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# Influence of Water Content on Biofiltration Performance

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In biofiltration, contaminants in a gas stream are transferred into a biofilm on the filter bed medium and are metabolized by the microorganisms. Water is essential for microbial growth/activity and for transport of nutrients. In both full-scale and laboratory-scale systems, the water content of the medium is difficult to control. In this study, a biofilter, with rigorous water content control and internal gas recycle, was used to determine the influence of the water content on the degradation of toluene. Soil was used as the medium for treating toluene-contaminated air at an average inlet concentration of 263 ppm and a flow rate of 21 ml min$^{-1}$. Through a water retention curve, gravimetric water content was related to matric potential. Results showed that lowering the water content from 79 to 48% (dry weight) or -20 to -400 cm $H_2O$ matric potential decreased the elimination capacity (EC) by 42% (29.8 to 17.3 g m$^{-3}$h$^{-1}$). Wetting the medium by increasing the matric potential from -400 to -10 cm $H_2O$ increased the elimination capacity to 43.9 g m$^{-3}$h$^{-1}$. However, further increase of the matric potential from -10 to -5 cm $H_2O$ decreased the elimination capacity by 57% (43.9 to 19.0 g m$^{-3}$ h$^{-1}$). Thus, this study suggests the soil water content should be controlled at about 96% (dry weight) or a matric potential of -10 cm $H_2O$ and the maximum elimination capacity is restricted to a narrow water content/matric potential. This narrow range impacts on the operation of full-scale biofilters as traditional techniques for water content control would make maintaining this range difficult.

***Keywords*****:** biofiltration; water content control; matric potential; soil; toluene

## INTRODUCTION

Biofiltration is an air pollution control technology where contaminants in a gas stream are metabolized by microorganisms and converted to water, carbon dioxide and biomass (Devinny *et al*., 1999). It does not produce secondary pollutants and does not involve expensive operation and maintenance costs. However, one of its disadvantages is the difficulty in water content control that may lead to poor biofiltration performance.

The main factors that play major roles in microbial growth are temperature, water availability, pH, and oxygen (Madigan *et al*., 1997). The water in the filter bed medium is essential for microbial growth and for transport of nutrients (Holden and Fierer, 2005). In biofiltration, low water content reduces microbial activity while high water content reduces mass transfer as water fills the biofilter pores (Swanson and Loehr, 1997). Drying leads to media cracking which reduces retention time while filter medium that are saturated causes nutrients to be washed out and produces leachate that requires disposal (Bohn and Bohn, 1999). Furthermore, as water is added in biofilters through use of humidified air and by sprinkling water over the top of the bed, excessive amounts of water result in an undesirable high pressure drop (Van Langenhove *et al*.,1986) and increase in operation cost.

Various studies on water content have been done showing results such as a strong dependence of removal on water content of the filter material (Poulsen and Jensen, 2007), increased bacterial count with increasing moisture content (Sun *et al*., 2002), non-recovery of the process when restarted after 24 hours of drying (Auria *et al*., 1998), channeling and loss of bed activity due to drying (Wright *et al*., 1997), and complete halt in biodegradation with air dry soil (Davis and Madsen, 1996). A study developed a dynamic one-dimensional model describing drying and its effect on biofiltration performance. (Morales *et al*., 2003). Some other studies cited optimum gravimetric moisture content of 30-55 % (Cardenas-Gonzalez *et al*., 1999), 40-60%. (Auria *et al*., 1998; Leson and Winer, 1991), 50-60% (Bohn and Bohn, 1999), 60% (Sun *et al*., 2002), at around 60% (Znad *et al*., 2006), close to 40% (van Lith *et al.*, 1997); 70-80% for peat biofilters (Martin *et al.,* 1996); and 65-78% for compost (Marek *et al*., 1999).

The objective of this study is to investigate the effect of water content, with matric potential as a measure of water availability, on biofiltration performance. Soil was used as the filter bed medium in a reactor (a biofilter) with rigorous control of water content. Performance is described as elimination capacity (EC) which is the mass of contaminant degraded per unit volume of filter material per unit time.

## MATERIALS AND METHODS

### Biofilter Reactor

A biofilter with water content control developed by Beuger and Gostomski (2009) was used in this study (Fig. 1). The biofilter operating conditions used in this study are as follows: temperature at 30°C, average flow rate of 21 ml/min, and average inlet concentration of 263 ppm of toluene as the contaminant in the gas stream. The head space of the reactor was well mixed exposing all of the compost to a uniform toluene concentration (i.e. CSTR operation). A suction cell was used to control and manipulate the water content in the soil bed.

