



Dual Functions of Nonwoven Activated Carbon Fiber for Adsorption of Cobalt(II) and Microorganisms from Waste Water

S.M. Abo El-Ola^{1*}, S. Mosleh¹, M.F. Nasr¹, Safaa S.M. Ali², Magda A. El-Bendary³, M. Abdelraof³, M.H. Elshakankery⁴

¹Protein & Manmade Fibres Department, Textile Industries Research Division, National Research Centre (Scopus Affiliation ID: 60014618), El Buhouth St., Dokki, Cairo, Egypt, Postal Code 12622.

²Spectroscopy Department, Physics Division, National Research Centre, Dokki, Cairo, Egypt, Postal Code 12622 (Scopus Affiliation ID: 60014618).

³Microbial Chemistry Department, Genetic Engineering and Biotechnology Research Division, National Research Centre, (Scopus Affiliation ID: 60014618), El Buhouth St., Dokki, Cairo, Egypt, Postal Code 12622

⁴Spinning & Weaving Department, Textile Industries Research Division, National Research Centre (Scopus Affiliation ID: 60014618), El Buhouth St., Dokki, Cairo, Egypt, Postal Code 12622.



ACTIVATED carbon fiber (ACF) is considered a superior absorbent material due to its numerous advantages such as, high surface area, several pore volumes and distinct surface chemistry. ACF has the ability to remove organic and inorganic compounds from waste materials. The present work aims to prepare activated carbon fiber from polyacrylonitrile waste fibers and evaluate its ability to remove Co(II) from waste water as well as microbes. The results revealed that, the maximum adsorption of Co(II) onto ACF was 92.9 % at pH 10 and 30 °C. The sorption capacity of ACF increased with increasing the pH of the solution from 1.27 mg/g to 44.4 mg/g. Increasing the adsorption time from 10-60 minutes increased the sorption capacity from 38.77 mg/g to 44.41 mg/g. The statistical analysis of the data revealed that there is a significant effect for both pH of the solution and adsorption time. The pathogenic microorganisms such as *E. coli*, *P. aeruginos*, *B. subtilis*, *St. aureus*, and *C. albicans* were efficiently removed by ACF. The characterization of surface chemistry of ACF before and after Co(II) adsorption was determined by FTIR and the surface topography was evaluated by SEM.

Keywords: Adsorption, ACF, PAN waste fiber, Co(II), Microorganisms removal, SEM, FTIR.

Introduction

Heavy metal pollution is spreading throughout the world with the expansion of industrial plants and their pollutant concentrations in air, water and soil. Trace metals are widely spread in environment and may enter the food chain [1]. The presence of heavy metals in aqueous solution beyond a certain limit creates serious problems to the environment due to their non-degradability and toxicity [2].

Cobalt is present in mining, electronics,

metallurgical, electroplating and paint industries. Cobalt as a pollutant has many toxic effects such as imparting neurotoxicological disorders, genotoxicity, carcinogenicity, cardiomyopathy and bronchial asthma. Therefore, the removal of cobalt from natural streams and industrial waste waters has received high importance in recent years. There are several methods to treat metal polluted effluents such as precipitation, coagulation, photolysis, electrolysis and adsorption. But the selection of a treatment technology is based on the concentration of wastes

*Corresponding author e-mail: samiham_2000@yahoo.com, Scopus ID: 8715190300, Postal code:12622, Tel.: +02 023371211-828-516 Extension: 2168; Fax: +2023370931

Received 29/7/2019; Accepted 4/8/2019

DOI: 10.21608/ejchem.2019.15395.1935

©2020 National Information and Documentation Center (NIDOC)

and the cost of the treatment process. Among the known physicochemical treatment methods, adsorption seems to be the most promising technique for the removal of metals from chemical process industries [3]. A large number of different adsorbent materials containing a variety of attached chemical functional groups have been reported for this purpose, using activated carbons as the most popular one. The adsorption density of inorganic species onto activated carbon fiber varies significantly with pH as it is the considerable parameter that significantly enhances the heavy metal removal and decreases the metal concentration to an acceptable limit for discharge. The magnitude of adsorption increases abruptly at a specific pH which is the characteristic acid–base behavior of activated carbons. However, in order to minimize processing costs for these effluents, recent investigations have focused on the use of low cost adsorbents [4].

Cobalt is present in nature and its sources are dust, soil and sea water. It is essential for human in trace amounts. It is well known that cobalt used in vitamin B12 manufacture, semiconductor, painting on glass, electroplating, nuclear medicine, and porcelain. It is also useful as a foam stabilizer in beer, grinding wheels and a catalyst for organic reactions. Recently there are increases in the research attention to the problems correlated with cobalt, to the methods of removing cobalt from wastewater. The acceptable limits of cobalt in water (irrigation and domestic animal watering) are 0.05 and 1.0 mg /L respectively, according to the Environmental Bureau of Investigation, Canadian Water Quality Guidelines [5]. Depending on cobalt concentration; it could be useful or harmful to humans. The severe effects of cobalt toxicity to human being are very dangerous such as asthma like allergy, injure to the heart; causing heart tiredness, damage to the thyroid and liver. Cobalt may also cause genetic changes in living cells [6].

Activated carbon material was activated with potassium oxalate for removal of Co(II) and Ni(II) by adsorption processes. The result revealed that the optimum conditions for adsorption was at temperature 70° and at pH 11, as confirmed by FTIR. The maximum value for Co(II) and Ni(II) uptake were 50.76 and 52.63 mg/g, respectively [7].

