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Comparative investigation of activated porous carbons treated by silver electroplating from aqueous solution

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Abstract : The electroplating of the Ag ions from aqueous solution on activated porous carbons was investigated over a wide range of plating time. The adsorption capacities of Ag metallic carbons were associated with their internal porosity and were related to physical properties such as surface area and pore size distribution. And, surface morphologies and quantitative analysis for the metal supported carbons are investigated by scanning electron microscopy (SEM) and energy disperse X-ray (EDX) measurements to explain the changes in adsorption properties. It is considered that the pH is an very important factor at the reason of water pollutant with increasing acidity in industrial field. The results of ICP-AES analysis showed that the residual concentration of Ag ions decreased with an increasing electroplating time. The metallic Ag-activated porous carbons electroplated showed microbicidal effects and strong antibacterial activity against six kinds of strains that were used. Finally, we confirmed that the presence of the electrolytic plated Ag-activated porous carbons is a determining factor in the HCl removal by chemical reaction, clarifying the surface chemical behavior.

Key words : adsorption, SEM, EDX, electroplating, antibacterial activity, HCl removal

1. Introduction

Activated carbons and their fibers are widely used in different branches of industry, for adsorption of unwanted substances from both gas and liquid phase, as catalytic supporters and catalysts in technologies characterized by requirements for very high quality products.[1] Adsorption properties play an important role in the modern industries, especially in the field of environmental treatment for large scale chemical, electrochemical, biochemical, environmental recovery, purification and protection engineering.[2] Adsorption processes in the industrial field are being employed widely in liquid-solid, gas-solid and gas-gas operation such as the decolorization of petroleum products, and for the removal of pollutants from aqueous or gaseous effluents. Most metals and metal salts present in industrial wastewater are toxic, poorly retrievable and not easily biodegradable. Adsorption on activated carbon is an attractive alternative to eliminate these contaminants from industrial effluents and water sources. However, the effect of process conditions on the electrochemical adsorption of metals and their salts must be fully understood in order to optimize the use of activated carbon on an industrial scale.

Usually, transition metals are deposited into the

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supports by electrochemical deposition,[3] ion exchange method[4] and vapor evaporation under vacuum.[5] Activated carbon fiber and activated carbon materials can also reduce ions of higher standard potentials to elemental metals or lower valence ions.[6,7] The applications of activated carbon fiber and activated carbon indicating electrodes in potentiometeric systems showed that when these materials are in contact with metal ions (Ag^{+}, Cu^{2+}, Ni^{2+}, Pd^{+} etc.) solutions its electrochemical properties changed, as a consequence of spontaneous metal ions deposition or the surface of the carbon materials.[8] Such metal modified carbon electrodes can also be used as antibacterial agents,[9] catalysis,[10] or electrocatalysis.[11] Because these metals are different from ionization tendency and Coulombic force and electrochemical behavior, the study of the properties of modified activated carbon is very important in the electrochemical treatment of metal ions. The inclusin of metal ions on granular activated carbon and activated carbon fiber can be used for shielding of electromagnetic field. The sorption capacity of the metal ions and electrochemical behavior of activated carbon fiber with pre-adsorbed metal ions are strongly influenced by the chemical surface structure of the supported activated carbon materials.

This paper deals with a comparative investigation of metallic Ag supported on activated porous carbons at a much lower concentration. This study is aimed to test a homemade activated carbon fiber and activated carbon monoliths, for example, is able to remove Ag ions from aqueous solutions and to use antibacterial agents. The variations in the surface properties, such as adsorption isotherms, surface areas and pore size distribution of the fiber and monolith typed carbons are investigated as a function of electroplating time. And, the surface morphologies on their carbon surfaces and quantitative elemental analysis are investigated by SEM and EDX to explain the changes in adsorption properties. After electroplating reaction, the quantitative properties in Ag ion solutions are also examined by pH variation and elemental analysis by ICP-Atomic Emission Spectrometer. For the biological effects of metallic Ag supported activated porous carbons, we investigated the bactericidal effects for six kinds of strains. Finally, we also investigated the catalytic removal of HCl by determining factor for the outlet concentration.

2. Experimental

2.1. Preparation of activated carbon fiber and monolith

Homemade ACFs were used as a raw materials and prepared from commercial PAN fiber. The fiber was burned off first at 450°C, then chemically activated with KOH and K_2CO_3 at the temperature range of 900~950°C. For the electrochemical metal treatment, $AgNO_3$ (Aldrich, 99+%, ACS reagent) were used as a Ag source.

For the preparation of activated carbon electrode, a powder activated carbon has been chosen from a series of chemically activated carbons prepared using KOH as the activating agent and an Indonesian coconut shell as the raw material. The results of elemental analysis (Ce 1110 Elemental analyzer, USA) for the non-plated PAN fiber and activated carbon are listed in *Table* 1. After preparing a large quantity of this activated carbon, novolac phenol resin (PR) as the binder material could be used for the preparation of the activated carbon electrodes. The amount of PR for the preparation was 15~20 wt%. For the binding effect, bentonite as the additive material was used for the preparation. The amount of that was about 5 (AC1) and 10 wt% (AC2). The

Table 1. Characteristics of the starting law materials

Law Materials	$S_{BET}(m^2/g)$	Volataile Matter (%)	Ash Content (%)	Elemental Analysis(%)				
				C	H	S	N	O
Activated Carbon Fiber	1921	1.93	0.12	95.66	0.92	0.00	1.13	2.25
Activated Carbon	1258	2.33	3.24	87.70	1.87	0.01	1.09	3.76

binder/bentonite/activated carbon mixtures were dried to a powder and then pressed into 9.95×39.5 ×5.95 hexagonal pellets in a mould. The curing temperature of the pelletized activated carbon monolith was about 150°C. The cured sample were then pyrolyzed at 750°C for 3h in order to completely carbonized the binder. The results of elemental analysis for the original activated carbon fiber and activated carbon are also listed in *Table* 1.

