ENHANCED BIOFILM ATTACHMENT ONTO POLYURETHANE FOAM, PACKED-BED BIOTRICKLING FILTERS FOR THE TREATMENT OF ODORS

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Abstract

The selection of an adequate support medium where the biofilm is immobilized in a biotrickling filter is critical for the optimization of the pollutant removal capacity of the unit. Recent efforts have focused in the development of synthetic media possessing properties such as high interfacial contact area, low density, high rigidity, high void fraction or porosity, sufficient water retention capacity, chemical resistance to severe acidity working conditions, and appropriate adhesion of the microflora to the medium surface. Polyurethane Foams (PUF) have been regarded as the media that best combines the aforesaid properties, yielding high removal efficiencies in the treatment of Volatile Organic Compounds (VOC) and Sulfur Reduced Compounds (SRC) while exhibiting low clogging and pressure drop.

In this study, PUF will be coated with different positively charged polymeric solutions aiming at increasing the attachment capacity of the foam surface to bacteria degrading Hydrogen Sulfide (H_2S) as substrate in a biotrickling filter. By means of this approach, typical negatively charged bacteria responsible for the oxidation of SRC will settle onto the foam media faster and more homogeneously, increasing the removal capacity of the unit during the start-up period and acclimatization stage compared to uncoated PUF. Aqueous solutions of polyethyleneimine, poly-d-lysine and animal collagen at different concentrations will be used as coating in SRC oxidizing cells growth on PUF during batch experiments. The solution providing the highest solid retention and cell growth will be used to coat PUF cubes filling a biotrickling filter as in a packed bed, treating H_2S at high concentrations up to 100 ppmv and Empty Bed Residence Times (EBRT) as low as 5 seconds. Experimental results will be fitted to a unique theoretical model that predicts the performance of a non-adsorbing, macroporous media packed-bed biotrickling filter, and accounts for the axial distribution of the biofilm and water layer thicknesses.

Keywords: Polyurethane Foam, Hydrogen Sulfide, Biotrickling Filter, Model, Polymer Coating.

1. Introduction

Biotrickling filtration has proven to be an effective process for the treatment of volatile organics and odors (Cohen, 2001). The mechanism of removal in a biotrickling filter involves a combination of absorption of the volatile organic or odor from the contaminated gas stream into a biofilm layer, rich in bacteria and fungi, where a biochemical reaction destroys the pollutants. Such biofilm grows on natural, synthetic or both support media, and fills the equipment as in a packed-bed reactor. Microorganisms that build-up the biofilm are intrinsically available in natural bed media, such as peat and compost, or need be inoculated into the system when synthetic media are used, by acclimatization with sludge from water treatment plants or isolated strands. During the acclimatization, the target substrate is fed into the reactor containing media wetted in sludge in order that specific target pollutant degrading bacteria grow as in a biological process of adaptation of the fittest species. Once within the biofilm, the volatile contaminant, formerly carried by the inlet polluted gas stream, is oxidized by the microflora while being utilized as source of energy for bacteria metabolic processes. In the meantime, harmless compounds and more biofilm are produced.

Recent studies have precisely concentrated in the selection of the most adequate media according to the degree they satisfy the properties mentioned above (Aizpuru, 2003). Compost, peat, soil, wood chips, bark, agricultural organic derivatives, activated carbon, ceramic beads, perlite, celite, manure, rubber latex, polyurethane foams, etc. constitute media that have received attention the most. From all of the aforesaid materials, foams seem to be the ones that best optimize the overall performance of biofilters; that is, biofilters using foams as biomedia carriers render high volatile organics and odors removal while maintaining low pressure drops along the bed (Benesse and Delebarre, 2003; Kim *et al*. 2002; Van Groenestijn and Liu, 2002; Moe and Irvine, 2000a, 2000b).

Besides variables such as removal effectiveness or loads and pressure drop, any media used to immobilize biofilms has to exhibit ability to attach the biomass rapidly, strongly, and uniformly, minimizing the acclimatization stage time during which low removals are attained in the reactor. Vancha *et al*., (2004) showed that by coating the support surfaces of culture dishes with small quantities of cationic, polymeric aqueous solutions, several cell lines attached more firmly and in bigger amounts onto the culture dishes, as opposed to non coated ones. The cationic polymers used in that study are being widely commercialized by several companies aiming at increasing the attachment of cells onto culture supports.

