

UTILIZATION AND CHARACTERIZATION OF ACTIVATED CARBON PREPARED FROM CIGARETTE FILTER WASTES: A REVIEW

Tahiat Mizan Orchi^{*1}

¹First Author, Khulna University of Engineering & Technology, Bangladesh, e-mail: orchi1601088@stud.kuet.ac.bd

***Corresponding Author**

ABSTRACT

Since trillions of cigarettes are smoked annually, the dispersal of cigarette filters (CF) is considered as one of the most hazardous litters around the world containing toxic substances and cellulose acetates. Therefore, recycling this kind of wastes will reduce the environmental risks and will lead to sustainable development. The objective of this review is to compile the extensive lists of activated carbon (AC) prepared from cigarette filters by carbonization and chemical activation and also to study the applications of cigarette filter based activated carbon (CFAC) for wastewater treatment which may provide a new strategy for future treatment of waste cigarette filters. The study shows an investigation of materials using SEM (Scanning electron microscopy) for the morphology of CF, AC, and phase structure of CM (carbonaceous material), CFAC. Furthermore, the surface area and adsorption capacity of activated carbon (AC) due to different chemical activations had been compared in this article. It was found that the highest BET (Brunauer–Emmett–Teller) surface area for CFAC was $2726 \text{ m}^2 \text{ g}^{-1}$ at ratio CFAC/KOH= 1:5 and temperature 900°C . Moreover, adsorption isotherms, adsorption kinetics, and adsorption thermodynamics of CFAC had been investigated for different contaminants. The results indicated that the Langmuir model was suitable to describe contaminants like ciprofloxacin (CIP), Sodium dodecyl sulfate (SDS), Uranium (UO_2)²⁺, phenol adsorption process whereas the Freundlich model was suitable to describe lead (Pb^{2+}) adsorption process of CFAC. For adsorption kinetics, the Pseudo-second-order model was suitable to describe all the contaminant's adsorption processes. The adsorption enthalpy of phenol had been studied where more negative standard free energy (ΔG) and negative entropy change (ΔS) of phenol adsorption with increasing temperature indicated spontaneous nature and decrease of randomness. Also, the negative value ΔH indicates the exothermic process of phenol adsorption. Nevertheless, the main purpose of compiling the previous work of CFAC for different water contaminants is to get the optimum value of pH, temperature, the ratio of carbonaceous material: chemical activating agent and also to know the type of contaminants for which CFAC works better so that the better result can be achieved for adsorption of those contaminants. Finally, compiling the previous literature reviews, conclusions had been drawn and proposals for future research were outlined.

Keywords: *Cigarette filters, activated carbon, adsorption isotherms, adsorption kinetics, future research*

1. INTRODUCTION

Cigarette filters are usually used to reduce inhaling harmful substances by smokers which are done by blocking the largest tar particles along with other toxic substances. The CF (cigarette filter) wastes are not biodegradable does not mean they will remain in the environment for the whole time. At some point the sunlight will degrade it into small pieces as a result harmful and toxic substances will release into the environment causing harm to humans, animals, and aquatic lives. The sales volume of cigarettes is still up to 5.8 trillion cigarettes per annum in recent years generating 800,000 metric tons of discarded CF wastes as a form of garbage and thrown everywhere (Blankenship & Mokaya, 2017). Even if the CF wastes are thrown into the garbage, it never mixes into the ground because of CF's non-

biodegradability. Hence, the recycling of CF wastes can assuage the problem related to the disposal of the wastes which has brought great attention to scholars. In previous studies, CFs had been recycled as raw material in brick production (Abdul Kadir & Mohajerani, 2012), biofilm carrier (media) which is a component of integrated fixed film activated sludge (IFAS) system (Sabzali, Nikaeen & Bina, 2012), sound-absorbent (Gómez Escobar & Maderuelo-Sanz, 2017), and also cigarette filter remaining cellulose acetate can be used as cellulose membrane-based separator for high performance lithium-based battery (Huang et al., 2015). According to industrial analysis, smoked cigarette filter contains 58% carbon content (Zhang et al., 2020). Holding high carbon amounts, cigarette filters can be a good raw material for activated carbon. Industrial activated carbon made from common precursors like coal, wood, coconut shell, peat is very costly and also there is a problem associated with regeneration. As a consequence, the low-cost precursor materials have become an attractive choice in the production of activated carbon. Ulva Lactuca (Ibrahim et al., 2016), bamboo (Lo et al., 2012), olive stone (Bohli et al., 2015), cattle bone (Cechinel et al., 2014), and orange peel are one of these low-cost precursors which have been used in the production of AC (activated carbon) in the past years. Considering cigarette litter as one of the largest wastes along with having a large amount of carbon, it can be used as new raw material for making AC which can create a new path for recycling the cigarette filter wastes and utilizing them in the water treatment process.