Granular activated carbon (GACs) have the

ability to remove organic compounds as well as inorganic compounds due to its unique properties such as, high surface area, distinct surface characterization (hydrophobicity, existing of the functional groups, pore size, shape and volume as well as their distribution within the carbon particles). These properties depend on the raw material from which ACs were prepared. On the other hand, most organisms are attached to the surface which is exposed to water. First, the attachment is resulted from physicochemical interactions (electrostatic forces and Van-der Waals). The extent of this attachment is governed by their nature. From thermodynamic point of view, adsorption on the hydrophobic surfaces is more favorable because of lowering the surfaces free energies of both surfaces. Microorganisms interact actively or passively with surface granules of activated carbon (GAC) which in contact with water. These interactions led to attachment and subsequently growth and maintenance of bacteria in GAC filters. The growth extent depends on the availability of material which provides a source of energy and/or carbon. Only the pores of outer surface with radius greater than 500 nm are available for microorganism attachment [8]. Activated carbon fiber (ACF) is considered as superior adsorbents in adsorption processes due to its numerous advantages compared to commercial materials. ACF has an excellent micro-porous with low meso-porosity and superior adsorption capacity, exhibited its importance in the adsorption processes for heavy metals removal, biomedical applications and regeneration as well. But it was reported that bacteria were found on the surfaces of ACF, and this problem become a goal for several researchers to develop antibacterial ACF. Other applications of activated carbon fiber are in the field of electrical conductivity [9].

The present work aims to prepare activated carbon fiber (ACF) from Polyacrylonitrile (PAN) fiber waste and evaluate its ability to remove Co(II) and microorganisms from waste water. The main focus will be on the removal of Co(II) by using different adsorption conditions with a view to study the adsorptive capacity of ACF by varying pH of the solution, adsorption time, temperature and initial metal ion concentration. The statistical analysis was done to determine the significant parameter(s) in the above mentioned process.

Experimental

Preparation of Activated Carbon Fiber

Activated carbon fibers were prepared from polyacrylonitrile (PAN) fiber waste. The fibers were pretreated at temperature range of 200-300°, followed by carbonization step at 700-900° under inert atmosphere. The final step was the activation at 800-1000° under mixture of steam and/or CO₂. The surface area characterization of ACF was performed on ASAP 2420 Accelerated Surface Area [10].

Materials and methods

All the reagents used were of AR grade chemicals. Stock solutions of the test reagents were prepared by dissolving Cobalt sulphate in distilled water. The pH of the investigated solutions was adjusted using reagent grade dilute hydrochloric acid and sodium hydroxide (0.1 mol/L).

Adsorption Procedure.

Adsorption experiments were carried out in batch processes by agitating 0.05 g of oven dried nonwoven Activated Carbon Fiber (ACF) samples with the prepared solutions of metal ion at constant pH in a thermostat bath with a shaker (Julabo AW21). The effects of initial pH, contact time, and initial metal ion concentrations on the adsorption of Co(II) onto ACF were studied. The nonwoven fabric samples were thoroughly mixed with 50 ml of a known amount of the investigated metal salt in a 100 ml Erlenmeyer flask and the ACF were shaken in a water bath (200 rpm) at room temperature (30 ± 1 °C). Adsorption studies were carried out in a range of initial concentration (30-150 ppm) of metal salts. The agitation time (5-180 min.) at the pH of maximum adsorption capacity was evaluated (first experimental run in this study). At the end of each adsorption experiment, the solution was filtered through a filter paper and the concentration of the investigated metal salts in the filtrate was determined with flame atomic absorption spectrometer (Agilent Technologies 200 Series AA; Jeol USA) at wavelength 304.4 nm for Co.

The properties of adsorption process were characterized by calculating the removal efficiency (R %), adsorption capacity (SC, mg/g) and distribution coefficient (D, l/g) using the following equations:

$$R = [(C_0 - C_i) / C_0] \times 100 \quad (\text{Eq. 1})$$

$$SC = [(C_0 - C_i) \times V] / W \quad (\text{Eq. 2})$$

$$D = [R / (100 - R)] \times V / W \quad (\text{Eq. 3})$$

Where: C₀ is the initial concentration of the investigated metal ion in the solution, mg/L, C_i is the concentration of metal ion solution after the adsorption onto ACF, mg/L, V is the volume of solution, (L); W is the weight of the sorbent material (ACF) per gram.

Statistical Analysis.

The results were statistically analyzed using one-way analysis of variance (ANOVA) test by using the ST. MINITAB 14 software, to determine the influence of the factors (pH, adsorption (temperature, time) and initial metal ion concentration) on the adsorption process. A factor was considered as a significant effect on adsorption of Co(II) when the calculated value of *P*<0.05, and as no significant effect when calculated *P*>0.05.

FTIR.

The chemical structure was determined using the Fourier Transformation Infrared (FTIR) Spectrometer (model NEXUS 670, NICOLET USA). The measurements were carried in the spectral range 4000 cm⁻¹ to 500 cm⁻¹. Reflection percentage measurement technique was applied (R %) to all investigated samples.

Scanning Electron Microscope (SEM)

Fiber morphology was characterized by scanning electron microscope (SEM) (JEOL-Model TSM T20).

Antimicrobial test

Microorganisms and growth conditions

The antimicrobial potential of ACF loaded with cobalt salt was tested using two Gram-positive bacteria (*Bacillus subtilis* ATCC 6633, and *Staphylococcus aureus* NRRL B-767), two Gram-negative bacteria (*Escherichia coli* ATCC 25955, and *Pseudomonas aeruginosa* ATCC 10145) and yeast, *Candida albicans* ATCC 10231. Bacterial and yeast strains were cultured overnight at 28-30°C in nutrient and potato dextrose broth, respectively, these cultures were used as inoculums in antimicrobial test.

Antimicrobial Assay

The antimicrobial activity was determined according to AATCC100 method [11] with some modifications. 100 mg of activated carbon fiber samples (before and after cobalt adsorption) were placed in test glass tubes and sterilized by an autoclave for 20 min at 120°C and 15psi. Overnight grown tested cultures were used for inoculation of the fiber samples then incubated at 30°C for 24h. Tenfold serial dilutions of each sample were prepared and were spread onto nutrient agar

plates for bacteria or potato dextrose agar plates for yeast (three replicates per dilution), then incubated at 28-30°C for 24 h. Microbial colonies that were grown on these plates, counted and compared to the control sample (culture without activated carbon fiber). The reduction percentage was calculated from the following equation.

$$\text{Reduction percentage (\%)} = ((\text{CFUU}-\text{CFUT})/\text{CFUU}) \times 100$$

Where CFUU is the number of colony forming units of untreated microorganism and CFUT is the number of colony forming units of microorganism after treatment with ACF samples.

