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Design of Nanofilter for Improving the Quality of Wastewater

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ABSTRACT

One of the most widespread problems affecting people throughout the world is generation of wastewater. There is a need to identify a low cost, less energy and environment-friendly method to purify the wastewater. A promising approach in this present study is to develop a nanofilter using modified silver nanoparticles (AgNPs) made from *Azadirachta indica* (neem) leaf extract to control the growth of bacteria. The nanofilter was designed by using polyurethane foam coated with AgNPs. This filter was tested for the effectiveness of removal of bacteria from the wastewater. Three filtration systems were set up using polyurethane foams embedded with crude AgNPs, modified AgNPs and charcoal separately and filtered with of wastewater. Further, the modified AgNPs filtration system was tested with 20 mg and 10 mg of modified AgNPs separately to determine the minimum amount of modified AgNPs needed for the nanofilter. The treated samples were collected at different time periods 4, 8 and 12 h and plated on nutrient agar plates. Results of treatment system revealed that the filter made with 20 mg of modified AgNPs gave the maximum colony reduction compare to crude AgNPs and charcoal. Interestingly the filter with 20 mg of AgNPs gave the 100% colony reduction. Further minimum time needed for maximum colony reduction was found to be 8 h. In conclusion, nanofilter made with 20 mg of modified AgNPs and filtered for 8 h was recommended as the best filter set up to remove the bacterial contaminants from the wastewater. However, further experiments are needed to test the other quality parameters to recommend the nanofilter for the industry.

KEYWORDS: *Azadirachta indica*, Nanofilter, Silver nanoparticles, Wastewater

INTRODUCTION

Wastewater is a term applied to any type of water that has been utilized in some capacity that negatively impacts the quality of the water. Common examples of wastewater include water that is discharged from households, office and retail buildings, and manufacturing plants. Wastewater may also refer to any water that is no longer considered fit for human consumption (World Water Council, 2012). The composition of wastewater varies widely. More than 95 percent is "water" which consists of pathogens such as bacteria, viruses and parasitic worms, soluble and non-soluble organic and inorganic material, heavy metals, gasess, emulsions and many other pharmaceuticals. Among them, pathogens can cause a variety of illnesses which can be very harmful to the health of human.

In Sri Lanka wastewater is becoming a huge problem as urban populations are projected to nearly double in 40 years (World Water Council, 2012). Most cities in Sri Lanka are lack of adequate wastewater management due to aging, absent or inadequate sewage infrastructure. Recent advances in nanotechnology offer opportunities to develop high performance, affordable wastewater treatment systems using the antibacterial effects of nanoparticles.

Silver nanoparticles (AgNPs) are a very promising approach to the development of filtration system using its antimicrobial activity. Nanoparticulate objects can bring significant improvements in the antibacterial activity, through specific effect such as an adsorption at bacterial surfaces and rupture of the cell wall. However, the mechanism of action is essentially driven by the oxidative dissolution of the nanoparticles (Benjamin and Francesco, 2015).

Previous works have been done on optimizing the suitable synthesis method of producing AgNPs using crude and modified neem leaf extracts (De Silva *et al.*, 2013). Treatment techniques have previously been improved to remove heavy metals from crude neem extract to obtain modified neem leaf extract (Warusawithana and Vivehananthan, 2010). The effect of AgNPs on microbial load to treat different types of wastewater by using the crude AgNPs has been reported previously (Kumar *et al.*, 2015). Moreover, AgNPs coated polyurethane (PU) foam has also been tested to detect the antibacterial effect in wastewater (Namratha and Monica, 2013) but there was no designed polyurethane filter and not tested for the needed parameters such as the minimum amount of AgNPs and time period required for the filtration.

Therefore, the present study initially focused on testing the effect of modified AgNPs and an attempt to develop a low-cost, non-toxic and eco-friendly filter to improve the quality of wastewater. This will be a great attraction in developing countries for controlling waterborne diseases and public health.

METHODOLOGY

Experimental Site

The study was conducted at the Department of Biotechnology, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka from December 2015 to June 2016.

Collection of Samples

Wastewater samples were collected from a canal near the Faculty of Livestock, Fisheries and Nutrition at Makandura premises. Collected samples were immediately used for the filtration. Disease-free neem leaves were also collected from Makandura premises.

