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Enhancement of Solar Water Disinfection using Nanotechnology

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Abstract

The main aim of this work is to investigate the effect of adding Titanium and Aluminum Oxides nano-particles on solar disinfection process of contaminated water. Samples of contaminated water were introduced into glass containers containing different concentrations of each type of nano-parrticles, these containers were placed side by side and hence all measurements were conducted at same time for comparison purposes. Having these contaminated water contained glass containers exposed to solar radiation for different time intervals, samples were withdrawn from each one to measure the total counts of both Coliform and E.Coli using IDEXX setup. It was found that the optimum concentration of Al_2O_3, which reduces the total counts of Coliform and E.coli was 0.06%. However the optimum concentration of TiO_2 to minimize the total Coliform was 0.06%, while the concentration to destroy all E.Coli ranges between 0.008 and 0.01%. In general, it was found that TiO_2 has more potential to speed up the disinfection process.

Keywords: *Solar Water Disinfections, Nano-particles, contaminated water*

1. Introduction

Chlorine is being actively promoted as a low cost disinfection technique but is found to have limited usage because it changes the taste of water. In addition, misuse of chlorine compounds poses a safety hazard. Removing excess chlorine is important to prevent taste problems. A disadvantage of chlorine is its ability to react with natural organic matter to produce other halogenated compounds.

Several techniques were introduced to convert non-potable water to fresh water. For example water desalination has been achieved by using membrane technology [1], solar still or thermal flashing [2], and reverse osmosis under direct heating or heat recovery from power plants [3]. Solar energy is becoming more significant in water desalination as a sustainable, free and abundant energy source. Various examples of solar driven water purification systems are given design of solar-water treatment installation based on ozone for the geographical conditions in Poland are presented [4].

Solar water disinfection is a simple and cheap method to improve the quality of drinking water by using sunlight to inactivate pathogens causing diarrhea. This method uses solar energy to destroy pathogenic microorganisms causing water borne diseases and therewith it improves the quality of drinking water. Pathogenic microorganisms are vulnerable to two effects of the sunlight: radiation in the spectrum of UV-A light (wavelength 320-400nm) and heat (increased water temperature) [5].

A portable, low cost, and low maintenance solar unit to disinfect the potable water has been designed and tested by Fatima et al [6]. The solar disinfection unit was tested for bore-well water. After running a batch of 10 minutes, E.coli, Salmonella and Shigella were found to be completely eliminated from the water sample. The results show that the disinfection achieved in bore well water in 8 min, is well within the WHO parameters for drinking water.

One potential method for enhancing the efficiency of solar disinfection is by the addition of a photo catalyst [7]. Photo catalysts transfer the energy from light into chemical energy through charge transfer, redox (reduction/oxidation) reactions and other electrochemical processes [8,9]. For example, in semiconductor (TiO_2) photo catalysis an incoming photon with energy equal to or greater than the band gap energy of the semiconductor creates an exciton (electron/hole pair). This

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energy can then be transferred to the material surface and participate in surface redox reactions resulting in the formation of reactive oxygen species (ROS). Different photo catalysts produce different ROS including hydroxyl radicals (•OH), superoxide (O2) or singlet oxygen (1O2), which can then react with target contaminants such as bacteria, viruses or organics [10].

Advances in nano-scale science and engineering suggest that many of the current problems involving water quality could be resolved or greatly diminished by using nona-scale materials [11]. Nanotechnology provides an opportunity to refine and improve existing technologies, and also provides new and innovative ways for treating domestic, industrial and mining wastewater. Basically, nanotechnology can offer solutions that are tailor-made to remove a specific contaminant or solutions that are "multi-task" using different nano-based techniques. This is ideal for water purification because water contains different forms of contaminants at different locations, such as heavy metals (e.g. mercury, arsenic), biological toxins including waterborne disease-causing pathogens (e.g. cholera, typhoid), as well as organic and inorganic solutes [12].

