Kinetics Study of Boron Adsorption onto Magnesium Aluminum and Iron Oxides

IbtihalL Abduljabbar Abdulqader **Saadi Kadhum Al- naseri**

Ministry of Science and Technology / Environment and Water Directorate

Baghdad – Iraq
E-mail: ibtehaljabbar2009@yahoo.com

Abstract

The boron adsorption process, onto magnesium, aluminum and iron oxide was described in term of mathematical equations and, taking into account the knowledge acquired by means of experimental data. The modelization has been carried out by establishing Langmuir, Freundlich and BET isotherms and kinetic laws for pseudo first order, pseudo second order and intraparticle diffusion model. The experimental results revealed that adsorption isotherm onto magnesium and iron oxide fits very well with Langmuir model while adsorption onto aluminum fits very well with Freundlich model. Results showed that adsorption of boron onto magnesium, aluminum and iron oxide followed pseudo second order kinetic

Key Words: Boron; Kinetics; Adsorption; Langmuir; Freundlich and BET

دراسة حركيات امتزاز البورون على اكاسيد المغنيسيوم والالمنيوم والحديد

ابتهال عبد الجبار عبد القادر **سعدي كاظم الناصري**

وزارة العلوم والتكنولوجيا / دائرة البيئة والمياه

بغداد–العراق

الخلاصة

درست الموديلات الرياضية لحركيات امتزاز البورون على اكاسيد المغنيسيوم، الالومينيوم والحديد،حيث تم استخدام ثلاث موديلات وهي لانكمير، فروندلج و بي اي تي و كذلك موديلات ميكانيكية الامتزاز الخاصة بالدرجة الاولى والثانية وموديل التنافذ داخل الجسيمة. بينت النتائج العملية ان عملية امتزاز البورون على اوكسيد المغنيسيوم والحديد يتطابق مع موديل لانكمير، بينما طابق موديل فروندلج مع عملية امتزاز البورون على اوكسيد الالمنيوم. بينت النتائج ان ميكانيكية امتزاز البورون على اكاسيد المغنيسيوم، الحديد والالمنيوم يتطابق مع موديل ميكانيكية الامتزاز من الدرجة الثانية

الكلمات المفتاحية: البورون; حركيات; الامتزاز; لانكمير; فروندلج و بي اي تي

Introduction

Boron could be released into the environment by both natural weathering processing and anthropic sources (Salih, *et al.,* 2012). Boron at low concentration is a nutrient for plant metabolic activities (Akerman, *et al.,* 2012), it is an important micronutrient for trees including sugar transport, cell wall synthesis, carbohydrate and RNA metabolisim and respiration (Imam and Al-Birfkany, 2012), but when the amount of boron adsorbed exceeds the nutritional concentration which was 0.3-1mg/ kg (Al-Ameri, *et al*., 2013), poisoning will occur (Abdulhalim *et al.*, 2012), so yellowish spots on leaves and fruits will appear (Liu, *et al*., 2007), also has an adverse effect on seed oil content for sun flower plants (Mohammed and Shaker, 2011). When animals absorb large amount of boron over a relatively long period of time through plant consuming animals, the male productive organs will be affect (Karc, *et al.,* 2013).The safe concentration of boron in irrigation water is 0.3 mg/l for sensitive plant, 1-2 mg/l for semi-sensitive plants and 2-4 mg/l for tolerant plants (Cengeloglu, *et al.,* 2007). The world health organization (WHO) recommends a maximum boron concentration as low as 0.5mg/l (Al-naseri, 2012).

Turkey suffers from the contamination of its water with boron, it is considered to be the largest boron source in the world, a big area around Manderes River in west Anatolia suffers from this problem (Karahan *et al.,* 2006).

The main sources of surface water boron contamination were detergents, cleaning products, fertilizers, insecticides and corrosion inhibiter in antifreeze formulated (Liu *et al.,* 2009; Abdhalim *et al*., 2012).

According to previous experimental data (Sulymoon *et al*., 2013) it can be suggested that maximum removal of boron was achieved at pH 8 for aluminum and iron oxide and 9.5 for magnesium oxide and batch results showed that the equilibrium time was 60, 90 and 240 minute for aluminum, iron and magnesium oxide respectively.

Materials and Methods

Boric acid (H_3BO_3) reagent used in this study to prepare synthetic water with the required feed concentration of 5 mgL^{-1} of boron.

Three types of materials were used as adsorbents. These are magnesium oxide (MgO), iron oxide (Fe_2O_3), and aluminum oxide (Al_2O_3) with purity of >99%.

- The concentration of boron was analyzed by means of HACH DR 2000 spectrophotometer (Carmine Method) at wave length of 605 nm (ASTM, D 3082).

