Sewage Odour Control – The Singapore Experience

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Odour control, biotrickling filter, scrubbers

ABSTRACT

Odour nuisance has become a major environmental issue worldwide with increasing public demand for better control of odorous emissions from municipal wastewater treatment facilities, chicken farms, chemical plants and other industrial works. Odour annoyance affects the population directly and there is a trend that more and more people are becoming less tolerable with obnoxious odour emissions. Bad smell is often regarded as an indicator for possible health risks. In Singapore, much investment has been placed on the prevention of nuisance odour emissions from all the public-owned wastewater treatment plants and continuing research has been put into the development of better and more cost-effective odour control procedures. The local authorities have invested significantly in covering up their existing waste treatment process units and treating all captured sewage air by a variety of technologies such as chemical scrubbers and activated carbon towers. Recently, a new biotrickling filter technology was developed and trial tested at a local wastewater plant and results from the past 3 years of operation indicate an extremely cost-effective biological way of treating sewage odour. Singapore's odour control experience from the use of the traditional chemical and activated carbon systems to this latest biotrickling filter technology is discussed and presented here.

INTRODUCTION

The nuisance impact of air pollutant emissions from water reclamation plants (WRPs) is a major issue of concern to the Singapore environment authority. Currently, all WRPs in Singapore have been covered to prevent odour emissions to ambient air. The covered odorous emissions are collected and treated by a variety of chemical scrubbers followed by activated carbon towers. Although chemical scrubbers provide high odour removal efficiencies, they are also costly in terms of recurrent chemical cost and dangerous in view of the need to handle vast quantities of chemical solutions. Due to inherent operation and maintenance issues related to fluctuating airflows, deterioration of chemical pumping and dosing systems etc, chemical scrubbers typically provide pollutant removal efficiencies in the range of 95 to 99%. In terms of odour, chemical scrubbers can reduce the overall odour by about 80 to 90% although significant chemical odour at the exhaust can often be detected if there is excessive dosing of chemicals.

Over the last decade, research (1-3) has shown that a special blend of bio-culture of the genus *Thiobacillus* is effective in adsorbing odorous hydrogen sulphide, a principal component of sewage air. By immobilising the bacteria onto the surface of packing material in a biological reactor, it is possible to develop an efficient biotrickling filter for treatment of sewage air. When sewage air passes through the biotrickling filter, the biofilm of pollutant degrading microorganisms will aerobically degrade the absorbed pollutants. The technology has been experimented under lab conditions, field tested and is now commercially implemented under the brand name of AroBIOS^{TM} by a spin-off university company, Aromatrix Pte Ltd. The technology has since been licensed and implemented in USA and Australia.

INITIAL LABORATORY STUDIES

In mid 1990s, a series of laboratory experiments were conducted to investigate the feasibility of using the BTF technology for sewage odour control. The packing medium used in many of these lab experiments was made of plastic and a selected bacteria population was immobilised onto the medium. A series of experiments where incoming air was deliberately injected with controlled concentrations of H_2S and air flow rates were varied to yield different gas resident time (GRT), were conducted and the treated air was regularly monitored for odour and H_2S levels. The medium was continuously dosed with either a solution containing trace nutrients or filtered secondary effluent obtained from a wastewater plant. Results of these lab studies have been published elsewhere (1-3) and they show that the lab-scale reactors performed reasonably well, indicating that the biotrickling technology is a feasible one for sewage air treatment.

CONVERSION OF A PILOT CHEMICAL SCRUBBER TO A BIOTRICKLING FILTER

In order to demonstrate the feasibility of the BTF technology for a real on-site system, a study was carried out to convert an existing pilot chemical scrubber to a biotrickling filter.

The existing chemical wet scrubber uses two commonly available alkali solutions, namely sodium hydroxide and sodium hypochlorite as the scrubbing solutions. The main parts of the filter include an acrylic tower column, a 300×300×300 mm recirculation sump, a spray nozzle with an orifice diameter of 0.045 mm, a vortex blower of 900 L/min maximum capacity, and a water recirculation pump of 1.2 L/min maximum capacity. The diameter (D) and length (L) of the packing column are 0.08 metre and 2 metres respectively. The packing material used in the packed tower was 75 mm Intalox Snowflake packing. A schematic diagram of the pilot-scale chemical scrubber is presented in Figure 1.

