Conversion of Full-Scale Wet Scrubbers to Biotrickling Filters for H_2S Control at Publicly Owned Treatment Works

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Abstract: Until recently, biological treatment of odors in biofilters or biotrickling filters was thought to require a longer gas contact time than chemical scrubbing, hence bioreactors for air treatment required a larger footprint. This paper discusses the conversion of chemical scrubbers to biological trickling filters. Initially, research was conducted with a laboratory-scale biotrickling filter. An effective open-pore polyurethane packing material was identified and H_2S biotreatment performance was quantified. Key technical issues in determining the general suitability of converting wet scrubbers to biotrickling filters were identified, and a generic ten-step conversion procedure was developed. Following the laboratory research, five full-scale chemical scrubbers treating odorous air at the Sanitation District of Orange County, Calif., were converted to biotrickling filters. The original airflow rate was maintained, resulting in a gas contact time as low as 1.6–3.1 s. The converted biotrickling filters demonstrated an excellent capability for treating high H_2S concentrations to concentrations below regulatory limits. This study shows outstanding potential for converting chemical scrubbers to biotrickling filters at publicly owned treatment works.

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Introduction

Many of the 16,700 publicly owned treatment works (POTWs) in the United States use chemical scrubbing for odor control because it is a well-known, widely established, and reliable technology. Odor control at POTWs usually focuses on H_2S removal because of its low odor threshold and ubiquity in wastewater treatment processes. Packed towers and atomized mist systems are the two leading technologies for odor control (Card 2001). In the former, the foul air stream contacts a scrubbing solution that flows over a packed bed contained in a vessel. Absorption of pollutants into the scrubbing solution is the primary removal mechanism, although subsequent pollutant oxidation by chemical reaction in the liquid phase is usually desired to enhance pollutant removal. The liquid solution is usually recirculated from the bottom to the top of the scrubber, while the airflow passes countercurrently through the packed bed.

Chemical scrubbers have several significant drawbacks, including high operating costs, generation of halomethanes (WERF 1996) and the need for hazardous chemicals on-site. In the past decade, these drawbacks have motivated engineers to look into alternatives such as biological treatment. Among the various biotreatment processes H_2S treatment, biotrickling filtration is the most promising (Cox and Deshusses 1998). Biotrickling filter configuration and operation are similar to wet chemical scrubbers, except that a biofilm of pollutant-degrading organisms grows at the surface of the packing, and the pollutants are converted into innocuous compounds by microorganisms rather than by chemicals (Cox and Deshusses 1998). No external addition is required other than a nutrient source and water to allow microorganisms to grow, and to compensate for evaporative water losses. To be cost effective compared to chemical scrubbing, biotrickling filters need to be inexpensive, reliable, and able to treat the same pollutant loads as chemical scrubbers. This may be achieved by careful packing material selection and reactor design, and optimum reactor operation and monitoring.

From a construction perspective, both chemical scrubbers and biotrickling filters share similar requirements. These include the need for a proper support for the packed bed, resistance of the vessel to corrosive chemicals, a liquid distribution system that provides a homogeneous distribution to avoid channeling, a reservoir space at the bottom of the vessel to collect and store the trickling liquid, various supply and purge lines, as well as monitoring and control equipment. Therefore, chemical scrubbers could be retrofitted to biotrickling filters without major investment costs if treatment objectives could be met. Motivations for such conversions include the lower operation and maintenance costs and the absence of use of toxic and dangerous chemicals in biological scrubbers. Despite similarities between both systems, a

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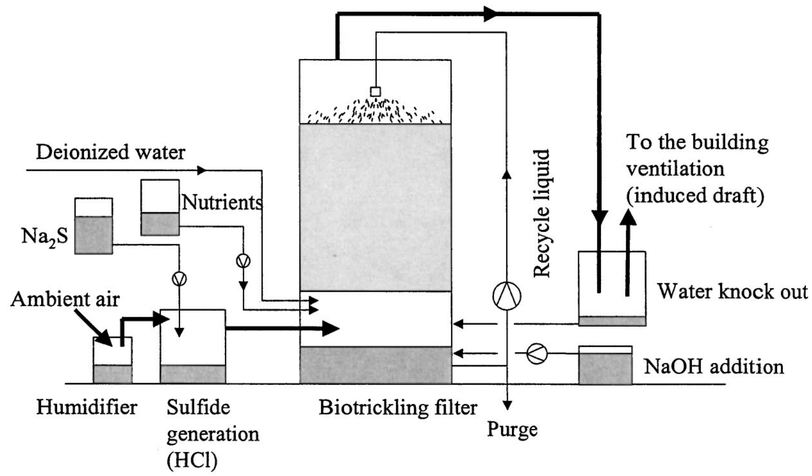

