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Using Silver Nanoparticles Coated on Activated Carbon Granules in Columns for Microbiological Pollutants Water Disinfection in Abu Rawash area, Great Cairo, Egypt

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Abstract: The present work highlights the high efficiency of silver nanoparticles (Ag-NPs) coated onto activated carbon (AC) granules in antimicrobial activities for water purification. Silver nanoparticles (Ag-NPs) were prepared by polysaccharide reduction method. Silver nitrate was taken as the metal precursor and glucose as a reducing agent. The formation of silver nanoparticles was monitored using UV-Vis spectroscopy. Activated carbon (AC) granules were coated with silver nanoparticles by impregnation of AC in super saturation solutions with different concentrations of Ag-NPs. The resulted Ag-NPs/AC were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). The antimicrobial susceptibility of the synthesized Ag-NPs/AC was investigated using inhibition zone, impregnation and column techniques against *E. coli*. The results reflect the high efficiency of the prepared Ag-NPs coated onto AC granules for the water disinfection from microorganism in a short period of time (maximum of 5 min) even at higher *E. coli* counts ~ 10^6 cfu/ml. Ag-NPs/AC was also used as column form for water purification. At a flow rate of 0.8 L/min, the output count of *E. coli* was zero when the input water had a bacterial load of□10^4 cfu/ml. Ag-NPs coated onto AC granules performed efficiently in bringing down the bacterial count of four actual polluted samples to zero. Combined with low cost and effectiveness in prohibiting the growth of *E. coli*, such materials should have wide applications to drinking water disinfectant.

Key words: *Silver nanoparticles, Activated carbon, Column, Water disinfection*

INTRODUCTION

Water resources are fast dwindling as a result of rapid increase in world population and global warming. Therefore, discrete utilization of water resources and reuse of treated wastewater for different purposes have been recognized as the most effective ways for conserving the limited resources of freshwater (Kalkan *et al*., 2011). The presence of bacteria is the main indication of water contamination. Bacterial contamination of water is a public health concern because it causes numerous diseases and some aesthetic problems such as malodor in water. Organisms such as *Escherichia coli, Shigella* spp., *Salmonella* spp., *Vibrio* spp., and *Cryptosporidiu*m are known to be transmitted by water and cause ill health in communities consuming water contaminated by bacteria (Lukhele *et al*., 2010).

World Health Organization (WHO) investigation showed that 80% of disease is due to contaminated drinking water. The WHO recommended that any water intended for drinking should contain fecal and total coliform counts of 0 in any 100mL sample (Prashant and Pradeep, 2005). Although disinfection methods currently used in drinking water treatment can effectively control microbial pathogens, researches in the past few decades have revealed a dilemma between effective disinfection and formation of harmful disinfection byproducts (DBPs). Chemical disinfectants commonly used by the water industry such as free chlorine, chloramines and ozone can react with various constituents in natural water to form DBPs, many of which are carcinogens (Li *et al*., 2008). Furthermore, the resistance of some pathogens, such as Cryptosporidium and Giardia, to conventional chemical disinfectants requires extremely high disinfectant dosage, leading to aggravated DBP formation. Therefore, there is an urgent need to re-evaluate conventional disinfection methods and to consider innovative approaches that enhance the reliability and robustness of disinfection while avoiding DBP formation.

Activated carbon (AC) has been proven to be an effective adsorbent for the removal of a wide variety of organic and inorganic pollutants from aqueous or gaseous media (Cook *et al*., 2001 and Crittenden *et al*., 1993). It is widely used, due to its exceptionally high surface area (ranges from 500 to 1500 $m^2.g^{-1}$), well-developed internal microporosity, and wide spectrum of surface functional groups. While the effectiveness of ACs to act as

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adsorbents for a wide range of contaminants is well documented, research on AC modification is gaining prominence due to the need to develop the affinity of AC for certain contaminants to facilitate their removal from water. It is essential to understand the factors that influence the adsorption of ACs prior to their modification in order to tailor their specific physical and chemical properties and enhance their affinity for metals and inorganic and/or organic species present in waters. These properties include their specific surface area, pore-size distribution, pore volume, and the presence of different types of surface functional groups (Rivera-Utrilla *et al*., 2011).

To meet this objective, it was found recently that the biological activated carbon (BAC) treatment, in which both adsorption and biological decomposition take place, has an advantage over conventional activated carbon treatment for the removal of organic substances (Suzuki *et al*., 1995; Takeuchi *et al*., 1995 and Mochidzuki, 1995). As the use of BAC treatment makes the whole facilities compact and the life of carbon longer, it has been attracting great attention as one of the most efficient advanced water treatment technologies, and is being applied to various treatment processes to remove pollutants (Suzuki *et al*., 1996). The rapid growth in nanotechnology has spurred significant interest in the environmental applications of nanomaterials. In particular, it's potential to revolutionize century-old conventional water treatment processes have been enunciated recently (USEPA, 2007 and Shannon *et al*., 2008).