Heredia and Manuel [13] investigated the optimization of fixed titanium dioxide film on PET bottles and visual indicator for water disinfection were presented. The improvement on the bottle coating process, using two coats of 10% W/V of TiO_2 in a solution of vinegar and sodium bicarbonate to form the TiO_2 film, the use of a different indigo carmine (1.25 X 10-1mg/pill) concentration in the pill indicator of contamination, the increase of the disinfection rate through shaking the bottles, degradation under intermittent UV radiation and the effect of bottle size on photo catalytic water disinfection were among the most important findings.

In this work, the addition effect of nanoparticles on the SWDIS process will be investigated. Two types of particles will be used, each with different concentration.

2. Materials and Methods

Figure 1 shows six containers, five of which contain contaminated water seeded with certain concentration of nanoparticles, while the sixth one contains only contaminated water. The contaminated water was obtained from a spring ground water collected from (Yajooz spring: Amman Jordan). The quality of this water is considered clear (low turbidity), but not potable as it contains high count of Total coliform, E.coli and Pseudomonas. It is to be noted that the total (Coliform and E.coli) values in this water was measured and found to be 2419, this values will be identified as "Baseline".

In this work the Enzyme Substrate Coliform Test" is used following the IDEXX system, which confirms total coliform, E. coli and P. aeruginosa. This technique is not only certificated, but also is rapid, safe and accurate. It deploys a Hydrolysable substrate in enzyme test for detection of total coliform and E. coli enzymes.

Figure 2 shows the IDEXX setup, which consists of a quanti tray/2000, sealer, UV lamp (6-watt fluorescent, 365 nm long-wave UV lamp with bulb), UV viewing cabinet, sterile vessel (100ml) with sodium thiosulfate, Incubators, anti-foam and Reagents (for specific testing).

Fig. 1. Experimental setup

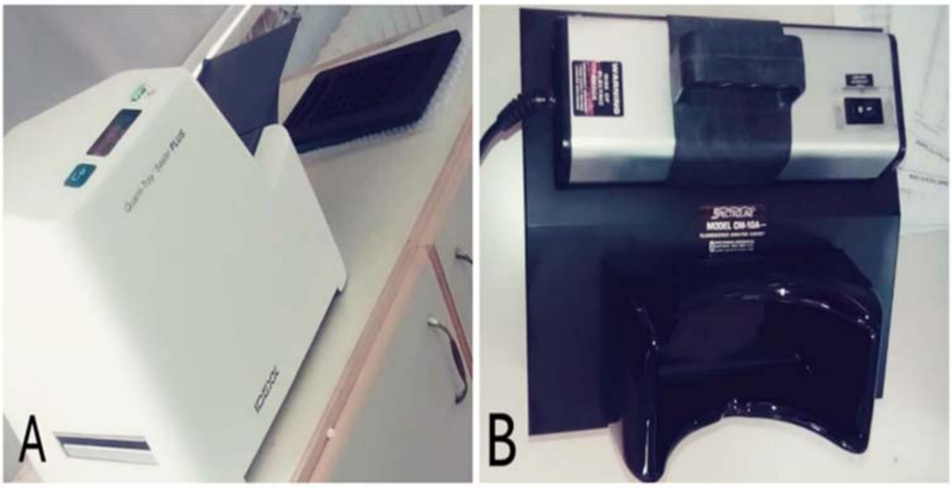

Fig 2. Idexx system hardware where, A, represent the quanti-tray sealer. B, show the UV lamp cabinet.

