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THE APPLICATION OF AIR MODELING TO SHOW THE REDUCTION OF OFF-GAS ODOUR FROM AN INDUSTRIAL FERMENTATION PROCESS USING BIOFILTRATION

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Abstract

Biofiltration is an inexpensive method of odour removal in which a contaminated air stream is passed through a moist, porous medium before being vented to the atmosphere. Contaminants are absorbed onto the surface of the medium and degraded by microorganisms. Using an air model, the odour reduction resulting from the use of a vertical, lab-scale biofilter in treating off-gases intermittently released from a local fermentation facility was described. The filter was operated for two months, totaling 30 medium sterilizations, and the relationship between odour reduction and off-gas flow rate was examined. The filter maintained an odour reduction above 35%, and sustained odour reduction over consecutive sterilization cycles. An AUSPLUME dispersion model was used by inputting all necessary parameters inherent to the study site and weather conditions to compare the theoretical dispersion of stack emissions before and after implementation of a the biofilter. The analysis showed that the biofilter reduced the odour to below the minimum annoyance level of 5 OUm^{-3}, thereby lowering the likelihood of complaints from neighbouring facilities.

1.0 INTRODUCTION

Many industries seek inexpensive and effective means of reducing odour emissions. A local pharmaceutical company desired a low-cost, non-hazardous means of reducing odorous emissions of volatile organic compounds from local fermentation stacks. The gases emitted from the facility were vented to the atmosphere through a stack located on the building roof. Odours were very strong immediately after the sterilization process until approximately 2h later. The odours emitted were non-toxic, of low emission, intermittent, and composed of the by-products of fermentation. Typical by-products of fermentation include such compounds as aldehydes, alcohols, esters, ethers, and amines. The intermittent nature of flow poses a challenge to biofiltration, as microorganisms prefer constant concentrations.

One proposed solution was biofiltration, which is an inexpensive method of odour removal where contaminated air is passed through a microbe-containing medium where contaminants are degraded. Although there is much information in the literature on biofiltration, published research relating to the treatment of fermentation off-gases using biofiltration is limited. Therefore a pilot biofilter was designed for odour removal with specific constraints posed by the fermentation process at the sponsor company. A closed bed, vertical biofilter was designed for reducing odorous emissions generated during a fermentation process and constructed to lab-scale, and an odour model was used to present the reduction in odour and the consequent impact to neighbours.

Biofiltration

Biofiltration is an inexpensive method of secondary air pollution control that can effectively remove biodegradable compounds without the production of further waste air streams. It involves passing a contaminated air stream through a mixture of organic material, such as compost, woodchips, or peat, where contaminants are degraded by microorganisms. The degradation of the contaminants is an important characteristic of biofiltration that is absent from most other air treatment processes.

The contaminants dissolve in a stationary water phase in the biofiltration medium, also known as the filter bed, and are then degraded by microorganisms. Water is periodically injected into the bed to maintain the proper moisture level. The microbes present in the filter bed oxidize the influent volatile organic compounds (VOCs), which are molecules with high vapour pressure present in the air at high concentrations, and oxidizable inorganic vapours. This produces harmless respiratory by-products, including water and carbon dioxide. The bacteria and fungi present on the filter medium acclimate to the absorbed or adsorbed contaminants, and a lower number of species flourish by metabolizing the incoming air contaminants [1]. Some species may thrive on the surface of the biofilm, which is a film consisting of live microorganisms, materials such as polysaccharides emanated by microorganisms, and debris of microbial and filter bed material origin. Others penetrate deeper into the pores where oxygen is scarce [2]. Degradation occurs under favourable moisture (between 40 and 80%, wet basis) and temperature conditions (between 20 and 45°C). Because the filter bed consumes the contaminants, the bed constantly contributes to its regeneration. An appropriate contact time between the microorganisms and the contaminants is achieved by controlling the airflow rate by which contaminants are introduced into the system. The biofilter bed itself is non-hazardous and remains non-hazardous after use. Biofilters are composed of an array of variables that can be manipulated to maximize system efficiency. These variables may be related to the influent air, the filter bed, or both.

