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Biofabrication of gold/activated carbon/polyvinyl alcohol (Au/Ac/PVA) polymer sheet and its application in seawater desalination

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ABSTRACT

Seawater is the most abundant source of drinking water and for industrial use in many parts of the world. Desalination of seawater became an urgent need to compensate the shortage in fresh water. It was aimed in this research to fabricate a convenient water treatment modern technology by designing a gold/activated carbon/polyvinyl alcohol (Au/Ac/PVA) polymer sheet for water desalination using the AuNPs (1–10 nm) synthesized by bacteria. This was carried through several steps; fabrication and characterization of Au/Ac/PVA polymer sheet, examining the cytotoxicity of the Au/Ac nanocomposites used throughout this research, and finally, measuring the quality insurance of desalinated seawater. The highest cells' toxicity (79.119 % of viability) was observed using 25 µg/ml of Au/Ac nanocomposite. Analysis of the resulted water revealed its purity and potability.

Keywords: Gold/activated carbon/polyvinyl alcohol polymer sheet; *Bacillus* sp. SDNS; Seawater desalination; Biofabrication; Cytotoxicity; Solar still

1. Introduction

Nowadays, the world is facing massive challenges in meeting the elevation in demands of clean water. Seawater is considered the most abundant available source of drinking water and water for industrial use in many districts, as only 3% of all available water on the planet being fresh water [1]. A cost-effective water refinement technology is a necessity and its fiasco might endanger our life and the human presence at the global scale. So to address the doubtless requirement for clean water, a lot of water treatment technologies were suggested and performed at experimental and field levels [2].

Desalination process aims to minimize the quantity of dissolved salts and minerals in salt water [3]. Solar desalination is considered one of the oldest techniques used which operates on the same principle as rainwater and as well as the greenhouse effect [4,5]. Nanotechnology offers new opportunities to improve more efficient and cost effective nanostructured and reactive membranes for water purification [1]. Metal and metal oxides nanoparticles, graphene and carbon nanotubes are nanomaterials that could be used in water purification and desalination technologies. An overview of recent advances in nanotechnologies for water and wastewater processes was recently published [6].

Carbon nanomaterials (CNMs) are a class of fascinating materials due to their unique structures and electronic properties which make them attractive for fundamental studies as well as diverse applications, especially in sorption processes [7]. To improve the adsorption, mechanical, optical, and electrical properties, carbon nanotubes are often combined with other metals or types of support [8]. Herein, we report the construction of a low-cost compatible gold activated carbon polyvinyl alcohol (Au/Ac/PVA) to be used for water desalination.

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2. Materials and methods

2.1. Preparation of gold-activated charcoal-polyvinyl alcohol (Au/Ac/PVA) polymer sheet

Gold nanoparticles (1–10 nm) were biosynthesized extracellularly from the marine bacterium *Bacillus* sp. SDNS [9]. Gold activated charcoal (Au-Ac) nanocomposite was prepared by mixing 100 mg of activated charcoal (Ac) with 100 ml of AuNPs solution for 15 min at room temperature, allowed to settle overnight, then filtered and air dried. The formed nanocomposite was characterized using SEM and XRD [10].

2.2. Cytotoxicity of the gold-activated charcoal nanocomposite

Isolation of lymphocytes from whole human blood was performed using Ficoll histopague [11]. Cytotoxicity and MTT(3-(4,5-dimethythiazol-2-yl)-2,5-diphenyltetrazolium bromide) assays were carried as described [12,13].

2.2.1. Solar still fabrication

A pyramid solar still was designed from locally available materials and manufactured components [14] using a square wood shaped basin (30 cm × 30 cm) with inclination angle of 45° (Fig. 1).

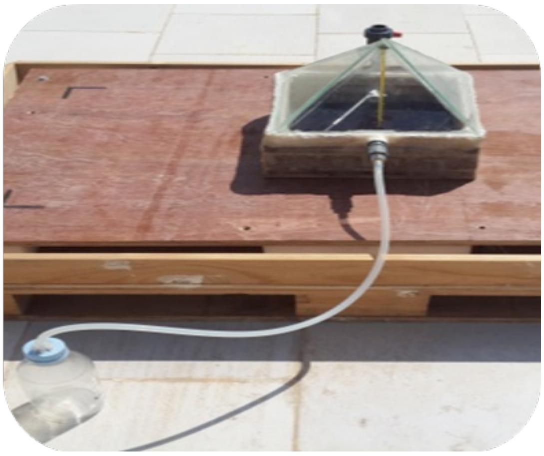


Fig. 1. A designed pyramid solar still.

