INVESTIGATING THE USE OF DATE SEED FOR REMOVAL OF BORON FROM SEAWATER

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ABSTRACT: Boron has been classified as a drinking water pollutant in many countries. It is harmful to many plants, exceptionally sensible plants, and human health. Therefore, boron level needs to be decreased to 0.3 mg/L for drinking water and within 0.5 mg/L to 1 mg/L for irrigation water. In this study, various operational parameters namely pH, contact time and liquid/solid ratio were investigated to determine the potential of using date seed (or date pit or date stone) to remove boron from seawater. This study's main objective was to determine boron adsorption capacities of date seeds prepared by various methods (i.e., powdered, activated, acid-treated and defatted seed) by batch adsorption process using boron contaminated synthetic seawater. The process parameters of the selected biosorbent among the four date seed preparations methods were optimized. The surface characteristics were analyzed by using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM). The results showed that acid-treated date seed was the best biosorbent in terms of removing 89.18% boron from aqueous solution at neutral pH, liquid to solid ratio of 5 within 2 hours of reaction time at room temperature (25°C±2°C).

KEY WORDS: *Water treatment, date seed, boron, adsorption, acid treatment*

1. INTRODUCTION

It is also a known fact that the rapid growth of the world's population, industrialization, and climate change are the causes of water scarcity. A global freshwater assessment report reveals that nearly 6 billion people will be affected by the clean water shortage by 2050 [1, 2]. The lack of freshwater decreases the quality of the drinking water, and as a result, the whole population of the countries concerned would suffer from the lack of water to drink [3, 4]. Boron is one of the common contaminants in seawater, and it is harmful to living things such as sensible plants and human health. Therefore, figuring out of boron chemistry is inevitable in developing a treatment method for boron removal from seawater. Boron has an atomic number of 5 located on IIIA of periodic table and is often bound to hydrogen and oxygen to compensate for electron deficiency. Boron has three or four coordination numbers shown in boric acid (B_3OH_3) and tetrafluoroborate anion BF_4^- , respectively [5]. Some experiments conducted on mice, rats, and rabbits to evaluate the boron toxicity showed that boron is not mutagenic and carcinogenic but it affected the development and reproduction of animals. Therefore, animal studies suggest that humans are not immune to the harmful problems of the boron element. Thus, excessive boron in our body affects the concentration of hormones, namely calcitonin, 17b-estradiol, 25-hydroxycholecalciferol, and triiodothyronine in plasma and serum. It has been observed from accidental poisoning that the acute lethal dose of boric acid is 3000 - 6000 mg for infants and 15,000 /- 20,000 mg for adults [6].

World Health Organisation (WHO) has set a limit of 0.3 mg/L of boron in drinking water. Indeed, the seawater desalination plant is gaining more attention in water-stressed countries. However, there is still trouble to achieve 0.3 mg/L of boron in drinking water from the desalination plant. The most common methods for boron removal from seawater are reverse osmosis membrane and ion exchange. Both of the processes are characterized by high energy intensity, high cost, and the presence of other competitive chemical elements [7 - 9]. Thus, biosorption is an alternative and promising method for removing boron, especially using the agricultural by-product known as biosorbent. The biosorption process has two phases, such as solid phase (sorbent or biosorbent) and liquid phase (solvent), which contains dissolved chemical substances (sorbate) such as the ions or heavy metals. The biosorption process's driving force is the chemical affinity between sorbate and sorbent; thus, adsorption of ions on the surface of biosorbent occurs until it reaches equilibrium adsorption capacity will be determined. Therefore, the biosorption is more attractive due to some privileges such as low cost operating, selective and efficient removal at low concentration, easiness in the regeneration of biosorbent, and environmental friendly effluent [10].

Phoenix dactylifera is commonly known as date palm, belongs to the palm family of Arecaceae. It is a flowering plant usually cultivated for edible sweet fruit and widely planted across northern Africa, the Middle East, and South Asia ([11]. The date palm production is concentrated in the Arab countries that they produce 75% of the world production of the date. While the Gulf countries plus Iraq and Yemen are responsible for half of the production, the other half is produced in North and East Africa. Pakistan alone produces 9.65% of the world's production of dates [12]. Date palm is one of the oldest crops that signifies life in the desert because of its tolerance to severe conditions such as very high temperature, drought, and salinity, unlike many plants. In this study, date seed is utilized as one of the promising biosorbent. Some studies stated that the date seeds are rich in minerals such as potassium and calcium, which has a chemical affinity towards boron [13], as shown in Table 1. It is essential to know date pits' chemical composition to understand how boron is adsorbed on the date seed surface.

Table 1: Physicochemical compositions of date seed [13]

Components	Concentration
Moisture content (%)	10.20±0.25
Matter oil dried matter (oil=weigh oil extracted*100/weigh of seeds)	0.23±0.29
Ash dried matter %	1.18±0.02
Protein (N%*6.5)	5.67±0.15
Carbohydrate obtained by difference	72.59±0.28
Potassium (in mg/100 g dried matter)	255.44±0.02
Magnesium in mg/100 g dried matter)	62.78±0.18
Calcium in mg/100 g dried matter)	48.56±0.56
Phosphorus in mg/100 g dried matter)	41.33±0.66
Sodium in mg/100 g dried matter)	8.77±0.22
Iron in mg/100 g dried matter)	3.21±0.034

Date seed is one of the most abundant agricultural wastes, and it was reported that the date flesh and seed contain boron up to 63 mg/100 g as it is essential for the growth of particular date palms [13]. Naturally, the date pits adsorb the boron via chemical affinity between the organic matter and minerals present in date stones and the boron. Previous findings have shown that date seed can remove up to 71% of boron from seawater at neutral pH [13, 14].

Therefore, this work is aimed to investigate the use of date seed as a promising biosorbent for the removal of boron due to easily accessible, non-toxic, and effective at neutral pH [8, 15]. The batch adsorption process was conducted using date seed, prepared by four different preparation methods (i.e., powdered, activated, acid-treated, and defatted seed) to determine the boron percentage removal. Then, the best sorbent process parameters among the four date seed preparation methods were optimized by varying parameters such as pH, liquid to solid ratio, and contact time. The surface characteristics of the best sorbent were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM). Equilibrium isotherm and kinetic studies of the best sorbent were also determined.

2. MATERIALS AND METHODS

2.1 Materials

The raw material used was a good quality of date seed called Deglet Nour from Tunisia purchased from Idaman shops, Kuala Lumpur, Malaysia.