Batch studies at approximately 30^{o}C were adopted to obtain the equilibrium data. Different adsorbents weight 1, 0.9, 0.72, 0.5, 0.45 and 0.34g of magnesium oxide, 1, 0.769, 0.623, 0.56, 0.514 and 0.425g of aluminum oxide and 1, 0.8, 0.6, 0.4 and 0.2 g of iron oxide were added in 18 conical flasks containing 5 mgL^{-1} boron solution of 100ml. The flasks were then placed on a shaker and shaked continuously for a period of 240, 90 and 60 minute which is enough to reach the equilibrium state (as the concentration does not change with time) (Nameni, *et al.,* 2008). Afterward the solution was filtered. The filtrate was analyzed by spectrophotometer at wave length of 605 nm (Carmine Method) to estimate the equilibrium concentration of boron.

The adsorption isotherm curves were obtained by plotting the weight of solute adsorbed per unit weight of adsorbent against the equilibrium concentration of boron in the solution.

$$qe = \frac{V_l(C_o - C_e)}{M}$$ (Ahmad *et al.*, 2005)

Where:

qe =Adsorbent capacity (mg/g)

V_l =Volume of sample (l)

Co = initial concentration of boron in sample (mg/l)

Ce = Concentration of boron in sample after adsorption (mg/l)

M = Mass of adsorbent (g)

The experimental data were compared using Langmuir, Freundlich and BET isotherm models which are given as follows:

Langmuir Model

The Langmuir equation is commonly written as follows (Mondai and Lalvani, 2000)

$$qe = \frac{abC_e}{1 + aC_e}$$

Where

qe is the amount of adsorbate adsorbed per unit weight of adsorbent, (mg/g)

C_e is the equilibrium concentration of adsorbate in water, (mg/l)

a and b are constants taking the reciprocalof both side of Langmuir equation yields:

$$\frac{1}{qe} = \frac{1}{b} + \frac{1}{abce}$$

If adsorption follows the Langmuir isotherm, a linear trace should result when the quantity l/q is plotted against $1/C_e$. Values of the constants *a* and *b* can be determined from the slope and intercept of the plot.

Freundlich Isotherm

Freundlich offered the following equation (Zwani *et al.*, 2009)

$$qe = Kf \cdot C_e^{\frac{1}{n}}$$

Where Kf and n are Freundlich adsorption isotherm constants.

Values of the constants *n* and K_f can be determined from the slope and intercept of the plot.

BET Isotherm

The equation, known as BET equation, is commonly written as follows (Volesky, 2000)

$$qe = \frac{BC_e x_m}{(C_s - C_e)\left[1 + \left((B-1)\frac{C_e}{C_s}\right)\right]}$$

The above equation can be arranged to be

$$\frac{C_e}{(C_s - C_e)qe} = \frac{1}{Bx_m} + \frac{(B-1)}{Bx_m}\frac{C_e}{C_s}$$

Where:

B is a constant relating to the energy of interaction with the surface

Xm is the amount of adsorbate adsorbed per unit weight of adsorbent for mono layer adsorption (mg/gm)

Data from adsorption processes that conform to the BET equation will yield a straight line when the left-hand side of the BET equation is plotted against C_e/C_s.

These methods were carried out for different adsorbents, magnesium, aluminum and iron oxide.

Adsorption Kinetic Models

The kinetics of adsorption based on the overall adsorption rate by the adsorbents is described by the first order Lagergren model, pseudo second-order and intraparticle diffusion model.

The Pseudo First-order Equation

Lagergren (Özcan A.S., Özcan A., 2004) suggested the pseudo first-order rate equation for the sorption of solid from a liquid solution. This pseudo-first- order rate equation is:

$$\frac{dq}{dt} = k_l (q_e - q_t)$$

Integrating the above equation for the boundary conditions t=0 to t=t and q=0 to q=q gives:

$$\ln(qe - q_t) = \ln(q_e) - k_1 t$$

Where:

qe and q_t are the adsorption capacity at equilibrium and at time t

Respectively, (mg/g).

K1 is the rate constant of pseudo first-order adsorption, (min^{-1}).

The values of ln (qe – q_t) were linearly correlated with t. The plot of the natural logarithm of (qe – q_t) versus t should give a linear relationship from which k_1 can be determined from the slope of the plot.

The Pseudo Second-order Equation

The pseudo second-order kinetic model (Ho and Mckay, 2000) can be represented as follows:

$$\frac{dq}{dt} = k_2 (q_e - q_t)^2$$

Integrating the above equation for the boundary conditions t=0 to t=t and q=0 to q=q and rearranged in a linear form gives:

$$\frac{t}{q_t} = \frac{1}{k_2 (q_e)^2} + \frac{1}{q_e} t$$

Where:

k_2 is the rate constant of pseudo second-order adsorption ($g \cdot mg^{-1} min^{-1}$).