Nanomaterials are excellent adsorbents, catalysts and sensors due to their large specific surface area and high reactivity. More recently, several natural and engineering nanomaterials have also been shown to have strong antimicrobial properties, including chitosan (Qi *et al*., 2004), silver nanoparticles (nAg) (Morones *et al*., 2005), photocatalytic TiO_2 (Cho *et al*., 2005 and Wei *et al*., 1994), fullerol (Badireddy *et al*., 2007), aqueous fullerene nanoparticles (nC60) (Lyon *et al*., 2006), and carbon nano tubes (CNT) (Kang *et al*., 2007). Unlike conventional chemical disinfectants, these antimicrobial nanomaterials are not strong oxidants and are relatively inert in water. Therefore, they are not expected to produce harmful effect. If properly incorporated into treatment processes, they have the potential to replace or enhance conventional disinfection methods.

Silver powders, having ultra fine and uniformly distributed particle size, are of considerable use in the electronics industry as thick film conductors in integrated circuits due to their unique properties such as high electrical and thermal conductivity, high resistance to oxidation (Janardhanan *et al*., 2009 and Lee and Chou, 2005). Apart from electronic applications, it has been known for centuries that silver has bactericidal properties. Silver is a safe and effective bactericidal metal because it is non-toxic to animal cells and highly toxic to bacteria such as *Escherchia coli* (*E. coli*) and *Staphylococcus aureas* (Klueh *et al*., 2000 and Sharma *et al*., 2009). Generally, silver nanoparticles (Ag-NPs) can be prepared by different methods. It was reported that Ag-Nps preparation by green synthesis approaches have advantages over conventional methods involving chemical agents associated with environmental toxicity. Among the green synthesis methods, there is polysaccharide method (Lee *et al*., 2007). This method has several distinct features: (i) Ag-Nps are prepared using water as an environmentally being solvent. (ii) sugars are available to be used as reducing agents. (iii) no other stabilizing agent or capping agent is required. (iv) sugars are very cheap and bio-friendly and (v) instead of keeping the nanoparticles in aqueous solution one can safely preserve in a desiccators for months and can be redispersed in aqueous phase whenever required (Kumar *et al*., 2004). The present work aims to study the coating of silver nanoparticles onto active carbon by green synthesis method where these nanoparticles are utilized in controlling the microorganisms in water. Further, the characterization of these materials is investigated by XRD and SEM techniques. Also, the advantages of these catalysts over the neat activated carbon have been emphasized in the study of the biological activity of these materials in controlling the microorganisms.

MATERIAL AND METHODS

2.1. Materials:

The chemical reagents used in this experiment were of analytical grade. Silver nitrate ($AgNO_3$, 99%) and glucose were obtained from Sigma-Aldrich and used as received. De-ionized ultra-filtered water prepared with a Milli-Q water purification system was used throughout the experiments. All glassware was washed by ultra-sonication in a mixture of de-ionized water and nonionic detergent, followed by thorough rinsing with Millipore water and ethanol for many times to get rid of any remnants of nonionic detergent and dried prior to use.

2.2 Activated Carbon Treatment:

The AC granules used in this study (commercial type) has been grinded, sieved to 1 mm size then purified by treatment with hot conc. HNO_3, a sequential hot distilled water, hot conc. NH_3 solution and a sequential hot distilled water for at least 3 times. AC was dried in an oven at 110 °C prior to its coating with silver nanoparticles.

2.3 Preparation of Silver Nanoparticles:

In this study, Ag nanoparticles were prepared using polysaccharide method. In this method, water was used

as an environmentally benign solvent and glucose as both reducing and capping agent. For the synthesis of silver nanoparticles, magnetic stirring was maintained during the entire experiment. Silver solution was ranged from 5 to 40 mM, while glucose quantity was kept at 4 times the weight ratio of $AgNO_3$ through this work, (Table 1).

Table 1: Compositional variables of silver nanoparticles preparation.

$AgNO_3$ (g)	Ag (mM)	Glucose (gm)	Water (g)
0.085	5	0.34	99.575
0.17	10	0.68	99.15
0.34	20	1.36	98.3
0.68	40	2.72	96.6

Firstly, glucose was dissolved in 20 ml de-ionized (di) water (solution A) in a dark reaction flask; silver nitrate of different amounts dissolved in the rest of di-water, given in table 1, (solution B) which was injected drop-wise into the reaction flask by a constant rate of 1 ml min^{-1}. The reaction mixture was then autoclaved at 15 psi, 121 °C for 15 min. A brownish colloidal solution of 500, 1000, 2000 and 4000 ppm of silver nanoparticles was obtained.

