

# Optimization of Preparation Conditions for Activated Carbon from Date Stones by Chemical Activation using Response Methodology on Removal of Cr (VI) from Aqueous Solution

Hédi Ben Amor and Aicha Mabrouk

Chemical Engineering Department, National School of Engineers of Gabes  
Omar Ibn Elkhatab Avenue 6029 Gabes, Tunisia

---

**ABSTRACT:** *Aims:* the objective of this work was to evaluate the adsorption potential of date stones based activated carbon for Cr (VI) removal from aqueous solution. *Study design:* Date stones (DS), agriculture wastes, available in large quantity in Tunisia, were used to prepare a low cost activated carbon (DSAC) for removing Cr (VI) from aqueous solution. Chemical activation method using sulphuric acid was employed for the preparation of the DSAC. *Place and Duration of Study:* Chemical Engineering Department, National School of Engineers of Gabes, between January and June 2013. *Methodology:* Response Surface Methodology (RSM) called central composite design (CCD) was applied to correlate the preparation variables (activation temperature, activation time and impregnation ratio) to the percentage removal of Cr (VI) from aqueous solution. The influence of the studied parameters on the Cr (VI) removal was also investigated by using the analysis of variance (ANOVA) to identify the significant variables. Moreover, the batch adsorptions of Cr (VI) on activated carbon prepared at optimal conditions were carried out and the experimental data were analysed by Freundlich and Langmuir isotherms models. *Results:* The results obtained showed that the optimum conditions for preparing activated carbon from DS for Cr (VI) adsorption were activation temperature of 150°C, activation time of 20 h and impregnation ratio of 4.85:1(acid/DS, wt basis) which resulted in 97.25 removal of Cr (VI) from aqueous solution. It was observed that experimental values obtained were in good agreement with the values predicted by the model. The adsorption studies indicated that the equilibrium data for adsorption of Cr (VI) on the optimum activated carbon was well described by both the Freundlich and Langmuir isotherm models which yielded maximum adsorption capacity of 58.82 mg/g at pH 2.0. *Conclusion:* The DSAC seems to be a good adsorbent for the removal of Cr (VI) from wastewaters.

**Keywords:** activated carbon; central composite design; optimization; date stones; Cr (VI) removal.

---

## INTRODUCTION

Chromium is one of the toxic heavy metal that is available in industrial effluents involved, leather tanning, textile dying, electroplating, cement industries and finishing industries [1]. It is present in wastewater mainly in Cr (III) and Cr (VI) oxidation states. Cr (VI) is considered to be potentially carcinogenic to humans because it's mutagenic and carcinogenic properties [2, 3] and is reported to be bioaccumulated into flora and fauna [4], creating ecological problems. The tolerance limit for the discharge of Cr (VI) into inland surface water is 0.1 mg/l and in potable water is 0.05 mg/l [5]. It is therefore essential to remove Cr (VI) from industrial effluents before

discharging them into aquatic environment or onto land. Several methods of Cr (VI) removal have been developed such as reduction precipitation, electrochemical precipitation, ultrafiltration, ion exchange and reverse osmosis [6, 7]. However, most of these methods are expensive and ineffective for low Cr (VI) concentration [8]. In contrast adsorption technique is by far the most widely used [9]. The most common adsorbent is activated carbon [10, 11] but commercial activated carbons are very costly, then there is a need to produce a low cost adsorbent from cheaper and readily available materials which can be used economically on large scale. In recent years, many researchers have tried to produce activated carbons for removal of Cr (VI) from aqueous solutions using renewable and cheaper precursors such as used tyres and saw dust [12] coconut coir pith

---

\* To whom correspondence be made:  
E-mail: benamorhedi@gmail.com

[13] hazelnut shell [14] coconut shell [15] Wood Apple [16] neem leaves [17] treated saw dust [18] and almond shell [19]. Date stones were found as a good precursors to produce activated carbon for removal of various pollutants [20-27]. In Tunisia, Date stones is one of alternative material that is readily available. Any attempt to reuse this waste will be useful. So the objective of this work was to evaluate the adsorption potential of date stones based activated carbon for Cr (VI) removal from aqueous solution. The effects of three variables (activation time, activation temperature and  $H_2SO_4$ : date stones impregnation ratio) were investigated by using the Response Surface Methodology (RSM). The activated carbon preparations conditions were optimised by maximising Cr (VI) adsorption. Also, the batch adsorptions of Cr (VI) on activated carbon prepared at optimal conditions were carried out and the experimental data were analysed by Freundlich and Langmuir isotherms models.