2.2.2. Water quality insurance

The water quality insurance analysis of desalinated seawater was carried out according to the standard methods described by American Public Health Association [15].

2.2.3. Bacteriological analysis

Nutrient broth (NB) (Oxoid LTD, England) was used for growth of bacteria in shake flasks. Plate count agar (PCA) (Difco™, Netherlands) was used for enumerating bacteria in saline and desalinated water [16]. Lauryl sulfate broth (LSB) (Merk KGaa, Germany) was used for the detection of coliforms [17].

3. Results and discussion

At present, the most extensively studied nanomaterials for water and wastewater treatment include zero-valent metal nanoparticles, metal oxides nanoparticles, carbon nanotubes (CNTs), and nanocomposites [7]. The synthesis of various nanocomposites has become the most active subject in the field of nanomaterials.

3.1. Characterization of fabricated gold/activated carbon/ polyvinyl alcohol (Au/Ac/PVA) polymer sheet

Biological synthesis of metal nanoparticles is the most benign method to develop environmentally safe nanoparticles [18]. The procedure involves the reduction of metal ions using cell extracts as a source of reducing agents either intracellularly or extracellularly [2]. The average particle size of AuNPs used in this work was 1–10 nm (Fig. 2).

In a sequential step, gold nanoparticles were used to prepare Au/Ac nanocomposite. The UV–visible spectral analysis of the prepared materials displayed surface plasmon resonance (λ_{max} at 550 nm) with slightly high absorption owing to Au/Ac nanocomposite formed (Fig. 3).

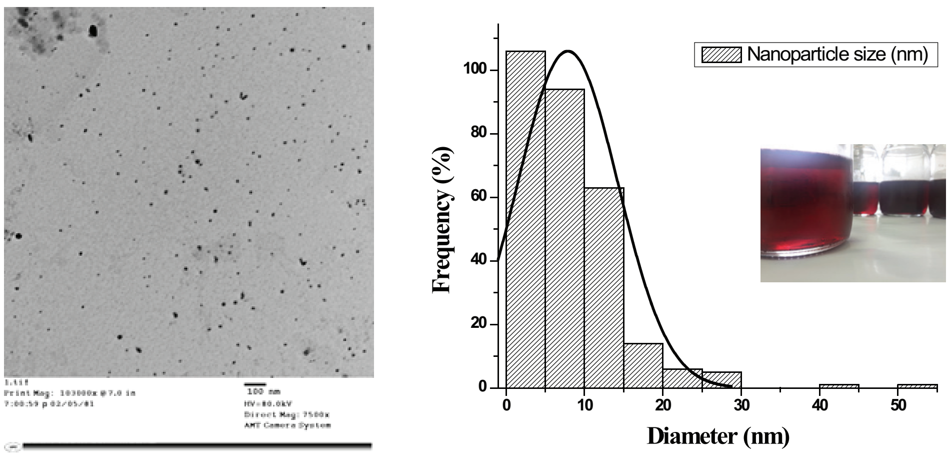


Fig. 2. TEM image of AuNPs solution synthesized by *Bacillus* sp. SDNS (left) & the corresponding size distribution (right).