2.4 Coating of Silver Nanoparticles Onto the Activated Carbon Granules:

A 50 gm of the treated AC granules was impregnated in 250 ml of silver nanoparticles solution of different concentration (500, 1000, 2000 and 4000 ppm) under vigorous stirring at room temperature overnight to make sure the coating is complete. The activated carbon coated with silver was then cured in a vacuum oven at 110 °C for at least 2h to allow full coating of the silver nano-particles onto the activated carbon. Thus, Ag-NPs/AC with different compositions (2.5 mg/g, 5mg/g, 10mg/g and 20mg/g, respectively) were prepared. Confirmation of the preparation was done by measuring the difference in weight of the activated carbon granules before and after coating process and measuring the residual silver in solution after coating process.

2.5 Characterization of the Prepared Material:

The ultraviolet–visible (UV–Vis) spectra of the Ag-NPs were measured on a Unicom model UV4-200 UK operated at a resolution of 2 nm. Histograms of size distribution were measured by Particle Sizing Systems, Inc., Santa Barbara, Calf., USA. The crystalline structure of silver nano-particle was examined by X-ray diffractometry (XRD) Philips Model PW 3710. Scanning electron microscopy (SEM) observations were carried out on a JEOL JSM5900LV equipped with an OXFORD EDX probe. For SEM analysis, the loaded activated carbon sample was coated with a thin film of Au.

2.6 Microbiological Experimentation:

The antimicrobial susceptibility of synthesized Ag-NPs/AC was investigated using inhibition zone, impregnation and column techniques. *Escherichia coli (E. coli)* was selected as an indicator of fecal contamination of water. MacConky agar, MacConky broth and nutrient agar were used as the growth media. A bacterial suspension of *E. coli* was diluted to 10^2, 10^4 and 10^6 CFU/mL (CFU = colony-forming units) in 10 ml ultra pure water.

Isolation and identification of indicator bacteria (E.coli): Isolates from the examined water samples were subjected to identification by biochemical characteristics using API 20E strip system (BioMereux). Each API 20E strip consists of twenty-seven wells containing dehydrated media. The isolate to be tested was suspended in sterile saline and added to each well. The inoculated strip was incubated for 16-24h and the color reactions were noted either positive or negative as presented in Table 2.

Table 2: API 20E biochemical characteristics for *E.coli* characterization**.**

Type	ONPG	ADH	LDC	ODC	CIT	H2S	URE	TDA	IND	VP	GEL	GLU	MAN	INO
E.coli	+	-	-	-	-	-	-	-	+	-	-	+	+	-
Type	SOR	RHA	SAC	MEL	AMY	ARA	OX	NO2	N2	MOB	McC	OF-O	OF-F	
E.coli	+	+	+	+	-	+	-	+	-	+	+	+	+	

2.6.1 Inhibition Zone Test:

For the granules of Ag-NPs/AC of different compositions, the bacteriological examination was performed using inhibition zone technique; melted nutrient agar media seeded with *E.coli* bacteria at different concentrations 10^2,10^4 and 10^6 cfu/ml was poured onto disposable sterilized Petri dishes and allowed to solidify. Pore hole was gently placed over the solidified agar using sterile cork poorer in different Petri dishes, and these holes were filled with 100 µL of different compositions of Ag-NPs/AC. The plates were incubated at 37°C for 24h. After incubation, the diameter of the clear zone of inhibition surrounding the sample was taken as a measure of the inhibitory power of the sample against the particular test organism.

2.6.2 Impregnation (Batch Method):

Several tests were done to detect the efficiency of the modified Ac with Ag nano-particles using impregnation technique. AC coated with Ag-NPs of 2.5 mg, 5 mg, 10 mg and 20 mg were equilibrated in the beaker containing E. coli. The tests include the effect of contact time, weight/volume ratio and *E.coli* cell count.

2.6.3 Column Test:

The antimicrobial activity of the modified Ag-NPs/AC granules was tested using column experiments. An amount of the granules to be tested was packed into a plastic column (Fig. 1).

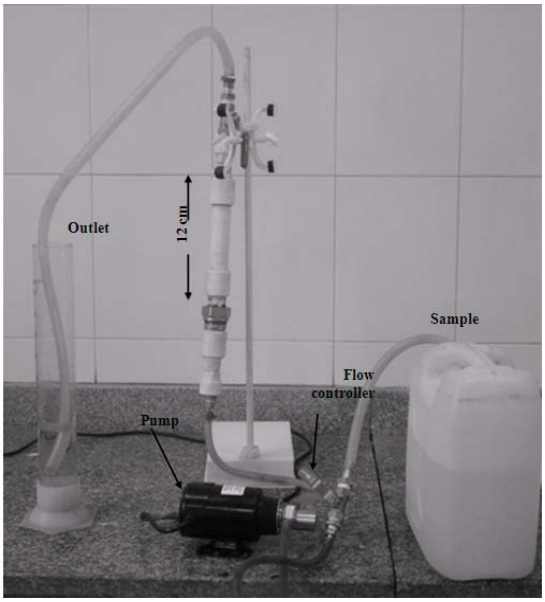

Fig. 1: Experimental set-up for column studies (showing columns 2.5 cm diameter).