2.2 Methods

2.2.1 Raw date seed

Date seeds were washed with a massive amount of distilled water to remove the dust. Then, the seeds were dried in an oven at 105°C overnight. Finally, date seeds were ground using the hammer and sieved, and the particle size of 106 μm was used for this study [16 - 18]. Fig. 1 below shows the raw date seed in powder form.

Fig. 1. Raw date seed

2.2.2 Activated Carbon from Date Seed

The date seeds were burned at 500 °C in a furnace for 1 hour and ground using the hammer, sieved, and used for this study [13, 16, 19]. The produced activated carbon from date seed is shown in Fig. 2.

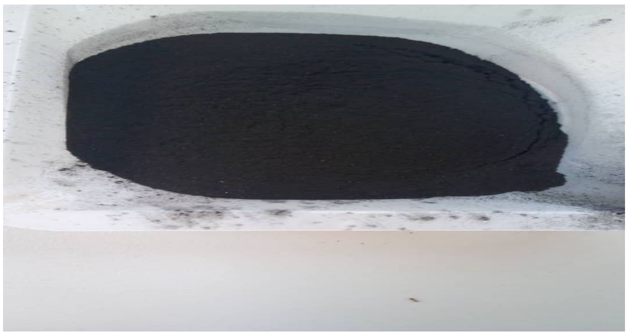

Fig. 2. Activated carbon from date seed

2.2.3 Defatted Date Seed

After sieving, the process of oil extraction from date seeds was conducted using Soxhlet extraction. The oil extraction process was carried out by adding 50 g of 106 μm of date seed and transferred to a 30 mm × 200 mm cellulose thimble. It is put in an extraction chamber of 250 mL Soxhlet apparatus fitted with a condenser placed on a 500 mL distillation flask containing 250 mL of *n*-hexane. The *n*-hexane was heated at its boiling temperature of 69 °C [13, 16, 19]. Fig. 3 shows the defatted date seed by the oil extraction method.

Fig. 3. Defatted date seed

2.2.4 Acid Treated Date Seed

After sieving, date seed (particle size = 106 μm) were used for this study. The date seeds were then treated with 1 mol/L of hydrochloride acid at a ratio of 4 g activated date seed to 25 mL of 1 mol/L of hydrochloric acid at room temperature (25 ±2°C) for 8 hours. The sorbent was then filtered and washed with a massive amount of deionized water. The chemically and thermally activated date seeds were then dried at 100 °C for 12 hours and sieved, and the particle size of 106 μm was ready for the adsorption process [16 -18]. Fig. 4 illustrates an image of an acid-treated date seed.

Fig. 4. Acid treated date seed

2.2.5 Batch adsorption experiment

The experiment was conducted batch-wise in a 200 mL Erlenmeyer flask mounted on a hot plate with a magnetic stirrer. The flask was securely covered with an aluminum foil paper to avoid splash. The agitation was maintained at 150 rpm, while the ambient temperature was adopted throughout. The percentage of removal was calculated as follows [20]:

$$Boron\ removal(\%) = \frac{(C_0 - C_e)}{C_0} \times 100 \tag{1}$$

Where C_0 and C_e are the initial concentration of adsorbate and equilibrium concentration at equilibrium, respectively.

2.2.5.1 Adsorption isotherm

Adsorption isotherm was conducted to determine the equilibrium point of boron adsorption on the date seed. Equilibrium isotherm experiments were carried out in batch by mixing different adsorbent dose from 10 mg, 20 mg, 40 mg, 60 mg, and 80 mg of acid-treated date seeds to the volumetric flask (200 mL) containing 50 mL boric acid solution with 80 mg/L of initial boron concentration at room temperature (25±2°C), pH (7), contact time (2 hours) and shaking speed (150 rpm). Then, after 2 hours, the sample was taken out of the shaker and left at room temperature 24 hours for sedimentation. Then filtered and 1 mL of supernatant was used to determine boron concentration remaining in the solution after adsorption [13, 14].

In this study, the most observed equilibrium isotherm models on the adsorption process are investigated: Langmuir, Freundlich and Brunauer, Emmet, and Teller (BET) [21, 22]. The amount of adsorbate adsorbed at equilibrium can be determined using the following equation [23, 24]:

$$q_e = \frac{V(C_0 - C_e)}{W} \tag{2}$$

Where $q_e\left(\frac{mg}{g}\right)$ is the amount of adsorbate adsorbed at equilibrium, $V\ (L)$ is the volume of the sample, $C_0\left(\frac{mg}{l}\right)$ is the initial concentration of adsorbate and $C_e\frac{mg}{l}\ W(g)$ is the concentration of adsorbate remained in bulk solution at equilibrium.

The linear form of the Langmuir equation can be written as follows [25]:

$$\frac{C_e}{q_e} = \frac{1}{K_L Q_0} + \frac{C_e}{Q_0} \tag{3}$$

where q_e is the quantity of adsorbate adsorbed in mg/g, C_e is the equilibrium concentration (mg/L), b is the constant of adsorption equilibrium (L/mg), and q_m (mg/g) is the maximum adsorption capacity.

Meanwhile, for the linearization of the Freundlich model is [21]:

$$\log q_e = log\, K_F + \frac{1}{n} logC_e \tag{4}$$

where K_f is an indicator of adsorption capacity, while *1/n* is a measure of the intensity of adsorption.

The linear form of the BET isotherm model is [21]:

$$\frac{C_e}{(C_s - C_e) \times q_e} = \frac{K_B - 1}{K_B \times Q^0} \times \frac{C_e}{C_e} + \frac{1}{K_B \times Q^0} \tag{5}$$

Where K_B is the BET constant or equilibrium distribution coefficient representing adsorption intensity, and Q^o is the maximum adsorption capacity (mg/g).

2.2.5.2 Adsorption kinetics

The kinetic models were used to understand the control mechanism, the adsorption process's behavior, and predict the adsorption rate at which the adsorbate is adsorbed from solution. Three different kinetic models were applied in this study: Lagergren pseudo-first-order, pseudo-second-order, and intra-particle diffusion.

