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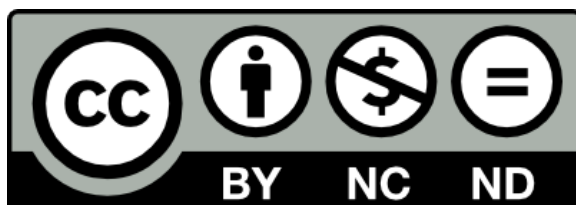
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# **Pilot-Scale biofilter for the simultaneous removal of hydrogen sulphide and ammonia at a wastewater treatment plant**

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**Highlights:**

- A pilot scale biofilter removed H<sub>2</sub>S and NH<sub>3</sub> in a wastewater treatment plant.
- The biofilter produced small volume of leachate which contains ammonium sulphate.
- The ammonium sulphate produced can be harvested for further use.

**Abstract**

Biofilters are popular for the removal of odours from gaseous emissions in wastewater treatment plants because of their low capital costs and low energy requirements. In an aerobic environment, the microbes in biofilter oxidize odorous gases like hydrogen sulphide (H<sub>2</sub>S) and ammonia (NH<sub>3</sub>) to non-odorous sulphate and nitrate. This paper describes a pilot plant biofilter setup at a local waste water treatment plant (WWTP) which has been in continuous operation for more than 150 days, removes both H<sub>2</sub>S and NH<sub>3</sub> at an average removal efficiency of 91.96% and 100% respectively. Unlike a conventional biofilter, the pH of this biofilter was not adjusted by addition of chemicals or buffers and the H<sub>2</sub>SO<sub>4</sub> produced from the biological conversion of H<sub>2</sub>S is periodically washed down and allowed to accumulate in a concentrated form at the base of the biofilter. NH<sub>3</sub> entering at the base is removed, not by biological oxidation, but by the chemical reaction of ammonium with sulphate to form ammonium sulphate. The ammonium sulphate produced in biofilter is washed down and the volume of leachate produced is less than 0.2mL of leachate/L of reactor/day. Estimated cost savings of converting the current chemical scrubber used at the WWTP to a similar biofilter described in this study is included with this paper.

Keywords: biofilter, chemical NH<sub>3</sub> removal, biological H<sub>2</sub>S removal, wastewater treatment plant, odour removal,

## Introduction

Air pollutants emanating from wastewater treatment plants (WWTP) are composed of a mixture of hundreds of chemical compounds including ammonia ( $\text{NH}_3$ ), hydrogen sulphide ( $\text{H}_2\text{S}$ ), limonene, butanone and other organic compounds [1-6]. Air pollution complaints from WWTP have been limited to unpleasant odours which are seen as a nuisance for residential areas around the plants [7-9]. Of all the odours originating from wastewater treatment plants, the rotten egg smell of  $\text{H}_2\text{S}$  and the pungent smell of  $\text{NH}_3$  is the most distinctive [10-12]. Toxic exposure to hazardous chemicals in the air is described by TLV–STEL (threshold limit values at short term exposure limit) which is the maximum concentration that workers can be exposed to continuously to a gas, for a short period of time (usually 15 or 10 min), without adverse health effects [13]. TLV–STEL for  $\text{H}_2\text{S}$  and  $\text{NH}_3$  in the air is  $69 \text{ mg/m}^3$  (50 ppm) and  $24 \text{ mg/m}^3$  (35 ppm) respectively and the concentrations of  $\text{H}_2\text{S}$  emanating from WWTPS without air pollution control systems typically exceeds the acceptable health limit [9, 14-21].

