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Efficacy evaluation of NH_4Cl-induced activated carbon in removal of aniline from aqueous solutions and comparing its performance with commercial activated carbon

Ahmad Alahabadi[a], Zahra Rezai[a], Abolfazl Rahmani-Sani[a], Ayoob Rastegar[a,*], Ahmad Hosseini-Bandegharaei[a,b,*], Abdolmajid Gholizadeh[c]

[a]*Department of Environmental Health Engineering, School of Public Health, Sabzevar University of Medical Sciences, Sabzevar, Iran, Tel. +98 5144419572; Fax: +98 5144445648; emails: ahmad_health@yahoo.com (A. Alahabadi), rezaiz41@yahoo.com (Z. Rezai), rahmani240@gmail.com (A. Rahmani-Sani), rastegar.89@gmail.com (A. Rastegar), ahoseinib@yahoo.com (A. Hosseini-Bandegharaei)*
[b]*Department of Engineering, Kashmar Branch, Islamic Azad University, P.O. Box 161, Kashmar, Iran*
[c]*Faculty of Health, North Khorasan University of Medical Sciences, Bojnurd, Iran, Tel. +98 5832240524; Fax: +98 5132247281; email: gholizadeh_eng@yahoo.com*

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ABSTRACT

This study tries to develop an inexpensive and advantageous adsorbent for the treatment of waters contaminated with aniline, using newly prepared NH_4Cl-induced activated carbon (NAC). It also reports the results obtained by comparing the sorption properties of NAC with those of the commercially granular standard activated carbon (SAC). To determine the structural properties of NAC and SAC, the techniques of pH_{zpc}, Fourier Transform Infrared Spectroscopy, BET, EDX, and SEM were used. The effect of various parameters like adsorbent dose, pH, contact time, and initial aniline concentration were carefully studied. The results showed that prepared NAC had a mesoporous structure and its adsorption capacity was higher than SAC so that the maximum adsorption capacity of aniline onto NAC and SAC was 1,666.7 and 1,000.0 mg/g, respectively. The results of equilibrium and kinetic experiments indicated that adsorption process of aniline onto both SAC and NAC fitted with the Langmuir isotherm model and pseudo-second-order models respectively. Entirely, it can be concluded that the developed NAC can be as a convenient, inexpensive, appropriate and alternative adsorbent for native Merck standard carbon for treatment of organic pollutants such as aniline from waters or wastewaters.

Keywords: Aniline; Adsorption; NH_4Cl-induced activated carbon

1. Introduction

Aniline is a colorless oily incendiary liquid which has a benzene ring and a NH_2-band in its structure [1]. This substance is naturally found in some foods, such as corns, grains, cereals, and tea, and is synthetically produced in large quantities for using in industries, so that only in the US this chemical is spent by more than one billion pounds [2,3]. It also is a byproduct in the oil, paper, and coal industries and is widely applied in the production of aniline dyes, explosives, pesticides, and drugs. This substance has

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*Corresponding authors.

been even used as a solvent in the manufacture of paints and wax polishes for shoes and flooring [4].

Aniline solubility in water is 5.3% and, therefore, this causes it to be found abundantly in a variety of sources such as surface and underground waters and industrial wastewater [5]. Aniline can enter the human body through food, water or breathing polluted air and skin contact. The existence of aniline in blood causes reduction in the oxygen-carrying capacity that can eventually lead to headaches, dizziness, coma, and even death [6]. Since the US EPA has reported that the aniline amount in underground water is about 6 mg/L [6], its removal from aqueous solutions seems necessary and various methods such as membrane separation, ultrasonic technique, photocatalytic processes, ozonation [7], wet air oxidation [8], biological degradation [9], catalytic electrochemical treatment [10], and adsorption [11] have been applied for this purpose. Among disadvantages of these mentioned methods we can imply to costly construction and utilization and production of toxic byproducts. Also, it should be mentioned that biological systems due to utilization difficulties and high sludge are not affordable [1]. Thus, among the above-mentioned methods, adsorption due to being economical, high efficiency and easy utilization is considered as an approved method for separating organic contaminants from aqueous solutions. Various types of adsorbents such as commercial activated carbon, minerals, and agricultural wastes have been employed for the removal of organic contaminants from aqueous solutions [12–14].

Although porosity, specific surface and high capacity of the activated carbon have resulted in increasingly use during the recent years [15], high prices and some problems in the carbon regeneration process has restricted the use of activated carbon in the full-scale treatment plans. Therefore, several studies have been conducted on low-cost adsorbents, such as coal, coconut shells, and wood, to remove organic contaminants from waters and wastewaters [16]. On the other hand, to reduce the costs and optimization of adsorption capacity, various methods, such as chemical treatment by potassium hydroxide, zinc chloride, sulfuric acid, sodium hydroxide, etc. have been recently applied for modifying activated carbon samples. However, it should be mentioned that using the metal oxides for chemical treatment leads to the occupation of the pores of the activated carbon [17].

