36862 PDF

DEVELOPMENT OF HIGH-RATE TRICKLE BED BIOFILTER

Francis L. Smith, George A. Sorial, Makram T. Suidan, and Pratim Biswas
Department of Civil and Environmental Engineering
University of Cincinnati
Cincinnati, OH 45221-0071

Richard C. Brenner
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

INTRODUCTION

Since enactment of the 1990 amendments to the Clean Air Act, the control and removal of volatile organic compounds (VOCs) from contaminated air streams have become a major public concern (1). Consequently, considerable interest has evolved in developing more economical technologies for cleaning contaminated air streams, especially dilute air streams. Biofiltration has emerged as a practical air pollution control (APC) technology for VOC removal. In fact, biofiltration can be a cost-effective alternative to the more traditional technologies, such as carbon adsorption and incineration, for removal of low levels of VOCs in large air streams (2). Such cost effectiveness is the consequence of a combination of low energy requirements and microbial oxidation of the VOCs at ambient conditions.

Preliminary investigations (3) were performed on three media: a proprietary compost mixture; a synthetic, monolithic, straight-channeled (channelized) medium; and a synthetic, randomly packed, pelletized medium. These media were selected to offer a wide range of microbial environments and attachment surfaces and different air/water contacting geometries. The results of this preliminary work demonstrated that 95+% VOC removal efficiency could be sustained by all three media at a toluene loading of 0.725 kg COD/m^3-d, but at different empty bed contact times (EBCTs). For the pelletized medium, this performance could be achieved at an EBCT of 1 min, for the channelized medium at 4 min, and for the compost medium at 8 min. Both synthetic media developed headloss over time, with the pelletized medium showing a pressure drop in excess of several feet of water after sustained, continuous operation. These results left open the question of which medium could provide the optimum combination of high VOC elimination efficiency at high loading with minimum pressure drop.

This paper discusses the continuing research being performed for development of biofiltration as an efficient, reliable, and cost-effective VOC APC technology. The objectives of the recent research were to conclude the evaluation of the three media and to develop workable strategies for the removal and control of excess biomass from the (ultimately) selected pelletized attachment medium.

METHODOLOGY

The biofilter apparatus used in this study consisted of three, independent, parallel biofilter trains, each containing 4 ft of attachment medium: biofilters "A", "B", and "C". A detailed schematic and equipment description is given elsewhere (4). Biofilter "A" was filled with a proprietary compost mixture, "B" with a Corning Celcor® channelized medium, and "C" with a Manville Celite® pelletized medium. Biofilters "A" and "B" were square and had an inner side length of 5.75 in., and biofilter "C" was round with an inside diameter of 5.75 in. The air supplied to each biofilter was highly purified for complete removal of oil, water, CO_2, VOCs, and particulates. After purification, the air flow for each

biofilter was split off, the VOCs were injected into it, and then it was humidified and fed to the biofilters. The air feed was mass flow controlled, and the VOCs were metered by syringe pumps. The flow direction of the air and nutrients inside each biofilter was downward. Each biofilter was insulated and independently temperature controlled.

Buffered nutrient solutions were fed to biofilters "B" and "C". A detailed description of the nutrient composition is given elsewhere (4). Each of these biofilters independently received a nutrient solution containing all the necessary macro- and micro-nutrients with a sodium bicarbonate buffer. The nutrients required in biofilter "A" were included as part of the original compost mixture.

RESULTS

Biofilter "A": This biofilter run on the compost medium was made to evaluate the effect of temperature, and then loading, on toluene removal efficiency. Figures 1a and 1b summarize the biofilter performance. The biofilter was started up and, after some operational difficulties, stabilized by day 10 at 52°F, 50 ppmv toluene, 2 min EBCT, and a removal efficiency of about 58%. On day 17, the temperature was raised to 60°F, resulting in a rise in efficiency to about 75%, which decreased after day 24 into the 60's, and after day 32 into the 50's. On day 41, the temperature was increased to 70°F, resulting in a gradual increase in efficiency to about 75% by day 47. On day 53, the temperature was increased to 80°F, resulting in an increase in efficiency into the low 80's. On day 61, the temperature was increased to 90°F, resulting in a further increase in efficiency to the mid 90's (Figure 1a). After day 77, the feed was increased slowly to about 95 ppmv toluene, resulting in a drop in efficiency to about 88%. Further increases in the feed concentration to a maximum of 180 ppmv toluene on day 139 resulted in a further decline in efficiency to about 58% (Figure 1b). The run was terminated on day 215.

