



## Removal of Dissolved Trivalent Chromium Ions from Contaminated Wastewater using Locally Available Raw Scrap Iron-Aluminum Waste

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### Abstract

The present study is to investigate the possibility of using wastes in the form of scrap iron (ZVI) and/ or aluminum ZVAI for the detention and immobilization of the chromium ions in simulated wastewater. Different batch equilibrium parameters such as contact time (0-250) min, sorbent dose (2-8 g ZVI/100 mL and 0.2-1 g ZVAI/100 mL), initial pH (3-6), initial pollutant concentration of 50 mg/L, and speed of agitation (0-250) rpm were investigated. Maximum contaminant removal efficiency corresponding to (96 %) at 250 min contact time, 1g ZVAI/ 6g ZVI sorbent mass ratio, pH 5.5, pollutant concentration of 50 mg/L initially, and 250 rpm agitation speed were obtained.

The best isotherm model for the batch single Cr(III) uptake by ZVI and / or ZVAI sorbent was found to follow Langmuir (I) with corresponding  $R^2$  greater than 0.9115. Kinetics data for the sorption of Cr(III) onto ZVAI/ZVI mixture and due to the good agreement between the fitted and the experimental results; the data was found to obey the pseudo second order model at which the chemisorptions mechanism was the most dominant in the sorption process. Scanning electron microscopy (SEM) for the ZVI and ZVAI has revealed highly surface changes and saturation by contaminant and apparent pores blockage that hindered and ceased the sorption process.

**Keywords:** Aluminum, Equilibrium, Langmuir, Sorption, Scrap iron, Scanning electron microscopy.

### 1. Introduction

One of the most common problems encountering the ecosystem pollution is the widespread contamination of surface water and groundwater with heavy metals. These metals are defined as metallic elements that have a relatively high density compared to water. Due to their mobile nature, they might infiltrate into the soil and pollute the groundwater. Natural sources of pollution also participate in the groundwater deterioration; Hee et al., 2005[1]; however, the high concentrations of heavy metals are generated from human activities. Water from agriculture sites or surface runoffs percolate down into the groundwater and may cause serious pollution; Gibert et al., 2013[2]; Adamcova et al., 2017[3].

Chromium constitutes the most major concern relating the contamination of the ecosystem recently; Arruti et al., 2010[4]. This metal has significant tendency to accumulate in body tissues when ingested via food chain; Di Natal et al., 2008[5].

For the past decades, the most conventional and cost prohibitive remediation techniques such as “impermeable barriers” or “pump and treat” systems were used. The high costs as well as difficulties concomitant with the operation and maintenance would render these passive *in situ* remediation techniques unfavorable. These barriers capture the pollutants that permeate through the saturated zone and therefore enhance the natural attenuation processes occurring in soil. The mobility of heavy metals dissolved in groundwater might be controlled by reactions that

cause metals to be adsorbed or to precipitate as well as by chemical reactions that keep metals associated with the solid phase of reactive materials composing the permeable reactive barriers PRBs; Powell et al., 1998[6]; Navarro et al., 2006[7].

An important PRB design consideration is the selection of the reactive media at which multi media should be considered: either mixed; Ludwig et al., 2009[8] or sequenced; Plagentz et al., 2006[9]; Huang et al., 2015[10]. Different materials either available in nature such as red mud, peat, bamboos, coconut shells, corns, and leaves or coming as waste from other industrial activities such as concrete, tires, limestone, paper, aluminum, iron and steel possesses different sorptive effectiveness and selectivity for the contaminants to be removed.

Based on previous studies; (1) Chang et al., 2001[11] examined the sorption of copper and chromium on lateritic silty-clay soils, (2) Lien and Wilkin, 2004[12] conducted a batch study using zero valent iron as reactive medium for the removal of hexavalent chromium from groundwater, (3) Gonzalez and Walton, 2009[13] studied the biosorption of Cr(III) onto *Agave lechuguilla* biomass, (4) Chalermyanont et al., 2013[14] studied the compatibility and ability of the mixture of the ZVI/activated sludge for the removal of heavy metals from contaminated groundwater, (5) Shaban and Abd Al Aziz, 2015[15] have studied the removal of chromium and red dye from simulated wastewater using cement kiln dust, (6) Han et al., 2016[16] studied the optimum conditions for clarifying a wastewater from the dissolved heavy metals using an acid prewashed ZVI/ZVAI, all the aforementioned studies are similar in principle to the current study and have taken the batch kinetics study into consideration for the removal of toxic heavy metals from contaminated water.