Before the commencement of the conversion process, several factors such as the bacteria for H_2S treatment, the packing material in the filter column and the type of recirculation solution to be used were considered. As the pilot scrubber was initially designed for chemical scrubbing, some parts of the scrubber, such as the orifice of the spray nozzle and other fittings were modified to suit the use and purpose of a biotrickling filter.

The most important factor to be considered was perhaps the type of bacteria to be used. The bacteria used in the study belong to the *Thiobacillus sp.,* - a natural sulphur-oxidising bacterium that is present in sanitary sewer systems and treatment plants. It is not recorded as a pathogenic bacterium according to the Cambridge World History of Human Disease (4). Biodegradation of H_2S gas produces sulphuric acid, which will eventually depress the pH of the recirculating liquid. Since the pH environment is likely to be acidic, it is vital to select a type of species that is most acid tolerant. The bacteria seed selected was isolated from activated sludge using selective culture medium at a local WRP(5). A SEM photo of the bacterium is shown in Figure 2.

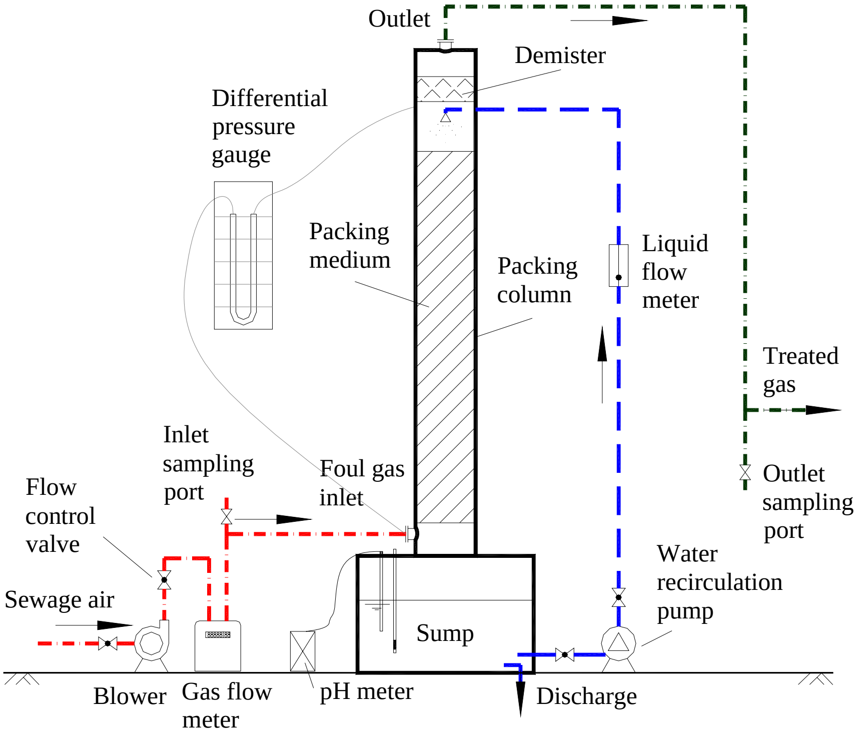

Figure 1 **Schematic diagram of the original pilot-scale chemical scrubber**

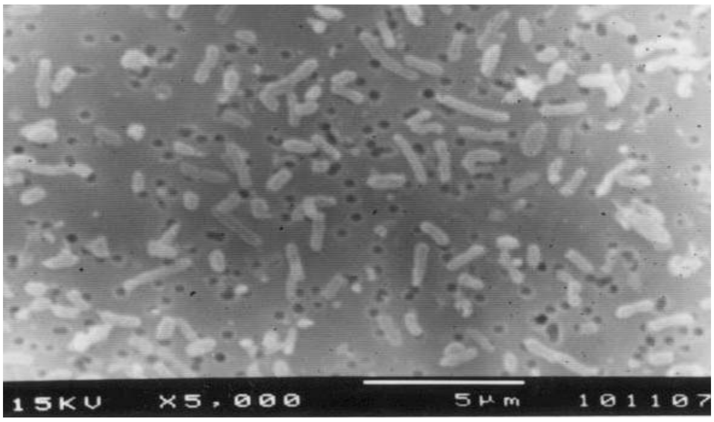

Figure 2 **SEM photograph of *Thiobacillus* in recirculation liquid**

Another important factor to be considered was the packing material to be used in the filter column. The selection of an appropriate packing media was primarily based on the specific surface area of the media. A larger specific surface area of the packing media would allow for more biofilm growth over the media surface in a given volume, thereby leading to higher H_2S removal. The plastic packing medium “Snowflake” from Intalox that was used in the chemical reactor has a specific area of 92 m^2/m^3. From previous works conducted by Koe and Yang (5), plastic “Pall Ring” from Jaeger Products, INC. (nominal size of 5/8”) having a specific surface area of 354 m^2/m^3 was found to be suitable for biotrickling filtration applications. Laboratory scale experiments conducted by Koe and Yang using “Pall Ring” as the packing media could achieve high H_2S removals. Manufacturer’s data also showed that pressure loses due to “Pall Ring” are not likely to be excessive and would probably approximate to “Snowflakes” as both have been used extensively in industrial chemical scrubbers. As such, the original “Snowflake” packing was replaced with “Pall Ring” as the packing medium for the converted BTF.