Fig. 1. Schematic of pilot-scale experimental setup

number of technical issues require further consideration. For example, a chemical scrubber can usually not be directly seeded with microorganisms and used as a biotrickling filter without any changes. The packing material of a biotrickling filter must be capable of holding enough microorganisms to efficiently compete with the treatment capability of chemical scrubbers. Another challenge is that biotreatment processes have been shown to work well for removal of odorous compounds, but usually at bed contact times much higher (10–60 s) than those for chemical scrubbers (1–3 s) (Yang and Allen 1994; Smet et al. 1998; Chung et al. 2000; Wu et al. 2001). Hence, conversion of chemical scrubbers to biotrickling filters requires further optimization and proof of sustainable treatment performance.

This paper presents the approach for converting chemical scrubbers to biotrickling filters. The characteristics of over 20 chemical scrubbers at Orange County Sanitation District (OCSD) were studied in order to identify key technical issues, and a general procedure to convert wet scrubbers to biotrickling filters was developed. Subsequently, five full-scale wet scrubbers treating odorous air from different locations at two different OCSD facilities were converted, and H_2S removal performance was studied. This paper focuses on the technical aspects of scrubber conversion. Other recent papers have focused on the performance of the converted scrubbers (Gabriel and Deshusses 2003a) and detailed analysis of the behavior of converted scrubbers under selected conditions and process biology (Gabriel and Deshusses 2003b).

Material and Methods

Pilot-Scale Biotrickling Filter

A schematic of the laboratory pilot biotrickling filter is shown in Fig. 1. The trickling filter consisted of a 3 m high, 0.38 m inside diameter (i.d.) Schedule 40 polyvinyl chloride (PVC) pipe with a packed bed height of 1.72 m (bed volume of 0.197 m^3). The reactor bottom served a reservoir for the liquid (0.31 m in height), which was recycled over the top of the bed using a 0.4 kW centrifugal pump (Grainger, Riverside, Calif.). A portion of the liquid pumped was directly returned to the bottom of the biotrickling filter to ensure mixing of the liquid. The usual trickling flow-rate was 0.91 $m^3\,h^{-1}$, which corresponds to a linear velocity of 7.99 $m\,h^{-1}$. Countercurrent operation was selected to match conditions of usual chemical scrubbers. Airflow rates were varied from 40 to 680 $m^3\,h^{-1}$, which corresponds to empty bed retention times ranging from 0.5 to 9 s. The reactor included an air plenum of 0.47 m below the bed, where the air was fed, and another air plenum of 0.51 m above the bed. The reactor was equipped with a water knockout drum consisting of a 210 L polyethylene drum. The reactor temperature was maintained between 18 and 24°C. 4 L of primary and secondary sludge from OCSD were used as a microorganism seed prior to the experiments.

The packings used in the laboratory study included 75 mm diameter TriPack (Jaeger Products Inc. Houston, Tex) and random dump cubes (40 mm) of an open-pore polyurethane foam (M +W Zander, Germany). TriPack is a widely used packing for chemical scrubbers at OCSD with a large void volume but a low surface area (120 $m^2\,m^{-3}$) for biofilm attachment. A larger area is desired since mass transfer limitation has often been reported for H_2S treatment in biotrickling filters (Lobo et al. 1999). The open-pore polyurethane foam used had been previously successfully used as packing support in other biotrickling filter applications (Loy et al. 1997). It is relatively stiff, making it reasonably resistant to compaction under the conditions encountered in the scrubber. According to the foam supplier (Zander, Germany), the packing material (40 mm cubes) is made of open-pore polyurethane foam with 10–15 pores per linear inch, and has a specific surface area of 600 $m^2\,m^{-3}$, a density of 35 $kg\,m^{-3}$, and a porosity of 0.97. Foam packing is resistant to temperatures between −40 and 100°C.