The objective of this study is to investigate the possibility of using zero valent iron/zero valent aluminum as inexpensive by-product materials in PRB for capturing chromium ions to contain, intercept, and limit its migration towards water resources and prevent any possible contamination and to find the best weight proportion of these sorbents that can be used in PRB to achieve maximum removal of contaminant based on the batch studies.

## 2. Experimental Work

### 2.1 Materials

The ZVI, ZVAI were collected from scrap wastes produced from Bab Al Sheikh and Betaween workshops in Baghdad, these sorbents were dusted, magnetically separated from other splinters, dirt, stubs, and other foreign matters; the ZVI and ZVAI were crushed, pulverized, and sieved using vibratory sieve 75 mesh number, the sorbents were finally washed using 0.1 M H<sub>2</sub>SO<sub>4</sub> solution for 10 min for the preparation of ZVI and 10 ml concentrated HCl solution for 20 min for the preparation of ZVAI.

The synthetic chromium wastewater was prepared by dissolving 7.696 g of hydrated chromium nitrate Cr(NO<sub>3</sub>)<sub>3</sub>.9H<sub>2</sub>O in 250 ml of deionized water and kept at room temperature of (25°C). The pH of the prepared solution was varied using 0.1 M NaOH or 0.1 M HNO<sub>3</sub> to obtain different values of pH (3-6).

### 2.2 Batch Tests

The effect of contact time, initial pH, initial concentration (C<sub>0</sub>) of Cr(III), ZVI-ZVAI dosage, and agitation speed on the removal of this contaminant was investigated based on constant temperature batch tests. Sorbent dosages of 0.25, 0.50, 0.75, and 1.00 g ZVAI/ 100 ml and 2, 4, 6, and 8 g ZVI/ 100 mL were placed into 250 mL flasks with 100 ml solution containing 50 mg/L of metal ions. The flasks were agitated using Shaker incubator type DAIKI, Korea using different agitation speeds of (50-250) rpm for different contact time of (50-250) min. An aliquot of 20 mL was withdrawn and filtered to measure the residual concentration of heavy metal left in aqueous solution. A sample of 10 ml of filtrate was withdrawn and measured for the concentration of dissolved metal ions using AAS flame (type Shimadzu, Japan).

The amount of metal ion retained in the solid phase, C<sub>s</sub> in mg/g, was calculated using:

$$C_s = (C_o - C_e) \frac{V}{m} \quad \dots (1)$$

Where C<sub>0</sub> is the initial concentration of the heavy metal in the solution before mixing with sorbent (mg/L), C<sub>e</sub> is the equilibrium concentration of heavy metals left in the solution at the end of the experiment (mg/L), V is the volume of solution in the flask (L), and m is the mass of sorbent in the flask (g).

### 3. Results and Discussion

#### 3.1 Selection of the Sorbent Material

A set of batch experiments were conducted at varied pH, contact time, and sorbent masses to investigate the suitability and affinity of the chromium ions for partitioning onto ZVI and/ or ZVAI. The determination of the optimum ratio of these sorbent masses was also specified to achieve maximum removal efficiency of the dissolved heavy metal under consideration. During the initial stages of the batch study, the ZVI and ZVAI have been examined for the sorption of chromium ions respectively onto the contaminated aqueous solution with different sorbent masses as shown in Figure 1. This figure revealed that the equilibrium concentration of the contaminant was attained such that 73% of the chromium was removed onto the sorbent dosage of 1 g ZVAI/ 100 ml at pH 5. The batch experiments were re-conducted at similar conditions with replacing the sorbent in such a way that the ZVI is the proposed sorbent for chromium. The method of replacing sorbents produced new batch kinetics (Figure 2) that revealed a good enhancement in the removal efficiency of 96% for chromium onto ZVI. This elucidated that the contaminant has had certain affinity to each sorbent; therefore; the increase in the removal efficiency was noticed after replacing these sorbents.