## MATERIAL AND METHODS

### Materials

All the chemicals used are of the analytical grade. Stock solutions of Cr (VI) was prepared by dissolving appropriate amounts of  $K_2Cr_2O_7$  (Prolabo, 99.5% purity) in distilled water. This solution is diluted as required to obtain solutions containing 5 or 10 mg/L of Cr (VI).

### Adsorbent Preparation

The stones were first washed with water to remove impurities, dried at  $105^\circ C$  for 24h, crushed and sieved. Fraction with average particle size of about 500  $\mu m$  was selected for this study. 10 g of dried stones were well mixed by stirring with sulphuric acid solution at different impregnation ratios (1.5- 4.85) and heated for different activation times (10-30 h) at different temperatures ( $100-200^\circ C$ ). At the end of activation time the samples were withdrawn from furnace and allowed to cool. For the removal of residual  $H_2SO_4$ , the samples were repeatedly washed with distilled water until the pH of washing solution reached 6.0-6.5. After that, the samples were dried at  $105^\circ C$  for 24h, crushed, sieved and stored in tightly closed bottles. Particles with size between 0.5 to 0.63  $\mu m$  were used for adsorption experiments.

### Adsorption Studies and Analytical Method

The adsorption tests were performed at fixed parameters (contact time of 10h, initial Cr (VI) concentration of 5 mg/l, and adsorbent dose of 0.2g/L at pH 2.0). The mixture was agitated at 200 rpm at  $25^\circ C$  until equilibrium was reached. The residual concentration of Cr (VI) solution was determined by the diphenylpicazide colorimetric method on a visible spectrophotometer (model DR 2000) at a wavelength 540 nm [28]. The adsorption capacity  $q$  (mg/g) and removal efficiency were calculated according to the equations (1) and (2) respectively:

$$q_{\max}(\text{mg/g}) = \frac{(C_0 - C_e)V}{m} \quad (1)$$

$$\text{Removal}(\%) = \frac{(C_i - C_f)}{C_i} * 100 \quad (2)$$

Where  $C_0$  and  $C_e$  were the concentrations of chromium (VI) initially and at equilibrium,  $V$  is the volume of solution and  $m$  is the amount of adsorbent.

### Design Experiments

In this work, a standard Response Surface Methodology (RSM) design called central composite design (CCD) was employed to study the various process parameters for preparing the activated carbon. The CCD is suitable for exploration a quadratic response surface and it helps to optimise the effective parameters with a minimum number of experiments and also to analyse the interaction between the parameters [29-33]. Generally the CCD consists of three kinds of runs which are the  $2^n$  factorial runs,  $2n$  axial runs and  $n_c$  center runs (replicates), where  $n$  is the number of variables. In this work the activated carbons were prepared by chemical activation method using sulphuric acid. Therefore the preparation variables investigated were activation temperature  $X_1$ , activated time  $X_2$  and activation ratio  $X_3$  indicating that altogether 20 experiments as calculated from the following equation:

$$N = 2^n + 2n + n_c = 2^3 + 2*3 + 6 = 20 \quad (3)$$

Where  $N$  is the total number experiments required.

These three variables together with their respective ranges chosen based on literature [34-

39] and preliminary studies are reported in Table I.

**Table I**  
Independent Variables and their Coded Levels for the Central Composite Design

| Variables (factors)         | Code values    | Coded variable levels |     |      |     |      |
|-----------------------------|----------------|-----------------------|-----|------|-----|------|
|                             |                | +α                    | +1  | 0    | -1  | -α   |
| Activation Temperature (°C) | X <sub>1</sub> | 234.1                 | 200 | 150  | 100 | 65.9 |
| Activation time (h)         | X <sub>2</sub> | 36.82                 | 30  | 20   | 10  | 3.18 |
| Impregnation ratio IR       | X <sub>3</sub> | 4.85                  | 4   | 2.75 | 1.5 | 0.65 |

The center points are used to determine the experimental error and the reproducibility of the data. The axial points are located at (±α, 0, 0), (0, ±α, 0) and (0, 0, ±α) where α (1.682) is the distance of the axial point from center and makes the design rotatable. The experimental runs sequence was randomized in order to minimize error as result of the effects of the uncontrolled factors. The response selected was the percentage removal of Cr (VI) from aqueous solution (Y). This response was used to develop an empirical model which correlated the response to the three preparation variables using a second-degree polynomial equation as given by:

$$Y = b_0 + \sum_{i=1}^n b_i X_i + \left(\sum_{i=1}^n b_{ii} X_i\right)^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n b_{ij} X_i X_j \quad (4)$$

Where Y is the predicted response, b<sub>0</sub> the constant coefficient, b<sub>i</sub> the linear coefficients, b<sub>ij</sub> the interaction coefficients, b<sub>ii</sub> the quadratic coefficients and X<sub>i</sub>, X<sub>j</sub> are the coded values of the activated carbon preparation variables. The experimental data obtained were analysed using a statistical software design Expert version 7.0.0 (STATE-EASE Inc; Minneapolis, USA) for regression analysis to fit the second degree polynomial equation and also for the analysis of variance.