2.2. Electrochemical characteristics

The working electrodes were consisted of the size of 20 (b)×50 (h)×5 (t) mm of felt type activated carbon fiber and of 9.95 (b)×39.5 (h)×5.95 (t) of monolith type activated carbon, respectively. The counter electrode was an artificial graphite rod. The electrolyte was 0.01 M silver nitrate solution. The electrodes were operated with 0.5 $mAcm^{-2}$ at room temperature for the investigation of behavior of electroplated metal silver on the carbon surface. The measured voltage was set to 4.5 V. For the electroplating of the Ag ions on the carbon surface from aqueous solution, deposition times in the ranges from 30 s (0.5 min) to 10 min were used.

2.3 Measurements and analysis

After electroplating reaction in Ag ion solution depending on plating time, characterization of all porous Ag-plated activated carbons was carried out by the physical adsorption of gases (N_2 at 77K) using an automatic adsorption system (Degisorb 2500, Micrometric Instrument Corp, USA). The micropore volume has been calculated from the application of the Dubinin-Radushkevich (DR) equation to the N_2 adsorption at 77K. Scanning electron microscopy (SEM, JSM-5200 JOEL, Japan) was used to observe the surface state and pore structure of metal plated activated carbon and the plated metal state. For the elemental analysis of metal contents in activated carbon, EDX was also used. For the quantitative analysis in Ag ion solutions after electroplating, Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES, Jovin Yvon Ultima-C) was used to obtain elemental quantitative data. A combination pH electrode (EYELA Model AR 10) was used to measure the solution pH.

Table 2. Test strain used of bactericidal effect

Test Strains	No
Escherichia coli	ATCC 25922
Staphylococcus aureus	ATCC 25923
Salmonella typhi	ATCC 19430
Shigella flexnari	ATCC9199
Vbrio parahaemolyticus	KCTC 2471
Bacillus cereus	ATCC 9634

2.4. Bactericidal test

For quantitative analysis of bactericidal effects, shake flask method was employed. The bactericidal activity against strains used was examined in cultivated culture medium. The strains are listed in *Table* 2. For the test, the prepared Trypticase Soy Broth (TSB badge, ca. 121°C, 15 min.) 300 mL of the solution was sterilized first. Then, each strains was cultivated for 24 h under the conditions of constant humidity and temperature of 37°C. After culturing, the phosphate buffer solution was added in above cultured solution. Strain in the solution was counted again. The solution of the counted strain was filtered through the filter media ACF and ACs plated Ag ions. After the filtering, the number of bacteria caused by bactericidal effects was counted. It was carried out again after 15 min under the constant humidity and temperature. Detailed procedures were presented in former study.[12]

2.5. HCl gas removal

The HCl gas removal experiments as followed by ASTM is detailed D3467-94 method for the determination of carbon tetrachloride activity.[13] A given amount of Ag-plated activated porous carbon (ca. 30 mg) was weighed and placed into a U-typed glass tube. The removal temperature, ranging from 278 to 354 K, was controlled by water bath. The pure liquid adsorbate, contained in a volumetric flask, was immersed in a separated water bath. Purging the nitrogen gas over the pure liquid adsorbate generated the HCl vapor continuously. The HCl concentration depended on the flow rate of the

nitrogen gas and the temperature of the water bath. The HCl removal efficiency was measured by using gas-detecting tubes of two types. In this study, the concentration of HCl was controlled at about 1000 ppm. The nitrogen gas carried the HCl vapor into the U-typed glass tube containing weighed Ag-plated activated carbon sample. The contact time of HCl vapor and Ag-plated activated porous carbon sample was 12 h.

3. Results and Discussion

The studies on the electroplating of metal ions to the activated carbon fibers and activated carbons indicated that such a process consists of several consecutive steps[8] : transfer of the solvated ions (metal ions) from the bulk solution to the proximity of the carbon surface, adsorption of the metal ions and growth of metals on the carbon surface, surface diffusion of metal ions toward active centers, reduction of metal ions on the carbon surface, incorporation of the metals into the carbon lattice. This method for the electroplating of metal has merits of homogeneous distribution of metals on the fiber carbon without impurities like a metal oxide compounds. The chemical industry generates wastewater that contains toxic matters like heavy metals in small concentrations so that their economic recovery is not

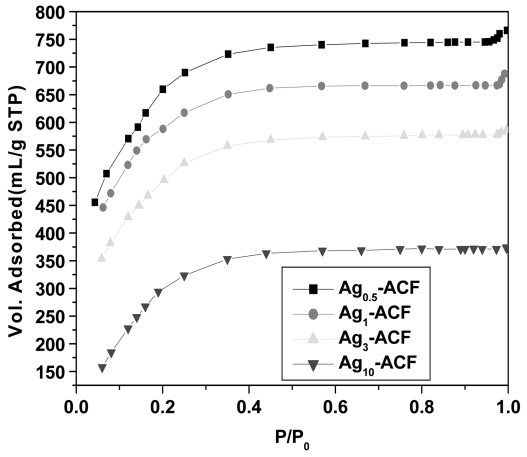

Fig. 1. Time dependence of adsorption isotherm for electroplated Ag-ACFs.

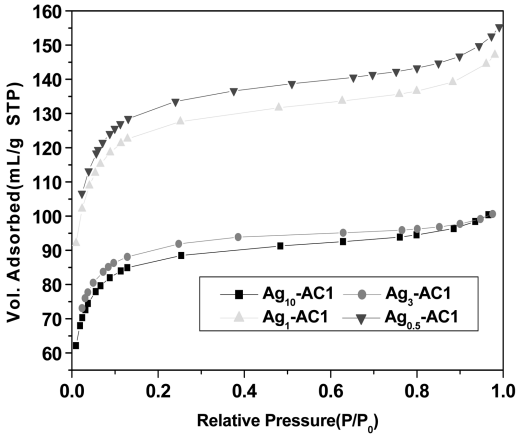

Fig. 2. Adsorption isotherm plotted on the relative pressure scale for the porous AC1s at 77.3 K.