Results and Discussion

Adsorption of Co(II).

Effect of solution pH.

The mechanism of metal ions adsorption onto ACF is governed by the pH of the adsorption medium. The pH of the adsorption process has a considerable effect on the adsorption of Co(II) at temperature 30°C. Increasing the pH of the medium increased the efficiency of ACF for Cobalt removal as shown in Fig.1. The maximum adsorption of ACF for Co(II) was 92.9 % which takes place at pH 10 and the total Co (II) removal decreased to 2.4 % at pH 2. This may be attributed to the deprotonating of oxygen containing reactive groups on the surface of ACF which led to increase in the attraction between metal ions species and the negatively functional groups on the ACF surfaces (pH=10). Therefore, the increase in the adsorption of cobalt metal ion

on the surface of ACF is due to the increase in the electrostatic interaction between the positive ions and the negative hydroxyl groups on the surface of ACF. On the other hand, at lower pH of the adsorption medium (acidic medium), the repulsion between the protonated ACF surfaces and cobalt metal ion led to decrease in the metal ions adsorption onto ACF[12-16].

It was noticed from Fig. 1 that the adsorption capacity (SC) of ACF increased with increasing pH of the adsorption solution from 1.27 mg/g to 44.4 mg/g. ACF is considered as amphoteric material, which mean carrying negative and positive charges depend on the pH of the solution. Attraction between ACF and anionic groups is principally related to the surface characteristics. Consequently, the pH is taken into consideration as an important factor to design the adsorption behavior of ACF according to what kind of pollutant(s) prerequisites to is removed. Therefore, negative charged groups are created and accumulated on the ACF surface at alkaline pH. As a result, it favors the uptake of positive ions due the increase the electrostatic attraction between cations and ACF surface and vice versa. In other word, at higher concentration of hydrogen proton there is a completion between the H⁺ and M⁺, which mainly explain the low adsorption of metal ions at higher hydrogen ions concentration. On the other hand, the positive charge on ACF leads to repulsion with the positive metal ions [17-18].The same observation was noticed with the distribution of Co(II) between the adsorbent solution and ACF (Fig. 2).

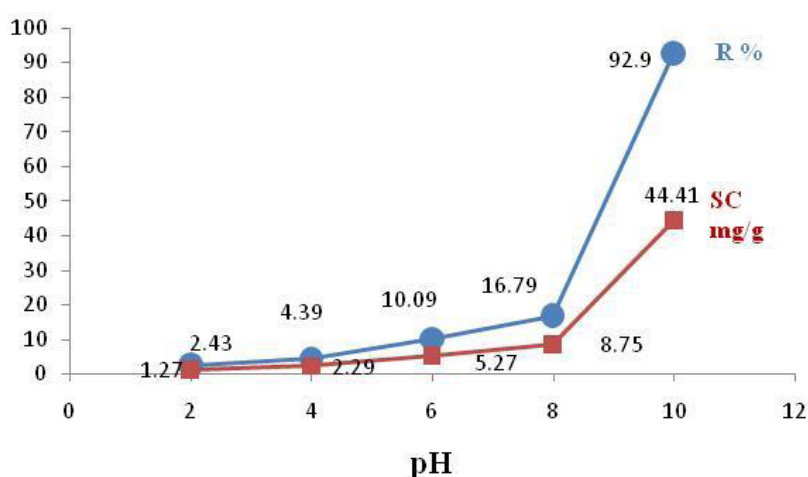


Fig. 1. Effect of the adsorption medium pH on the removal efficiency R % and Adsorption capacity SC mg/gm of Co(II) onto ACF

Adsorption Conditions: Initial concentration 50 ppm, Adsorption temperature 30 °C, Adsorption time 60 min., M: L, 1:50

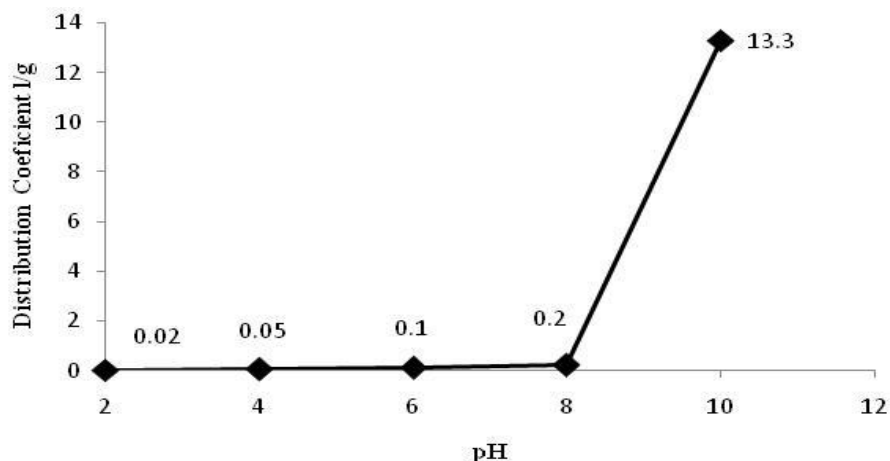


Fig. 2 . Effect of adsorption medium pH on the distribution Coefficient of Co(II) onto ACF

Adsorption Conditions: Initial concentration 50 ppm, Adsorption temperature 30 °C, Adsorption time 60 min., M: L 1:50.

Statistical calculations were made to investigate the effect of pH values on the three responses (removal efficiency %, adsorption capacity and distribution coefficient). It is clear that the responses increased with the increasing of the pH of the solution bath, and rapidly increases at pH of 10. Table 1 shows the regression model, R-Square values and the mathematical models fit (F-test) at pH values from 2 to 8. It was seen that, the P-values of pH parameter from 2 to 8 were less than 0.05. Interestingly, at these levels, there is significant effect of pH parameter on each response.

Effect of adsorption temperature.