Biofilter "B": This biofilter run was made on the synthetic channelized medium to evaluate the effect of temperature, and then nutrient feed rate, on removal efficiency. The biomass in the channels of the medium remaining from the previous run was removed by hydroblasting the eight 6-in. high medium blocks from top and bottom. The corners of these square blocks were filled with grout to provide a "round" active block. This last step was taken to match a round block cross section with the round pattern of the nutrient delivery spray nozzle. Figure 2 shows the biofilter performance as a function of time. The biofilter was started up at 52°F, 50 ppmv toluene, and 2 min EBCT. By day 36, the removal efficiency had drifted over a range from about 62% to 80%. On day 36, the nutrient feed rate was increased from 30 to 60 L/day while keeping the mass loading of the nutrients constant. The increased nutrient flow rate effectively doubled the wetting cycle from 20 sec/min to 40 sec/min. An immediate increase in efficiency to 99% was observed, which then quickly dropped and ranged by day 50 between about 30% and 70%. On day 50, the nutrient feed rate was increased to 90 L/day (increasing the wetting cycle to 60 sec/min), but the efficiency dropped from 69% and ranged by day 67 from about 22% to 65%. On day 67, the temperature was raised from 52°F to 60°F and the efficiency increased to 66%. By day 75, the efficiency was 87% and this level was maintained to day 83. After day 83, the temperature was raised further, in 10°F steps, to 90°F but the efficiency did not improve. In fact, for the rest of the run, at 90°F and 60 L/day, the efficiency ranged between about 58% and 83%. The run was terminated on day 152.

Biofilter "C": The first biofilter run on the synthetic pelletized medium was made to evaluate the effect of pressure drop, and then temperature, on toluene removal efficiency. The biofilter was charged with pellets used in the previous run. These pellets were washed by hand in hot water (150°F) until the accumulated surface biomass had been removed and the pellets were free flowing. Figure 3 presents the biofilter performance as a function of time. The biofilter was started up at 52°F, 50 ppmv toluene, and 2 minutes EBCT. By day 21, the removal efficiency was 99% and, by day 27, it had reached 100% and remained at this level until day 50. From day 51 to day 57, the EBCT was gradually reduced to 1 minute, causing the efficiency to drop to 84%. Subsequently, the toluene removal efficiency rapidly increased to the low 90's and remained in that range until day 81. On day