2. Materials and Methods

Batch experiments were carried out using open pore, black PUF cubes of 2.54 cm in side length and 8-12 pores per inch (PPI) submerged in a 4000 mL beaker containing a nutrients solution with the following composition [g compound per 1000 of g deionized water]: Na_2HPO_4, 1.2; KH_2PO_4, 1.8; $MgSO_47H_2O$, 0.1; $(NH_4)_2SO_4$, 0.1; $CaCL_2$, 0.03; $FeCl_3$, 0.02; $MnSO_4$, 0.02 and agar, 1.5. The batch was bubbled with 15 sccm of a 5% v/v

H_2S in nitrogen source, while stirring gently. Before submersion, 6 different cationic solutions were used to coat the PUF, 8 cubes per solution, while other 8 cubes were submerged without any previous treatment. The aqueous solutions were poliethyleneimine (PEI) at 25, 50 and 100 mg/L, poly-d-lysine (PDL) at 50 and 100 mg/L and animal collagen at 3 g/L. The coating was accomplished by submerging the cubes in a beaker containing the solution and stirring gently for 20 minutes. The cubes were then removed and allowed to dry by natural convection under a stream of room temperature air. In addition, 2.5 g of a microbial blend used for BOD_5 analysis was used to inoculate the medium. The increase in mass attached to the cubes was monitored for 40 days.

Open pore, white PUF cubes of 1.25 cm in side length and 8-12 PPI were used to pack two PVC columns of 10 cm in diameter, up to a total bed length of 60 cm. One column was packed with coated foam, being the coating material a 25 mg/L aqueous solution of PEI. The other column was packed with untreated, plain PUF cubes.

The two columns were seeded with a 50% mixture of secondary sludge from Cincinnati's Mill Creek Waste Water Treatment Plant and the nutrients solution described previously. H_2S was continuously injected in the system while mixed with compressed air to create inlet pollutant concentrations ranging between 10 ppm_v and 150 ppm_v. H_2S concentrations were measured through an inline electrochemical sensor (Industrial Scientific Corp., PA) attached to a data acquisition system, as depicted in Figure 1.

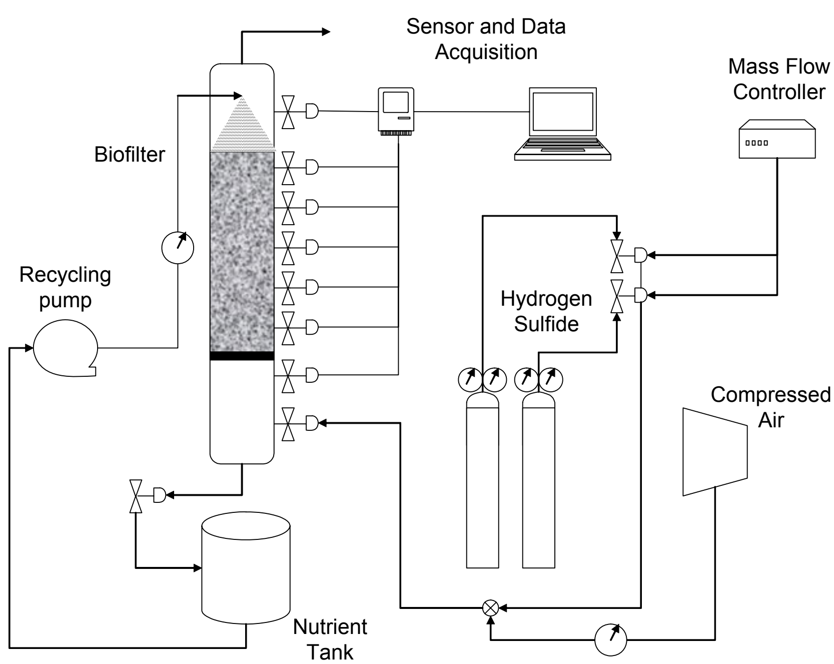

Figure 1. Schematic of the biofiltration system used in this work

3. Preliminary results

Figure 2 shows the average dry mass increase of the black PUF cubes used during the batch experiments. One cube coated with each solution was taken at the same time during a period of 40 days at different intervals, in order to determine the transient growth of the biomass onto the PUF. Figure 2 shows the average during the 40 days the experiment was carried out. As observed, PUF coated with 25 mg/L PEI aqueous solution yielded the highest increase of mass in the foam due to attachment of biomass and salts from the batch media. This result is congruent with those found by Vacha *et al*., (2004) whom reported better attachment with this polymer when compared to PDL and collagen as coating materials. It is worth noting that the plain foam with no coating exhibited good relative increase in dry mass, too, with values even higher than other polymeric coatings at high concentrations. This could indicate that high concentrations of cationic polymers on the PUF surface may inhibit the growth of biomass and attachment of solid crystals from the media. A heterogeneous concentration of nutrients and the channeling of the H_2S bubbles in the beaker experiment, as well as the partial dissolution of the coatings may have been variables that could have yielded different quantitative results under tighter control. More experiments with a different approach are under way to confirm the results shown in Figure 2.

