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Scientific design of potable water filter for the rural masses by using textile fibrous media

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One of the possible approaches to remove the *Pseudomonas* bacteria from surface water by using textile fibrous media has been studied in this article. The attachment of *Pseudomonas* bacteria inside textile fibrous media was studied using laboratory column experiment. Physicochemical parameters i.e. pH, salt concentration, type of fiber and fiber orientation are taken into account to optimize the amount of fiber mass in a given volume (porosity) and then designed a standard filter bed for long column experiment. After that life cycle and reusability of the filter media are determined on long column experiment by using optimized physicochemical data. It is found that the design filter bed can also achieve 94 % removal efficiency up to 10 litres of water. Same media material can be reused after hot washing and shows nearly same removal efficiency when compared with the virgin media. Furthermore, different source of surface water (pond and lake) also treated in designed filter media and it is observed that water quality like turbidity, colour, pH and total dissolved solid are coming within the permissible limit recommended for drinking water after the treatment. The bacteria removal efficiency for pond water is 85 % and for the lake water is 72 % this because of the slightly higher alkaline pH of the surface water resulted in lower removal efficiency. But when the pH of the lake water brings down to 6 then the removal efficiency increased up to 92 % which is very close to the IS standard value of drinking water. This filter media may provide safe water for drinking, cooking and other emergency needs on a sustainable basis and meet minimum water quality standards and be readily and conveniently accessible at all times and in all situations.

Keywords: Textile fiber, Bacteria filtration, Breakthrough curve, surface water, Column experiment

1 Introduction

Water is a precious need of life. This is certainly true in most parts of Africa and Asia. Even in relatively developing country such as India, safe drinking water is not readily available, particularly in rural areas[1].

However, much of the world’s population does not have access to safe drinking water. Out of the 6 billion people on earth, more than one billion (one in six) of the world population is having no accesses to safe drinking water. Moreover, about 2.5 billion (more than one in three) do not have access to adequate sanitation services.

Rural India has more than 700 million people residing in about 1.42 million habitations spread over 15 diverse ecological regions. Lack of safe and secure drinking water continues to be a major hurdle and a national economic burden. Around 37.7 million Indians are affected by waterborne diseases annually, 1.5 million children are estimated to die of diarrhea every year [2-3].

There is an urgent need to develop a filter media which may provide safe water for drinking, cooking and other emergency needs on a sustainable basis for rural India.

The filtration through porous media is one of the effective processes used for colloidal removal from surface water[4]. According to the media structures, filtration can be divided into granular filters and textile filters[5]. Significant efforts have been made by number of researchers in developing colloidal filtration (mainly sand, glass bed etc.) based on the physicochemical interaction between colloids and media[6]. In granular filters, the major limitation is the capacity for the retention of the colloidal particles within the pore spaces and low filtration rate, only can be 0.1- 0.3 m^3/m^2 h in that range[8]. However, granular filtration theory is well developed based on the physicochemical interaction of the bed and colloidal particles. In recent years, the textile material is emerging as a substrate to be used as filter media for the removal of colloidal particles from the surface water[9]. Superior performance in removal of colloidal particles from the water can achieved by the

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textile fibrous media under 10-fold higher filtration velocities as compared to granular media[10].

The filter media is an important and very critical component of every filtration step and can make it from either an economic or a performance point of view. Textile materials have been used to design the commercial filter media through the trials[11]. Few engineering criteria exist for the selection of existing filter media or for the design and construction of new media for the efficient performance in the various types of filtration services. There is a lack of quantitative basis for both the design and selection of the filter media, which is largely responsible for the wide and continuously changing the variety of filter media in general uses[12]. Need for the development of effective and efficient textile fibrous filters system for removal of suspended particles from waste water is necessary to understand the media-suspension particles interaction[13].

In our previous study we have used the colloidal filtration and Derjaguin-Landau-Verwey-Overbeek (DLVO) theory to investigate the effect of different media material (nylon and polyester) on bacteria attachment at the various salt concentrations. It was found that 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. The DLVO profile of the bacteria attachment on polyester shows the existence of a high energy barrier (710 K_bT) as compared to the nylon fibrous media (398 K_bT) 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[14].

