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Comparison of different activated carbon fibers for natural organic matter removal from lake water

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ABSTRACT

The removal characteristics of natural organic matter (NOM) from lake water using carbon fiber (CF), activated carbon fiber (ACF), ACF impregnation with copper (ACF-Cu) and ACF impregnation with silver (ACF-Ag) were investigated by using kinetic and isotherm models. The characteristics of raw and treated water were studied by fluorescence excitation emission matrix and liquid chromatography–organic carbon detection. Various fractions of NOM including dissolved organic carbon (DOC), hydrophobic organic carbon (HOC), chromatographic dissolved organic carbon (CDOC), biopolymers, humic substances (HS), building blocks (BB) and low molecular weight (LMW) neutrals were explored. Results showed that ACF is the best adsorbent followed by ACF-Ag for the removal of NOM at optimum dosage of 2.5 g/L for 12 h while ACF-Cu was found comparatively better than CF. Fractional studies indicated 41% of DOC was removed by using both ACF and ACF-Ag while 27% in case of ACF-Cu and only 9% by CF adsorbent. HOC elimination was highest by ACF up to 59% followed by 51% by ACF-Ag while ACF-Cu showed 34% elimination. CDOC removal was 39%, 42%, 25%, and 11% for ACF, ACF-Ag, ACF-Cu and CF adsorbents, respectively. ACF-Ag, ACF and ACF-Cu presented removal of HS as 33%, 35%, and 25%, respectively, on the other hand CF showed 11% retention of HS. Adsorption of biopolymers was 28%, 26%, and 21% by ACF-Ag, ACF and CF, respectively, while 15% by ACF-Cu. Moreover, ACF-Ag was found as the best adsorbent for BB removal as 63% followed by ACF with 60% while 44% retention was achieved by ACF-Cu and a similar trend of LMW neutrals removal was noted.

Keywords: Activated carbon fibers; Adsorption; impregnation; Natural organic matter

1. Introduction

Recently, worldwide reports are showing continuous increase of natural organic matter (NOM) in surface water which causes adverse effect especially in drinking water purification. Generally, NOM is considered a complex heterogeneous mixture of different organic compounds [1–3] which are derived from disintegration of plants, aquatic plants and byproducts of algae and bacteria [4]. It comprises an ample variety of compounds with a wide range of molecular weights [5,6] such as humic substances, polysaccharides, amino sugars, proteins, peptides, lipids, and it also contains both hydrophobic and hydrophilic components [4]. Humic substances consist of hydrophobic acids rich in aromatic carbon which are more than half of the NOM [6–8]. The hydrophilic substance comprises less refractory components including proteins, carbohydrates, amino acids and sugars [9]. The quantity and properties of NOM in water surface significantly depend upon the geology, climate and topography [10]; moreover, external sources such as leaching, snow melting and other human activities such as effluent from wastewater treatment plants [11,12].

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The presence of NOM results in a number of problems in water treatment systems such as yellow/brown color to water, taste and odor issue, a major cause of membrane fouling, promotes biological growth in water distribution system [13], increases sludge volume, formation of disinfection byproducts [14] and also compete with other pollutants during adsorption process [2,15,16]. Because of the aforementioned problems, drinking water industry is facing a challenging issue due to the continuous increase of NOM and changes in its compositions. In literature various approaches for the removal of NOM were employed including membrane techniques and hybrid processes in combination with membrane are coagulation, oxidation, adsorption and membrane bioreactors [17]. As studied, adsorption is one of the most commonly used techniques for organic matter removal from water using granular activated carbon as adsorbent to remove synthetic organic pollutants [18]. The activated carbon adsorbent is capable of removing health concerned pollutants from drinking water supplies and used in water and wastewater treatment applications due to its heterogeneous and microporous structure [1].

Mainly adsorbents are classified into three groups such as natural organic, inorganic and man-made sorbents. The natural organic materials can absorb water 3–5 times their weight but they adsorb water and sink down, their structure is loosely packed and difficult to collect after spreading in water. Natural inorganic sorbents that can adsorb 4–20 times their weight are economical and easily available but cannot be used on water surface. Synthetic adsorbents are man-made materials capable to adsorb 70 times their weight and adsorb onto the surfaces [19]. In recent decades, newly formulated activated carbon known as activated carbon fibers (ACFs) has been developed. They have attracted attention of researchers as adsorbent for water purification which are prepared from synthetic or naturally available precursors [1,20,21]. The adsorption of ACFs depends upon different factors, such as basic raw materials, activation process, nature of pore structure and surface functionalities [20].