Unlike chemical scrubbers, the recirculation solution in a BTF is not only used as a medium for gas transfer, but also a source of necessary nutrients and moisture for the inoculated microorganisms. Effluent from the secondary sedimentation tanks of a WRP was used as the recirculation solution for the converted biotrickling filter to provide the required nutrients at a low cost. The recirculation solution is also used to buffer sudden pH changes. The characteristics of the secondary effluent from the WRP are listed in Table 2.

Table 2 Characteristics of treated secondary effluent

Components	COD (mg/L)	SO_4^{2-} (ppm)	PO_4^{3-} (ppm)	NH_3 (mg/L)	NO_2^- (ppm)	NO_3^- (ppm)	pH
Average concentration	50-80	94	6	12	79	49	6.5-7.5

The sprays used in the original chemical scrubber were of a mist type having an orifice size of approximately 0.045 mm, located at the top of the scrubber tower. There was, however, a concern that during the operation of the BTF, shreds of biomass produced by the microorganisms might plug up the nozzle, thus preventing inflow of the recirculation solution. To avoid this, the mist nozzle was replaced with a non-clogging full cone nozzle.

As the recirculation solution in the BTF is likely to be acidic, several copper fittings in the original caustic scrubber were replaced with either stainless steel or plastic make. The original packing column and sump were made of acrylic and is not expected to corrode in the anticipated low pH environment.

The conversion process began with the thorough flushing of the chemical scrubber using acid solution and secondary effluent from the WRP. This flushing ensured the thorough cleansing of former traces of alkali scales from previous chemical applications, which may affect the growth of acidophilus bacterium *Thiobacillus*.

After flushing, the BTF was set into an “acclimatisation and immobilisation” phase by recirculating enriched *Thiobacillus sp* secondary effluent while passing 10 – 50 ppm H_2S gas through the BTF column. The acclimatisation and immobilisation stage was conducted at a laboratory to ensure that there was sufficient bacteria growth in the BTF prior to conducting the field experiments at the local WRP. After running for 80 days, the acclimatisation and immobilisation stage was considered completed as the BTF could achieve H_2S removal efficiency of greater than 90% at a 3 s empty-bed gas residence time (GRT).

The BTF was then deployed at the Odour Treatment Facility at a local WRP. The inlet sewage air stream was drawn from the primary sedimentation process. Filtered secondary effluent was topped up batch-wise into the sump to set initial pH conditions and provide the necessary nutrients for bacterial growth. The GRT was decreased from 30 s to 3 s stepwise in the following manner: 30 s, 15 s, 7.5 s, 5 s, 4 s, to 3 s. The operating conditions are summarised in Table 3. Several experiences and observations during the field test were described as follows.