In this paper, optimized laboratory experimental data of physicochemical parameters that account for single collector contact efficiency (η) and attachment or collision efficiency (*α)* i.e., pH, salt concentration, type of fiber and fiber orientation presented our previous studies[14-15] are taken into account to optimize the amount of fiber mass in a given volume (porosity) and then designed a standard filter bed for long column experiment. After that life cycle and reusability of the filter media are determined on long column experiment by using optimized physicochemical data. Finally experiment is carried out with surface water from different sources through the designed filter media. The result of the surface water after filtration is very encouraging and may be used as potable water at all times and all situations.

2 Materials and Methods

For the study, 100% nylon 6 fibers (Polyventure, Kolkata, India), 1.5 denier, 38 mm fiber used as packing material in column experiments. Microbial culture used in this study was *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 (Deejay Corporation, Jalandhar, India). All these chemicals are laboratory grade and used as received.

2.1 Sample pretreatment

Nylon fibers are scoured with 5 gl^{-1} soda ash (Na_2CO_3) solution at 60 °C for 15 minutes to the liquor ratio 1:50 in order to remove added oils, lubricants, dust etc. present on the fiber surface.

2.2 Bacteria culture

A liquid media is prepared for bacteria culture by adding 1.3 g nutrient broth in 100 ml distilled water in a conical flux. This liquid media is kept in the autoclave for 4 h at 120 °C. Transferring 2 ml from an active culture of *Pseudomonas aeruginosa* grown at 35 °C in conical flux containing liquid media and incubated (Innova 42, Eppendorf, USA) at 35 °C for 18 h. 10 ml of fresh culture is centrifuged (Centrifuge 5810 R, Eppendorf, USA) at 5000 *g*, 6 °C for 15 min. The resulting pellet is suspended in phosphate buffered solution and stored at 4 °C for column experiment.

3 Fundamental Concepts of Filtration and Design of Deep Bed Filter

C.R. O'Melia[16] have developed filtration equation using mass balance equation based on particles removal by an isolated sphere, assuming a packed bed is an assemblage of isolated sphere (Fig. 1). If a liquid of initial concentration C_0 is passed through a bed of length Z, packed with sphere of diameter d, and the concentration of liquid after filtration is C, then based on the mass balance equation, the relationship between and C can be expressed by the Eq. 1:

$$ln\frac{C}{C_0} = -\frac{3}{2}(1-f)\alpha\eta\left(\frac{z}{d}\right) \quad \text{... (1)}$$

Where α is the collision efficiency, f is porosity or void fraction of filter media and η is the single collector contact efficiency.

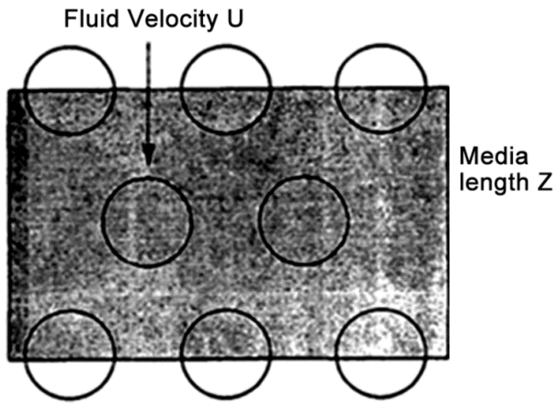

Fig. 1 — Flow through packed bed (Logan et al., 1995).

The concept of single-collector contact efficiency is useful in considering the transport step in filtration. Physical parameters that account for the colloids collisions with the porous media are incorporated into the single collector contact efficiency. The collector contact efficiency of a single media particle or collector (*η)* is a ratio-i.e., the rate at which colloids strike the collector divided by the rate at which colloids flow toward the collector.

An attempt to include quantitative measurement of attachment in filtration has been made by Yao *et al.*[16]. Following the practice of coagulation, a collision efficiency factor, is used to describe that fraction of all particle to media collisions which result in successful attachment[17]. All the chemical factors influencing the particle attachment are incorporated into collision efficiency factor (*α*), is the ratio of the number of the particle removed by the collector to the number of particle colloid with collector, or the possibility that a collision in an attachment[18-19].

Based on the optimized laboratory experimental data of physicochemical parameters (pH, salt concentration, type of fiber and fiber orientation) that account for single collector contact efficiency (η) and attachment or collision efficiency (*α)*, a standard filter bed designed for column experiment.

4 Fabrication of a Portable Deep Bed Water Filter

Fabrication of the portable deep bed water filter long column is designed on basis of previously reported studies[16]. A transparent acrylic column with internal diameter and length of 5 cm and 20 cm (Fig. 3) respectively selected[20]. A perforated plate of stainless steel is used at 5 cm height from bottom of the column for the support of packed fibrous column. A feed tank is used for the water storage of 4 litres capacity. Two pressure gauges are used to measure the pressure drop. Two Rota meter are used for measuring the inlet and outlet flow rate.