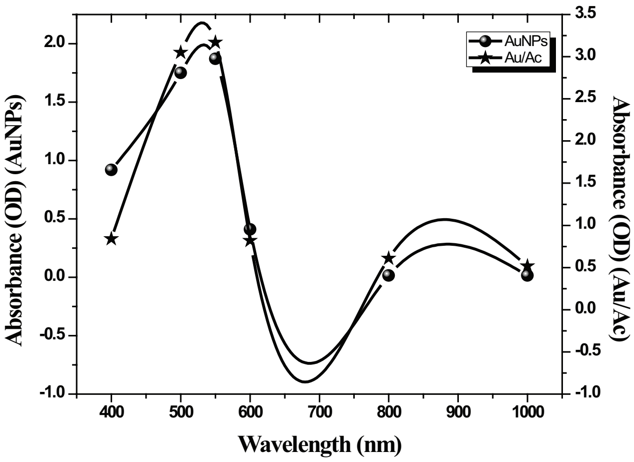
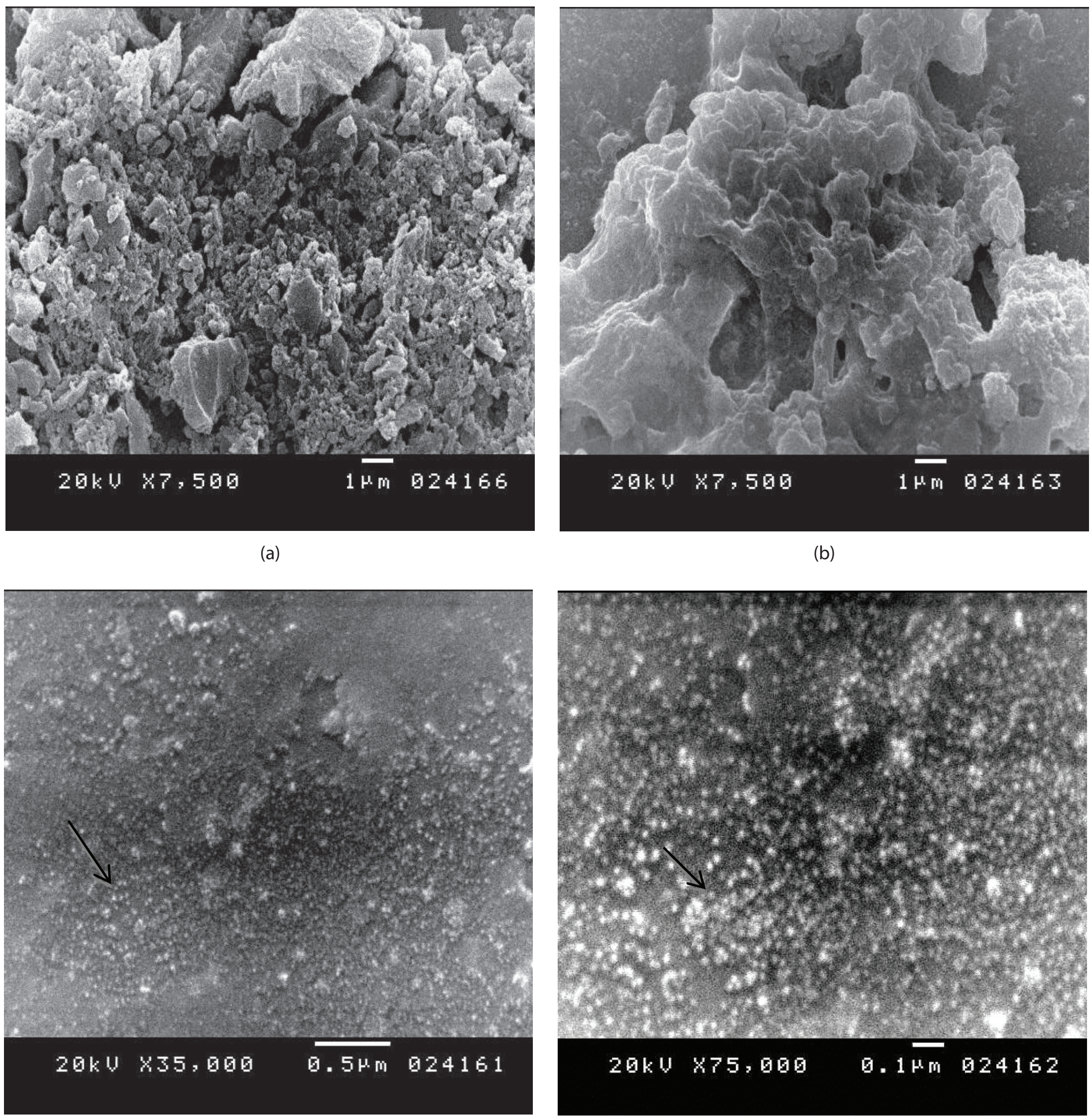


Fig. 3. UV-Vis spectrum of AuNPs and Au/Ac nanocomposite.