Adsorption kinetics study was conducted by adding a known amount of acid-treated date seeds (10 mg) in a volumetric flask containing 50 mL of boric acid solution with 80 mg/L of initial boron concentration and agitated at 150 rpm, pH (7) at room temperature for 2 hours. The samples were taken out in 10 minutes and every 30 minutes. After 2 hours of reaction, the samples were removed from the shaker and left for 24 hours for sedimentation at room temperature. Then, the supernatant was taken out, filtrated using (Structure From Motion (SFM) 102 filter paper. 1 mL of the aliquot was used to determine the amount of boron remaining in the sample [13, 14]. The adsorption capacity a time t, q_t were determined using the below equation [26]:

$$q_t = \frac{(C_o - C_t) \times V}{W} \tag{6}$$

Where q (mg/g) is the amount of adsorbate by an adsorbent at time t, C_0 and C_e are the initial and remaining adsorbate concentration in the solution. Whereas V(L) is the sample's volume, and W (g) is the adsorbent dose.

A pseudo-first-order linear equation is determined using the following equation [27, 28];

$$\ln(\ln q_e - q_t) = \ln q_e - k_1 t \tag{7}$$

Where k_1 is rate constant, t is time (min^{-1}), q_e (mg/g) is the amount of adsorbate at equilibrium, and q_t (mg/g) is the amount adsorbed at time t. The linear form of the pseudo-first-order gives a linear regression of ln(q_e–q_t) as a function of time t (min), and k_1 is determined from the slope [28].

Moreover, the linear form of pseudo-second-order can be formulated as following [28]:

$$\frac{t}{q_t} = \frac{1}{K_s q_e^2} + \frac{1}{q_e} t \tag{8}$$

Where K_s is the rate constant of the pseudo-second-order model (g/mg min) and q_e is the adsorption capacity (mg/g) or the amount of adsorbate adsorbed at equilibrium.

Meanwhile, for the interparticle diffusion model that assumes the adsorption capacity is proportion to $t^{1/2}$ and the linearized form of this model is [20]:

$$q_t = K_{id}t^{1/2} + C \tag{9}$$

Where K_{id} (mg $g^{-1}min^{-0.5}$) and C is slope and intercept of plot q_t versus $t^{1/2}$, besides, the intercept C reflects an idea about the thickness of the boundary layer, and the high C gives a great boundary layer.

2.3 Design of experiment (DOE)

In this study, the experiments were designed by Design-Expert version 6.0.8 using Response Surface Methodology based on Factorial Central Composite Design (FCCD). The three optimized parameters by using FCCD are pH, contact time, and liquid to solid ratio. The other parameters set as constant throughout the experiment were agitation speed fixed at 150 rpm, and the experiments are conducted at room temperature. The analysis was done using a dispersive liquid microextraction coupled UV-spectrophotometer [29, 30].

3. RESULT AND DISCUSSION

3.1 Screening of Adsorption Potentials of Various Preparation Methods of Date Seeds

Fig. 5 shows the percentage of boron removal by different methods of preparing the date's seed.

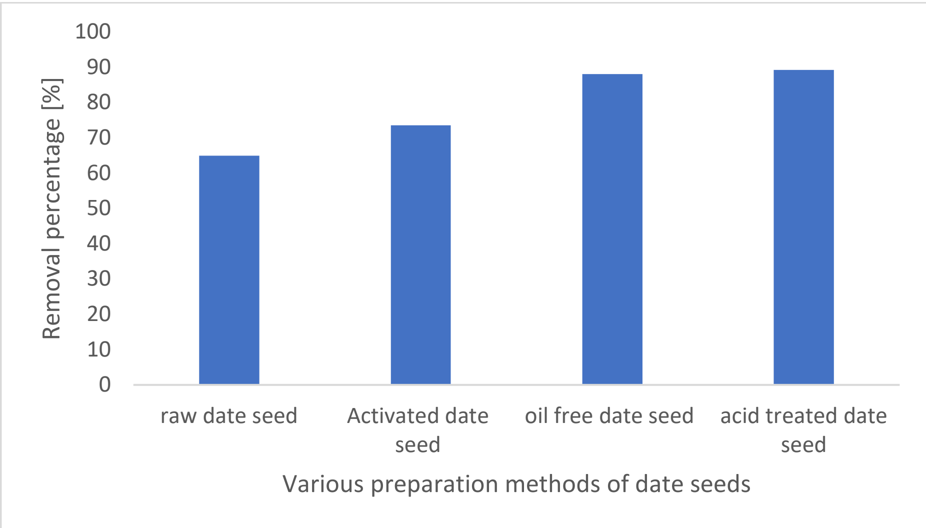

Fig. 5. Percentage of boron removal by various date seed preparation methods

It is observed from Fig. 5 that acid-treated date seed (ATDS) and oil-free date seed (ODS) are much better in terms of boron adsorption than raw date seeds (RDS) and the active carbon of date seed (CDS), which were 89.18, 80%, 46%, and 73%, respectively. In this study, activated carbon from date seed removed 73% of the boron present in the aqueous solution, an amount almost identical to that reported by Al. Haddabi et al., on their study on boron removal from seawater by date seed ash [13]. The highest removal of boron by acid-treated date seed can be explained by the fact that acid removes the small cavities and cracks on the surface of date seed, which can close the pores on the surface reported by Chen et al. [31].

3.2 Effect of Time on Removal of Boron

Fig. 6 illustrates the effect of contact time on removing boron at pH 7, liquid to solid ratio of 5 (50 mL of boron contaminated water, and 10 mg of acid-treated date seed) at room temperature.

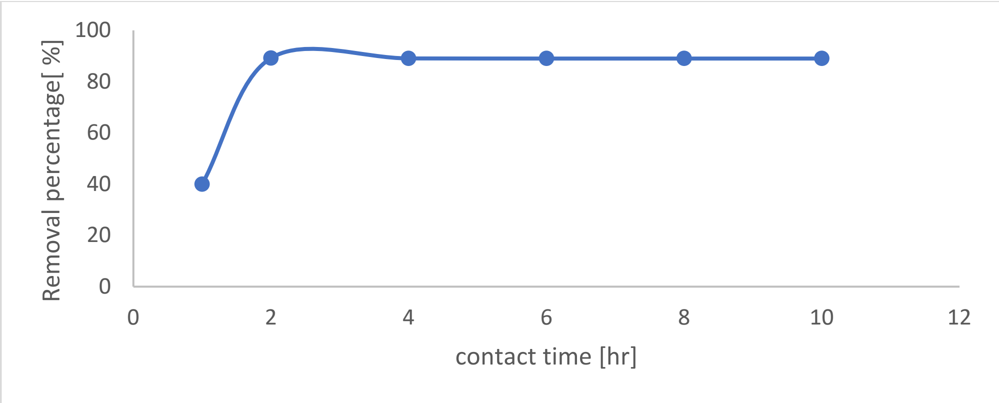

Fig. 6. Impact of contact time on boron adsorption by acid-treated date seeds.