Table 3 Operating conditions of biotrickling filter at the WRP

Operating parameters	Range
Gas retention time (seconds)	3 — 30
Inlet H_2S concentration (ppmv)	5 —20
Gas flow rate (L/min)	20 — 200
Liquid recirculation rate (L/min)	0.2 — 1.0
Gas/liquid ratio	50 — 500
pH of recirculation solution	1.2 — 2.5

The H_2S removal efficiencies during the field experiments are shown in Figure 3. At GRTs more than 4 seconds, the average outlet H_2S concentrations were less than 0.5 ppm. The corresponding inlet H_2S concentration ranged from 0.2 to 20 ppm. It should be noted that numerically lower H_2S efficiency levels instances at GRTs more than 4 seconds were largely due to very low inlet H_2S concentrations. At GRT of 3 to 4 seconds, the system began to exhibit some instability at higher inlet H_2S concentrations. The results suggested that the performance of the system was sensitive to the inlet H_2S concentration when operating at very low GRTs, which may indicate that the system could be reaching its loading capacity. The presence of other sewage gases (VOCs) could also have affected the performance of the converted pilot-scale BTF.

Since the proposed converted BTF was to potentially replace the chemical scrubbers for odour control, it was important to investigate the odour removal ability of the converted BTF. Figure 4 shows the inlet and outlet odour concentrations as well as the odour removal efficiencies of the BTF. Majority of the odour removal efficiencies of the BTF ranged from 50% to 87%. Typical outlet odour concentrations of the treated sewage gas ranged from 512 sou/m^3 to 5,800 sou/m^3 when inlet odour concentrations varied from 5,800 to 46,000 sou/m^3. From Figure 4 it was noted that the low efficiencies were related to low inlet odour concentrations rather than high outlet odour concentrations. The average odour removal efficiency for inlet odour concentrations of more than 20,000 sou/m^3 was about 75%. The residual odour may be due to the presence of VOCs that were not degraded efficiently in the biological process.

Diurnal variation of H_2S concentration in sewage air was simulated by introducing standard H_2S gas into the real sewage air, following a synthetic diurnal pattern of varying H_2S concentration over 3.5 hours as shown in Figure 5. This diurnal H_2S variation was derived based on the influent sewage flow variation. When the inlet H_2S concentration was manipulated to vary from 15 ppm to 90 ppm in 2 hours, the H_2S removal efficiency dropped from about 90% to 70%. As the inlet H_2S concentration was reduced from 90 ppm to 75 ppm, the H_2S removal efficiency recovered after one and half hours. When inlet H_2S concentration was adjusted back to 20 ppm, the system recovered to 88% H_2S removal. This result suggested that the converted BTF was able to react and respond fairly quickly to variations in H_2S loading in a typical diurnal loading cycle.