The formation of Au/Ac nanocomposite was confirmed using SEM (Fig. 4) and XRD analyses (Fig. 5). SEM micrograph shows the regular distribution of activated charcoal (Ac), in the nanometer scale displaying a cancellous morphology (Fig. 4a). The examined Au/Ac nanocomposite appeared porous in the SEM micrographs with uniformly spherical dispersed gold nanoparticles adsorbed onto the porous areas of Ac (Figs. 4b, c, and d).

To confirm the adsorption of AuNPs onto the activated charcoal surface, XRD patterns of activated charcoal as control alongside with Au/Ac nanocomposite were examined. The pattern consolidated the existence of gold in the sample. The XRD pattern of Au/Ac nanocomposite displayed diffraction peaks at 2θ angles of 38.15, 44.31, 64.49, 77.97, and finally 81.51 corresponding to the Au (111), Au (200), Au (220), Au (311), and Au (222) crystal planes of a cubic lattice structure of gold nanoparticles not found in the XRD of AC pattern (Fig. 5).



(a) (b) (c) (d)

Fig. 4. SEM images of Ac only (a) and Au/Ac at different magnifications (b, c, d).

Nanoparticles tend to aggregate, which crumble their unique properties originated from their size effect [19]. Immobilizing nanoparticles on supports such as powders and plates is a candidate to hinder the aggregation as well as cytotoxicity. Therefore,a film of gold nanoparticle/activated charcoal/poly vinyl alcohol (Au/Ac/PVA) was prepared (Fig. 6).

During the formation of Au/Ac/PVA sheet, SiO_2 was used as a support, which has many advantages to highlight the chemical reactivity of nanoparticles especially with the lower size [20].

3.2. Cytotoxicity of Au/Ac nanocomposite

For effective application of nanocomposite in water desalination, it is essential to study and understand the biological destiny and potential toxicity of these nanomaterials. So it was aimed in this experiment to estimate in vivo potential toxicity of Au/Ac nanocomposite used in water desalination, by performing the MTT assay [13,21]. The activity of the enzyme reduces the yellow color of MTT into formazan salt (purple color) that is measured in the mitochondrial region. Data obtained clearly indicate that using different concentrations of nanocomposite showed no cell toxicity after 72 h of incubation. The highest cell toxicity (79.119% of viability) was observed with 25 μg/ml. As stated by Shin et al., [22] the nanoparticle toxicity to live cells are mainly due to the chemistry of the materials used, their very small size, or shape. Kong et al., [23] denoted that at the same concentration the number of about 200 nm nanotubes was sacrificially 2.5-times higher than those of 500 nm nanotubes. They hypothesized that the increased number of 200 nm nanotubes, as well as the smaller size, participated in the increased resulted toxicity.

Indeed, it is preferable to use supported nanoparticles to offer a certain degree of comfort during the utilization of synthesized nanocomposite for several applications. In this study the advantages of fabricated Au/Ac/PVA membrane to reduce or prevent the probable toxicity appeared during the application of this interesting nanocomposite and prevent the aggregation of nanomaterials.

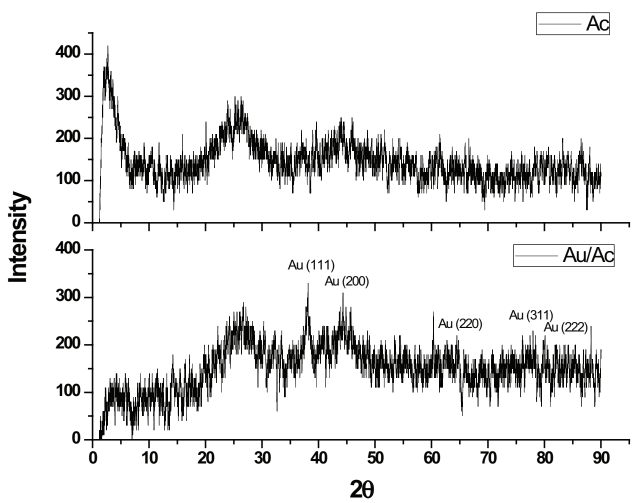


Fig. 5. XRD Bragg reflections of AuNPs adsorbed on Ac compared to Ac only.

3.3. Productivity of manufactured solar still & water quality insurance

Desalination technologies are costly for the production of inconsiderable amount of fresh water. Also, the use of traditional energy sources is expensive and not eco-friendly. Solar distillation was the most fascinating and the simplest mechanism among all other distillation processes [5,24]. The system developed in this study for seawater desalination was manufactured from locally synthesized materials (Fig. 7) in which Au/Ac/PVA membrane was used as an efficient photothermal material instead of the conventional used material.