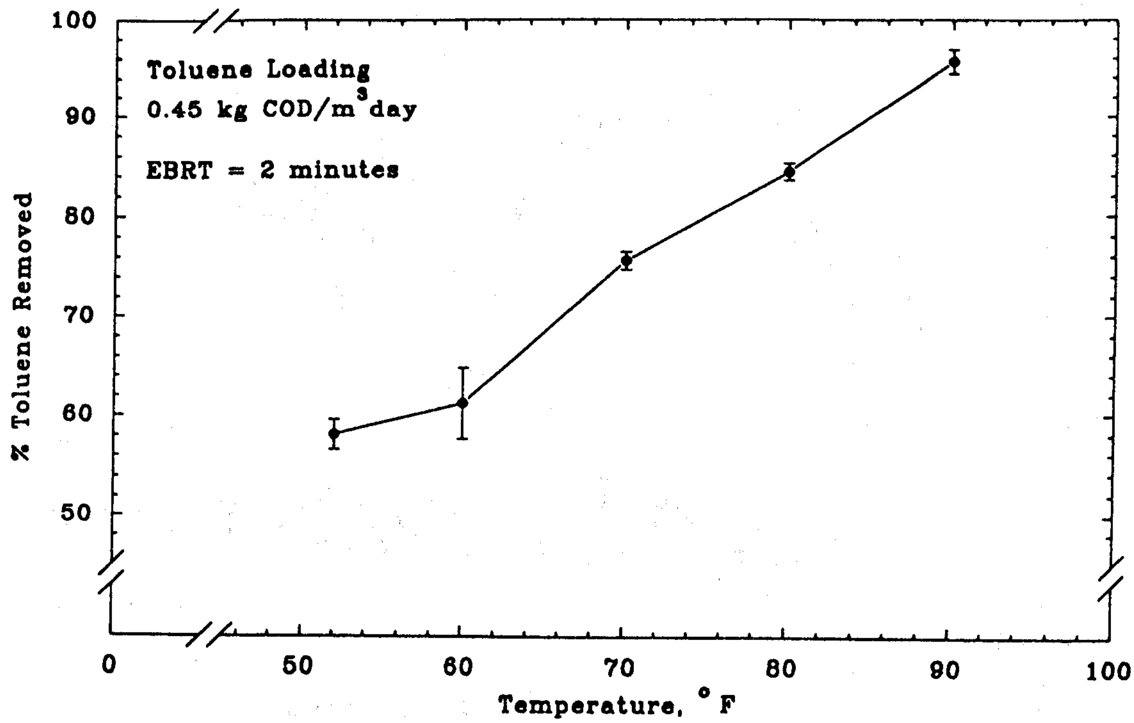

Figure 1a. Effect of Temperature on the Performance of the Compost Biofilter

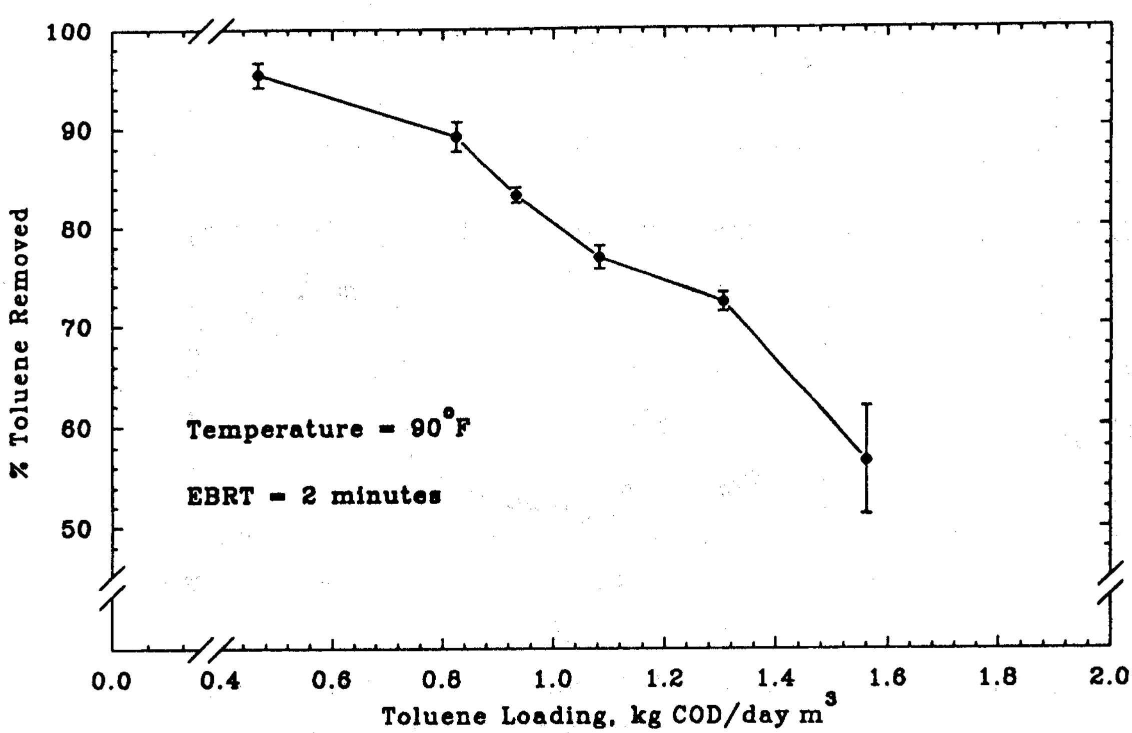

Figure 1b. Effect of Toluene