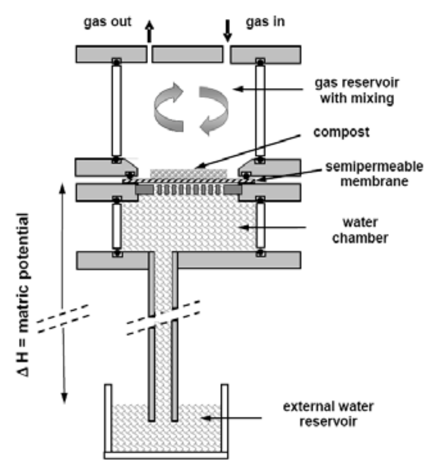


**Figure 1.** A cut-away of the biofiter with water content control

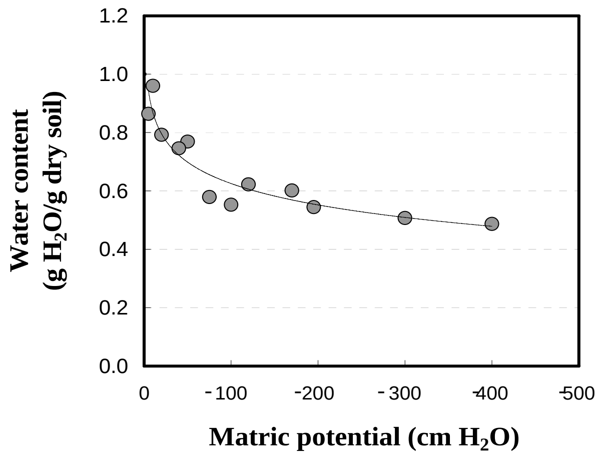


**Figure 2.** Water retention curve of soil in dry weight

### Suction Cell

In a suction cell (Ranasinghe and Gostomski, 2003), the soil is hydraulically connected to a water reservoir by a semi-permeable membrane (permeable to water but not to air). A vacuum is applied to the membrane. The matric potential of the soil equilibrates with the vacuum applied to water reservoir causing water to move in and out of the pore space of the soil. The suction is changed by changing the height of the water reservoir (ΔH) in relation to the barrier or membrane.

### Analytical Method

The concentration of toluene was measured using a gas chromatograph (Varian CP-3800) with flame ionization detector. The temperature of the injector, oven and detector were 220, 180 and 200 $^0$C, respectively. Helium was used as carrier gas. Gas samples of 0.2 ml were taken daily at the inlet and outlet sample ports of the reactor using a 1-ml gas tight syringe.

The water content of the soil, after an equilibration period of about 10 days in a suction cell, was determined using a moisture analyzer (Sartorius, MA-30) and through weight loss after drying in an oven at 105°C for 24 hours.

The amount of carbon dioxide produced was measured using a $CO_2$ analyzer (Vaisala GMP343) connected to the gas outlet port during sampling.

## RESULTS AND DISCUSSION

### Water Retention Curve

Water in soil and other porous media is mainly retained by matric forces in pores. Matric potential is a measure of water availability to microorganisms which is fundamental in biofiltration (Papendick and Campbell, 1981a). Reporting data in matric potential rather than water content allows comparing results obtained for a variety of soils.

Figure 2 shows the water retention curve of soil obtained by starting with dry soil being wetted as it equilibrates based on the desired matric potential. The figure follows typical soil water retention curve. Saturation capacity or water-holding capacity is taken as the water content at saturation where the matric potential is zero.