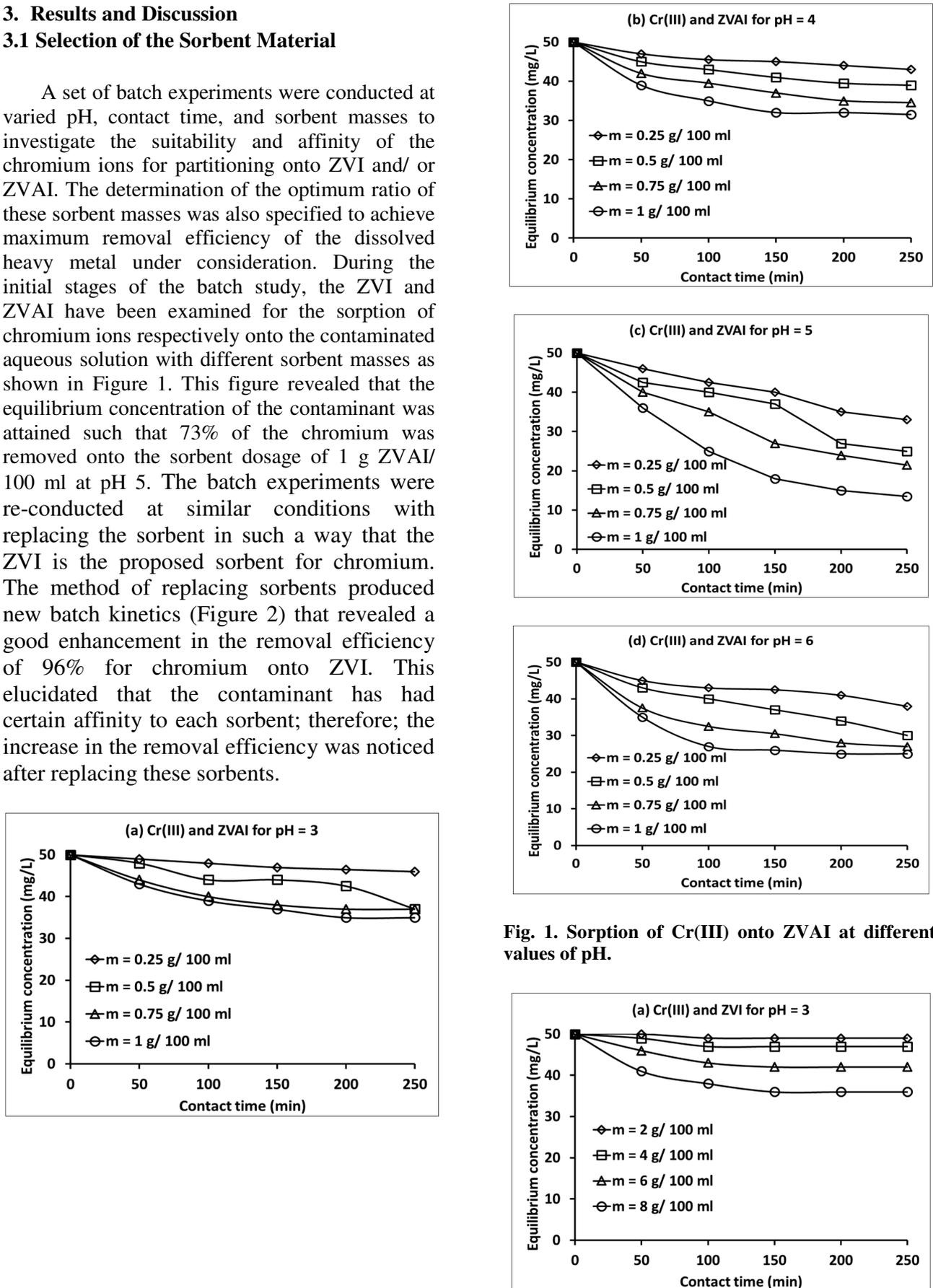


Fig. 1. Sorption of Cr(III) onto ZVAI at different values of pH.