This study was aimed to produce a carbon modified with ammonium chloride (NH_4Cl-induced activated carbon (NAC)) to remove aniline from aqueous solutions as a model of water polluting hydrocarbons, and the adsorption properties this new adsorbent was compared with those of Merck standard commercial carbon (SAC). The influence of various parameters, such as adsorbent dose, pH of the solution, temperature, contact time, and concentration of aniline, were evaluated, and the kinetics, equilibrium, and thermodynamic studies were carefully performed.

2. Materials and methods

This is a fundamental applied study in which all the adsorption experiments for the removal of aniline from synthetic solutions by two adsorbents, Merck activated carbon and carbon modified with ammonium chloride, were performed in a batch system. The method of preparation of carbon modified with ammonium chloride has been noted in our previous study [18]. To determine the structural properties and the nature of NAC and SAC, the techniques of pH_{zpc}, FTIR, BET, EDX, and SEM were used.

Laboratory pure aniline was purchased from Sigma Company. Double-distilled water was used in all the experiments. pH of the solutions was adjusted using 0.1 N solutions of NaOH and HNO_3 and measured by a pH meter (HACH-HQ-USA). The aniline residuals in the solutions were determined by UV–vis spectrophotometer (CECIL CE7400).

2.1. Adsorption experiments

This study was conducted at a laboratory scale in which all the working solutions were prepared by diluting the prepared stock solution, and all adsorption experiments were carried out in 250-mL Erlenmeyer flasks at a known pH and ambient temperature. In a typical experiment, a certain amount of each activated carbon was placed in Erlenmeyer flask containing 100 mL solution of known aniline concentration and shaken at the agitation speed of 100 rpm. After a given time period, the solutions were centrifuged and the concentration of aniline was spectrometrically measured at 280 nm. The effect of four variables, including carbon dose (0.2, 0.4, 0.6, 0.8, and 1 g/L), contact time (2, 5, 10, 20, 40, 60, 80, and 100 min), pH (2–11) and initial concentration of aniline (50–300 mg/L), were tested in such a way that the considered factor changed and all other factors were constant. To ensure repeatability, all experiments were repeated twice. The removal percentage and the adsorption capacity of the NAC and SAC were computed from the following equations:

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

$$q_t = \frac{(C_0 - C_t)V}{M} \tag{2}$$

$$q_e = \frac{(C_0 - C_e)V}{M} \tag{3}$$

where R (%) is the removal percentage, C_0 (mg L^{-1}) is the initial concentration of aniline, C_t (mg L^{-1}) is the aniline concentration remaining in the solutions at time "t", C_e (mg L^{-1}) is the equilibrium concentration of aniline in the aqueous phase, q_t (mg g^{-1}) is the amount of aniline adsorbed onto each carbon sample at time "t", q_e (mg g^{-1}) is the amount of aniline adsorbed onto each carbon sample at equilibrium, V (L) is the volume of the solution, and M (g) is the mass of the carbon sample used in the adsorption experiments.

3. Results and discussion

3.1. Characterization of NAC and SAC

Table 1 indicates the structural properties for both NAC and SAC, including specified surface, pore volume and average pore diameters. According to the data reported in Table 1, both NAC and SAC have high specified surface as 1,029 and 1,024 m^2/g, respectively. Also, according to the IUPAC size classification in which microporous materials have pore diameters of less than 2 nm, mesoporous materials have pore diameters of 2–50 nm and macroporous materials have pore diameters of greater than 50 nm, the results of the pore size distribution show that both NAC and SAC are mesoporous adsorbents.

For more investigation on the adsorbents surface properties, Fourier transform infrared spectroscopy (FTIR) technique was used (Fig. 1), and the results showed that both carbon types have similar peaks, with notable differences in 3,443, 2,900, 2,400, 1,500, and 1,200 cm^{-1} peaks which are, respectively, related to the hydroxyl group, C–H stretching, C≡C bond, carboxyl group, and C–O bond. One reason for adsorption interaction of aniline with the studied carbons can be due to the presence of strong bonds of hydroxyl groups in their structures.

Table 1
The main structural properties of the NAC and SAC

Parameter	NAC	SAC	Unit
Area	1,029	1,024	m^2/g
Total pore volume (P/P_0 = 0.990)	0.633	0.572	cm^3/g
V_m (monolayer volume)	236.4	235.5	cm^3/g
Mean pore diameter	2.46	2.23	nm
BET C constant	1,088.7	691.8	–
pH_{zpc}	7.4	6.6	–

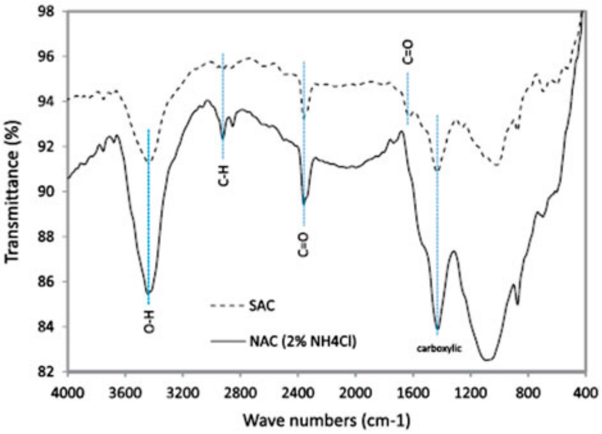

Fig. 1. FTIR spectra of NAC and SAC.