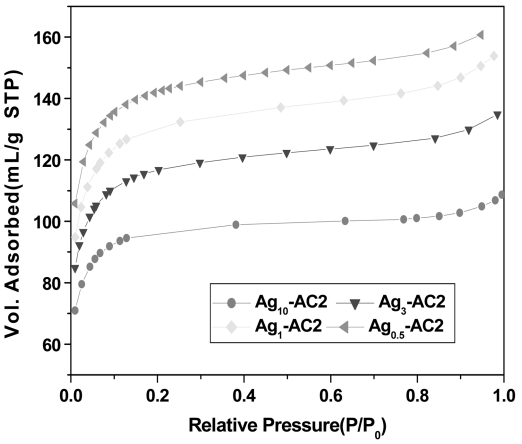

Fig. 3. Adsorption isotherm plotted on the relative pressure scale for the porous AC2s at 77.3 K.

feasible. But, the method using activated carbon fiber electrode can be used to withdrawal of heavy metals in wastewater. To compare the adsorption properties after metallic Ag electroplating, the N_2 (at 273K) adsorption isotherms of Ag-plated samples were obtained in a volumetric system. The isotherms of series of silver electroplated activated carbon fibers and activated carbons prepared from various amounts of Ag solution are obtained and shown in *Fig.* 1, 2 and 3. The isotherms are on Type I, characteristics of microporous solids and they show a plateau isotherm reflecting a minimum presence of mesopores. In those figures, it can be seen that nitrogen adsorption capacities decrease with increasing

electroplating time. It is consider that the formed macropore, mesopore and wider micropore on the surface before electroplating are transformed to micropore and narrow micropore. The isotherms are characteristics of predominantly micropores solids with some contribution by the micropores. The adsorption isotherms presented in these Figures that the total sorption uptake decreases with increasing plating time. Comparing the isotherms for these samples, it is noticed that the amount of adsorbed N_2 is slowly increased in the region where the relative pressure is lower than 0.3, but the amount is nearly constant, once the pressure becomes higher than 0.3. In case of isotherms in *Fig*. 2 and 3, the amount of adsorbed N_2 is abruptly increased in the region where the relative pressure is lower than 0.2. Those phenomena are known as typical characteristics for microporous carbons. From the isotherms, it is known that the Ag-ACFs, Ag-AC1s and Ag-AC2s obtained under 30 s and 1 min treatment exhibit higher adsorption volume than that of any other samples. As shown in those Figures, the amounts of adsorbed volume decrease with prolonged plating time for the electroplating. It can be observed that the nitrogen adsorption capacity is very similar in these cases. Thus, it can be said that the preparation process of the activated porous carbon electrodes does not produce mesoporosity due to transformed to micropores and narrow micropores by the increased density due to high contents of silver.

Table 3 shows the specific surface area (S_{BET}) and average pore diameter from BET method and the application of the DR equation of the Ag supported samples obtained. The areas of Ag supported activated porous carbons are in the range of 913.8~1642.3 m^2/g for ACFs, 329.7~499.7 m^2/g for AC1s and 317.7~544.3 m^2/g for AC2s. The surface area decreases by the factor of plating time. And average pore diameters are distributed to the range of 11.6~17.7 Å for Ag-ACFs, 25.29~30.23 Å for Ag-AC1s and 23.63~30.54Å for Ag-AC2s, respectively. The average pore diameter is almost constant for samples plated to deposition time. The biggest difference do not exists among samples.

The pore size distributions (PSDs) calculated for our materials using the density functional theory are shown in *Fig*. 4, 5 and 6. In case of *Fig*. 4, especially, it is natural to assume that such sub-micropore was formed by the widening of micropores which existed in the samples after metallic Ag supported. The developments of micropores for Ag-AC1s and micro- and mesopores for Ag-AC2s are observed with increasing plating time. For the pore analysis of Ag-plated activated carbons, it is believed that treatment time produces a significant increase in number of micropore and small mesopores along with a decrease in number of mesopores. Consequently, the AC2s have a border pore size distribution, the AC1s

Table 3. Comparison of S_{BET} and pore radius after electroplating for (a) Ag-ACFs, (b) Ag-AC1s and (c) Ag-AC2s

Sample		S_{BET} (cm^3/g)	Average Pore Diameter(Å)
Ag-ACFs	$Ag_{0.5}$-ACF	1642.3	17.67
	Ag_1-ACF	1583.6	15.98
	Ag_3-ACF	1321.7	13.40
	Ag_{10}-ACF	913.80	11.61
Ag-AC1s	$Ag_{0.5}$-AC1	499.7	29.47
	Ag_1-AC1	484.7	25.29
	Ag_3-AC1	342.5	30.23
	Ag_{10}-AC1	329.7	25.87
Ag-AC2s	$Ag_{0.5}$-AC2	544.3	23.63
	Ag_1-AC2	502.3	25.89
	Ag_3-AC2	448.3	24.89
	Ag_{10}-AC2	317.7	27.63

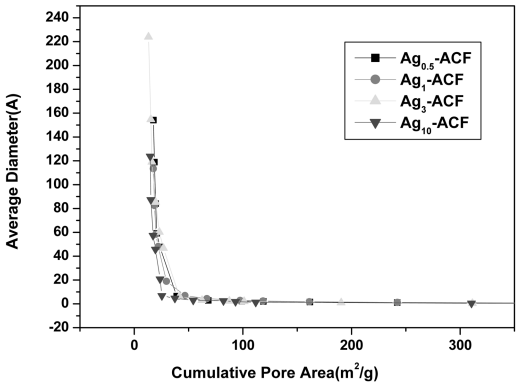

Fig. 4. Pore size distributions obtained from the porous Ag-ACFs.