In adsorption process, ACFs are the most important carbon-based nano-porous materials because of their well-defined porous structure and fibrous shape. They have numerous advantages including, outstanding volumetric capacity, packing density, easy to handle and higher adsorption rate. Nevertheless, ACF processing cost is higher because it includes both fiber processing cost and activation cost although various studies suggested ACF production from lower cost precursors but facing difficulties to prepare required shape of the fiber and their processing afterwards [22,23]. The literature review studies on adsorption capability of ACFs proved that they are very efficient at removing pollutants from liquid or air [24], with improved adsorption rates and have higher capacities than granular activated carbon (GAC). The previous studies proved that ACFs provided higher adsorption rate 2–50 times than GAC [18] because of their less diameter which provides maximum surface area for contact that enhances adsorption rate. It was observed that applications of ACFs for the removal of micro-organics including phenols and pesticides performed better [25].

NOM causes number of problems in drinking water production systems, including, taste, odor and color that demands more chemical consumption to treat, forms disinfection byproducts, fouls membrane systems and promotes biological growth in water distribution systems as thoroughly mentioned in a review article [1]. So, it is important to remove the NOM from water streams to minimize the aforementioned problems. Adsorption is the most commonly used technique for the removal of NOM; therefore, we investigated four types of ACFs named as carbon fiber (CF), ACF, ACF impregnation with silver (ACF-Ag) and impregnation with copper (ACF-Cu) because of their good adsorption characteristics. As NOM has prominent impact on water treatment systems to determine the cost of system and their purification efficiency, NOM removal from water is a challenging issue and an efficient treatment technology is required to combat this problem.

As per author's knowledge, no study was found regarding NOM removal efficiency of targeted adsorbents; hence, this study was conducted to find the best ACF in terms of time and dosing rate by using kinetic and isotherm models. Additionally, characteristics of raw and treated water were studied by fluorescence excitation emission matrix (FEEM) analysis and liquid chromatography–organic matter detection (LC–OCD) to investigate the NOM removal efficiency of each adsorbent. This detailed study can be also treated as a model for providing theoretical guidance to select an appropriate adsorbent for the removal of NOM from lake water.

2. Materials and methods

In this study, following methodology was implemented to determine the adsorption efficiency of targeted ACFs. The performance efficacies of adsorbents were investigated through kinetic and isotherm models, and water characteristics were studied using FEEM and LC–OCD techniques.

2.1. Materials

Water samples used in this study were collected from the lake of Kumoh National Institute of Technology Gumi, Republic of Korea, that contains campus runoff water. Adsorbents including, carbon fiber (CF), ACF, ACF impregnation with silver (ACF-Ag) and copper (ACF-Cu) were supplied by BSM, Republic of Korea, specifications are listed in Table 1. The impregnation of CF before activation allows the adsorption through chemisorption as shown in Fig. 1. The water characteristics are presented in Table 2.

2.2. Kinetic and isotherm tests

The kinetic studies have an utmost importance to understand the mechanism, equilibrium conditions and the

Table 1
Adsorbents specifications

Adsorbent	Surface area (m^2/g)	Bulk density (g/mL)
CF	22.2 ± 0.3	0.75–0.81
ACF	1,280.9 ± 16.9	0.52–0.70
ACF-Ag	1,137.6 ± 14.8	1.3–1.36
ACF-Cu	1,187.4 ± 16.2	1.06

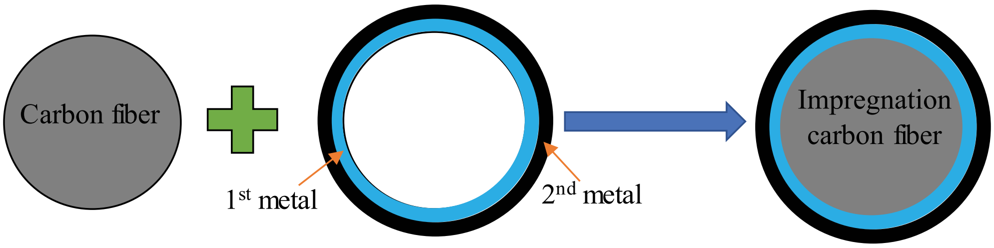

Fig. 1. Impregnation process of carbon fiber.