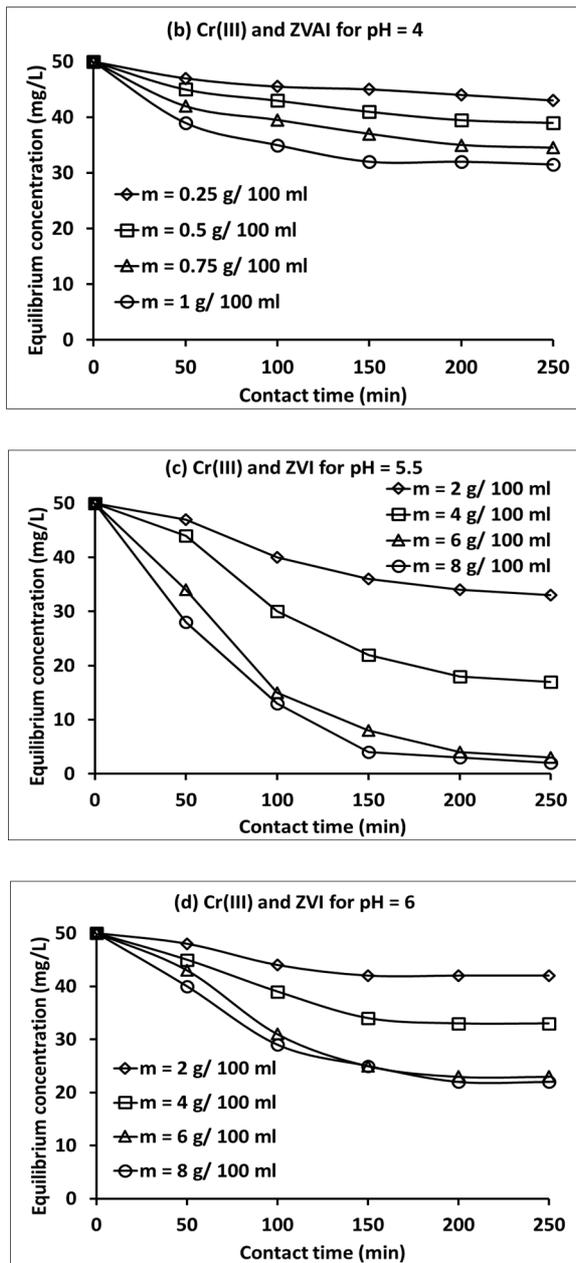


Fig. 2. Sorption of Cr(III) onto ZVI at different values of pH.

### 3.2 Equilibrium Time

The contact time for the batch experiments has been chosen up to 250 min where the mass transfer rate of the contaminants from the bulk solution to the sorbent solid phase had been ceased. It is almost that Figure 2 for the sorption of chromium ions onto (2-8) g ZVI at different pH values revealed a sort of stabilization near 200 to 250 min. This elucidated that most active sorption sites have become covered with chromium such that no vacant sites were available; therefore, the

sorption curves have been stabilized after almost 200 min.

The figures mentioned previously also signified that the rate of contaminant uptake during the initial stages of the sorption process was relatively higher than the rate at later times; therefore, rapid increase in the removal efficiency was noticeable. Generally, the longer the contact time; the higher the removal efficiency is associated. The contact time for the removal of 96% chromium was almost 250 min and the equilibrium concentration for the dissolved heavy metal ions in the bulk solution was kept constant even beyond 200 min. All other batch experiments were conducted at this contact time later on.

### 3.3 The Hydrogen Exponent Measure pH

#### 1) Initial pH of the Solution

It is one of the most significant batch experimental parameters that influence to a large extent the heavy metal remediation processes. The sorption of chromium ions onto ZVI and/or ZVAI was investigated using different values of pH in the range of (3-6) corresponding to 50 mg/L contaminant initial concentration and different times of contact at temperature of 25°C. The pH values were adjusted by adding few droplets of 0.1 M nitric acid or sodium hydroxide as required. Figures 1 and 2 have revealed that the maximum sorption of chromium ions onto ZVI for pH ranged from 3 to 6 was achieved at value of pH approximately equal to 5.5 to yield maximum removal efficiency 96% of chromium.

At lower pH values in the vicinity of 3 to 4; more hydrogen cations are evolved and this is a case of competition between cationic contaminants Cr(III) and the H<sup>+</sup> over the surface of the sorbent materials. The competition would ultimately hinder the contaminants binding to the solid phase and consequently reduces the removal efficacy (sorption curves are shifted away from the contact time axis). Similarly, at pH higher than 4, no more hydrogen cations prevail and no competition for the active sites exists; the rate of the sorption increases and a concomitant increase in the removal efficiency is attained; but at higher pH values (near 6 and higher) a precipitation in the form of hydroxides may be occurred which reflects the sensitivity of the chromium ions to form complexes and hydroxides due to their low solubility at higher pH.

## 2) Effect of pH on the Sorption Capacity

Figure 3 depicted the sorption capacity dependence on the pH variation since the sorption capacity has slightly and linearly increased with increasing pH. This elucidated that once the ZVI and/or ZVAI being placed in aqueous solution, the surfaces of the sorbents will be enriched with functional hydroxyl groups which constitute grabbing arms for the capture of the cationic heavy metal ions, but the presence of such sorbents in acidic medium (low pH) will bring about sort of competitive interactions between heavy metal ions Cr(III) and the protons ( $H^+$ ) found in the bulk solution. As a result, the surface will then be covered with a blanket of positive charges that are responsible for the poor adsorption.

Obviously; the hydroxyl ( $OH^-$ ) groups are formed at higher pH values and the adsorption is enhanced with the increase of pH up to 5. Beyond this point, the sorption rate is ceased and maximum sorption capacity is attained. The sorption capacity has declined after pH 5.5 as shown in Figure 3; this is due to the formation of metal hydroxides (precipitants) at higher pH. The ongoing accumulation of such precipitants will cover the surface of the sorbents, besides, not only precipitants cause a decrease in the removal effectiveness but also they tend to clog the pores of the medium, the flow velocity of the contaminant will consequently increase which causes lower retardation.