The Au/Ac/PVA membrane was examined under scanning electron microscope at different magnifications before and after the distillation process (Fig. 8). The

Fig. 6. Gold nanoparticles/Activated charcoal/Polyvinyl alcohol sheets.

Fig. 7. An image of the locally manufactured simple water distillation system.

images explain the precipitation of wastes found in saline water after distillation that might be salts, minerals, or heavy metals (Figs. 8c, d), compared to carbon nanotubes along with nanogold images taken before the process (Figs. 8a, b).

The locally manufactured pyramid solar still was run in a sunny day under the following conditions; 32°C temperature, 0% precipitation, 60% humidity and 18 km/h wind for 11 h from 8:00 am to 7:00 pm. It was observed that the temperature inside the system increased to 60°C. The distillate output was 3330 mL/m^2/d. This is in good agreement or even higher than those previously reported [14,25,26] where productivity of 3300, 3250, 1500 ml/m^2/d respectively was declared. The quality insurance of the purified water was carried out chemically and biologically. The obtained results were compared to the standard international protocols for drinking water as described in Table 1. Data obtained indicate that the resulted water was totally pure and palatable to human drink.

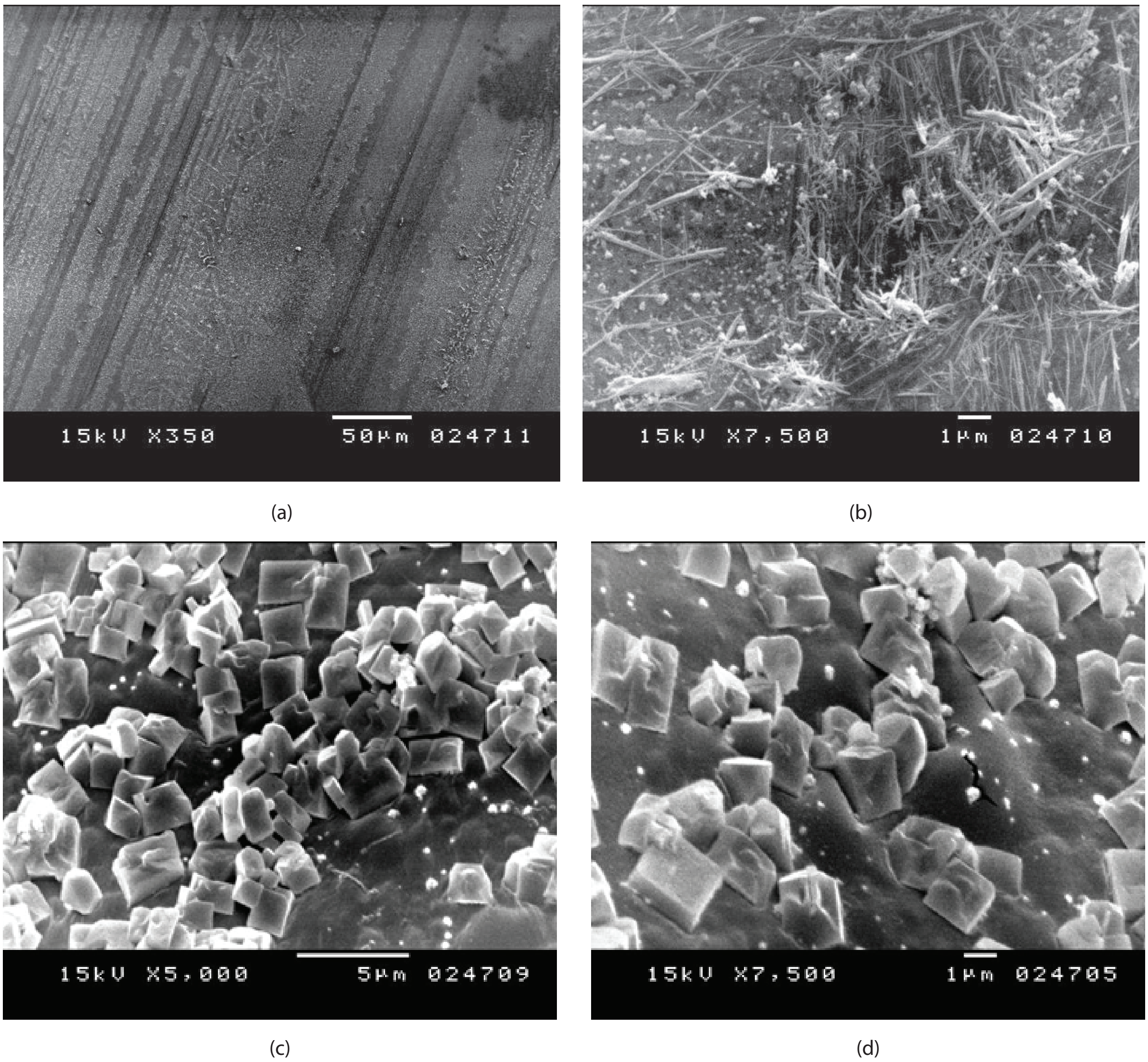


Fig. 8. SEM images of Au/Ac/PVA membrane before (a, b) and after (c, d) distillation process.

Table 1
Water quality of the desalinated water obtained in this study compared to the American and Egyptian water standards

Water quality test	Sea water	Desalinated water	Egyptian standards*	USEPA standards**
pH	8.40	7	6.5–8.5	6.5–8.5
Turbidity (NTU)	1.4	0.9	1	<5
Electric conductivity (µs/cm)	53.6	5.37	–	–
Residual chlorine	Zero	Zero	5	4
Total alkalinity	134, 136, 139	21.4	–	–
Nitrate ion (NO_3^-) (mg/l)	17.530	10.975	45 (as NO_3^-)	10 (as N)
Nitrite ion (NO_2^-) (mg/l)	0.019	0.009	0.2 (as NO_2^-)	1(as N)