The weight of tested Ag-NPs/AC granules was about 50 ±1g. The tested column was washed using pumped continuous tap water for 30 min, and distilled water for 5 min before any run. The efficiency of tested modified AC in the antimicrobial activity was performed on distilled water injected with different concentrations of *E. coli* and polluted raw water.

The raw water was represented by four samples collected from the sewage stations drain of Abu-Rawash area, southwestern portion of Cairo, Egypt, with the characteristics shown in Table 3. The effluent from the column was analyzed by the analysis methods described above.

Table 3: Chemical characteristics of raw water collected from Abou-Roash area.

Parameter	Concentration			
	Sample 1	Sample 2	Sample 3	Sample 4
T.C Stander plate count (SPC)	1800	1600	2000	1200
C.C Coliform count	1200	1000	1600	600
TDS, mg/l	486.9	504	529.1	536.1
Total N, mg/l	16.28	4.26	16.31	8.93
P, mg/l	56.2	61.4	56.6	53
Ca^{++}, mg/l	47	47	43.1	43.1
Mg^{++}, mg/l	23.8	21.4	26.2	26.2
Na^{+}, mg/l	85	93	95	97
$SO4^{--}$, mg/l	88	91.9	102.4	106.9
Cl^{-}, mg/l	76.1	76.1	91.3	91.3
Fe, mg/l	0.93	1.21	1.22	0.72
Al, mg/l	0.41	0.52	0.75	0.31
Si, mg/l	4.9	5.0	5.2	4.5
B, mg/l	0.16	0.17	0.15	0.18

RESULTS AND DISCUSSION

3.1 Characterization of Ag-NPs and Ag-NPs/AC:

Silver nanoparticles were prepared according to the method described in the previous section. The solution's

color turns from initial colorless to yellowish gray, correponding to the formation of decahedral seeds, which are essential to the subsquent formation of silver wires. The formation of silver nanoparticles was monitored using UV-Vis spectroscopy. UV-Vis spectroscopy is one of the most widely used techniques for structural characterization of silver nanoparticles. A single broad peak centered at 420 nm was observed that corresponding to the Plasmon excitation of silver nanoparticles (Fig. 2).

The absorption peak whose maximum occurs at around 420 nm is related to the formation of silver metal particles as well as the distance between neighboring nanoparticles, and its height corresponds to the concentration of the silver metal particles (Lee *et al*., 2007). The particle size histograms of silver particles show that the particles range in size from 12 to 70 nm with mean diameter 26 nm (Fig. 3).

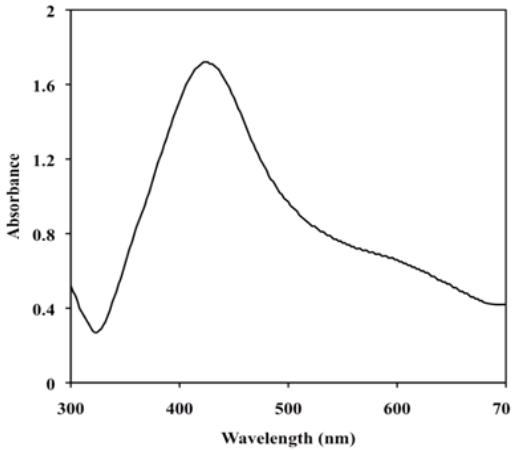

Fig. 2: UV-Vis absorption spectra of the synthesized Ag-NPs.

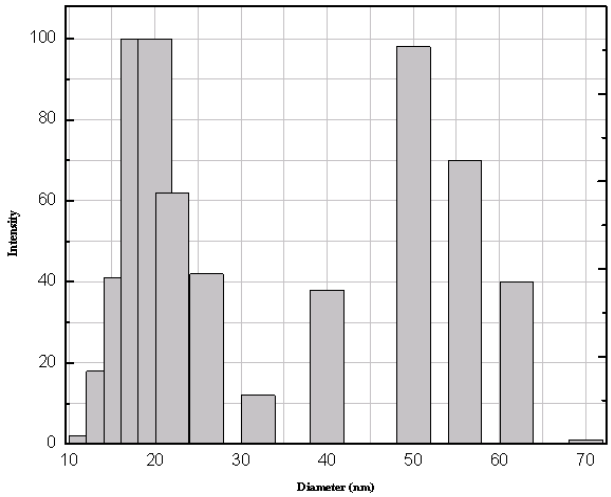

Fig. 3: Particle size distributions of Ag-NPs.

The different modified Ag-NPs/AC was characterized by scanning electron microscopy (SEM) and X-ray diffraction (XRD) techniques. SEM patterns (Fig. 4) show the distribution of Ag-NPs on the porous surface of activated carbon.