The plot of (t/q_t) and t should give a linear relationship from which k_2 can be determined from the intercept of the plot.

The Intraparticle Diffusion Model

The intraparticle diffusion model is expressed as (Weber and Morris, 1964)

$$q = k_p t^{0.5}$$

Where: k_p is the intraparticle diffusion rate constant ($mg\ g^{-1}\ min^{-0.5}$)

Results and Discussion

Magnesium Oxide

Figures (1,2 and 3) illustrate the use of the Langmuir, Freundlich and BET models for adsorption of boron at initial boron concentration of 5 mg / l, pH 9.5, stirring time 240 minutes and adsorbent dosage from 3.4 to 10 g per liter.

Langmuir isotherm was achieved by plotting 1/Ce versus 1/qe to give a straight line with a coefficient of determination (R^2) equal to 1. The constant (a) which represents adsorption capacity, (b) which is related to the energy of adsorption were estimated from the slope and intercept of the linear plot and they were equal to 0.5577 mg/mg and 2.053 l/mg respectively.

Freundlich isotherm was achieved by plotting (Ce versus qe) to give a line with exponential equation and the coefficient of determination (R^2) is equal to 0.997. The values of kf and n which were an indicative of adsorption capacity and intensity for adsorption were calculated from the equation and they were equal to 0.7214 mg/mg and 1.5 mg/l respectively.

BET isotherm was also applied for boron adsorption and was achieved by plotting Ce /Cs versus Ce /(Cs-Ce)*q to give a straight line as shown in Figure 3 with a coefficient of determination equal to 0.99. The constant A which represents adsorption capacity was estimated from the slope and intercept of the linear plot and it was equal to 9.03.

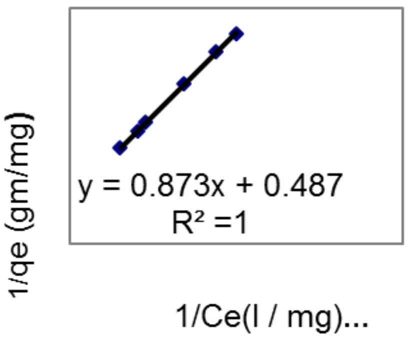

Figure (1) Langmuir Isotherm for Adsorption of Boron onto Magnesium Oxide at pH=9.5; Magnesium Oxide Conc. =10gm/l and Initial Boron Conc.=5mg/l

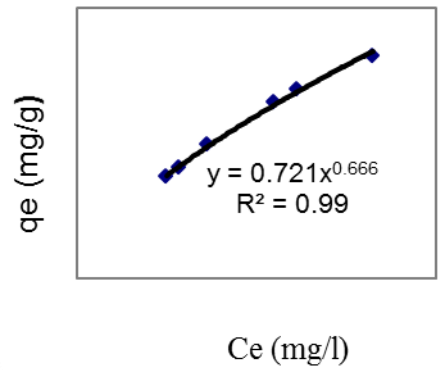

Figure (2) Freundlich Isotherm for Adsorption of Boron onto Magnesium Oxide at pH=9.5; Magnesium Oxide Conc. =10gm/l and Initial boron Conc. =5mg/l

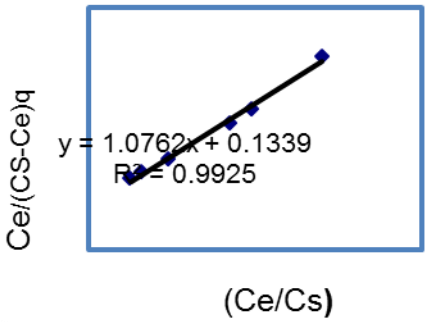

Figure (3) BET Isotherm for Adsorption of Boron onto Magnesium Oxide at pH=9.5; Magnesium Oxide Conc. =10gm/l and Initial boron Conc.=5mg/l

From the values of coefficient of determination of the three models, Langmuir isotherm fit very well with the experimental data and this is similar to another showed in literature by using magnesium oxide as adsorbent (De la Fuente and Eugenio, 2006).

Aluminium Oxide

In order to investigate the adsorption isotherm; Langmuir, Freundlich and BET models were analyzed to quantify adsorption capacity of aluminum oxide.

Figures (4, 5 and 6) illustrate the use of the three models for adsorption of boron have an initial concentration of 5 mg / l, pH=8, stirring time 60 minute and adsorbent dose range from 4.25 to 10 g / l.

Langmuir isotherm was achieved by plotting 1/Ce versus 1/qe to give a straight line as shown in Figure (4) have a coefficient of determination of 0.97. The constants (a) and (b) were estimated from the slope and intercept of the linear plot and they were equal to-0.2592 mg/mg and -0.07195 1/mg respectively.