Sulfate ion (SO_4^{2-}) (mg/l)	221.903	0.340	250	250
Total iron (Fe) (mg/l)	0.205	0.174	0.3	0.3
Chloride ion (Cl^-) (mg/l)	High value to measure	15.4	250	250
Phosphate ion (PO_4^-) (mg/l)	0.372	0.224	–	1.4330 (326 mg)
Salinity (%)	37.6	0.38	1000 ppm	–
HPC (cfu/ml)	83, 85, 89	37	50 cells/1cm^3	–
Total coliforms	Negative	Negative	2 cells/100 cm^3	–

* According to the Egyptian drinking water standards[27]
**According to USEPA standards [28]

References

[1] M.B. Mohamed, Low cost nanomaterials for water desalination and purification, Final technical report, United Nations Unsco, 2011.

[2] R. Das, M.D.E. Ali, S.B.A. Hamid, S. Ramakrishna, Z.Z. Chowdhury, Carbon nanotube membranes for water purification: A bright future in water desalination, Desalination, 336 (2014) 97–109.

[3] R. Clayton, Desalination for water supply: Foundation for Water Research, UK,2011, pp. 3–44.

[4] J.K. Mechell, B. Lesikar, Desalination Methods for Producing Drinking Water, Austin: Agrilife Communications. URL [Accessed: 05.03.2012], (2010).

[5] A. Bhattacharyya, Solar stills for desalination of water in rural households, Int. J. Environ. Sustain., 2(1) (2013) 21–30.

[6] I. Gehrke, A. Geiser, A. Somborn-Schulz, Innovations in nanotechnology for water treatment, Nanotechnol. Sci. Applic., 8 (2015) 1–17.

[7] H. Lu, J. Wang, M. Stoller, T. Wang, Y. Bao, H. Hao, An overview of nanomaterials for water and wastewater treatment, Adv. Mater. Sci. Eng., Article ID 4964828, (2016) 10 p. http://dx.doi.org/10.1155/2016/4964828.

[8] P.Z. Ray, H.J. Shipley, Inorganic nano-adsorbents for the removal of heavy metals and arsenic: a review, RSC Adv., 5(38) (2015) 29885–29907.

[9] S.S. Abouelkheir, Gold Nanoclusters from *Bacillus* sp. SDNS and Their Applications, PhD thesis, Faculty of Science, Alexandria University, 2015.

[10] V.S.A. Kiruba, A. Dakshinamurthy, P.S. Subramanian, P.M. Selvakumar, Green synthesis of biocidal silver-activated charcoal nanocomposite for disinfecting water, J. Experim. Nanosci., 10(7) (2013) 532–544.