Figure 5 depicts the XRD patterns of AC and Ag-NPs/AC. The XRD pattern of impregnated Ag over active carbon showed amorphous carbon phase and silver in metallic phase (Kumar *et al*., 2004). All prominent peaks at respective 2θ values known for zero-valent fcc silver representing the 111, 200, 220, 311 and 222 crystal planes due to Bragg's reflections are present (Khanna *et al*., 2007).

3.2 Antimicrobial Activity:

Monitoring of water quality for microbial parameters requires the selection and use of indicator organisms. The coliform groups, total and fecal coliforms, are most widely used as indicator organism, particularly for fecal contamination of water Escherichia coli, which is classified under fecal coliform, has been used worldwide as a specific indicator of bacterial contamination in drinking water.

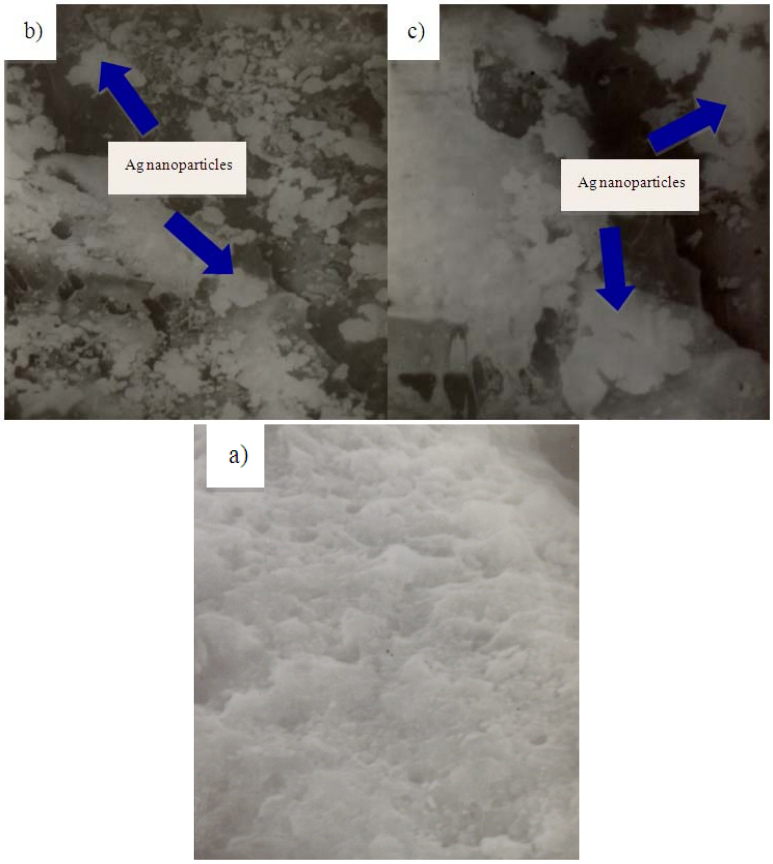

Fig. 4: SEM image of a) neat AC at magnification 1000 and Ag-NPs/AC (20 mg/g) at different magnification; b) 1000 and c) 3000.

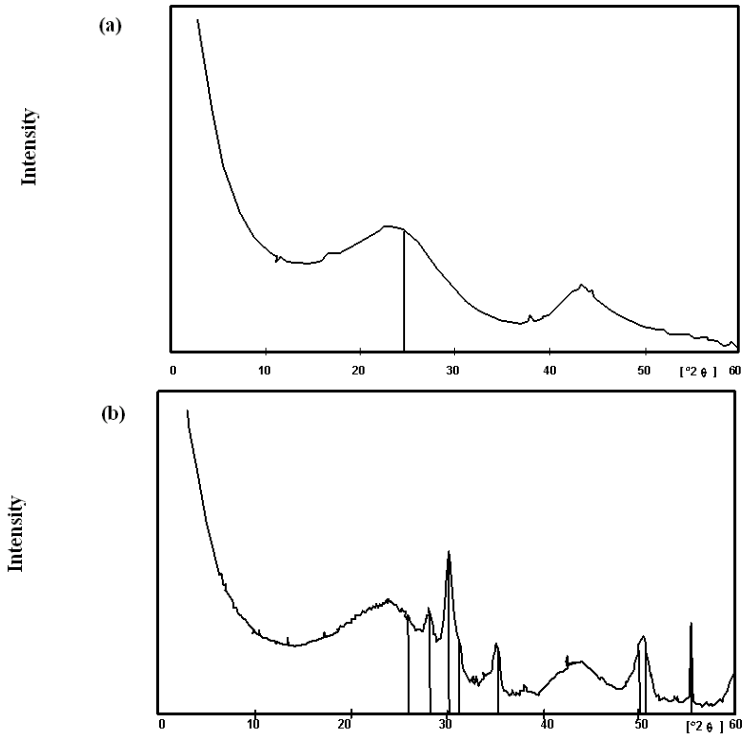

Fig. 5: XRD patterns; (a) neat activated carbon, (b) Ag-NPs/AC (20mg/g).