It can be observed from Fig. 6 that the contact time has no significant effect on boron adsorption by acid-treated date seeds and that 2 hours reaction time is the equilibrium time with maximum removal of boron of 89.18%. Alhadabi et al. also observed that contact time did not significantly impact boron adsorption, and 2 hours of contact time would be economically preferred [13]. Mouni et al. reported that 1 hour was the equilibrium time for adsorption of Pb^{2+} and Zn^{2+} on activated carbon from date seed [32].

3.3 Effect of pH on Boron Removal

Fig. 7 illustrates the effect of pH on removal of boron from aqueous solution using acid-treated date seed at the liquid to solid ratio of 5 (50 ml of boon sample with 10 mg of acid-treated date seed) at room temperature (25°C±2°C) for 2 hours of reaction time.

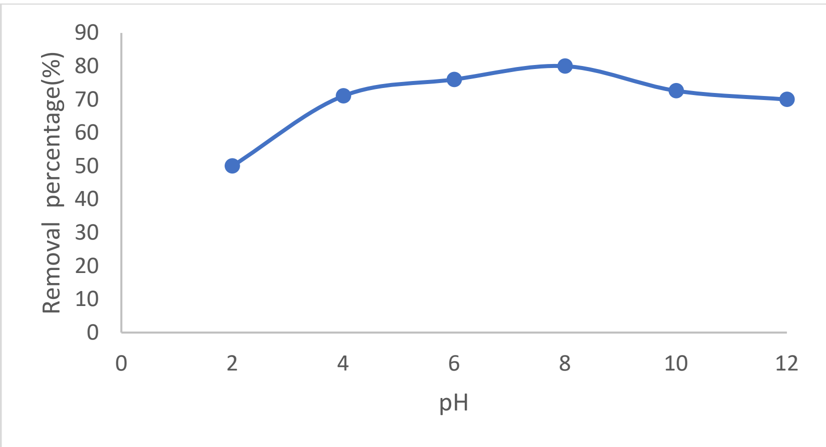

Fig. 7. Effect of pH on boron adsorption at 2 hours of reaction with liquid to solid ratio of 5 at room temperature

The figure briefly illustrates the impact of pH on boron's adsorption in an aqueous solution by acid-treated date seed. It was observed that the acid-treated date seed adsorbs boron regardless of the pH value. Alhaddabi et al. [13] have also observed that the date seed's boron adsorption is possible at acidic, neutral, and basic pH [9]. However, the maximum removal of boron is reached at neutral pH with a removal percentage of 89.18%. The work of Abu Auwal et al., Al-Ithari et al., and Alhaddabi illustrated that the date seed is adsorbed to the maximum at neutral pH [13, 14, 33].

3.4 Effect of Liquid to Solid Ratio on Removal of Boron

Fig. 8 shows the effect of liquid to solid ratio on boron adsorption from aqueous solution by acid-treated date seed at 2 hours of reaction time with pH 7 at room temperature (25°C±2°C).

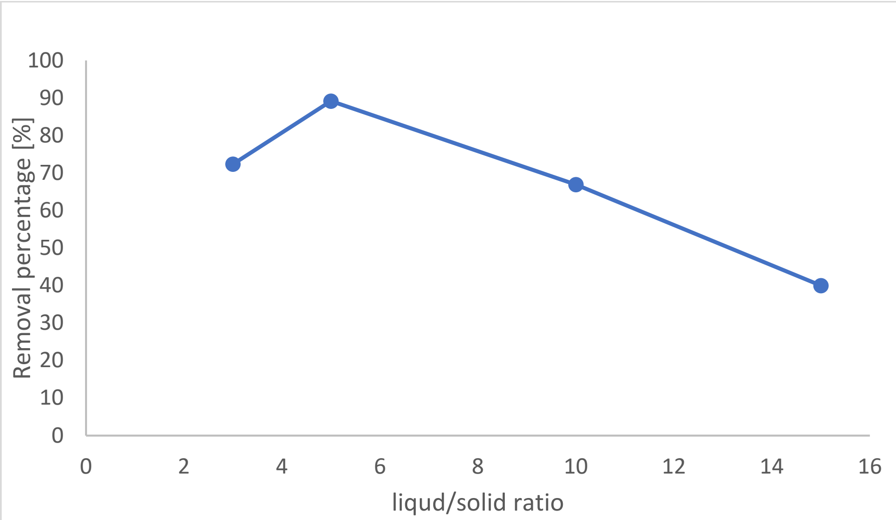

Fig. 8. Effect of liquid to solid ratio on the removal of boron

It shows the impact of the liquid to solid ratio on boron's adsorption in an aqueous solution by acid-treated date seed. It is evident that the higher the liquid to solid ratio, which is from a ratio of 3 to 15, the lower the adsorbent removal capacity. Indeed, acid-treated seed removed 89.18% of boron from an aqueous solution at the liquid to solid ratio of 5, at neutral pH within 2 hours of reaction time at room temperature (25°C±2°C). Alhaddabi et al. also showed that the liquid to solid ratio of 5 removed the most significant amount of boron from an aqueous solution [13, 19].

3.5 Modeling by Statistical Analysis

Table 2 below shows different runs from Design-Expert version 6.0.8, where the design was created by using Response Surface Methodology based on Factorial Central Composite Design (FCCD). The pH (6, 7, and 8), liquid to solid ratio (3, 5, and 7), and contact time (1, 2, and 3 hours) were varied accordingly to determine the percentage of boron removal. The results illustrated that when pH increases, the boron removal efficiency decreases.

Table 2: Design of experiment (DOE)

Run	Factor1 pH A	Factor 2 liquid/solid ratio B	Factor 3 contact time C	Removal percentage (%)
1	8	7	3	16
2	6	3	3	79.63
3	8	7	1	18.27
4	8	3	3	31.91
5	7	5	2	89.18
6	8	3	1	38.73
7	6	7	1	72.82
8	6	7	3	70.55
9	6	3	1	81.81
10	7	5	2	89.18

According to the ANOVA, the model was significant with R^2, adjusted R^2 and predicated R^2 were 0.9995, 0.9981, and 0.8740, respectively. Adequate precision compares the range of the predicted values at the design point to the mean prediction error. Its value is more significant than four is desirable and confirms the applicability of the model for navigation of the design space. The adequate precision of 72.725 in the present case shows that the model is acceptable. The lack of fit is not significant, which is suitable for the model [29].