The surface morphology of both adsorbents was investigated using scanning electron microscopy (SEM) micrographs. The SEM micrograph of both carbon types (Fig. 2) indicates that NAC has a form like compressed and porous fibers with a series of parallel and long channels, but SAC has a smooth surface with scattered holes. Also the findings resulted from EDX analysis for NAC adsorbent prior to adsorption process are shown on the Fig. 3 in which NAC has a compound with 93.4% carbon, 2.5% oxygen, 1.1% chloride, 9.0% potassium, 7.0% sulfur, 7.0% calcium, 3.0% sodium, and 3.0% magnesium, while SAC contains chemicals such as carbon (75.4%), oxygen, zinc, and lead [18].

Analysis of the elements in the structure of both the adsorbents showed that the percentage of carbon in the structure of NAC is higher than that of SAC, which can cause the higher adsorbency of aniline on the newly produced carbon compared to Merck activated carbon. Also, it should be mentioned that modification with ammonium caused the explosive properties of ammonium at high temperatures and increasing pores in the produced carbon compared to Merck activated carbon. The EDX graph can be a verifying reason for ammonium explosion since no ammonium is observed in the produced carbon structure. The results of this study are compatible with those of Moussavi et al. [18] study on the removal of amoxicillin.

3.2. Effect of pH on the adsorption process

Since pH is one of the most important parameters in adsorption systems, the effect of pH on the removal

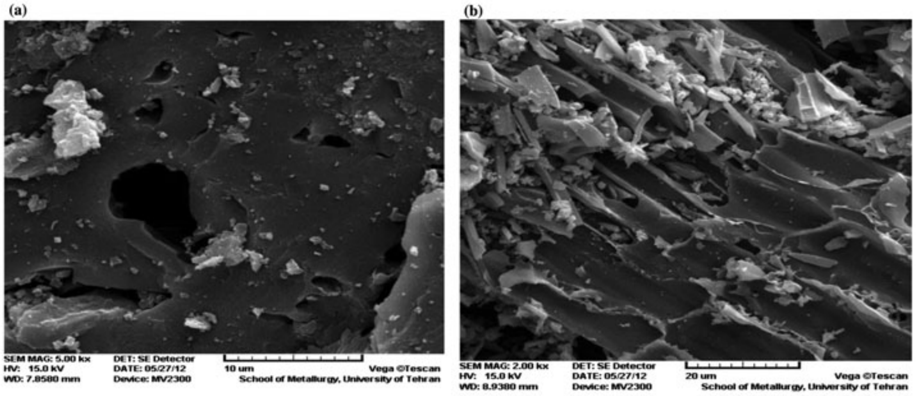

Fig. 2. SEM images of SAC (a) and NAC (b).

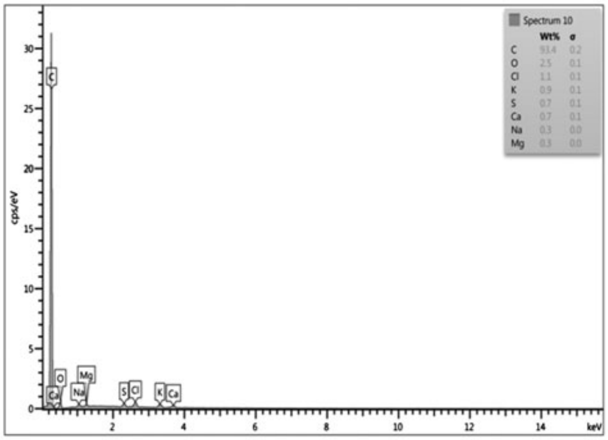

Fig. 3. Results of EDX analysis of NAC.

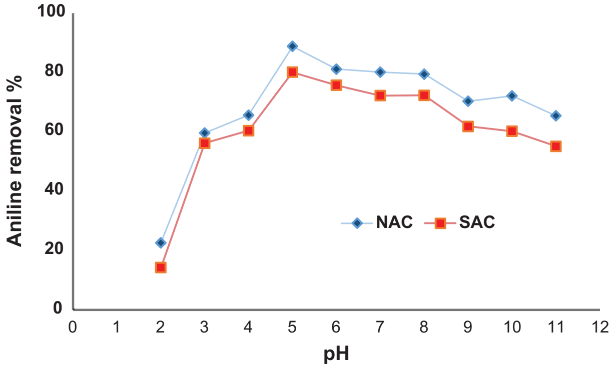

Fig. 4. Effect of solution pH on removal percentage at equilibrium for aniline adsorption onto NAC and SAC (volume, 100 mL; adsorbent dose, 0.4 g/L; initial concentration, 100 mg L^{-1}; contact time, 100 min; temperature, 298 K).

