Design, construction and long-term performance of novel type of industrial biotrickling filters for VOC and odour control

Vladimir Popov, Vasiliy Khomenkov, and Vitaliy Zhukov
A.N.Bakh Institute of Biochemistry, Russian Academy of Sciences, Leninskiy pr. 33, 119071 Moscow, Russia
Mary Cavanagh and Phillip Cross
Chemviron Carbon Ltd., Edgar House, Lockett Road, Ashton-in-Makerfield, Lancashire WN4 8DE, United Kingdom

An intensive biotrickling filter technology has been developed in Moscow Bakh Institute of Biochemistry in cooperation with Chemviron Carbon which enables degradation of toxic compounds by specially adapted, highly active strains of micro organisms, immobilized on an innovative artificial carrier in a specially engineered system. The degradation efficiencies achieved are generally in the range of 80 to >99% for VOC concentrations of up to 1,500 mg/m^3 and contact times of 2 to 20 seconds. The technology is applicable both for VOC and odour control that is illustrated by two case applications: removal of dichloromethane at industrial facility in UK and pilot deodouration studies at Moscow water works. A long-term sustainable performance of bioreactors operating at 3-4 s contact time and efficiency of 85-95 % has been achieved. High throughput characteristics and efficiency of developed biotrickling filters enable a reduced site area, whilst minimizing overall capital and operational costs.

1 INTRODUCTION

Trickling bed biofilters offer a number of advantages over conventional biological methods of treating off-gases. Although conventional biofilters are somewhat cheaper to install and easier to operate compared to trickling bed systems, their major disadvantages arise from the difficulties in providing comprehensive process control which hinders their use in applications which are detrimental to the required biofilter environment (e.g. acidification in the course of utilization of chlorinated and sulphurous compounds). Trickling bed biofilters due to accurate control of the process parameters are devoid of these problems and provide efficient solution to complex biofiltration applications.

In many cases the contact time between the VOC laden air and the biocatalyst in trickling bed biofilters may be reduced to below 10 s range thus minimizing the overall system foot-print, dimensions and power requirements. In spite of the obvious advantages of the trickling bed biofiltration the technique still remains in its infancy and only a few examples of full-scale systems are available to date (Kraakman, 2005) mainly confined to odour control applications.

In a previous publications we provided a number of examples of highly intensive full-scale biotrickling filters operating in 3-6 s contact time range (Popov *et al*., 2002; Popov *et al*., 2004). The present paper extends our experience into the case of treating a complex oscillating emission of a chlorinated compound, dichloromethane (DCM) and long-term monitoring of a pilot plant for removal obnoxious H_2S odour at Moscow Water Works.

2 RESULTS AND DISCUSSION

2.1 DCM abatement system at Senior Aerospace

Senior Aerospace of UK designs and manufactures ultra-lightweight low pressure air distribution ducting and cabin insulation systems for aircraft. These are manufactured from the fibre reinforced composite materials. DCM is used to dissolve the resins used in the manufacturing process. The off-gas stream of 40,000 m^3/h mainly consisted of DCM (>95%), however, small volumes of acetone and cyclohexane dependent on the process parameters were also present. The average DCM end-of-pipe concentration prior to installing the abatement system in 2002 was approximately 500 mg/m^3 (~ 70 mgC/m^3). The emission profile from the factory is highly variable and due to the nature of the process there tends to be an initial "flash" of solvent with a spike in concentration of up to 1,500 mg/m^3.

Table 1. System parameters.

Parameter	Senior Aerospace, UK	Water works, Moscow
Type of the system	industrial	pilot
Airflow (nominal), m^3/hour	2x20,000	115
Dimensions	2.5 m diam x 8.75 m	0.50x0.48x1.95 m
Operating weight	~ 2x24 tonnes	170 kg
Volume of the carrier, m^3	2x17.5	0.1
Bed arrangement	4 layers	3 layers
Packing, m^2/m^3	polypropylene, 180	fibrous packing, ~1,000
Biocatalyst	proprietary	consortium based on *Th.thioparus&Th.novellis*
Contact time, s	4	3.2
Bed temperature, °C	20–30	16-30
Average VOC concentration, mg/m^3	500 (DCM)	16 (H_2S)
Range of VOC concentrations, mg/m^3	100-1,500	10-100
Average efficiency, %	>85	95

An initial pilot plant study performed at 3 to 6 s contact times demonstrated that the trickling-bed biofilter developed by a joint Russian-British team, and marketed by Chemviron Carbon Ltd. (Sutcliffe Speakman PLC until 2004) under the trade name SC-BIOREACTOR™ could reduce the emission of DCM to the level compliant with the legislation that existed at that time (EU Solvent Directive 2001, 20 mgC/m^3). The SC-BIOREACTOR at Senior Aerospace was erected and commissioned in 2002. The overall view of the plant is presented in Figure 1, whilst Table 1 provides the operating parameters. The plant is arranged in two modules each rated to treat 20,000 m^3 of air per hour. To cope with oscillating inlet DCM concentrations and to ensure an even flow of the pollutants through the biocatalyst an activated carbon smoothing filters have been installed at each of the modules inlets as has been discussed earlier (Popov *et al*., 2004).