## RESULTS AND DISCUSSION

### Development of Regression Model Equation

Table II shows the complete design matrixes together with the response values obtained from the experimental work.

**Table II**  
Experimental Design Matrix for Preparation of DSAC

| Run Number | Activated carbon preparation variables     |                                    |  | Response              |
|------------|--|------------------------------------|--|-----------------------|
|            | Activation temperature X <sub>1</sub> (°C) | Activation time X <sub>2</sub> (h) | Impregnation ratio IR X <sub>3</sub> (W/W) | Cr(VI) removal, Y (%) |
| 1          | 100  | 10                                 | 1.5  | 38.32                 |
| 2          | 200  | 10                                 | 1.5  | 32.16                 |
| 3          | 100  | 30                                 | 1.5  | 51.24                 |
| 4          | 200  | 30                                 | 1.5  | 39.68                 |
| 5          | 100  | 10                                 | 4  | 68.17                 |
| 6          | 200  | 10                                 | 4  | 54.86                 |
| 7          | 100  | 30                                 | 4  | 89.18                 |
| 8          | 200  | 30                                 | 4  | 79.14                 |
| 9          | 65.9                                       | 20                                 | 2.75                                       | 58.21                 |
| 10         | 234.1                                      | 20                                 | 2.75                                       | 46.17                 |
| 11         | 15   | 3.18                               | 2.75                                       | 28.20                 |
| 12         | 150  | 36.82                              | 2.75                                       | 53.16                 |
| 13         | 150  | 20                                 | 0.65                                       | 40.94                 |
| 14         | 150  | 20                                 | 4.85                                       | 97.25                 |
| 15         | 150  | 20                                 | 2.75                                       | 59.85                 |
| 16         | 150  | 20                                 | 2.75                                       | 64.45                 |
| 17         | 150  | 20                                 | 2.75                                       | 66.12                 |
| 18         | 150  | 20                                 | 2.75                                       | 68.45                 |
| 19         | 150  | 20                                 | 2.75                                       | 65.56                 |
| 20         | 150  | 20                                 | 2.75                                       | 63.45                 |

It can be seen from table II that the optimum percentage removal of 97.25 was obtained at 150°C of activation temperature, 20h of activation and 4.85 of impregnation ratio.

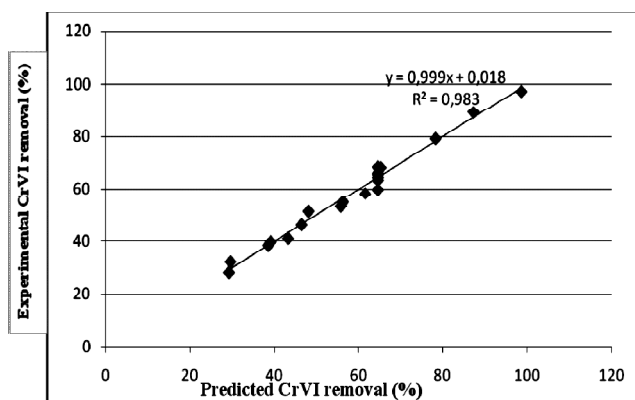
According to the sequential model sum of squares, the model was selected based on the highest order polynomial where the additional terms were significant.

The final empirical formula models for the removal of Cr (VI) (Y) in terms of coded factors (parameters) after excluding the insignificant terms is represented by following equation:

$$Y = 64.54 - 4.49 X_1 + 7.89 X_2 + 16.45 X_3 - 3.72 X_{21} - 7.79 X_{22} + 2.26 X_{23} + 3.11 X_2 X_3 \quad (5)$$

It can be seen that the coefficient of X<sub>2</sub> and X<sub>3</sub> are higher than others. This indicates that time and impregnation ratio have higher effect on Cr (VI) removal, also the positive sign of these terms indicating that increasing time and impregnation ratio increasing the removal of Cr (VI). The negative sign of X<sub>1</sub> indicating that decreasing temperature increases amount of Cr (VI) adsorbed. The interaction effect between X<sub>2</sub> and X<sub>3</sub> was found to be moderate.