Synthetic H_2S contaminated air was produced by dripping a solution of Na_2S (technical grade, Gallade Chemicals, Calif.; concentration of 10–50 $g\,L^{-1}$ as required) into an acidic solution of HCl (2M, technical grade) and sweeping the resulting H_2S gas with the main air stream. A concentrated mineral salt solution (composition in de-ionized water: 2 $g\,L^{-1}$ K_2HPO_4; 1 $g\,L^{-1}$ KH_2PO_4; 0.75 $g\,L^{-1}$ NH_4Cl; 0.5 $g\,L^{-1}$ $MgSO_4$; 0.018 $g\,L^{-1}$ $CaCl_2$; and 1 $mL\,L^{-1}$ trace element solution) was fed continuously to the biotrickling filter by a peristaltic pump at an average flow rate of 13.9 $mL\,h^{-1}$. De-ionized water was added continuously at a rate of 10–100 $mL\,min^{-1}$ to dilute the salts and compensate for the evaporation occurring in the reactor. A Masterflex peristaltic pump and an overflow ensured purging the excess recycle liquid. A stand-alone pH controller (Cole Parmer)

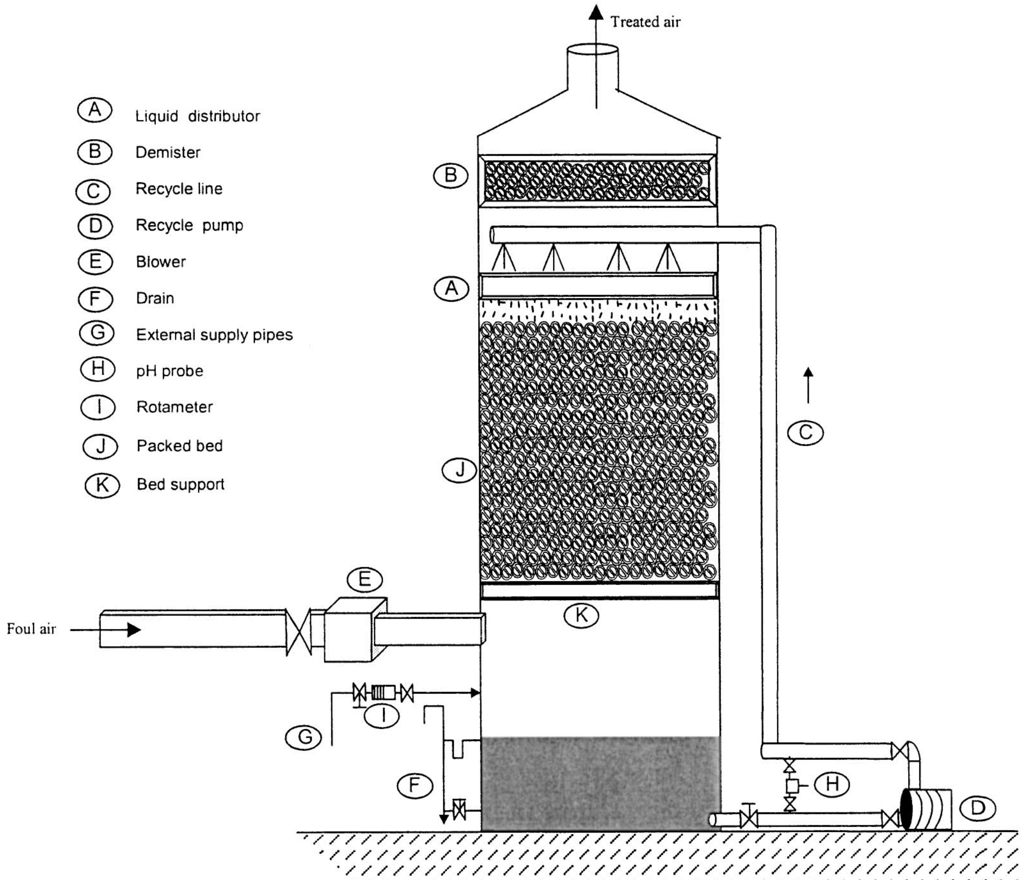

Fig. 2. Schematic of typical Orange County Sanitation District scrubber (monitoring and control systems not shown)

was installed to regulate addition of a concentrated solution of NaOH directly into the bottom of the reactor. The pH was usually maintained between a value of 2 and 3.

H_2S was measured using a Jerome 631X series meter (Arizona Instruments, Tempe, Ariz.); inlet air flow was measured using an anemometer (Fisher Scientific, Pittsburgh, Pa.); pressure drop across the bed was measured using a U tube manometer filled with water; liquid recycle rate was measured with a rotameter installed in-line (Dwyer, Michigan City, Ind.); and the pH of the recycle liquid was measured off-line using an Accumet pH meter (Fisher Scientific, Pittsburgh).