Increasing the adsorption temperature had a noticeable impact on the adsorption of cobalt onto the surface of ACF. Fig. 3 represents the effect of temperatures on the removal efficiency of ACF for cobalt ions and the adsorption capacity as well as the distribution coefficient. The data revealed that increasing the temperature from 30°C to 70°C (optimum pH), increased the removal efficiency of Co (II) (from 92.9 to 96.6 %). Also, the adsorption capacity increased from 44.4 mg/g to 46 mg/g. This data can be explained by the fact that increasing the adsorption temperature will increase the kinetic energy of the Co(II) ions and facilitate the penetration onto the porous structure of ACF.

Statistical analyses were made to investigate the effect of adsorption temperature factor on the responses mention above. Table 2 shows the regression model, R-Square values and the mathematical models fit (F-test) at adsorption temperature values. It was seen that from the P-values of adsorption temperature parameter

were greater than 0.05. The results show that no significant influence where noticed for the adsorption temperature.

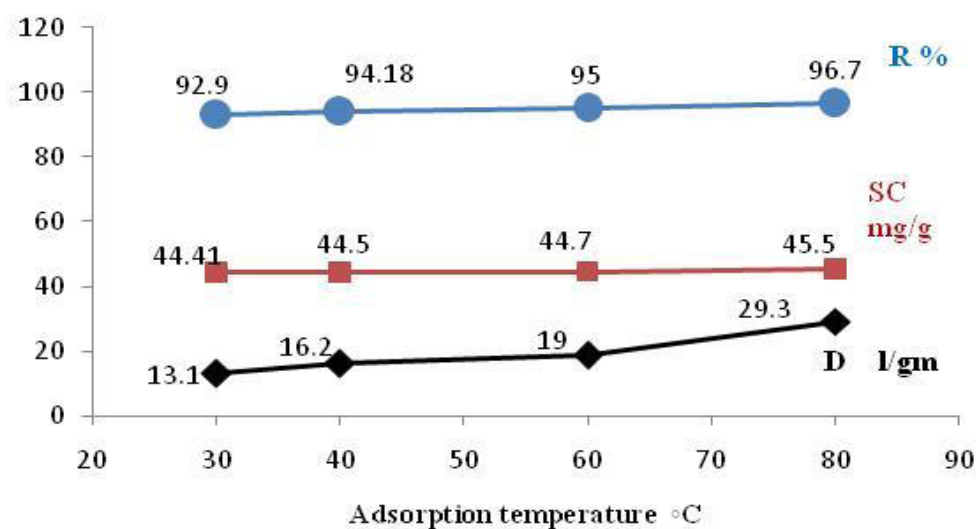
Effect of adsorption time.

Fig. 4 represented the effect of adsorption time on the removal efficiency % of ACF for Co(II) and the adsorption capacity as well as the distribution coefficient. The results revealed the effect of increasing the adsorption time from 10 to 120 minutes, which increase both the removal efficiency % from 81.7% to 93.5% and the adsorption capacity from 38.77 mg/g up to 44.41 mg/g. As the adsorption time increases, the chance for Co(II) ions to penetrate into the porous structure of ACF increases, therefore, the adsorption process increases. Removal efficiency % of Co(II) adsorbed onto nonwoven ACF at adsorption time 60 min. was 92.9 %, further increase in the adsorption time has almost no effect observed on the removal efficiency % of Co(II), which reveal to the establishment of the equilibrium state between the adsorbed and non-adsorbed Co(II) ions onto the structure of ACF[7].

Statistical analyses were made to study the effect of adsorption time on the removal efficiency %, adsorption capacity and distribution coefficient of Co(II) onto ACF. The results show that a significant influence was noticed at different adsorption time intervals. Table 3 shows the regression model, R-Square values and the mathematical models fit (F-test) at different adsorption time values. The P- values of the contact time factor were shown to be less than 0.05. This means that there is a significant effect of contact time on the adsorption process.

TABLE 1. Statistical analysis for effect of pH on removal efficiency%, sorption capacity and distribution coefficient of Co (II) onto ACF

Response	regression model	R-Square	F-test	P-values
Removal efficiency %	$y = 2.439x - 3.77$	0.952	39.709	*0.0243
Sorption capacity mg/gm	$y = 1.244x - 1.87$	0.955	43.165	*0.0224
Distribution coefficient l/gm	$y = 0.03x - 0.055$	0.952	40.000	*0.0241

*Significance level : $P < 0.05$ **Fig. 3. Effect of adsorption temperature on the removal efficiency R %, Adsorption capacity SC mg/gm, and the distribution coefficient of Co(II) onto ACF**

Adsorption Conditions: pH 10, Initial concentration 50 ppm, Adsorption time 60 min., M: L 1:50.

TABLE 2. Statistical analysis for effect of adsorption temperature on the removal efficiency %, sorption capacity and distribution coefficient of Co (II) onto ACF.

Response	regression model	R-Square	F-test	P-values
Removal efficiency %	$y = 0.0563x + 92.446$	0.5547	2.491276	0.255223
Sorption capacity mg/gm	$y = 0.2287x + 10.471$	0.6353	1.866712	0.305187
Distribution coefficient l/gm	$y = 0.3087x + 42.664$	0.4828	3.483586	0.202958