Biofilters are becoming more popular as a treatment for gases like  $\text{H}_2\text{S}$  and  $\text{NH}_3$  emanating from wastewater treatment plants because they work at ambient temperatures and pressure, have low capital costs and have better environmental performance than chemical methods [22-27]. Studies done on removal of  $\text{H}_2\text{S}$  and  $\text{NH}_3$  using biofilters show efficiencies greater than 90% for both the gases [16, 19, 20, 28-31]. In aerobic conditions, sulphur oxidizing bacteria (SOB) in biofilters convert  $\text{H}_2\text{S}$  in contaminated air to sulphate ( $\text{SO}_4^{2-}$ ). Examples of SOB include *Thiobacillus denitrificans*, *Thiobacillus thioeparus* and *Acidithiobacillus thiooxidans*. The pH range for optimal growth of *T. denitrificans* is 6.8 to 7.4, *T. thioeparus* is 5.5 - 7.0 and *A. thiooxidans* is 1.8 - 2.5 [32-34]. However, studies have shown that the production of sulphuric acid by these microorganisms can drop the pH in the biofilter to below 1 and *A. thiooxidans* has been shown to operate even at a pH of 0.2 [33, 34]. In an aerobic environment,  $\text{NH}_3$  is oxidized to nitrite ( $\text{NO}_2^-$ ) by ammonia oxidizing bacteria (AOB) like those of the genera *Nitrosomonas* and the conversion of nitrite ( $\text{NO}_2^-$ ) to nitrate ( $\text{NO}_3^-$ ) is achieved by nitrite oxidizing bacteria (NOB) like those of the genus *Nitrobacter* [35]. For optimal operation, *Nitrosomonas* prefer a pH of 6.0 – 9.0 and *Nitrobacter* prefer pH between 7.3 and 7.5.

For the microorganisms to operate at optimal performance, the pH of the biofilter in WWTP is typically maintained by washing the biofilter with chemicals or a buffered solution [19, 23, 36]. In an industrial scale biofilter, this leads to production of large volumes of leachate which contains ions like  $\text{SO}_4^{2-}$ ,  $\text{NO}_2^-$  and  $\text{NO}_3^-$  which needs to be measured and the leachate requires

proper disposal [18, 19, 37]. Simultaneous biological removal of  $\text{H}_2\text{S}$  and  $\text{NH}_3$  from air by biofiltration have also shown that oxidation of high concentrations of  $\text{H}_2\text{S}$  ( $140 \text{ mg/m}^3$ ) affects the growth and activity of the nitrifying bacteria leading to reduction in the  $\text{NH}_3$  removal efficiency [12, 38, 39]. This is because the oxidation of  $\text{H}_2\text{S}$  produces an acidic environment in the biofilter which does not promote the growth of AOB or NOB and thus hampers the removal of  $\text{NH}_3$  [12, 38-40].

Subiaco Wastewater Treatment Plant (WWTP) in Western Australia treats domestic wastewater collected from the Perth central metropolitan area and is designed to treat up to 61.4 million L/day and produces  $65,000 \text{ m}^3$  of contaminated gas per hour with maximum concentrations of  $\text{H}_2\text{S}$  and  $\text{NH}_3$  at 75ppm and 5 ppm respectively [41]. The Subiaco WWTP currently uses a series of chemical scrubbers to remove the  $\text{H}_2\text{S}$  and  $\text{NH}_3$  produced at the plant producing almost 300L of leachate per day [41]. The leachate, which contains low concentrations of ions like sulphate ( $< 0.02\text{M}$ ) and nitrate ( $< 0.01\text{M}$ ), is further diluted with the final treated wastewater from the WWTP and discharged into the ocean [41]. A biofilter can be setup at this plant where the  $\text{H}_2\text{SO}_4$  produced by the biofilter is accumulated at the base of biofilter, rather than washed away, and the  $\text{NH}_3$  can be removed through acid stripping and formation of ammonium sulphate. This will also avoid the problems associated with the AOB or NOB growing in an acidic environment since the removal of  $\text{NH}_3$  will be achieved by the chemical reaction with sulphate to produce ammonium sulphate. No nitrate or nitrite will be formed in this process and the ammonium sulphate formed can be washed down the biofilter and collected as a product to be recovered from the process. The formation of low concentration of ammonium sulphate has been observed before in biofilters, but they are usually considered a nuisance, specially when wood chips or compost were used as filter media [37, 38, 42]. High concentration of ammonium sulphate is useful as a fertilizer that provides sulphur and nitrogen to plants as nutrients and has been shown to be better than ammonium nitrate [43, 44]. Industrial processes for the production of ammonium sulphate from flue-gas desulfurization has been studied but they involve high temperatures and long residence times [45]. There is potential for an inexpensive process that produces ammonium sulphate at ambient conditions.