The operation of the plant was very stable and reliable. No considerable increase in the pressure drop of the system was observed over its long-term operation. The pressure drop of the modules was maintained in the range of 100 – 140 mm of water gravity and required a regular service / cleanout of the system not more often than once a year. Very little pH drift of the system medium was observed both during the pilot study as well as long-term operation. The pH of the system was generally maintained between pH 6.8 - 7.5 by addition of stabilising stock buffer solution.

Figure 1. Biotrickling filter for DCM abatement, Senior Aerospace, UK. 2x20,000 m^3/h, 4 s contact time.

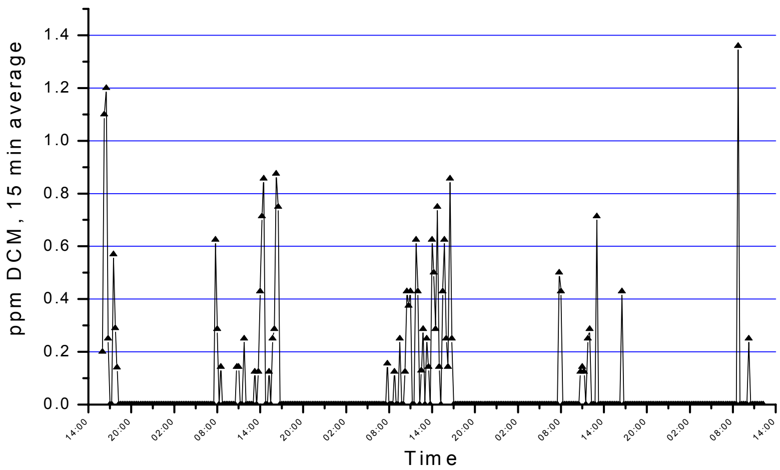

Figure 2. 92 hours continuous DCM outlet concentrations measurements at Senior Aerospace biotrickling filter. Contact time 4 s. Average inlet concentration ~40 ppm DCM.

In order to verify the performance of the system, a series of continuous monitoring tests were undertaken at various time periods. The results of one of such tests are presented in Figure2. The emissions from one of the SC Bioreactor modules were continuously measured for a period of 92 hours during which the factory was running a normal production cycle. The emissions to atmosphere were constantly monitored and measured using an infrared Miran 1BX Portable Ambient Air Analyser. The analyser was linked to a chart recorder and a datalogger to enable continuous recording of the emissions. From the measurements taken the mean emission level over the 92 hour period, calculated from the 15 minute mean values, was 0.0358 $mg(C)/m^3$, with a maximum exhaust concentration of 1.4 ppm DCM, equivalent to 0.75 $mg(C)/m^3$ (5.3 mg/m^3 of solvent).

Thus the plant at Senior Aerospace for DCM removal provides a clear example of the advantages provided by a trickling bed system: high efficiency at extremely low contact time, high throughput combined with a small foot-print, stability and consistency of operational parameters.

2.2 High-performance air deodouration

Deodouration of air is one of the most popular applications of biological systems for air purification. Biofiltration of malodorous air from waste water treatment plants containing sulphur compounds (H_2S and mercaptanes) became a standard and well-developed technique. All known types and classes of biofilters have been successfully used for this purpose. In general conventional biofilters operate at 30-120 s contact times providing 95-99 % efficiency towards odour removal at H_2S concentration up to 20-100 ppm.

Recently several publications addressed a problem of high-performance air deodouration at extremely low residence times. Deshusses demonstrated efficient conversion of a chemical scrubber into biotrickling filter capable of operating at 2-3 s contact times with efficiencies >97 % (Gabriel and Deshusses, 2003; Deshusses and Gabriel, 2005) while a range of deodouration plants rated from 5,000 to 50,000 m^3/h and operating at about 3 s contact time have been launched in co-operation with Russian scientists in Korea (Popov and Zhukov, 2005). The concept of a high-performance air deodouration plant developed in A.N.Bakh Institute of Biochemistry, Moscow in the 90-s of the last century and originally tested on a pilot scale for deodouration of air emission from a pet-food facility (Zhukov *et al*., 1998) is based on the use of the carriers with a high specific area (fibres or foams with a regular pore structure) and unification of all the parts of the air purification plant (humidifier, bioreactor chamber, demister, heater, etc.) into one functional unit that could be arranged in modules to achieve desired throughput.

Figure 3. Trickling bioreactor for air deodouration. Module with a capacity of 12,000 m^3/h and recommended EBRT of 3-3.5 s.

Figure 3 presents a view of a developed by us typical biotrickling module for deodouration of air emissions which can be operated at ~3-4 s residence time giving a capacity of 12,000 m^3/h. Efficiency of the system was tested towards a number of odorous emissions including sulphur containing air streams from municipal water works, emissions from garbage utilising facilities and food processing factories. In all the trials the system showed 95-99 % removal efficiency when assayed by GC/MS technique towards individual substances comprising these odours.

Similar strategic approach is currently being implemented at Moscow municipal waterworks.

