Contribution of solution chemistry on bacterial attachment in textile fibrous media

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Abstract:

An approach to the removal of *Pseudomonas* bacteria from contaminated water by using textile fibrous media has been proposed in this article. The attachment of *Pseudomonas* bacteria on different media material was studied in laboratory column experiment. Two types of textiles media made of polyester and nylon fibers were selected for the experiment. The experimental design included the various level of salt concentration of calcium chloride (i.e. 1 mM, 50 mM, 100 mM, and 150 mM). The colloidal filtration and Derjaguin-Landau-Verwey-Overbeek (DLVO) theory was used to investigate the effect of different media material on bacteria attachment at the various source of water quality. Bacteria attachment on nylon fibrous media is found to be greater as compared to the polyester fibrous media. This can be attributed to the higher collision (attachment) efficiency for nylon fiber (0.24-0.46) as compared to polyester fiber (0.23-0.42) for the ionic strength range of 1mM to 150 mM. It is also found that nylon fiber exhibited positive zeta potential at higher salt concentration resulted in reduction in energy barrier to attachment of bacteria on fibers surface. The DLVO profile of the bacteria attachment on polyester shows the existence of a high energy barrier ($710 K_b T$) as compared to the nylon fibrous media ($398 K_b T$) at an ionic strength 1 mM. These high energy barriers resist the deposition of the bacteria in the primary minima resulted in lower removal efficiency of the polyester media material.

Keywords: Bacterial attachment, Textile fibers, DLVO theory, transport mechanism, attachment mechanism, collision efficiency

Introduction

Most of the current outbreaks of diseases in the world are as a result of the consumption of contaminant water. Water disinfection is the removal, deactivation or killing of the pathogenic microorganism in water. Both physical and chemical are the effective means to disinfection the harmful microbial from the water (Unuabonah, Ugwuja, Omorogie, Adewuyi, & Oladoja, 2017).

Physicochemical filtration is a favored method for removal of bacteria from the potable water and wastewater because of its simplicity, high efficiency, and low-cost operation. The governing mechanism of this filtration technique is adsorption and this process does not produce by-products as is found in chemical disinfection process used for water purification (Link, 2017).

There is no such studies have been done on the textile fibers used as a collector in column experiment for bacteria filtration. In addition to this, the data on the attachment behavior on different media material in textile fibrous media as a function of salt concentration is limited. The specific objective of this study is to examine, in a systematic way, the combined effects of different media material and salt concentration on the bacteria attachment on the fibers media surface. The experimental observations are explained based on the collision efficiency, change in the surface properties of bacteria and the fibrous substrates in the presence of different salt concentration and Derjaguin-Landau-Verwey-Overbeek (DLVO) Theory.

Materials and Methods

For the study, 100% trilobal nylon 6 fibers (Polyventure, Kolkata, India), 3denier, 18mm and 100% polyester (Vardhman Textile, Ludhiana, India), 4denier, 38 mm are used as packing material in column experiments. Microbial culture used in this study is *Pseudomonas aeruginosa* (gram-negative, rod-shaped) provided by

Department of Biotechnology, NIT Jalandhar (India). Sodium Hydroxide (NaOH), Hydrochloric Acid (HCl), Sodium Carbonate (Na_2CO_3), Calcium Chloride Dihydrate ($CaCl_2.2H_2O$) and Nutrient broth are purchased from Deejay Corporation, Jalandhar, India.

Sample pretreatment

Nylon and polyester fiber are scoured with 0.5 gl^{-1} soda ash (Na_2CO_3) solution at 60^0 C for 15 minutes to the liquor ratio 1:50 in order to remove added oils, lubricants, dust etc. present on the fiber surface.

Bacteria culture

A liquid media is prepared for Bacteria culture by adding 1.3 gm nutrient broth in 100 ml distilled water in a conical flux. This liquid media is kept in the autoclave for 4 h at 120^0 C. transferring 2 ml from an active culture of *Pseudomonas aeruginosa* grown at 35^0 C in conical flux containing liquid media and incubated at 35^0 C for 18 h. 10 ml of fresh culture is centrifuged at 5000 *g*, 6^0 C for 15 min. The resulting pellet is suspended in 10 ml of 0.01 mole NaCl solution and stored at 4^0 C for column experiment.