Loading on the Performance of the Compost Biofilter

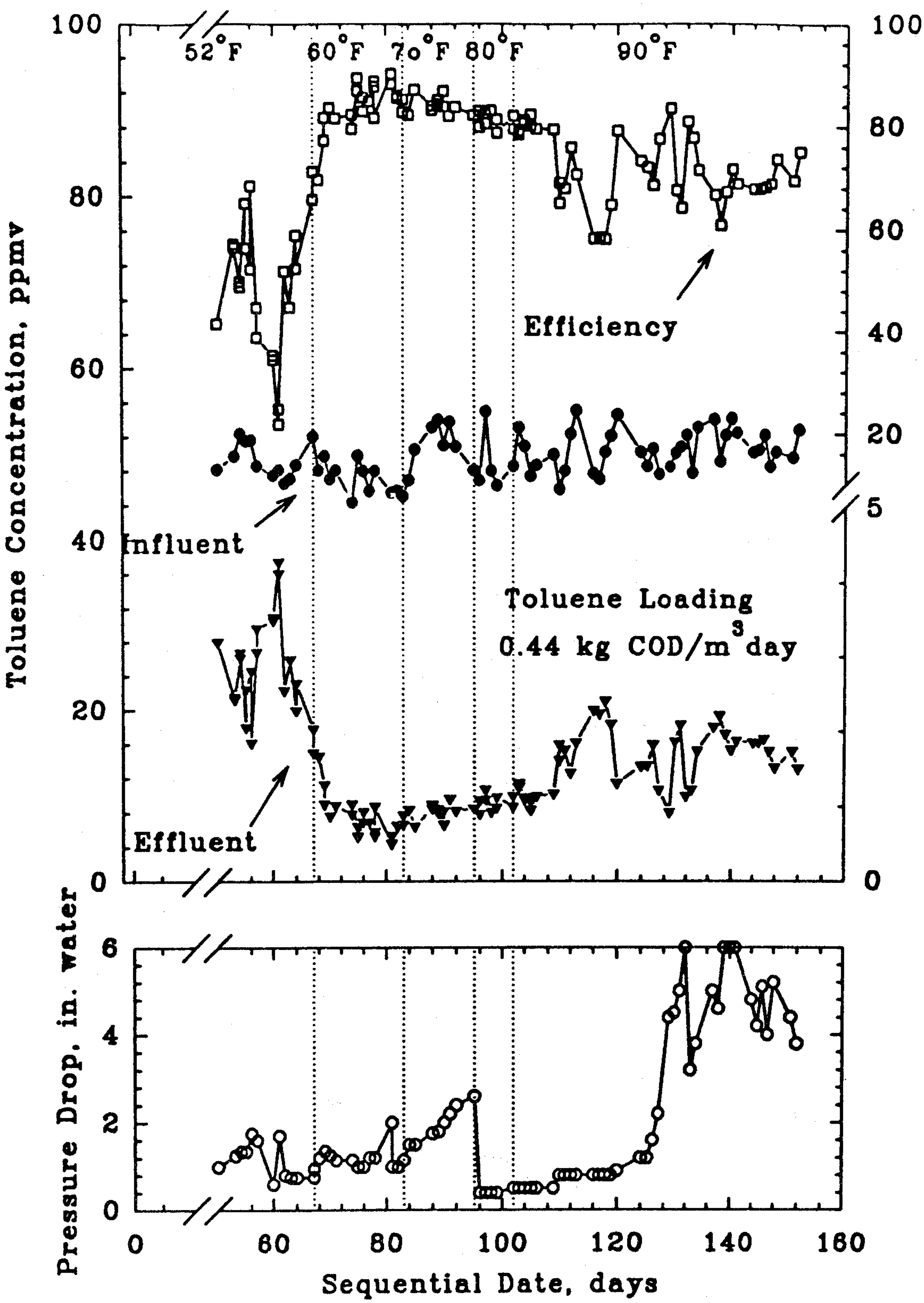

Figure 2. Performance of Channelized Biofilter with Respect to Toluene Removal at an EBRT of 2 Minutes