This article had viewed the physical and chemical activation for preparing activated carbon with the different temperatures that had been applied for different contaminants of water. The chemical activation including KOH, HNO₃, NaOH is used for improving the activation properties like activation capacity, porosity. Furthermore, phase structure and morphology related to activated carbon have been investigated. Also, adsorption capacity, adsorption isotherm, adsorption kinetics, adsorption thermodynamics has been analyzed to get a better result. The main purpose of this article is to investigate the effectiveness of removing water contaminants by cigarette filter-based activated carbon using different chemical activations as well as different temperatures and also to propose future researches on this topic.

2. METHODOLOGY

The activated carbon can be gained by two methods known as physical activation and chemical activation. In the physical activation process, the carbon materials are activated by elevating certain temperatures in the presence of gasses like carbon dioxide, steam, air, or their mixtures (Chen et al., 2011). The chemical activation is done by a combination of two processes that are carbonization and chemical activation using chemical constituents like KOH, NaOH, HNO₃, ZnCl₂, etc. When it comes to comparing the two processes, chemical activation is more effective due to increasing the porosity and the activation capacity.

2.1 Preparation of CFAC

The capacity of CFAC depends on factors like temperature, pH level, the ratio of CM: chemical constituents during chemical activation, type of contaminants, and type of chemical constituents. Apart from all these factors, the overall process of making CFAC is the same. First, the CF needs to be unwrapped and washed with hot water. The CFAC can be obtained either by physical activation-chemical activation or by physical activation-chemical activation-physical activation. Activated carbon made by physical activation has a lower specific surface area compared to the chemical activation process. During physical activation, the CFs are placed in a crucible and put in a tabular furnace for carbonization at certain temperatures which usually range from 65°C-900°C for different duration ranges from 2-24 hours under argon atmosphere. During chemical activation, the CMs (carbon materials) are impregnated into chemical constituents like KOH, NaOH, ZnCl₂, HNO₃ for certain ratios of CM: chemical activating agent e.g. 1:3, 1:4, 1:5, 1:6, 2:3 or chemical activation can also be done by using a mechanical stirrer for the mixture of CM and chemical constituents.

Among all the chemical activating agents, the alkali hydroxides (special NaOH and KOH) can be attractive activating agents for preparing microporous carbon due to producing valuable materials in the following process (Freitas et al., 2007). The overall process is given in reaction (1).



The overall reaction indicates the formation of alkali carbonate, hydrogen, and alkaline metal where Me = K or Na (Guo et al., 2002). The detection of the metal traces Me= K or Na (Guo et al., 2003; Lillo-Ródenas et al., 2004) are the validation of this proposed reaction (Lillo-Ródenas et al., 2003; Díaz-Terán et al., 2003). The hydrogen can be detected in the temperature ranges from 200-600°C depending on the reactivity of the carbon precursor (Lillo-Ródenas et al., 2004). The detection of CO or CO₂ can be found due to the decomposition of Me₂CO₃ with the devolatilization of the carbon precursor itself at a high temperature above 800°C. The porosity of carbon material increases due to interaction with SiO₂ producing alkaline silicates and CO₂. The CO₂ will then react with the carbon phase that will produce CO (Chen et al., 2011). The reaction (2) is given below:



The carbonates can also interreact with the carbon phase. In case of K₂CO₃, it interacts with the carbon phase at temperatures 700°C-950°C (Gupta et al., 1998). The process is the same for NaCO₃ also. Finally, the adsorption characteristics such as BET surface area, average pore volume, and pore diameter can be determined at a specific temperature.