Preparation of Neem Leaf Extracts

Crude neem leaf extract was prepared by taking 2.5 g of thoroughly washed and finely cut neem leaves in a 500 mL Erlenmeyer flask with 100 mL of distilled water for 2 min. The mixture was then filtered using whatmann paper (De Silva *et al.*, 2013; Kumari *et al.*, 2014). Modified neem leaf extract was prepared according to the protocol described in Warusawithana and Vivehananthan (2010).

Synthesis of Silver Nanoparticles

Crude and modified AgNPs were synthesized by mixing crude neem leaf extract and 0.001 M silver nitrate solution at 1:8 ratio and modified neem leaf extract and 0.001 M silver nitrate at 1:2 ratio respectively and kept for 3 h. AgNPs were pelleted by centrifugation at 12 000 rpm for 15 min. Pelleted AgNPs were mixed with 5 ml of 100% acetone and mixture was air-dried for two days to obtain AgNPs.

Wastewater Treatment with AgNPs

Initially, AgNPs were added directly to the wastewater at the concentration of 5 mg/L and 10 mg/L. For that newly prepared 10 mg and 20 mg of AgNPs were added separately to 2 L of wastewater in manually made wastewater tank. A treated wastewater sample (50 µL) was collected and plated out on nutrient agar to find out the effectiveness of AgNPs in wastewater treatment.

Designing of Nanofilter

Polyurethane (PU) foam of 7 cm diameter and 1.5 cm thickness in size was washed with deionized water, dried and then autoclaved. Then it was soaked in 20 mg of AgNPs in 10 mL of distilled water and kept for two days in a shaker at 120 rpm to obtain the AgNPs coated PU foam. This AgNPs coated PU foam was placed on top of an autoclaved Whatmann paper in an autoclaved Büchner funnel (550 mL). Two sets of autoclaved Whatmann paper and piece of autoclaved gauze were placed alternatively on top of the PU foam. Open end of the bottom of the funnel was closed by an autoclaved cotton plug and sealed with parafilms.

Determination of the Antibacterial Effect using the Designed Filter

Filtration systems with designed filters were set up to determine the antibacterial effects. Initially three filters were prepared by using both crude and modified AgNPs with 20 mg and 50 mg of charcoal separately. Further two filtration systems were set up by using 20 mg and 10 mg of modified AgNPs separately to determine the minimum amount of AgNPs required for the filtration. For each filter, 150 mL of wastewater was added. Sample filtrates were collected at 4 h, 8 h and 12 h for plating. Control system was set up with only polyurethane filter without adding AgNPs or charcoal.

Consecutive Filtration and AgNPs Coated Polyurethane Double Layer Filtration of Wastewater

For the consecutive filtration of wastewater, two filtration systems were set up. For the 1st filtration set up, 150 mL of wastewater was added and filtrate samples were collected after 8 h. Then the remaining filtrate from the 1st set up was immediately transferred to the 2nd set up and again filtrate samples were collected after 8 h at 1 h interval upto 12 h. For the AgNPs coated polyurethane double layer filtration, two layers of polyurethane filters were used. Sample filtrates were collected at 4 h, 8 h and 12 h. For both of these experiments, 20 mg AgNPs embedded polyurethane filters were used. All filtrate samples were plated on nutrient agar. Control system was setup with only polyurethane filter without modified AgNPs.

RESULTS AND DISCUSSION

Antibacterial Effect of AgNPs on Wastewater

This study was mainly focused on to determine the antibacterial effects of AgNPs in wastewater treatment. Therefore, initially the AgNPs were synthesized and used in the solid form directly to treat the wastewater. Previous work has revealed that 95% inhibition of bacterial growth in household wastewater and 80% of inhibition in farmyard wastewater with the presence of crude AgNPs in 20-50 µg/mL concentration range (Kumar *et al.*, 2015). Also, AgNPs were found to be effective in controlling the growth of *Escherichia coli* and *Staphylococcus aureus* (Nelson *et al.*, 2010). In the present study, wastewater treatment with two different concentrations (5 mg/L and 10 mg/L) of modified AgNPs showed the colony reduction of 80% and 50% for 5 mg/L system for 1 h and 3 h after treatment respectively while 95% and 45% reduction of colony for 10 mg/L system for 1 and 3 h respectively (Figure 1). This result further revealed that the 10 mg/L modified AgNPs concentration had considerable antimicrobial activity in the wastewater treatment. The mechanism behind this may be the attachment of released silver ions to the negatively charged bacterial cell wall and rupture of it, thereby leading to protein denaturation and cell death (Nalwade and Jadhav, 2013).