Table 2
Characteristics of raw water

Parameter	Result
pH	8.25
UV Absorbance at 254 nm (UVA_{254})	0.189
Electrical conductivity (μS/cm)	480

rate constant for adsorption of adsorbate onto the adsorbent. The kinetic studies of a process provide an important understanding of reaction pathway [26]. In kinetics, testing samples with duplicates were prepared with fixed dosing rate of 2.5 g/L for each adsorbent against time intervals as 12, 24, 36, 48, 60 and 72 h. Isotherm samples and their duplicates were prepared with dosing rates of 0.5, 1, 2, 3, 5 g/L of selected adsorbents and investigated for fixed time intervals such as 12 and 24 h separately. The isotherms were interpreted in view of Langmuir and Freundlich isotherm models defined by the following equations:

$$\frac{1}{Q_e}=\frac{1}{q_m}+\left(\frac{1}{q_m}\times\frac{1}{K_L}\right)\frac{1}{C_e} \tag{1}$$

$$\log Q_e=\log K_F+\frac{1}{n}\log C_e \tag{2}$$

In the above equations, q_m is maximum adsorption of monolayer, K_L is the Langmuir constant, K_F is the Freundlich constant and n is the heterogeneity factor. In these model equations, Q_e is amount of adsorbed adsorbate per unit weight of adsorbent and C_e is concentration of unadsorbed adsorbate in the solution at equilibrium.

2.3. Analytical methods

To evaluate adsorption efficiency of NOM onto the CF, ACF, ACF-Ag and ACF-Cu, series of experiments were conducted. To examine water characteristics, we analyzed pH with ORION STAR A series pH meter, electrical conductivity by ORION STAR A212. UVA_{254}, an extensively used indicator for quantification of dissolved NOM [27], was measured by using UV spectrophotometer (HACH DR6000, USA) but, these techniques are only capable of approximate characterization of NOM. Therefore, researchers have developed new techniques for improved characterization of the NOM particularly in wastewater and surface water. For this purpose, more sophisticated characterization techniques such as fluorescence excitation–emission matrix (FEEM) and liquid chromatography organic carbon detection (LC–OCD) have been used to study the NOM properties. The LC–OCD technique is a highly sensitive technique that requires minimum pretreatment of water samples. This technique is accomplished by separating NOM into different distinctive fractions of dissolved organic carbon (DOC) including, humic substances, biopolymers, low molecular weight (LMW) acids and neutrals and building blocks (BB) [28]. Both FEEM and LC–OCD techniques were used in this study to analyze the characteristics of raw and treated water samples.

2.3.1. FEEM analysis

FEEM is a better technique to characterize NOM as compared with conventional (UV–Vis) method because of its advanced sensitivity and selectivity [29]. The fluorescence excitation emission measurements were conducted using Shimadzu (Japan), RF-5301 spectrometer. In this spectrometer, xenon was used as excitation source and slits were set at 10 nm for both excitation and emission for analysis. The wavelengths of FEEM excitation emission were increased from 200 to 400 nm at 2 nm steps and excitation emission was noted from 250 to 600 nm at 1 nm steps. During preparation, samples were acidified to pH 3 by using HCl and then diluted to 1 mg/L, a final concentration of DOC with 0.01 M KCl. The blank sample response was subtracted from spectra of the NOM fractions. FEEM figures were drawn with SigmaPlot 11.0 with 20 contour lines.

2.3.2. Liquid chromatography–organic carbon detection

The NOM was computed in terms of DOC concentration and fractionated by using LC–OCD (Model 8, DOC-Labor, Germany). During experiments, samples were passed through dual chromatographic columns by using a mobile phase (phosphate buffer, 12.5 g KH_2PO_4 [Fluka, USA] + 7.5 g $Na_2HPO_4\cdot 2H_2O$ [Fluka, USA] to 5 L) at flow rate of 1.5 mL min^{-1}. During this experiment, 2,000 μL injection volume was retained for 180 min, for all samples [28]. The fractions and concentration of DOC, HOC, CDOC, humic substances, BB, biopolymers and LMW neutrals were evaluated on the basis of peaks and their retention times observed in the chromatographs [30].

3. Results and discussion

In adsorption process, pore structure of the adsorbent with large surface area can achieve the target of NOM removal from water. This process is getting more attention to remove NOM from raw water because of energy efficiency. It was noted that activated carbon with high porosity and large surface areas is capable of removing color, odor and NOM in water treatment systems [31]. Detailed discussion of selected ACFs in terms of NOM removal is described in the following sections.

3.1. Kinetic adsorption measurements

The duplicate samples were prepared for each adsorbent with dosing rate of 2.5 g/L in glass tubes. Then sample tubes were capped tightly and put on a shaker rotated at 120 rpm taken at predetermined intervals over 72 h. UVA_{254}, an indicator for quantification of dissolved NOM, was measured by using UV spectrophotometer. The kinetic adsorption analysis results were drawn as a ratio of final concentration to initial concentration of NOM with respect to time are presented in Fig. 2. Adsorption is a continuous process that occurs starting from starved condition of the adsorbent to the saturated dense layer formation. As time passes, adsorbed mass increases but the bound fraction decreases because newly arrived matter cannot find sufficient places to adsorb so they adsorb at the surface weakly. The kinetic changes are caused due to the newly arrived matter at the surface of the adsorbent and its adsorption may be associated with internal change of adsorbed layer. It can be noted clearly where solvent is used as adsorbent and there are no later arrived matter but replacement of solution by the solvent can keep the adsorbed mass constant during experimental work. The behavior of adsorption changes from fast bulk adsorption known as physio-sorption at the start of the process to slower adsorption called chemisorption that is accomplished by rearrangement of adsorbed layers [32].