2.1.1 Adsorption Experiment and Characterization of CFAC

The adsorption experiment is carried out in a temperature control shaker where CFAC of a certain amount and the pollutant's solution are mixed at initial temperature and concentration for equilibrium. After the equilibrium, CFAC is removed using filter paper and then the concentration of the pollutant from the solution is determined using the spectrometer. The adsorption equilibrium capacity is calculated using equation (1) (Xu et al., 2016; Hu et al., 2019).

$$q_e(\text{mg/g}) = \frac{(C_0 - C_e)V}{M} \quad (1)$$

where q_e (mg/g) is the pollutant's equilibrium adsorption capacity, C_0 (mg/L) is the initial concentration of the pollutants, C_e (mg/L) is the pollutant's concentration after adsorption by CFAC, V (L) is the pollutant's solution volume, M (g) is the mass of CFAC.

Scanning electron microscopy (SEM) can be used for the morphology of CF and AC. For SEM analysis, the samples are placed on carbon-coated stubs and sputter-coated (Polarz et al., 2002). The XRD diffractometer can be used for the phase structure of CM, CF, and CFAC. Physical properties like Brunauer–Emmett–Teller (BET) surface area, pore-volume, pore diameter can be depicted by a surface analyzer with the N₂ gas as adsorbate at relative pressure $P/P_0 = 0.97$ or 77K.

3. RESULTS AND DISCUSSIONS

3.1 Characteristics and Properties of CFAC

When it comes to preparing activated carbon, different types of polymeric materials have been used as carbonaceous precursors in the past few years (Vázquez-Santos et al., 2008). The main component of a cigarette filter is cellulose acetate which contains fibrous matter. It has been said that the cigarette filters have the potentiality to act as raw material for preparing activated carbon as a cause of being polymeric material though some modification needs to be done to increase the porosity (Hamzah & Umar, 2017).

The observation of physical morphology has been done by scanning electron microscopy (SEM) in Figure 1 where the images of cellulose acetate fiber and transformation of CFAC from CF residue have been shown.

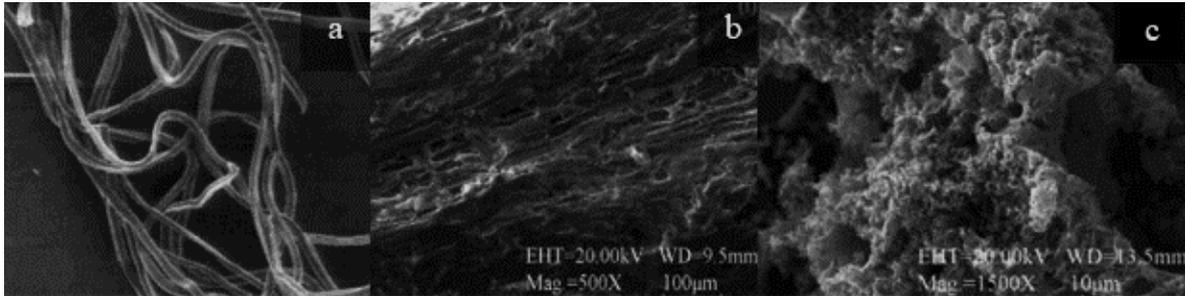


Figure 1: SEM images of (a) Cellulose acetate fiber from CF (Polarz et al., 2002), (b) Raw tobacco residue, (c) CFAC prepared using K_2CO_3 chemical activation (Kilic et al., 2011)

Figure 1 (a) has showed the SEM image of cellulose acetate from CF which has thin wire morphology. Figure 1 (b) has revealed the thick wall structure having a little porosity for raw tobacco residue. Figure 1 (c) shows the activation of tobacco residue due to chemical activating agent K_2CO_3 where numerous micropores are the proof of that activation.

