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## A Comparative Study for Attenuation of Residual Free Chlorine by Mesoporous Adsorbent from Scrap Tire Rubber and Commercial Activated Carbon

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### Abstract

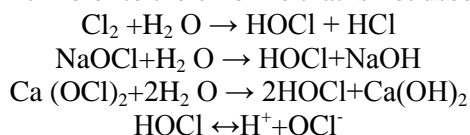
In this study, a series of experiments was performed for assessing and comparing the potential of two types of activated carbon for adsorbing free-residual chlorine (FRCL) from aqueous mixture. The first type was prepared from waste tire rubber (WTRAC) and the second one was commercially available (CAC). The impact of different operational factors such as contact time, preliminary concentration of free chlorine, dose and particle size of the active carbon on the free chlorine removal are also studied. To describe the sorption kinetics and equilibrium in the liquid-solid phase, the experimental data were adjusted with pseudo first-order, pseudo second-order, and intra-particle diffusion models, and with the Langmuir, Freundlich, and Temkin sorption isotherms. Results showed that WTRAC is an excellent and cheap material for free-residual chlorine reduction (78%), and it is outperformed the adsorption capacity of CAC (64%). The optimum time for higher FRCL

removal was 15 min using WTRAC and 6 min using CAC, as adsorbent materials. Pseudo second-order equation was fitted with the kinetics data using WTRAC, and pseudo first-order equation was adjusted with the kinetics data using CAC. Freundlich isotherm was the supreme model to define the adsorption of free-residual chlorine by both of WTRAC and CAC. The features of WTRAC as an adsorbent material, confirming the ability of its implementation in dechlorination processes. In addition, it helps to reduce the objectionable taste and odor in drinking and tap water valuably.

**Keywords:** Adsorption, carbon, chlorine, isotherm, kinetics, waste tire rubber.

## 1 Introduction

Chlorine is one of the common agents that widely utilize in drinking water disinfection process within the treatment units [1]. This was due to the features of chlorine (Cl), for instance, the acceptable cost, long-term impact of remaining in water versus to ozone and UV, and valuable for killing all viruses and bacteria, which are inhibiting waterborne illnesses [2]. The process of adding Cl as a gas or compounds, such as; sodium hypochlorite, chlorine dioxide and calcium hypochlorite, to the water is termed chlorination. During chlorination, Cl compounds are immediately dissect in water to hypochlorous acid (HOCl), which also hydrolyzes to hydrogen ions and hypochlorite ions. Hypochlorite ion (ClO<sup>-</sup>) is termed as a free-residual chlorine (FRCl), which refer to the chlorine that is not used [2].



Drinking water containing FRCl of more than 0.5 mg/l can attract the public concern. This is due to the unacceptable taste and odor of water, which are generating from the impact of combined chloramine (FRCL and ammonia, amine, or amino acid) on the final product. Additionally, FRCL (at high levels) has confirmed to cause heart, lung, kidney, and liver diseases, as well as it is could enhance the cancer risk. Furthermore, excess FRCL damaging the polyamids layer in reverse osmosis stages within desalination units. Therefore, the removal of residual chlorine after disinfection has become a significant area of research. Also, increasing the concern of the problems posed by FRCL has been encouraged the researchers to find efficient and cost-effective technologies for water dechlorination [3].

## **2 Literature Survey**

Adsorption is an appropriate technology that universally applied for attenuation of pollutants from liquids, as recommended by WHO and EPA [4]. A number of adsorbent materials have been used to eliminate the concentration of FRCL from aqueous solution [5]. However, the process being more attractive in case of using specific adsorbents derived from easily available and inexpensive sources [6]. In this context, activated carbons manufactured from solid industrial and agricultural/municipal wastes is well known as an effective and cheap adsorbent that widely used in water treatment plants, such as coconut shells, peat, fly ash, wood and waste tires [7, 8].

Among all of these sources, activated carbon developed from scrap tires is the ideal choice for pollutants reduction from water and wastewater. Because of the recycling of discarded tires, as free raw materials, reduces the total cost of adsorbent (AC) manufacturing. In addition, the reuse of the waste tires has solved the problems associated with scrap tires rubber disposal and solid waste management [7]. Furthermore, adsorption by AC does not required any further chemicals or additives for contaminants removal [9], as the surface of AC is oxidizing very quickly by chlorine [10].