Orange County Sanitation District Scrubber Characteristics

Orange County Sanitation District manages two wastewater treatment facilities (Plants 1 and 2) that treat a total average daily flow of 910,000 m^3. The District has implemented many measures to reduce odors, and the plants now have extensive odor control facilities. A total of 34 packed tower chemical scrubbers are used for treatment of odor emissions from both facilities. Orange County Sanitation District wet scrubbers use sodium hydroxide and hydrogen peroxide or sodium hypochlorite. Ferric chloride is also added to the trunklines to lower H_2S emissions. Odor control costs are \$3.5 million/year.

Most of the OCSD scrubbers are of similar design, differing mainly in the foul air composition and the chemical feeds. A schematic of a characteristic design is depicted in Fig. 2, and dimensions are provided in Table 1. All chemical scrubbers at OCSD are made of fiberglass reinforced plastic (FRP) shells, with a foul air fan to blow the gases upward through the scrubber by forced draft. Fans are typically fixed speed or two-speed floor-mounted FRP centrifugal blowers. The scrubber towers contain a multi beam type packing support, a packed bed contact section, a liquid distribution system and a demisting section (usually made of packing of smaller nominal size). All scrubbers have two recirculation pumps, one in operation and one in standby, a U type overflow pipe, a liquid reservoir at the bottom with a plenum for air inlet, makeup, water and chemical reagents feed points. All scrubbers are connected to a supply of plant water, which is used in the case of the converted scrubbers to both control pH and as nutrient supply to the process culture. (Converted scrubbers do not need any caustic/oxidant chemical feed.)

Chemical scrubbers at OCSD are highly instrumented. At the time of the study, scrubbers No. 10, Q, and I had on-line H_2S meters (Vapex Sentinel System, Vapex Inc., Ocoee, Fla.) with independent sensors connected for air inlets and outlets that displayed H_2S inlet and outlet concentrations every 4 s and stored the average of 12 min segments. The units were regularly calibrated by the manufacturer, and calibrations were checked against H_2S determinations made using a Jerome 631X series meter (Arizona Instruments, Tempe, Ariz.). Also, each scrubber had an in-line pH sensor connected to the supervisory control and data acquisition (SCADA) system of OSCD used for continuous monitoring. Before conversion, the pH reading served to control caustic addition, however this was later deactivated, as pH control was achieved by supplying only plant water to the biotrickling

Table 1. Summary of Design Parameters for Chemical Scrubbers Converted at Orange County Sanitation District

Parameter	Scrubber 10	Scrubber I	Scrubber Q	Scrubber G	Scrubber J
Reactor location	Plant 1	Plant 2	Plant 2	Plant 2	Plant 2
Scrubber type	Pretreatment	Pretreatment	End-of-pipe	End-of-pipe	End-of-pipe
Air source	Influent sewer trunkline	Influent sewer trunkline	Primary treatment	DAFT off-gases[a]	Dewatering off-gases
Packed height (m)	3.9	3.3	3.3	3.1	4.9
Diameter (m)	2	2	3.3	2	3.3
Bed volume (m^2)	12	10	27.7	15	41.6
Liquid distributor	Parting box and weir troughs	Parting box and weir troughs	Nozzles	Nozzles	Parting box and weir troughs
Fan low/high speed (kW)	30[b]	30[b]	33[b]	30[b]	28[b]
Recirculation pump (kW)	5.6	2.2	11	15	7.5
Liquid recycle (m^3/h)	136	79	136	168	150
Air flow low/high (m^3/h)	17,000[b]	17,000[b]	40,800/68,000	47,000[b]	39,000[b]
EBRT high/low (s)[c]	2.03[b]	2[b]	1.96/1.18	0.93[b]	3.07[b]
Average inlet H_2S (ppm_v)[d]	20	40–100	10	0–10[e]	0–2[e]

[a]Dissolved air flotation thickeners.

[b]High flow not available, single speed blower.

[c]Empty bed retention time=bed volume/air flow.

[d]Estimated from on-line data and information collected during site visits prior to actual conversion to biotrickling filter.

[e]Nuisance is mostly organic odors, not H_2S.

filter. The scrubbers also include a water-filled U-tube manometer to measure the pressure drop across the bed, on-line rotameters for measuring water makeup supply, low liquid level alarms, and a low pressure switch for recycle pump shutdown.