*Significance level : $P < 0.05$

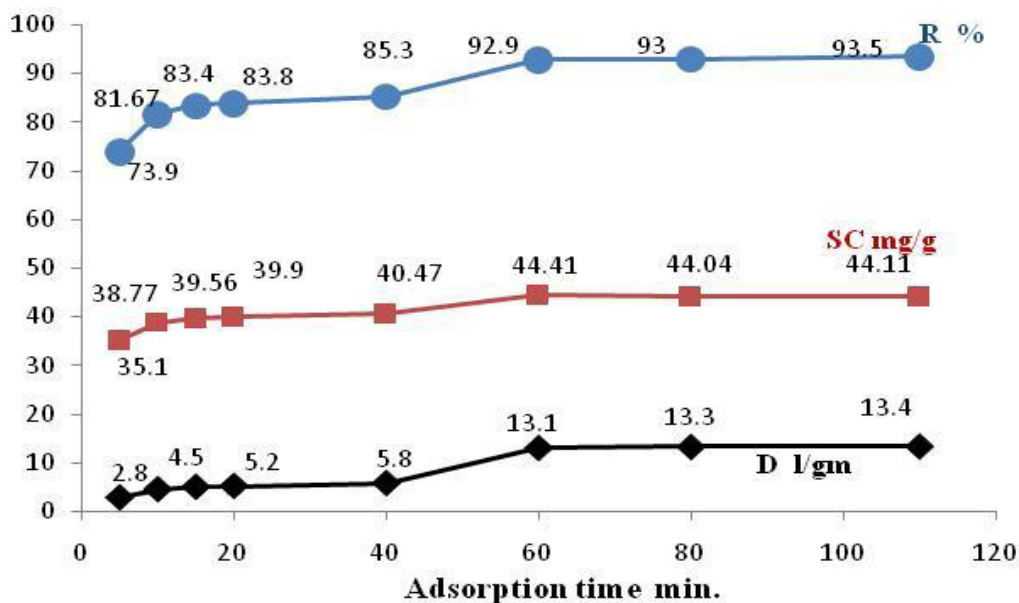


Fig. 4. Effect of adsorption time on the removal efficiency R%, Adsorption capacity SC mg/gm, and the distribution coefficient D l/gm of Co(II) onto ACF

Adsorption Conditions: Initial concentration 50 ppm, pH 10, Adsorption Temperature 30 °C, M: L 1:50

TABLE 3. Statistical analysis for effect of adsorption time factor on the removal efficiency%, sorption capacity and distribution coefficient of Co (II) onto ACF

Response	regression model	R-Square	F-test	P-values
Removal efficiency %	$y = 0.1607x + 79.105$	0.7821	21.5377	*0.003537
Sorption capacity mg/gm	$y = 0.0743x + 37.637$	0.7505	18.0525	*0.005387
Distribution coefficient l/gm	$y = 0.1112x + 3.1604$	0.8583	36.352	*0.00094

*Significance level : $P < 0.05$

Effect of initial concentrations.

Effect of initial metal ion concentrations on the adsorption process of Co(II) onto the ACF surface at 30 °C was shown in Fig.5. An increase in the concentrations from 30-70 ppm leads to increase on the removal efficiency % from 91 to 96%, adsorption capacity from 29.4 to 63.59 mg/g and the distribution coefficient from 10.4 to 24 l/mg. Initially, there is a rapid increase where a significant surface area and pores on the structure of ACF accessible for Co(II) to be adsorbed at low concentration. As the concentration increases, the competition between cobalt ions to be adsorbed on ACF increases and the adsorption efficiency decreases. Also, the availability of remaining

available surface sites decreases. Therefore, the removal efficiency % and sorption capacity became almost constant at high metal ions concentration. Further increase in the Co(II) concentration had no effect on the adsorption process due to the occupation of most adsorption sites on ACF[19].

Statistical calculations were made to investigate the effect of initial concentration values on the removal efficiency %, adsorption capacity and distribution coefficient of Co (II) onto ACF. Table 4 shows the regression model, R-Square values and the mathematical models fit (F-test) at initial concentration values. It was seen that from

the *P*-values of initial concentration parameter were greater than 0.05, indicating that there is no significant influence for the Co(II) concentration on the adsorption process onto ACF.

Biological Activity of ACF.

The result presented in Table 5 showed that the nonwoven ACF prepared from waste acrylic fabric have excellent antimicrobial activity against Gram-negative bacteria (*E. coli* and *P. aeruginosa*), Gram-positive bacteria (*B. subtilis* and *St. aureus*) and yeast (*C. albicans*). Also, there is no effect on

the antimicrobial activity of ACF after adsorption of cobalt ions. It may be due to the characteristics of ACF which have a high surface / volume ratio, greatly affecting the contact with microbial cells; an increased penetration of the microbial cells and the adherence to the ACF pores and voids contributed to micro- being separated from their environment. Adsorption of cobalt metal ions on the activated carbon perhaps makes the cobalt ions in contact with the microorganisms and leading to cell death.

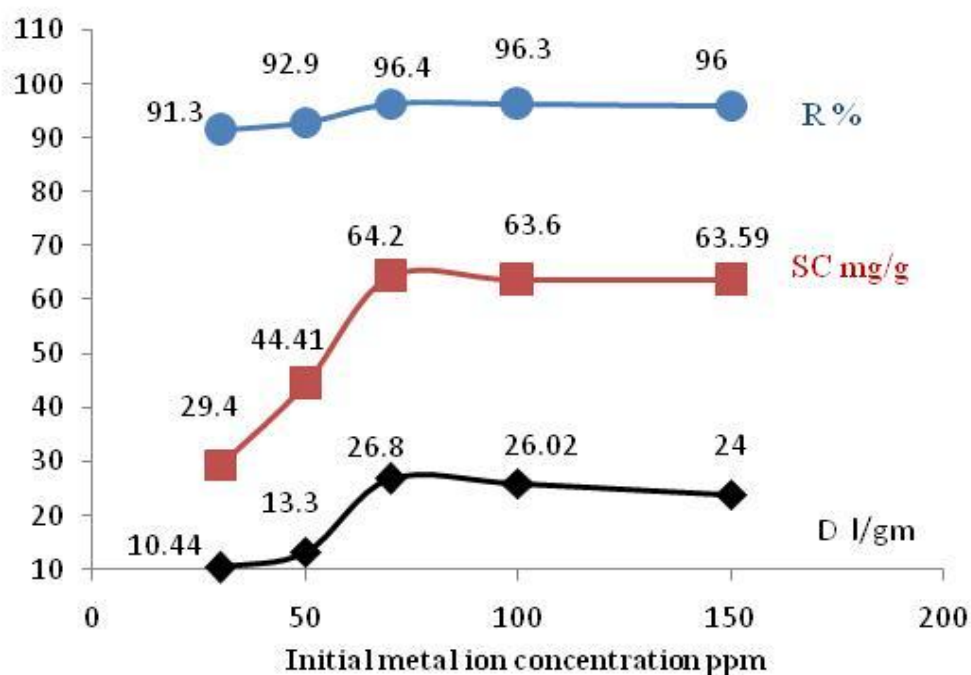


Fig. 5. Effect of initial metal ion concentration on the removal efficiency R%, Sorption capacity SC mg/gm, and the distribution coefficient of Co(II) onto ACF
Adsorption Conditions: pH 10, Adsorption Temperature 30 °C, Adsorption time 60 min., M: L 1:50