Column Experiment

Attachment of *Pseudomonas aeruginosa* is evaluated in short column containing nylon and polyester to verify the effect of different media material on the microbial attachment at various ionic strength. Glass column of 10 cm in length and 5 cm in diameter (PMI, India) is packed with 10g of each fiber nylon and polyester.

200 ml distilled water is used to prepare the model test water according to the experimental design. Calcium Chloride Dihydrate ($CaCl_2$. $2H_2O$) is used for maintaining the ionic strength ranges from 1 mM to 150 mM. 0.1 M Hydrochloric acid (HCl) and 0.1M Sodium hydroxide (NaOH) are used to adjust pH at7 of the model test water. 2 ml of fresh *pseudomonas aeruginosa* culture is mixed with the 200 ml model test water and optical density is measured. Initially, tap water is passed through fibers packed bed until the concentration of inlet and outlet became same. Concentration is measured in terms of OD (optical density) by Spectrophotometer (Lambda 365, PerkinElmer). Same pH and ionic strength as model test water without bacteria is passed through the column at the start of each the experiment. The model test water with bacteria is passed through fiber column and outlet bacteria concentration is measured.

Optical Density measurement (OD)

The optical density of the bacteria concentration in the inlet and outlet model test water is measured by the spectrophotometer (Lambda 365, PerkinElmer) at 600 nm.

Zeta potential measurement

Scoured nylon and polyester fiber are kept in distilled water for 2 h before the zeta potential measurement to eliminate the swelling effect. Zeta potential is measured using Zeta potential analyzer Zeta Plus™ (Brookhaven Instruments Corporation, USA). Fiber is cut into small pieces and dispersed into the distilled water of various concentration of $CaCl_2$ (i.e. 1 mM, 50 mM, 100 mM and 150 mM). A small aliquot of the stock solution is fed into the sample cell to measure the zeta potential as a function of salt concentration at constant pH 7.

Table 1.Parameter values used in calculating single collector contact efficiency, collision efficiency and interaction energy between bacteria and fiber

Parameters	Symbol	Nylon Media	Polyester Media
Media characteristics			
Length (m)	L	3.5×10^{-2}	5.5×10^{-2}
Porosity	f	0.86	0.92
Mass of media (g)	M	10	10
Bacteria/collector characteristics			
Bacteria diameter (m)	d_p	1.2×10^{-6}	1.2×10^{-6}
Bacteria density (Kgm^{-3})	ρ_p	1040	1040
Collector diameter (m)	d_c	19.20×10^{-6}	20.30×10^{-6}
Fluid Characteristics			

Temperature (K)	T	293	293
Density (Kgm^{-3})	ρ	1000	1000
Velocity (ms^{-1})	U_0	1.6×10^{-3}	3.30×10^{-3}
Viscosity (Nsm^{-2})	μ	1×10^{-3}	1×10^{-3}
Kinematic viscosity (m^2s^{-1})	ϑ	1×10^{-6}	1×10^{-6}
Physical constant			
Dielectric constant	ε_r	80	80
Permittivity (F/m)	ε_0	8.85×10^{-12}	8.85×10^{-12}
Electron charge (coulomb)	e	1.60×10^{-19}	1.60×10^{-19}
Avogadro's number (/mole)	N_A	6.02×10^{23}	6.02×10^{23}
Characteristics wave-length (m)	λ	1×10^{-7}	1×10^{-7}
Boltzmann constant (JK^{-1})	K_b	1.381×10^{-23}	1.381×10^{-23}
Hamaker constant (J)	A	1×10^{-20}	1×10^{-20}

Results and Discussion

Effect of ionic strength on bacteria removal efficiency

To study the effect of ionic strength on bacteria attachment on different media material, model test water at various salt levels is passed in a column packed with 10g of each fiber nylon and polyester. Calcium chloride ($CaCl_2$) is used to vary the ionic strength between 1 mM to 150 mM. The experimental results are shown in *figure* 1. The values in the figures represent average values of 3 experiments. In case of nylon fibers media, the bacteria removal increased from 53% to 77% with the increase in ionic strength of $CaCl_2$ from 1 mM to 150 mM. In case of polyester, with the increase of ionic strength from 1 mM to 150 mM bacteria removal efficiency increases from 39% to 58%. The variations in the removal efficiency for the nylon and polyester media are explained by the calculated collision efficiency and energy interaction profile and measured surface charge of bacteria and textile fibrous media and discussed in the next paragraph.