of aniline by both NAC and SAC (Fig. 4) was studied. The results indicated that the adsorption of aniline increased from pH 3 to 5 and then decreased so that the maximum aniline removals on both adsorbents occurred at pH 5, which is close to pH_{zpc} values, and were 80.1% for SAC and 88.8% for NAC. Also, the removal percentages of aniline in acidic pH (pH 3) for SAC and NAC were 14.3 and 22.3%, respectively, while these amounts in alkaline pH (pH 11), respectively, were 55.1 and 65.4%. These results indicate that acidic pH less than the pK_a of aniline (4.6) reduce the adsorption of aniline, which could be due to the presence of electrostatic repelling force between the positively charged adsorbents surface and aniline cations [19,20]. Also, the main reason for the reduced adsorption under alkaline conditions could be due to the competition between hydroxyl ion OH^- and aniline for occupying the adsorption sites of activated carbons. In addition, it should be mentioned that occurring the maximum adsorption of both NAC and SAC at pH 5.0 indicates that the adsorption process of aniline is of non-electrostatic interaction type, because the aniline molecule is in its neutral state at this pH. These findings are consistent with those of Bin Tang who conducted a study in 2012 on the removal of aniline from aqueous solutions [21].

3.3. Effect of adsorbent dosage on the adsorption process

The results of changes in adsorbent dose on aniline removal efficiency at pH 5 for both NAC and SAC (Fig. 5) indicated that with an increase in adsorbent dosage the removal efficiency of both activated carbons increase so that with increasing carbon dose from 0.2 to 1 g/L the percentages of removal changed from 56.1 to 99.1% for NAC and from 45.8 to 94.2% for SAC, while, at the same time, the adsorption capacities decreased from 561.2 to 99.1 mg/g for NAC

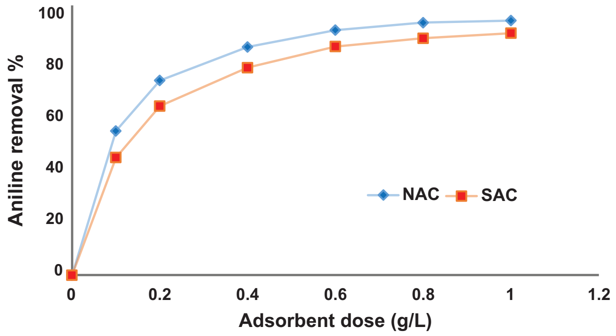

Fig. 5. Effect of adsorbent dose on removal percentage at equilibrium for aniline adsorption onto NAC and SAC (volume 100 mL; adsorbent dose 0.4 g/L; initial concentration 100 mg L^{-1}; contact time 100 min; temperature 298 K).

and from 450 to 94.2 mg/g for SAC. However, the most suitable adsorbent dose was chosen 0.6 g/L for both carbon types because the removal percentage increased up to these values but after that no significant increase was observed. Increase in the amount of an adsorbent cause an increase in the amount of adsorption surface and more access of aniline molecules to adsorption sites, resulting in higher removal percentage of aniline from the aqueous solutions and more reduction of its concentration. On the other hand, increasing adsorbent dose will reduce available aniline molecules to create the maximum surface coverage, which leads to a reduction in the amount of aniline adsorbed per unit weight of adsorbent [22–24]. In addition, it is also seen that the process of decrease in adsorption capacity as a function of concentration in a form of a exponential equation [13]. This trend indicates that the material adsorbed onto the adsorbent surface or molecules remaining in the solution will cause either closing inner holes or the accumulation and coherence of adsorbent particles which leads to a reduction in active sites [25]. Somewhat similar findings have resulted from a number of other studies, for example Kakavandi et al. conducted aniline adsorption on magnetized Merck carbon and the results showed that, firstly, the adsorption capacity increased with the increase in adsorbent dose and, then, decreased at the higher adsorbent doses [1].

3.4. Aniline adsorption equilibrium and isotherm models

The results about the effect of initial aniline concentration (50–400 mg/L) on the removal efficiency and adsorption capacity for both adsorbents (Fig. 6) showed that the highest removal efficiency was obtained at a concentration of 50 mg/L, so that the removal percentages were 90.9 and 88.1% for NAC and SAC, respectively. Like other Adsorbents, activated carbons have certain and limited adsorption sites and there are more adsorption site available on the adsorbent surface at low concentrations, which cause rapid adsorption of aniline and increase in the removal efficiency. But at higher concentrations, with an increase in the materials to be adsorbed on the adsorbent, the adsorption sites become saturated and the removal efficiency of adsorbent is decreased. The obtained results in the present study showed that the capacity of aniline adsorption by changing the concentration from 50 to 400 mg/L increased from 110.13 to 458.1 for SAC and from 113.6 to 697 for NAC. Increasing the adsorption capacity with an increase in initial concentration of aniline is likely because of an increase in the chances of contact between the adsorbent and adsorbed material [4,26–28]. Also, another factor that can affect is that in such circumstances the mass transfer force increases, which is the dominant phenomenon on resisting force against the adsorption and causes some considerable propulsion force for transferring the pollutants from the liquid phase to the adsorbent–liquid common surface [29].