One hundred milliliters of water sample placed on sterile vessel containing sodium thiosulfate to eliminate the effect of residual chlorine in water samples. The colisure reagent was used for total coliform and E.coli test, while Pseudalert was used for P. aeruginosa test. Then the proper reagent powder (colisure or Pseudalert) was applied on the water sample and dissolved manually by swirling the vessel (if any foam appeared in water samples we need to add 5 drops of anti-foam). After that water samples were placed on the quanti tray/2000 to weld it by the sealer, and incubated at (35℃ ± .5℃ for total Coliform & E.coli, 38℃ ± .5℃ for P. aeruginosa) for 24 hours. As a results positive cells for total Coliform appear magenta or red color, for E.coli and P. aeruginosa trays were exposed to UV light, cells containing E.coli will appear with fluorescent red and magenta, while cells positive for P. aeruginosa give blue fluorescent color after UV exposure. The number of positive tube counted in each tray was used to obtain the MPN number / 100 ml.

As a first step, the optimum concentration of each nanoparticles that results in complete disinfection in the shortest period of time has to be determined. This optimum concentration was found by preparing five different samples of contaminated water, each one contains certain concentration of nanoparticles (0.02%, 0.04%, 0.06%, 0.08% and 0.1%), while the sixth container contains only contaminated water and will be used for comparison purposes. The containers were exposed to the direct solar radiation. Samples were withdrawn at regular periods of time and introduced into a Colisure, which is used to detect total Coliform and E. coli in water. This procedure was repeated for the other nano-fluid in order to determine the optimum concentration of each nano-fluid (Titanium and Aluminum Oxide) and the effect of adding mixtures of both nano-fluid to the contaminated water.

The sample collected after filtration and after chlorination. In each solar setup, the volume of water that has been used for each concentration is 5 ml. The total period of time was 3hr (from 11:00 AM – 2:00 PM), the first reading was recorded after two hours and the second reading after three hours from the start of the experiment. Table 1. below represents a summer of the testing procedure using IDEXX system.

Table 1. Procedure summary for indicator organism testing using IDEXX system.

Reagents / Description	Colisure	Pseudalert
Bacteria Type	Total coliform & *E.coli*	*P. aeruginosa*
Reagent color	Yellow	Baby yellow
Incubation Temperature	35°C ± 0.5°C	38°C ± 0.5°C
Incubation Time	24 hours	24 hours
Maximum Incubation time	48 hours	28 hours
Color of Positive cells	Magenta and red (total coliform)	_____
Under UV lamp	Magenta/fluorescent (E.coli)	blue fluorescent under UV light (Pseudomonas)

The experiments have been conducted during the month of September– October 2016. The value of solar radiation and ambient temperatures were obtained from the output data of weather station. The measured parameters included, physiochemical parameter (temperature, light exposure time and conductivity), and microbial parameters (E.coli, total Coliform).

3. Results and Discussion

3.1. Result of Aluminum Oxide (Al_2O_3)

Figure 3 illustrates the variation of total Coliform with the concentration of Al_2O_3 after two and three hours. As it can be noticed, the total Coliform decreases rapidly with concentration after two and three hours to a minimum value of 0.06% nanoparticles concentration, beyond which the total Coliform starts to increase. Consequently, this value of nanoparticles concentration represents the optimum value. Furthermore, and as expected the total Coliform is significantly reduced after three hours of exposing the sample to solar radiation in comparison to two hours exposure time.

As indicated in figure 4 and after two and three hours of exposure time to solar radiation, the total E.coli in the contaminated water reduces rapidly to minimum for a concentration of nanoparticles equals to 0.06, beyond which this value of E.coli it starts to increase. Also it may be noted that the reduction in the E.coli decrease with the exposure time to direct solar radiation. Consequently, the addition of Al_2O_3 seems to speed up the disinfection process from several days to a few hours.

3.2. Result of Titanium Oxide (TiO_2)

Figure 5 illustrates the variation of total Coliform with the concentration of TiO_2 after two and three hours. As it can be noticed, the total Coliform count decreases rather sharply with concentration after two and three hours. This reduction in the total Coliform continues and reaches a minimum value at a concentration of 0.06, which represents the optimal value of TiO_2.