Freundlich isotherm was achieved by plotting Ce versus qe to give a line with exponential equation as shown in Figure (5) and have a coefficient of determination equal to 0.99. The constants k_f and n were estimated from the slope and intercept of the linear plot which were equal to 0.001 mg/mg and 0.202 mg/l respectively.

To study the applicability of BET isotherm for adsorption of boron onto aluminum oxide Ce/Cs was plotted versus Ce/(Cs-Ce)*q to give a straight line as shown in Figure (6) with a coefficient of determination equal to 0.92 and the constant (A) was estimated from the slope of the linear plot.

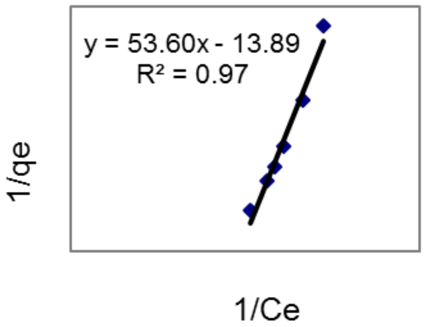

Figure (4) Langmuir Isotherm for Adsorption of Boron onto Aluminum Oxide at pH=8; Aluminum Oxide Conc. =10gm/l and Initial Boron Conc.=5mg/l

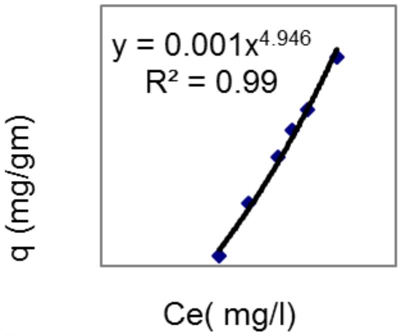

Figure (5) Freundlich Isotherm for Adsorption of Boron onto Aluminum Oxide at pH=8; Aluminum Oxide Conc. =10gm/l and Initial Boron Conc. =5mg/l

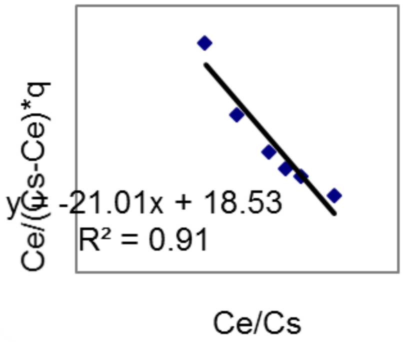

Figure (6) BET Isotherm for Adsorption of Boron onto Aluminum Oxide at pH=8; Aluminum Oxide Conc. =10gm/l and Initial boron Conc.=5mg/l.

The coefficient of determination for Freundlich isotherm plot was higher than that for Langmuir and BET, so Freundlich model describes the adsorption data within the entire correlation range. Comparison with results showed in literature by using aluminum oxide as adsorbent, Bouguerra *et al*., 2009 stated that Langmuir and Freundlich isotherm models fitted with the result obtained from adsorption of boron have an initial concentration of 50 mg/l0, pH=8-8.5 and adsorbent dose of 5g.

Iron Oxide

The adsorption data which were obtained from adsorption of boron onto iron oxide were tested using Langmuir, Frundlich and BET models.

In testing the Langmuir isotherm, the adsorption data were plotted as 1/Ce versus 1/qe to get a straight line as shown in Figure (7) and have a coefficient of determination equal to 0.93. Constants for Langmuir isotherm (a) and (b) were estimated from the slope and intercept of the straight line which were equal to-0.298 mg/mg and -0.0312 l/mg respectively.

Figure (8) illustrates the use of Freundlich isotherm model for adsorption of boron by plotting Ce versus qe to get a line with exponential equation have a coefficient of determination equal to 0.81. The constants (k_f) and (n) were estimated from the slope and intercept of the straight line and their values were $1.42*10^{-7}$ mg/mg and 0.0758mg/l respectively.

Figure (9) describes the use of BET isotherm model for adsorption of boron by plotting Ce/Cs versus Ce/ (Cs-Ce)*q to yield a straight line with a coefficient of determination equal to 0.86. Slope and intercept were used to estimate the constant (A) and its value was -0.4723.

From comparison of the coefficient of determination of the three models, Langmuir isotherm have a correlation coefficient higher than that for Freundlich and BET isotherm, so Langmuir isotherm fits best with the experimental data.