Based on the literature review, several investigators have examined the efficiency of scrap tires activated carbon for adsorption of dyes [11], lead and nickel [7], and chromium and manganese [12]. In terms of free chlorine, there are only few studies have been reported on free chlorine adsorption onto activated carbon, which was produced from coal, coconut shell [9, 3], and coconut shell loaded by zirconia [2]. However, there is no previous study try to compute the potential of scrap tires activated carbon for adsorption of free chlorine. Therefore, this area of study has required more insight into the parameters that could affect the reduction of free chlorine based on activated carbon prepared from WTR. This because the chlorine adsorption capacity onto AC may be vary depending on the raw materials characteristics, chlorine concentration, size of carbon's particles, pH, dose of carbon [5].

## **3 Aim and Objectives**

The aim of this study is to compare and assess the capacity of WTRAC and CAC for attenuation of free chlorine in aqueous solution based on serious of experiments. The objectives are to rank and evaluate the dechlorination capacity of WTRAC in comparison with CAC, compute the impact of different operational parameters such as contact time, initial concentration of free chlorine, dose and particle size of adsorbent materials on the free chlorine removal. As well as, to describe the sorption using different isotherms.

## 4 Materials and Methods

### 4.1 Materials

Calcium hypochlorite ( $\text{Ca}(\text{OCl})_2$ , CAS number; 7778-54-3) was used in this study as a source of chlorine. It is purchased from Nirou Chlor Co. (Iran). All the chemicals utilized were analytical grade. Two sources of active carbon (AC) were used, the first one is prepared from WTR, which collected from a general place of car tires disposal (Basrah, Iraq). The second source of AC is commercially available, produced from 100% coconut shells by PT Java Palma Indonesia, and purchased from a local shop (Basrah, Iraq).

### 4.2 Sorbent Preparation and Characterization

The active carbon generated from WTR was prepared based on the common physical activation method [13]. The WTR is cleaned with distilled water to get rid of any strange materials, then dried in an oven at a temperature of 150 °C for three hours, to avoid any wetness from the tires. After that, tires were crushed and sieved using *Retsch* sieve shaker for 20 minutes. In the carbonization stage, the tires were placed horizontally in the electrical furnace at temperature of 600°C for 1.5 hours at a heating rate of 20 °C/min. The samples were placed in the furnace then  $\text{N}_2$  flow started to purge the air in the tubular furnace for 10 minutes. After purging, the furnace was started to heat up until the desired carbonization temperature is reached. The temperature controller of the furnace was set to keep the desired temperature stable. The period of heating was decided after several runs with different periods of heating. In activation stage, the nitrogen gas cylinder was replaced with a carbon dioxide cylinder, and heating was continued for another 1.5 hours. The flow of carbon dioxide gas coming from the end of the tubular furnace was passed through the tires, forcing the formation of mesoporous. When the heating duration was raised to more than 1.5 hours, it was observed that the tires have begun to carbonize into ash. As activation time is reached, the furnace was stopped and left to cool down till 100 °C. The product was taken out, cooled, and placed in a decanter before to use. This type of AC labelled as WTRAC.

The commercial AC was washed with distilled water, dried overnight at 120°C, and kept to cool in a desiccator. It is labelled as CAC. Both CAC and WTRAC were sieved to get the decided size of particle (1.18 -2.36 mm). All samples were stored in separate vacuum desiccators until the starting of the experiment.

The typical compositions of car tires are 14% natural rubber, 27% synthetic rubber, 28% carbon black, 14-15% steel, and 16-17% fiber, filter, accelerators, antiozonants, ect. The average weight is 11 kg for the new tires and 9 kg for the scrap ones [14].

### **4.3 Batch Experiments**

Batch mode of experiments was designed to study the kinetic of adsorption capacity of FRCl onto WTRAC and CAC in aqueous solutions. The initial concentration of free chlorine was 1 mg/l, which was more than the allowable concentration 0.2- 0.3 mg/l recommended by Water and Health Organization [15]. A Stock solution of 25 mg/l of free-residual chlorine was prepared by dissolving a specific amount of  $\text{Ca}(\text{OCl})_2$  in one liter of distilled water. The solution was kept in dark at 4 °C, and further dilution for the solution was applied for preparing the desired concentrations.

Three doses (1, 5, and 10 g/l) of the adsorbents were selected and mixed, separately, with 50 ml of free chlorine solution (1 mg/l) in 250 ml beaker using magnetic stirrer (150 rpm at 25 °C) to assess the impact of AC mass and equilibrium time. Samples, each particular time, were withdrawal and the reduction of FRCl was calculated using Equation 1. The adsorption capacity of FRCl per unit mass was evaluated using Equation 2.