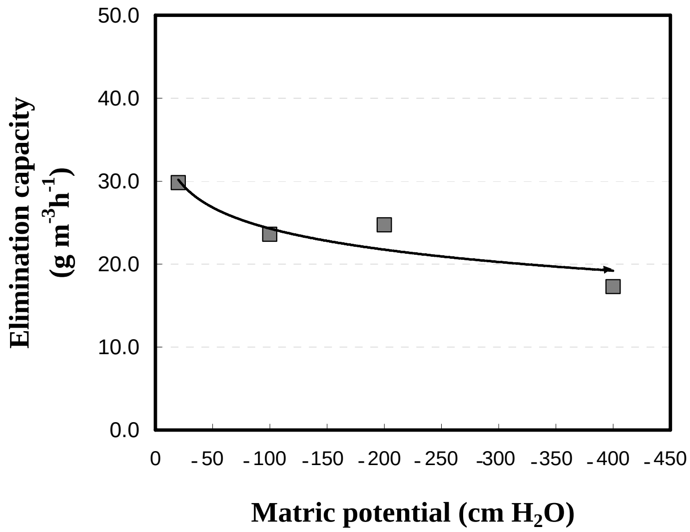


**Figure 3.** Influence of matric potential on EC during drying of the bed medium

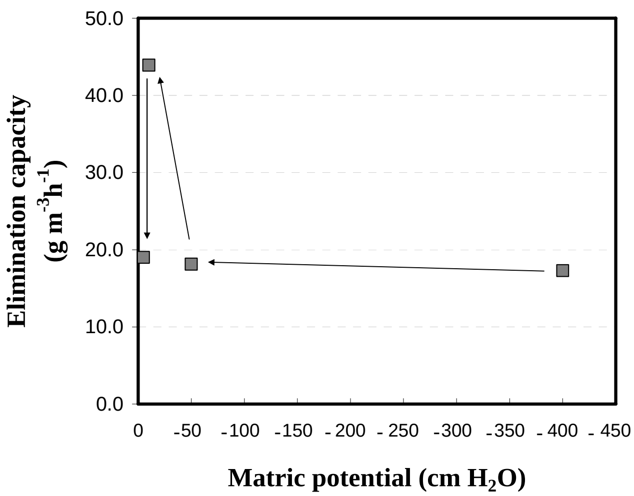


**Figure 4.** Influence of Matric Potential on EC During Wetting of The Bed Medium

### Influence of Water Content on Biofiltration Performance

The biofiltration reactor was run for 147 days. Data points were obtained at steady state which was assumed to be achieved when the EC was nearly constant for about 5 days for a given set of conditions. The matric potentials studied were -20, -100, -200 and -400 cm $H_2O$ in the drying process and -50, -10 and -5 cm $H_2O$ in the wetting process. Changes in EC with water content took about two to four weeks to develop.

Initially, a matric potential of -20 cm $H_2O$ (0.79 g water/g dry soil) was applied which gave a steady state EC of 29.8 g $m^{-3}h^{-1}$. Then, the matric potential was lowered to -100 cm $H_2O$ and further to -200 cm $H_2O$ which resulted to an EC of 23.6 and 24.8 g $m^{-3}h^{-1}$, respectively, lowering the EC by about 15-20%. These results indicate that the EC decreases as water content in the soil filter bed decreases as shown in Figure 3.

A further decrease in matric potential to -400 cm $H_2O$ (0.48 g water/g dry soil) gave an EC of 17.3 g $m^{-3}h^{-1}$ or a decrease in EC by 42%. Similar results have been observed in a study on moisture content effect on toluene degradation in a compost medium between matric potentials of -36 and -6 cm $H_2O$ (Ranasinghe and Gostomski, 2003) and -20 to -300 cm $H_2O$ (Beuger and Gostomski, 2009) where maximum EC was observed at the highest water contents. Studies state this decrease in EC may be caused by reduced biomass (Bottner, 1985), impaired bacterial survival in provoked leakage of cellular solutes (Potts, 1994), altered water retention and mechanical properties of the media (Roberson and Firestone, 1992) and reduced available nutrients (Chenu and Roberson, 1996). Decreasing water potential (decreasing water content) decreases the ability of substrate molecules to diffuse to the bacterial cells (Papendick and Campbell, 1981b). Microbial activity will be inhibited if only the tiniest pores in the media hold water. (Devinny *et al.*, 1991).

Furthermore, the matric potential was increased from -400 to -50 cm $H_2O$ (Figure 4). The resulting EC was 18.1 g $m^{-3}h^{-1}$ which followed the same trend of increased EC with increasing matric potential. However, the resulting EC should have been about 26 g $m^{-3}h^{-1}$ if it were to follow the water retention curve in Figure 2. This decrease in EC of about 30% is possibly due to hysteresis and shows that wetting process follows a different path in the water retention curve. The equilibrium water content at a given matric potential is greater in drying than in wetting (Hillel, 1971). Hysteresis or the lagging effect was also observed in the study of Ranasinghe and Gostomski (2003). This effect may be attributed to causes such as the non-uniformity of individual pores, the spatial connectivity of pores during wetting and drying, the surface wetting that varies liquid-solid contact angle, and air entrapment. Water usually traps some air in the pores, but the reentry of water creates a slightly different wetting pattern. (Jury *et al.*, 1991)

Aside from investigating EC as a measure of biofiltration performance, carbon dioxide production provides a measure of the extent of biodegradation or substrate utilization in aerobic digestion. A high value of carbon