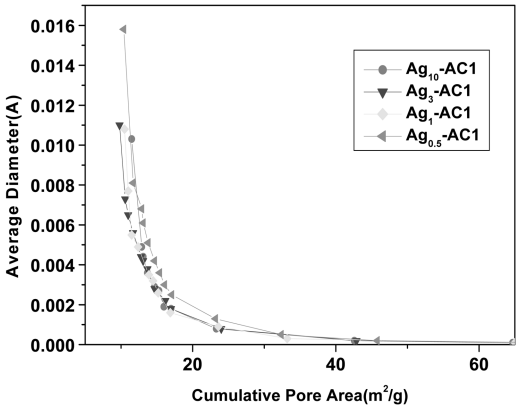

Fig. 5. Pore size distributions obtained from the porous Ag-AC1s.

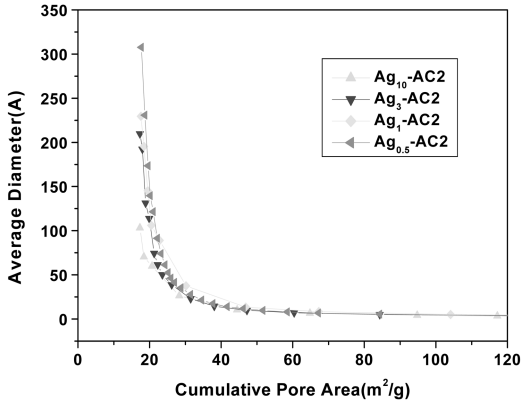

Fig. 6. Pore size distributions obtained from the porous Ag-AC2s.

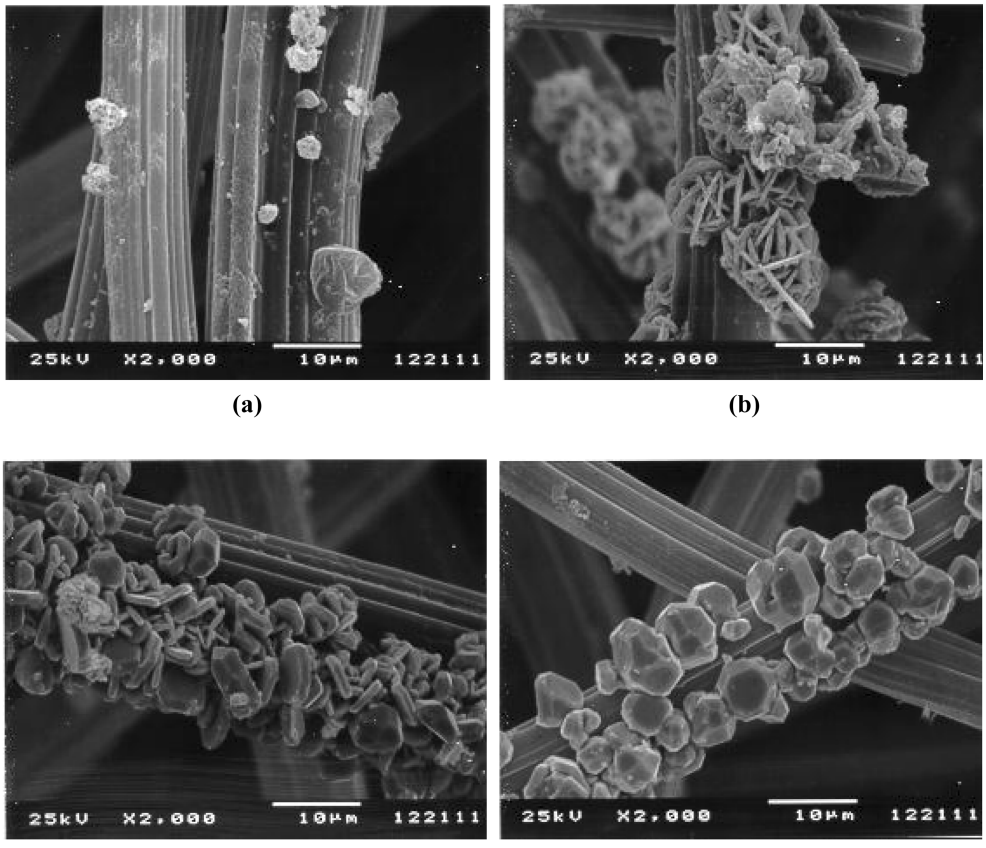

Fig. 7. SEM images after electroplating of Ag with ACF in 0.01 M Ag solutions ; (a) Ag $_{0.5}$-ACF, (b) Ag $_{1}$-ACF, (c) Ag $_{3}$-ACF and (d) Ag $_{10}$-ACF.

have obviously mesopores.

The surface morphology and crystal grown state of metal on the carbon surface are investigated by scanning electron microscopy. The SEM images are