The kinetics data of free-residual chlorine adsorption was fitted with the pseudo first-order, pseudo second-order, and intra-particle diffusion models (Equations 3, 4, and 5, respectively). Free chlorine concentration was measured using Free and Total Chlorine Photometer, Hanna Instruments HI 93711 (store.clarksonlab.com).

Equilibrium study and the impact of particle size were assessed by series of experiments using 50 ml of FRCl solution. Particles size of the active carbon and the initial concentrations of FRCL ranging from 1.18 to 2.6 mm and 0.5 to 25 mg/l, respectively. The optimum dosage was fixed based on the results of batch kinetic tests as 0.5 g/50 ml for both studied active carbons. Samples were taken for FRCL analysis after the equilibrium time has reach. The impact of pH parameter was fixed without neutralization. This because free chlorine adsorption by activated carbon increases when pH values goes down, below 8 [16] and from 7.5 to 4.5 [2]. In this study the mean values of the solution was  $6.7 \pm 0.015$ .

The equilibrium results were simulated using the common Langmuir, Freundlich, and Temkin models, which are helpful to explain the rate of FRCl adsorption onto WTRAC and CAC, Equations 6, 7 and 8, in that order.

$$\text{FRCL adsorption (\%)} = \frac{(C_o - C_i)}{C_o} \times 100 \quad (1)$$

$$q_e = \frac{(C_o - C_e)}{m} v \quad (2)$$

$$\log(q_e - q_t) = \log q_e - \frac{k1}{2.303} t \quad (3)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (4)$$

$$q_t = K_{dif} * \sqrt{t} + C \quad (5)$$

$$\frac{1}{q_e} = \frac{1}{Q_m} + \frac{1}{bQ_m C_e} \quad (6)$$

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (7)$$

$$q_e = B_1 \ln k_T + B_1 \ln C_e \quad (8)$$

Co	Initial concentration at time zero
C <sub>i</sub> and C <sub>e</sub>	Remaining concentrations at time t and at equilibrium time, respectively.
v and m	Solution volume (0.05 l) and AC dose amount (0.05, 0.25, and 0.5 g), respectively.
q <sub>t</sub>	Amount of FRCL adsorbed at time t (mg/g).
K <sub>1</sub> and K <sub>2</sub>	Pseudo first (per min) and second (g/mg.min) order rate constants.
K <sub>dif</sub>	Intra-particle diffusion rate constant (mg/g.min <sup>1/2</sup> ).
q <sub>e</sub>	Amount of FRCL adsorbed per unit weight (mg/g).
b	Langmuir adsorption constant (l/mg).
Q <sub>m</sub>	Maximum monolayer coverage capacity (mg/g).
K <sub>f</sub>	Freundlich constant (adsorption capacity indicator) (mg/g).
1/n	Refer to the adsorption strength (intensity) during the process of adsorption.
B <sub>1</sub>	A constant related to heat of sorption (J/mol).
k <sub>T</sub>	Temkin equilibrium binding constant (l/g).

## 5 Results and Discussion

### 5.1 Adsorbents Characteristics

The characteristics of WTRAC and CAC showed that the surface area, total volume, micro volume and the meso volume of activated carbon prepared from waste tire rubber was 680 m<sup>2</sup>/g, 0.99 cm<sup>3</sup>/g, 0.33 cm<sup>3</sup>/g, and 0.66 cm<sup>3</sup>/g, respectively. In comparison, the corresponding characteristics of commercial active carbon were 1011 m<sup>2</sup>/g, 0.71 m<sup>3</sup>/g, 0.4 m<sup>3</sup>/g, and 0.31 m<sup>3</sup>/g, in that order. These values showed that total volume and meso volume of WTRAC is more than CAC, and vice versa for micropore. These characteristics could affect the adsorption capacity of adsorbent materials as will be discussed later.

### 5.2 Optimization Of Parameters Affecting Frcl Adsorption

#### 5.2.1 Influence of Ac Dosage

The impact of AC masses on RFCL reduction was assessed using three different doses of 1, 5, and 10 g/l mixed with 1 mg/l of free chlorine solution

at normal pH and particle size of 1.4 mm. Rotation speed was 150 rpm at 25 °C. Results showed that the reduction of free chlorine was improved with increasing the adsorbent dose until reached to a constant value (equilibrium state), for both studied AC samples (Fig. 1). This is because higher adsorbent masses enhancing the surface area of sorbent and consequently increasing the available adsorption sites [17]. It noticed that FRCL removal after the equilibrium time was not significant (44%, 45%, and 48%) for all WTRAC masses (1, 5 and 10 g/l, respectively) (Fig.1a). However, the removal values after equilibrium using CAC as adsorbent material were varied, 22%, 33%, and 39% corresponding to 1, 5, and 10 g/l of CAC masses, respectively (Fig. 1b).