The quality of the model developed was evaluated based on the correlation coefficient ( $R^2$ ) value. The closer the  $R^2$  value to unity, the better the model will be as this will give predicted values which are closer to the actual values for the response. As shown by fig. 1, the  $R^2$  value is 0.983, which is considered high, indicating that there was a good agreement between the experimental and the predicted values for the Cr (VI) removal as suggested by the model.



**Figure 1:** Correlation between the experimental and predicted values for Cr (VI) removal

### Analysis of Variance

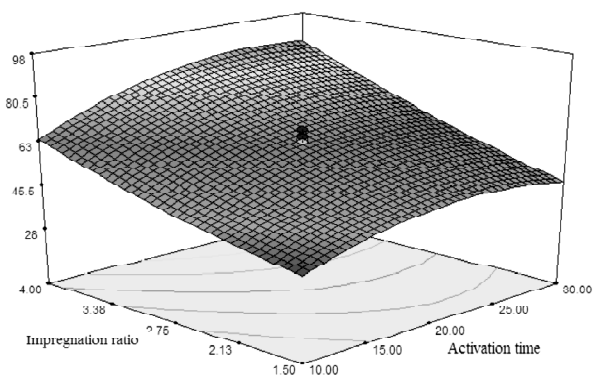
The validity of the model was further justified through analysis of variance (ANOVA). Results obtained are reported in table 3. The higher of F-test value and the lower of P-values, the higher the significance of corresponding coefficient. Values of P less than 0.05 indicate that the model terms are significant.

From table 3, it can be seen that the prediction of the model is significant with F-value of 70.13 and Prob > F less than 0.0001. In this case,  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_2X_3$ ,  $X_1^2$ ,  $X_2^2$  and  $X_3^2$  were significant model terms to the response.

Fig. 2 shows the three dimensional response surface which was constructed to demonstrate the effect of two significant variables on Cr(VI) removal. It was observed from this figure that the activation time and the activation ratio imposed greater effect on Cr (VI) removal than the activation temperature. At higher values of these factors, the removal of Cr (VI) becomes more extensive. Similar results were obtained by NAWABANNE and IGBOKWE [32].

**Table 3**  
For Response Surface Quadratic Model for Cr (VI) Removal

| Source   | Sum of squares | Degree of freedom | Mean square | F value | Prob > F |
|----------|----------------|-------------------|-------------|---------|----------|
| Model    | 6061.71        | 9                 | 673.52      | 70.13   | < 0.0001 |
| $X_1$    | 275.32         | 1                 | 275.32      | 28.67   | 0.0003   |
| $X_2$    | 849.46         | 1                 | 849.46      | 88.45   | < 0.0001 |
| $X_3$    | 3695.46        | 1                 | 3695.46     | 384.78  | < 0.0001 |
| $X_1X_2$ | 0.57           | 1                 | 0.57        | 0.059   | 0.8129   |
| $X_1X_3$ | 3.96           | 1                 | 3.96        | 0.41    | 0.5351   |
| $X_2X_3$ | 77.19          | 1                 | 77.19       | 8.04    | 0.0177   |
| $X_1^2$  | 199.20         | 1                 | 199.20      | 20.74   | 0.0011   |
| $X_2^2$  | 873.92         | 1                 | 873.92      | 90.99   | < 0.0001 |
| $X_3^2$  | 73.54          | 1                 | 73.54       | 7.66    | 0.0199   |
| Residual | 96.04          | 10                | 9.60        | -       | -        |



**Figure 2:** Three dimensional response surface plot for Cr (VI) removal (Activation time /impregnation ratio)

### Process Optimization

One of the main aims of this study was to find the optimum process parameters at which activated carbon will have a high Cr (VI) removal. The optimum response was obtained by using 150°C, 20 h and 4.85 of activation temperature, activation time and impregnation ratio respectively. The insignificant error for the Cr (VI) removal (1.37%) as presented in table IV showed that the experimental data was in good agreement with the predicted data.