Silver is known for its antimicrobial properties and has been used for years in the medical field for antimicrobial applications (Nino-Martinez *et al*., 2008). Additionally, silver has been used in water and air filtration to eliminate microorganisms (Chou *et al*., 2005). Silver ions interact with thiol groups in proteins, resulting in inactivation of respiratory enzymes and leading to the production of ROS (Matsumura *et al*., 2003). It was also shown that Ag^+ ions prevent DNA replication and affect the structure and permeability of the cell membrane (Feng *et al*., 2000). To date, several mechanisms have been postulated for the antimicrobial property of silver nanoparticles: (1) adhesion of nanoparticles to the surface altering the membrane properties, nAg particles have been reported to degrade lipo-polysaccharide molecules, accumulate inside the membrane by forming ‘‘pits’’ and cause large increases in membrane permeability (Sondi and Salopek-Sondi, 2004); (2) nAg particle penetrating inside bacterial cell, resulting in DNA damage; (3) dissolution of nAg releases antimicrobial Ag^+ ions (Morones *et al*., 2005). The mechanism of the bactericidal effect of silver and Ag-NPs remains to be understood. Moreover, smaller Ag-NPs having the large surface area available for interaction would give more bactericidal effect than the larger Ag-NPs (Kvitek *et al*., 2008).

3.2.1 Inhibition Zone Technique:

For the different prepared Ag-NPs/AC granules, the bacteriological examination was performed using inhibition zone technique. The diameter of inhibition zone (in cm) around the different granules with tested strain are shown in Table (4) which revealed that a positive response of *E.coli* concentrations (10^2,10^4 and 10^6 cfu/ml) to inhibition with all Ag-NPs concentrations.

Table 4: Inhibition zone test results for *E. Coli* on different Ac/Ag NPs granules.

E.coli conc. (cfu/ml)	Inhibition zone (cm)			
	Ag-NPs/AC 2.5mg/g	Ag-NPs/AC 5mg/g	Ag-NPs/AC 10mg/g	Ag-NPs/AC 20mg/g
10^2	1.1	1.2	1.3	1.4
10^4	1.1	1.1	1.2	1.3
10^6	0.9	1.0	1.1	1.3

The inhibition zone diameter increased with increasing NPs concentration. On contrast the inhibition zone decreased with increasing bacterial concentration. Thus, the minimum inhibition zone was 0.9 for *E.coli* concentration 10^6 cfu/ml at Ag-NPs/AC (2.5mg/g) whereas the maximum inhibition zone diameter was 1.4 cm with *E.coli* concentration of 10^2 cfu/ml at Ag-NPs/AC (20mg/g).

3.2.2 Impregnation Technique:

Several preliminary tests were done to detect the efficiency of the modified AC with Ag-NPs using impregnation technique. The tests include the effect of contact time, weight/volume ratio and *E.coli* cell count. The bacterial cell concentration was in the range of 10^2 to 10^6 CFU/ml. Activated carbon granules without silver nanoparticles were used as blank. Beakers containing bacterial suspensions were kept in the shaker for 5 min and fractions were drawn after 1 min, 3 min and 5 min to check the bacterial reduction as a function of time (Table 5).

Table 5: Efficiency of different Ac/Ag-NPs granules for water disinfection at different E. Coli concentration by batch technique, w/v; 2.5 gm/ 50 ml

Time (min)	Neat AC			Ag-NPs/AC(2.5mg/g)			Ag-NPs/AC(5mg/g)			Ag-NPs/AC(10mg/g)			Ag-NPs/AC (20mg/g)		
	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml
1	269	$1.9x10^4$	$2.1x10^6$	40	520	3500	6	392	1407	3	81	960	0	68	208
3	239	$1.1x10^4$	$0.9x10^6$	3	292	2100	0	200	1200	0	55	728	0	13	54
5	220	$1.03x10^4$	$0.4x10^6$	0	176	1500	0	140	960	0	24	600	0	0	0

At constant granules/solution (wt./vol) ratio (2.5/50), the general conclusion of data showed that, as Ag-Nps concentration and contact time increased, bacterial counts of *E.coli* decreased and the decrease in counts was more obvious as bacterial concentration decreased (i.e.10^2 was preferable than 10^4 and 10^6). Ag-NPs/AC (2.5mg/g) showed 60%-99.6% reduction of bacteria within 1 min of contact time. This percentage reaches 97%-99.7% and 98.2%-100% after 3 min and 5 min of contact time, respectively. Also from Table 4 we can see a general trend of increasing the activity of bacterial reduction as the amount of Ag-NPs loading onto the AC granules increases, to reach 99.3%-100% after 1 min and 100% after 5 min in case of Ag-NPs/AC (20mg/g). This indicates the very fast removal of *E. coli* by the prepared NPs coated onto AC granules. On the other hand activated carbon only gave bacterial count with all contact time used but the count decreased with increasing contact time (Fig. 6).