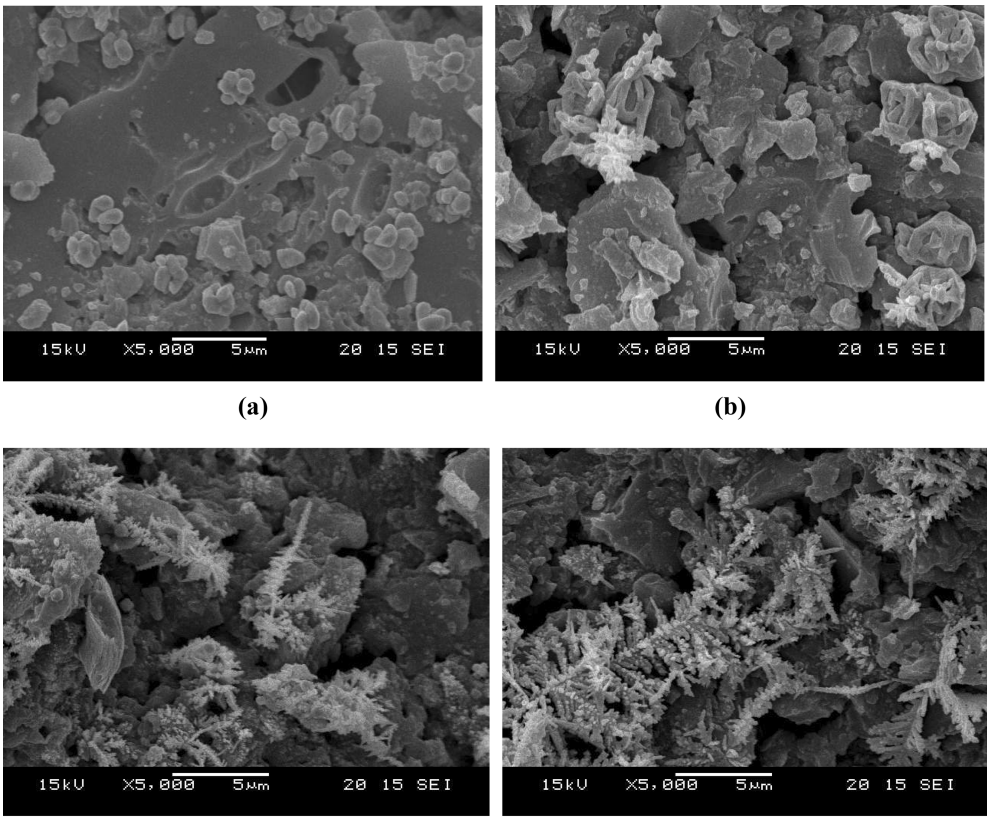

Fig. 8. SEM images of porous AC1s; (a) Ag $_{0.5}$-AC1, (b) Ag $_{1}$-AC1, (c) Ag $_{3}$-AC1 and (d) Ag $_{10}$-AC1.

shown in *Fig.* 7, 8 and 9. In the *Fig.* 7, one can clearly observe the highly developed creaks and cavities, and homogeneously distributed metals and grown crystal particles plated on the fiber surface. It is considered that developed crcaks and cavities, distributed metal and their crystal particles are affected to pore structures like a S_{BET}, micropore volume and pore radius. The outer surface states of activated carbon fibers are transformed by the plated metallic silvers. In case of the *Fig.* 7, it is observed that metallic Ag particles on the surface are dispersed to heterogeneous and random distribution. Almost all of the particles are larger than 0.01 nm in size when the plated time is longer than 1 min. Since the size of particles is larger than that of cavities or crcaks, several metal particles are observed in blocked cavities or crcaks and coated carbon surface. As the plated time becomes longer, the particles are growing to form greater crystals. From the SEM micrographs for AC1s and AC2s samples with different metal loading time of Fig. 8 and 9, all samples seem as a porous metallic Ag supported activated carbon with any visible pores, cavities and bulk solid on the surface. At the same time, the measured specific surface area of the samples is very low and ranged from 317.7 m^2/g to 544.3 m^2/g. This fact is well correlated with previous works[4,6,7] and a unique microporous structure of metal-plated activated carbon was demonstrated; activated carbon contains mainly micropores with narrow size distribution between 0.001 and 0.002 nm invisible in the images presented in *Fig.* 8 (a) and (b), and 9 (a) and (b). The effect of increasing electroplating time on the Ag-plated activated carbon surface morphology is

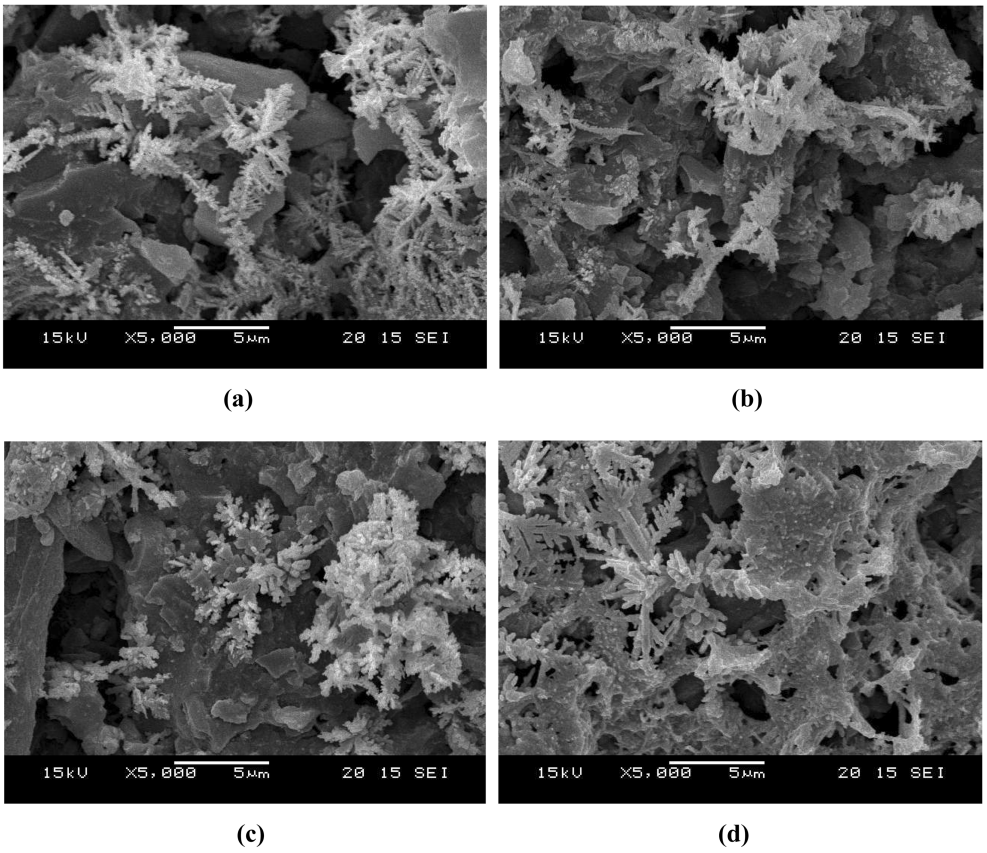

Fig. 9. SEM images of porous AC2s; (a) Ag $_{0.5}$-AC2, (b) Ag $_{1}$-AC2, (c) Ag $_{3}$-AC2 and (d) Ag $_{10}$-AC2.

clearly observed by the SEM images (*Fig.* 8 and 9). The image of activated carbon electroplated for 30 s in Ag solution is much the same as that of the original activated carbon. This observation indicated that practically all the Ag introduced is located inside the micropores and consequently, it is dispersed into very small crystallites. Ag contents above plating time of 3 min in Ag solution lead to drastic morphology changes: large Ag particles on the activated carbon outer surface are clearly visible and presented in the *Fig.* 8 (c) and (d), and 9 (c) and (d) for the plating time 3 min and 10 min, respectively. The increasing time of large Ag particles on the activated carbon surface resulted in clogging and blocking of micropores and this fact is well considered with specific surface area measurements. Finally, the metallic Ag supported is located between micropores and out side surfaces of activated carbon and the metallic Ag plated to above 3 min is distributed on the out side surface in the form of metallic crystal and aggregates. So, in this study, it two types of Ag/activated porous carbons were prepared and investigated ; the first one is that all Ag is located in macropores with pore filling and blocking, another one is that the Ag is located both in macropores and on the out to cated surface of activated carbon.