This study investigates a small scale pilot plant which was set up at the Subiaco WWTP for the simultaneous removal of  $\text{H}_2\text{S}$  and  $\text{NH}_3$  from the existing waste air stream with the production of a minimal volume of leachate. The scale of the pilot plant was setup so that potential problems can be identified and solved before the full-scale plant is built.

## Materials and Methods

### 2.1 Biofilter Construction

A biofilter was set up at the Subiaco WWTP and a schematic diagram of the biofilter is given in Figure 1.

The biofilter was constructed from acid-proof PVC piping (Holman Industries) with an internal diameter of 15 cm. The biofilter had three detachable sections (the top, middle and bottom sections) with dimension as shown in Figure 1 and a 5L Schott glass bottle at the bottom for the collection of solution. Each section was filled with equal amounts of acid resistant polyethylene packing material (AMB Biomedica Bioballs (ABB media)) with dimensions of 11mm x 7mm and a total surface area of 834 m<sup>2</sup>/m<sup>3</sup>. Each section was filled with packing material to a height of 47cm giving a total working volume of 24.93 L. The number of packing material per L of reactor was 1,157 ABB media/L of reactor with a free space of 77% inside the biofilter. The packing material in each section was supported by sieve plates made of Plexiglas. The three sections and the bottom glass bottle could be detached for sample collection. Flow of air into the biofilter was controlled using a flow control valve attached to a flow meter (Cole Palmer Instrument Company) and a peristaltic pump (Masterflex C/L Dual-Channel Variable-Speed Tubing Pump, Cole Palmer Instrument Company) was used for intermittent supply of deionized water to the biofilter.

### 2.2 Biofilter setup at the Subiaco WWTP

The Subiaco WWTP currently uses a series of chemical scrubbers to remove H<sub>2</sub>S and NH<sub>3</sub> (Figure 2) [41]. The first scrubber uses 34% sulphuric acid as the scrubbing solution and the second scrubber uses 50% sodium hydroxide as the scrubbing solution. The outlet from the second scrubber is fed, together with the gaseous emissions from the secondary treatment area, to the last two scrubbers which are washed with a mixture of 12.5% sodium hypochlorite and 50% sodium hydroxide to remove trace amounts of any other odorous gases before discharging the uncontaminated air into the atmosphere.

The experiment at the Subiaco WWTP was conducted in two stages. In stage I of the experiment, the biofilter was placed after the first acid scrubber (Stage I in Figure 2) where  $\text{NH}_3$  in the gaseous emissions had been removed by the acid scrubber. The inlet to the biofilter at stage I contained  $\text{H}_2\text{S}$  and the biological oxidation of  $\text{H}_2\text{S}$  forms  $\text{H}_2\text{SO}_4$  at the bottom of the biofilter. The aim of this stage was to develop a biofilm for the removal of  $\text{H}_2\text{S}$  and to generate sufficient  $\text{H}_2\text{SO}_4$  at the base of the biofilter to remove incoming  $\text{NH}_3$  in stage II.

In stage II of the experiment, the same biofilter was moved and placed in the main inlet of the chemical scrubber where the gaseous emissions contained a mixture of  $\text{H}_2\text{S}$  and  $\text{NH}_3$  (Stage II in Figure 2).

### **2.3 Seeding method and moisture control**

At the start of the study period, the biofilter was seeded with an inoculum from an existing lab scale aerobic biofilter which removed  $\text{H}_2\text{S}$ . In order to maintain suitable media moisture levels for bacterial growth and to wash the ions down the biofilter, 250 mL of deionised water was trickled from the top of the biofilter once every week. Before seeding the biofilter with inoculum, the volume of water required to wash the biofilter was determined by trial and error and 250 ml of water was determined to be the minimum amount sufficient to wash contaminants from top to the base of this particular biofilter. Other than water, no additional nutrients, chemicals, or inoculums were added to the biofilter during the course of the study.