Overall, WTRAC was predominated in FRCL reduction comparing with CAC. Additionally, the optimum dosage of WTRAC and CAC for higher reduction was 10g/l.

### **5.2.2 Influence of Contact Time**

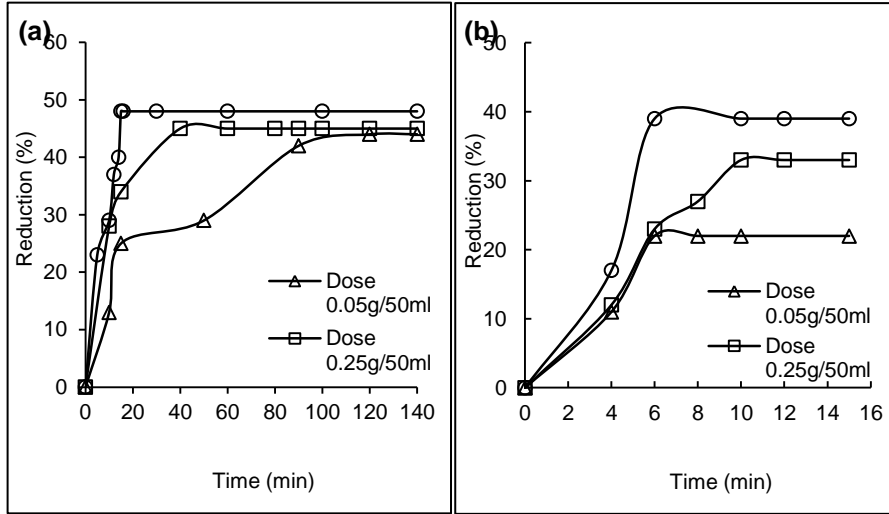
The influence of contact time on free chlorine attenuation was examined using three doses of WTRAC and CAC (1, 5, and 10 g/l, separately) mixed with 1 mg/l of free chlorine solution with a rotation speed of 150 rpm at normal pH and 25 °C. Particle size was 1.4 mm.

Results showed that free chlorine reduction by WTRAC was raised rapidly within the first 15 min of the experiment, demonstrating the time of adsorption occurrence (Fig. 1a). This is attributed by the presence of enough sites for binding the adsorbate on the accessible surfaces of WTRAC [6]. After that, the reduction values tend to be stable (at dose of 10g/l), or increased slowly and then tend to be plateau (using lower doses). This adduced to the accumulation of free chlorine on the adsorbent's binding sites until the equilibrium time was attained. These results matched with Ferreira et al. 2014, authors confirmed that the adsorption process is impacted by the time (speed) of conveying the adsorbate from the external to the internal surface of active sites on the adsorbent's particles. Equilibrium time reached after 120, 40, and 15 min in case of adsorbent dose of 1, 5, and 10 g/l, which are achieved adsorption capacity of 44, 45, and 48%, respectively. In terms of the second adsorbent material (CAC), results in Figure 1b indicated that the adsorption of free chlorine was increased within the first 6-10 min of experimental starting, and thereafter all values tend to be stable. Equilibrium time attained after 6, 10, and 6 min in case of adsorbent dose of 1, 5, and 10 g/l, which were achieved adsorption capacity of 22, 33, and 39%, respectively.

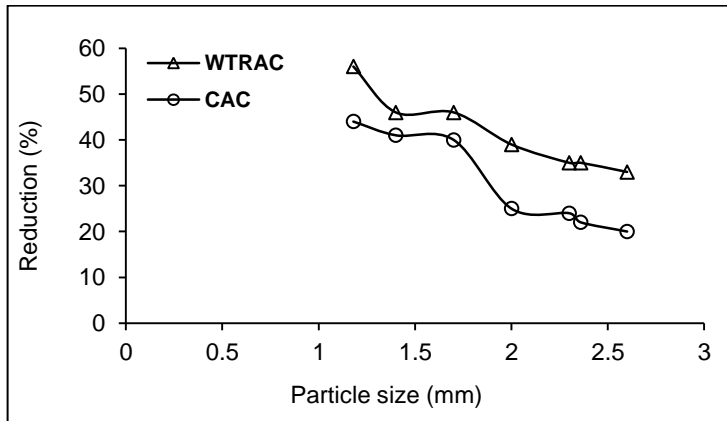
Accordingly, the optimum time for highest percentage of free chlorine removal was 15 min using 10 g/l of WTRAC, and 6 min using 10 g/l of CAC. Note that, although the time required for equilibrium in case of using CAC was less than that for WTRAC. However, higher reduction was linked

with the last one.