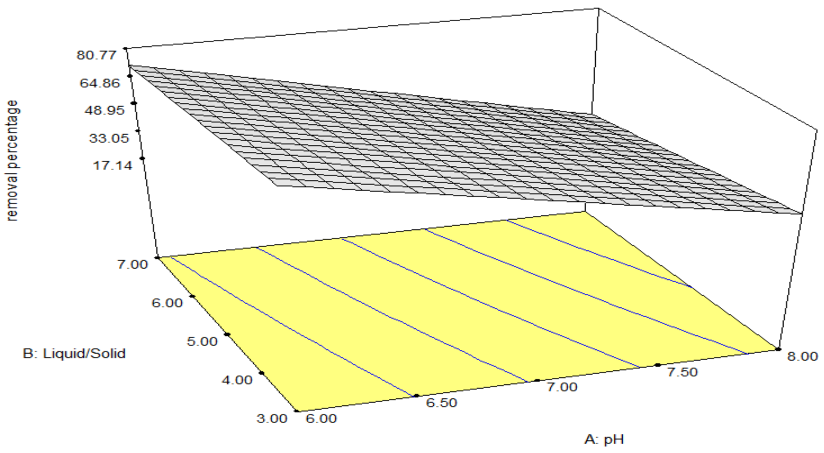

Fig. 9 (a). Effect of liquid to solid to pH

Fig. 9 (a) illustrates the three-dimensional surface plot as a function of pH and liquid to solid ratio. It is observed that boron removal efficiency increases from pH 8 to pH 6, liquid to solid from 7 to 3 in 2-hour time. It can be concluded from Fig. 9 (a) that the optimum conditons for the best boron removal efficiency lie in the range of pH 6 to 7, and liquid to the solid ratio between 5 to 6 at 2 hours equilibrium time. The same conclusions were made by Al-Ithari et al. and Alhadabi et al. [13, 14].

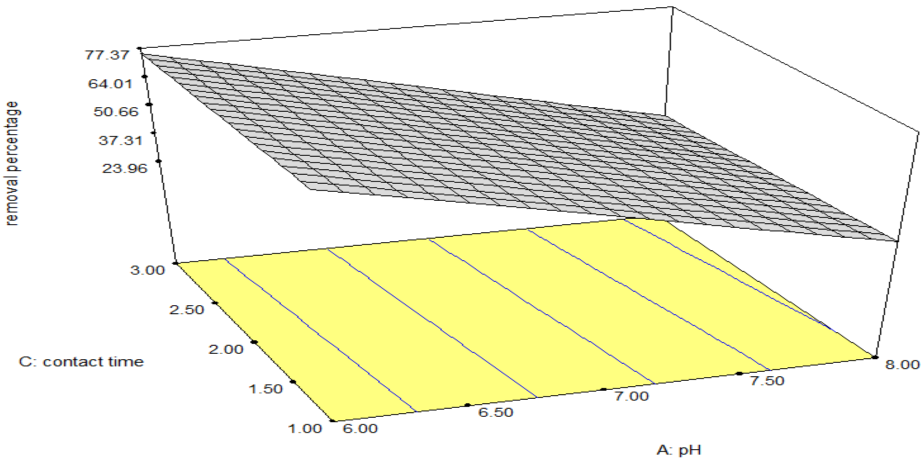

Fig. 9 (b). Effect of contact time and pH

Fig. 9 (b) illustrates the effect of contact time and pH. It is clear from Fig. 9 (b) that maximum removal of boron is achieved between pH 6 and pH 7. It is observed that removal percentages from 1 hour to 3 hours increased slightly. This information is quite the same as what Alhaddabi et al., Auwal et al., and Al-Ithari et al. reported on adsorption onto date seed [13, 14, 33].

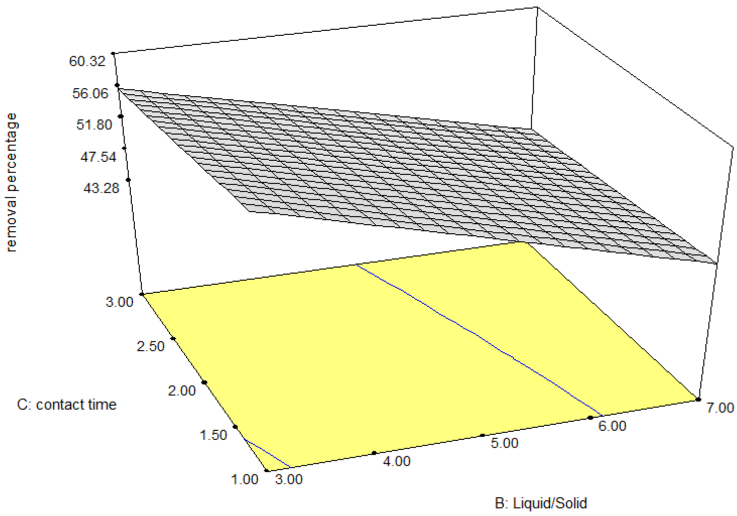

Fig. 9 (c). Effect of contact time and liquid to solid ratio

Fig. 9 (c) shows the effect of contact time and liquid to solid ratio. In this figure, the boron removal efficiency increased well from liquid to solid ratio 3 to 5. It seems that contact time does not affect that much boron removal efficiency. Alhaddabi et al. reported no difference between 2 hours and 24 hours of reaction time on boron adsorption onto date seed [13].

3.6 Characterization of Acid treated date seed

3.6.1 Fourier Transform Infrared Spectroscopy (FTIR)

The biosorption of boron on date seed was attributed to active groups and bonds present on the surface. The driving force for solute adsorption onto date pits is because the solute present has high solubility onto date seed than solvent. The second is the specific chemical interaction between date seed and solute. The date's seed consists of three main components, such as cellulose, hemicellulose, and lignin. Chemically, cellulose and hemicellulose have an oxygen functional group present in lignin, but lignin also contains an aromatic group. Indeed, the adsorption mechanism can be explained by the presence of dispersion forces, complexion, hydrogen bonds, and electrostatic interactions [34].