As depicted in Fig. 2, the removal of NOM was >50% after 12 h using ACF, afterwards no significant increase was observed. ACF-Ag showed very close results as ACF, that is, 50.8% removal was noted after 12 h and no noteworthy change as time increased. It means there were no sites available and no internal change occurred therefore all the adsorption caused by only physio-sorption. Although CF showed least results, the trend of adsorption was similar as ACF and ACF-Ag. On the other hand, NOM removal was continuously improved using ACF-Cu that indicated that physio-sorption was followed by chemisorption but got slower with the passage of time. Resultantly, it was clear from the kinetic study that ACF is an efficient adsorbent followed by ACF-Ag where adsorption was caused mainly due to the physio-sorption while ACF-Cu adsorption followed both types of adsorption physio and chemisorption. But CF was least efficient to remove NOM from the lake water that may be caused due to the less active pores available for adsorption process. In addition, maximum removal was done during the first 12 h afterwards there was no further significant elimination excluding ACF-Cu where NOM removal was slightly increased till 72 h. The adsorption was fast initially then decreased with time and becomes nearly constant afterwards. This happened because at start vacant sites for adsorption were highly available and then repulsive forces increased due to the adsorption of ions that make other ions difficult to access the remaining sites. Therefore, ACF, ACF-Ag could be an option for fast removal of NOM from water but ACF-Cu can be used where slow adsorption is affordable.

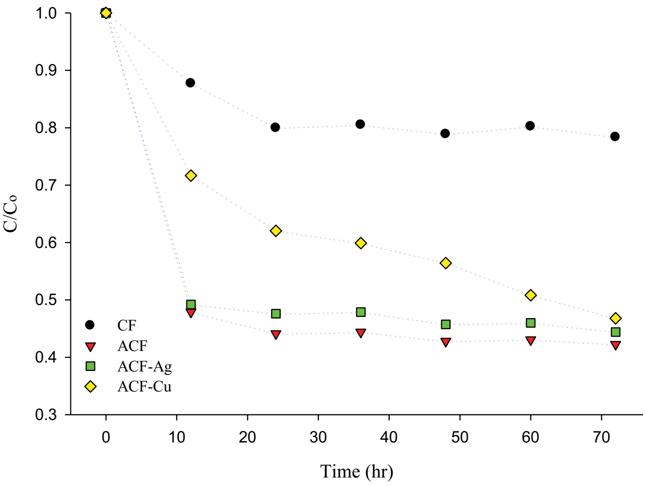

Fig. 2. Kinetic adsorption plots of activated carbon fibers (CF, ACF, ACF-Ag and ACF-Cu).

3.2. Adsorption isotherm measurements

The physio-chemical properties of an adsorbent along with adsorbate characteristics, including molecular size, solubility and molecular weight, are significant factors in adsorption process. At adsorption equilibrium, the adsorbed amount of an adsorbate can be determined; then the obtained data are adjusted to a mathematical model that can define the experimental behavior of adsorbent [33]. In this study, two prominent isotherm models, including Langmuir and Freundlich were used to explore the experimental data by using Eqs. (1) and (2). Langmuir isotherm model considers monolayer coverage, energetically equivalent surface sites and adsorbing ability at a specific site of a molecule to be independent of surrounding sites [34,35]. Freundlich isotherm is based upon the sorption of adsorbate on the heterogeneous surface of the adsorbent [36]. The isotherm of NOM adsorption from lake water of selected ACFs including ACF, ACF-Ag and ACF-Cu was determined by using bottle-point method. In this method, dose of adsorbents varied such as 0.5, 1, 2, 3, 5 g/L in 50 mL glass bottles separately with duplicate samples. Adsorption isotherm testing was performed at two different time intervals by keeping same dosing of adsorbents. The prepared two sets of samples were placed on a shaker in a temperature-controlled room 25°C and rotated at 120 rpm for 12 and 24 h, respectively. The ratio of final concentration to initial concentration was plotted as a function of adsorbent dose. The isotherm adsorption analysis results of three selected adsorbents are presented in Fig. 3 with respect to time. It is demonstrated that by increasing adsorbent dose, removal efficiency was increased in both cases 12 and 24 h. The NOM removal efficiency of ACF and ACF-Ag was found optimum at 2.5 g/L and further on even by doubling the dosing rate there was slight increase of adsorption but it was not the case for ACF-Cu. In this case, there was no significant change in adsorption efficiency