Also in acidic medium, a proliferation of protons (high concentration of  $H^+$ ) reveals another elucidation for the poor sorption of the heavy metal ions when ZVI and/or ZVAI reduce ( $H^+$ ) to liberate hydrogen gas and form iron and aluminum ions ( $Fe^{+2}$  and  $Al^{+3}$ ). The latter ions will impose further burden for the competitive adsorption along with heavy metal ions; in addition, the reduction of aluminum to iron ions will induce iron precipitates over the surface of the aluminum itself resulting in a decreased sorption capacity. Consequently, the repulsive forces induced between protons and positively-charged heavy metal ions are dominated and this results in a point of positive charge at which low sorption occurred. The sorption had gradually enhanced and increased as the point of charge approached zero (neutral charge); furthermore, the sorption rapidly increases beyond the  $pH_{pzc}$ , this is due to the deprotonization at which most protons were eliminated causing the surface of the sorbents negatively charged.

At higher pH and far beyond the  $pH_{pzc}$  the sorption rate slowed down and then declined; this is due to the accumulation of precipitates of chromium hydroxides as well as the ferric and aluminum hydroxides which cover the active sorptive sites. The best pH value for the sorption of chromium ions onto the ZVI was found to be in the range between 4.3 and 4.5.

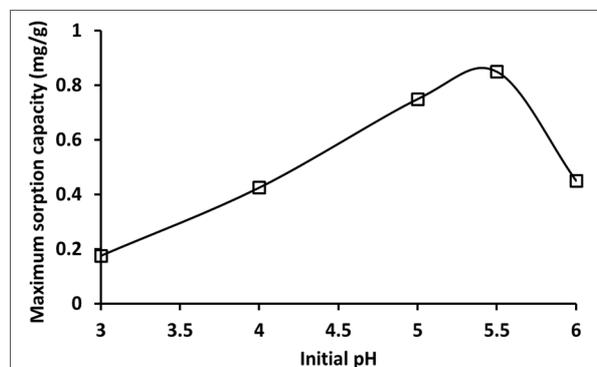


Fig. 3. Effect of initial pH on the removal of Cr(III) from aqueous solution.

## 3.4 Effect of Sorbent Mass

The number of grams of both ZVI and ZVAI per 100 ml solution was examined to study the effect of sorbent mass onto the removal efficiency for chromium heavy metals at fixed experimental parameters of pH 5.5, 50 mg/L initial contaminant concentration, and 250 rpm agitation speed. Ranges of masses of adopted sorbents used in this regard were (2-8) g ZVI and (0.25-1) g ZVAI per 100 ml of aqueous solution. Figures 1 and 2 revealed that the higher the sorbent mass; the higher the removal efficiency is attained; this is obviously can be elucidated when larger masses provide more available and tremendous number of active sorption sites than the smaller ones. Further increase in the mass of the sorbent does not necessarily mean achieving higher removal efficiency; this is due to highly coverage of the contaminants over the surfaces of the larger masses of the targeted sorbents and the removal efficiency would remain constant even with further addition of the sorbents.

## 3.5 Initial Contaminant Concentration

Different initial concentrations for chromium were prepared to examine the relationship between initial concentration of the contaminant and the removal efficiency. Figure 4 revealed that marginal drop occurred in the removal efficiency

of chromium ions onto the ZVI when the Cr(III) initial concentration had increased from 50 to 200 mg/L with a corresponding removal efficiency of almost 93%; this Figure also revealed rapid drop in the removal efficiency of chromium ions to 76%. The reason for the decline of the removal efficiency may be attributed to the higher driving force of the mass transfer from the bulk solution to the surface of the sorbent materials that usually occurred at higher concentration and this will obviously make no more sorption sites available particularly during the first stages of the sorption process; Shawn, 2000[19] and Puls, 2003[20].

### 3.6 Agitation Speed

Different agitation speeds of (0-250) rpm were conducted to examine the effect of these speeds on the removal efficiency of chromium ions at fixed experimental parameters; pH 5.5, 50 mg/L initial contaminant concentration, and 250 min contact time. Figure 5 revealed an exponential increase in the removal efficiency of chromium from zero speed (no agitation) corresponding to 20% chromium removal to 250 rpm corresponding to 96% chromium removal. The reason for increasing the removal efficiency of the contaminant with increasing the number of rpm's impaired to the mass-liquid medium can be explained as the higher the speed of agitation; the higher the migration of heavy metal ions toward the active sites on the sorbents. This is due to the decrease in the Nernst film that all the resistance to the contaminant migration towards the solid phase can be concentrated on and whenever the agitation speed increases, the thickness of this film can be reduced or even eliminated at higher speeds.