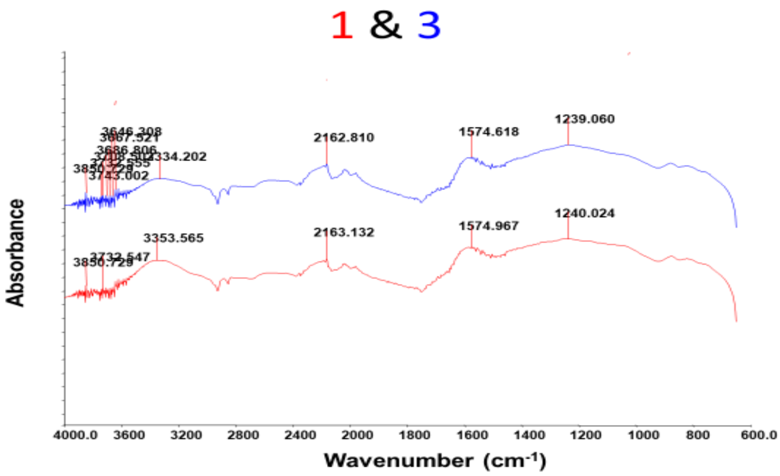

Fig. 10. Functional groups of acid-treated date seed before adsorption (3, blue color) and date seed after adsorption (1, color red)

Fig. 10 compares different functional groups on acid-treated date seed before adsorption (3) and after adsorption of boron from aqueous solution. Some picks were observed on acid-treated date seed before adsorption at 2162 cm^{-1}, 1574 cm^{-1}, 1239 cm^{-1} and fingerprint region from 3334 $cm^{-}1$ to 3850 $cm^{-}1$ which were assigned to Alkyne (-C---C), aromatic (C—C) and Amine group (C-N) and O-H stretch, respectively. But, the spectrum after boron adsorption showed disappearance, shifting or decrease in peaks intensities at 3646 cm^{-1}, 3667 cm^{-1}, 3686 cm^{-1}, 3743 cm^{-1}, 3334 cm^{-1}, 2162 cm^{-1}. A peak at 3646 cm^{-1}, 3667 $cm^{-1,}$ and 3686 cm^{-1} and 3743 cm^{-1} disappeared after boron biosorption showed active O-H group involvement in the biosorption. The O-H stretch, an amine group (C-N), aromatic group were observed on the date seed surface by Alhaddabi et al. and Mohammad et al. [13, 34].

3.6.2 Scanning Electron Microscope (SEM)

A scanning electron microscope was used to study the surface morphology of acid-treated date seed before and after boron adsorption [13].

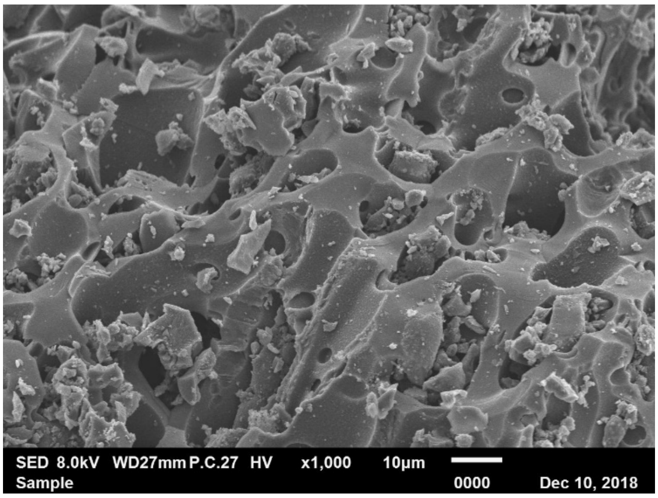

Fig. 11. Scanning electron microscope of activated date seed

Fig. 11 shows the surface morphology of activated carbon made from the date seed. The figure shows that there are so many small cavities, fine particles attached to the activated date seed's surface, forming a pore-blocking system. Chen et al. observed a similar pattern [31].

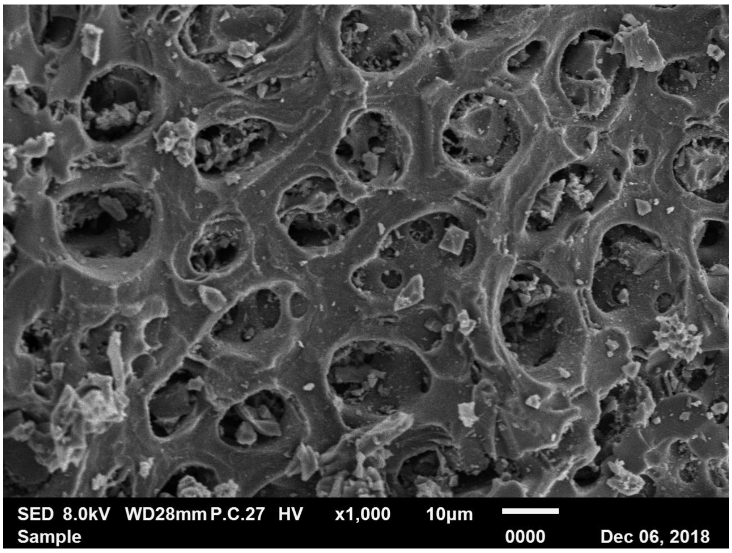

Fig. 12. SEM of acid-treated date seed before adsorption

Fig. 12 illustrates an image of the surface morphology of acid-treated date seed before boron adsorption. In the figure, there are so many pores on the surface of an acid-treated date seed. Alhaddabi et al. observed quite the same image of surface morphology of date seeds and their study on boron removal from seawater by date seed ash [13].

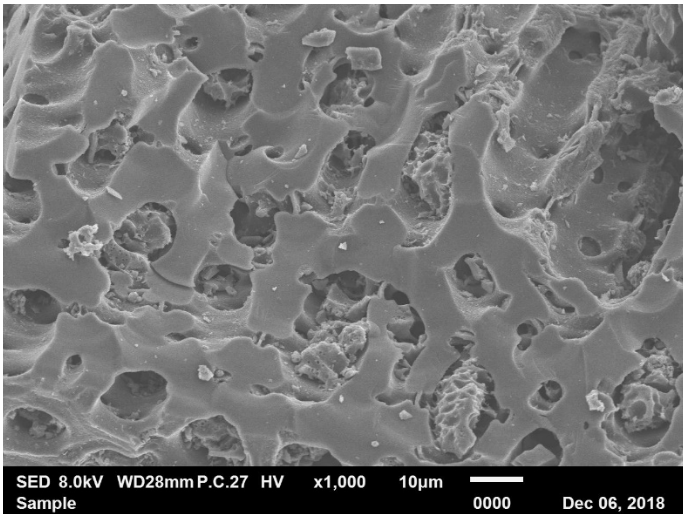

Fig. 13. SEM of acid-treated date seeds after boron adsorption

Fig. 13 shows an image for surface morphology of acid-treated date seed after boron adsorption. It was observed that the pores on the surface of the acid-treated date seed were fully occupied by boron via functional group on the surface. Al Haddabi et al has observed it. That after boron adsorption onto date seed, the pores of date seed surface are fully occupied [13].