### **2.4 Sampling and chemical analysis**

The  $\text{H}_2\text{S}$  concentration in the inlet and outlet of the biofilter was measured in real time by means of an inline sensor (GD 2529  $\text{H}_2\text{S}$  Sensor, GasTech). The  $\text{NH}_3$  concentration in the inlet and outlet of the biofilter was measured twice a week using Dräger Tubes (Ammonia 2/a) with Accuropump (Dräger Safety, Inc.). Humidity and temperature of the gas mixture in the inlet and outlet of the biofilter were measured in real time using the HOBO Pro v2 external temp/RH probe and data logger (Onsetcomp). The operation of sensors and water pump were controlled by a connected computer using a Labjack USB interface and National Instruments



LabView 7.1 control software. Ten pieces of randomly chosen ABB media was taken and their weights recorded and compared to the weight of dried ABB media. The moisture content in the different sections of the biofilter and was expressed as the gravimetric water content [46]:

$$M_n = M_w / M_o$$

where,  $M_n$  is the moisture content,

$M_w$  is the mass of medium with water

$M_o$  is the mass of the medium without water

The concentration of soluble ions in the biofilter was determined by collecting samples from different sections of the biofilter once a week. At each sampling event, 10 pieces of the packing material, sampled from the top, middle and bottom sections of the biofilter was shaken with 10 mL of distilled deionized water for 15 minutes in a glass vial to extract the water soluble ions. This solution and the leachate was analysed once a week for pH, sulphate ( $\text{SO}_4^{2-}$ ), sulphide ( $\text{HS}^-$ ), ammonium ion ( $\text{NH}_4^+$ ), nitrate ( $\text{NO}_3^-$ ) and nitrite ( $\text{NO}_2^-$ ). The pH of the samples solution was determined using an Ecoscan pH meter (Eutech instruments). Sulphate was determined by the standard method based on precipitation as  $\text{BaSO}_4$  followed by photo spectrometric quantitation at 420nm with a HACH DR 2700 Portable Spectrophotometer [35]. Sulphide ( $\text{HS}^-$ ) was determined based on the reaction of copper sulphate ( $\text{CuSO}_4$ ) in an acidic solution producing copper sulphide precipitate which was measured photometrically at 480 nm [47].  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{NO}_2^-$  was determined by the standard photometric analysis as described in the literature [35].

## Results and Discussion

An experiment was set up at Subiaco WWTP to remove  $\text{H}_2\text{S}$  and  $\text{NH}_3$  with high efficiency without the use of high concentrations of sulphuric acid or sodium hydroxide as in a chemical scrubber.

### 3.1 Stage I – Removal of $\text{H}_2\text{S}$ with production of sulphate solution

### 3.1.1 H<sub>2</sub>S removal efficiency

In the first stage of the experiment, the objective was to remove H<sub>2</sub>S from the incoming air and accumulate the H<sub>2</sub>SO<sub>4</sub> produced in the leachate. The biofilter was placed after the acid scrubber in the chemical scrubber system (Figure 2) and operated continuously for 15 weeks. Empty bed residence time (EBRT) is defined as the working volume of the biofilter divided by the air flow rate. The average flow rate through the biofilter was 25 L/min at this stage of the experiment giving an EBRT of 1 minute. The average concentration of H<sub>2</sub>S entering the biofilter over the first 15 weeks was 31.85 ppm (0.04 g/m<sup>3</sup>) and after an initial incubation period of about 4 days, the biofilter removed H<sub>2</sub>S from the inlet air at an average removal efficiency of 94.38% (Figure 3). At this stage of the experiment, the H<sub>2</sub>S was effectively removed from the gaseous emissions from the WWTP by the biofilter and the results show the robustness of the system over a wide range of inlet loads.

Removal Efficiency (RE) is a measure of how effective the biofilter is at removing the pollutant [37]:

$$RE = ((C_{IN} - C_{OUT}) / C_{IN}) \times 100 \quad \text{where, } C_{IN} \text{ is the inlet pollutant concentration,}$$

$C_{OUT}$  is the outlet pollutant concentration.

Elimination capacity (EC) is the mass of pollutant removed by the biofilter ( $C_{IN} - C_{OUT}$ ) and normalized for the flow rate and the volume of the reactor and is defined as [37]: –

$$EC = (F_R \times (C_{IN} - C_{OUT})) / V_R \quad \text{where, } F_R \text{ is the airflow rate,}$$

$V_R$  is the bed volume of the reactor.