Results and Discussion

Before converting any chemical scrubber at OCSD, a pilot-scale biotrickling filter was used to determine the expected H_2S removal performance and the suitability of both the existing packing (TriPack) used at OCSD and a specialized biotrickling filtration packing for biotrickling filtration purposes. An additional objective was to define which changes would be required to convert any scrubber. This research identified several key issues and a conversion procedure was elaborated before the first full-scale scrubber was converted.

Testing of Packing Materials in Laboratory Pilot-Scale Biotrickling Filter

The pilot-scale biotrickling filter was initially packed with the TriPack packing, and started at a linear gas velocity of 1.8–2 m s^{-1}, i.e., close to the average value to be used if converting an OCSD scrubber to a biotrickling filter. By selecting an equal air velocity rather than an equal bed residence time, similar mass transfer characteristics existed in the pilot-scale reactor and the OCSD full-scale chemical scrubber. This was important because gas film mass transfer could be rate limiting (Lobo et al. 1999). Prediction of the performance of actual scrubbers (2–3.3 m bed height) would require a stagewise combination of pilot experiments (1.7 m bed height).

Removal of H_2S with the TriPack as support was poor over the entire test phase of 41 days, and little removal of H_2S was likely for the conditions expected at OCSD (Table 2). Observed elimination capacities ranged from 2 to 4 g H_2S m^{-3} h^{-1}, well below usual values reported in the literature, e.g., H_2S elimination capacities typically range from 15 to 30 g m^{-3} h^{-1} (Smet et al. 1998; Chung et al. 2000; Koe and Yang 2000; Wu et al. 2001; Cox and Deshusses 2002), though most studies use much higher H_2S concentrations and longer gas contact times. Some improvement was obtained by decreasing the liquid trickling rate (Table 2), indicating some liquid mass transfer limitations existed using TriPack.

Although not thoroughly investigated, the low specific surface area of the TriPack packing was suspected to be a major contributing factor for poor reactor performance. After dismantling the biotrickling filter at the end of the experiment, inspection revealed

Table 2. Typical Performance (Average of At Least Five Determinations) of Pilot-Scale Biotrickling Filter Packed with Tripack Or Polyurethane Foam Packing

Packing material	Liquid recycle flow rate (L min^{-1})	Gas velocity (m s^{-1})	Empty bed retention time (s)	H_2S inlet (ppm_v)	H_2S outlet (ppm_v)	Removal efficiency (%)	Elimination capacity (g H_2S m^{-3} h^{-1})
Tripack	11	0.75	2.3	5.78	4.80	17	2.1
Tripack	0[a]	0.76	2.3	6.01	4.22	30	3.9
Polyurethane foam	15	0.84	2.02	13.7	0.81	94	31
Polyurethane foam	15	0.72	2.35	64.0	45.2	29	38.8
Polyurethane foam	15	1.50	1.15	15.3	5.28	65	42.9
Polyurethane foam	0[a]	1.50	1.15	15.2	5.05	67	43.4

[a]Transient conditions maintained for less than 4 h.

Table 3. Summary of General Technical Questions Used to Evaluate Feasibility of Converting Wet Scrubbers and Specific Answers for Orange County Sanitation District (OCSD) Scrubbers

Question	Specific answer for most OCSD scrubbers
Will odor/H_2S treatment in the converted scrubber meet treatment objectives?	H_2S/odor removal will require case-by-case evaluation
Is the existing packing material suitable for biotrickling filtration of targeted compounds?	Jaeger Tripack packing needs to be replaced by a new packing
Is the support for the packing strong enough to handle the additional weight of the packing and biomass?	Probably yes. However, the maximum weight allowable by the supports was not always available. For safety, an additional support may be installed, especially for large/old scrubbers
Is the demister resistant to low pH and resistant to clogging by biomass?	Demisters in all scrubbers are resistant to low pH. But clogging of the demisters need to be checked during operation as a biotrickling filter
Is the existing blower suitable? (biotrickling filter operation will result in an increase in pressure drop)	Yes. Pressure loss in the pilot-scale reactor packed with foam was less than 3 cm of water column per m of packed bed at an air velocity of 2 $m\,s^{-1}$. Accounting for higher velocities and packing compaction will be necessary
Is the liquid distribution system suitable to operate at 10 times lower flow rates?	Scrubbers fitted with nozzles need replacement of the nozzles. Scrubbers with weir troughs need no modification but testing for adequate liquid distribution is warranted
Is the scrubber layout (proximity, general air stream configuration) suitable for conversion?	Case to case analysis is needed. Answer will depend on whether air duct modification is required
Is secondary effluent/reclaimed water available at a reasonable distance from the scrubbers?	Secondary effluent is already plumbed into existing scrubbers
Can the controls be modified to accommodate for biotrickling filter operation?	In most cases, yes, but requires further case-by-case detailed evaluation and recalibration of some probes

that the actual amount of biomass attached at the surface of the TriPack was very low. It was estimated that less than about 30% of the packing was covered with biofilm. The actual biomass density was not determined. Based on these observations, it was concluded that the TriPack was not suitable for a high performance biotrickling filter for the removal of H_2S. Packings for biotrickling filtration of H_2S probably require a larger surface area for high biomass attachment and rapid mass transfer.