There are numerous choices of filter bed media available. Compost is a natural medium that contains a diversity of microorganisms that facilitate the breakdown of a range of contaminants. Nutrients necessary for the survival and proliferation of the microorganisms are already present and, unlike the case for synthetic or inorganic medium, do not need to be added. Compost also is appealing due to its good water retention properties and neutral pH. Although compost acts as a good medium in the beginning, it compresses with

time, breaking up into smaller particles and continually compacting. Compaction raises airflow resistance to unacceptable levels and creates fissures that cause problems [3].

The woodchips are a good bulking agent, intended to reduce pressure build-p by decreasing density, without allowing the air to stream through. The pieces serve as a good surface for bacterial attachment as they are rough, porous, and hydrophilic. In addition, the fragments are reasonably light and are therefore resistant to compaction. Wood has a pleasant, natural smell. As wood is a natural product, its disposal is simple and need not be treated as a hazardous waste in this situation.

Biofilters simultaneously treat a wide variety of compounds, including odorous gases and hydrocarbons. They have shown effective removal of contaminants from a variety of sources, from the coatings industry to petrochemical manufacturing. They are very beneficial from an environmental perspective, with removal efficiencies over 90%. These filters operate at ambient temperature and very low pressure drop. Compared to other methods, the financial cost of the system is minimal.

Biofilters have a large space requirement for installation and are not as effective for high concentrations of pollutants. As every situation is different, each biofilter has to be specifically designed and adjusted to treat the influent contaminant. Clogging of the filter may be caused by growth proliferation, mineralization, excess water, particulate matter, or clumping due to drying. Channelling occurs when air contaminants pass through a filter bed without contacting any microorganisms in the biofilm. Channels may be caused by dry cracking, compaction, or non-uniformity in the medium. Channelling or clogging may require the medium to be changed, which results in temporary shutdown of the biofilter, and used medium must be landfilled.

Dispersion Modelling

A dispersion model is a mathematical description of the meteorological transport and dispersion process relating to a specific source and set of meteorological parameters. An air dispersion model can predict concentrations of emissions at all points around a source for a range of conditions at a given height. Factors affecting the transport, dilution, and dispersion of air pollutants include stack characteristics, emission rate, nature of contaminant, meteorological conditions, surrounding terrain, and building effects.

The major stack parameters influencing contaminant dispersion are stack height, stack diameter, gas exit rate, and exit temperature. These factors may be optimized to provide maximum dispersion of contaminants. Meteorological conditions have a strong effect on dispersion, making representative downwind sampling problematic. For example, concentration due to stack emissions will always be the highest at a particular location when the wind is blowing directly towards it. Other factors include ambient air temperature, wind speed, atmospheric stability, and mixing height.

Several commercial packages exist for dispersion modeling, including AUSPLUME. AUSPLUME was developed in 1986 in Australia for predicting ground level concentration of air pollutants. The program incorporates into its models local meteorological and terrain conditions, effects of background concentrations, contribution of adjacent sources, and continuing need to surrounding air to accept possible future emissions.

4.0 MATERIALS AND METHODS

All aspects of this experiment were designed to simulate the present fermentation operation procedures at the sponsor company. An AUSPLUME dispersion model was prepared to compare the theoretical dispersion of stack emissions before and after implementation of a biofilter. The reactor simulated the fermentation vessel

which generates odorous VOCs. Since the fermentation operation is run in batch mode, compressed air was passed through the biofilter while the reactor was not venting to maintain aerobic conditions in the biofilter.

Biofilter

The filter structure consisted of a 23 L, 343 mm inner diameter plastic bucket with a sealable lid (Fig. 1). This structure was of sufficient volume to experiment with numerous flow rates and retention times, while keeping the filter a manageable size for potential relocations and changes in filter medium. A plenum was made in the bottom of the bucket by placing three 0.06m long legs to support a mesh screen. A bottom-loaded system was selected to facilitate pH buffering by the water trickling from the top of the filter. A bulk head fitting was placed in the bottom of the plenum to drain any water that should accumulate. The filter medium was placed on top of the mesh and filled to 0.09 m below the rim, making a total filter medium volume of 0.02 m^3. Air entered the filter from an inlet in the plenum area through tubing connected to the fermentation reactor which was the source of VOCs for the experiment. The inlet tubing had a bypass connector that was attached to a separate air line, such that when the air from the reactor was turned off during sterilization, ambient air would still enter the system to keep the filter aerobic. The lid of the filter had an outlet port for the gas, which was attached to tubing that leads to an effluent pipe. At each of the ends of the outlet and inlet ports closest to the filter shell, there was a sampling valve used to collect air samples. The apparatus sat in a long plastic storage container to collect any spills of the medium material or water.