TABLE 4. Statistical analysis for effect of initial concentration on removal efficiency%, sorption capacity and distribution coefficient of Co (II) onto ACF

Response	regression model	R-Square	F-test	<i>P</i> -values
Removal efficiency %	$y = 0.0375x + 91.58$	0.5659	3.910776	0.142394
Sorption capacity mg/gm	$y = 0.259x + 32.322$	0.6018	4.534502	0.123077
Distribution coefficient l/gm	$y = 0.115x + 10.92$	0.4953	2.943849	0.184711

*Significance level : $P < 0.05$

TABLE 5. The efficiency of ACF samples for microorganisms removal.

Sample code	Colony forming units (CFU) and Reduction (%)									
	<i>E. coli</i>		<i>B. subtilis</i>		<i>St. aureus</i>		<i>P. aeruginosa</i>		<i>C. albicans</i>	
	CFU	Reduction (%)	CFU	Reduction (%)	CFU	Reduction (%)	CFU	Reduction (%)	CFU	Reduction (%)
#1	22x10 ³	99.82	16x10 ³	99.77	49x10 ³	99.39	3x10 ³	99.91	29x10 ³	99.42
#2	39x10 ³	99.67	44x10 ³	99.37	48x10 ³	99.4	37x10 ³	99.79	19x10 ³	99.62
#3	19x10 ³	99.84	61x10 ³	99.13	51x10 ³	99.36	16x10 ³	99.9	64x10 ³	98.72
#4	12x10 ⁶	0.00	7x10 ⁶	0.00	8x10 ⁶	0.00	18x10 ⁶	0.00	5x10 ⁶	0.00

#1 Blank sample;

#2: 30°C, pH=10, adsorption time 10min, R=92.92%;

#3 :30°C pH 2 ,adsorption time 60min R=2.43% ;

#4: Medium without activated carbon

Several mechanisms were proposed for the antimicrobial activity of metal ions. It was reported that the toxic effects of metals on microorganisms can be due to protein lyses function, antioxidant depletion, DNA damage, impaired membrane function and/or interference with nutrient assimilation. It was reported that cobalt ions can increase intracellular reactive oxygen species, leads to DNA damage, membrane activity disturbance, and inhibition of enzyme activities that are vital for cell growth. Also, it can bind to the proteins, enzymes and other electronegative chemical groups of the cell wall and cell membrane of the microorganism causing structural changes that disrupt the permeability leading to lyses of the cells. As well as cobalt ions can access inside the bacterial cell, complexing with apoenzyme or displacing any metal ion that is essential for the enzymatic action preventing protein synthesis and/or inhibiting nucleic acid synthesis [20, 21].

FTIR.

The characterization of surface chemistry of ACF surface before and after adsorption was determined by FTIR. Fig. 6 represents the spectra of ACF surface before and after adsorption process. It was observed that new absorption peaks appeared at 1742 cm⁻¹ corresponding to C=O stretching band. The peak appeared at 1046 cm⁻¹ in the blank of ACF shifted to 1030 cm⁻¹ after adsorption (ACF surface was deprotonated), which may be assigning to C-O stretching of ester group. These shifts in the peak could be attributed to the change in pH of the adsorption medium, which affects the active groups of the ACF surface [22].

Scanning electron microscopy.

The surface topography of ACF fabrics before and after adsorption process was investigated using SEM technique. The obtained results represented in Fig. 7 reveal that, ACF surface are characterized by smooth surfaces and the surface differ after Co (II) adsorption as some precipitation on the surfaces topography which appeared due to the adsorption and accumulation Co (II) ions into ACF.

Conclusion

Activated carbon fiber is considered a superior absorbent and has the ability to remove different organic as well as inorganic waste compounds due to its unique properties such as, high surface area, and pores size variation. The maximum adsorption of ACF prepared from PAN fiber waste for Co(II) was 92.9 % , which takes place at pH 10 and 30°C., 50 ppm, for 60 minutes. The adsorption capacity (SC) of ACF for Co(II) increased with increasing the pH of the solution from 1.27 mg/g to 44.4 mg/g. From statistical analysis, it was found that there is a significant effect for the pH of adsorption solution on the adsorption process. Also, the adsorption temperature shows an impact on the adsorption process by increasing the removal efficiency percentage from 92 % at 30 °C up to 97 % at 80 °C. Increasing the adsorption time from 10 minutes up to 60 minutes increases both the removal efficiency percentage from 81.7% to 93.5% and the adsorption capacity from 38.77 mg/g to 44.41 mg/g. An increase in the concentrations from 30-70 ppm leads to increase in the percentage removal efficiency from 91 to 96%.The statistical

