent's surface. However, the Freundlich isotherm was best fitted for the adsorption of Cr(VI) ions onto sugar beet pulp.

The maximum adsorption capacity of sugar beet pulp was found to be 11.299 mg/g.

3.6. Two dimensional (2D) contour plots

These plots were used to gain a better understanding of the interaction effects of the variables under consideration on the percent removal. The relationship between certain variables and their influence on the percentage removal are investigated using 2D contour plots constructed by OriginPro software based on the data obtained. Concentration-time, concentration-pH, and concentration-S/L ratio interactions on the percent removal are all being investigated when the temperature and the agitation speed were 25°C and 100 rpm respectively. These plots are depicted in Figs. 10, 11 and 12.

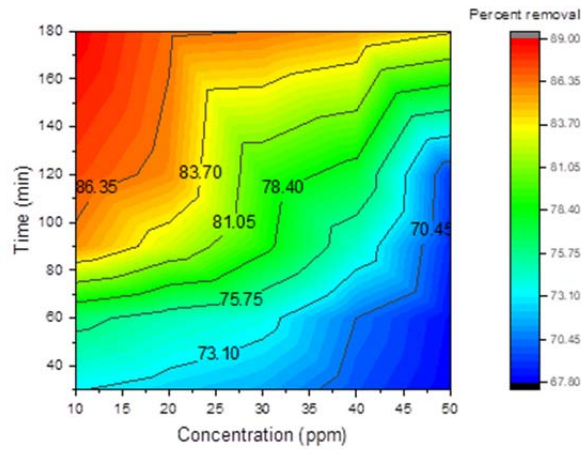


Fig. 10. Effect of concentration-time interaction on percent removal (pH: 5, S/L ratio: 1/100 g/mL)

The contour plot, as shown in Fig. 10, suggests that the area of the highest percent removal was attained at the low level of Cr(VI) concentration and high level of contact time. The percent removal increases with the decrease of concentration and increase of contact time. However, above 85% removal, increasing the concentration has no effect on contact time. Considering this plot, a recovery of about 85 % is obtained at a time of 90 minutes, corresponding to orange-yellow area at 10 ppm concentration. Above 120 minutes of contact time and 10-20 ppm concentration, the area turns completely orange, with a removal rate of around 89 %. After 90 minutes of contact time, the area turns blue (corresponding to a 68% percent removal) when the concentration reaches 45-50 ppm. As a result, it confirms the discussion from Figs. 4 and 5 showing, on the one hand that when the contact time increases the percent removal increases also, and on the other hand when the concentration increases the percent removal decreases.

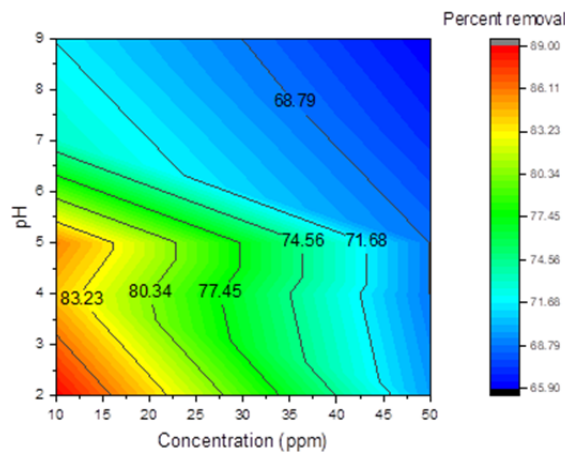


Fig. 11. Effect of concentration-pH interaction on percent removal (Time: 90 min, S/L ratio: 1/100 g/mL)

The effect of pH on percent removal as shown in Fig. 6 was investigated for 10 and 50 ppm Cr(VI) concentrations. Also as shown in Fig. 11, it can be seen the result simulation of percent removal from 10 to 50 ppm Cr(VI) concentrations. The percent removal decreases with the increase of pH, and for fixed value of percent removal the pH decreases with the increase of concentration. Moreover, the completely orange color area (88-89% percent removal) corresponds to a pH of 2.0-2.4 when the concentration is 10-12 ppm, according to the concentration-pH interaction. The percent removal decreases as the concentration increases, and the corresponding area becomes light-blue (69-70% percent removal) at 46-50 ppm and pH range of 2-5. From the above consideration, pH value of 2 is more suitable for Cr(VI) removal from wastewater.

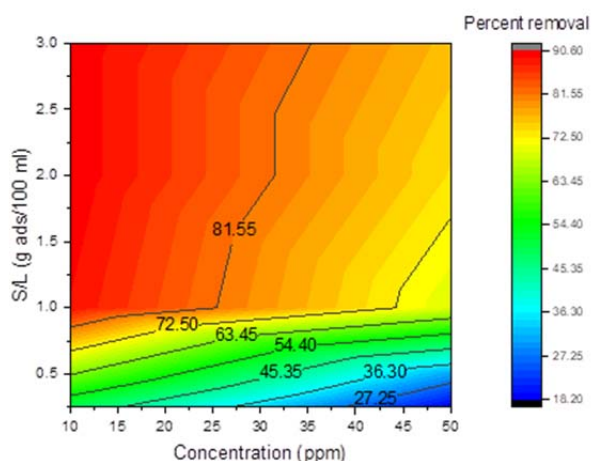


Fig. 12. Effect of concentration-S/L ratio interaction on percent removal (Time: 90 min, pH: 2)

In terms of the concentration and S/L ratio interaction, S/L ratios of 1-3 g/100 mL correspond to the completely orange area (88-90 %) for 10-12 ppm concentration, confirming that equilibrium is reached at 1 g/100 mL. The area color is light-yellow for 50 ppm concentration and 1 g/100 mL, corresponding to approximately 70% percent removal; above 1 g/100 mL, the percent removal increases progressively from 70% to 75% (passing from light-yellow to light-orange).

IV. CONCLUSIONS

Adsorption has been used as an effective method to solve environmental problems in the Democratic Republic of the Congo by removing hexavalent chromium pollutant from industrial wastewater using agricultural waste.

- Increasing the initial concentration decreases the percent removal of Cr(VI).
- Low pH(≈ 2) is recommended for high removal of Cr(VI).
- A S/L ratio of 1/100 is recommended to achieve high percent removal of Cr(VI).
- The highest percent removals of 90.53% (for 10 ppm concentration) and 76.34% (for 50 ppm concentration) were achieved at the following conditions: pH 2, contact time 90 min, and S/L ratios of 2 g/100mL and 3 g/100mL respectively.

According to the research results, sugar beet pulp is an effective low-cost adsorbent that can be used to remove hexavalent chromium from industrial wastewater, as well as an alternative adsorbent in wastewater treatment to solve environmental issues. Furthermore, the benefits of using sugar beet pulp include its availability and low cost during the preparation process.

V. ACKNOWLEDGMENT

This study was supported by the Faculty of Engineering (Chemical Engineering Department) of Alexandria University and the generosity of MSc. Pascal Daniel Pele Omalanga. The authors greatly appreciate their sponsorships and support.

VI. DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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