Kur'anovsk aeration station is the biggest Moscow waste water treatment plant. With a capacity of 400,000 m^3/day, it occupies 500 hectares and is located close to densely populated urban areas. Despite the absence of significant complaints from local population, the administration of the station has considered a range of preventive measures to reduce potential malodorous air emissions. A number of options have been tested in past years, including conventional biological methods for air treatment. However, the large volumes of air to be treated prompted a search for a high intensity solution.

Extensive pilot tests have been performed in 2003-2005 by Moscow municipal water works in co-operation with Bakh Institute of Biochemistry at a number of sites of Kur'anovsk station exhibiting different emission levels of H_2S. Figure4 shows the results obtained at the residue sedimenting and dewatering site characterised by the highest local level of H_2S emission. The average H_2S concentration was around 16 mg/m^3 with frequent spikes from 40 up to 100 mg/m^3. Other operating parameters are presented in Table 1.

A fibrous carrier with high specific surface area was used as a support for the microbial consortium. The results of the long-term monitoring tests confirmed a possibility of efficient removal of rather high H_2S concentrations at relatively low contact times, ~3 s, Figure4. In about a month the pilot plant reached its optimal performance and operated stably for nearly a year showing an average removal efficiency of 95±3 % and effectively handling spike emissions.

Currently the first prototype plant in a series of full scale systems of different productivity for air deodouration rated for 5,000-10,000 m^3/h is under construction and will be put into operation in 2006. Subject to its performance results Moscow water works authorities will take a decision of nominating this technology as standard for all the available municipal waste water treatment facilities.

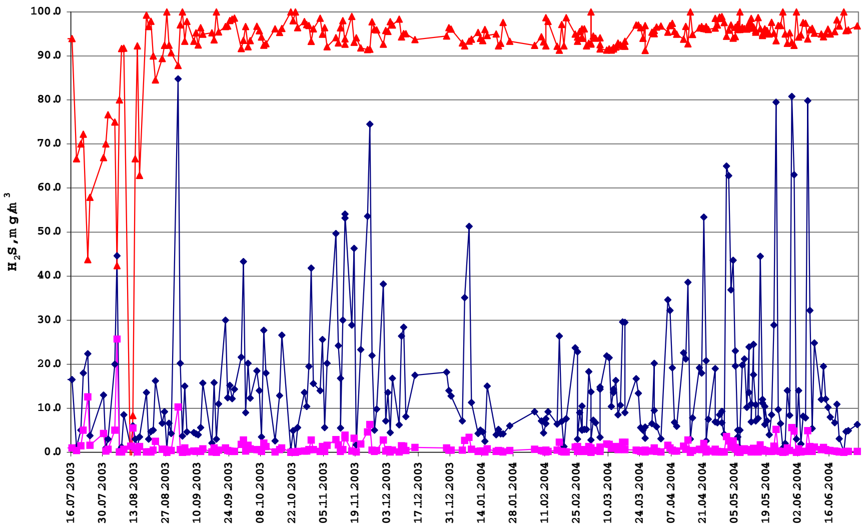

Figure 4. Start-up and performance of the pilot trickling bioreactor for odour control operating at Kur'anovsk Water Treatment Plant, Moscow. EBRT 3.2 s.

3 REFERENCES

Deshusses, M.A. and Gabriel, D. (2005) Biotrickling filter technology. In (Shareefdeen, Z. and Singh A., eds.) Biotechnology for Odour and Air Pollution Control, Springer-Verlag, Berlin Heidelberg, Germany, pp. 147-168.

Gabriel, D. and Deshusses, M.A. (2003) Retrofitting existing chemical scrubbers to biotrickling filters for H_2S emission control. *Proc. Natl. Acad. Sci. USA*. 100: 6308-6312.

Kraakman B. (2005) Biotrickling and bioscrubber applications to control odour and air pollutants: developments, implementation issues and case studies. In (Shareefdeen, Z. and Singh A., eds.) Biotechnology for Odour and Air Pollution Control, Springer-Verlag, Berlin Heidelberg, Germany, pp. 355-379.

Popov, V.O., Bezborodov, A.M., Cross, P. and Jackson, W. (2002) Design, construction and long-term performance of novel type of industrial biotrickling filters for VOC control. In Proc. of Air&Waste Management Association 95th Annual Conference, June 23-27, 2002 Baltimore, USA, paper #42602.

Popov, V.O., Bezborodov, A.M., Cavanagh, M. and Cross, P. (2004) Evaluation of industrial biotrickling filter at the flexographic printing facility. *Environ.Prog.* 23: 39-44.

Popov, V.O. and Zhukov, V.G. (2005) Odour removal in industrial facilities. In (Shareefdeen, Z. and Singh A., eds.) Biotechnology for Odour and Air Pollution Control, Springer-Verlag, Berlin Heidelberg, Germany, pp. 305-326.

Zhukov, V.G. Rogozhin, I.S., Ushakova, N.A., Zagustina, N.A., Popov, V.O. and Bezborodov, A.M. (1998) Development of technology for microbial air deodouration with the use of a pilot plant under real operational conditions. *Appl.Biochem.Microbiol.* (Rus) 34: 370-376.