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A study on the characteristics of upflow matrix filter materials for the treatment of domestic sewage water

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ABSTRACT

This study was aimed at the development of robust mixed bed upflow matrix filters for use in an in-situ, household sewage treatment and recycling system. Several filter materials were studied to determine their relative filtration properties, measured by their filter coefficient and ability to regenerate via back-washing. Fecal coliforms were used as monitor organism, for direct application to sewage treatment processes. The filter materials included a range of different particle size of smooth, spherical (Ballotini) glass particles, uniform quartz sand particles, activated powdered charcoal, chemically methylated glass particles and alumina particles. An inverse correlation was observed between filter coefficient and potential for regeneration. The surface properties of the powdered materials, such as hydrophobicity, zeta potentials and surface charge densities were found to be important in determining their filtration properties.

1. Introduction

From an international perspective, the world community faces huge challenges in the field of water supply and sanitation. According to a World Bank report approximately 1 billion people still lack safe water and almost 2 billion people lack safe sanitation across the globe. More than 3 million people die each year from avoidable water related disease [1]. This issue is relevant to Australia and to many parts of the world, where the availability of water and the proper reuse of urban water is becoming increasingly important. The importance of this project is highlighted by the fact that around 17% of households in Australia treat their sewage on-site [2]. This means that there are about 1 million on-site treatment units in Australia, many of which are based on septic tank systems, which if not carefully maintained present serious contamination issues and can be a threat to local community health and disrupt the safe use of surrounding land [3,4]. Concern is growing that the failure of septic tanks would contaminate streams and reduce groundwater quality in non-sewered catchments. The breadth and spread of nitrates and pathogens in water bodies would cause (Soil Absorption System) SAS-related waterborne disease outbreaks [5].

Bacterial numbers in treated sewage water are often used as a monitor of purity. In this project fecal coliforms were used as the fecal indicator organism (FIO) [6–8]. The physical removal of microorganisms in sewage by membrane and depth filtration often depends on bacterial adhesion. Clean glass has a high negative surface charge density at physiological pH (due to the de-protonation of surface hydroxyl groups) and is also very hydrophilic and hence it was therefore expected that cell adhesion to glass would be dominated by electrostatic interactions [9]. For example, the strong influence of surface electrostatic interactions on bacterial adhesion to glass implies that glass will preferentially be colonized by low-charged cells [9].

Research on the electrostatic surface charge on *Escherichia coli* by Rad et al. show that the surface has a negative electrostatic potential (or Zeta potential) and that this potential varies with both electrolyte type and concentration [10,11]. These zeta potentials can be used to calculate the corresponding surface charge densities in different concentrations of NaCl and $CaCl_2$ solutions.

Strategies that change the surface properties of the materials to increase bacterial adhesion were studied in this project. In most cases bacterial attachment on material surfaces has been interpreted in terms of the hydrophobic attraction [12,13]. However, there is also a strong effect of surface electrical charges on the bacteria and the filter material [10]. Most bacteria are negatively charged and in aqueous media these surface charges are counter balanced by oppositely charged ions, some of which are bound to the surface, whereas the rest are distributed within an electrical diffuse layer [14]. The thickness of this diffuse electrical layer depends on pH, the ionic strength of the solution, and the valences of the counter ions. Electrical interactions between the particles (such as bacteria) in solution are governed by the extension of this diffuse layer.

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The current work formed an initial part of a program to develop a mixed-bed filter for incorporation into an in situ, treatment process for household sewage. The novelty in this study is related to the development of a depth bed filter suitable for incorporation into a household in situ water treatment and recycling system. Several types of granular depth filters were studied as individual components in regards to coliform removal and ability to regenerate by back-washing. Depth filters offer a high surface area system producing a reliable physical barrier or filtration system which could be used to protect the final membrane filtration stage, typically a 0.1 μm PVDF hollow-fiber (HF) membrane filter, required as a final barrier to microorganisms in the household sewage recycles system currently being developed.

This final step is crucial to guarantee the purity of re-use class A water, which is required by the Australian Government [15]. However, these membrane filters are very susceptible to contaminant fouling and so a mixed-bed media filter can be used to reduce fouling to extend their continuous operation. These filters offer a cheap method for removing most of the coliforms, metal ions and organic impurities present in the partially treated sewage water and hence will reduce the contaminant load to the final membrane filter in the household water recycling unit.

2. Materials and methods

The procedures used in this study were based on the measurement of fecal coliform levels, as a biological monitor microorganism [6]. The source of these coliforms was close to the shore of a natural lake which had a pH in the range 6.5–8.5 [16], an electrical conductivity of under 400 μs cm^{-1} [17], turbidity of 20–40 NTU and fecal coliform densities under 1000 CFU/mL [16,17]. The coliforms found in natural lake water are typically 0.5–1.0 × 2 μm, rod shaped bacteria. A natural source of water was used in this study to more closely model the behavior of secondary treated sewage water and because it was reasonably safe to use [18], with basic precautions on cleanliness (i.e. at Biosafety Level 1).