$C_{IN}$  is the inlet pollutant concentration,

$C_{OUT}$  is the outlet pollutant concentration.

### 3.1.2 Moisture and pH gradient in biofilter

Conventional biofilters have their pH maintained by adding a buffer solution or chemicals like sodium hydroxide to the biofilter [21, 34, 48]. In this biofilter, deionized water (pH = 7) was

added intermittently to the top of the biofilter which washed the ions down from the biofilm. In order to maintain suitable media moisture levels for bacterial growth and to wash the ions down the biofilter, 250 mL of deionised water was trickled from the top of the biofilter once every week. Note that the concentration of ions like ammonium, nitrite, nitrate and sulphate were monitored throughout the experimental period to determine mass balance of S and N in the biofilter. To ensure that these ions were the result of incoming hydrogen sulphide and ammonia and their microbial conversion products only, deionised water rather than nutrient solution was used. For long term operation, nutrients are required to sustain the microbial function within the biofilter. The moisture content and the pH in the biofilter were monitored over the study period and the average values of these parameters are shown in Table 1. The moisture content in the lowest section of the biofilter was lower than the top and middle sections which is like examples in the literature [25, 42]. The pH of the bottom section was lower than the top and middle sections, but was still in the range for the operation of sulphur oxidizing bacteria (SOB) [32-34]. The low pH in the bottom section favoured the transfer of  $\text{NH}_3$  from gaseous phase to liquid phase and will be used to replace the current acid scrubber used at the WWTP.

### **3.1.2 Volume of leachate produced**

The leachate produced by the biofilter was collected at the bottom in a sealed Schott glass bottle and the cumulative volume collected over time is given in Figure 4. One of the objectives of this biofilter is the production of a minimum amount of leachate without drying out the biofilter and since the amount of leachate produced in the biofilter is dependent on the humidity of the air, both the humidity of the incoming air and the outgoing air from the biofilter was monitored. During stage I, the average humidity of the air entering the biofilter was 98 ( $\pm 4\%$ ) and the average humidity out of the biofilter was 100 ( $\pm 4\%$ ). The high humidity entering the biofilter was expected since the gaseous emissions passes through the acid scrubber (Figure 2) and the contaminated air carries the moisture into the biofilter. The loss in moisture from the biofilter was estimated from the average humidity entering and leaving the biofilter and was calculated to be 134 mL per week. The actual leachate collected in stage I (week 0-15) was 163mL per week, which is reasonable considering the variation in moisture content of air entering and leaving the biofilter and considering the estimation of water loss due to temperature

fluctuations. The amount of leachate produced by this biofilter at this stage was less than 1mL of leachate/L of reactor/day.

During stage II, the volume of water used to wash the biofilter remained at 250 mL but the average humidity of the air entering the biofilter was 64 ( $\pm$  23%) due to placing the biofilter at the entrance to the chemical scrubber system (Figure 2), while the outlet humidity was still at 100 ( $\pm$  4%). The lower humidity entering the biofilter at this stage compared to stage I led to a smaller volume of leachate being produced (Figure 4) and the moisture content of filter media remained unchanged (Table 2). The amount of leachate produced by this biofilter at this stage was less than 0.2 mL of leachate/L of reactor/day. This is significantly less than similar systems which produce leachate in the range of 80 to 714,000 mL of leachate/L of reactor/day [34, 49-51].

### **3.1.3 Concentration of ions in leachate**

The increase in the concentration of the sulphate and hydrogen ion in the leachate over the study period is shown in Figure 5. The sulphate concentration steadily increases during the course of the experiment; the hydrogen ion concentration is roughly double that of the concentration of sulphate in the leachate giving an indication that  $\text{H}_2\text{SO}_4$  is being accumulated in the leachate (Figure 5). The pH of the leachate was just below 1 at the end of this stage, which was important as this would prevent the growth of NOB and AOB when  $\text{NH}_3$  was introduced into the biofilter. Previous examples in the literature for the simultaneous biological removal of  $\text{H}_2\text{S}$  and  $\text{NH}_3$  from air by biofiltration have highlighted the difficulty in trying to establish a suitable environment for AOB or NOB while the oxidation of  $\text{H}_2\text{S}$  produces an acidic environment in the biofilter. [12, 38, 39]. In this case, since the ammonia is being removed by a chemical process, there is no need to maintain conditions for the biological oxidation of  $\text{NH}_3$ .