**Table IV**  
**Model Validation**

| Temperature (°C) | Activation time (h) | Impregnation ratio (IR) | Cr (VI) removal (%) |           |           |
|------------------|---------------------|-------------------------|---------------------|-----------|-----------|
|                  |                     |                         | Experimental        | Predicted | Error (%) |
| 150              | 20                  | 4.85                    | 97.25               | 98.6      | 1.37      |

### Isotherm Studies

The equilibrium adsorption isotherm is important in the design of adsorption systems. Two commonly used isotherm models, Langmuir and Freundlich have been applied to describe the adsorption of Cr (VI) onto the activated carbon prepared at optimal conditions (DSAC). The applicability of the isotherm models to fit the adsorption data was compared by judging the correlation coefficients,  $R^2$  values.

Langmuir (Eq. 4) and Freundlich (Eq. 5) given below, have been applied to describe the adsorption of Cr (VI) onto the (DSAC).

$$\frac{C_e}{q_e} = \frac{1}{K_L q_{\max}} + \frac{C_e}{q_{\max}} \quad (6)$$

$$\ln q_e = \frac{1}{n} \ln C_e + \ln K_F \quad (7)$$

Where  $q_e$  and  $C_e$  are the amount of adsorbate adsorbed per unit weight of adsorbent and equilibrium concentration of adsorbate remained in solution, respectively. In Eq. 6,  $q_{\max}$  indicates the theoretical monolayer adsorption capacity ( $\text{mg g}^{-1}$ ) and  $K_L$  is the equilibrium constant ( $\text{L mg}^{-1}$ ). In Eq. 7,  $K_F$  is the Freundlich constant and  $1/n$  is the adsorption intensity. The essential characteristic of the Langmuir isotherm can be expressed in terms of dimensionless equilibrium  $R_L$  which defined by:

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

The value of  $R_L$  indicates the shape of the isotherms to be either unfavorable ( $R_L > 1$ ) or favorable ( $0 < R_L < 1$ ).

The adsorption isotherms for Cr (VI) were studied using initial concentration of an adsorbent between 0.05 g/L and 0.35 g/L at Cr (VI) initial concentration of 10 mg/L. The experimental data were fitted to the isotherm models and graphical representations of these models are presented in

Fig. 3 and 4. The slope and the intercept of each linear plot in these figures are used to calculate Langmuir and Freundlich parameters which are listed in table V along with associated correlations. Based on the correlation coefficient  $R^2$ , it can be concluded that the adsorption of Cr (VI) on DSAC at 25°C was described well by both of Langmuir and Freundlich isotherm models. The adsorption process was favorable as Langmuir separation factor,  $R_L$  was  $0 < R_L < 1$  and supported by  $1/n$  values of Freundlich which was less than one. In addition, DSAC has adsorption capacity  $q_{\max}$  (58.82 mg/g) which demonstrates that DSAC has high adsorption ability toward Cr (VI).

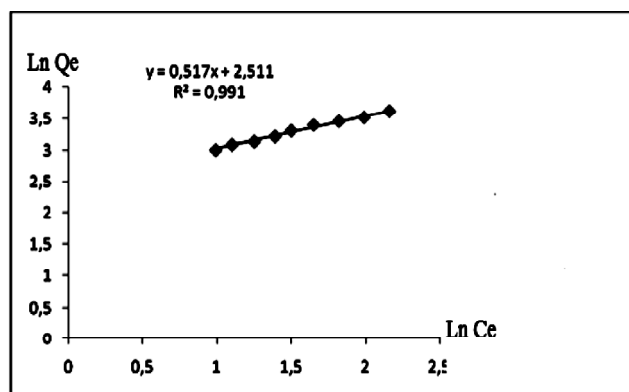
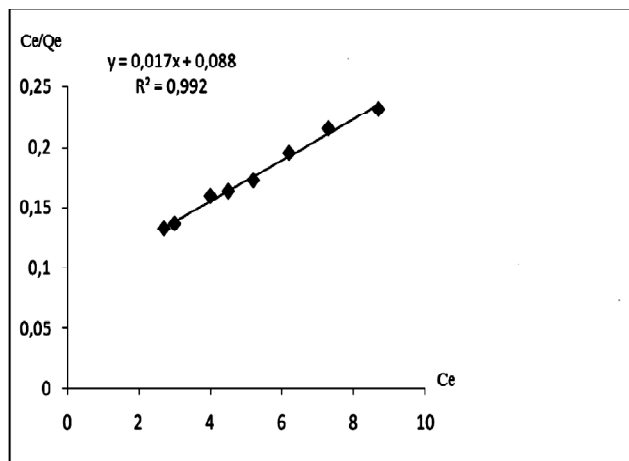