Figure 6 illustrates the variation of total E.coli with the concentration of TiO_2 after two and three hours of solar exposure time. As it can be seen the total count of E.coli decreases rapidly with the concentration of TiO_2 after two and three hours of exposure time. A shown and after two hours of exposure time, the total E.coli reduces rapidly to minimum value of almost zero when the concentration of TiO_2 is 0.015%, beyond this value it starts to increase. While after three hours of exposure the total E.coli reduces to zero values at a very small concentrations of TiO_2 , i.e. from 0.008 up to 0.02 %.

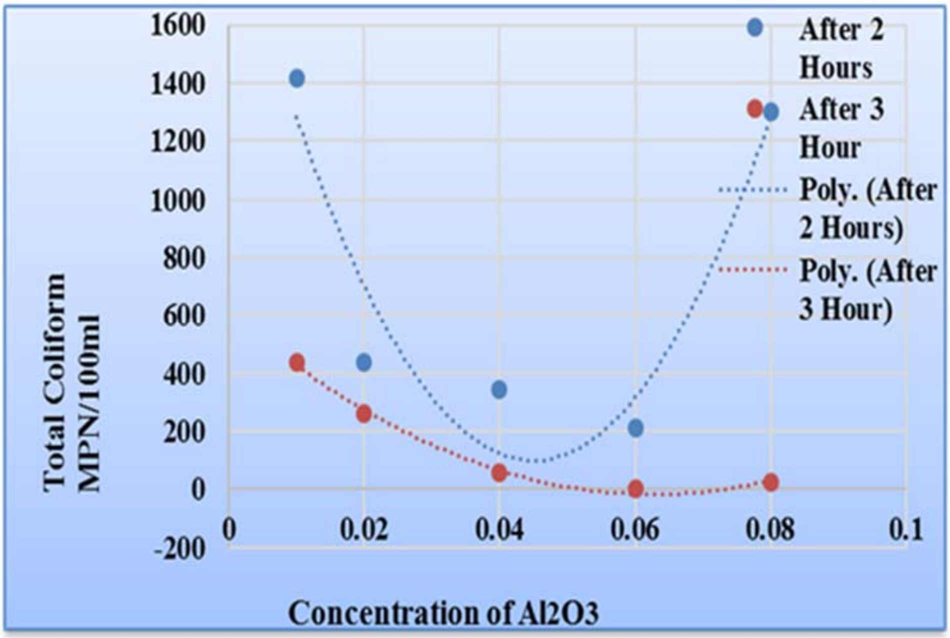