82, the temperature was raised to 60°F and the efficiency steadily rose until complete biodegradation of the toluene was reached on day 89. This essentially 100% efficiency in toluene removal was maintained through day 97. During the period between day 54 and day 97, pressure drop across the system increased from 0.2 to 5.5 in. water. From day 97 to day 111, the efficiency dropped steadily from 100% to 86% while the pressure drop increased from 5.5 to 6.0 in. water. On day 112, the temperature was increased to 70°F and the efficiency rebounded by day 113 to a peak value of 97%, after which it dropped to 85% by day 188. On day 119, the temperature was raised to 80°F and the efficiency rose to about 89% by day 120. During the period from day 112 to 120, the pressure drop increased from 6 to 18 in. water. By day 128, the efficiency had steadily dropped from 89% to 77% as the pressure drop increased from 18 to 27 in. water. This pattern of a steady loss of efficiency with a coincident increase in pressure drop suggested the development of short circuiting within the biofilter medium due to biomass accumulation, which resulted in a significant reduction in actual contact time.The first run was terminated on day 128.

The second biofilter run on this medium was conducted to evaluate routine biomass control by backwashing. The biofilter was charged with a 50:50 mixture of fresh pellets and pellets from the previous run. The used pellets were thoroughly washed by hand in tepid water (90°F) until the accumulated surface biomass had been removed and the pellets were free flowing. Figure 4 shows the biofilter performance as a function of time. The filter was started up at 90°F, 50 ppmv toluene, and 2 min EBCT. By day 4, the removal efficiency was 100%. (Note: this second run, started up with pellets washed in tepid water, contrasts with the slower start-up in the first run, where the pellets were washed with hot water.) On day 8, the feed was increased to 250 ppmv toluene and the efficiency dropped to 97%, ranged between 92% and 98% until day 25, when it again reached 99%. Subsequently, the efficiency dropped as low as 86% before regaining 99% on day 81, after which the efficiency was nearly always 99+%. Initially, backwashing was performed once per week by using 100 L of fresh water at a rate of 6 gpm. After day 28, the frequency was increased to twice per week and, after day 38, the volume was increased to 200 L. These changes were made because measurable pressure drop was observed between backwashings. On day 73, the backwash rate was increased to 15 gpm in order to induce full fluidization. Although the pressure drop increase was minimal, the efficiency did not improve, suggesting some form of channelizing within the bed. Therefore, on day 80, the length of the backwash period was increased to 1 hour by recirculating the backwash water. After this final adjustment, the toluene removal efficiency, as mentioned above, achieved and sustained 99+%. During this latter period, the total volume of water used per backwash was optimized to 120 L. Of this volume, 70 L were used for the 1-hour backwash recycle, while the remaining 50 L were used to flush the released solids from the reactor.

CONCLUSIONS

A marked improvement in toluene removal efficiency with increasing temperature was demonstrated in this study for the compost mixture, the channelized medium, and the pelletized medium. The direct consequence of this finding is that much less medium would be needed for a biofilter operating at 90°F than at 52°F, resulting in a proportional reduction in capital cost. The economic tradeoff with the cost of heating the incoming air should usually favor operation at these warmer conditions.

The modest performance of the compost mixture with respect to increased loading complimented our earlier findings with respect to decreasing EBRT (3). Unfortunately, implicit limitations of the experimental apparatus may have resulted in reduced performance. Specifically, the manufacturer recommended using a width-to-depth ratio of 1/1, rather than 1/8. They also stated that from their experience the only effective means of controlling bed moisture content was to weigh the entire biofilter. This was impossible with the heavy stainless steel unit used here, which was bolted to a support frame. Several moisture measurement and control strategies were attempted, but it was never possible to be certain that the bed moisture content was consistently at the reported optimum range, i.e., between about 50% and 60% (5,6). The sometimes erratic performance may