### 3.7 Sorption Kinetics

Diffusion across the boundary layer, intra-particle diffusion, and physicochemical sorption have great influence on the sorption process, Ho et al., 2002[17]. Table 1 exhibited the batch experimental kinetics for the sorption of chromium ions onto the best mass ratio of the sorbent mixture ZVAI/ZVI and optimum conditions. Rather than the fitted pseudo first order kinetics model Eq.(2), the last two columns of the table have revealed good agreement between the fitted pseudo second order model Eq.(3) and the experimental data.

These equations have been linearized and fitted for the kinetics data for the sorption of chromium

ions and the constants for best equation, i.e. pseudo second order model, are summarized in table 2

$$\frac{dC_s}{dt} = k_1(C_{se} - C_s) \quad \dots (2)$$

$$\frac{dC_s}{dt} = k_2(C_{se} - C_s)^2 \quad \dots (3)$$

**Table 1,**

**Kinetics data for the sorption of Cr(III) onto ZVAI/ZVI mixture at optimum pH 5.5,250 min contact time,50 mg/L initial metal concentration, and 250 rpm agitation speed.**

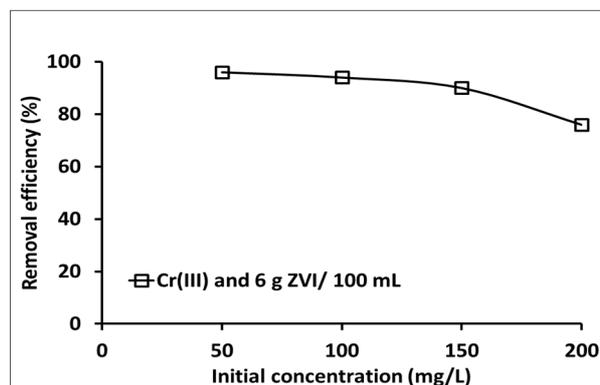
Time (min)	C <sub>e</sub> (mg/L)	C <sub>s</sub> (mg/g)
50	22	0.400
100	10	0.571
150	7	0.614
200	5	0.643
250	2	0.686

**Table 2,**

**Constants corresponding to the pseudo second order for the Cr(III) sorption onto the ZVAI/ZVI mixture**

Metal	Parameter	Value
Cr(III)	C <sub>se</sub> (mg/g)	0.6860
	k <sub>2</sub> (g/mg min)	0.0760
	R <sup>2</sup>	0.9877

Results proved that the sorbed amount at equilibrium for the pseudo second order kinetics of chromium was equal to 0.6373 mg/g and this value was almost as close as the experimental 0.643 mg/g. The results have elucidated that the chemisorptions is the most predominant mechanism for the sorption process under consideration.



**Fig. 4. Effect of initial concentration on the removal efficiency of chromium ions onto ZVI at pH 5.5, 50 mg/L initial contaminant concentration, and 250 min contact time.**

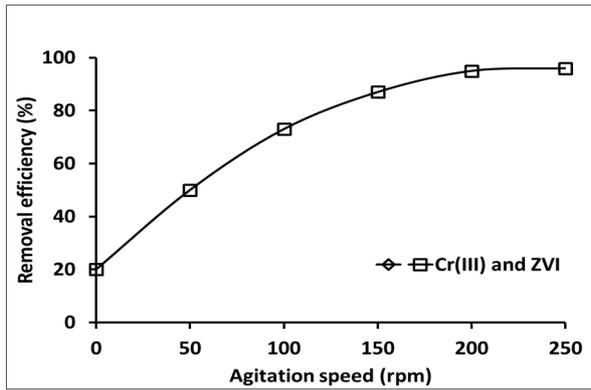


Fig. 5. Effect of agitation speed on the removal efficiency of chromium ions onto ZVI at pH 5.5, 50 mg/L initial contaminant concentration, and 250 min contact time.

### 3.8 Selection of the Best ZVI/ZVAI Mass Ratio

Since removal efficiency for the contaminant was remarkably enhanced by randomly mixing up different masses of ZVI and ZVAI, different proportions were anyhow examined such that the equilibrium concentrations of the chromium ions as a function of contact time for different proportions of ZVAI and ZVI were plotted in Figure 6 in where the concentration has dropped from 50 to 30 mg/L to yield a removal efficiency of 40% using 0.75 g ZVAI/ 5 g ZVI per 100 ml while dropped to 2 mg/L to yield a removal efficiency of 96% using 1 g ZVAI/ 6 g ZVI per 100 ml.