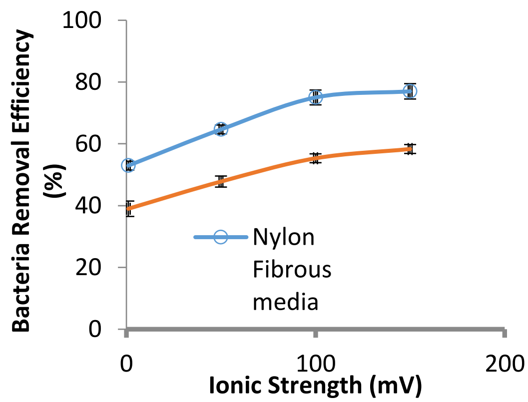

Figure 1.Effect of ionic strength on bacteria removal in different fibrous media at constant pH 7

Effect of media material and ionic strength on collision efficiency

To quantitatively compare the experiments conducted with two different media materials under changing solution conditions, values of collision (attachment) efficiency, α, are calculated. The collision efficiency is defined as the ratio of the experimental single collector contact efficiency (η) and the predicted single collector contact efficiency (η_0). The results are tabulated in table 2.

Table 2.Experimental condition and measured collision efficiency

Experiment	Ionic strength (mM)	pH	Fraction of Penetration(F_p)	Collision efficiency (α)

			Nylon	polyester	Nylon	polyester
1	1	7	0.47	0.61	0.24	0.23
2	50	7	0.35	0.52	0.34	0.30
3	100	7	0.24	0.44	0.45	0.38
4	150	7	0.24	0.41	0.46	0.42

$\alpha = {}^{\eta}/_{\eta_0}$, Values of single collector contact efficiency (η_0=7.94×10^{-3} for nylon and η_0=6.47×10^{-3} for polyester) are calculated using equation 6 and parameter values of table 1, experimental single collector contact efficiency (η) is calculated using equation 2.

Collision efficiency used to determine the effect of chemical parameters on removal efficiency empirically. It is seen that with the increase in the ionic strength the collision efficiency increases. For the nylon fibrous media the collision efficiency increases from 0.24 to 0.46 for the ionic strength range of 0 mM to 150 mM. In case of polyester, with the increase in the ionic strength from the 1 mM to 150 mM collision efficiency increases from 0.23 to 0.42. It is observed that changes in the collision efficiency became less pronounced above an ionic strength of 100 mM (as shown in Table 2). This was in agreement with the previous studies (A.Abbot, 1983), in which they have reported that above an ionic strength of 100 mM there is little change in the collision efficiency. Enhanced attachment of bacteria on the fibrous surface with the increase of ionic strength can be attributed to the change in the collision efficiency. It is seen from figure 2, that the change in collision efficiency is higher for nylon as compared to polyester resulted in higher removal efficiency by nylon fibrous media.

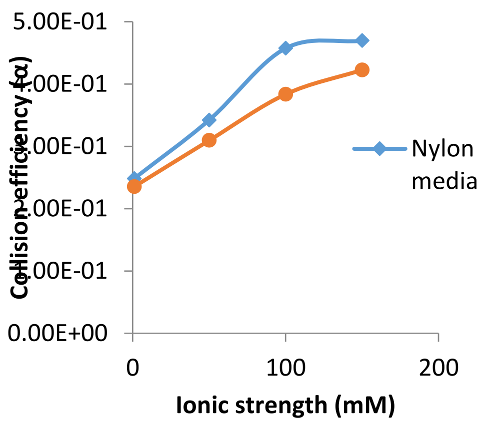

Figure 2.Collision efficiency as function of ionic strength for different media material

Surface charge of fibrous media and bacteria

The surface charge of the fibrous media and bacteria is measured using zeta potential analyzer at various salt levels. *Table 3* shows the effect of ionic strength on the surface charge of the bacteria and fibers in the presence of calcium chloride.