[11] G.C. Preza, O.O. Yang, J. Elliott, P.A. Anton, M.T. Ochoa, T lymphocyte density and distribution in human colorectal mucosa, and inefficiency of current cell isolation protocols, PLoS One, 10(4) (2015) e0122723.

[12] Y. Budama-Kilinc, R. Cakir-Koc, T. Zorlu, B. Ozdemir, Z. Karavelioglu, A.C. Egil, S. Kecel-Gunduz, Assessment of nano-toxicity and safety profiles of silver nanoparticles, In: Silver Nanoparticles - Fabrication, Characterization and Applications, Intech Open, 2018, pp. 185–208.

[13] A. Mishra, S.K. Tripathy, R. Wahab, S.H. Jeong, I. Hwang, Y.B. Yang, Y.S. Kim, H.S. Shin, S.I. Yun, Microbial synthesis of gold nanoparticles using the fungus *Penicillium brevicompactum* and their cytotoxic effects against mouse mayo blast cancer C_2C_{12} cells, Appl. Microbiol. Biotechnol., 92(3) (2011) 617–630.

[14] T. Arunkumar, K. Vinothkumar, A. Ahsan, R. Jayaprakash, S. Kumar, Experimental study on various solar still designs, Int. Schol. Res. Network Renew. Energy, Article ID 569381, (2012) 10 p., doi:10.5402/2012/569381.

[15] American Public Health Association, American (APHA), Water Works Association, and Water Environment Federation Copyright, Standard Methods for the Examination of Water and Wastewater, 2012.

[16] D. Stratev, O.A. Odeyemi, Antimicrobial resistance of *Aeromonashydrophila* isolated from different food sources: A mini-review, J. Infection Public Health, 9(5) (2016) 535–544.

[17] R.M. Atlas, Handbook of Microbiological Media, 4th ed., CRC press, 2010.

[18] R. Raliya, P. Biswas, Environmentally benign bio-inspired synthesis of Au nanoparticles, their self-assembly and agglomeration, RSC Adv., 5 (2015) 42081–42087.

[19] Y. Kobayashi, Y. Ishii, Fabrication of gold nanoparticles-deposited glass plate by electroless metal plating technique and immobilization of proteins on it, International Conference on Innovations in Engineering and Technology (ICIET), 25(26) (2013) 233–236.

[20] I. Plesa, P.V. Notingher, S. Schlögl, C. Sumereder, M. Muhr, Properties of polymer composites used in high-voltage applications, Polymers, 8(173) (2016) 1–63.

[21] Y. Yang, J. Nan, J. Hou, B. Yu, T. Zhao, S. Xu, S. Lv, H. Zhang, Cytotoxicity of gold nanoclusters in human liver cancer cells, Int. J. Nanomed., 9 (2014) 5441–5448.

[22] S.W. Shin, I.H. Song, S.H. Um, Role of physicochemical properties in nanoparticle toxicity, Nanomaterials, 5 (2015) 1351–1365.

[23] B. Kong, J.H. Seog, L.M. Graham, S.B. Lee, Experimental considerations on the cytotoxicity of nanoparticles, Nanomedicine, 6(5) (2011) 929–941.

[24] R. Saidur, E.T. Elcevvadi, S. Mekhilef, A. Safari, H.A. Mohammed, An overview of different distillation methods for small scale applications, Renew. Sustain. Energy Rev., 15(9) (2011) 4756–4764.

[25] A. Riahi, K.W. Yusof, M.H. Isa, B.S.M. Singh, N. Sapari, Solar stills productivity with different arrangements of PV-DC heater and sand layer in still basin: a comparative investigation, Res. J. Appl. Sci. Eng. Technol., 8(11) (2014) 1363–1372.
[26] A. Mehta, A. Vyas, N. Bodar, D. Lathiya, Design of solar distillation system, Int. J. Adv. Sci. Technol., 29 (2011) 67–74.
[27] Egypt Standards, Standards and specifications of water quality for drinking and domestic uses, Internal Report 1-8. Minister of Health and Population decree No. 458, 2007.
[28] Edition of the Drinking Water Standards and Health Advisories, Office of Water U.S. Environmental Protection Agency Washington, DC, EPA 822-S-12-001(2012).