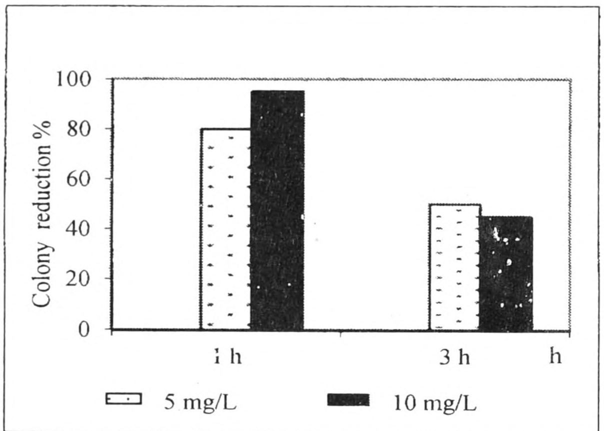

Figure 1. Percentage reduction of Colony in wastewater treated with silver nanoparticles (AgNPs)

Antibacterial Effect of Nanofilter

The active antimicrobial compound which used in the preparation of the nanofilter is AgNPs and PU foam is the main source where AgNPs coated. Polyurethane is one of the freely available, most cost-effective, food-grade polymers, and it is commonly used material in rural communities.

Effectiveness of crude and modified AgNPs and charcoal were also evalulated to compare with the control. In addition to that, the minimum time duration which is needed to filter the wastewater was tested in this study. As expected there was no colony reduction observed (1-2%) for charcoal filtrate for all the time period tested in this experiment. For crude AgNPs filtrate, 35, 45 and 25% colony reduction was observed for 4, 8 and 12 h respectively. Interestingly no colony was oberved for modified AgNPs at 8 h and 12 h and 95% colony reduction was observed for 4 h (Figure 2). This revealed that the modified AgNPs had the highest antibacterial activity.

Since the modified AgNPs showed a greater colony reduction compare to crude AgNPs, modified AgNPs were selected for the further experiments. Most effective filtration duration was also found to be 8 h.

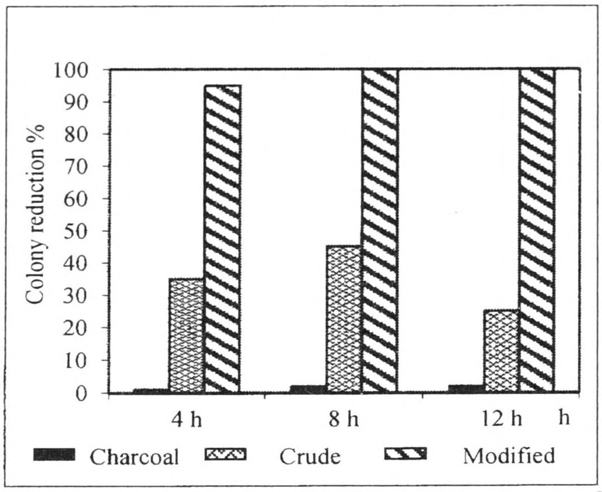

Figure 2. Colony reduction percentage of wastewater filtration using crude silver nanoparticles (AgNPs), modified AgNPs and charcoal added nanofilters

In determining the effective amount of modified AgNPs for the preparation of nanofilter, two different amounts of AgNPs (20 mg and 10 mg) were used. As expected, there was no colony observed with the increased amount (20 mg) of modified AgNPs while 98% and 50% were observed for 10 mg of modified AgNPs at 8 h and 12 h respectively (Figure 3). This revealed that the 20 mg filter system used for the wastewater treatment was found to be more effective especially at 8 h. Therefore, 20 mg of modified AgNPs embedded polyurethane filter was used for the rest of the experiments and treated for 8 h as it was confirmed through series of experiments in the present study.