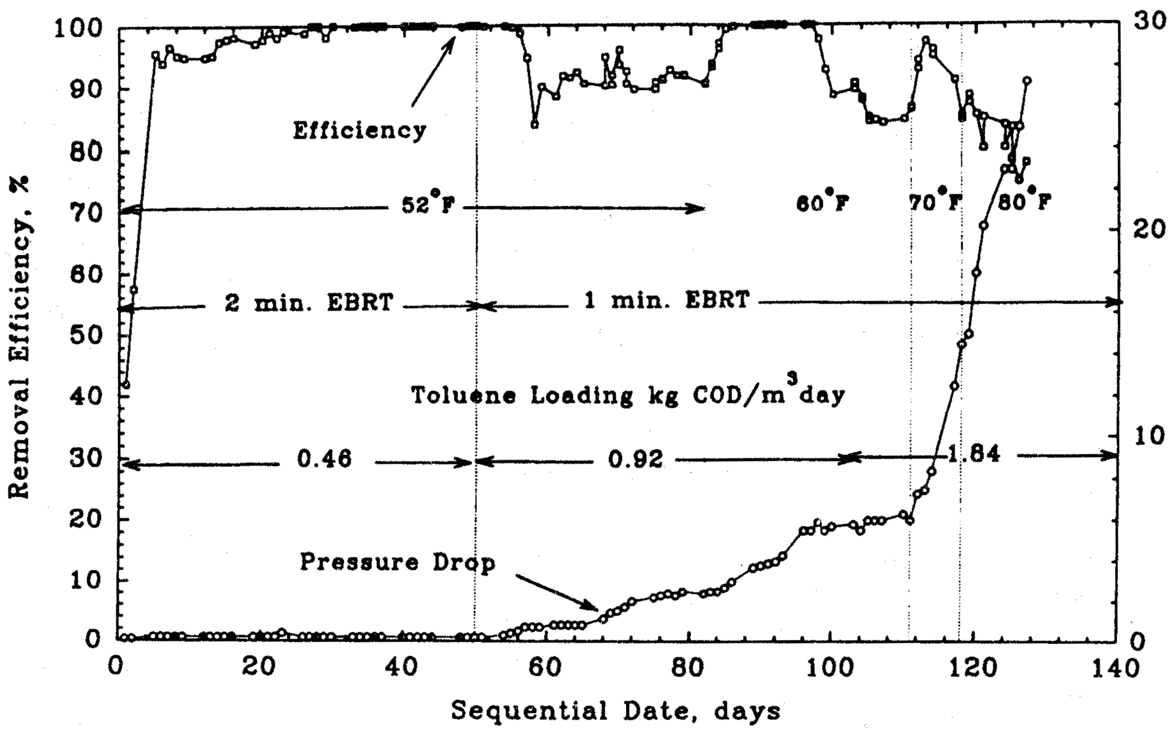

Figure 3. Performance of Pelletized Biofilter with Respect to Toluene Removal at 1 and 2 Minutes EBRT without Backwashing