3.7 Adsorption isotherm and kinetic studies

The experimental equilibrium data were investigated for boron adsorption on acid-treated date seed at the optimum conditions and constant temperature (25°C±2°C). The adsorption capacity was calculated and then fitted with BET, Langmuir, and Freundlich isotherms equations. The constant and correlation coefficient (*R^2*) for the three isotherm models were determined.

Figure 14 (a) is about BET isotherm of boron adsorption on acid-treated date seed with the coefficient of correlation (R^2) value of 0.763, while Figure 14 (b) shows the linear plot of Langmuir isotherm model represented by C_e/q_e versus C_e. Figure 4.15 illustrates that R^2 value was 0.8625.

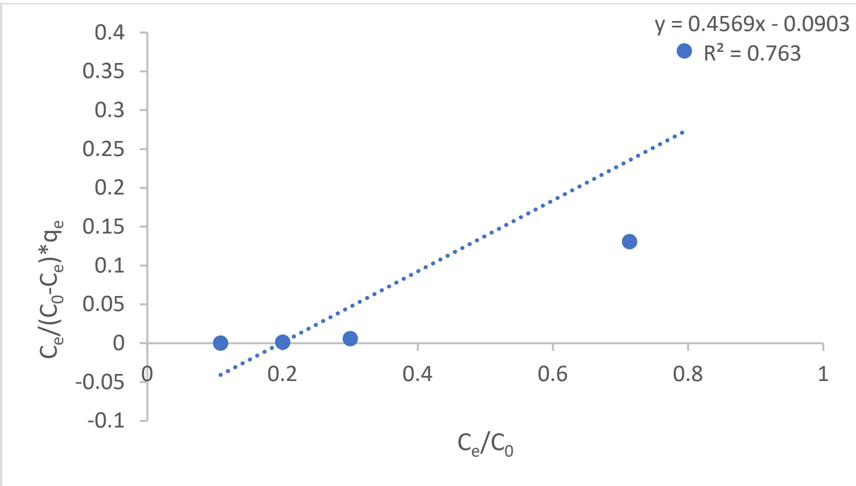

Fig 14 (a). BET isotherm model (dotted line refers to model)

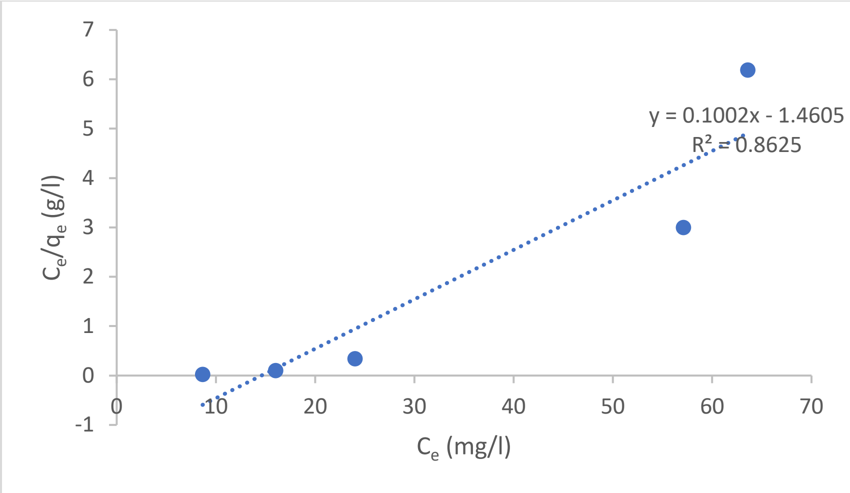

Fig 14 (b). Langmuir isotherm model (dotted line refers to model)

Meanwhile, Figure 14 (c) shows the Freundlich isotherm model. Indeed, the R^2 value of Freundlich isotherm was 0.9853, indicating the favourability of boron adsorption on an acid-treated date seed. Therefore, the equilibrium data of this study is fitted better with Freundlich isotherm. Indeed, El-Bakouri et al. reported that adsorption on acid-treated date seed is fitted better with the Freundlich isotherm model with R^2 value of 0.998 compared with Langmuir isotherm with a regression value of R^2 is 0.92. However, this study's slope is negative -1.7185, and Mohammed et al. [35] observed a negative slope with the Freundlich isotherm model with a correlation coefficient of 0.9842. They explained that the slope value of less than 1 indicates that the intercept decreases with increased concentration [35].

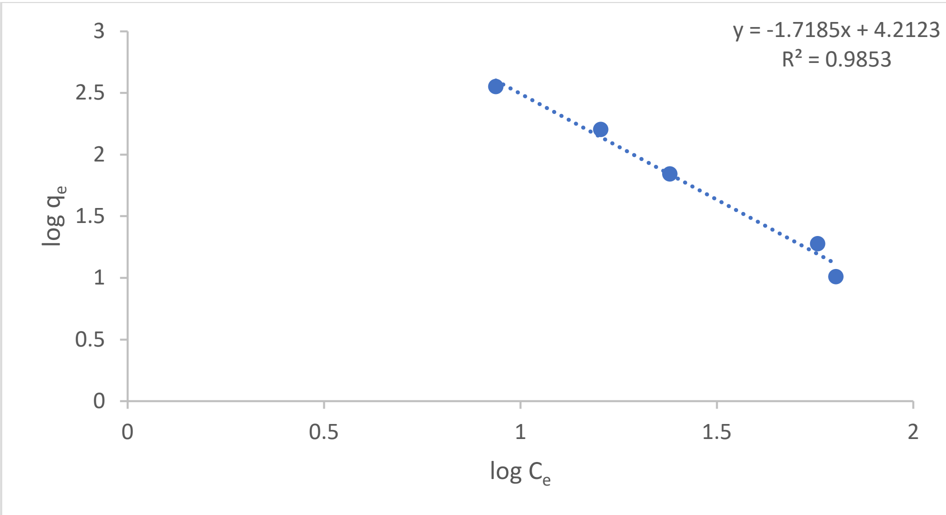

Fig 14(c) Freundlich isotherm model (dotted line refers to model)

Fig. 15 (a) shows the pseudo-first-order model with a correlation coefficient R^2 of 0.6912, while Fig. 15 (b) shows the pseudo-second-order model with a higher correlation coefficient $R^{2,}$ which is 0.9509. Therefore, adsorption of boron from aqueous solution on acid-treated date seed is fitted with pseudo-second-order with a coefficient of correlation R^2 of 0.9509. El Bakouri et al. reported on their work on acid-treated date seed that the adsorption on acid-treated date seed is fitted with pseudo-second-order model [36].