The best mass ratio was found to be 1 g ZVAI and 6 g ZVI (equivalent to the 14% ZVAI and 86% ZVI) corresponding to contact time of 250 min, pH of 5.5 and agitation speed of 250 rpm for initial contaminant concentration of 50 mg/L.

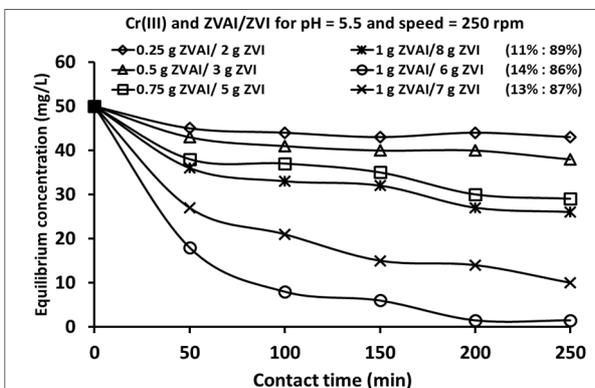


Fig. 6. Variation of equilibrium Cr(III) concentration as a function of contact time using different proportions of ZVAI / ZVI.

### 3.9 Sorption Isotherms for Single Metal Uptake

Sorption isotherms describe the significant phenomenon that governs the release or retention of the contaminant species from the bulk liquid phase to the solid one at fixed pH and constant temperature; Hameed et al., 2016[18]. The mathematical equations or empirical equations that depict the sorption isotherm are often relating the number of contaminant's milligrams sorbed onto one gram of the sorbent material to the contaminant concentration at equilibrium. There are several sorption isotherms such as Hill De Boer, Temkin, Kesiliv, Elovich, etc., but the two most well-known isotherms are the Langmuir and Freundlich. In this study, the two latter isotherms were investigated using the experimental isotherm data obtained from the interaction of ZVI/ZVAI with aqueous solution contaminated with Cr(III).

The sorption data have already been fitted using Freundlich model and different forms of Langmuir models I,II,III, and IV to examine which model yields highest coefficient of determination ( $R^2$ ). Table 3 presents the linearized forms of Freundlich and Langmuir isotherm model.

Table 3, Linearized forms of Freundlich and Langmuir isotherm models used in the present study for the describing the uptake of Cr(III) onto ZVAI and ZVI

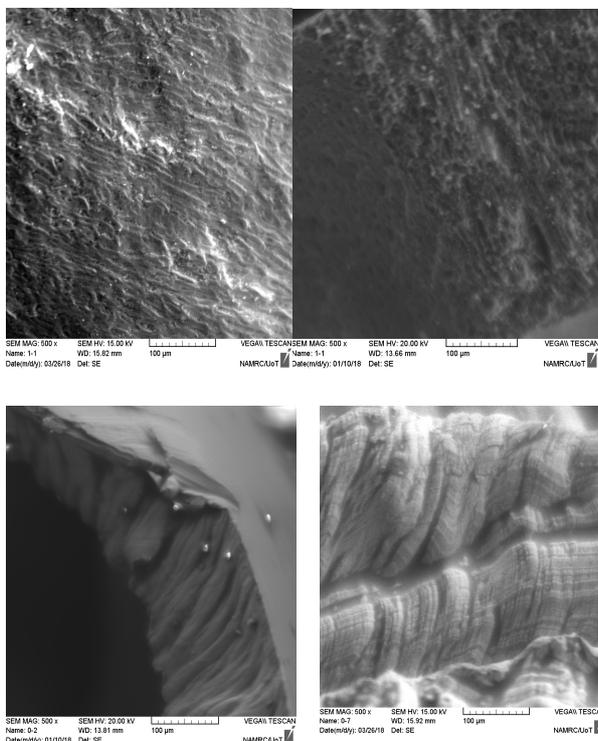
Model Isotherm	Linearized Formula
Freundlich	$\ln C_s = \ln k_F + n \ln C_e$
Langmuir (I)	$\frac{C_e}{C_s} = \frac{1}{ab} + \frac{1}{a} C_e$
Langmuir (II)	$\frac{1}{C_s} = \frac{1}{ab} \left( \frac{1}{C_e} \right) + \frac{1}{a}$
Langmuir (III)	$C_s = a - \frac{1}{b} \left( \frac{C_s}{C_e} \right)$
Langmuir (IV)	$\frac{C_s}{C_e} = ab - bC_s$

### 3.10 Scanning Electron Microscopy Analysis (SEM)

The scanning electron microscopy (SEM) is an essential tool to characterize the surface morphology of sorbent materials; particularly the ZVI and ZVAI before and after the reaction with the heavy metal ions. The SEM has revealed distinct comparison over the shape, particles distribution, and morphological changes before and after the reaction with both ZVI and ZVAI.