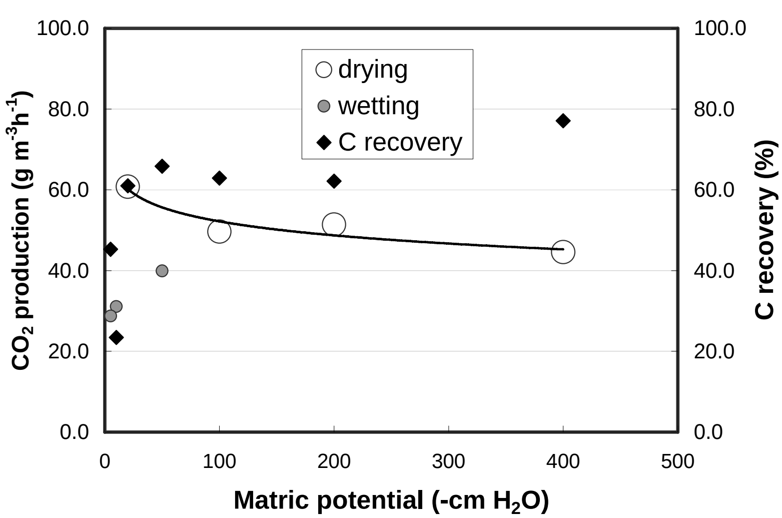


**Figure 5.** $CO_2$ Production and C Recovery at Different Matric Potentials

recovery confirms effective biodegradation (Chang and Lu, 2003).

In Figure 5, the $CO_2$ production followed the same trend as the EC in the drying process. The study of Rodrigo et al. (1997) states that optimal decomposition and mineralization rates in soil have been observed to be in the range between -100 and -500 cm $H_2O$. Carbon recovery in this study was highest at -400 cm $H_2O$ and may give support to such statement. In another study (Auria *et al*., 1999), 48% to 64% of the eliminated toluene was emitted as $CO_2$. The low carbon recovery at -10 cm $H_2O$ may show that the high EC is due to the increased mass transfer rate at high water content. In addition, the $CO_2$ produced may accumulate in the biofilm as dissolved carbonates and bicarbonates (Jorio *et al.,* 1998; Singh *et al*., 2006).

Wetting the medium by increasing the matric potential to -10 cm $H_2O$ (96% water content) increased the EC to a maximum steady state value of 43.9 g $m^{-3}h^{-1}$. However, further increase of the matric potential from -10 to -5 cm $H_2O$ decreased the elimination capacity by 57% (43.9 to 19.0 g $m^{-3}$ $h^{-1}$). This result may be explained by the gas diffusion rate markedly influenced by slight changes in the water content of soils near saturation. Matric potential is not likely to have much influence on microbial activity since potentials are near zero in soils that are wet enough to limit gas diffusion. Water content is probably the best variable to use in studying the effects of limited aeration since aeration is related directly to soil water content for all textural classes of soil. (Papendick and Campbell, 1981b). The study of Davis and Madsen (1996) on factors affecting the biodegradation of toluene in soil stated that the moisture content of the soil appeared to limit degradation only at very low water content but this study showed very high water content (>96%) decreases the elimination capacity. The study of moisture in biofilters by Bohn and Bohn (1999) indicates 0.2 to 0.3 bars (about -200 to -300 cm $H_2O$) moisture potential for optimal biofilter function as compared to the -10 cm $H_2O$ matric potential found to give maximum elimination capacity in the range of -5 to -400 cm $H_2O$ matric potential being investigated in this study. The discrepancy may be explained by the change of moisture with bed depth (50% at the surface and about 70% at the bottom) cited in the study of Bohn and Bohn whereas in this study, uniform moisture was established.

## CONCLUSIONS AND RECOMMENDATIONS

Water content of the soil as filter bed medium in the biofilter was controlled through the use of the suction cell. Soil, with its rich microflora taken to full advantage without inoculants and additional nutrients, biodegraded toluene at a maximum elimination capacity of 43.9 g $m^{-3}$ $h^{-1}$ at -10 cm $H_2O$ in treating a gas stream at an average flow rate of 21 ml/min and an average concentration of 263 ppm of toluene as contaminant.

The interaction between biodegradation and mass transfer of contaminants in biofiltration was prominent in the results of this study. It showed the influence of water content on both microbial activity and diffusion which makes treatment in biofiltration possible. Fluctuations in water content impede biofiltration efficiency. Elimination capacity varies directly with water content of the media and hysteresis may occur during wetting. Increased mass transfer of the contaminant increases the elimination capacity at high water content. Thus, this study suggests the soil water content should be controlled at about 96% (dry weight) or a matric potential of -10 cm $H_2O$. The maximum elimination capacity is restricted to a narrow water content/matric potential and this narrow range impacts on the operation of full-scale biofilters as traditional techniques for water content control would make maintaining this range difficult.

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