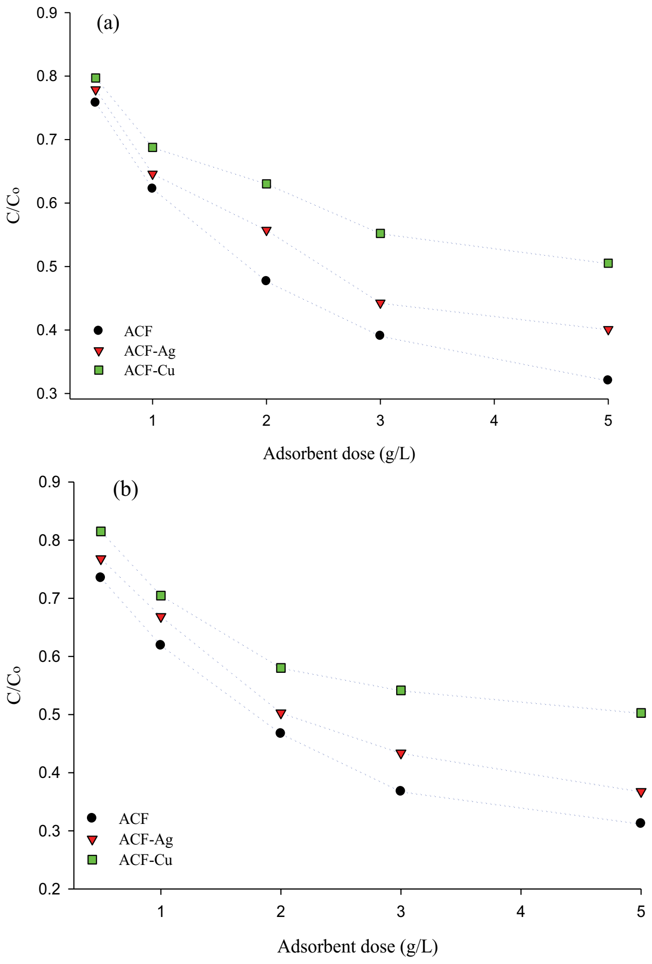

Fig. 3. Isotherm adsorption of selected ACFs for 12 h (a) and 24 h (b).

on increasing dosing rate of ACF-Cu more than 2.5 g/L as compared with the other two adsorbents. The results of other set of samples prepared for 24 h presented the results having no noteworthy difference from the results obtained after 12 h. It is evident from these results that 2.5 g/L dose of selected adsorbents found an optimum value for adsorption of NOM from lake water.

3.2.1. Langmuir and Freundlich isotherms

In this study, we used Langmuir and Freundlich isotherms to determine the equilibrium characteristics by calculating parameters of isotherm equations using linear regression analysis for adsorption process. Langmuir isotherm studies the chemical phenomena by assuming that adsorbent does not react, all the available sites are considered similar and monolayer formation in adsorption process [36]. The calculated parameters and correlation coefficient (R^2) of both aforementioned isotherms for ACF, ACF-Ag and ACF-Cu adsorbents are summarized in Table 3. The fitting of experimental data using Langmuir isotherm provided good results in case of ACF and acceptable results for ACF-Cu but not fitted well for ACF-Ag. Freundlich isotherm performed well providing highest R^2 values as 0.992, 0.951 and 0.968 for ACF, ACF-Ag and ACF-Cu, respectively. ACF adsorbent experimental data fitting with Langmuir isotherm proved the monolayer formation and homogeneous distribution of available active sites but overall Freundlich isotherm outperformed the Langmuir isotherm.

The equilibrium data for the adsorption of selected adsorbents (ACF, ACF-Ag and ACF-Cu) were best fitted with the Freundlich isotherm might be because of heterogeneous surfaces of the adsorbents as shown in Table 3. It indicates that adsorption was carried out because of multilayer formation with heterogeneous distribution of the enthalpy. It is evident that energy decreases and becomes