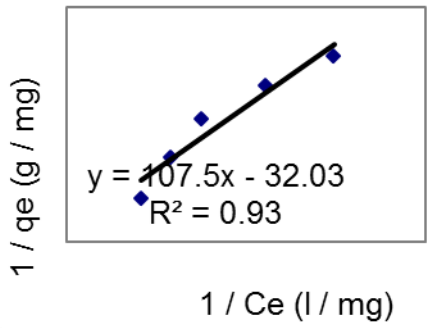

Figure (7) Langmuir Isotherm for Adsorption of Boron onto Iron Oxide at pH=8; Iron oxide conc. =10gm/l and Initial boron conc. =5mg/l

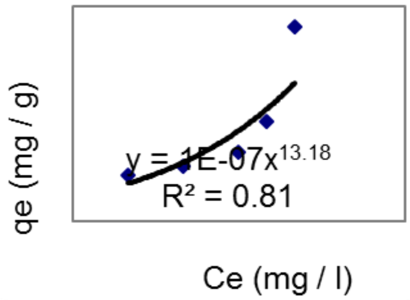

Figure (8) Freundlich Isotherm for Adsorption of Boron onto Iron Oxide at pH=8; Iron oxide conc. =10gm/l and Initial boron conc. =5mg/l

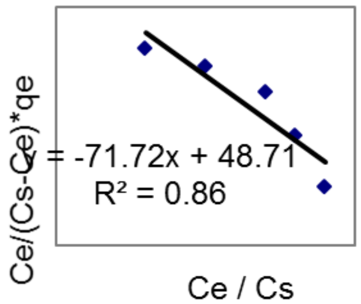

Figure (9) BET Isotherm for Adsorption of Boron onto Iron Oxide at pH=8; Iron oxide conc. =10gm/l and Initial Boron conc. =5mg/l

Table (1) Constants for Langmuir, Freundlich and BET Isotherm, and Coefficient of Determination R^2

R^2	B	1/n	K_f mg/mg	b l/mg	a mg/mg	Adsorbent
1 0.997 0.99	9.03	0.6662	0.7214	2.053	0.5577	Magnesium oxide
0.97 0.99 0.92	-0.3188	4.946	0.0011	-0.0719	-0.259	Aluminum oxide
0.93 0.81 0.86	-0.4723	13.18	$1.42*10^{-7}$	-0.0312	-0.298	Iron oxide

Adsorption Kinetic Models

Several kinetic models have been applied with view to find out which model represents the adsorption mechanism of boron adsorption onto magnesium, aluminum and iron oxide:

The Pseudo First Order Equation

ln (q_e –q_t) was plotted versus t to investigate the fit of pseudo-first-order kinetic to boron adsorption. The coefficient of determination R_1^2 for pseudo first-order are 0.88, 0.88 and 0.74for magnesium, aluminum and iron oxide respectively as shown in Figures (10, 11 and 12). From these figures the value of k_1 was determined from the slope. The higher the value of k_1, pointed to greater the adsorption.

Adsorption kinetic by magnesium, aluminum and iron oxide shows that pseudo-second-order kinetic model represents the adsorption mechanism of boron adsorption because that the coefficient of determination for pseudo second order kinetic model is higher than that for pseudo first order kinetic model for the three adsorbents.

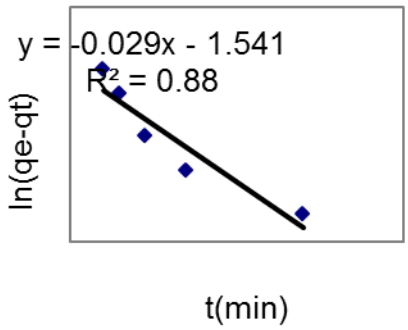

Figure (10) Pseudo First–order Kinetics to Boron Adsorption onto Magnesium Oxide at Initial boron conc.=5mg/l; MgO Conc.=10gm/l and pH=9.5

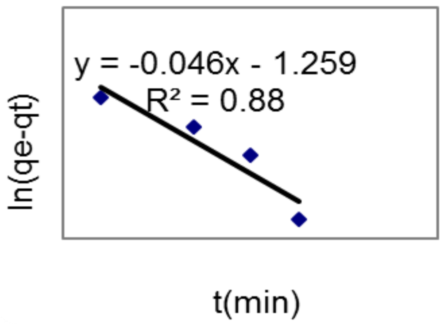

Figure (11) Pseudo First–order Kinetics to Boron Adsorption onto Aluminium Oxide at Initial Boron Conc.=5mg/l;Aluminium Oxide Conc.=10gm/l and pH=8

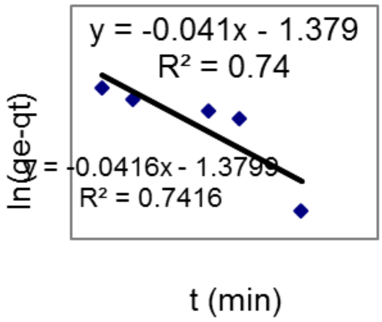

Figure (12) Pseudo First–order Kinetics to Boron Adsorption onto Iron Oxide at Initial Boron Conc.= 5mg/l; Iron Oxide Conc.=10gm/l and pH=8

The Pseudo Second Order Equation

The plot of t/q_t versus t gives a straight line with a slope of 1/qe and an intercept of $1/k_2qe^2$.