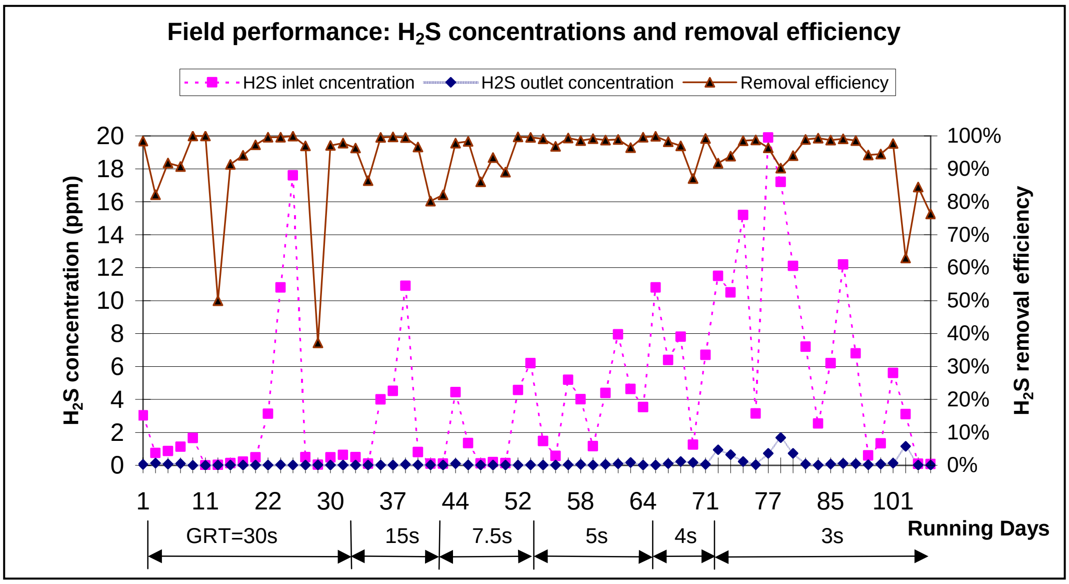

Figure 3 H_2S removal efficiency with step-wise reduction in gas residence time (GRT)