Table 3
Freundlich and Langmuir isotherms of selected adsorbents

Adsorbents	Dosing rate (g/L)	Q_e	C_e	Q_m	K_F	Freundlich (R^2)	Langmuir (R^2)
ACF	0.5	0.093	0.146	1.82	0.872	0.992	0.983
	1	0.073	0.120				
	2	0.050	0.092				
	3	0.039	0.075				
	5	0.026	0.062				
ACF-Ag	0.5	0.085	0.150	0.198	1.631	0.951	0.798
	1	0.068	0.124				
	2	0.043	0.107				
	3	0.036	0.085				
	5	0.023	0.077				
ACF-Cu	0.5	0.019	0.158	0.169	19.878	0.968	0.915
	1	0.029	0.142				
	2	0.036	0.133				
	3	0.061	0.126				
	5	0.078	0.119				

constant when equilibrium is achieved. The heterogeneity factor depends upon interaction between adsorbate ions, coordination number of adsorbates, Avogadro number and Boltzmann constant. Therefore, heterogeneity of an adsorbent is depending upon available active sites, binding energy and interaction between last layer with adsorbent ions. From the equation, it in understood that $1/n$ is the slope and K_F is the slope intercept by plotting $\log q_e$ and $\log C_e$. It can confirm that adsorption and physical processes can be favorable for n values more than one as it was the case in ACF adsorbent where $n = 1.45$ [37]. The best results were obtained with ACF adsorbent followed by ACF-Ag as adsorbed amount Q_e, Q_m, K_F and unabsorbed amount C_e data presented in this study while comparatively ACF-Cu was found to be the less efficient adsorbent. Additionally, it was observed that 2.5 g/L was the optimum dosage rate because there was no significant change in adsorption efficiency on increasing dosing rate afterwards, of selected adsorbents.

3.3. FEEM analysis

The FEEM contour plot of NOM is presented in the contour (Fig. 4). Each FEEM was delineated into five sections by using constant wavelength boundaries of excitation and emission. In general, as presented in Table 4, peaks appeared at shorter wavelength of excitation (<250 nm) and emission (<350 nm) are associated to simple aromatic proteins including tyrosine in sections I and II [38]. The peaks at transitional wavelength of excitation (250–280 nm) and shorter wavelength of emission (<380 nm) are correlated to soluble microbial byproduct-like material as observed in section IV [39,40]. Moreover, peaks at longer excitation (>280 nm) and emission wavelengths (>380 nm) are known as humic acid-like organics in section V [41,42]. Literature studies showed that 50%–80% of all NOM in water are humic substances (HSs). The structure of HSs has complex and high molecular weight substances that are composed of carbon, oxygen, hydrogen and smaller amounts of phosphorous, sulfur and nitrogen. These substances are mixtures of polydisperse and amorphous polyfunctional materials having heterogeneous polyelectrolytic properties that are affected by atmospheric conditions [43,44]. It is important to define the characteristics of HSs to maximize their removal from aquatic system and to evaluate the performance of water treatment systems. Literature studies classified the HSs into three types such as fulvic acid, that is soluble in acidic and basic mediums, humic acid is only soluble in basic media but not in acidic more specifically pH < 2 and humin, insoluble in both acidic and basic media.

The FEEMs of raw water and adsorbents treated water are presented in Fig. 4. It can be seen that raw water sample contained fulvic acid (FA) and humic acid (HA) like materials as two peaks were observed at Ex/Em 258/430 and 325/430 nm. A similar trend was noted after CF treatment showing two peaks at Ex/Em 250/430 and 320/430 nm and shows small portion removal of those materials. It may happen because small superficial area was provided for adsorption by CF adsorbent whereas, FA and HA molecular size varies and big sized molecules may have low velocities as well. On the other hand, ACF showing much better results as peaks were appeared at Ex/Em 240/430 and 310/430 nm followed by ACF-Ag treated water peaks were shown at 250/430 and 310/430 nm. Previously, activated carbon was mostly used to remove FA and HA at water treatment systems because of its better adsorptive characteristics such as porosity, surface area and low reactivity. It may be caused due to the high meso-porosity of ACF and ACF-Ag adsorbents as compared with CF. Moreover, ACF-Cu adsorbent was proved less efficient where peaks were detected at 250/430 and 310/430 nm that might be due to the impregnation of ACF with copper decreased the meso-porosity of the adsorbent that resulted in lower efficiency. In all the cases, adsorption of FA- and HA-like materials was different which might be due to the difference of surface heterogeneity and active surface sites available for adsorption.