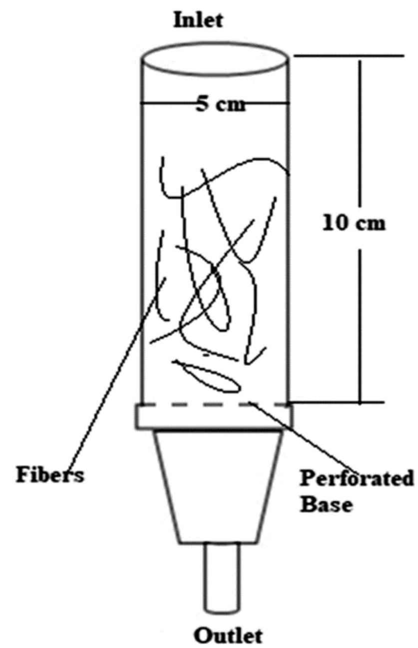

Fig. 2 — Short column Experimental setup.

5 Column Experiment

5.1 Short column experiment

Short column experiment is conducted for the mass optimization of designed bed. Glass column (Fig. 2) of 10 cm in length and 5 cm in diameter (PMI, India) was packed with fibers according to the experimental design to verify the effect of media mass (8 g to 12 g) on the microbial attachment at constant ionic strength (0.1M) and pH (6) and fiber orientation (90^o). The ionic strength and pH of the model test water are chosen on the basis of previous presented studies [Roy *et al*., 2018a; Roy *et al*., 2019]. 5 litres of distilled water is used to prepare the model test water according to the experimental plan. Calcium Chloride Dihydrate ($CaCl_2$. $2H_2O$) is used for maintaining the ionic strength at 0.1 M. 0.1 M Hydrochloric acid (HCl) and 0.1M Sodium hydroxide (NaOH) are used to adjust pH at 6 of the model test water. Fresh *pseudomonas aeruginosa* culture is mixed with the 5 litres model test water. After the packing of fibrous media, the column was flushed under a saturated condition with tap water for 10 min to ensure a uniform packing and to liberate any trapped air bubbles.

The flow was then continued until the concentration of inlet and outlet became same. Concentration is measured in terms of OD (optical density) by Spectrophotometer (Lambda 365, PerkinElmer). Prior to each experiment, same pH and ionic strength as model test water without bacteria is passed through the column to free the effluent from the background contaminants in packed fibrous media. The model test water with bacteria is passed through fiber column and outlet bacteria concentration is measured.

5.2 Long column experiment

Long column experiment is conducted for the determination the life cycle and reusability in designed filter bed based. Long glass column (PMI, India) of 20 cm in length and 5 cm in diameter (Fig. 3) was packed with optimized nylon fibers mass of 46 g at 90^o orientation angle. 10 litre distilled water is used to prepare the sample water according to experimental deign design. Calcium Chloride Dihydrate ($CaCl_2$. $2H_2O$) is used for maintaining the ionic strength at 0.1 M and 0.1 M Hydrochloric acid (HCl) and 0.1M Sodium hydroxide (NaOH) are used to adjust pH of the sample water at 6. Fresh *pseudomonas aeruginosa* culture is mixed with the 10 litre sample water. After the packing of fibrous media, the column was flushed under a saturated condition with tap water for 10 min to ensure a uniform packing and to liberate any trapped air bubbles. The flow was continued until the concentration of inlet and outlet became same. Concentration is measured in terms of OD (optical density) by Spectrophotometer (Lambda 365, Perkin Elmer). Prior to each experiment, same pH and ionic strength as model test water without bacteria is passed through the column to free the effluent from the background contaminants in packed fibrous media. The model test water with bacteria is passed through fiber column and outlet bacteria concentration is measured.