Fig. 3. Relation between the total Coliform and Al_2O_3 concentration

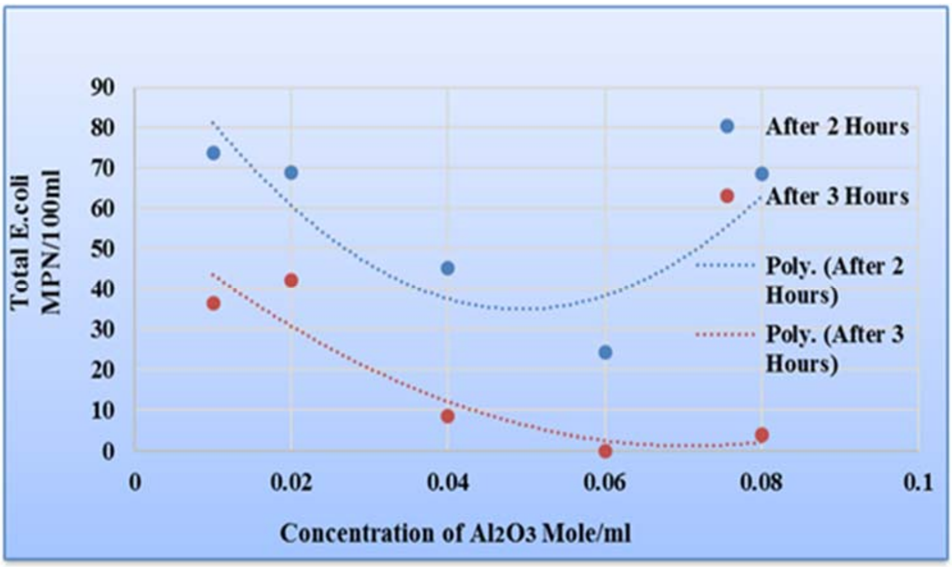

Fig. 4 Illustration of the variation of total E.coli with the concentration of Al_2O_3 after two and three hours

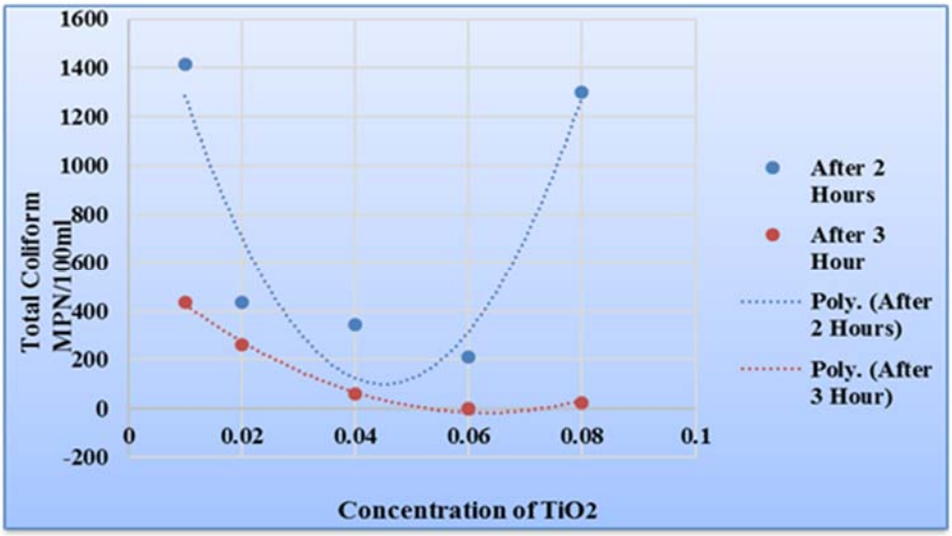

Fig. 5 Relation between the total Coliform and TiO_2 concentration

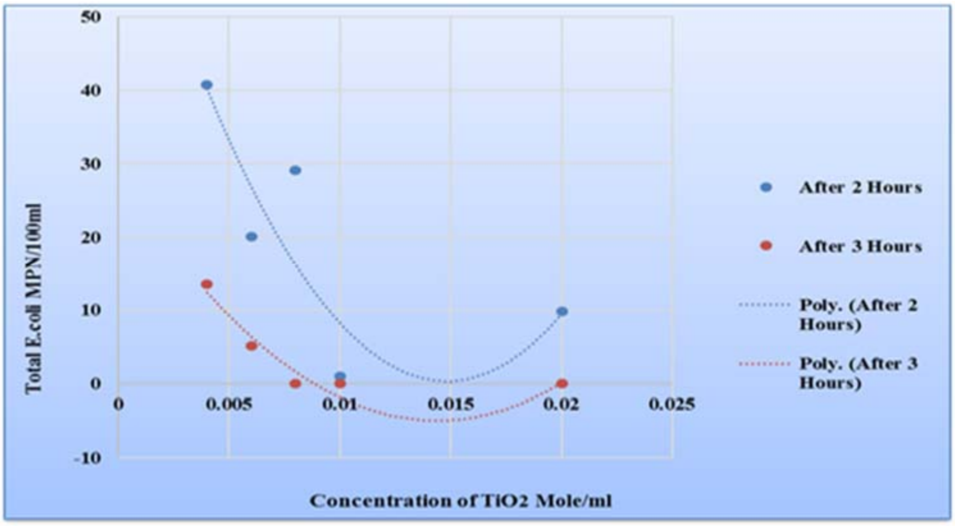

Fig. 6. Relation between the total E.coli and TiO_2 concentration

4. Conclusion

The work was conducted to investigate the effect of adding two types of nano-particles namely Al_2O_3 and TiO_2 on the solar water disinfection of contaminated water process.