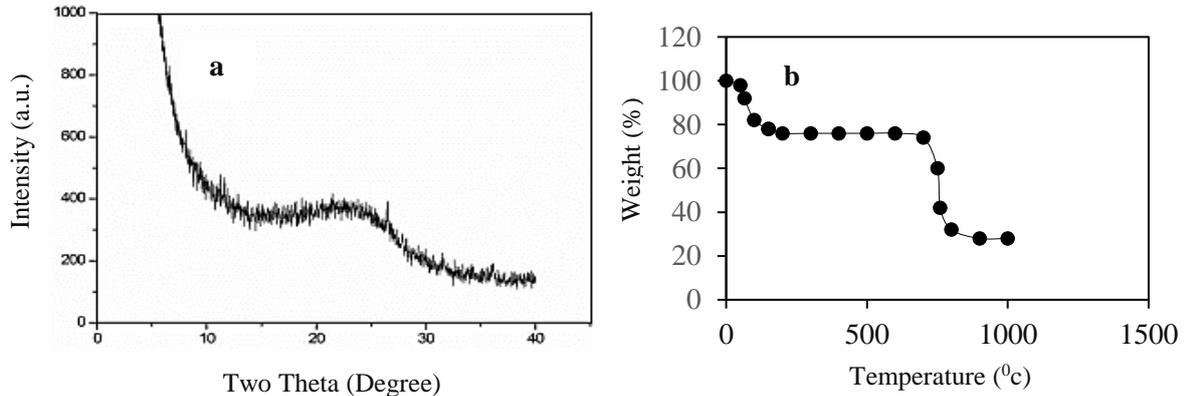


Figure 2: (a) XRD pattern of CFAC using $ZnCl_2$ chemical activating agent (Mudyawabikwa et al., 2017). (b) TG curve of CM/ KOH (b). (Zhang et al., 2020)

It is important to study the effect of the chemical activating agent on the phase structure and the formation of micropores of CFAC which has been shown in Figure 2. The XRD pattern of CFAC for chemical activation $ZnCl_2$ with the ratio of CM: $ZnCl_2 = 2:3$ has been shown in Figure 2 (a). It has been noticed that there are no broad peaks except broad peaks between 25° and 27° . The broad peak between 25° and 27° indicates the presence of carbon and no other peaks indicate the removal of any other detectable compounds due to activating agent $ZnCl_2$. The pyrolysis process due to KOH activation has been shown in Figure 2 (b) by the TG curve of CM/KOH mixture (mass ratio 1:1) with a heating rate of $10^\circ C \text{ min}^{-1}$ under nitrogen flow. Two obvious weight loss and a modest weight loss can be noticed between room temperature and $1000^\circ C$. Weight loss of about 22% has occurred in the first slope stage which is between room temperature and $200^\circ C$ because of the evaporation of water and pyrolysis of residual organics. A slight weight loss of about 3.5% has occurred at $400-700^\circ C$ where KOH transformed into potassium metal oxides due to dehydration. After that potassium will begin to decompose forming potassium metal at $762^\circ C$ (Xu et al., 2012). At the same time, the carbonized material will have redox reactions with vapor, potassium metal oxide, and potassium vapor to form numerous micropores on the surface of the carbon.

The previous researches on textural properties (BET specific surface area, total pore volume, average pore diameter) of CFAC for different chemical activating agents and different temperatures have been listed in Table 1. From table 1, the highest BET specific surface area has been found for KOH activation which is 2726 m²g⁻¹ obtained at 900°C at the ratio of CM: KOH= 1:5. The chemical activated carbon CT ZnCl₂ has also given higher BET specific surface area compared to others.

Table 1: Textural properties of activated carbon prepared from cigarette filters

Chemical constituents	Temperature (°C)	S _{BET} (m ² g ⁻¹)	V _{total} cm ³ g ⁻¹	d _{average}	Reference
KOH	900	2726	1.29	2.18	Zhang et al., 2020
T in natura	750	0.27	0.0008	2.18	Conradi et al., 2019
CT NaOH	750	76.61	0.0525	1.90	Conradi et al., 2019
CT ZnCl ₂	750	479.40	0.06012	1.67	Conradi et al., 2019
KOH	600	328.13	1.29	2.18	Hamzah & Umar, 2017
HNO ₃ modified	900	439	0.24	3.24	Masoudi Soltani et al., 2013
HNO ₃ non-modified	900	597	0.33	3.32	Masoudi Soltani et al., 2013

The lists of previous researches in the utilization of CFAC have been demonstrated in Table 2. Here MB indicates methylene blue and CFAC-3,4,5,6 indicates the ratio of CM: KOH ratio is 1:3,1:4, 1:5, 1:6 respectively. MCMs indicate mesoporous carbonaceous materials. Even though a good adsorbent should possess a porous texture and high surface area, the adsorption capacity also depends on the experimental conditions. As the capacities vary depending on the experimental conditions, the comparison of the adsorption capacity is difficult to make. This list of previous works is demonstrated just to show the optimum conditions to get the best results for the following contaminant's adsorption.