### 5.2.3 Influence of Particle Diameter



**Figure 1** Free Chlorine Reduction By WTRAC and CAC Using Different Dosages and at Different Contact Times (Concentration; 1 mg/l, Particle Size; 1.4 mm, pH; Un Buffered, Speed; 150 rpm. (a) Waste Tire Rubber Active Carbon (b) Commercial Active Carbon.

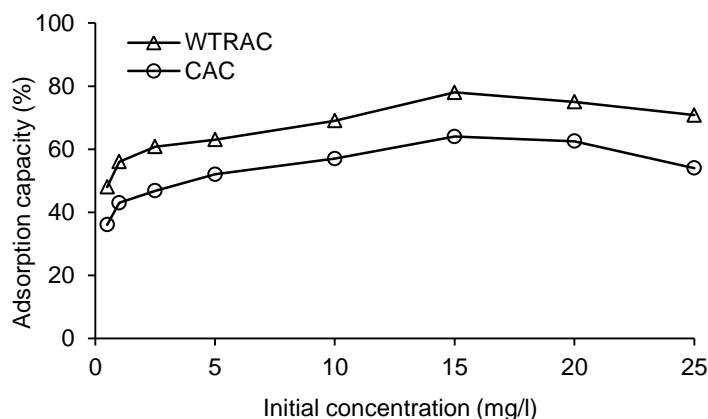


**Figure 2** Free Chlorine Reduction Using Different Grain Sizes of Adsorbent Materials. (Concentration; 1mg/l, pH; Un Buffered, Speed; 150 rpm, Dose; 10 g/l, Contact Time; 15 min for WTRAC and 6 min for CAC). WTRAC: Waste Tire Rubber Active Carbon, CAC: Commercial Active Carbon



The effect of grain size on free chlorine elimination was assessed based on the results of batch experiment, an optimal dose of 10 g/l with contact duration of 15 min (in case of WTRAC) and 6 min (in case of CAC). Each adsorbent with mass of 0.5 g and particles diameter ranging between 1.18 and 2.16 mm was equilibrated with 50 ml of free chlorine solution (1 mg/l) at normal pH and 25 °C. Rotation speed was 150 rpm. Figure 2 showed a clear impact of particles size on adsorbate attenuation. Higher adsorption capacity of 56% and 44% was achieved using grain size of 1.18 mm (smaller size) in case of both adsorbent materials (Figure 2). These results revealed that free chlorine reduction increases with decreasing the grains diameters. This because smaller particles size could reduce the thickness of the stagnant film around the grains, decreasing the distance inside the pores of the adsorbent, and consequently enhancing the reduction of free chlorine. Other interpretation suggests that at similar masses, smaller particle sizes mean more surface area for contaminant adsorption [17]. Similar outcomes confirmed by [5].

#### **5.2.4 Influence of Initial Concentration**



**Figure 3** Free Chlorine Reduction Using Different Initial Concentrations. (pH; Un Buffered, Speed; 150 rpm, Dose; 10 g/l, Contact Time; 15 min for WTRAC and 6 min for CAC, Grain Size; 1.18 mm). WTRAC: Waste Tire Rubber Active Carbon, CAC: Commercial Active Carbon.

For examination the impact of initial concentration on free chlorine attenuation, all other predetermined parameters were kept constant (pH; un buffered, speed; 150 rpm, dose; 10 g/l, contact time; 15 min for WTRAC and 6 min for CAC, particle size; 1.18 mm). Wide limits of FRCL concentrations (0.5-25 mg/l) were taken to assess the variability in adsorption capacity of chlorine residue. The mixtures were withdrawn and analyses

after achieving the equilibrium period. The results in Figure 3 showed that the adsorption capacity was increased with increasing the initial concentration of free chlorine, for both studied adsorbents, as the reaction was fast. However, after specific concentration, the reduction was reach to the optimum value, and then started to reduce. This was due to the presence of much available sites for adsorption on the surface of activated carbons. Whereas, the remarkable or extreme increasing in free chlorine concentration lead to declining the adsorption capacity. This may be because the binding sites of adsorbent materials reaches to the saturation stage.