A foam liner (5mm x 32mm, or 3/16” x 1-1/4”, foam tape) was added just above the mesh screen inside the filter shortly after commencing the experiment to prevent channelling of air flow along the filter wall. The foam was looped around the inside of the bucket several times to form a 10mm layer. It was then sealed with acrylic silicon caulk, and dried for two hours.

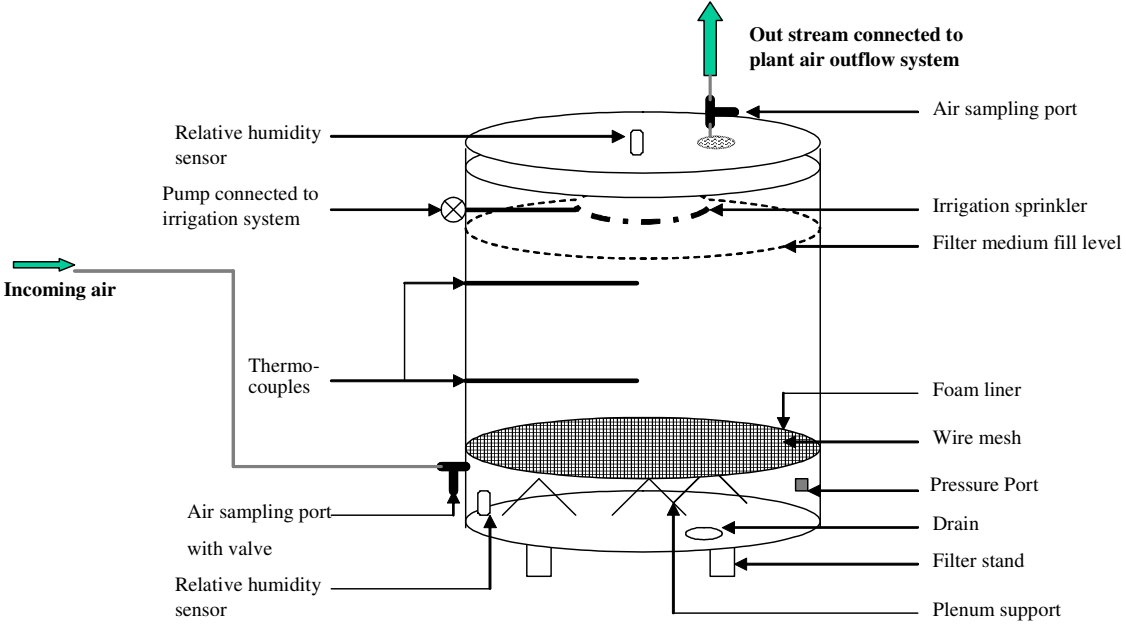


Figure 1: Schematics of biofilter

Filter medium

The filter medium was a 40:60 c:w ratio by volume of compost and cedar woodchips (mass ratio approximately 3:1 c:w, using measured compost density of 800 kgm^{-3}, woodchip density of 171 kgm^{-3}). Large pieces of wood and chunks of compost were removed to prevent channelling of the air stream in the filter. The compost was collected from Niverville, Manitoba. Moisture-related damages, such as hydrophobicity due to excessive drying, are prevented by moistening the filter medium in stages and allowing the water to soak in. The filter medium was mixed in a cement mixer, and the moisture content of the mixture was determined by the oven dry method to be 57.3 $\pm$ 0.6% at the top of the filter and 59.5 $\pm$ 1.5% in the centre of the filter. A total of eight samples were dried for 24 h at 130°C. Porosity of the filter medium was found to be 48.0 $\pm$ 2.3 % by Sadaka *et al.* [3].