Table 2: Previous researches in the utilization of CFAC for different water pollutants

Adsorbate	Adsorbent Type	Initial Concentration C ₀ (mg/l)	Adsorption Capacity Q (mg/g)	Reference
UO ₂ ²⁺	CFAC using KOH	150	106	Pu et al., 2019
Pb ²⁺	HNO ₃ -modified CFAC	600	74.5	Masoudi Soltani et al., 2013
MB	CFAC using ZnCl ₂	600	167	(Mudyawabikwa et al., 2017).
CIP	CFAC-3	0.5	279	Zhang et al., 2020
	CFAC-4		304	
	CFAC-5		462	
	CFAC-6		431	
Phenol	MCMs	700	261.7	Chen, 2015
Pb ²⁺	HNO ₃ -nonmodified CFAC	600	66	Masoudi Soltani et al., 2013
SDS	CFAC-3	4	325	Zhang et al., 2020
	CFAC-4		378	
	CFAC-5		560	
	CFAC-6		582	

The pH values for the highest adsorption capacity are given in Table 3 where the pH value varies depending on the contaminants and chemical activation agents. The highest adsorption capacities for pH values have been obtained by batch adsorption experiments. Again these optimum pH values from previous researches can be helpful to obtain the best results for adsorption of the following contaminants.

Table 3: Effect of pH on adsorption capacity

Adsorbate	Chemical treatment	Highest adsorption at pH	Adsorption capacity (mg/g)	Reference
UO ₂ ²⁺	KOH	6±0.1	97	Pu et al., 2019
Pb ²⁺	HNO ₃ -nonmodified	5	26.2	Masoudi Soltani et al., 2013
Pb ²⁺	HNO ₃ -modified	4	28.5	Masoudi Soltani et al., 2013
CIP	KOH	7	450	Zhang et al., 2020
SDS	KOH	5	595	Zhang et al., 2020

3.2 Adsorption Isotherm of CFAC

The adsorption isotherms express the specific relation between the concentration of adsorbate and its degree of accumulation at the adsorbent's surface at a constant temperature. To investigate the adsorption behavior, the previous researches on the Langmuir and Freundlich isotherm of CFAC due to different contaminants has been illustrated in Table 4 where ACK1 and ACK2 indicate activated carbon using chemical activating agents K₂CO₃ and KOH respectively. The FDU-15 and PCMs indicate ordered mesoporous carbon and porous carbonaceous materials.

The Langmuir equation (2) is based on the assumptions of homogenous adsorption on the adsorbent surface with the same adsorption site and no transmigration of adsorbate in the plane of the surface. Moreover, there will be no steric hindrance between the adsorbed molecules and incoming ions. The linear equation of Langmuir isotherm can be shown as :

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{q_m K_L} \quad (2)$$

Where q_e (mg/g) is the equilibrium adsorption amount, C_e (mg/L) is the equilibrium concentration of the solute, q_m (mg/g) and K_L (L/mg) are constants related to the adsorption capacity and energy of adsorption. The values of q_m and K_L is calculated from the slope and intercept of Langmuir plot of C_e/q_e .

The Freundlich equation (3) is based on the assumption of surface heterogeneity and an exponential distribution of active sites of adsorbents along with their energies towards adsorbate (Clayton, 1926).

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (3)$$

Where K_F is roughly an indicator of the adsorption capacity and n is the heterogeneity factor.

The values correlation coefficient R^2 of all the pollutants except Pb²⁺ for Langmuir model is higher than that for Freundlich equation indicates that Langmuir isotherm is feasible to describe all the pollutant's adsorption process of CFAC except Pb²⁺ from table 4 whereas Freundlich isotherm is more feasible to describe lead adsorption process of CFAC.