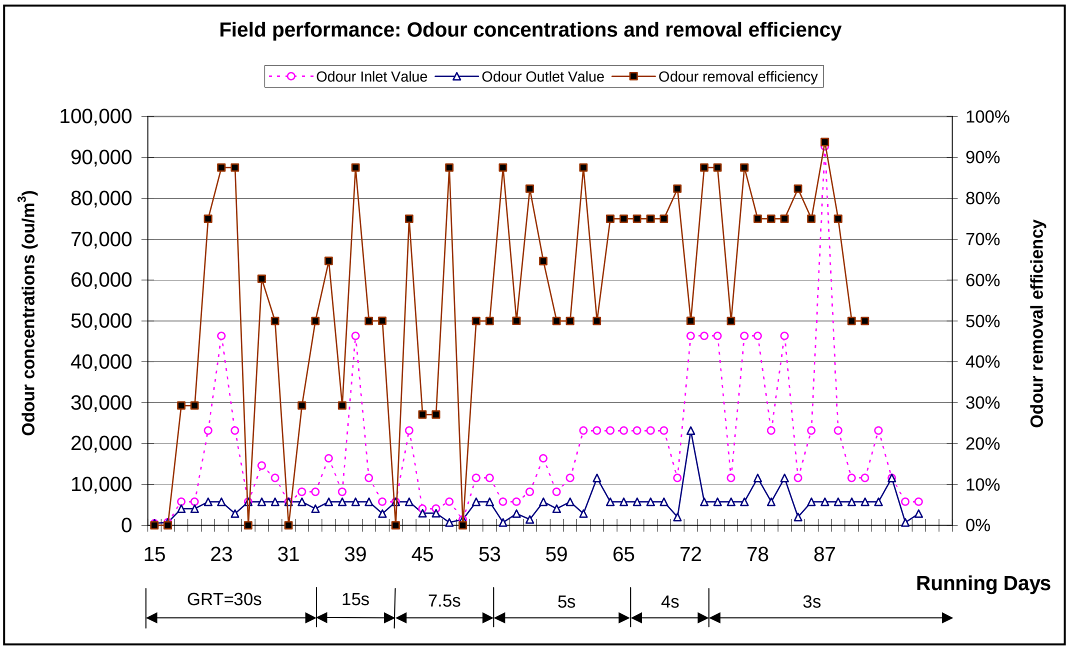

Figure 4 Odour removal efficiency of the BTF

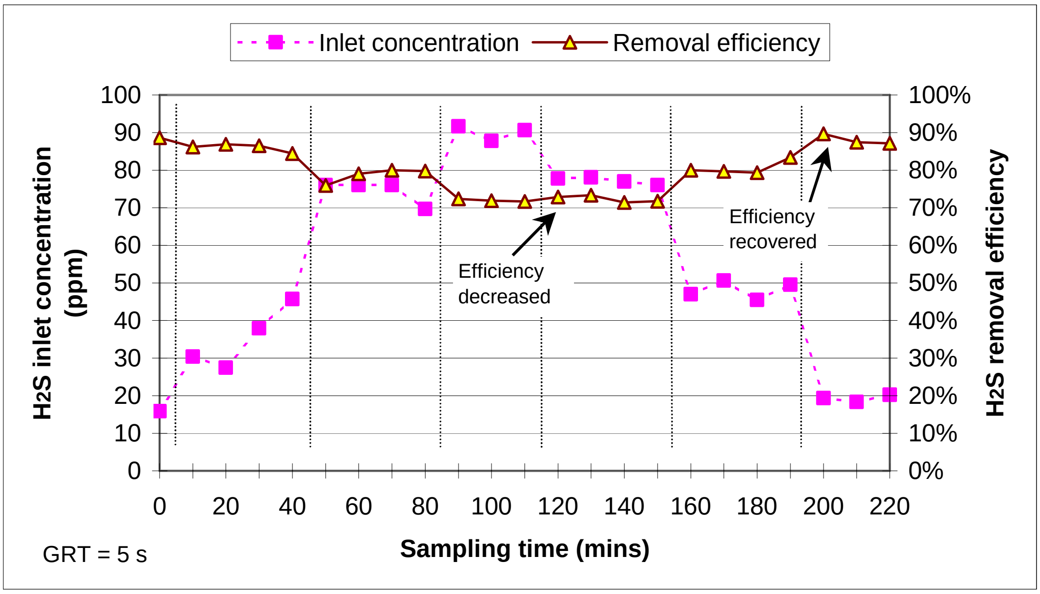

Figure 5 Influence of varying inlet H_2S concentration on H_2S removal efficiency

FULL SCALE CONVERSION OF AN EXISTING CHEMICAL SCRUBBER TO AroBIOS TECHNOLOGY

Some experiences gained in the use of the AroBIOS technology in the lab and pilot scale experiments described above were applied to the conversion of an existing multi stage chemical scrubber with airflow of 200 m^3/min. A number of operational challenges that were encountered during the conversion project are briefly discussed here. Currently, the chemical scrubber has been fully converted to a biotrickling filter operating at full flow capacity. It is able to achieve a consistent high performance of exceeding 97% H_2S removal at a short gas residence time of 7 seconds. The influent sewage off-gas contains high levels of H_2S ranging from 50 to 60 ppm.

During the conversion process, it was discovered that scrubber packing material had significant influence on the performance of the biotrickling filter. The original packing material used in the chemical scrubber was found unsuitable for bioscrubbing applications because of its low specific surface area. It was then replaced with a new composite packing material with much higher specific surface area. After replacement, the composite packing outperformed the original packing with an H_2S removal efficiency of more than 90% compared to the previous efficiency of 44% at 9 seconds GRT.

During a normal field performance operation, the biotrickling filter encountered system shocks. It was due to rapid build-up of undesirable metabolic products and an increase of acidity in the recirculation liquid. By flushing the packing in the horizontal biotrickling filter with filtered effluent water and reducing the H_2S loading (higher GRT) for a period of one day, the biotrickling filter could recover from the shock in less than 48 hours.

Further investigations showed that regular discharge and replacement of recirculation liquid were essential in maintaining stable and high performance of the biotrickling filter. This helped in reducing build-up of metabolic products that would affect stability of the biotrickling filter.

The converted biotrickling filter has been subjected to various testing scenarios such as shock H_2S loading, system overhaul, interruption of feeds, and interruption of liquid recirculation. The study has also shown that the converted biotrickling filter was robust, with only 2 – 3 days of recovery period from system upsets and downtimes.

In short, conversion of a chemical scrubber to a biotrickling filter has been shown to be feasible. The converted system has a good and stable performance with low operating costs and maintenance efforts. The AroBIOS technology is the latest in the series of new development in the application of biotechnology for odour control and several water reclamation plants in Singapore are beginning to adopt this new technology.

CONCLUSIONS

Biotrickling filtration is a cost effective and environmentally friendly technology that treats H_2S without the use of any chemical reactants. This cheap and intrinsically safe technology has been effectively deployed for sewage air treatment at municipal wastewater treatment plants in Singapore. Significant savings particularly from the non-use of chemicals and easier operation and maintenance requirements can be obtained. Singapore has gone through a series of experiences from lab-scale testing to on-site field testing of the biotrickling filter technology. To-date, results have indicated very promising application of the technology for treating odorous sewage air. It is envisage that soon, this technology will replace all chemical scrubbers worldwide.

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