The scrubber was then repacked with the open-pore polyurethane foam packing. With this packing, 82% H_2S removal was measured 3 days after startup, and in less than 5 days, a quasi-steady state and nearly complete removal of H_2S was achieved. Under the same experimental conditions, Table 2 shows that the performance with the polyurethane foam packing was much better than with the TriPack. Although Table 2 does not show the full spectrum of H_2S concentrations that can be successfully treated to less than 1 ppm_v (the discharge limit for OCSD), results clearly show that the open-pore polyurethane foam achieved a high removal efficiency and elimination capacity, suggesting that the foam is a suitable packing for the full-scale biotrickling filters.

The polyurethane foam packing was tested for possible liquid film mass transfer limitations. Its performance remained the same after the liquid recycling was stopped (Table 2), a slight surprise in light of the improvement observed after stopping the recycle liquid in the TriPack biotrickling filter. Since no performance increase was observed with the polyurethane foam, it was concluded that liquid film mass transfer of H_2S was not limiting.

Technical Feasibility of Converting Full-Scale Chemical Scrubbers to Biotrickling Filters

The feasibility of retrofitting any existing chemical scrubber depends on technical and economical viability. However, a minimum and critical requirement is that the shell, the packing support and most of the wetted parts need to be reused. The shell must be strong enough to support the weight of the packing and of the biomass and, in case of H_2S degrading biotrickling filters, all wetted parts must be resistant to acidic conditions (pH 1–2). Those conditions are often satisfied since typical chemical scrubber construction materials are plastic resins (PVC, PP, and FRP) or less frequently metal alloys (stainless steel or Hastelloy). The main parts of all OCSD chemical scrubbers had adequate shell strength and chemical resistance. The shells and packing supports are made of Hetron 922 FRP and pipes are made of CPVC Schedule 80. Both provide strong corrosion resistance to acids and bases, while FRP provides a tensile strength of 150 MPa at 65°C.

Other technical issues were identified at this stage. Table 3 shows key technical questions posed to evaluate chemical scrubber construction and biotrickling filter requirements, and the an-

Table 4. Generic Ten-Step Procedure for Conversion of Wet Chemical Scrubbers and Application to Trunkline Scrubber No. 10 at Orange County Sanitation District (OCSD)

Step	Action	Application to OCSD scrubber No. 10
1	Removal of unnecessary parts	Replacement of the 5.6 kW liquid recycle pump. Backup pump was kept in place.
2	Removal of old packing	Certified outside contractor was used due to confined entry space classification of the scrubber.
3	Packing support reinforcement	Strengthening of the bed support plate with a 0.15 m diameter Schedule 80 CPVC pipe as a reinforcement pillar under the lower packing chamber grating.
4	Modification of the liquid distribution system	Not necessary (distribution via weir trough).
5	Modification of the mist eliminator	Not necessary, mist eliminator is adequate.
6	Liquid recycle pump replacement	Re-piping with 30 mm diameter CPVC Schedule 80 of a section of the recycle line to fit a 0.4 kW pump and an on-line rotameter.
7	Modification of the inlet/outlet air ducts	Not necessary, no air flow/path change.
8	Installation of secondary effluent supply	Not necessary, already installed.
9	Installation of the new packing	Dumping new packing material in the scrubber through the upper manhole.
10	Modification of the controls to accommodate biotrickling filter operation	Low pH alarm was disconnected. Liquid feed supply rate was modified.

swers for the OCSD scrubbers. Several questions required a case-by-case analysis. Often a general cost–benefit analysis of the conversion will be required as well.

The technical issues listed in Table 3 should be considered as a starting point for the evaluation of the conversion of chemical scrubbers to biotrickling filters at other POTWs. Generally a case-by-case analysis will be necessary due to differences in scrubber construction and operation. Extensive modifications to the liquid distribution system or mist eliminator may influence the economical viability of the conversion. It is particularly critical to provide a uniform water distribution, taking into account that biotrickling filters require much smaller flow rates than chemical scrubbers.