The optimum removal was 78% for WTRAC and 64% for CAC at concentration of 15 mg/l (Figure 3). This interoperated by Salama et al. (2016), the binding sites of the adsorbent materials were saturated and there was no more site for chlorine adsorption at higher concentrations. Higher reduction of FRCL by WTRAC indicated that the reduction was due to the adsorption and chemical reduction, as confirmed by Li et al. [9].

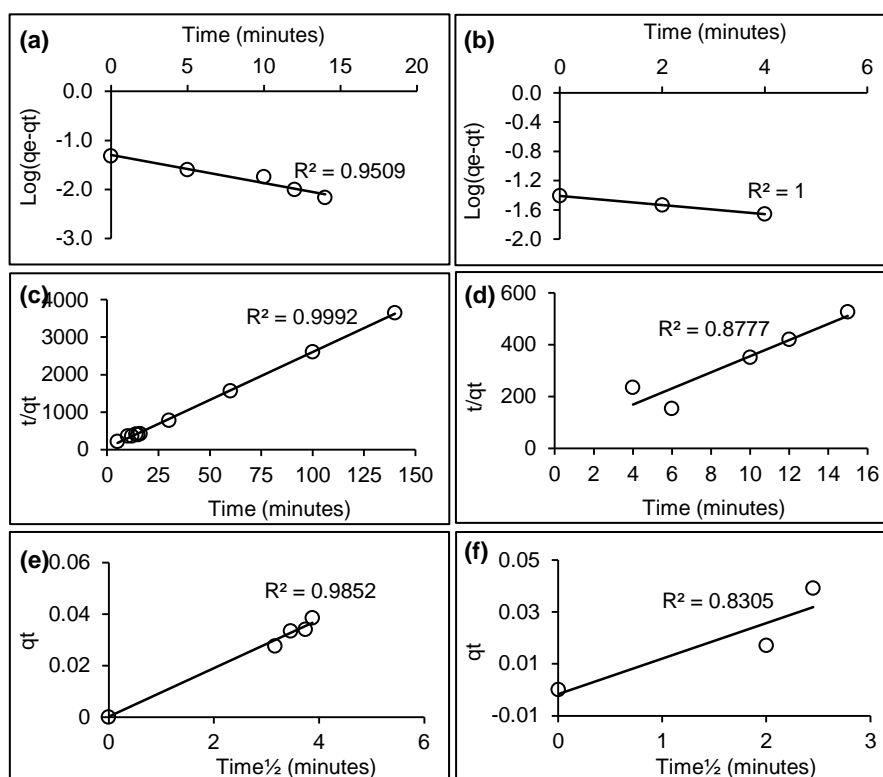
### 5.2.5 Adsorption Kinetics Data

**Table 1** The Calculated Parameters With The Correlation Coefficients of Kinetic Models.

Model	parameters	Adsorbent material	
		WTRAC	CAC
Kinetic equations	$q_e$ experimental (mg/g)	0.0384	0.039
pseudo first-order	$q_e$ calculated (mg/g)	0.050466	0.039003
	K1 (1/min)	0.131962	0.143247
	$R^2$	0.9509	1
pseudo second-order	$q_e$ calculated mg/g	0.039096	0.032208
	K2 (g/mg.min)	13.88796	21.12598
	$R^2$	0.9992	0.8777
Intra-particle diffusion	Kdif (mg/g.min <sup>0.5</sup> )	0.0094	0.0137
	C	0.0003	-0.016
	$R^2$	0.9852	0.8305

The kinetic results were fitted with pseudo first-order, pseudo second-order, and intra-particle diffusion models to understand chlorine transferring from the liquid phase to the solid phase. The plots of the time versus  $\log(q_e - qt)$ , the time versus  $t/qt$ , and the time<sup>0.5</sup> versus  $qt$  are shown in Figure 4. The correlation coefficient of pseudo second-order kinetics was higher than that of pseudo first-order kinetics in case of using WTRAC. In addition, the value of the calculated  $q_e$  was very close to the experimental value (Fig. 4a and c). Therefore, chlorine adsorption by WTRAC follows the pseudo second-order kinetics. This suggests that the rate-determining step is chemisorption or chemical adsorption and the forces of valence between the AC and the adsorbate might be involved in the adsorption [18]. However, the correlation

coefficient of pseudo first-order kinetics was higher than that of pseudo second-order kinetics in case of using CAC. In addition, the predicted value of  $q_e$  by this model was very accurate with the experimental value (Fig. 4b and d). Therefore, chlorine adsorption by CAC follows the pseudo first-order kinetics. Table 1 showed the calculated parameters of both kinetic models. The intra-particle diffusion model is fitted with the experimental data as a rate-controlling step, in case of the line goes towards origin [19]. The constants and correlation coefficients of this model are presented in Table 1 and Fig. 4 e and f for both adsorbent material.