3.4. LC–OCD results

For further insight, LC–OCD analysis was conducted for raw water and treated water by each adsorbent and results are presented in Fig. 5. We considered various important fractions for LC–OCD testing including, total DOC, hydrophobic organic carbon (HOC), chromatographic dissolved organic carbon (CDOC), biopolymers, humic substances (HS), BB and LMW neutrals that are weakly charged hydrophilic or slightly hydrophobic compounds. In this study, we discuss the results in terms of % removal of specified fraction with respect to selected adsorbent. The DOC removal was maximum around 41% for both ACF and ACF-Ag treated water while 27% removal was achieved in ACF-Cu and only 9% in case of CF adsorbent. HOC elimination was highest in ACF treated sample up to 59% followed by 51% in ACF-Ag treated water sample while ACF-Cu showed 34% and least efficient was CF. CDOC removal was 11%, 39%, 42%, and 25% for CF, ACF, ACF-Ag and ACF-Cu treated water. Previous studies proved that lake waters contain higher proportion of biopolymers as compared with river waters and they are an important factor in fouling of low pressure membranes used for water treatment [45]. The biopolymers are expected to contain polysaccharides accounted for 8%–12% DOC in lake waters and also protein-like materials, in addition. The results of biopolymer removal provided highest elimination 28% and 26% for ACF-Ag and ACF. The CF adsorbent showed better results in case of biopolymer removal 21% than ACF-Cu which presented only 15% removal of biopolymers this might be happened due to the structure of biopolymers.

As noted, humic substance was the significant fraction in all water samples. As reported previously, these substances characteristically account for 50%–75% of the total DOC [6]. Further insight into their character can be expanded by using humic substances diagram developed by Huber et al. [28]. For humic substances elimination, ACF-Ag, ACF and ACF-Cu showed results as 35%, 33%, and 25%, respectively, on the other hand CF treated water showed 11% removal of humic substances from water sample. In case of BB, ACF-Ag was the best adsorbent in terms of removal efficiency around 63% followed by ACF 60% while 44% removal was observed in ACF-Cu treated water. The LMW neutrals removal pattern was similar as presented in BB that was 63%, 58%, and 34% removal for ACF-Ag, ACF and ACF-Cu adsorbents, respectively. LMW acids were not detected. By considering