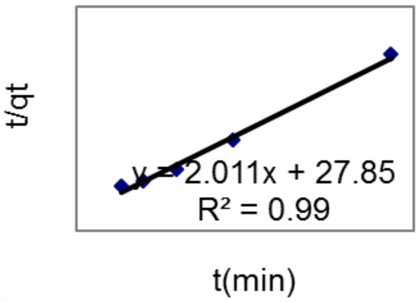

Figure (13) Pseudo Second-order Kinetics to Boron Adsorption onto Magnesium Oxide at Initial Boron conc.=5mg/l; MgO Conc.=10gm/l and pH=9.5

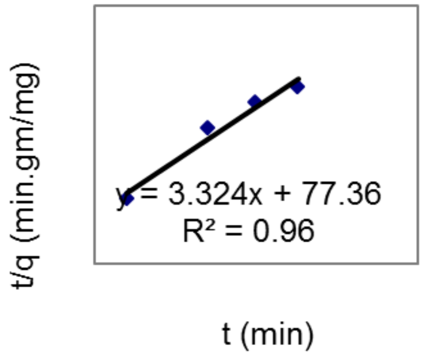

Figure (14) Pseudo Second-order Kinetics to Boron Adsorption onto Aluminium Oxide at Initial Boron conc.=5mg/l; Alumina Conc.= 10 gm/l and pH=8

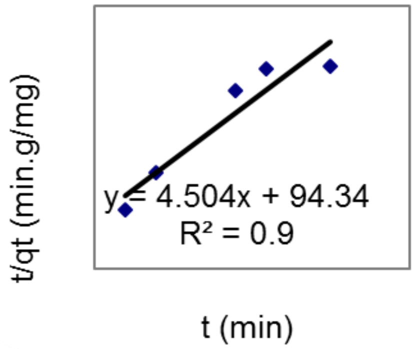

Figure (15) Pseudo Second-order Kinetics to Boron Adsorption onto Iron Oxide Oxide at Initial Boron conc.=5mg/l; Iron Oxide Conc.= 10 gm/l and pH=8

As shown from Figures (13, 14 and 15), the linearity of the plots implies the applicability of the pseudo-second-order kinetic equation for adsorption of boron onto magnesium oxide, alumina and iron oxide. Correlation coefficient (R^2) for pseudo-second-order kinetic values is obtained to be 0.99 , 0.96 and 0.9for magnesium, aluminum and iron oxide respectively. From these Figures the value of K2 was determined from the slope.

The kinetic results can be used to determine if intraparticle diffusion is the rate-limiting step for boron adsorption onto magnesium, aluminum and iron oxide.

Beside adsorption at the outer surface there is also possibility of intraparticle diffusion from the outer surface into the pores of the material. The adsorption mechanism of sorbate onto the adsorbate follows three steps, film diffusion, pore diffusion and intraparticle transport. There is a high possibility for pore diffusion to be the rate-limiting step in a batch process (Panday, *et al.*, 2006).

If intraparticle diffusion is involved in the sorption process then a plot of sorbate uptake versus the square root of time would result in a linear relationship and that particle diffusion would be the rate-controlling step if this line passes through the origin (Weber and Morris, 1964).

In order to determine the rate limiting step in the present adsorption system, intraparticle diffusion model was also applied on the experimental data. The values of kp were calculated from the slope of the linear plot of q (amount of boron adsorbed per unit mass of adsorbent) versus $t^{0.5}$ as shown in Figures (16, 17and18) for magnesium oxide, aluminum and iron oxide respectively.

As elucidated in Figures (16, 17and18) the result can be represented by a linear relationship but they do not pass through the origin. This indicates that intraparticle diffusion involved in the sorption process but it is not the only rate-limiting mechanism is involved. Such a deviation of the straight line from the origin may be due to boundary layer effect (Hussain, *et al.,* 2012; Yakout and Elsherif, 2010).

A first linear part in the Figures ended with a smooth curve followed by a second linear part. The double nature of the curve reflects the two stage boundary diffusion usually could be represented by the initial curved portion and intraparticle diffusion by the final curved portion. The rate constant of intraparticle diffusion kp, as obtained from the slope of the final linear portion was tabulated in table 2. The correlation coefficient obtained for this stage was 0.9449 for magnesium oxide and 1 for aluminum and iron oxide.