In the present study, the Langmuir and Freundlich isotherm models were applied to investigate the relation between the concentration of adsorbed material and the adsorption capacity. The Langmuir isotherm model is based on a monolayer and constant (homogeneous) adsorption of the adsorbed material on the adsorption sites with the same energy, and its linear form is as follows:

$$\frac{C_e}{q_e} = \frac{1}{b\,q_{\max}} + \frac{C_e}{q_{\max}} \tag{4}$$

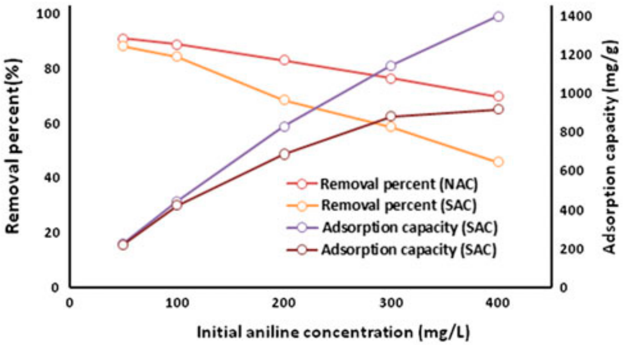

Fig. 6. Effect of initial aniline concentration on the removal percentage of aniline and adsorption capacity of NAC and SAC (volume 100 mL; pH 5; adsorbent dose 0.4 g/L; initial concentration 100 mg L^{-1}; contact time 100 min; temperature 298 K).

where q_e (mg/g) is adsorption capacity at equilibrium time, C_e (mg/g) is aniline concentration in the equilibrium point, b (L/mg) is Langmuir constant, and q_{max} (mg/g) is the maximum adsorption capacity. The values of q_{max} and b can be obtained from the slope and intercept of linear plot of C_e/q_e vs. C_e values. One of the important Langmuir isotherm parameters is separation factor (R_L) which highlights the ability of the adsorbent for adsorption of the interested contaminant and is obtained from Eq. (5):

$$R_L = \frac{1}{1 + bC_0} \tag{5}$$

where C_0 is the initial concentration of aniline. The values of $0 < R_L < 1$ represent the favorable adsorption and the values of $R_L > 1$ represent unfavorable adsorption.

Unlike Langmuir model, the Freundlich's empirical isotherm equation is based on a multi-layer and heterogeneous adsorption of the materials on adsorbents. The linear form of Freundlich is given as Eq. (6):

$$\ln q_e = \ln K_f + \frac{1}{n} \ln C_e \tag{6}$$

where C_e (mg L^{-1}) is the equilibrium concentration, K_F ($mg^{1-(1/n)}/L^{1/n}$ g) is roughly an indicator for the adsorption capacity and n is related to the adsorption intensity which has a numerical value and varies with heterogeneity.

Fig. 7 show the linear plots of both Langmuir and Freundlich equilibrium isotherms for adsorption of aniline on NAC and SAC, and the parameters of these models are represented in Table 2. The results obtained from the regression coefficients of Langmuir and Freundlich equations for both adsorbents indicate that the adsorption of aniline on NAC and SAC follows from Langmuir isotherm, suggesting that aniline adsorption process is of mono-layer type and occurs at specific homogeneous adsorption sites. The obtained values of R_L for both adsorbents are located in the range 0–1 which shows that the adsorption process is favorable. It was also found that the maximum monolayer adsorption capacity of aniline on NAC and SAC based on the Langmuir model were 1,666.7 and 1,000.0 mg/g, respectively.

Up to now, the performance of a number of adsorbents in the removal of aniline has been investigated [11,16] as Kakavandi et al. reported that aniline adsorption onto magnetic activated carbon followed from Langmuir model and the maximum capacity of adsorption was around 90.91 mg/g [1]. On this basis, the provided adsorbent in this study has a higher adsorption capacity than the other investigated adsorbents and, therefore, the NAC can be used for the removal of aniline from contaminated waters and wastewaters. Similar results have been reported by other researcher [4].

