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Bio-inspired "Point of use" fibre filtration for domestic water purification - A concept of ultra filtration

Asoke Banerji
Amrita School of Biotechnology, Amrita Vishwa Vidyapeetam, Amritapuri,
Kollam, Kerala, India.
banerjiasoke@gmail.com

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Abstract

Lack of access to safe drinking water to a large number of people is still a major health problem in India as well as in many other developing countries. This motivated us for the development of a ''point of use'' water purification system, particularly for rural population. The system should be efficient, cost effective, maintenance free, eco-friendly and should require no or low energy for its operation. After screening several materials, we concluded that attributes of cellulosic fibre could be convenient. It effectively removes particulate materials, iron and some of the other pollutants. Partial reduction of microbial contaminants was also observed. Addition of copper (powder or coupon) into the system make process more effective in reducing the microbial load. In this communication, we report proof of the concept for using a cost effective method for water purification.

Keywords: Cellulose, Jute, Fabric filtration, Ultra filtration, Point of use filters, Anti-microbial metals, Bioremediation, Theoretical plates, Water purification in Ayurveda.

1. Introduction

Diseases caused by contaminated water take a heavy toll of life, particularly in developing countries. Still a large number of households do not have access to direct supply of safe water. According to recent assessment by the Ministry of Urban Development, as much as 80% of surface water in India is polluted to different extents (Government of India, 2013). It is estimated that most these diseases are preventable through providing safe drinking water. Therefore, it is necessary to offer "point of use" water purification systems at affordable cost and preferably without the use of electricity. All individuals require safe water for drinking, cooking and other house hold activities. Water obtained from most of the sources are contaminated with various inorganic and biological pollutants and suspended particles (Government of India, 2013; Gadgil A, 1998; Nimbkar & Rajvanshi, 2013). In addition, they may be polluted with vector borne enterotoxigenic microbes *eg. Escherichia coli*, rotavirus and *Shigella* spp. *Vibrio cholerae* which are the main causes of diarrhea and take huge toll of life. As per WHO report (2007) about 1.8 million people die globally from diarrheal diseases annually.

Ayurvedic and other ancient literature describe the use plant materials as well as metals for purification of water. Even presently, some of these methods are in use in the rural areas of Kerala and other states.

Several methods are in use for purification of water for domestic purposes (Stauber *et al*., 2006). They include biosand filtration (Schumutezdecke), biofloculation using plants and microbes, chemical sterilization using chlorination, chlorine dioxide and solar energy, plant xylem filtration, fabric filtrations using cotton layers inconjunction with solar sterilization. Extensive field trials have been reported in some countries using biosand filtration but efficiency of the process still remains ambiguous with variable microbial load reduction (between 63-99%). More recently, nano composites and specially designed bricks (terafil) have been prepared for the purification of water and are already under trials in several parts of rural India (Boutilier *et al*., 2014; Khuntia, 2015).

2. Concept of ultra filtration

In response to societal needs, we are exploring simple methods for filtration for development of low cost, maintenance free filters, without using electricity, particularly for rural India. Use of fabric filtration using biomaterials such as cotton sari in conjunction with solar disinfection has been attempted but with limited success. An elegant use natural products based approach using xylems from plants has been demonstrated for purification of water but this requires some infrastructure which may not be available in many of the Indian villages (Sankar *et al*., 2013; Pradeep & Anshup, 2009; Peng *et al*., 2011). Membrane filtration and use of ultra-violet radiation provide desirable results but cost, regular maintenance and dependence on electricity make them unsuitable for use in majority of places in rural India (Technical Information Document, 2010).

2.1. The rationale: We contemplated the use of universally available natural cellulosic fibres for filtration. Because of its unique chemical structural features, cellulose seems to be an attractive option. It is the most abundant renewal eco-friendly natural biopolymer $(C_6H_{10}O_5)_n$. The presence of large number of contiguous hydroxyl groups in cellulose makes it hydrophilic and also good chelating agent for the removal of cations present in the polluted waters. Cellulose is a biopolymer of 1,4-linked β-glucopyranose moieties having different molecular sizes. The 1,4-linkages in cellulose impart to its fibrous nature (**Fig. 1**). It is conjectured that these features could be useful for filtration of pollutants and transport of fluids by siphon action without the use of external energy. Moreover, the presence of large number of suitably placed hydroxyls could be useful for retaining certain metal pollutants through chelation. Unlike the conventional filtration (e.g. filtration through multiple folds of cotton cloth), the present approach using cotton *fibre* has the advantage that it provides large number of theoretical plates and the contaminated water passes through multiple stages of filtration (ultra-filtration). In this respect, it is similar to conventional column chromatography thus contributing to the efficiency as it passes through the matrix.

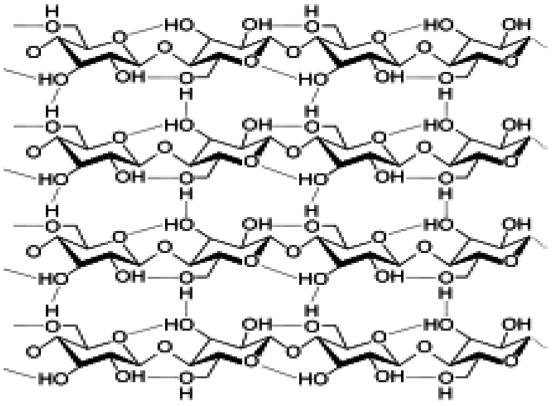

Fig 1. Structure of cellulose

The efficiency (theoretical plates) and the capacity are directly related to the parameters such as width and length of the fibre. These features allow us to make designer filters of different capacities and efficiencies. With suitable modification, it is conceivable that this could filter microbes also.