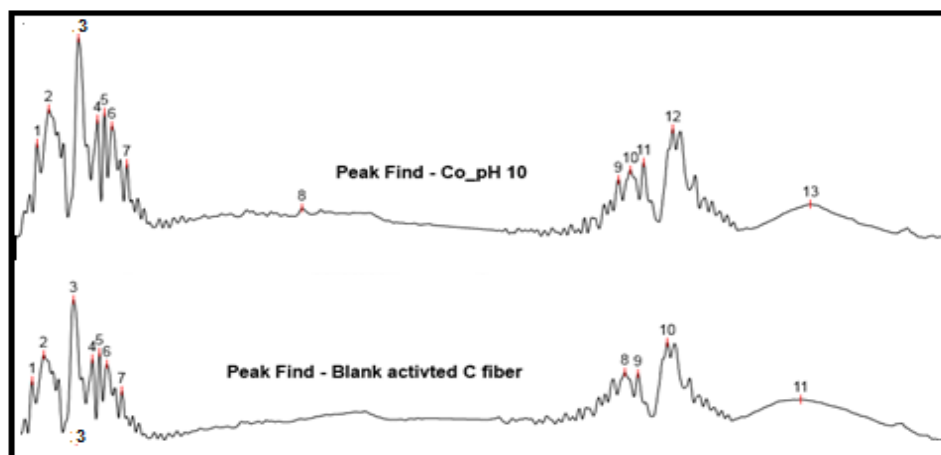
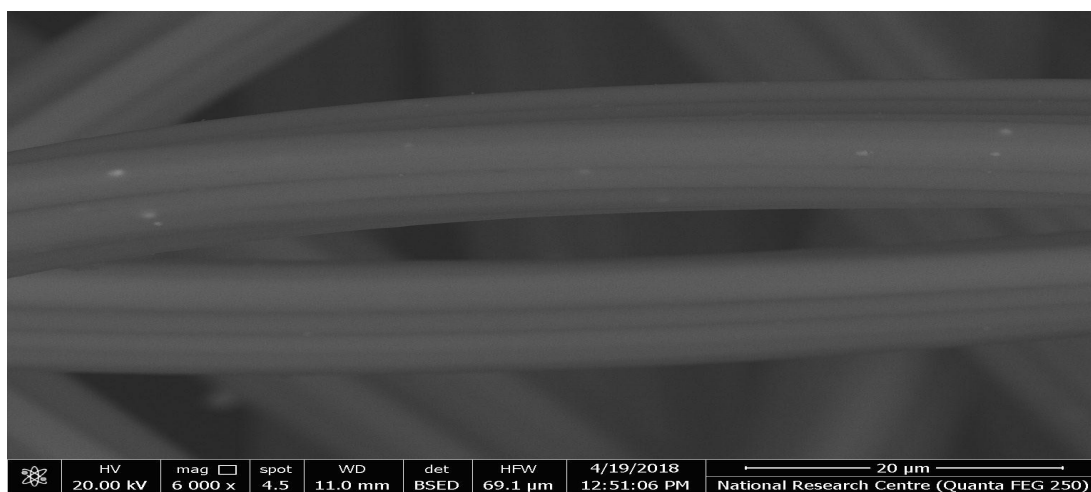
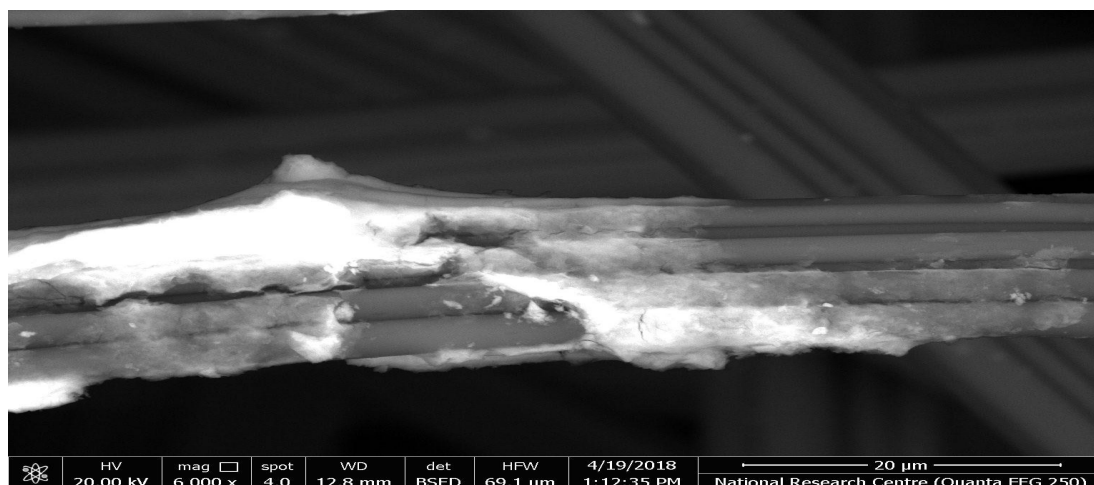


Fig. 6. FTIR spectrums for ACF before and after adsorption of Co(II) onto ACF.



Blank



ACF after Co(II) adsorption

Fig. 7. SEM of ACF before adsorption (blank sample) and after Co(II) adsorption .

analysis showed that there is a significant effect of the adsorption time on the adsorption process. Whereas, the initial concentration, the adsorption temperature have no significant influence on the adsorption process. It was also detected that the samples of blank ACF and Co(II) adsorbed-ACF have a significant activity against the *E. coli*, *P. aeruginosa* (gram negative) and *B. subtilis*, *St. aureus* and *P. aeruginosa* (gram positive) and *C. albicans*. This is considered as an important finding because the used ACF in the removal of Co ions from the waste water could be used to remove the microorganisms effectively. The characterization of surface chemistry of ACF surface before and after adsorption was determined by FTIR and SEM. It was found that ACF surface is characterized by clear surfaces before the metal ion adsorption. This clear surface changed after Co(II) adsorption through aggregation, precipitation and pores filling by Co(II) ions on the surfaces topography.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