**Figure 3:** Freundlich isotherm for the adsorption

**Figure 4:** Langmuir isotherm for the adsorption

Table V  
Langmuir and Freundlich Models Parameters for the Adsorption of Cr(VI) onto the DSAC at 25°C

| Model | Langmuir     |                  |       | Freundlich |       |       |       |
|-------|--------------|------------------|-------|------------|-------|-------|-------|
|       | $K_L$ (l/mg) | $q_{max}$ (mg/g) | $R^2$ | $R_L$      | $K_F$ | $1/n$ | $R^2$ |
|       | 0.93         | 58.82            | 0.992 | 0.097      | 12.32 | 0.52  | 0.991 |

### Comparison with others Adsorbents

Table 5 compares the adsorption capacities of different adsorbent prepared by activation with sulphuric acid and used for removal of Cr (IV). The value of  $q_{max}$  in this study is larger than those in most previous works. This suggests that the Cr (VI) can be easily adsorbed by the DSAC.

Table VI  
Comparison of Activated Carbons Prepared from Various Raw Materials and the Optimum Conditions of Cr (VI) Removal

| Precursor                              | Preparation conditions | $q_{max}$ (mg/g) | Source     |
|--|------------------------|------------------|------------|
| Olive Stones                           | 600°C, 3h              | 71.0             | 34         |
| Tamarind Seeds                         | 110°C, 5h              | 29.1             | 33         |
| Wood Apple                             | 110°C, 24 h            | 13.0             | 16         |
| Ground nut husk                        | 150 °C, 24 h           | 7.0              | 33         |
| Hazelnut shell                         | 150°C, 24 h            | 170.0            | 14         |
| Cornelian cherry (CC)                  | 200°C, 24 h            | 21.0             | 33         |
| Apricot stone (AS)                     | 200°C, 24 h            | 34.7             | 39         |
| Almond shells (ASC)                    | 200°C, 24 h            | 20.0             | 19         |
| Tridax procumbens                      | 160 5°C                | 9.7              | 33         |
| Gingelly oil cake                      | 140-160°C, 24 h        | 30.58            | 40         |
| Palmyra palm fruit seed                | 200°C, 10h             | 32.14            | 41         |
| Pterospermum acerifolium fruit capsule | Room temperature, 24 h | 76.92            | 42         |
| Commercial activated carbon            | -                      | 54.64            | 43         |
| Peach kernel                           | 160 ± 5, 8 h           | 47.5             | 44         |
| Nutshell                               | 160 ± 5, 8 h           | 46.64            | 44         |
| Aquacarb207EA" work                    | 150-155°C, 24 h        | 7.0              | 45         |
| Date Stones                            | 150°C, 20 h            | 58.82            | this study |

### CONCLUSIONS

Date stones were used as precursor to produce an activated carbon with high Cr (VI) removal from aqueous solution. A central composite design was conduct to investigate the effects of three activated carbon preparation factors: activation temperature, activation time and impregnation

ratio. The optimum condition was activation temperature of 150°C, activation time of 20 h and impregnation ratio of 9.6. Langmuir and Freundlich isotherms described well the process isotherm. The maximum adsorption capacity obtained from Langmuir isotherm model is 58.82 mg/g, which is higher than the most others low cost adsorbents. The present study shows that activated carbon prepared from date stones can be used as a good adsorbent for the removal of Cr (VI) from aqueous solutions.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

### REFERENCES

- [1] Gode F, Pehlivan E. Removal of Cr (VI) from aqueous solution by two Lewatit-anion exchange resins. *J. Hazard. Mater.* **2005**; 119: 175, 182.
- [2] De Flora S, Bagnasco M, Serra D, Zanacchi P. Genotoxicity of chromium compounds. A review. *Mutation Research.* **1990**; 238: 99 -172.
- [3] Costa M. Potential hazards of hexavalent chromate in our drinking water. *Toxicology and Applied Pharmacology.* **2003**; 188: 1-5.
- [4] Sing VK and Tivari PNJ. Removal and recovery of chromium (VI) from industrial wastewater. *Biotechnol.* **1997**; 69: 376-382.
- [5] EPA, Environmental Pollution Control Alternatives EPA/625/5-90/25, EPA/625/4-89/023. *Environmental Protection Agency Cincinnati OH, USA* 1990.
- [6] McLay WJ, Reinhard FP. Waste minimization and recovery technologies. *Metal Finishing.* **2000**; 98: 817-850.
- [7] Owlad M, Aroua MK, Daud WAW and Baroutian S. Removal of hexavalent chromium-contaminated water and wastewater: a review. *Water, Air, and Soil Pollution.* **2009**; 200(1-4): 59-77.
- [8] Gupta VK, Gupta M, Sharma S. Process development for the removal of lead and chromium from aqueous solutions using red mud-an aluminum industry waste. *Water Res.* **2001**; 35(5): 1125-1134.
- [9] Huang CP, Wu MH. The removal of chromium (VI) from dilute aqueous solution by activated carbon. *Water Res.* **1977**; 11(8): 673-679.
- [10] Aggarwal D, Goyal M, Bansal RC. Adsorption of chromium by activated carbon from aqueous solution. *Carbon.* **1999**; 37: 1989 -1997.