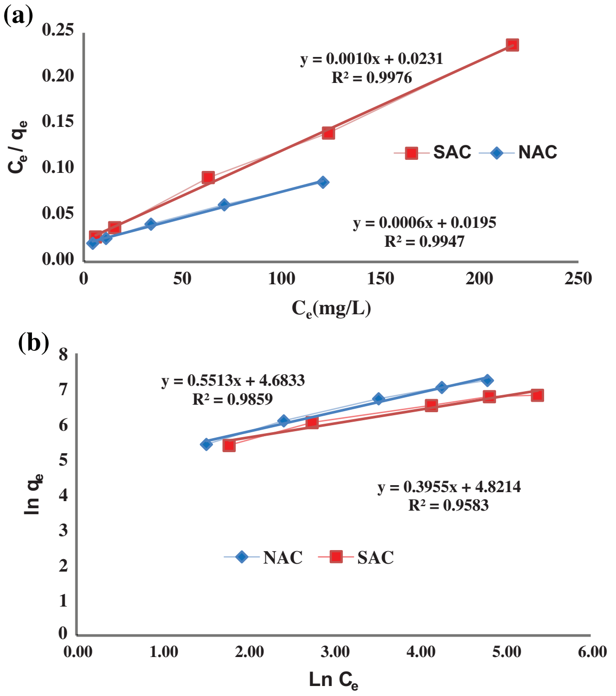

Fig. 7. Isotherm models for adsorption of aniline on NAC and SAC: (a) Langmuir isothermal model and (b) Freundlich isothermal model (T = 298 K).

Table 2
The isotherm information of aniline adsorption onto NAC and SAC

		Adsorbent	
Isotherm	Parameters	SAC	NAC
Langmuir	R^2	0.9976	0.9947
	b	23.1	32.5
	R_L	0.0008	0.0006
	q_{max}	1000.0	1666.7
Freundlich	R^2	0.9583	0.9559
	n	2.5	1.8
	K_F	124.1	108.1

3.5. Adsorption kinetics

Fig. 8 indicates that by increasing the contact time, the removal efficiencies are significantly increased.

The results showed that aniline adsorption process on NAC and SAC was faster during early times and at all times the NAC adsorption speed and percentage was higher than of SAC ones. The required time for reaching equilibrium for the NAC and SAC was 30 and 60 min, respectively, and the maximum removal percentage at the point of equilibrium time was 81.2% for SAC and 88.3% for NAC.

At the beginning of the adsorption process, due to the large number of adsorption sites, the large gradient of concentration between the material adsorbed in solution and its amount on the adsorbing cause a high sorption speed. But over the time, the slope will be very gentle, which is due to both the existence of a layer of aniline on the surface of the adsorbent [22] and the difficulty of occupation of the remaining vacant surface sites. Adsorption kinetics at different times (2–60 min) were analyzed for the NAC and SAC by fitting the experimental data with the following kinetic models [4,30]:

$$\text{Pseudo-first-order (PFO): } \log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t \tag{7}$$

$$\text{Pseudo-second-order (PSO): } \frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{8}$$

where k_1 (1/min) and k_2 (g/mg min) are, respectively, the rate constants of the pseudo-first-order adsorption and pseudo-second-order adsorption, q_t is the adsorption capacity at time "t" and q_e is the adsorption capacity at equilibrium. The correlation coefficient (R^2) and the normalized standard deviation ($\Delta q\%$) were exploited for model comparison and for goodness-of-fit evaluation. The $\Delta q\%$ values were calculated from the following equation which is proposed by Basha et al. [25]:

$$\Delta q(\%) = 100\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{q_{\text{exp}} - q_{\text{model}}}{q_{\text{exp}}}\right)_i^2} \tag{9}$$

where q_{exp} and q_{model} are, respectively, the experimental adsorption capacity and the calculated adsorption capacity from the isotherm model and N the number of experiments. The plots of both pseudo-first-order and pseudo-second-order models for aniline adsorption on NAC and SAC were shown in Fig. 9, and the calculated kinetic parameters were summarized in Table 3 in which high levels of R^2 and low values of $\Delta q(\%)$ indicate that, at the studied aniline concentration (50 mg/L), aniline adsorption on both SAC and NAC follows the PSO model.

For better understanding of the adsorption process and gaining insight on the physical chemistry of aniline removal, more studies were performed to find the

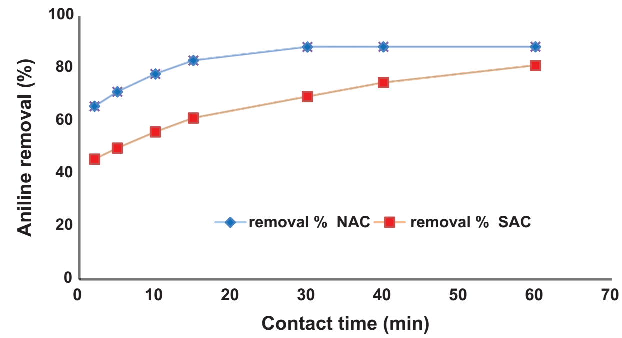

Fig. 8. Effect of contact time on adsorption capacity and removal of aniline onto the NAC and SAC (volume 100 mL; pH 5; adsorbent dose 0.4 g/L; initial concentration 50 mg L^{-1}; temperature 298 K).