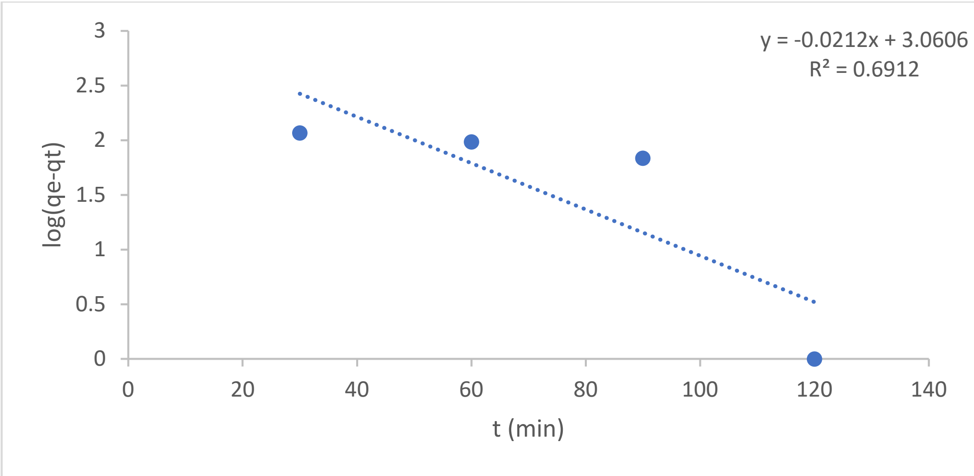

Fig. 15 (a). Pseudo-first-order kinetic model (dotted line refers to model)

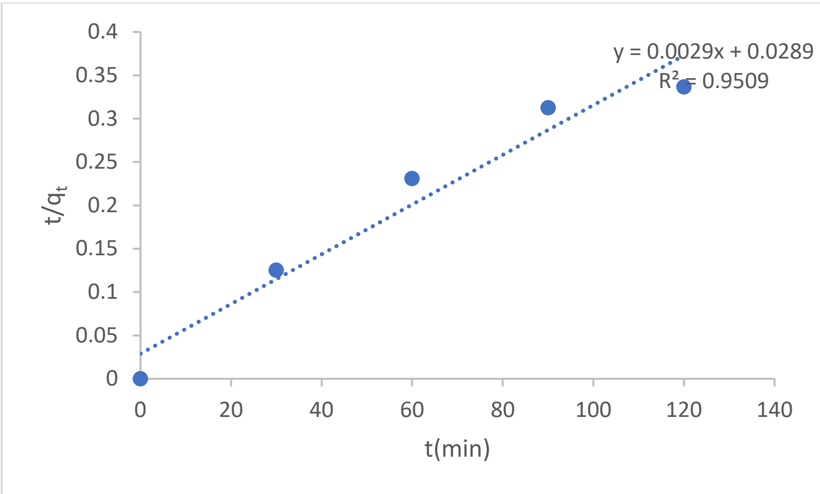

Fig. 15 (b). Pseudo-second-order kinetic model (dotted line refers to model)

Fig. 15 (c) illustrates the intraparticle diffusion model with a lower value of the coefficient of correlation $R^{2,}$ which is 0.8602 showing that the adsorption process is not fitted with the model.

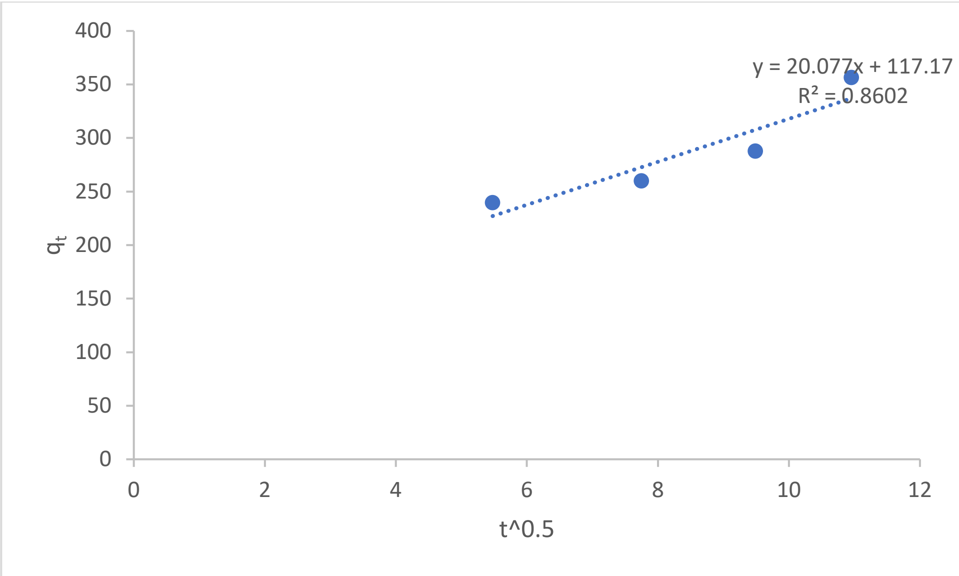

Fig. 15 (c). Intraparticle diffusion kinetic model (dotted line refers to model)

4. CONCLUSION

The date seed is a potential adsorbent for the removal of boron from seawater. Acid treated date seed removed 89.18% of boron from the aqueous solution. Indeed, the date seed is abundant, non-toxic, and eco-friendly. What is pertinent in date seed is that it works well at neutral pH and room temperature. This study might be considered for future research in advanced technology of seawater treatment, which could be included in the desalination process.

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