6 Results and Discussion

6.1 Mass optimization from breakthrough curve (short column experiment)

The breakthrough curves of column filtration are presented as C/C_0, C and C_0 are the effluent and influent concentrations of bacteria with respect to volume of filtrate water (see fig. 4). Breakthrough completed after passing the 1500 ml of water. As observed, the removal efficiencies, 1- C/C_0, increases from 82% to 95 % (as seen in the Table 1) with the increase in media mass from 8 g to 12 g. This was in agreement with the previous studies [Roy *et al.*, 2018a, Roy *et al.*, 2019; Roy *et al.*, 2018b; Roy *et al*., 2018c] in which they have reported that bacteria attachment and removal efficiency increased with an

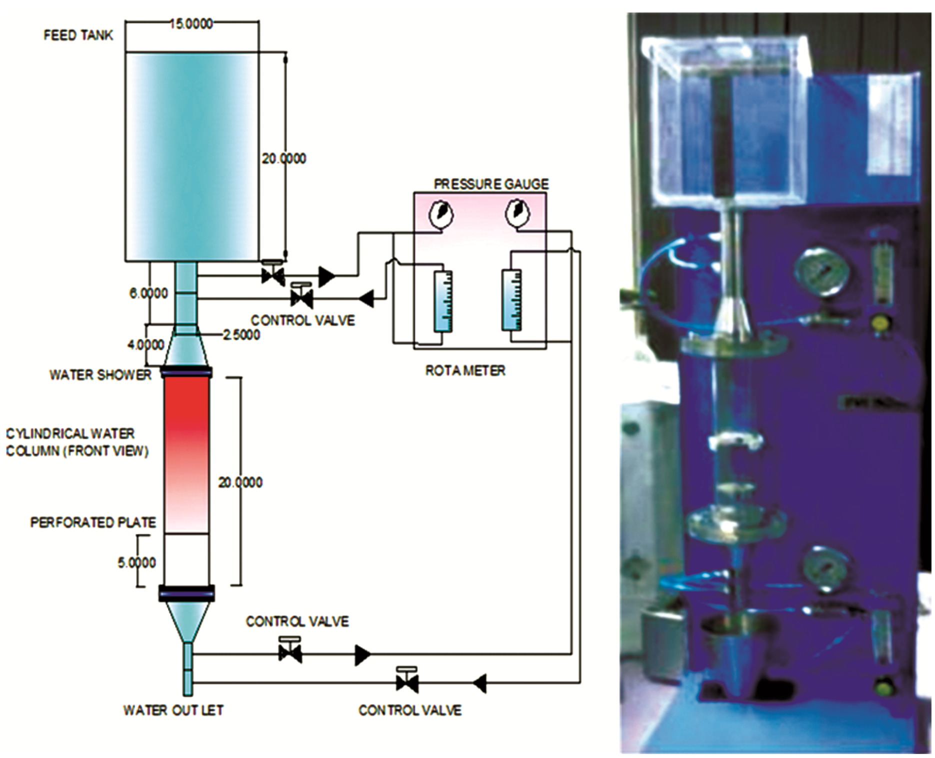

Fig. 3 — Long water filter column.

increase in media mass and change in solution chemistry. According to colloidal filtration theory, this is possibly due to a change in the single collector contact efficiency and (η) collision (attachment) efficiency (α) of the fibrous media in higher values. There is no appreciable change found in removal efficiencies (93% to 95 %) with the increase of media mass from 10 g to 12 g. So any further increase of media mass may not be improved the removal efficiency of the filtration process.

6.2 Long column experiment for determination of life cycle and reusability of designed bed

From the short column experimental data the optimized mass of media material is calculated for the long column experiment. Long glass column of 20 cm in length and 5 cm in diameter (PMI, India) was packed with optimized nylon fibers mass of 46 g to determine the life cycle and reusability of designed filter bed at optimized value of ionic strength (0.1 M) and pH of 6.

It is observed from figure 5; the design filter bed for long column can also achieve 94 % removal efficiency when experimental with 10 litres volume of water. Same media material is reused after hot washing. The result shows nearly same removal efficiency when it is compared with the virgin media.

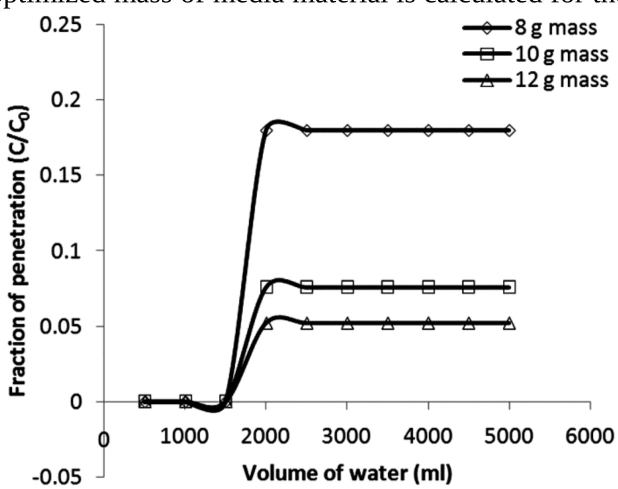

Fig. 4 — Breakthrough curve as function of media mass.