This experiment was conducted to optimize the quantity of silver nanoparticles bound AC granules required to render 100% biocidal action. Therefore, Ag-NPs/AC (20mg/g) was able to reach zero bacterial count regardless of all impregnation times at 10^2 initial bacterial concentration. For bacterial concentration 10^4 and 10^6, Ag-NPs/AC (20mg/g) was able to reduce the amount of *E.coli* to zero after 5 min.

Moreover, the effect of different Ag-NPs/AC granules concentration was studied at constant contact time, 5 min. 0.5, 1, 2.5, 5 and 10 gm of Ag-NPs/AC were equilibrated with 10^2, 10^4 and 10^6 *E.coli* concentrations (Table 6).

The obtained results given in table (5) demonstrated that the bactericidal reduction effect increased with increasing Ag-NPs content and Ag-NPs/AC concentration for all *E.coli* concentrations.

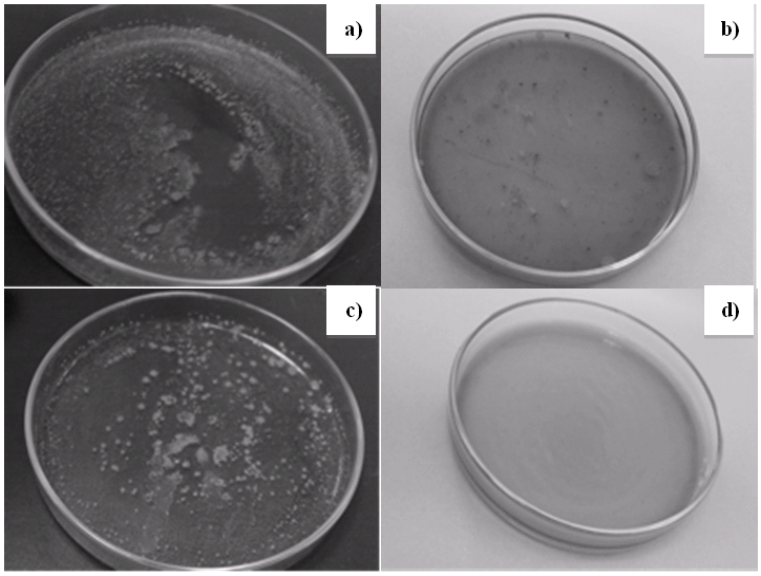

Fig. 6: Residual *E.Coli* after impregnation for 5 min and w/v; 2.5 g/ 50 ml of; (a) neat AC in 10^4 cfu/ml, (b) Ag-NPs/AC (2.5mg/g) in 10^4 cfu/ml, (c) neat Ac in 10^6 cfu/ml and (d) Ag-NPs/AC (20mg/g) in 10^6 cfu/ml.

Table 6:. Efficiency of different Ac/Ag-NPs concentration in solution for water disinfection at different E. Coli concentration by batch technique, time; 5min.

wt/v	Neat AC			Ag-NPs/AC(2.5mg/g)			Ag-NPs/AC(5mg/g)			Ag-NPs/AC(10mg/g)			Ag-NPs/AC (20mg/g)		
	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml	10^2 cfu/ml	10^4 cfu/ml	10^6 cfu/ml
0.5/50	347	$13.3x10^4$	$1.4x10^6$	34	578	5689	3	390	2356	0	78	1560	0	0	56
1/50	290	$2.8x10^4$	$0.8x10^6$	11	360	3300	0	276	1200	0	56	900	0	0	0
2.5/50	220	$1.03x10^4$	$0.4x10^6$	0	176	1500	0	140	960	0	24	600	0	0	0
5/50	180	$0.3x10^3$	$0.5x10^5$	0	0	980	0	0	679	0	0	321	0	0	0
10/50	60	$0.1x10^3$	$0.6x10^4$	0	0	430	0	0	230	0	0	112	0	0	0

In conclusion, the results of the impregnation tests reflect the high efficiency of the prepared NPs coating AC granules for the water disinfection from microorganism in a short period of time (maximum of 5 min) even at higher counts.

3.2.3. Small-Scale Water Disinfection System:

A lab scale packed column (2.5 cm diameter and 12 cm high) disinfection syste of 50 gm Ag-NPs/AC (20 mg Ag-NPs coated onto every one gram activated carbon granules) was applied in order to purify water-containing microorganism (Fig. 1). The system was operated with a continuous and constant flow rate of 0.8 L/min. Firstly; the flow test for pure water containing *E.coli* ($\square 10^4$ cfu/ml) was conducted. No bacteria were found in the output water after passing through the nanosilver coating onto activated carbon (Fig. 7a). However, there appeared substantial growth in the output water that passed through the blank activated carbon at the same flow rate (Fig. 7b).