Energy disperse X-ray (EDX) spectra of metallic Ag supported activated porous carbons are shown in *Fig.* 10, 11 and 12. And, the results of EDX elemental microanalysis of metallic Ag plated activated porous carbons are shown in *Table* 4, 5 and 6. Almost all samples are richer in carbon and silver than any other elements. The most important heteroatoms in the activated carbon are oxygen, which is usually bonded to peripheral carbon atoms at the edges of the crystallites. The most common functional groups

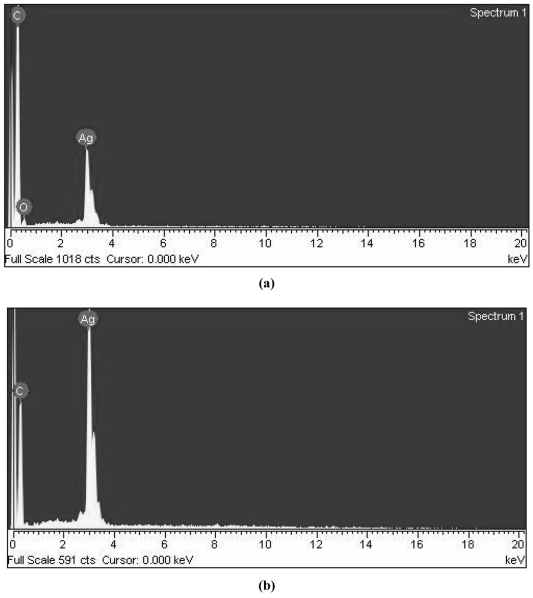

Fig. 10. Typical EDX microanalysis of the Ag-ACFs; (a) $Ag_{0.5}$-ACF and Ag_{10}-ACF.

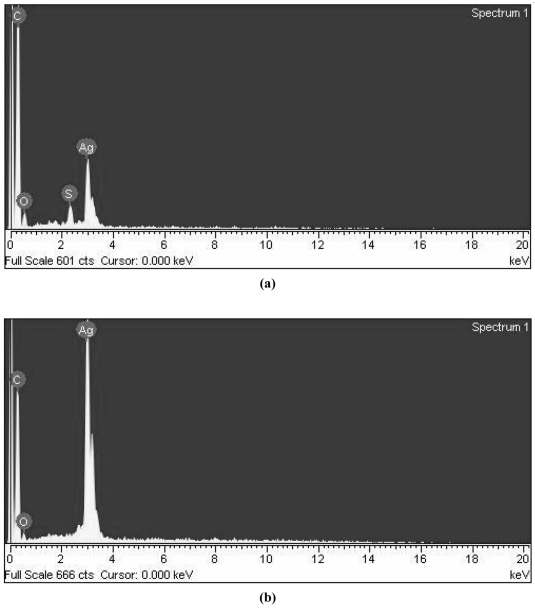

Fig. 11. Typical EDX microanalysis of the Ag-AC1s; (a) $Ag_{0.5}$-AC1 and Ag_{10}-AC1.

are carboxylic, carbonyls, phenols and lactones. These functional groups may play a role in the sorption and deposition of nonpolar molecules and metallic ions by creating obstacles for physical

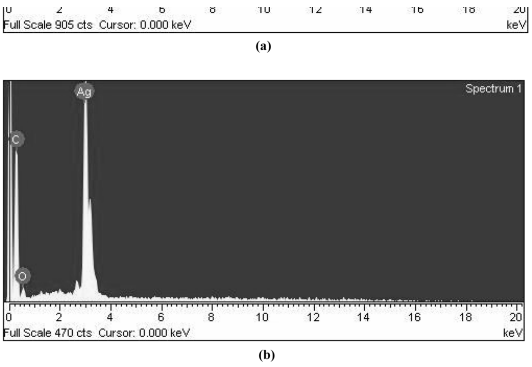

Fig. 12. Typical EDX microanalysis of the Ag-AC2s; (a) $Ag_{0.5}$-AC2 and Ag_{10}-AC2.

Table 4. EDX Elemental micro-analysis of Ag-ACFs

	Elements(%)		
	C	Ag	O
$Ag_{0.5}$-ACF	66.15	25.76	8.06
Ag_1-ACF	60.30	36.21	3.49
Ag_3-ACF	51.45	41.34	7.21
Ag_{10}-ACF	28.95	65.84	5.21

Table 5. EDX Elemental micro-analysis of Ag-AC1s

	Elements(%)			
	C	Ag	O	others
$Ag_{0.5}$-AC1	81.66	8.01	7.36	2.97
Ag_1-AC1	72.95	13.75	10.91	2.39
Ag_3-AC1	55.32	35.68	7.26	1.74
Ag_{10}-AC1	9.78	87.34	2.25	0.63

Table 6. EDX Elemental micro-analysis of Ag-AC2s

	Elements(%)			
	C	Ag	O	others
$Ag_{0.5}$-AC2	82.11	9.44	6.25	2.20
Ag_1-AC2	69.34	24.09	3.96	2.61
Ag_3-AC2	18.14	75.84	4.88	1.14
Ag_{10}-AC2	7.96	85.24	4.41	2.39

adsorption and occuring the molecule from occupying the most energetically favorable position on the carbon surface. And, *Fig.* 10 (b), 11 (b) and 12 (b) presented for each samples (Ag_{10}-ACF, Ag_{10}-AC1 and Ag_{10}-AC2) show the spectra corresponding to almost all samples rich in silver with increased plating time. Note that for the electrochemically 30s-plated activated carbon sample (*Fig.* 10 (a), *Fig.* 11

(a) and *Fig.* 12(a)) a nonhomogeneous distribution of Ag is obtained, which becomes more homogeneous as the carbon surface is oxidized. These changes seem to indicate that the functionality of activated porous carbons surface affects the dispersion of the Ag, which is enhanced with increasing of concentration of (+) charges on the activated porous carbons electrode on the condition of increasing of acidity in solution.