Sensors

Two relative humidity sensors (General Eastern Model RH5, Wilmington, MA, USA) were installed in the system to monitor the filter medium moisture content. A pressure transducer was located in the plenum to measure the pressure drop through the filter bed (air at the filter exit is assumed to be at atmospheric pressure). Six constantan/copper thermocouples were located in the filter; three were situated in the middle

of the filter depth, staggered to the centre of the filter medium, and another three were situated 0.05 m from the plenum mesh. All of the input received from these sensors was recorded by a data acquisition system situated near the apparatus (HP 3852A, Hewlett-Packard Canada Ltd. Mississauga, Ontario). Sensor output was read off of a monitor such that the experimenter had current information on the state of the filter.

A small water fountain pump (M60A, Beckett Corp., Irving, Texas) was connected to the data acquisition and control system that intermittently activated the pump. The timer could be controlled through the computer, therein activating irrigation of the filter, had the system moisture level declined. The system provided a uniform sprinkler irrigation to facilitate frequent watering in short durations. Water was discharged from a perforated polyethylene tube formed into a ring and placed below the lid of the filter. Leaching was easily detected by opening the bulkhead on the bottom of the bucket and visually observing water accumulation.

Reactor

A reactor was used to generate VOCs for this experiment. The reactor was a 1:1400 scale replica of the full-scale 14000 L production fermentation vessel used the sponsor company, which exhausts off-gases between 1000-8000 $Lmin^{-1}$, although 4000 $Lmin^{-1}$ is rarely exceeded. The 19 L experimental reactor had a working volume of 14 L, and contains 2 flat-blade Rushton (D6) impellers and 4 baffles. Pressure inside the reactor was controlled to approximately 550 kPa (80 psi). A pH probe could be inserted into the reactor to automatically take readings, and two sampling ports facilitated collection of samples. Temperature was monitored and control

The fermentation medium was sterilized every 2 d in the reactor, following an identical procedure each time. Contents of this fermentation medium are privileged information, and therefore not discussed in herein. As is done in a full-scale situation, off-gases were retained in the reactor until completion of the sterilization, and were vented through a system of tubes into the biofilter

Experimental Procedure

Fermentation medium was sterilized every two days in the 19 L fermenter. Contents of the fermentation medium and sterilization times were kept the same in all trials, as were moisture content, temperatures, and pH of the filter medium. Two off-gas samples were taken for chromatography analysis using Tedlar bags upon commencement of experimentation to quantify odour constituents, particularly VOCs. Air samples were sent to a commercial lab for component analysis. Continuous pH sampling of filter medium was not performed, as this would have lead to disruption of the medium and would have promoted channelling [4].. The organic filter medium naturally had a high buffering capacity and major changes in pH were not a concern. Air samples for olfactometry analysis were taken the second week after commencement of sterilizations at the influent and effluent ends at various points in the venting of the off-gas, particularly during the peak emission of medium sterilization. The experiment lasted approximately 65 d, with a total of 30 medium sterilizations.

The procedures of sterilization used in the lab-scale testing were the same as those used in large-scale production. The purpose of the medium sterilization is to eliminate foreign organisms from a liquid that will serve as a culture medium for bacteria which are used to produce pharmaceuticals. Each sterilization lasted for approximately 4 h. During this time, clean air from a compressed air line was run through the system to prevent development of anaerobic zones. The off-gasses were vented at a temperature 30°C from the sterilization reactor. After running the experiment for three weeks, the temperature of venting was raised to 34 °C to increase the temperature in the biofilter medium, and therein potentially increase microbial activity.

The back pressure to the reactor was held constant at 0.2 bars (20 kPa), and the baffles rotated at 300 rpm. The rate of venting into the biofilter was initially controlled at 20 $Lmin^{-1}$ (60s EBCT), then decreased to 15 $Lmin^{-1}$ (120 s EBCT) after 12 d, then decreased to 10 $Lmin^{-1}$ after another 9 d to increase the residence time

of air flowing through the filter to 180 s. Five days later the venting rate was again decreased to 5 $Lmin^{-1}$ (240 s EBCT).