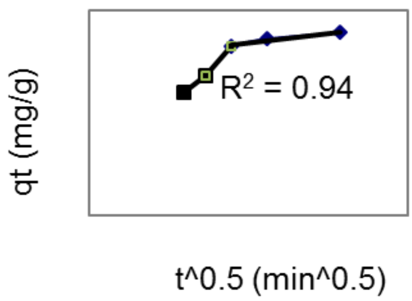

Figure (16) Intraparticle Diffusion Model for Boron Adsorption onto Magnesium Oxide Oxide at Initial boron conc.=5mg/l; MgO Conc.= 10gm/l and pH=9.5

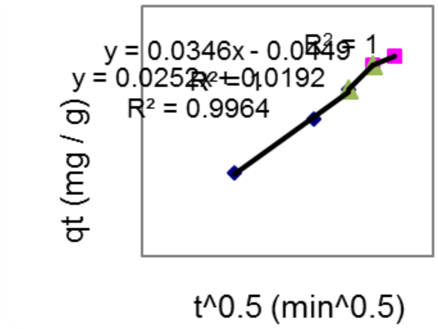

Figure (17) Intraparticle Diffusion Model for Boron Adsorption onto Alumimuim Oxide at Initial Boron conc.=5mg/l; Aluminum Oxide Conc.= 10gm/l and pH=8

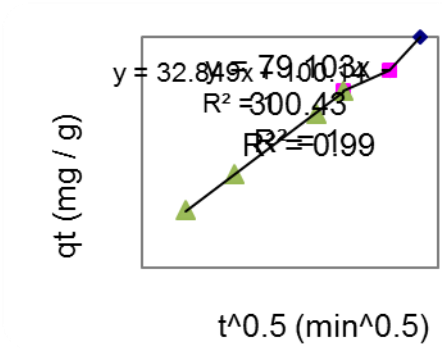

Figure (18) Intraparticle Diffusion Model for Boron Adsorption onto Iron Oxide at Initial Boron Conc.= 5mg/l; Iron Oxide Conc.= 10gm/l and pH=8

Table (2) Rate Constants for Pseudo First-order, Pseudo Second- order Kinetic and Intraparticle Diffusion Model for the Three Adsorbents

R^2 for Intraparticle diffusion model	R^2 for 2^{nd} order kinetic	R^2 for 1^{st} order kinetic	Kp ($mg/g.min^{0.5}$)	K_2 (g/min.mg)	K_1 (min^{-1})	Adsorbent
0.94	0.99	0.88	0.006	0.1452	0.0292	Magnesium oxide
1	0.96	0.88	0.034	0.14287	0.0466	Aluminum oxide
1	0.90	0.74	0.028	0.35014	0.0416	Iron oxide

Conclusions

- The coefficients of determination show that Langmuir model fit very well with magnesium and iron oxide, so there were a mono layer coverage of boron onto magnesium and iron oxide, while Freundlich model fit very well with alumina, so the uptake of boron by aluminum oxide occurs by multilayer adsorption.

-Adsorption of boron onto magnesium, aluminum and iron oxide followed pseudo-second-order kinetic and the mechanism is complex and both the surface adsorption as well as intraparticle contributes to the rate determining step.

-It is important to study the kinetics of boron adsorption onto magnesium, aluminum and iron oxide because from the kinetics and adsorption isotherm we can get knowledge of adsorption efficiency, maximum adsorption capacity, and in order to desighn and to optimize separation, the knowledge of the adsorption is mandatory.

References

Abdulhalim, A.; Thaldiri, N.H.; Awang, N. and Latif, M.T., (2012), Removing Boron from an Aqueous Solution Using Tumeric Extract-aided Coagulation-flocculation, American Journal of Environmental Sciences,8 (3), 322-327

Abdhalim, A.; Abubakar, A.F. ; Hanafiah,M.A.K.M. and Zakaria,H., (2012), Boron Removal from Aqueous Solution Using Curcuim – aided Electro - coagulation, Middle-east Journal of Scientific research, 11 (5), 583-588

Ahmed, R.; Rao, R. A. K. and Masood, M. M. (2005), Removal and Recovery of Cr(VI) from Synthetic and Industrial Wastewater Using Bark of Pinus Roxburghi*i* as an Adsorbent, Water Qual. Res. J. Canada, 40, (4), 462–468

AKermabn, E.B.; Simhon, M.V. and Vitaly, G., (2012), Advanced Treatment Options to Remove Boron from Water, Desalination and Water Treatment, 46, 285-294

Al-Ameri, B.H.A; Ali, N.S. and Afj, A.H., (2013), Effect of Zinc and Boron Application on Growth and Corn yield, Iraqi Journal of Science and Technology, 4, (2), 60-74

Al-Imam, N.M.A. and Al-birfkany, A.M.A., (2012), Effect of Nitrogen

Fertilization and Foliar Application of Boron on Fruit Set, Vegetative growth and Yield of ANNA Apple Cultivar (Malus Domestica Borkh), Mesopotamia. J. of Agric., 38, (4)

Al-Naseri, S.K., (2012), Boron Removal from Shat Al-arab River Water Using Electrocoagulation, Eng.&Tech.Journal, 30, (13), 2175-2185

Bouguerra, W.; Marzouk, I. and Hamrouni, B. (2009), Equilibrium and Kinetic Studies of Adsorption of Boron on Activated Alumina. Water Environ Res. 81(12), 2455-2459.