The 500 times magnified SEM images (Figure 7) have revealed the followings:

1. Before the reaction, the nature of the ZVI surface was characterized by rough homogenous texture with tremendous number of pore channels to considerably increase the sorption of contaminant and entrap it deep into these channels of the active sorption sites.
2. After the reaction, the nature of the ZVI surface was characterized by almost smooth homogenous texture with highly blocked channels and surface saturation of traces of contaminant in white color. The sorption; as a result; has considerably been reduced such that no more contaminant is sorbed thereafter.
3. Before the reaction, the nature of the ZVAI surface was characterized by extremely smooth homogenous texture of remarkable abrupt change in surface morphological shape with descending grooves that have seemingly responsible for the sorption of contaminant.
4. After the reaction, the nature of the ZVAI surface was characterized by groovy lumped and rough texture with remarkable traces of whitish color contaminant sorbed that almost covered the ZVAI surface and due to such coverage, the sorption consequently reduced.



**Fig. 7. SEM images for the ZVI (top) and ZVAI (bottom) sorbents before and after the reaction with Cr(III).**

## 4. Conclusions

Batch experimental runs proved that the chromium ions interactions with the ZVAI and/ or ZVI significantly affected by number of parameters to achieving maximum removal efficiency. These parameters included the initial contaminant concentration, contact time, initial pH, sorbent dosage, agitation speed corresponding to 50 mg/L, 250 min, 5.5, 1 g ZVAI/ 6 g ZVI per 100 mL, and 250 rpm respectively to achieve 96% Cr(III) removal. The mixing up of both sorbents ZVAI and ZVI proved better contaminant removal efficiency than using these sorbents individually and at the optimum batch experimental parameters aforementioned. A mass ratio of 1 g ZVAI/ 6 g ZVI has remarkably revealed 96% Cr(III) ions removal rather than using 0.75 g ZVAI/ 5 g ZVI to yield 40% Cr(III) ions removal among several investigations over different sorbent mass ratios. Kinetics data for the single sorption of chromium ions onto ZVI/ZVAI mixture was fitted on several sorption isotherm equations and among the Freundlich and other four types of the Langmuir models, the Langmuir (I) sorption isotherm was found to well fit the sorption data with coefficient of determination ( $R^2$ ) greater than 0.9115; the Langmuir sorption constants were (0.307-6.34) mg/g as maximum sorption capacity and (0.19-1.54) L/mg as sorption affinity.

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## ازالة ايونات الكروم ثلاثية التكافؤ من المياه الملوثة باستخدام فضلات برادة الحديد- المنيوم والمتوفرة محليا

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### الخلاصة

تعكف الدراسة الحالية على امكانية استخدام ملوثات اخرى بشكل فضلات برادة الحديد والالمنيوم متوافرة محليا وتفيد في احتجاز ايونات الكروم والحد من حركتها في نموذج من المياه الملوثة. لقد تم اختبار معالم مختبرية مختلفة في اختبارات الوجبة مثل زمن التماس (0-250) دقيقة، جرعة (1-0.25) غم برادة المنيوم و(2-8) غم برادة حديد\ 100مل من المحلول المائي الملوث، دالة حامضية (3-6)، وسرعة تقلب (0-250) دورة في الدقيقة حيث تحققت 96% ازالة للكروم مقترنة بأفضل معالم تجريبية وهي زمن التماس (250) دقيقة، جرعة (1) غم برادة المنيوم و(6) غم برادة حديد\ 100مل من المحلول المائي الملوث، دالة حامضية (5.5)، تركيز ملوث بدائي (50) mg/L وسرعة تقلب (250) دورة في الدقيقة ومن خلال تجارب الوجبة تبين ان موديل لانكمير (I) هو الافضل لامتزاز الكروم على برادة الالمنيوم والحديد وبمعامل ارتباط اكبر من 0.9115 ونتيجة للتقارب بين النتائج النظرية والعملية لامتزاز الكروم على خليط البرادتين وجدت ان بيانات التفاعل لامتزاز الكروم تخضع الى تفاعل الرتبة الثانية الكاذبة مما يدل على ان الامتزاز الكيميائي هو الميكانيكية المهيمنة في عملية الامتزاز. اظهرت نتائج الفحص المجهرى (SEM) لبرادتي الحديد والالمنيوم مابعد التفاعل تغييرات جذرية في سطحها ومقدارا للتشبع من قبل الملوث والمسبب بغلق القنوات المسامية بشكل واضح وبالتالي اعاقه عملية الامتزاز وتوقفها.