The filter medium was mixed to the appropriate compost to woodchip ratio and water was added. A lid was placed on the bucket and the medium was allowed to absorb the water for two days prior to its introduction into the filter. A dry run was conducted to test the apparatus for air leaks without the filter medium inside. The pre-soaked filter medium was then added and clean air once again was forced through the system.

Odour Measurement

Odour is multidimensional, and there are several parameters used to describe it including character, hedonic tone or pleasantness, concentration, and intensity. There are numerous factors effecting odour detection, such as sex, age, memory, adaptation, health, and cultural background. These factors make odour description difficult and inevitably somewhat subjective. It is therefore common to use human sensory panels to measure the odour of the whole sample rather than examining its constituents individually, for example through chromatography, as combinations of VOCs may effect how the odour is perceived [5].

Odour concentrations of collected air samples were measured using an olfactometer (Ac'Scent International Olfactometer, St. Croix Sensory, Inc., Stillwater, Minnesota) with odour panels composed of six pre-screened individuals who had odour detection abilities representative of the general population. In olfactometry, the odorous sample is diluted with odour free air in varying ratios. The diluted samples are then presented to a panel of humans to sniff. The measured odour concentration is expressed as an odour unit (OUm^{-3}), which is defined as the amount of odorant that, when evaporated into 1.0 m^3 of neutral gas, elicits a physiological response from a panel equivalent to that elicited from one reference odour mass. The reference odour mass is equivalent to 123 μg n-butanol evaporated in 1.0 m^3 of neutral gas [6]. For each

sampling session, three replicate samples were taken in sterile Tedlar bags one after the other, beginning with the outlet samples followed by the inlet samples.

The olfactometer had limited dilution ability, and could not handle samples of extremely high concentration. Therefore, both the influent and effluent samples taken immediately after sterilization were diluted. The time to fill the bag was measured, and as the inlet flow rate was steady at 5 $Lmin^{-1}$, the volume inside the bag can be calculated. Outlet airflow was measured using a hot wire anemometer, taking the average of three readings. Using a sterile syringe, sterile air filtered in a HEPA filtration system was injected into the Tedlar bag in the appropriate quantity to give the desired dilution ratio. Later trials simply involved filling the bag with sterile air from a syringe, then adding contaminated air with a syringe.

Dispersion modelling

Concentration values were predicted to be the 15 min average in OUm^{-3} immediately after sterilization at a receptor height of 5.1 m, which is the air intake height of local buildings. Weather data was taken from a one year period from 1988-1989 in Winnipeg.

Receptors were located at every 20 m interval up to 200 m from the source. The building dimensions were input as 30 m wide by 10 m high. The background concentration, terrain effects, and contaminant decay were considered negligible. The plume rise was selected to be gradual, and stack tip downwash and temperature gradients were included. The stack was 12 m above the ground (as it was on the building roof) and was 0.10 m high. The temperature at venting was 30 ºC with the biofilter and 125 ºC without, and the effluent exited the stack at 4.2 ms^{-1} as determined using an anemometer. The emission rate from the stack after using the biofilter was 877 OUm^3s^{-1}, and was 2190 OUm^3s^{-1} without using a biofilter. These values were averages of measured odour concentrations.

5.0 RESULTS AND DISCUSSION

For the 40:60 c:w filter medium, 240 s EBCT immediately after sterilization, odour was extremely strong at the influent end, 32 839 OUm^{-3}, and was 9266 OUm^{-3} after passing through the filter. This effluent odour level immediately after sterilization was higher than the influent odour level for all 24, 28, and 50 h tests. Although this may seem to imply that the filter was not effectively removing odour, the odour has been reduced by 72 % immediately after sterilization. Although biofiltration is commonly used for lower concentrations, effective treatment of VOCs has been achieved with inlet concentrations of 32 000 OUm^{-3} previously. Sironi and Botta [7] achieved 97 % odour abatement, generated at a composting plant, from this initial odour level using biofiltration.

Odour reduction ranged from 38 % to 67 % 24 h after sterilization, which seem to be low, however, the final odour concentration was only between 640 and 852 OUm^{-3}, which were two orders of magnitude lower than that immediately after sterilization. This odour level is low enough that dispersion will make the downwind odour imperceptible.