3. Results and Discussion

3.1. Proof of concept: To prove the feasibility of the concept of repetitive filtration (ultra filtration) using cellulosic fibre, experiments were carried out under different conditions. A typical experiment is described here Contaminated water (about 300ml, unfiltered tap water), with suspended particles was taken in beaker A (Fig. 2). A household cotton rope (about 50 cm in length and 1 cm in diameter) was pre-soaked in water and then placed in the beaker A; longer portion of the rope was put in the receiver beaker B. Soon water movement is initiated by the siphon action from beaker A to beaker B. The liquid passes the cellulose fibre, which offers many theoretical plates (https://en.wikipedia.org/wiki/Theoretical_plate) by providing a framework for multiple filtration. Thus, by altering the length and thickness of the cotton matrix, the efficiency and capacity could optimized as the situations demand. In preliminary experiments using this method of filtration, a substantial reduction in microbial load was observed. For further reduction in microbial load, use of well-known antimicrobial activity of copper was envisaged. The use of copper vessels in ancient India is well documented. Validity of this method of water purification has been corroborated by several studies including the one recent systematic study has which has confirmed the antimicrobial activity of copper; the dissolved copper level in water was found to be well within the WHO permissible level (Sudha *et al.*, 2012). Through independent experiments, we have established that copper powder also possess good antimicrobial activities. Thus the antimicrobial activities can be improved by using copper powder or copper coupons/coins. In addition, copper also imparts other beneficial effects such as anti-inflammatory, anti-aging through anti-oxidant activity, brain stimulation *etc.* Conductivity measurements before and after filtration by this process suggest that there are no significant change in the total dissolved materials.

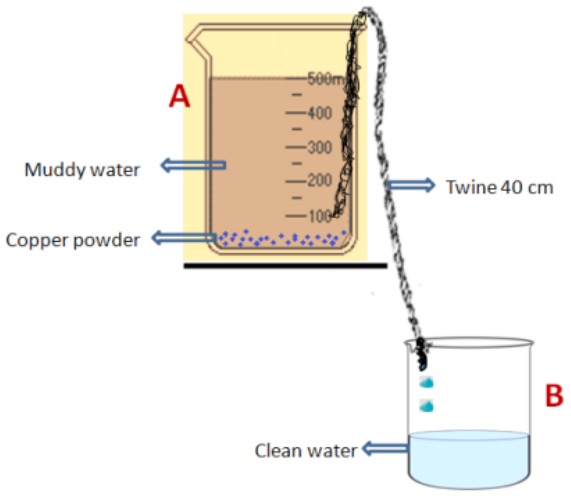

Fig 2. Filtration of contaminated water using cotton ropes

Several types of matrices have been tried for filtration (see supplementary figure, SF1 and SF2). Industrial cotton waste was found to be equally effective for filtration. Jute fibre can also be used. Jute is mainly cellulosic but also contain lignin based materials which may improve its quality of filtration by removing the metallic impurities.

SF1. Cotton waste for water purification. Suspended impurities are held in the beginning of the filtration.

SF2. Continuous filtration using cotton towel.

3.2. Adsorption: Adsorption on porous matrix or bioremediation, are the other options for developing low cost, maintenance free filters, without using electricity. We have observed that sponge pieces can be used to remove suspended particulate materials (including iron oxides) efficiently and the water thus obtained was suitable for house hold washing purposes. Our experience shows that the sponge piece (about 6" X 4" X 4") could be used repeatedly over a period of several months (at 20 liter per day) without requiring any change.

3.3. Biofloculation: Use of biofloculants and metals (eg. copper) have been mentioned in the Ayurvedic literature for water purification (Sharma, 2004). Biofloculants can be used in conjunction with other methods. Biofloculation can reduce the total dissolved solid below 500 ppm locally available plants such as *Strychnos potatorum,* Gooseberry bark*, Moringa oleifera* (seeds)*, Desmodium* sp.*, Sesuvium portulacastrum, Coccinia glauca,* tulsi seeds, etc. are examples of readily available biofloculants. This method gives excellent crystal clear water free from iron and suspended materials.

4. Conclusion

A low cost, maintenance free procedure for removal of suspended impurities in water supply is described. It does not require any electricity. The water thus obtained is acceptable for regular domestic purposes such as washing of clothes. Biofloculation, copper including the conductivity measurements show that there is only a marginally decrease in dissolved solids.

Use of adsorption and preliminary results on microbial counts before and after filtration are encouraging. Use of copper metal in the form of coupon or powder reducing the microbial load further. However, for potable purposes, it would be necessary to determine the quality of water as per specifications of Indian Standard Institute or WHO (WHO/UNICEF, 2005; Anonymous, 2003).The process is scalable and is amenable for modifications as the situations demand.

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