- [11] Bhatnagar A, Minocha AK. Conventional and non-conventional adsorbents for removal of pollutants from water-a review. *Indian journal of chemical technology*. **2006**; 13(3): 203-217.
- [12] Hamadi NK, Chen D, Farid MM, Lu MGQ. Adsorption kinetics for removal of Cr (VI) from aqueous solution by adsorbents derived from used tyres and sawdust. *Chem. Eng. J.* **2006**; 84 (2): 95-105.
- [13] Namasivayam C, Surehkumar MV. Removal of chromium (VI) from water and wastewater using surfactant modified coconut coir pith as a biosorbent. *Bioresource Tech.* **2008**; 99: 2218-2225.
- [14] Kobya M. Adsorption, kinetic and equilibrium studies of Cr (VI) by hazelnut shell activated carbon. *Adsorption Science and Technology*. **2004**; 22(1): 51-64.
- [15] Babel S and Kumiawan TA. Cr (VI) removal from synthetic waste water using coconut shell charcoal and commercial activated carbon modified with oxidizing agents and/or chitosan. *Chemosphere*. **2004**; 54: 951-967.
- [16] Sartape AS, Raut PD and Kolekar SS. Efficient Adsorption of Chromium (VI) Ions from Aqueous Solution onto a Low-cost Adsorbent Developed from Limonia acidissima (Wood Apple) Shell. *Adsorption Science and Technology*. **2010**; 28(6): 547-560.
- [17] Badu BV and Gupta S. Adsorption of Cr (VI) using activated neem leaves, kinetic studies. *Adsorption*. **2008**; 14: 85-92.
- [18] Garg, VK, Gupta P, Kumar R and Gupta R K. Adsorption of chromium from aqueous solution treated saw dust. *Bioresource. Tech.* **2004**; 92: 79-81.
- [19] Demirbas E, Kobya M, Konukman AES. Error analysis of equilibrium studies for the almond shell activated carbon adsorption of Cr (VI) from aqueous solutions. *Journal of Hazardous Materials*. **2008**; 154: 787-794.
- [20] Sekirifa ML, Hadj-Mohamed M, Pallier S, Baameur L, Richard D, Al-Dujaili AH. Preparation and characterization of an activated carbon from a date stones variety by physical activation with carbon dioxide. *Journal of Analytical and Applied Pyrolysis*. **2013**; 99: 155-160.
- [21] El-Kady A, Carleer R, Yperman J and Farah JY. Optimum Conditions for Adsorption of Lindane by Activated Carbon Derived from Date Stones. *World Appl. Sci. J.* **2013**; 27(2): 269-279.
- [22] Ackacha MA and ElMahdy SA. Utilization of New Activated Carbon Drived from Date Stones to Reduce Lead and Cadmium Ions from Aqueous Solutions. *2nd International Conference on Environmental Science and Technology IPCBEE2*, **2011**, Vol. 6 IACSIT Press, Singapore.
- [23] Haimour NM, Emeish S. Utilization of date stones for production of activated carbon using phosphoric acid. *Waste Management*. **2006**; 26: 651-660.
- [24] Bouchelta C, Medjram MS, Bertrand O and Bellat JR. Preparation and characterization of activated carbon from date stones by physical activation with steam. *J. Anal. Appl. Pyrolysis*. **2008**; 82: 70-77.
- [25] Yahia A, Alhamed. Activated Carbon from Dates Stone by  $ZnCl_2$  Activation. *JKAU: Eng. Sci.* **2006**; 17(2): 75-100.
- [26] Salman JM, Alsaad K. Adsorption of 2, 4-dichlorophenoxyacetic acid onto date seeds activated carbon: Equilibrium, Kinetic and thermodynamic studies. *Int. J. Chem. Sci.* **2012**; 10(2): 677-690.
- [27] Abbas AF and Ahmed MJ. Optimization of Activated Carbon Preparation from Date Stones by Microwave Assisted  $K_2CO_3$  Activation. *Iraqi Journal of Chemical and Petroleum Engineering IJCPE*. **2014**; 15(1): 33-42.
- [28] Clesceri, L.S, Greenberg AE, Eaton AD. Standard methods for the examination of water and wastewater. A.P.H. Association, Washington, D.C. **1998**; 366.
- [29] Bacaoui A, Yaacoubi A, Dahbi A, Bennouna C, Phantanluu R, Maldonado-Hodar FJ, Rivera J, Moreno-Castilla C. Optimization of conditions for the preparation of activated carbons from olive-waste. *Carbon*. **2001**; 39: 425-432.
- [30] Karacan F, Ozden U, Karacan S. Optimization of manufacturing conditions for activated carbons from Turkish lignite by chemical activation using surface response methodology. *Appl. Therm. Eng.* **2007**; 27: 1212-1218.
- [31] Sahu JN, Achrya J, Meikap BC. Optimization of production conditions for activated carbons from tamarind wood by zinc chloride using response surface methodology. *Bioresource. Tech.* **2010**; 101: 1974-1982.
- [32] Igbokwe JT, Nwabanne PK. Preparation of Activated Carbon from Nipa Palm Nut: Influence of Preparation Conditions. *Research Journal of Chemical Sciences*. **2011**; 1(6): 53-57.
- [33] Gottipati R. Preparation and Characterization of Microporous Activated Carbon from Biomass and its Application in the Removal of Chromium (VI) from Aqueous Phase (Roll No - 507CH001). *Department of Chemical Engineering National Institute of Technology Rourkela, Odisha - 769008, India January 2012*.
- [34] Attia A, Khedr SA and Elkholy SA. Adsorption of Chromium Ion (VI) by Acid Activated Carbon. *Brazilian Journal of Chemical Engineering*. **2010**; 27(1): 183-193.
- [35] Moumni L., Merabet D, Bouzaza K, Belkhiric L. Removal of  $Pb^{2+}$  and  $Zn^{2+}$  from the aqueous solutions by activated carbon prepared from Dates stone. *Desalination and Water Treatment*. **2010**; 16: 1-8.
- [36] Selvi K, Pattabhi S, Kadirvelu K. Removal of Cr(VI) from aqueous solution by adsorption onto activated carbon. *Bioresource Tech.* **2001**; 80: 87-89.
- [37] Mohamed FSh, Khater WA, Mostafa MR. Characterization and phenols sorptive properties of carbons activated by sulphuric acid. *Chemical Engineering Journal*. **2006**; 116(1): 47-52.
- [38] Gupta S, Babu BV. Utilization of waste product (tamarind seeds) for the removal of Cr (VI) from aqueous solutions: Equilibrium, kinetics, and regeneration studies. *Journal of Environmental Management*. **2009**; 90: 3013-3022.
- [39] Kobya M, Demirbas E, Senturk E. Adsorption of heavy metal ions from aqueous solutions by activated carbon prepared from Apricot stone. *Bioresource Tech.* **2005**; **96**: 1518-1521.
- [40] Nagashanmugam KB and Sirinivasan K. Removal of Chromium (VI) from aqueous solution by chemically modified gingelly oil cake carbon. *Indian Journal of Chemical Technology*. **2011**; 18: 207-219.