Table 3.Effect of ionic strength on zeta potential of bacteria and fibers in presence of calcium chloride

Ionic Strength of $CaCl_2$ (mM)	Zeta potential (mV)		
	Bacteria (*Pseudomonas*)	Polyester Fiber	Nylon Fiber
1	-32	-37	-25
50	-20	-25	-15
100	-10	-15	+3
150	-9	-14	+6

It is seen that the absolute value of zeta potential of bacteria decreased (surface charge became less negative) from -32 mV to -9 mV with the increase in the concentration of $CaCl_2$ in model test water from 1 mM to 150 mM (as shown in Table 3). In case of the polyester absolute value of zeta potential decreased from -37 mV to -14 mV. However, the absolute value of zeta potential of nylon fiber became positive (-25 mV to 6 mV) with the increase in the concentration of $CaCl_2$ from 1 mM to 150 mM. This can be reason for the more attachment of bacteria on nylon fibers surface as compared to the polyester fibers. It is also reported that for the removal of the bacteria under the relatively favorable attachment conditions, the media should have the highest differences in surface charge with respect to the charge of bacteria (Stevik, Aa, Ausland, & Hanssen, 2004). It is seen that after 100 mM the zeta potential of each bacteria, nylon and polyester fibers did not show the appreciable change. This is commonly been attributed to the reversal effect of cations deposition.

Table 4.The calculated DLVO interaction parameters for polyester fiber

Ionic strength (mM)	Energy barrier (K_bT)	Secondary minimum depth (K_bT)	Secondary minimum Separation (nm)	Primary minimum depth (K_bT)	Primary minimum Separation (nm)
10	710	-0.41	50	ND	ND
20	C	ND	ND	-53	1
100	C	ND	ND	-178	1
150	C	ND	ND	-191	1

$\Phi_{EDL}(h)$ and $\Phi_{VDW}(h)$ values are estimated using Eq. (2) and Eq. (4) and total interaction energy, $\Phi_{DLVO}(h)$ is estimated using Eq. (12) and parameter values in Table 1, at different values of separation distance. Fig. 3 shows the plot for polyester studied at various concentration of $CaCl_2$.

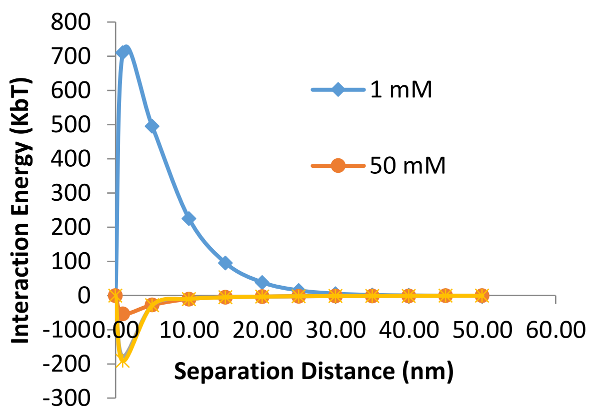

Figure 3.Calculated DLVO interaction energy as a function of separation distance at different solution ionic strengths for polyester fibrous media and bacteria

The DLVO profile for polyester and bacteria reveals the existence of energy barrier at ionic strength 1mM is 710 K_bT (as shown in Table 4) and removal efficiency is 39 % this is due to the attachment of bacteria at the depth of the secondary minimum (-0.41 K_bT) which is formed at separation distance of 50 nm in the energy interaction profile. A bacterium will remain associated with the fiber surface in this energy minimum unless it has been sufficient energy to allow bacteria to escape. Further increase in concentration of $CaCl_2$ from 50 mM to 150 mM it is found that there is no energy barrier exists. The bacteria entered into the favorable zone of chemical-bacteria interaction. At this stage depth of the primary minima is responsible for bacteria attachment. It is increases from the -53 K_bT to -178 K_bT with the increase in concentration of $CaCl_2$ from 50 mM to 100 mM resulted in increase of removal efficiency to 55 %. After that there no appreciable change is observed in depth of primary minima (-191K_bT) as the concentration increased up to 150 mM that is why there is less increase in removal efficiency and remained at around 58 %.