The electroplating of metallic Ag ions with pH variation in solution was studied using activated porous carbons depending on several different times. It is observed that the pH variation is abruptly decreased in the beginning of electroplating reaction, but the concentrations in each Ag solutions are nearly constant once the time becomes higher than 3 min. In addition to, the pH in each Ag solutions is continuously decreased from the beginning point to the end point. It is considered that the pH is very important factor at the reason of water pollutant with increasing acidity in industrial field. According to Bansal *et al.*,[14] it is suggest that the amount of adsorption was a function of the total metal ion concentration and pH of the solution as well as the nature of the used carbon. Activated carbon and ion exchange resins have been used to remove trace metal ions from liquid waste and drinking water. From the results, it is revealing that the pH used for removing the trace metal ions of solution is decreased with increasing adsorbed metal contents on activated porous carbon electrode. The differences in adsorption properties among the metal species are mainly due to electrochemical behavior of metal ions in solution. The results from *Fig.* 10, 11 and 12 seem to corroborate those obtained by pH variations (*Fig.* 13). Oxidation of the carbon surface is the principal vehicle for achieving high Ag dispersion by introducing (–) charged oxygen functional groups that serve as anchoring sites for the metallic Ag. The access of silver anions to these sites is, therefore, favored by attractive electrostatics forces. One could expect that very low treatment pH values, when the interactions between the activated carbon and the Ag ions are favorable, could be appropriate to achieve

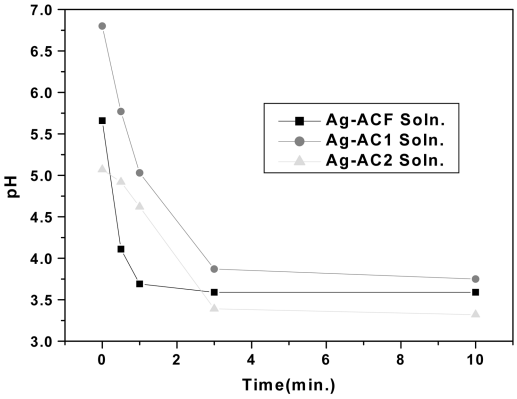

Fig. 13. pH variation after electroplating reaction in Ag solution.

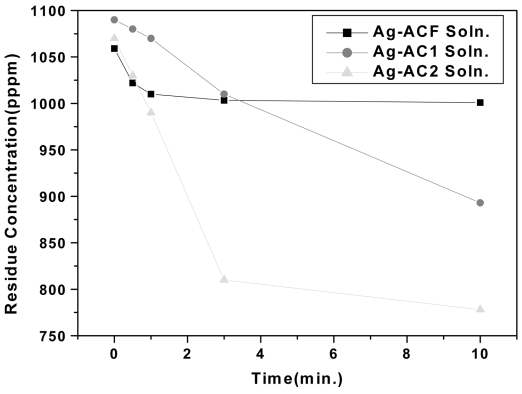

Fig. 14. Result of ICP analysis after electroplating reaction in Ag solution.

high Ag dispersion. The problem of an insensible metallic Ag to the changes produced on the surface functionality of carbon seems to stem from the conflict that exists between active site creation and surface accessibility.[9]

The results of quantitative analysis using inductively coupled plasma-atomic emission spectrometer of metal after electroplating reaction in Ag solution depending on time are shown in *Fig.* 14. The results are shown that the amount of all of Ag used was decreased with increasing time electroplated. Especially, the amount of Ag ions of Ag-AC2 operated was abruptly decreased in the beginning of electroplating reaction. But, the amount of Ag ions of Ag-ACF operated was nearly constant once the time becomes higher than 10 min. It is believed that

Table 7. Results of bactericidal effect for activated porous carbon

		$Ag_{0.5}$-ACF (CFU/ml)	$Ag_{0.5}$-AC1 (CFU/ml)	$Ag_{0.5}$-AC2 (CFU/ml)
E. Coli	Initial	5.3×10^5	4.1×10^5	6.2×10^5
	After 15 min.	< 10 (99.9%)	< 10 (99.9%)	< 10 (99.9%)
S. aureus	Initial	2.9×10^5	2.4×10^5	3.1×10^4
	After 15 min.	1.1×10^2(99.9%)	7.2×10^3(97.9%)	1.2×10^2(99.9%)
S. typhi	Initial	4.0×10^5	3.2×10^5	2.8×10^5
	After 15 min.	< 10 (99.9%)	< 10 (99.9%)	< 10 (99.9%)
S. flexneri	Initial	2.1×10^5	2.3×10^5	3.1×10^5
	After 15 min.	< 10 (99.9%)	< 10 (99.9%)	< 10 (99.9%)
V. parahaemolytic	Initial	2.4×10^5	2.1×10^5	1.9×10^5
	After 15 min.	< 10 (99.9%)	< 10 (99.9%)	< 10 (99.9%)
B. cereus	Initial	1.0×10^5	1.9×10^5	1.3×10^5
	After 15 min.	7.0×10^3(93.0%)	5.2×10^3(97.3%)	6.3×10^3(95.2%)

the trend of plating on activated porous carbon electrodes is concerned with ionization tendency and reactivity between used carbon and metal. Before metallic Ag ions reach the carbon surface, they must diffuse from the bulk solution through the concentration boundary layer to the carbon/solution interface. According to its character it is simply an ion transfer phenomena,[8] and consequently, should be well described by the simplified diffusion equation. For the fluidization, metallic Ag ions from the solution to the porous carbon surface may take place by a combination of diffusion and convection.