- [41] Kaman A, Thambidurai S. Removal of Hexavalent Chromium from aqueous solution using activated carbon derived from palyra palm fruit seed. *Chem.Soc.Ethiop.* **2008**; 22(2): 183-196.
- [42] Kothial NC and Sharma S. Study of Chromium (VI) adsorption using Pterospermum-Acerifolium Fruit capsule activated carbon (FCAC) and commercial activated charcoal (CAC) as selective adsorbents. *The Holistic Approach to environment.* **2013**; 3(2): 63-82.
- [43] Gholipour M, Hashemipour H, Mollashahi M. Hexavalent Chromium removal from aqueous solution via Adsorption on granular activated carbon: Adsorption, Desorption, Modeling and simulation studies. *ARPJN Journal of Engineering and Applied sciences.* **2011**; 6(9): 10-18.
- [44] Mordrogan C, Costache C, Orbulet DO. Removal of Hexavalent Chromium from aqueous solutions by adsorption on peach kernel and nutshell. *The first international Proficiency testing conference, Sinai, Romania.* **2007**; 371-377.
- [45] Thilagavathy P, Santhi T. Sorption of Toxic Cr(VI) from aqueous solutions by using treated Accacia Nilotica leaf as adsorbent, single and binary system. *BioResources.* **2013**; 8(2): 1813-1830.