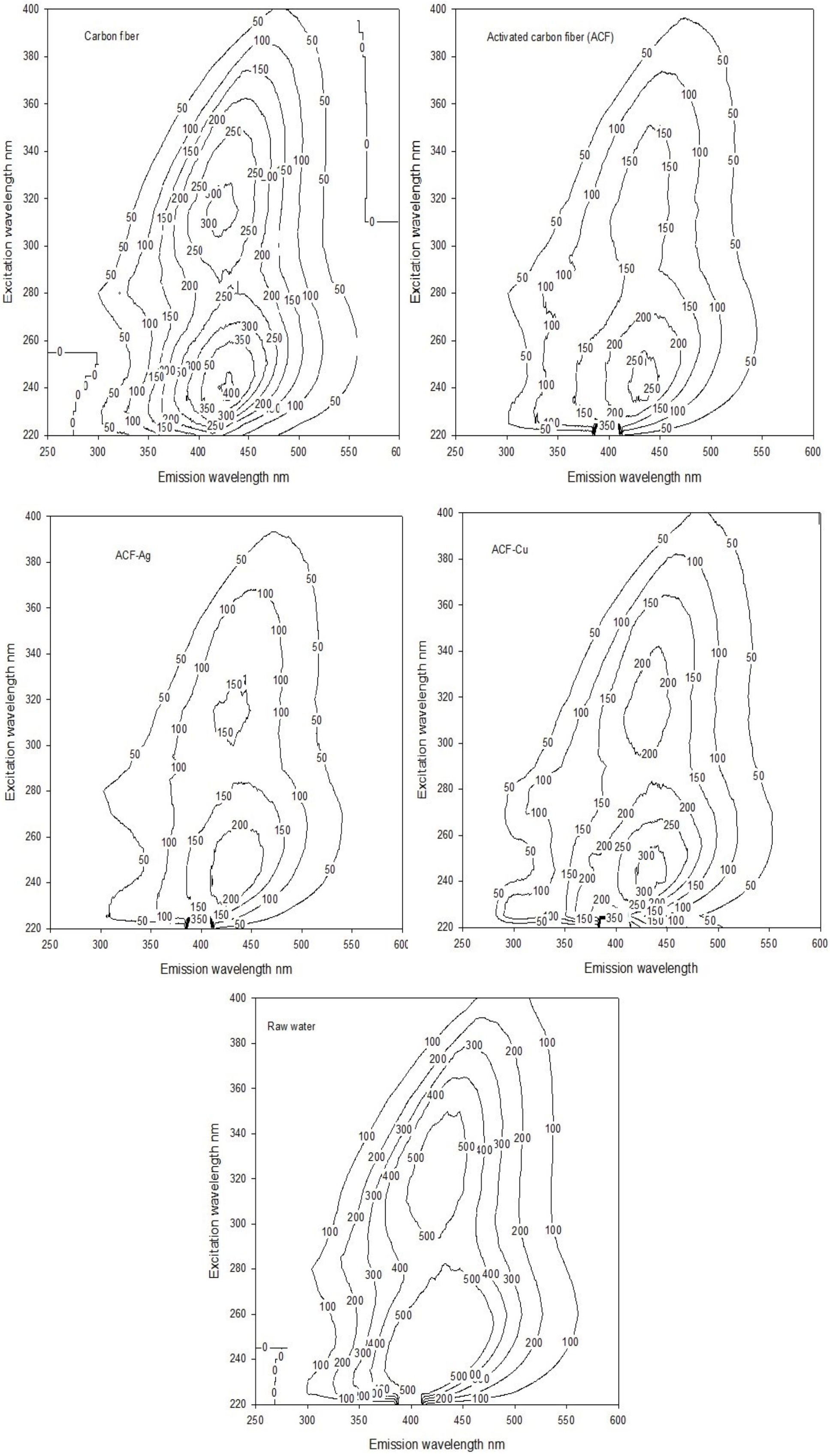

Fig. 4. FEEMs of adsorbents treated water and raw water.

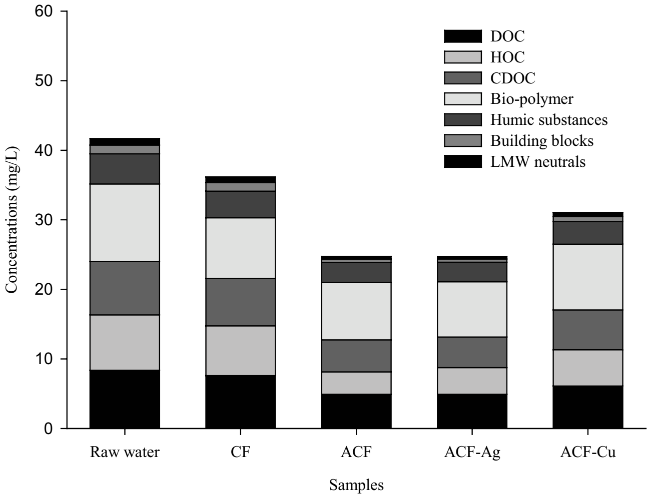

Fig. 5. Contribution of main parameters from LC–OCD testing.

Table 4
FEEM spectra sections with respect to excitation/emission ranges [35]

Spectra regions	Description	Excitation/emission ranges (nm)
I	Aromatic proteins I	<250/<330
II	Aromatic proteins II	<250/330 < Em < 380
III	Fulvic acids	<250/>380
IV	Microbial byproducts	>250/<380
V	Humic acids	>250/>380

all the factors, ACF was found to be a better adsorbent for the removal of NOM from lake water.

It is clear from this study that ACF is a better adsorbent for NOM removal from water because it provides more active spaces as compared with other adsorbents. Unlike ACF, the CF showed very low efficiency that might be due to low ratio of available active spaces for organic matter removal. On the other hand, ACF-Ag and ACF-Cu presented better results than CF but not as good as observed in ACF, it may be happened due to the impregnation of ACF with other metals that resulted in reduction of active sites available for the adsorption process. There might be other factors such as change in the characteristics of the adsorbent; occurrence of side reactions may be a reason or different operating conditions are required to achieve better results. Therefore, it is important to continue this study for further investigations by considering all related parameters one by one.

4. Conclusion

In this study, four adsorbents including carbon fiber (CF), ACF, ACF impregnation with silver (ACF-Ag) and impregnation with copper (ACF-Cu) were investigated by kinetic and isotherm model tests. Moreover, for characterization of NOM, FEEM and LC–OCD techniques were employed. The results demonstrated that ACF is the best adsorbent followed by ACF impregnation with silver for the removal of NOM while ACF-Cu was found comparatively better than CF. In case of CF, it might be due to low ratio of active spaces which resulted in lower organic matter removal efficiency while high ratio of active spaces in ACF showed an increased adsorption capacity. Although ACF-Cu showed better results than CF, it is not much attractive as compared with ACF and ACF-Ag adsorbents. It might be due to the more Cu ions impregnation on ACF surface which requires further investigations. In the light of this study, one can recommend that frequently conducting, encouraging and extending the application of ACFs for the removal of various pollutants through selected adsorbents may lead to optimization of this process for organic matter and bacteria removal from water. Since, ACF proved a promising microporous adsorbent with a fiber shape and well-defined porous structure having higher adsorption capacity as presented in this study. Further studies are required to investigate the decrease in NOM removal efficiency after impregnation of ACF that may be caused due to the change in adsorbent characteristics or occurrence of side reactions and moreover, in future studies operating parameter can be changed to check their impact on NOM removal efficiency of impregnation ACF adsorbents.

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