Cengeloglu, Y.; Tor, A.; Arslan, G.; Ersoz, M. and Gezgin, S., (2007), Removal of Boron from Aqueous Solution by Using Neutralized Red Mud, Journal of Hazardous Materials, 142, 412-417

De la Fuente.M.M. ; Soto. G. and Camachob,E. M., (2006) Separation and Boron Removal by means of Adsorption with Magnesium Oxide, Separation and Purification Technology 48, 36–44

Ho, Y.S. and McKay, G., (2000), the Kinetics of Sorption of Divalent Metal Ions onto Sphagnum Moss Peat, Water Research, 34, 736

Hussain, A. A.; Mohammed, S. R;. Nallu, M.; and Arivoli, S. (2012), Kinetic and Isotherm Study of Copper (II) Removal from Water and Wastewater Using Activated Acanthaceae, International Journal of Chemical Sciences and Applications,3 (1),207-216

Karahan, S.;Yurdakoc,M.; Seki,Y. and Yurdakoc,K., (2006), Removal of Boron from Aqueous Solution by Clay and Modified Clay, journal of Colloid and Interface Science,293, 36-42

Karc, Z.; Karabas, O.; Yilmaz, M.T.;Boncukcuoglu, R. and Karabas, I.H, (2013), The Effect of pH of the Solution in the Boron Removal Using Polyaluminum Chloride (PAC) Coagulant with Chemical Coagulation Method, *ICOEST Cappadocia*, 18-21, 340-346.

Liu,H.;Ye,X.S.;Li,Q.;Kim,T.;Qing,B.;Guo,M.;Ge,F.Wu,Z. and Lee,K. T., (2009), Boron Adsorption Using a New Boron-selective Hybrid Gel and the Commercial Resin D564, Colloids and Liu, R.; Ma, W.; Jia, C.Y.; Wang, L. and Yan,N., (2007), Effect of pH on Biosorption of Boron onto Cotton Cellulose, Desalination, 207,257-267

Mondai, K. and Lalvani, S.B. (2000), Modeling of Mass Transfer Controlled Adsorption Rate Based on the Langmuir Adsorption Isotherm, Separation Science and Technology, 35, (16), 2583-2599

Nameni, M.; Moghadam, A., M., R. and Arami, M. (2008). Adsorption of Hexavalent Chromium from Aqueous Solutions by Wheat Bran, Int. J. Environ. Sci. Tech., (5) , No(2) , 161-168.

Özcan,A.S. and Özcan,A., (2004), Adsorption of Acid Dyes from Aqueous Solutions onto Acid-activated Bentonite, Journal of Colloid and Interface Science, 276 (1), 39-46

Panday,P; Sambi,S.S; Sharma,S.K. and Singh,S., (2009), Batch Adsorption Studies for the Removal of Cu(II) Ions by Zeolite NaX from Aqueous Stream, Proceeding of the World Congress on Engineering and Computer Sciece,1.

Salih, W.M.; Alnasri, S.K. and Alabdalali, A.A., (2012), Removal of

Boron from Simulated Iraqi Surface Water by Electrocoagulation Method, Journal of Engineering, 18, (11), 1266-1284

Sulaymon, A.H.; Al-naseri, S.K. and Abdulqader, I.A.J., (2013), Boron Removal by Adsorption onto Different Oxides, Journal of Engineering, 19 (8), 970-977

Volesky, B., (2003), Biosorption: Application Aspects Process Simulation Tools, Hydro- metallurgy, 71, 179-190

Weber, W.J.and Morri, J.C. S., (1964), Equilibria and Capacities for Adsorption on Carbon, J Sanitary Eng. *Div*. 90, 79–91.

Yakout, S.M. and Elsherif, E., (2010), Batch Kinetics, Isotherm and Thermodynamic Studies of Adsorption of Strontium from Aqueous Solutions onto Low Cost Rice Straw Based Carbons, *Carbon- Sci.Tech*. 1,144-153

Zwani, Z.; Luqman, C. A. and Thomas, S. Y. C. (2009), Equilibrium, Kinetics and Thermodynamic Studies; Adsorption of Removal Black 5 on the Palm Kernel Shell Activated Carbon(PKS-AC), European Journal of Scientific Research, 37, (1), 67-76