General Procedure to Convert Full-Scale Chemical Scrubbers and Case Study at Orange County Sanitation District

After analyzing the different types of wet scrubbers at OCSD and taking into account all key factors required for conversion of chemical scrubbers to biotrickling filters, a general conversion procedure was established. This procedure takes into account that in most cases the packing should be replaced with one that can support effective biotrickling filtration. The procedure consists of ten steps that are followed for each scrubber, independently if they are end-of-pipe scrubbers or scrubbers that possess a post-treatment (Table 4). The physical implementation of the procedure for the first scrubber converted at OCSD (scrubber No. 10) is shown as an example.

There were essentially two types of applications for biotrickling filtration at OCSD. The first was conversion of scrubbers that had a post-treatment so that biotrickling filtration would serve as pre-treatment for chemical scrubbing. The second was the conversion of end-of-pipe scrubbers where usually low concentrations were treated down to regulatory requirements. The former case usually involved concentrations of H_2S from 10 to 150 ppm_v, while the latter was in the 3–15 ppm_v H_2S range or for the treatment of organic odors.

Scrubber No. 10 (see Table 1) was selected after a review of all scrubbers at OCSD because the conversion was thought to be economically viable and the exhaust had further downstream treatment by other scrubbers at the headworks complex. Thus, none of the air treated in the converted scrubber would be released directly to the atmosphere. In addition, scrubber No. 10 was not used on a continuous basis, but was only turned on during peak H_2S emissions.

The conversion required some preparatory work to isolate the scrubber prior to conversion. This was performed by locking and tagging valves and lines that would not be used. In addition, for the first conversion, an acid wash was used prior to any other task to remove the scale that had built up on the packing and in the pipes. According to the general procedure for acid washing scrubbers at OCSD, the scrubber was flushed with diluted hydrochloric acid for 12 h. The acid wash step was not included in subsequent conversions. The scrubbers were only rinsed with water to flush the caustic solution out the system and the scrubber shell was pressure washed as needed.

The conversion of scrubber No. 10 was performed following the ten-step procedure, however, it should be stressed that the first conversion was experimental and therefore the fewest changes were made in order to allow for returning to chemical scrubber operation if biotrickling filtration was discontinued at the end of the project. Thus, most of the unnecessary parts, e.g., pipes, scrubber backup recycle pump, and pumps for chemicals feeding, were kept in place. Some plumbing work was necessary because of the large differences in the diameter of the ports between the old and the new pumps. The packing support was reinforced, but for subsequent conversions, strengthening of the bed support was not deemed necessary and this step was omitted. A complication for the conversion came from the confined entry space [Occupational Safety and Health Administration (OSHA) regulation No. 1910.46.] designation of the scrubbers. Thus, removal of the old packing was performed by an outside and OSHA-certified contractor.

The subsequent implementation of the ten-step procedure on four other OCSD scrubbers had some minor particularities that