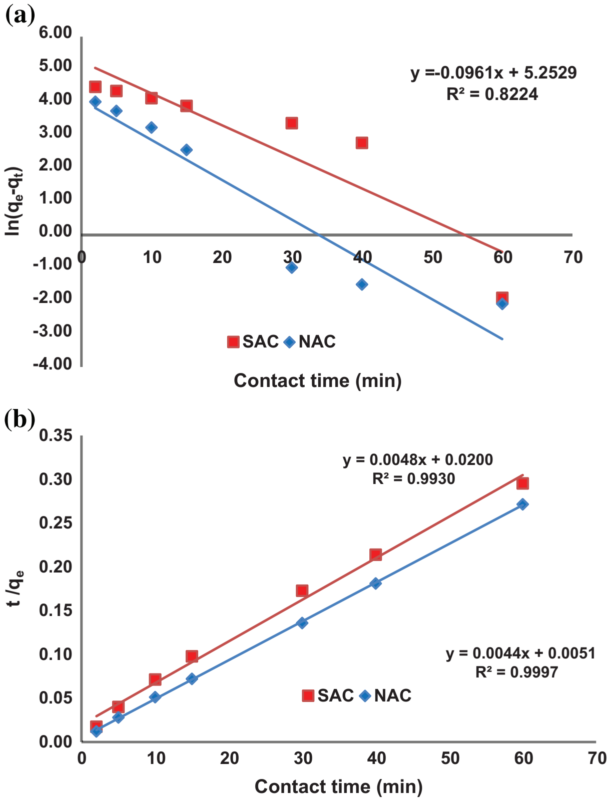

Fig. 9. Kinetic models for adsorption of aniline on NAC and SAC: (a) pseudo-first-order model and (b) pseudo-second-order model (volume 100 mL; pH 5; adsorbent dose 0.4 g/L; initial concentration 50 mg L^{-1}; contact time 100 min; temperature 298 K).

Table 3
Kinetic parameters for the adsorption of aniline onto NAC and SAC

Model	Parameters	Unit	Adsorbent	
			SAC	NAC
Pseudo-first-order equation (PFO)	R^2	–	0.908	0.8783
	k_1	min	0.096	0.121
	$q_{e,\mathrm{exp}}$	mg/g	203.1	221.0
	$q_{e,\mathrm{mod}}$	mg/g	191.1	59.5
	$\Delta q(\%)$	–	27.3	23.8
Pseudo-second-order equation (PSO)	R^2	–	0.9959	0.9927
	k_2	g/mg min	0.069	0.228
	$q_{e,\mathrm{exp}}$	mg/g	203.1	221.0
	$q_{e,\mathrm{mod}}$	mg/g	208.4	227.3
	$\Delta q(\%)$	–	1.8	2.1

mass-transfer step which may controls the aniline adsorption onto the studied activated carbon. Since the adsorption of aniline onto/into a porous activated carbon, like the NAC and SAC, can be considered as a heterogeneous reaction between solid carbon phase and aniline solution, two mass-transfer steps which may control the rate of aniline adsorption on the NAC and SAC include mass-transfer of aniline molecules through the liquid film surrounding the carbon particles (called film diffusion) and mass-transfer of aniline through the particles pores (called intra-particle diffusion). Therefore, the experimental data were fitted with both film diffusion and intra-particle diffusion models which are given as the following equations [31,32]:

$$\text{Film diffusion: } \ln\left(1-\frac{q_t}{q_e}\right) = -k_{\mathrm{fd}}\, t \tag{10}$$

$$\text{Intra-particle diffusion: } q_t = k_{\mathrm{ip}} t^{0.5} + C \tag{11}$$

where k_{fd} and k_{id} are film diffusion constant and intra-particle diffusion, respectively, q_t is the adsorption capacity at time “t”, q_e is the adsorption capacity at equilibrium time, and the values of C is proportional to the boundary layer.

The corresponding kinetic plots for both the film diffusion and intra-particle diffusion models were presented in Fig. 10, and the R^2 values in the intra-particle diffusion model for aniline adsorbed on NAC and SAC was higher than those of film diffusion model. Therefore, it can be concluded that the intra-particle diffusion is the the rate-controlling step in the adsorption of aniline onto both the NAC and SAC.