1. Monser, L., Adhoum, N. Modified activated carbon for the removal of copper, zinc chromium and cyanide from wastewater. *Separation and Purification Technology*, **26**, 137-146 (2002).
2. Barakat, M. A. New trends in removing heavy metals from industrial wastewater. *Arabian Journal of Chemistry*, **4**, 361-377 (2011).
3. Babel, S., Kurniaw, T. A. Cr (VI) removal from synthetic wastewater using coconut shell charcoal and commercial activated carbon modified with oxidizing agents and/or chitosan. *Chemosphere*, **54**, 951-967 (2004).
4. Deng, Z. L., Liang, M. N., Li, H.H., Zhu, Z.J. Advances in preparation of modified activated carbon and its applications in the removal of chromium (VI) from aqueous solutions. International Conference on Water Resource and Environment (2016). *Publishing IOP Conf. Series: Earth and Environmental Science*, 39. doi:10.1088/1755-1315/39/1/012065.
5. Rengaraj, S., Moon, S. Kinetics of adsorption of Co(II) removal from water and wastewater by ion exchange resin. *Water Research*, **36**, 1783-1793 (2002).
6. Gunjate, J. k., Gholve, S. B., Khope, R.U. Adsorption studies of cobalt ions on surface modified granular activated carbon. *Journal of Environmental Research and Development*, **9**(2), 293-297 (2014).
7. Henry, K. H., Kekana, P. T., Saghti, A. A., Bolton, K. Adsorption characteristics of cobalt and nickel on oxalate-treated activated carbons in sulphate media. *World Academy of Science, Engineering and Technology*, **76**, 707-712 (2013).
8. Knezev, A. Microbial activity in granular activated carbon filters in drinking water treatment. *PhD Thesis*, Wageningen University, Wageningen, NL, pp. 11-16 (2015).
9. Saad, M. A., Nasr, M. F., Yassen, H. A., Turkey, G. M. Electrical and dielectric properties of stitched non-woven engineered fabrics containing activated carbon fiber. *Egypt. J. Chem.* **61**(3), 559-568 (2018).
10. Junior, M. A., Matsushima, J. T., Rezende, M. C., Gonçalves, E. S., Marcuzzo, J. S., Baldan, M. R. Production and characterization of activated carbon fiber from textile PAN fiber. *J. Aerosp. Technol. Manag.* **9**, 423-430 (2017).
11. AATCC Test Method 100-2012 Antibacterial Finishes on Textile Materials: Assessment of technical manual of the American Association of Textile Chemists and Colorists (2012).
12. Leyva-Ramos, R., Berber-Mendoza, M. S., Salazar-Rabago, J., Guerrero-Coronado, R. M., Mendoza-Barron, J. Adsorption of lead (II) from aqueous solution onto several types of activated carbon fibers, *Adsorption*, **17**, 515-526 (2011).
13. Cronje, K. J., Chetty, K., Carsky, M., Sahu, J. N., Meikap, B. C. Optimization of chromium(VI) sorption potential using developed activated carbon from sugarcane bagasse with chemical activation by zinc chloride. *Desalination*, **275**, 276-284 (2011).
14. Mohan, D., Singh, K. P. Single- and multi-component adsorption of cadmium and zinc using activated carbon derived from bagasse an agricultural waste. *Water Research*, **36**, 2304-2318 (2002).
15. Karaa, M., Yuzera, H., Sabah, E., Celik, M. S. Adsorption of cobalt from aqueous solutions onto sepiolite. *Water Research*, **37**, 224-232 (2003).
16. Bansal, R. C., Goyal, M. "Activated Carbon Adsorption" by Taylor & Francis Group, LLC, CRC Press Taylor & Francis Group 340, Boca Raton, Florida, USA (2005).

17. Kadirvelu, K., Senthilkumar, P., Thamaiselvi, K., Subburam, V. Activated carbon prepared from biomass as adsorbent: elimination of Ni (II) from aqueous solution. *Bioresource Technology*, **81**, 87-90 (2002).
18. Krishnan, K. A., Anirudhan, T. S. Kinetic and equilibrium modeling of cobalt (II) adsorption onto bagasse pith sulphurised activated carbon. *Chemical Engineering Journal*, **137**, 257-264 (2008).
19. Prabakaran, R., Arivoli, S. Removal of Cobalt(II) from Aqueous Solutions by Adsorption on Low cost activated carbon. *International Journal of Science, Engineering and Technology Research*, **2**(2), 271-283 (2013).
20. Vaidya, M. Y., McBain, A. J., Butler, J. A., Banks, C. E., Whitehead, K. A. Antimicrobial efficacy and synergy of metal ions against *Enterococcus faecium*, *Klebsiella pneumonia* and *Acinetobacter baumannii* in Planktonic and Biofilm Phenotypes. *Scientific Reports*, **7**:591 (2017) DOI:10.1038/s41598-017-05976-9.
21. Lemire, J. A., Harrison, J. J., Turner, R. J. Antimicrobial activity of metals: Mechanisms, molecular targets and applications. *Nature Reviews Microbiology*, **11**, 371-384 (2013).
22. Meye, R. A. "Interpretation of Infrared Spectra, A Practical Approach in Encyclopedia of Analytical Chemistry", John Wiley & Sons Ltd, Chichester, (2000).

وظائف مزدوجة من ألياف الكربون النشط غير المنسوجة لامتناس الكوبالت (II) والكائنات الدقيقة من مياه الصرف

تعتبر ألياف الكربون النشط (ACF) مادة فائقة الامتناس نظراً لمزاياها المتعددة مثل ، مساحة السطح العالية، أحجام المسام المتعددة و سطح ذوكيمياء متميزة. ألياف الكربون النشط لديها القدرة على إزالة المركبات العضوية و الغير العضوية. يهدف هذا العمل لتحضير ألياف الكربون النشط من نفايات ألياف بولي أكريلونيتريل وتقييم قدرتها على إزالة (Co (II) من مياه الصرف الصحي ، ثم إزالة الكائنات الدقيقة. كشفت النتائج أن الحد الأقصى لامتناس (Co (II) على ACF كان 92,9 ٪ في أس هيدروجيني 10 ، عند 30 درجة مئوية. زادت قدرة الامتناس لـ ACF بزيادة الأس الهيدروجيني من 2 إلى 10. و بزيادة زمن عملية الامتناس من 10 دقائق إلى 60 دقيقة تزداد قدرة الاليف على الامتناس من 38,77 ملغ / جم إلى 44,41 ملغ / جم. وكشف التحليل الإحصائي للبيانات أنه ، هناك تأثير كبير لكل من الأس الهيدروجيني وزمن الامتناس. لقد اثبتت الدراسة قدرة اليف الكربون النشط (الغير منسوج) ACF على إزالة الكائنات الدقيقة مثل *P. coli* و *E. coli* و *aeruginosa* و *B. subtilis* و *St. aureus* و *C. albicans* بفعالية. وبعد أن تم اثبات الامتناس بواسطة FTIR وتم تقييم الامتناس السطحي بواسطة SEM.