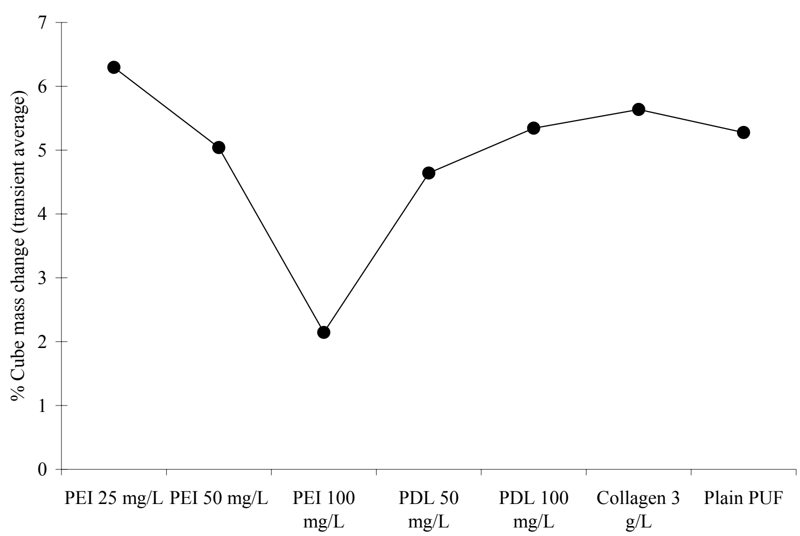

Figure 2. Dry mass increase in the coated and uncoated PUF cubes during batch growth of bacteria in dissolved sulfide.

Figure 3 shows an SEM micrograph of the PUF surface both before and after carrying out the batch experiments. The biomass and crystals attached to the revealed foam are typical of all foam cubes in the batch experiment, including the uncoated ones. The main difference is the total amount of biomass and crystals attached to each cube, which seems to have been a function of both the polymeric solution chemical nature and its concentration.

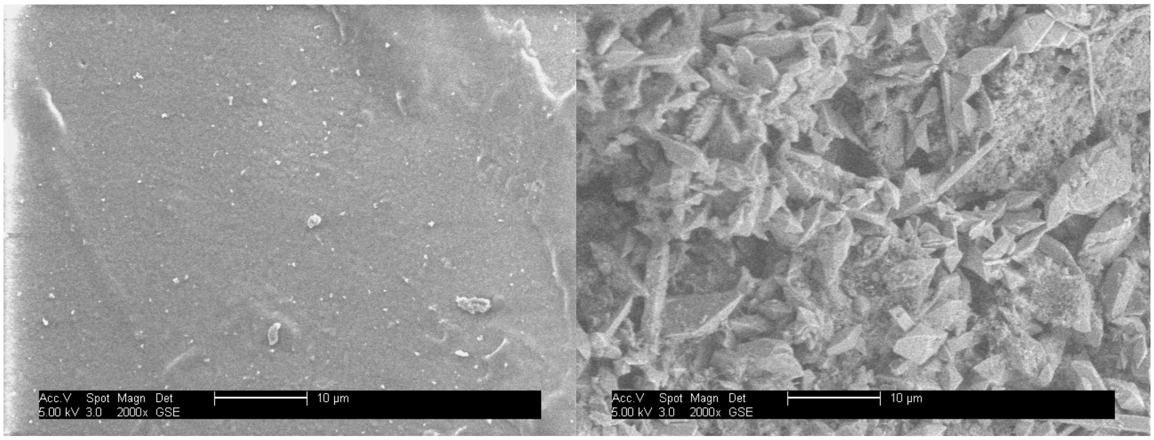

Figure 3. SEM micrograph of a PUF cube strut before and after the batch growth of bacteria in dissolved sulfide.

Once these preliminary results were obtained, the continuous treatment of a stream of air polluted with H_2S was performed in the two biotrickling filters containing the coated and uncoated white PUF cubes, as described in the previous section. Figures 4 and 5 show the performance of the two bioreactors during the initial acclimatization stage of the treatment. The EBRT used was 60 sec and a recycle of 0.2 L/min of the nutrients solution was maintained during the length of the experiment.