Table 4: Previous researches on Langmuir and Freundlich isotherm of CFAC

Adsorbate	Samples	Langmuir model			Freundlich model			Reference
		q_m (mg/g)	K_L	R^2	K_F	n	R^2	
UO ₂ ²⁺	CFAC	108.21	0.12	0.99 8	28.2 2	3.41	0.94 7	Pu et al., 2019
Phenol	MCM	257.6	0.19	0.99 8	45.0 2	2.502	0.94 7	Chen et al., 2015
	FDU-15	143.9	0.11	0.99 4	17.1 7	2.704	0.92 0	
	PCMs	99.1	0.05	0.99 0	6.39	2.232	0.91 1	
MB	ZnCl ₂ (2:3)	123.46	2.89	1	124. 05	2.27	0.99	(Mudyawabikwa et al., 2017).
Phenol	ACK1	17.83	0.46	0.99 92	12.4 8	0.86	0.99 8	(Kilic et al., 2011)
	ACK2	0.55	2.68	0.92 7	134. 64	0.31	0.99 1	
SDS	CFAC-3	330.8	0.012	0.98 6	2.94 1	1.722	0.92 7	Zhang et al., 2020
	CFAC-4	401.7	0.003	0.97 9	2.34 0	1.472	0.89 6	
	CFAC-5	613.1	0.002	0.98 0	2.38 9	1.369	0.81 3	
	CFAC-6	628.5	0.003	0.97 8	1.20 1	1.25	0.85 3	
Pb ²⁺	T	56.818	0.018	0.98 4	1.48 0	1.303	0.99 1	Conradi et al., 2019
	CT ZnCl ₂	84.746	0.018	0.97 9	7.16 0	2.306	0.99 0	
	CT NaOH	34.36	0.013	0.93 0	2.27 0	1.730	0.94 0	
CIP	CFAC-3	288	0.059	0.99 7	26.3 10	2.187	0.88 4	Zhang et al., 2020
	CFAC-4	294.5	0.081	0.99 8	36.3 13	2.433	0.91 1	
	CFAC-5	464.4	0.353	0.99 9	69.8 26	1.754	0.82 5	
	CFAC-6	435.7	0.436	0.90 9	47.4 65	1.805	0.84 5	
Pb ²⁺	CFAC by nonmodified-HNO ₃	43.23	0.393 41	0.95 6	1.98 6	2.624 79	0.99 3	Masoudi Soltani et al., 2013
Pb ²⁺	CFAC by modified HNO ₃	94.29	0.499 75	0.96 99	2.11	3.621 18	0.99 7	Masoudi Soltani et al., 2013

3.3 Adsorption Kinetics of CFAC

To investigate the valuable reaction pathways and mechanism of adsorption reactions, a pseudo-first-order kinetic model and second-order-kinetic model can be used. The adsorption kinetics of the CFAC process is expressed by pseudo-first-order and pseudo-second-order model that is illustrated in Table 5. The pseudo-first-order model is expressed as :

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (4)$$

The pseudo-second-order model is expressed as:

$$\frac{t}{q_t} = \frac{1}{k_2 \cdot q_e^2} + \frac{t}{q_e} \quad (5)$$

where q_t is the amount of adsorbate adsorbed (mg/g) at time t (min), q_e is the amount of adsorbate adsorbed at equilibrium (mg/g). K_1 and K_2 are the pseudo-first-order and pseudo-second-order rate constant respectively from equation (4) and equation (5).

The values of the correlation coefficient R^2 of all the pollutants depicted from Table 5 for a pseudo-second-order kinetic model is higher than that for the pseudo-first-order kinetic model which indicates the pseudo-second-order kinetic model is more feasible to describe the pollutants from Table 5.

Table 5: Previous researches on adsorption kinetics of CFA

Adsorbate	Sample	Pseudo-first-order model		Pseudo-second-order model		Reference
		K_1	R^2	$K_2 (10^{-5})$	R^2	
MB	ZnCl ₂ (2:3)	0.03	0.96	0.235	1	(Mudyawabikwa et al., 2017).
Phenol	ACK1	0.083	0.8195	0.083	1	(Kilic et al., 2011)
	ACK2	0.192	0.8023	0.52	1	
SDS	CFAC-3	0.052	0.961	52	0.999	Zhang et al., 2020
	CFAC-4	0.067	0.971	59	0.999	
	CFAC-5	0.063	0.990	17.4	0.999	
	CFAC-6	0.072	0.993	12.6	0.998	
UO ₂ ²⁺	CFAC	0.014	0.963	11700	0.999	Pu et al., 2019
Phenol	MCM	0.418	0.952	0.039	0.997	Chen et al., 2015
	FDU-15	0.327	0.965	0.026	0.996	
	PCM	0.172	0.616	0.019	0.992	
Pb ²⁺	CFAC by nonmodified HNO ₃	0.0032	0.9517	0.000116	0.9771	Masoudi Soltani et al., 2013
	CFAC by modified HNO ₃	0.00527	0.9598	0.00016	0.9923	
CIP	CFAC-3	0.040	0.979	5.01	0.977	Zhang et al., 2020
	CFAC-4	0.037	0.983	6.1	0.984	
	CFAC-5	0.048	0.981	6.3	0.990	
	CFAC-6	0.048	0.964	8.3	0.967	