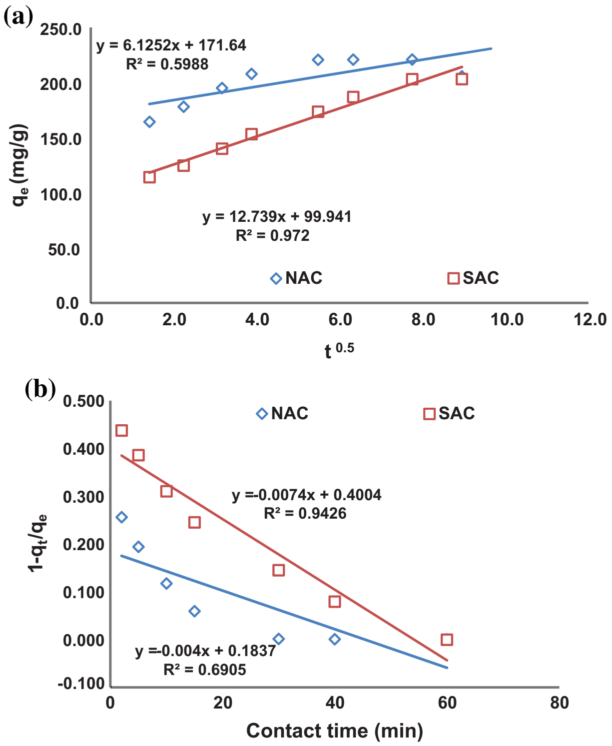

Fig. 10. Intra particle diffusion (a) and film diffusion (b) diagrams of aniline adsorption onto NAC and SAC (volume 100 mL; pH 5; adsorbent dose 0.4 g/L; initial concentration 50 mg L^{-1}; contact time 100 min; temperature 298 K).

3.6. Performance of the adsorbents in the treatment of real waters

In order to evaluate the performance of the NAC and SAC under real conditions, adsorption studies were carried using real water samples. For this purpose,

Table 4
Comparison of adsorption capacities and equilibrium times of different adsorbents used for aniline removal

Adsorbent	Equilibrium time (min)	Equilibrium capacity (mg/g)	Refs.
Fe_3O_4-activated carbon magnetic nanoparticles	300	90.9	[1]
MWCNTs (10–20 nm)	200	–	[32]
MWCNTs (20–40 nm)	200	–	[32]
Oxygen plasma-irradiated bamboo based activated carbon	480	104.2	[33]
Lignin grafted acrylic acid	90	79.1	[34]
Hypercross-linked fiber adsorbent	20	121.6	[35]
Granular activated carbon	–	177.8	[36]
NAC	30	1,666.7	This work
SAC	60	1,000.0	This work

instead of distilled water, three aniline solutions with the concentration of 100 mg/L were prepared using drinking water, well water, and river water. Then, 100-mL portions of these solutions were contacted with 1.0 g of each activated carbon and, after 100 min of contact time, the residual concentrations of aniline in the solutions were determined. The results showed that, in the case of NAC, the removal percentage of aniline from drinking water, well water, and river water respectively were 88.38, 85.98, and 81.11% which were higher than those obtained in the case of SAC (respectively 80.51, 76.19, and 69.23%). These results indicate that the NAC has a better performance than SAC for using in the full-scale treatment plants. Also, it should be mentioned that higher removal percentages can be easily reachable by higher adsorbent dosages.

3.7. Comparison of adsorption capacities with other adsorbents

Adsorption capacity and equilibrium time of aniline adsorption on the NAC and SAC were compared with other solid supports reported in literature [1,32–36], and the results are reported in Table 4. It can be seen from the table that both the adsorption capacity and equilibrium tim of NAC is excellent in comparing with the other adsorbents reported. The NAC is suitable for aniline adsorption from aqueous solutions since it has a relatively high adsorption rate and the cost of the adsorbent is also low. Also, the comparison of adsorption capacity of other adsorbents with NAC shows that it is effective for using in the full-scale treatment plants.

4. Conclusions

In this study, aniline adsorption from aqueous solutions by NH_4Cl-induced activation carbon obtained from pomegranate tree wood (NAC) was evaluated and the obtained results were compared with those obtained from using standard activated carbon (SAC). The structural properties of both NAC and SAC were carefully studied using pH_{zpc}, FTIR, BET, EDX, and SEM techniques. Specially, EDX analysis showed that the percentage of carbon in the structure of NAC is higher than that of SAC. The adsorption of aniline on both activated carbons was investigated for pH, adsorbent dose, initial concentration, and time. The NAC showed a higher affinity to aniline than SAC, and the maximum adsorption of aniline occurred at pH 5.0 for both adsorbents. The removal process of aniline was relatively fast and the equilibrium could be reached within 30 and 60 min for NAC and SAC, respectively. The equilibrium data were analyzed using the Langmuir and Freundlich isotherm models, and the correlation coefficients and Δq_e values indicated that, for both carbons, the Langmuir model fits better than the Freundlich isotherm model. The monolayer saturation capacities (q_{max}) of NAC and SAC (from Langmuir equation) were 1,666.7 and 1,000.0 mg/g, respectively, indicating the higher adsorption capacity of NAC compared to SAC. The kinetic data conformed better to the pseudo-second-order kinetic model and, for both carbons, the resistance to intra-particle diffusion had the greatest impact on the control of adsorption process. Overall, the results could suggest that, for aniline adsorption, the produced activated carbon (NAC) is of higher performance compared to Merck activated carbon (SAC). Thus, the NAC can be used as a convenient, inexpensive, and appropriate adsorbent for treatment of waters or wastewater containing aniline and it is a very useful alternative to native Merck standard carbon.

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