## **3.2 Stage II – Simultaneous removal of $\text{H}_2\text{S}$ and $\text{NH}_3$**

### 3.2.1 H<sub>2</sub>S and NH<sub>3</sub> removal efficiency

In stage II, the biofilter prepared in stage I was placed at the entrance to the chemical scrubber system (Figure 2). The inlet to the biofilter contained both NH<sub>3</sub> and H<sub>2</sub>S. The aim was to use acid stripping to remove NH<sub>3</sub> in the gaseous while the sulphur oxidizing bacteria (SOB) in the biofilter continued to remove H<sub>2</sub>S from the gaseous emissions. The biofilter was operated continuously for 7 weeks. The airflow rate at this stage was 50 L/min giving an EBRT of 30s. The average concentration of H<sub>2</sub>S and NH<sub>3</sub> entering the biofilter over the 7 weeks was 31.86 ppm (0.04 g/m<sup>3</sup>) and 1.94 ppm (1.35 mg/m<sup>3</sup>) respectively. The biofilter removed H<sub>2</sub>S and NH<sub>3</sub> from the inlet air at an average removal efficiency of 91.96% and 100% (Figure 6, Figure 7). Mass loading rate is defined as the mass of contaminant entering the biofilter per unit volume of filter material per unit time [1]. This biofilter at its current configuration had a mass loading rate of 5.37 g of S/m<sup>3</sup>/hr. and 0.14 mg of N/m<sup>3</sup>/hr.

### 3.2.2 Concentration of ions in leachate

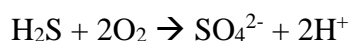
During stage II, the sulphate concentration continued to increase indicating that the biological oxidation of H<sub>2</sub>S is maintained during this stage (Figure 8). No appreciable change in the removal efficiency for H<sub>2</sub>S observed in this stage compared to stage I indicate that the NH<sub>3</sub> in the incoming stream has no effect on the oxidation of H<sub>2</sub>S. This finding is inline with studies in the literature [12, 38-40].

There was no evidence of NO<sub>3</sub><sup>-</sup> and NO<sub>2</sub><sup>-</sup> in the biofilter or leachate indicating that biological oxidation of NH<sub>3</sub>, which was unlikely at this low pH, was not occurring. There was also evidence of some NH<sub>4</sub><sup>+</sup> in the bottom section of the biofilter indicating that the ammonia with the inlet gas was absorbed by the bottom section of the biofilter before it could go to the middle or top sections (Table 2). Periodic washing of the biofilter washed down the ammonium ion to the leachate avoiding the accumulation of ammonium sulphate in the biofilter. The concentration of ammonium ion steadily increased in the leachate (Figure 8).

Analysis of the hydrogen ion concentration of the leachate at this stage provided further evidence for the neutralization of the sulphuric acid by the ammonia being trapped in the

biofilter. In stage I, hydrogen ion concentration in the leachate was almost twice that of the sulphate ion concentration indicating that there was almost complete dissociation of the sulphuric acid produced in the biofilter (Figure 5). In stage II, the measured  $H^+$  concentration is less than expected from the sulphate ion alone. Figure 9 shows the measured concentration of  $H^+$  in the leachate labelled as ‘ $H^+$  concentration measured in leachate’. This is less than the theoretical hydrogen ion concentration based on the complete dissociation of the sulphuric acid produced in the leachate (labelled ‘Expected  $H^+$  from dissociation of  $H_2SO_4$ ’ in Figure 9). The  $NH_3$  in the gaseous emissions was being converted to  $NH_4^+$  in the acidic leachate leading to a reduction in the concentration of hydrogen in the leachate and the hydrogen ion concentration due to the sulphate concentration minus the amount reacting with ammonia is labelled ‘Calculated  $H^+$  from sulphate and ammonium concentration’ in Figure 9. The pH of the leachate at the end of this stage of the experiment was still below 1 which still did not encourage the growth of ammonia oxidizing bacteria (AOB) or nitrite oxidizing bacteria (NOB).