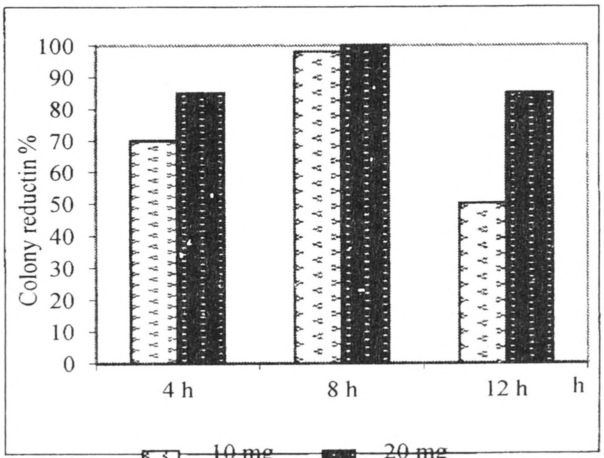

Figure 3. Colony count reduction percentage for different amount of modified silver nanoparticles (AgNPs)

Effectiveness of Consecutive Filtration and Polyurethane Double Layer Filtration

Consecutive filtration was done to observe the effect of colony reduction when two immediate filtrations were done to the same wastewater. In addition, AgNPs coated polyurethane double layer filtration was used to observe whether there was any considerable different when layers of filters are increased. In parallel, the amount of AgNPs and filtration time were tested for effective treatment.

Both of these experiments indicated that there was a considerable amount of colony reduction. In consecutive filtration experiment, from the 1st filtration system after 8 h, the colony reduction was 96% and from the 2nd filtration tested at 8, 9, 10 h resulted in 99% colony reduction in all time period tested. However, there were no colony appeared for the 11 h and 12 h filtrates from 2nd filtration indicating the efficiency of the use of two filtrations consecutively (Figure 4).

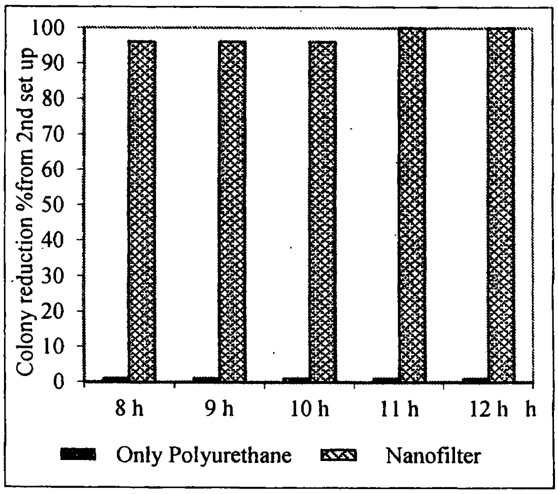

Figure 4. Colony count reduction percentage for consecutive filtration

In polyurethane double layer experiment also there was no colony observed for the 8 h filtrate. Colony reduction was 90% and 95% for 4 h and 12 h respectively (Figure 5).

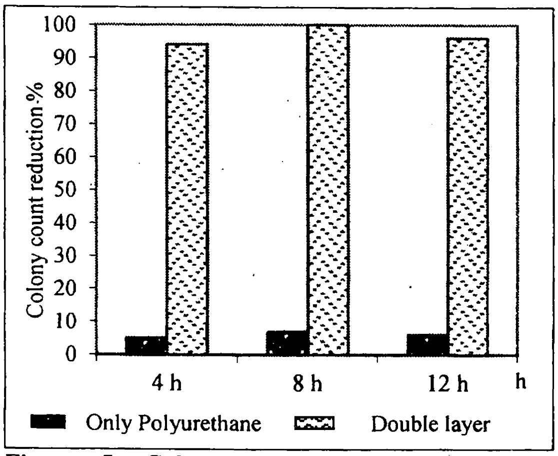

Figure 5. Colony reduction percentage for polyurethane double layers filtration

Both of these experiments resulted 100% colony reduction by filtration with 20 mg of modified AgNPs after 8 h from filtration which can be applied in further designing the nanofilter.

CONCLUSIONS

The PU foams embedded with 20 mg of modified AgNPs for single layer and double layer filters gave 100% colony reduction at 8 h. Further, consecutive filtration also gave 100% colony reduction at 11 h and 12 h of filtration. Collectively these filtration set ups can be recommended for large-scale wastewater treatment plants. Further experiments can be done to determine COD, BOD and heavy metal analysis to confirm the effectiveness of nanofilter.

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