3.4 Adsorption Thermodynamics of CFAC

The adsorption thermodynamics of CFAC has been studied using the following equation (Liu et al., 2010)

$$\Delta G = -RT \ln K_0 \quad (6)$$

$$K_0 = \frac{c_{ad}}{c_e} \quad (7)$$

$$\Delta G = \Delta H - T \Delta S \quad (8)$$

$$\ln K_0 = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \quad (9)$$

The thermodynamics parameter standard free energy (ΔG), enthalpy change (ΔH), and entropy change (ΔS) has been determined using these equations where R (8.314 J/(mol K)) is the gas constant, T (K) is the absolute temperature, K_0 is the equilibrium constant, C_{ad} (mg/L) is the equilibrium concentration of adsorbate adsorption, C_e (mg/L) is the equilibrium concentration of adsorbate in an aqueous solution. ΔH and ΔS can be calculated from the intercept and slope of Vant Hoff plots of $\ln K_0$ versus $1/T$. The adsorption thermodynamics of CFAC using K_2CO_3 for phenol adsorption has been shown in Table 6 where more negative ΔG and ΔS with increasing temperature indicate spontaneous nature and decrease of randomness for phenol adsorption process. Also, the negative value ΔH indicates the exothermic process of phenol adsorption.

Table 6: Adsorption thermodynamics of CFAC (Kilic et al., 2011)

Adsorbate	Temperature (K)	ΔG (kJ/mol)	ΔH (kJ/mol)	ΔS (kJ/ mol k)
Phenol	293	-7.423	-13.97	-22.96
	303	-6.710		
	313	-6.789		

4. CONCLUSIONS

The review represents (i) the characteristics of activated carbon prepared from cigarette filters, (ii) introduces the preparation of activated carbon from cigarette filters (iii) the utilization of CFAC for water contaminants. The literature review revealed that the low-cost activated carbon from CFs can be a great alternative for water purifying. In this literature review, table 1-6 has been demonstrated to show the previous works on removing water contaminants using CFAC where the optimum value has been given to get the best result for removing those contaminants. It was found that the CFAC prepared from KOH chemical activation with the ratio of 1:5 (CM: KOH) at 900°C can achieve a higher BET surface area which is $2726 \text{ m}^2 \text{ g}^{-1}$. The CFAC shows good adsorption capacity for different pollutants where the comparison is difficult since it varies depending on the experimental conditions and also on pH values. The previous researches on the adsorption isotherm and adsorption kinetics of CFAC for different pollutants have been listed in this review also. The result shows that the Langmuir isotherm is more suitable to describe all the pollutants except lead adsorption from an aqueous solution. The Freundlich isotherm is more suitable to describe lead adsorption. The result also shows that the Pseudo-second-order model was more suitable to describe all the pollutants adsorption processes from an aqueous solution. Adsorption thermodynamics has also been described in this review for phenol adsorption where the adsorption process shows spontaneous nature and decrease of randomness due to more negative ΔG and ΔH .

The recommendations for future works are outlined below:

- (i) As the adsorption capacity depends on different factors like adsorbate-adsorbent relationship, variety of compounds, size of the adsorbent, type of adsorbates, more detailed works needed to be done to understand the interactions to correlate and compare.
- (ii) Even though a little modification of adsorbent can increase the adsorption capacity, less work has been done on the improvement of adsorption capacity.
- (iii) There are several studies on CFAC that have been utilized for removing pollutants from water, gas. Thus, there can be a lot more scope on utilizing CFAC in various sectors that can enrich the activated carbon industry.
- (iv) Even though the amount of CFAC produced at an industrial scale will be small in number, it is worthy of producing CFAC at an industrial scale to keep the environment safe. So, the Government should take the necessary steps on it.

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