The followings may be concluded:

- In general, the addition of nano-particles to the contaminated water has positive effect on the disinfection process such that it speeds up the disinfection process seen by reducing the count of the pathogenic microorganisms
- The optimum concentration of Al_2O_3 that reduces the counts of both total Coliform and E.coli in the contaminated water was observed to be 0.06%.
- The optimum concentration of TiO2 that reduces the counts of total Coliform in the contaminated water was 0.06%.
- The optimum concentration of TiO2 that reduces the counts of total E.coli in the contaminated water was in the range from 0.008 to 0.01 %.

References

[1] I. Janajreh, D. Suwwan, H. Faith, Flow analysis of low energy direct contact membrane desalination, Int. J. Therm. Environ. Eng 8 (2), 133-138.

[2] I. Janajreh, A. Hasania, H. Fath, Numerical simulation of vapor flow and pressure drop across the demister of MSF desalination plant, Energy conversion and management 65, 793-800.

[3] A. Alsarayreh, M. Majdalawi, R. Bhandari, Techno-economic study of pv powered brackish water reverse osmosis desalination plant in the Jordan valley, Int. J. Therm. Environ. Eng 14 (1), 83-88.

[4] S. J. Pawłat, H. StryczewskaSolar Energy for Water Conditioning World Academy of Science, Engineering and Technology 58 2011.

[5] R. Meierhofer, and W. Martin (2002), Solar water disinfection: A guide for the application of SODIS,

Dübendorf, London: Intermediate Technology Development Group Publishing.

[6] Fatima, A., Hany, O., Ali Khan, M., Shahzad, A.and Siddiqui, S. (2012), "Low cost water disinfectant system using solar energy", Journal of basic & applied sciences, 46-52.

[7] Malato, S., Ferna´ndez-Iba´n˜ ez, P., Maldonado, M.I., Blanco, J., Gernjak, W., (2009). Decontamination and disinfection of water by solar photocatalysis: recent overview and trends. Catal. Today 147, 1-59.

[8] Fujishima K, Sugahara J, Tomita M, Kanai A. (2008). Sequence evidence in the archaeal genomes that tRNAs emerged through the combination of ancestral genes as 5' and 3' tRNA halves. PLoS One 3:e1622

[9] Hoffmann, M.R., Martin, S.T., Choi, W., Bahnemann, D.W., (1995) Environmental applications of semiconductor photocatalysis, Chem. Rev., 95, 69–96.

[10] Toepfer, B., Gora, A., and Li Puma, G. (2006). "Photocatalytic oxidation of multicomponent solutions of herbicides: Reaction kinetics analysis with explicit photon absorption effects." Applied Catalysis B: Environmental, 68(3–4), 171-180.

[11] Colvin, V.L., (2003). The potential environmental impact of engineered nanomaterials. Nature Biotech., 10: 1166-1170.

[12] The Nanotechnology Public Engagement Programme (2010), Nanotechnology's compaign for safe drinking water, Republic of South Africa.

[13] Heredia-Munoz, Manuel Antonio, Optimization of fixed titanium dioxide film on PET bottles and visual indicator for water disinfection, ProQuest Dissertations And Theses; Thesis (Ph.D.)--University of Massachusetts Lowell, 2011.; Publication Number: AAT 3500033; ISBN: 9781267209160; Source: Dissertation Abstracts International, Volume: 73-06, Section: B, page: 3854.; 105 p.