**Figure 4** Sorption Kinetics of (a and b) Pseudo First-Order, (c and d) Pseudo Second-Order, and (e and f) Intra-Particle Diffusion Model Using (a, c, and e) WTRAC, and (b, d, and f) CAC for Free-Residual Chlorine Adsorption.

## 5.4 Adsorption Isotherms Data

### 5.4.1 Langmuir Adsorption Isotherm

This model explains the configuration of a monolayer free-residual chlorine on the external surface of the active carbon till the equilibrium,

quantitatively. The magnitudes of  $Q_m$  and  $b$  were analyzed based on the slope and intercept of  $C_e$  versus  $C_e/q_e$  for the Langmuir chart. The dimensionless parameter  $RL$  was used as an equilibrium factor (equation 9) to present this isotherm. If the value of  $RL$  is equal to zero, more than zero and less than one, equal to one, or more than one, the nature of adsorption is classified to irreversible, favorable, linear, and unfavorable, respectively [20].

$$RL = \frac{1}{1+(1+bC_0)} \quad (9)$$

In this study, the values of  $Q_m$  and  $b$  for both adsorbent materials were negative (Table 2). In addition, the values of correlation coefficients were very low (Figure 5a). These results indicated that the Langmuir isotherm was not adequate to describe the outcomes of this research, although the values of  $RL$  imply that the adsorption nature was favorable. This means that the Langmuir assumption of no decreases in the heat of adsorption with the coverage surface has not occurred [21].

#### **5.4.2 Freundlich Adsorption Isotherm**

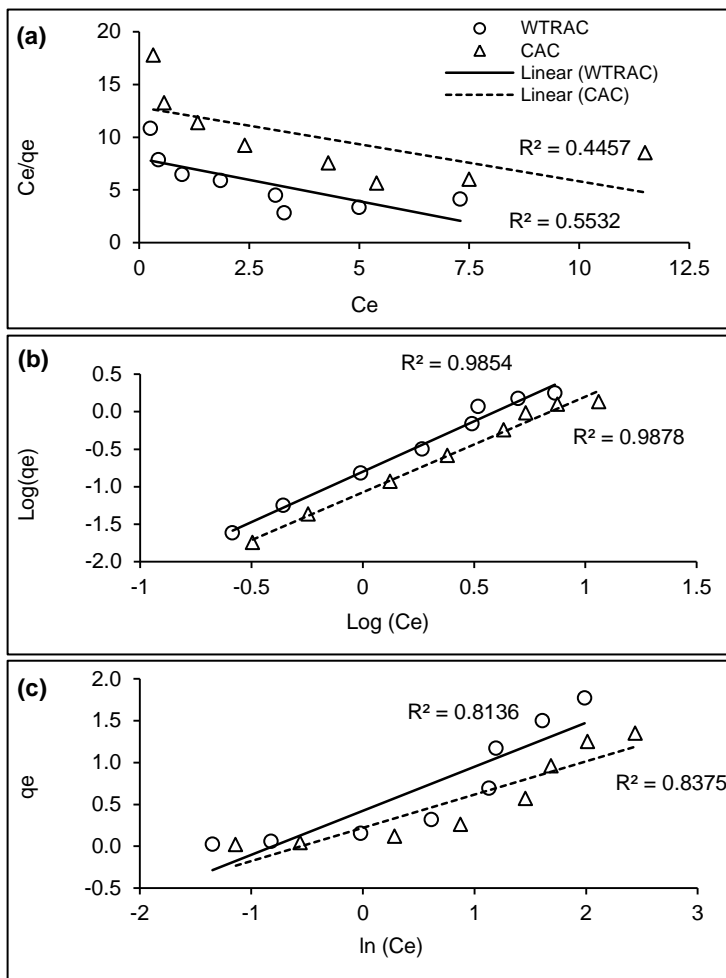
Freundlich model explains the characteristics of adsorption for the non-homogeneous surface. The values of  $K_f$  and  $n$  were computed, respectively, from the slope and intercept of the plots between  $\log C_e$  and  $\log q_e$ . The magnitude of empirical dimensionless parameter  $n$  is reflecting the adsorption process as a normal process when this value is more than one and as a cooperative process when  $n$  is less than 1 [20].