Table 5.The calculated DLVO interaction parameters for nylon fiber

Ionic strength (mM)	Energy barrier (K_bT)	Secondary minimum depth (K_bT)	Secondary minimum Separation (nm)	Primary minimum depth (K_bT)	Primary minimum Separation (nm)
10	398	-0.42	45	ND	ND
20	C	ND	ND	-95	1
100	C	ND	ND	-220	1
150	C	ND	ND	-221	1

[C] No energy barrier to deposition predicted, [ND] Not determined

strength 1mM 398 K_bT is lower compared to that of polyester 710 K_bT (as shown in Table 5) and showing removal efficiency 53%.

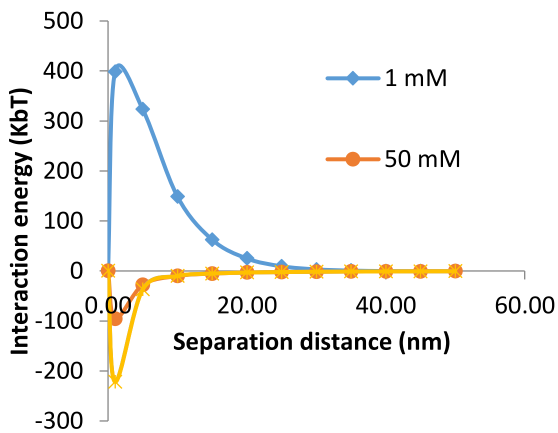

Figure 4.Calculated DLVO interaction energy as a function of separation distance at different solution ionic strengths for nylon fibrous media and bacteria

This is due to the presence of calcium ions made the surface charge of nylon fibers less negative (as shown in Table 3) leading to increase in van der Waals force of attraction and decrease in the electrical double layer repulsion force. This reduces the energy barrier between bacteria and nylon fiber as compared to that of polyester hence providing a better chance of attachment of bacteria on the surface of the fiber. In addition to that, it found that the increase in the depth of the secondary minimum (-0.42K_bT) and its position (45 nm) came closer to the nylon fiber surface as compared to polyester fibrous media. Further increase in concentration of $CaCl_2$ from 50 mM to 150 mM it is found that there is no energy barrier exists. The bacteria entered into the favorable zone of chemical-bacteria interaction for the attachment on the fiber surface. It is seen that the increase in the depth of the primary minima for nylon fibrous media (-95 K_bT to -220 K_bT) is higher than that of polyester fibrous media (-53 K_bT to -191 K_bT) this may resulted in increased of removal efficiency from 64 % to 75 % for the ionic strength range of 50 mM to 100 mM. After that there no appreciable change is observed in depth of primary minima (-221K_bT) as the concentration increased up to 150 mM due to this the change in removal efficiency became less pronounced and reminded at around 77 %. This was in agreement with the previous studies (Gordon & Millero, 1984), in which the reduction in bacteria attachment on fibers surface at high salt concentration (>100 mM) was related to the molar concentration of Cations in the medium, not to the ionic strength of the medium.

Conclusions

It is important to understand the effect of different media material at the various source of water quality on the performance of the filter designed to remove bacteria in water purification device. An attempt has been made to interconnected nature of these factors governing the attachment of the bacterial cells in textile porous media. Experimental evidence in this study has been demonstrated that different media material plays an important role in bacterial attachment in fibers packed bed.

In this study, two types of textiles media made of polyester and nylon fibers are selected for the experiment at a various salt concentration of $CaCl_2$. Nylon fibrous media showing the high removal efficiency as compared to the polyester fibrous media due to the change in surface properties. Nylon fibers exhibited positive zeta potential at higher salt concentration resulted in lower energy barrier to attachment of bacteria on fibers surface. So nylon fibers could be used a media material instead of polyester to design a filter for removal of bacteria in water purification device.

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