Table 1 — Effect of mass variations on fraction of penetration and removal efficiency.

Experiment	Mass of Fiber (g)	Fraction of Penetration (C/C_0)	Removal efficiency (%)
1	8	0.18	82
2	10	0.07	93
3	12	0.05	95

6.3 Water quality after filtration through designed filter

Surface water of different sources like pond and lake water is collected from Punjab and Himachal. Filter media is prepared with combination of 44 g mass of nylon 6 fiber and 2 g of charcoal. The *pseudomonas aeruginosa* bacteria is mixed with 10 litres of each surface water and passed through deigned filter media. Water quality before and after filtration is tabulated in the Table 2, with Indian Standard (IS) of drinking water as per the BIS (Bureau of Indian Standards) specifications.

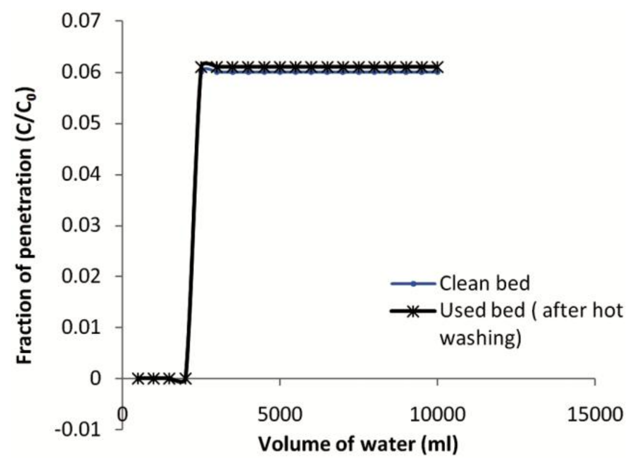

Fig. 5 — Breakthrough curve of clean bed and single used bed.

Table 2 — water quality before and after treatment.

Source of water	Turbidity (NTU)			Colour(CU)			pH			TDS			Bacteria Removal Efficiency (%)	
	Before	After	IS10500: 1991	Before	After	IS10500: 1991	Before	After	IS10500: 1991	Before	After	IS10500: 1991	Experimental value	IS10500 1991
Pond	26.4	2.77		43.7	8.7		7.40	7.75	6.5-8.5	280	309		85	95% free from bacteria in 100 ml
Lake	1.11	0.80	5-10	10.6	7.50	5-25	8.24	8.00		178	206	500-2000	72	
Lake	1.11	0.80		10.6	7.50		6	6.8		178	206		92	

IS10500:1991= Indian Standard for drinking water as per the BIS (Bureau of Indian Standards) specifications

From the Table 2, it is seen that for the both pond and lake water all the quality parameters data after filtration are coming within permissible limit according to the IS 10500 1991. The total dissolved solid increases after the treatment. This may due to conversion of some suspended particles into dissolved solid as a result of chemical reaction. The bacteria removal efficiency indicates an encouraging result after filtration. However, the bacteria removal efficiency ranges from 72% to 85%. This may be due to high pH value of natural source pond and lake water. If the pH of the water is lowered to 6 (i.e., optimum value of pH to get highest removal efficiency), then the removal efficiency will be increased to 92 % which is very close to IS standard value of drinking water.

7 Conclusions

By using the above knowledge a standard filter bed for the filtration of water is designed. The design filter bed can also achieve 94 % removal efficiency up to 10 litres of water. Same media material can be reused after hot washing and shows nearly same removal efficiency when compared with the virgin media.

Furthermore, different source of surface water also treated in designed filter media and it is observed that water quality like turbidity, colour, pH and total dissolved solid and bacterial content are coming within the permissible limit recommended for drinking water after the treatment. The bacteria removal efficiency for pond water is 85 % and for the lake water is 72 % this because of the slightly higher alkaline pH of the surface water resulted in lower removal efficiency. But when the pH of the lake water brings down to 6 then the removal efficiency increased up to 92% which is very close to the IS standard value of drinking water. This filter media may provide safe water for drinking, cooking and other emergency needs on a sustainable basis and meet minimum water quality standards and be readily and conveniently accessible at all times and in all situations.

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