The overall biological reaction that occurs in an aerobic biofilter that removes hydrogen sulphide is given below [28, 52]:



$H_2S$  can be oxidised to either elemental sulphur or  $SO_4^{2-}$  depending on the ratio of  $H_2S$  to  $O_2$  in the treated air [49, 53]. In their study of aerobic acidic biofilters for the removal of  $H_2S$ , Chaiprapat and his co-workers [49] showed that the highest efficiency of conversion of  $H_2S$  to sulphate or sulphuric acid was when the  $H_2S$  to  $O_2$  ratio was 1:4. In this study, elemental sulphur was not detected in any of the samples in the biofilter, indicating that the biofilter operated under aerobic conditions.

The uniqueness of the biofilter setup described in this study is the use of the sulphuric acid formed by the biological oxidation of  $H_2S$  for the removal of  $NH_3$  in the contaminated air and accumulating the ions that are washed down from the biofilter. Since 2 moles of  $H^+$  can potentially be produced from one mole of  $H_2S$ , as long as the ratio of  $H_2S$  to  $NH_3$  in the contaminated air is greater than 0.5, there will be enough  $H^+$  to remove  $NH_3$  from air. In this study, the ratio of the amount of  $H_2S$  to  $NH_3$  in the contaminated air is greater than 15, which is more than adequate for the removal of  $NH_3$  in the air. One of the objectives of this biofilter was to show that ions like hydrogen, sulphate and nitrate are washed down the biofilter and

would be accumulated in the leachate. There was a gradient of ions and pH in the biofilter (Table 1 and Table 2) which shows that even when the leachate and the lower section of the biofilter has a very low pH (<1.5) or high ion concentration (~130mM sulphate), the top section of the biofilter still has an environment favourable for biological oxidation of H<sub>2</sub>S (pH <4.6 and 1.46 mM sulphate). The amount of water or nutrient solution needed to add to the biofilter for this to happen is a lot less than the water or nutrient that is added to conventional biofilters (Section 3.1.2).

At the Subiaco WWTP, with an average odorous gas flow of 62,500m<sup>3</sup>/h, the complete removal of ammonia and hydrogen sulphide in air has the potential to produce 8 kg/day of ammonium sulphate. Since the solubility of ammonium sulphate is 0.7 kg/L, the volume of leachate produced by the biofilter needs to be as low as 11 L/day to precipitate ammonium sulphate as a solid. If the existing acid scrubber at Subiaco, with a volume of 17.18m<sup>3</sup>, is converted to a biofilter, then the rate of leachate production would have to be less than 0.65mL/L/day to form precipitate of ammonium sulphate. It is worth noting that in stage 1 of this study, the volume of leachate produced was less than 1 mL/L/day and in stage II it was 0.2mL/L/day. Of course a full scale study would have to be undertaken to examine whether the ammonium sulphate produced in the full scale biofilter can be washed down into the leachate with this trickling rate. If all the ammonium sulphate produced in the biofilter can be washed down into the leachate and concentrated, then there is a potential to produce solid ammonium sulphate as a product.

### **3.3 Full scale conversion of chemical scrubber to biofilter setup**

As the biofilter process described above relies on acid produced by H<sub>2</sub>S oxidation to strip off ammonia, the application is suitable for waste air stream containing higher concentrations of hydrogen sulphide compared to ammonia. This scenario is common in wastewater treatment plants where the air stream has a higher concentration of hydrogen sulphide compared to ammonia [1, 39]. There are several examples in the literature of full scale conversion of chemical scrubbers into biological systems for the treatment of gases in wastewater treatment plants [36, 54-56]. A convenient ten step protocol was developed by Deshusses and his co-workers as a general procedure for the conversion of chemical scrubbers to biofilters in WWTP [37, 55]. Following this protocol, the conversion of chemical scrubbers at Subiaco WWTP to biofilters can be achieved by using the same chemical scrubber tank, packing material and