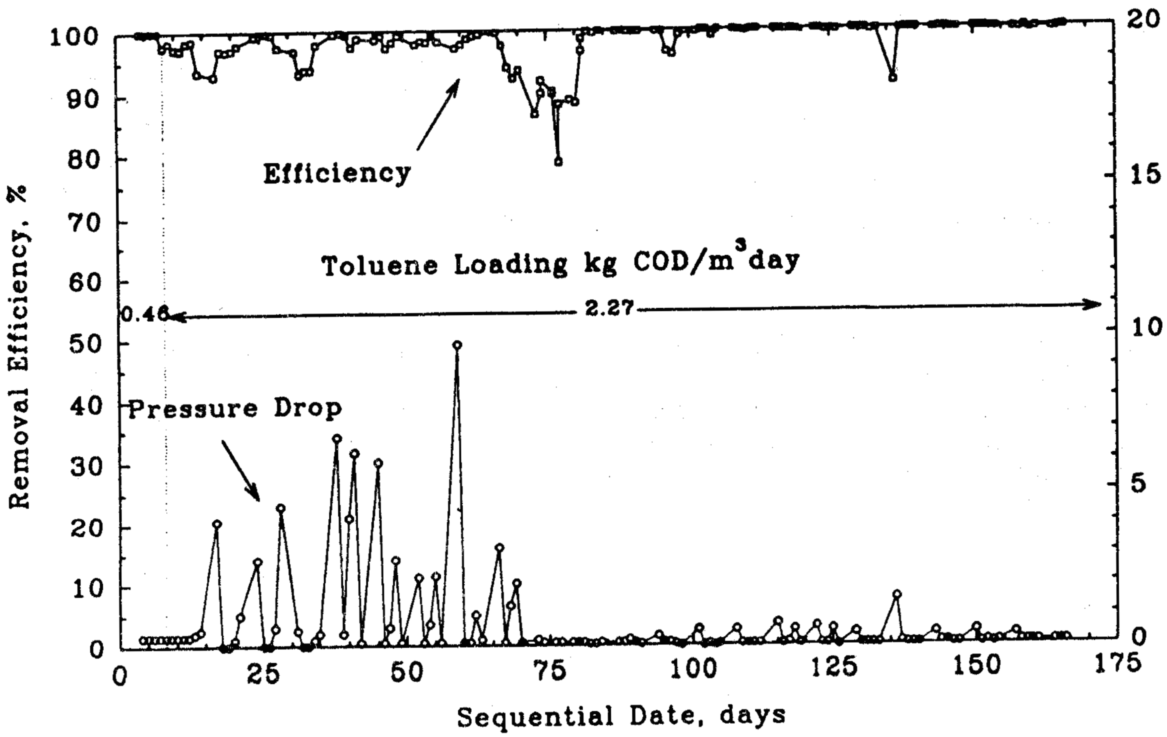

Figure 4. Performance of Pelletized Biofilter with Respect to Toluene Removal at 2 Minutes EBRT with Backwashing

have been influenced by variations in bed moisture content. However, it can be seen that the best removal efficiencies achieved by the compost mixture were better than exhibited by the channelized media but worse than exhibited by the pelletized media.

The performance of the channelized medium also confirmed our earlier findings that this medium is distinctly inferior to the pelletized medium (3). The best performance was achieved during the use of new medium blocks. After biomass accumulation within the channels and subsequent removal by hosing, the performance never regained the previous, still modest, levels. Attempts to adjust nutrient flow as a means of testing the effect of the duration of the wetting in the nutrient application cycle did not overcome the previously demonstrated efficiency limitations. The more erratic performance of this medium after removal of the biomass suggests that this medium may be unsuitable for sustained efficiency after periodic cycles of biomass removal. This erratic performance, due to suspected random uneven plugging of channels by biomass, coupled with its relatively low overall removal efficiency, difficulty in biomass removal, and intrinsicly high medium cost suggests that this medium may not be a viable option for this application.

The pelletized medium exhibited the best and most consistent performance of the three media tested. It rapidly achieved high removal efficiencies at high toluene loadings. As the first run demonstrated, however, an excessive accumulation of biomass, shown by a rise in the pressure drop across the medium, results in a substantial loss in efficiency, followed by a very rapid rise in pressure drop. This suggested that efficient, sustained performance might be achieved through early and periodic control of biomass accumulation by backwashing. In the second run, the implementation of a suitable backwashing strategy for biomass control was achieved by using full medium fluidization. This strategy permitted sustained operation of the biofilter at high loadings with efficiencies consistently at 99+%.

REFERENCES

1. Lee, B. Highlights of the Clean Air Act Amendments of 1990. J.Air Waste Manage. Assoc. 41(1):16, 1991.
2. Ottengraf, S.P.P. Exhaust Gas Purification. In: H.J. Rehn and G. Reed (eds.), Biotechnology. Vol. 8. VCH Verlagsgesellschaft. Weinham, 1986.
3. Sorial, G.A., Smith, F.L., Smith, P.J., Suidan, M.T., Biswas, P., and Brenner, R.C. Evaluation of Biofilter Media for Treatment of Air Streams Containing VOCs. In: Proceedings of the Water Environment Federation 66th Annual Conference and Exposition, Paper No. AC93-070-002. Anaheim, California, 1993. pp. 429-439.
4. Sorial, G.A., Smith, F.L., Smith, P.J., Suidan, M.T., Biswas, P., and Brenner, R.C. Development of Aerobic Biofilter Design Criteria for Treating VOCs, Paper No. 93-TP-52A.04. Paper presented at 86th Annual Meeting and Exhibition of Air and Waste Management Association, Denver, Colorado, June 13-18, 1993.
5. Bohn, H.L. Biofiltration: Design Principles and Pitfalls, Paper No. 93-TP-52A.01. Paper presented at the 86th Annual Meeting and Exhibition of Air and Waste Management Association, Denver, Colorado, June 13-18, 1993.
6. Van Lith, C., David, S.L., and March, R. Design Criteria for Biofilters. Trans. Inst. Chem. Eng. 68B:127-132, 1990.

FOR MORE INFORMATION

Richard C. Brenner
Risk Reduction Engineering Section
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive
Cincinnati, OH 45268
513/569-7657