Effects of variable contaminant loading

The effluent odour concentrations are consistently lower than the influent throughout the fermentation-sterilization cycles, however the initial concentration of the influent is higher immediately after sterilization than at other points of sampling (Fig. 2). This initial release of off-gas is the point where odour reduction is crucial.

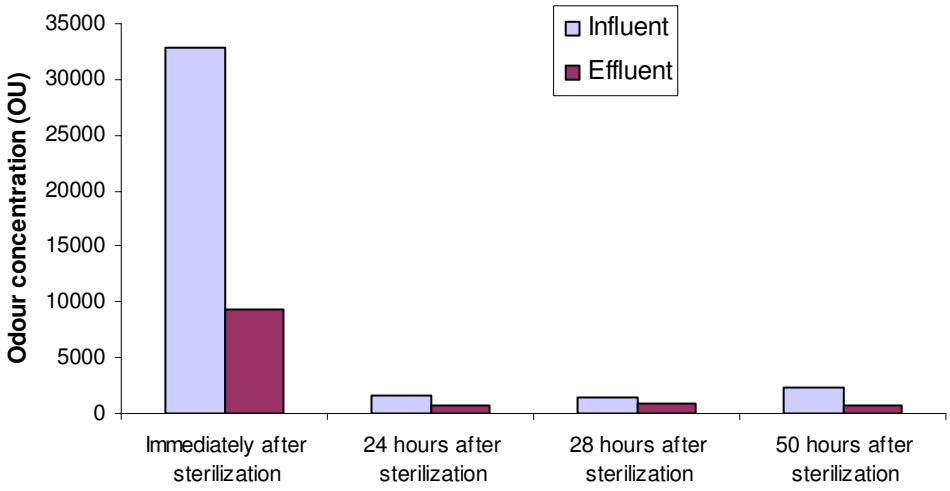


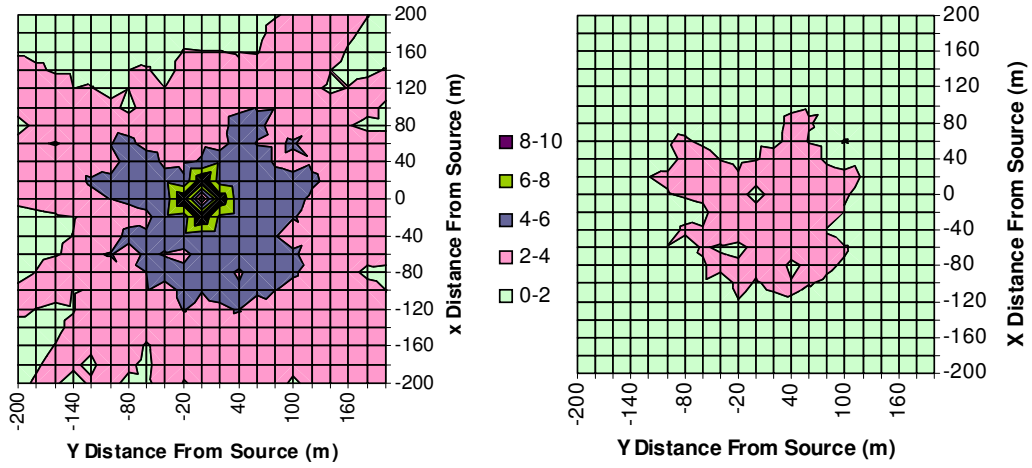
Figure 2: Comparison of influent and effluent odour concentration with 40:60 c:w filter medium, 240 s EBCT. Odour concentration can be expressed as OUm^{-3}.

At later points in the sterilization venting, there was a less dramatic reduction in odour. The influent odour level 50 h after sterilization was higher than both the influent levels 24 and 28 h post-sterilization. This is likely due to error from a lower number of replicates for the 50 h sampling and the inherent variation from using human panellists, rather than from an increase in odour level. As the biofilter medium is composed of substances which already contain odour, a residual odour will always be present. Complete elimination of odour is not possible by any existing method, and biofiltration is no exception. Odour panellists commented that, although an odour was frequently apparent in the effluent, it was of a different hedonic tone ("woody" smell). This suggests that the air passing through the filter was picking up an odour from the cedar chips.