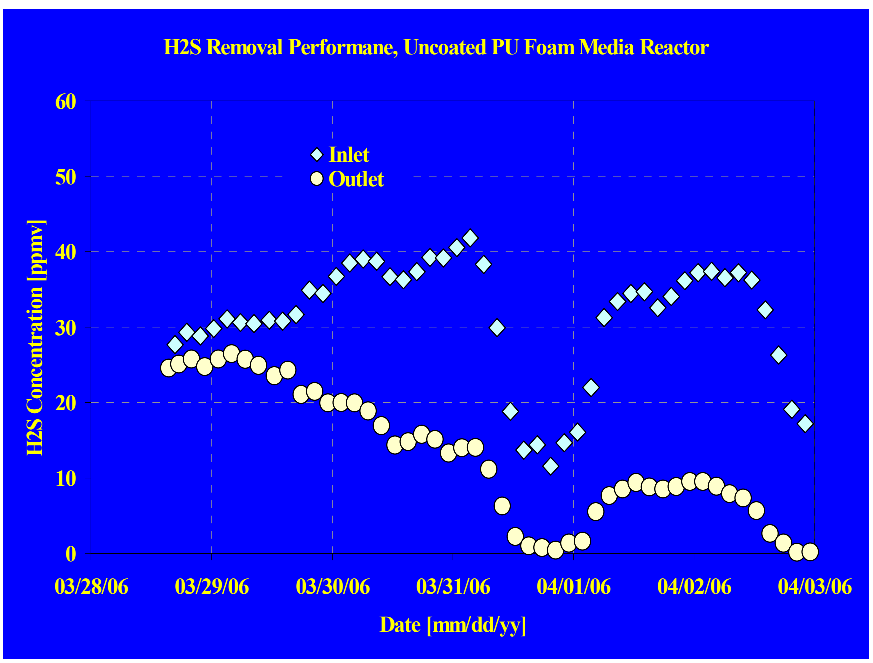

Figure 4. H_2S removal performance in a biotrickling filter packed with plain PU foam. EBRT: 60 sec.

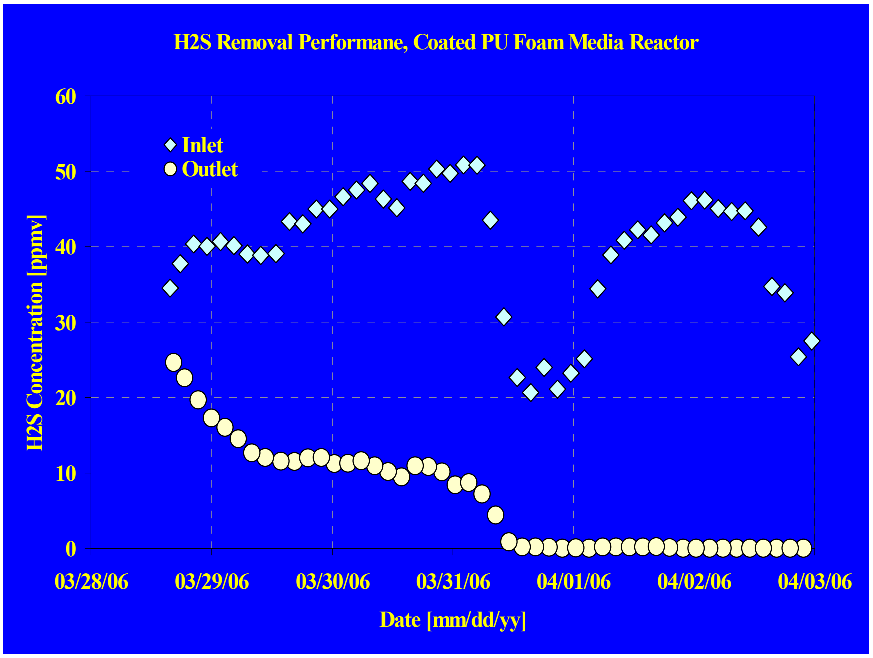

Figure 5. H_2S removal performance in a biotrickling filter packed with PEI coated PU foam. EBRT: 60 sec.

It is clear from these figures that the performance of the reactor packed with the cubes coated with the 25 mg/L PEI solution is better than that of the column packed with plain PUF. Higher removals are attained in the former while reaching complete removal after 3 days as opposed to 5 on the uncoated media reactor. This is a plausible qualitative indication that bacteria were more firmly attached and widespread on the coated media. Long term (120 days) results including removal efficiencies and capacities were evaluated for inlet airstreams with pollutant concentrations up to 150 ppm_v and EBRT as low as 5 sec that confirm these preliminary observations. Relevant removal capability data for both biotrickling filters will be presented, and the biokinetic parameters that describe the biomass grown in the system will be calculated by means of a new model that predicts the performance of this type of units (Goncalves and Govind, 2005).

4. References

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