In this research, the values of  $n$  (Table 2) were less than one, for both adsorbent materials (Table 2), indicating that the adsorption of free-residual chlorine on to WTRAC and CAC was cooperative (Dada et al. 2012). The values of correlation coefficients (Figure 5b) were close to one, for both adsorbents, which indicates that this model is fitted well with sorption data better than Langmuir isotherm. These results suggests that the occurrence of adsorption on the non-homogenous coverage surface was through a multilayer adsorption mechanism, and increasing the concentration enhances the efficiency of adsorption, as the heat of adsorption is reduces logarithmically with the coverage surface [21].

#### **5.4.3 Temkin Adsorption Isotherm**

This model assumed that the heat of adsorption decreases linearly with the surface coverage [6]. This decrease is related to the interactions between the sorbent and sorbate [22]. The values of Temkin constants were computed from the slope and intercept of the plot between  $\ln C_e$  and  $q_e$ . The values of Temkin parameters, corresponding to each adsorbent materials, suggested a physical adsorption process as documented in Table 2 and Figure 5c. Correlation coefficients ( $R^2$ ) values indicated that this model is described

the adsorption results better than Langmuir isotherm. The adsorption capacity of WTRAC was higher than CAC (Table 2), this may due to the impact of higher total volume and meso volume of WTRAC comparing with CAC. Al- Degs et al. [23] confirmed same results. The authors mentioned that the mesopore volume of adsorbent material has a greater impact on the adsorption capacity enhancement during the adsorption process, if compared with the micropore volume.



**Figure 5** Linearized Plots of a) Langmuir, b) Freundlich, and c) Temkin Isotherms For Adsorption of Free-Residual Chlorine

**Table 2** Langmuir, Freundlich, and Temkin Parameters for Free-Residual Chlorine Adsorption

Isotherm	Parameter	WTRAC	CAC
Langmuir	$Q_m$ (mg/g)	-1.23442	-1.42207
	$b$ (l/mg)	-0.1016	-0.05475
	$R^2$	0.5532	0.4457
	RL	0.943189	0.669537
Freundlich	$n$	0.743937	0.783638
	$K_f$ (mg/g)	0.158526	0.084723
	$R^2$	0.9854	0.9878
Temkin	$B_1$ (J/mol)	0.5268	0.3965
	$KT$ (l/g)	2.232989	1.746527
	$R^2$	0.8136	0.8375

## 6 Conclusions

The results of free-residual chlorine adsorption onto waste tire rubber and commercial activated carbon suggest the following conclusions:

- Active carbon prepared from waste tire rubber as a cheap adsorbent material has successfully proven to be an efficient product for removing of FRCL.
- Free-residual chlorine attenuation at concentration of 15 mg/l using WTRAC is much better (78%) compared with the corresponding reduction using CAC (64%).
- The optimum amount of WTRAC and CAC for higher FRCL reduction is 10g/l
- The removal percentage of FRCL increases with increasing the contact time until reaches the equilibrium time, which was after 15 min in case of using WTRAC and 6 min in case of using CAC as adsorbent materials.
- The initial concentration of FRCL is the main role for its attenuation, as the adsorption increases with rising the preliminary concentration. However, escalating the initial concentrations extremely leads to decline the adsorption capacity.
- The reduction of free chlorine increases with decreasing the grain diameters of the adsorbent materials, and the best particles diameter of active carbon was 1.18 mm.
- The correlation coefficient for adsorption data achieved by Freundlich isotherm is higher than the corresponding values based on Langmuir and Temkin isotherm models. Therefore, the Freundlich isotherm was the best to describe the adsorption of free-residual chlorine by WTRAC and CAC.
- The highest adsorption capacity of FRCL by WTRAC and CAC were 0.158526 and 0.084723 mg/g, respectively.

- Pseudo second-order equation showed a very well adjustment with the kinetics results in case of WTRAC. In comparison, the adsorption kinetics data of pseudo first-order equation was adjusted very well in case of CAC.
- Free-residual chlorine transferring from the liquid phase to the solid phase was due to macropore and mesopore diffusion, followed by micropore diffusion.

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