For the wastewater reclamation/reuse experiment, four samples were collected from the secondary treated water of the sewage treatment plant in Abu Rawash area and were used as the raw water for application to the real wastewater reclamation/ reuse system. The characteristics of the wastewater samples before the treatment process are summarized in Table 3, from which we can see that the samples contain total microbial counts and coli form counts ranged from 1200-2000 cfu/ml and 600-1600 cfu/ml, respectively. The system of 20 mg Ag-NPs coated one gram activated carbon granules was tested for antibacterial properties on the collected four-wastewater samples using the lab scale packed column with a continuous flow rate of 0.8 L/min. The effect of the silver nanoparticles on microorganism is shown in Fig. 8. Whereas, the total microbial counts and coliform counts has been reduced to nil because of the antibacterial action of the nanosilver particles, meanwhile, growth was observed in the control (neat activated carbon), as shown in Fig. 8.

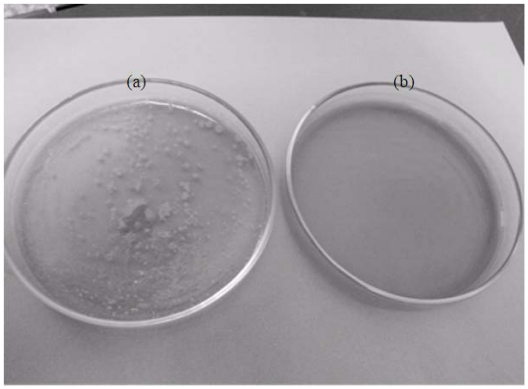

Fig. 7: Flow test result for *E. coli* (10^4 CFU/mL). (a) After passing through blank activated carbon. (b) After passing through nanoparticle-silver coating activated carbon. The bacterium count is clearly visible in (a), while the count was zero in (b).

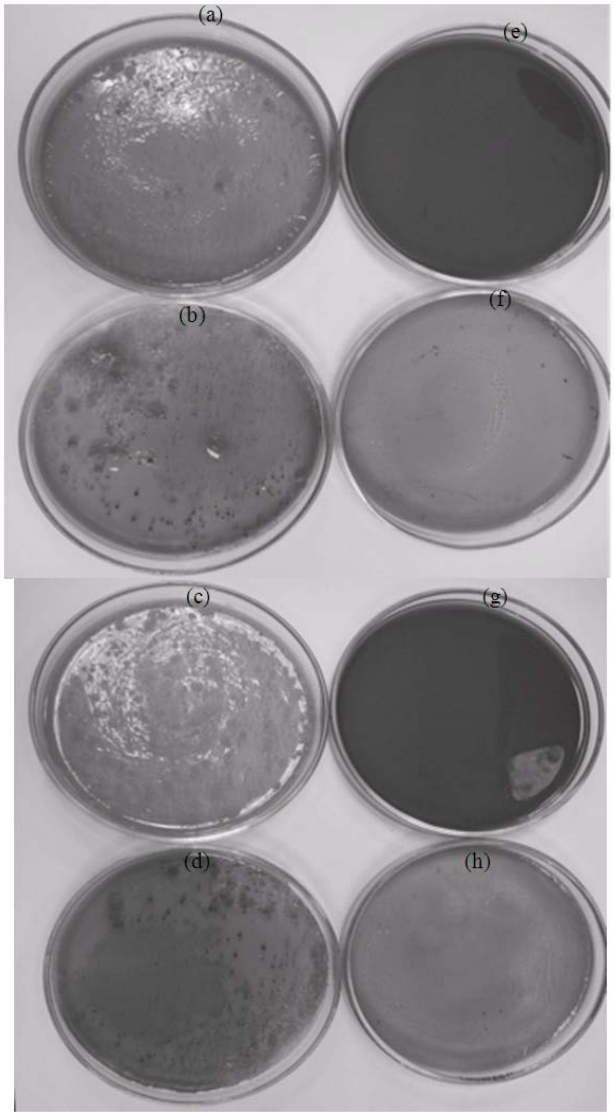

Fig. 8: Flow test result for wastewater samples. (a-d) After passing through blank activated carbon. (e-h) After passing through nanoparticle-silver coating activated carbon. The bacterium count is clearly visible in (a-d), while the count was zero in (e-h).

4. Conclusion:

Silver nano-particles were coated onto activated carbon supports from silver nitrate solutions using glucose as a reducing agent. The prepared Ag-NPs and Ag-NPs/AC were characterized by UV-Vis spectrophotometer, XRD and SEM. The contact active antibacterial property was measured by the clear zone formed by the silver containing activated carbon granules on the plate. The batch method showed that with the increase in contact time and the decrease in the bacterial count, complete inhibition was achieved. In column test, the prepared Ag-NPs/AC showed a complete bacterial reduction in synthetic water and actual polluted water samples.

Data revealed a direct relation between Ag-NPs concentration and contact time toward bactericidal activity against *E.coli* which represented as an indicator for microorganisms pollution, where as the concentration of Ag-NPs and contact time increased, bacterial counts of E.coli decreased and inhibition zone increased for all bacterial concentrations used.

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