In this project, sodium chloride, calcium chloride ($CaCl_2{\cdot}2H_2O$), powdered alumina oxide (10 μm), and the trimethylchlorosilane were all supplied by Sigma–Aldrich (NSW, Australia), with greater than 99% purity. The high-purity alumina balls (3 mm uniform sized) were supplied by Henan Union Abrasives Corp. (Zhengzhou, China), with a density of 3.2–3.5 g/cm^3 and purity beyond 99.995%. Furthermore, all uniform sized Ballotini particles were supplied by Potters Industries (Dandenong, Australia) with 90% sphericity and 0% free silica content. The activated charcoal and uniform quartz sand particles used in this project were supplied by Blackwater Treatment Systems (BTS) Pty., Ltd. (Ulladulla, Australia).

2.1. Water samples & filter materials preparation

The water samples were collected from a natural lake in Canberra. The samples were taken near a bird habitat where there was also considerable run off into the lake. Typically, the water samples were stored in the collection containers for about 30 min before measuring coliform densities and then the samples were stored in a fridge for one day before being diluted for the filtration and back-flushing experiments. Standard glassware cleaning, using hot, soapy water followed by extensive rinsing with distilled water was used in this study. The coliform density of the water samples were in the range: 160–245 CFU/mL. In the experiments, the coliform levels used in this study were diluted to correspond to the level produced within a commercially developed pilot plant. The coliform concentration in the water samples were diluted to a reasonably low concentration to facilitate the use of total feed-water volumes of over 400 mL, which corresponded to about 100× the empty bed filter volume, of around 4 mL. These coliform levels also correspond to the typical contaminant levels expected in the partially treated household sewage water being developed [8]. In addition, natural organic matter and other charged colloidal particles, which could influence the performance of the filter, would also be minimized by the dilution. The coliform density of water samples was measured a day before starting each of the experiments and the water samples were only used for two days. The coliforms detected were those responding to the selected growth media and the same bacterial suspension was used for each particular experimental series, for a given filter medium. Microbiological media is used not only to grow microorganisms, but also to select or identify a particular type of microorganism based on some unique or distinctive aspect of its biochemistry. Most of the "selective growth" media contain a protein source, often a hydrolysate of casein, and a fermentable sugar, like lactose or glucose. This selective media employs chromogenic substrates, which makes the *E. coli* present a blue color. These media indicate *E. coli* by the presence of β-D-glucuronidase (GUD) and other coliforms by the presence of β-D-galactosidase [19].

Using the coliforms as monitor material [8,20], several filter materials were tested to determine their filtration properties, such as filter coefficient, and ability to regenerate by back-washing. The rate of release of the adsorbed coliforms was used as a relative measure of the potential for media regeneration via back-washing. The filter materials used in this study included a range of different particle size (spherical Ballotini) glass particles, uniform swimming pool sand filter particles, activated charcoal and spherical alumina particles. The size of the Ballotini particles used were between 0.1–0.12 mm and 0.6–0.8 mm and the size of uniform quartz sand particles and the activated charcoal were around 0.8 mm. The alumina spheres used in this study were the largest particles, of about 3 mm diameter.

As bacterial attachment to many material surfaces can be affected by a hydrophobic attraction due to the natural [13], slight, hydrophobicity of many bacteria [21–23], surface methylated Ballotini particles were also studied as a model, smooth hydrophobic substrate. Trimethylchlorosilane in the vapor phase was used to react with the glass surfaces of the Ballotini particles to increase their hydrophobicity. The vapor phase reaction was carried out in an airtight environment, over one hour to ensure the surface of the Ballotini particles (typically about 10 g, of 0.1–0.12 mm diameter) was fully reacted with the vapour phase trimethylchlorosilane. The effects of methylation can be readily observed because methylated glass powder floats on the surface of water whereas un-methylated glass powder (i.e., normal glass) sinks.

2.2. Filter coefficient and regeneration rates

The filter coefficient is defined in this study as the percentage of fecal indicator organism, as coliforms, which can be removed from the water sample after passing through the depth filter. The regeneration rate is defined as the percentage of the coliforms adsorbed by the filter materials, which can be removed by back-washing with distilled water. The amount of coliforms adsorbed by the filter materials, as the feed-water passed through the filter, was calculated from the measured rate of coliform removal multiplied by the total flow volume. The total amount of coliforms released during back-washing was calculated from the measured rate of release multiplied by the total back-washing volume.

Each of the filter materials were washed by distilled water to remove most of the filter material dust, metal ions and other unexpected small sized particles before placed into an adjustable length (15–20 cm), vertical chromatography column with a 1.5 cm inner diameter, which was used for the flow studies. The column length was adjusted to ensure a measurable effluent concentration [11]. A