The initial high odour strength of the off-gases acted as a shock load onto the biofilter, and the gas stream tapered to a low-concentration stream over the two day venting period. Although challenged with an inconsistent flow stream, the biofilter continued to remove contaminants throughout experimentation. The response of biofilters to shock loading with toluene and xylene, and periods of starvation were observed by

Metris *et al.* [8], who found that biological degradation continued throughout these stresses. Also, microbial degradation persisted despite fluctuating hydrogen sulphide levels and starvation of the biofilter [9].

Dispersion Modelling



(a) (b)

Figure 3: Dispersion models of emissions from fermentation stacks at the sponsor company, with values in OUm^{-3}. Dispersion of contaminants before implementation of the biofilter is shown in (a), and (b) shows predicted dispersion after biofilter use. Concentrations in Fig. 3b have been reduced to an average of 40% of the concentrations in Fig. 3a, reflecting odour reduction by the biofilter within one standard deviation.

It is clear from these plots that the concentration a given distance away from the contaminant source is decreased by the presence of the biofilter. Neighbours of the sponsor company have air intake to their facilities approximately 65-70 m away from the emission stack of the sponsor company. This dispersion model shows a reduction in odour levels at this distance upon implementation of the proposed biofilter. Odour levels 65 m away from emission source were reduced from between 4 and 6 OUm^{-3} before the biofilter was inputted, to between 2 and 4 OUm^{-3} after. Odour becomes an annoyance between 5 and 10 OUm^{-3} for 98 % of the population [10]. Applying these numbers to the sponsor company emissions odour,

the biofilter has reduced the odour to a level below the minimum annoyance level of 5 OUm^{-3}, therein reducing the likelihood of complaints from neighbours.

CONCLUSIONS

Biofiltration is an effective means of reducing odour emissions from fermentation at the sponsor company. A closed bed, vertically-loaded biofilter using woodchips and compost as the filter medium consistently showed a reduction in odour levels at various stages in the sterilization off-gas venting. A dispersion model revealed a reduction in odour levels upon emission of gases from the proposed biofilter. Neighbouring industries of the sponsor company, with air intakes located between 65 and 70 m from the stack at the sponsor company, would experience weaker odour entering their air intake then before the implementation of the biofilter.

REFERENCES

1. Cherry, R. and Thompson, D. 1997. Shift from growth to nutrient-limited maintenance kinetics during biofilter acclimation. *Biotechnology Bioengineering* 56:330-339.

2. Devinny, J., Deshusses, M., Webster, T. 1999. *Biofiltration for Air Pollution Control*, 1st edition, Boca Raton, Florida: CRC Press.

3. Sadaka, S., Magura, C., Mann, D. 2002. Vertical Airflow Characteristics of Wood/Compost Mixtures. *Applied Engineering in Agriculture* 18(6): 735-741.

4. Schwarz, B., Devinny, J., Tsotsis, T. 1999. Degradation of PCE in an anaerobic waste gas by biofiltration. *Chemical Engineering and Science* 54:3187-3195.

5. Knudsen, H., Kjaer, U., Nielsen, P., Wolkoff, P. 1999. Sensory and chemical characterization of VOC emissions from building products: impact of concentration and air velocity. *Atmospheric Environment* 33:1217-1230.

6. Qu, G., Feddes, J., Leonard, J., Coleman, R., Armstrong, W. 2001. Normalization of the olfactory response of an odour panel. *Transactions of the ASAE* 44(6):1833-1838.

7. Sironi, S., and Botta, D. 2001. Biofilter efficiency in odor abatement at composting plants. *Compost Science and Utilization* 9(2):149-155.

8. Metris, A., Gerrard, A., Cumming, R., Weigner, P. 2001. Modelling shock loadings and starvation in the biofiltration of toluene and xylene. *Journal of Chemical Technology and Biotechnology* 76:565-572.

9. Wani, A., Branion, R. Lau, A. 1998. Effects of periods of starvation and fluctuating hydrogen sulphide concentration on biofilter dynamics and performance. *Journal of hazardous Materials* 60:287-303.

10. Sheridan, B., Hayes, E., Curran, T., Dodd, V. 2003. A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland. *Bioresource Technology* 91:145-152.