According to the former studies,[15,16] antibacterial activities were not shown quantitative properties for their effect. *Table* 7 shows the changes in the residual amount of strains used, respectively. Antibacterial activity of carbon samples ($Ag_{0.5}$-ACF, $Ag_{0.5}$-AC1 and $Ag_{0.5}$-AC2) was judged counting the number of each strain. The concentration of pristine used are presented about 10^5 CFU/mL (CFU, colony forming unit). In case of *E. coli, S.typhi, S. flexnari* and *B cereu,* the residual amount showed a constant value <10 CFU/mL (99.9%) in the all carbon samples after 15 min. However, the residual amounts of *S. aureus* and *B. cereus* were distributed to ranges between 1.1×10^2 CFU/mL (99.9%) and 7.0×10^3 CFU/mL 93.0%) after 15 min. The antibacterial effects with $Ag_{0.5}$-ACF, $Ag_{0.5}$-AC1 and $Ag_{0.5}$-AC2 appeared after a very short contact time between cells and porous carbons. As confirmed by bactericidal tests, the electroplated metallic Ag-activated porous carbons showed microbicidal effects and strong antibacterial activity against strains used.

The activities of Ag-activated porous carbons for HCl removal are shown in *Fig.* 15. The electrochemically plated Ag_1-ACF, Ag_1-AC1 and Ag_1-AC2 for the each classified samples shown much higher removal efficiency then that of any other samples. It is considered that the removal efficiency depended on Ag-content and specific surface area. Overall of the samples are present to very excellent HCl removal efficiencies over Ag plated activated porous carbon catalysts. These observations are consistent with the conclusion that silver chloride compound on the carbon surfaces take place until all available silver is reacted after which additional occurs as a result of electroplating. On the basis of the results obtained during this research, the removal and sequestration of chloride by Ag-activated porous carbons is interplay between chloride concentrations, silver content of activated carbons. Especially, the removal results of Ag-ACFs showed minimal out concentration of HCl to 200 min contact time. The detecting outlet concentration for all samples decreases with increasing electrolytic plated time. The orders of HCl removal efficiency are present to Ag-ACFs >

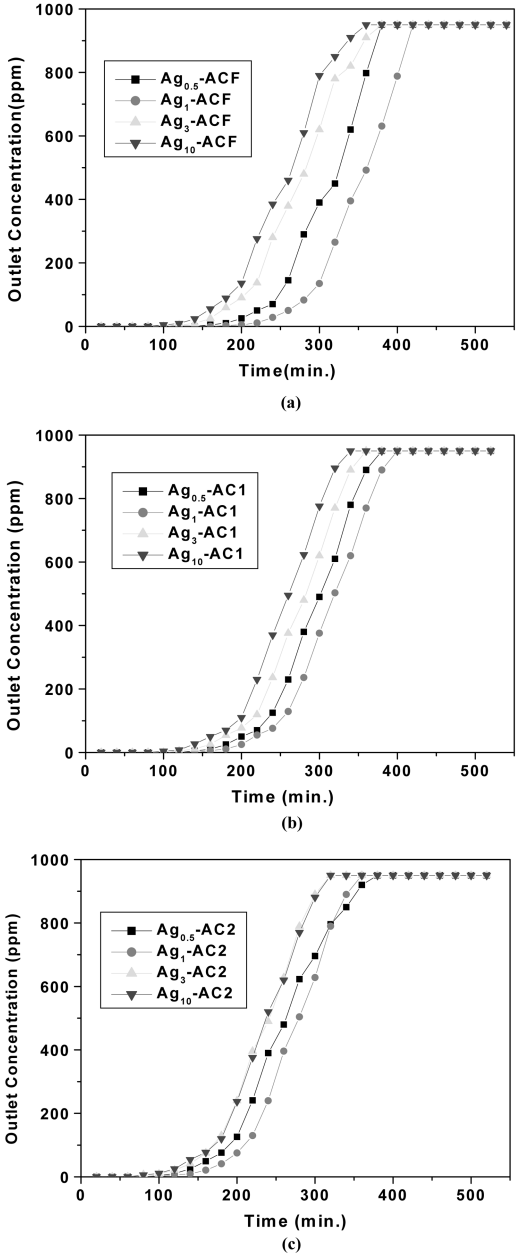

Fig. 15. HCl removal efficiency of the electroplating Ag-plated activated porous carbons; (a) Ag-ACFs, (b) Ag-AC1s and (c) Ag-AC2.

Ag-AC1s > Ag-AC2s.

4. Conclusion

These methods for the electroplating of metal have merits of homogeneous distribution of metals on the fiber carbon. The chemical industry generates wastewater that their economic recovery like heavy metals is not feasible. But, the method using activated porous carbons can be used to withdrawal of heavy metals in wastewater. In this study, the electroplating of the Ag ions from aqueous solution on activated porous carbon was investigated over the wide range. The results obtained show that adsorption capacities of Ag-activated porous carbons were associated with their internal porosity and were related properties such as surface area, pore size distribution. And, the surface morphologies and quantitative analysis for the metal plated carbons are investigated by SEM micrographs and EDX spectra to explain the changes in adsorption properties. From the pH variations, it is observed that the pH is abruptly decreased in the beginning of electroplating reaction, but the concentrations in each Ag solutions are nearly constant once the time becomes higher than 3 min. The result of quantitative analysis using ICP-AES of metal after electroplating reaction in Ag solution depending on time are shown that the amount of all of Ag used was decreased with increasing time electroplated. As confirmed by bactericidal tests, the electroplated metallic Ag-activated porous carbons showed excellent micro-bicidal effects and strong antibacterial activity against strains used. Finally, we confirmed that the removal efficiency is depended on Ag-content and specific surface area.

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