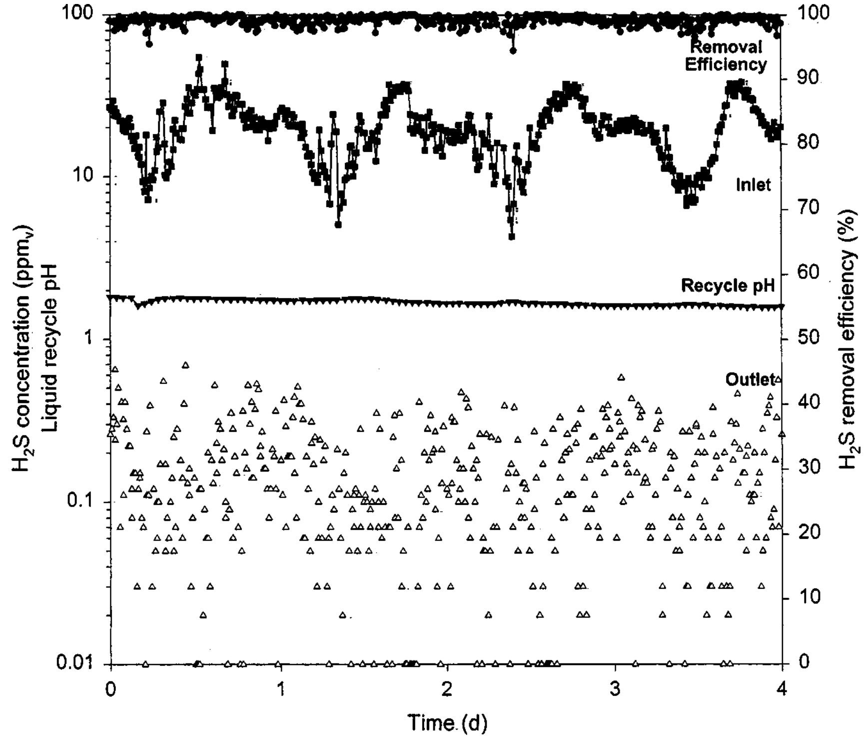

Fig. 3. H_2S removal in biotrickling filter No. 10 at gas contact times of 1.8–2.2 s; performance shown is representative of long-term operation; and nondetected H_2S is shown as 0.01 ppmv

were considered and solved case-by-case. As an example: on scrubber No. I, both liquid recycle pumps were changed to provide for a backup because of the importance of that scrubber to control odor emissions at that facility. Overall, the ten-step procedure proved adequate for the five OCSD scrubbers that were converted. A reasonably short period was required for each conversion, therefore limiting downtime. Obviously, downtime depends on the complexity of the changes that need to be performed, but in general terms, assuming that all required materials were in place, an average of 4 days was required per scrubber.

Economical Evaluation of Conversion of Chemical Scrubbers

Exact conversion costs are difficult to evaluate due to the experimental nature of these first conversions. The cost of the packing ($500–1000/m^3) is a major part of the total expense. The commercial cost of converting a chemical scrubber may be between $40,000 and 80,000, depending on the size of the scrubber. This should be compared to the resulting cost savings in terms of chemicals, electricity, operation, and maintenance, etc., which vary greatly with each application. Savings are in the range of $10,000–50,000 worth of chemicals and electricity per scrubber per year, depending on the size of the scrubber and the H_2S loading. Additional savings include lower liability insurance, and worker health and safety benefits since biotrickling filters do not require caustic for pH control or any chemicals for operation. A preliminary estimate, assuming a yearly probability of a fatal accident of 0.002–0.005 and a cost of life of $5 million (a figure often used by insurance companies), suggests that the liability benefit may be as high as $10,000–25,000/year. This is of the same order of magnitude as the direct savings.

H_2S Treatment Performance

Typical H_2S removal in scrubber No. 10 is shown in Fig. 3 where time 0 h corresponds to 12:00 AM on September 5, 2001. Inlet concentrations fluctuated daily between 5 and 40 ppm$_v$, while outlet concentrations were always well below the 24 h averaged discharge limit of 1 ppm$_v$. Such performance is representative of long term operation. Evaluation of 1 year of operation of biotrickling filter No. 10 reveals that the biotrickling filter successfully treated H_2S at rates comparable to those of chemical scrubbers (Gabriel and Deshusses 2003a). On average, 97.5% H_2S removal was achieved for H_2S inlet concentrations of up to 25 ppm ($N = 15{,}000$ data points). For many of the 12 min average samples, H_2S removal exceeded 98% for inlet H_2S concentrations as high as 30–50 ppm$_v$, corresponding to elimination rates of 95–105 g H_2S m^{-3} h^{-1}, which is exceptionally high compared with other biofilters or biotrickling filters removing low H_2S concentrations, even at higher gas contact times (Smet et al. 1998; Koe and Yang 2000; and Cox and Deshusses 2002). Significant removal of reduced sulfur compounds (35–70% removal of carbonyl sulfide, methyl mercaptans, and carbon disulfide), ammonia ($>99\%$), and volatile organic compounds (e.g., toluene removal of 29%, 45% of xylenes, 30% of chloroform) present in traces in the air was also observed. Detailed performance of the converted scrubbers is discussed elsewhere (Gabriel et al. 2002; and Gabriel and Deshusses 2003a, b).

The biotrickling filters were found to be very stable, providing sustained H_2S treatment over time. Restarting the biotrickling filters after an occasional shut down of the blower for maintenance revealed that treatment resumed immediately, with optimum performance reached about 4 h after restarting normal operation.

Conclusions

Converting chemical scrubbers to biotrickling filters is feasible and relatively simple. In operation, biotrickling filters provided and sustained effective H_2S removal, even at gas contact times as low as 1.6–3.1 s. Overall, the study shows great promise for converting existing chemical scrubbers treating H_2S at POTWs to biotrickling filters.

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