recirculation pump that is being currently used in the chemical scrubber system. For the existing chemical system at the Subiaco WWTP, the acid and base scrubbers have a volume of 17.18 m<sup>3</sup> and the hypo scrubber has a volume of 40 m<sup>3</sup>. If all the scrubbers at the Subiaco WWTP are converted to a biofilter, then an EBRT of 8.2 s can be achieved with the minimum allowed flow rate of 50,000 m<sup>3</sup>/h for the incoming gas. Further reduction in the flow rate would risk the safety of the workers at the WWTP as this would lead to high H<sub>2</sub>S and NH<sub>3</sub> concentrations. The biofilter system described above has an EBRT of 30s at the final stage (Stage II). To test the effectiveness of the biofilter system at low EBRT, both the top and middle sections of the biofilter were removed leaving a biofilter with only one section with a volume of 8.3L and an EBRT of 9.3s. This was the most convenient way to come as close to the desired EBRT of 8.2s without making significant changes to the biofilter. After an initial incubation period of a few hours, the removal efficiency was 90.24% for H<sub>2</sub>S and 100% for NH<sub>3</sub>. The result of the experiment comparing the biofilter with all three sections and a biofilter with only one section is summarized in Table 3.

It should be noted that there are examples in the literature of biofilters treating H<sub>2</sub>S with EBRT of 9 seconds but with pH control using buffered solutions and open pore polyurethane foam as the support material [16]. In another study, an EBRT of 2-10 seconds was sufficient for the removal of ammonia [57]. It could be possible to convert only the first or second chemical scrubber in the odour control system into a biofilter (leading to biofilters with EBRT of 2s) leaving the last two hypo scrubbers (which are washed with a mixture of sodium hypochlorite and sodium hydroxide) to remove trace amounts of any other odorous gases before discharging into the air (Figure 2). This would give EBRTs closer to the residence times of the pollutants in each tank of the chemical scrubber process, however, it is important that the suitability of the conversion needs to be tested by running a full scale trial of the biofilter.

The economic viability of a conversion of the chemical scrubber to a full scale biofilter setup on the principles described above is dependent on the savings obtained from capital and operating costs. Since the proposed biofilter system will intermittently add water instead of harsh chemicals, there will be savings on reagent consumptions. The cost calculation is summarized in Table 4 based on the current cost of the chemicals in the Australian market. Savings on electricity due to the intermittent use of the recirculation pump instead of the continuous use is also summarized in Table 4. The total saving on operating cost from not using chemicals and curtailed use of the recirculating pump comes to a total of \$ 56,794/yr. This does



not include saving from reduced water use, cost associated with waste stream treatment or disposal. Furthermore, there will also be savings in the form of reduced insurance derived from elimination of chemical handling issues.

It is being assumed that the current packing material being used at the chemical scrubber is suitable for the conversion to the biofilter. However, if the packing material needs to be changed then the removal of the old packing material and installation of new packing material would add to the cost. Some modifications of the pump controls may also be required. All these would be better estimated by running a full scale trial of the system rather than a small scale described in this paper.

### **Conclusion**

A biofilter setup at a local wastewater treatment plant removed both H<sub>2</sub>S and NH<sub>3</sub> from gaseous emissions with average removal efficiency of 91.96% and 100% respectively. This biofilter process produced a very small amount of leachate (0.2mL of leachate/L of reactor/day) and the ammonium and sulphate ions were accumulated at the bottom of the biofilter. In stage I of the experiment, biological oxidation of H<sub>2</sub>S produces SO<sub>4</sub><sup>2-</sup> in the biofilter which is accumulated in the bottom. In stage II, the NH<sub>3</sub> in the gaseous emissions is removed by the formation of ammonium sulphate - while the sulphur oxidizing bacteria (SOB) in the biofilter continues to remove H<sub>2</sub>S from the gaseous emissions. The low pH of the biofilter in stage II (4.63 – 1.51) prevents the growth of nitrifying bacteria in the biofilter. This process provides a possible alternative to the current chemical scrubber used in the plant that uses harsh chemicals and produces large volumes of waste stream. Within the parameters of the study conducted at the wastewater plant, the concentration of ammonium sulphate in the leachate of the biofilter kept increasing but further investigations on the suitability of this biofilter for the harvesting of ammonium sulphate as a solid in a full scale trial should be investigated.

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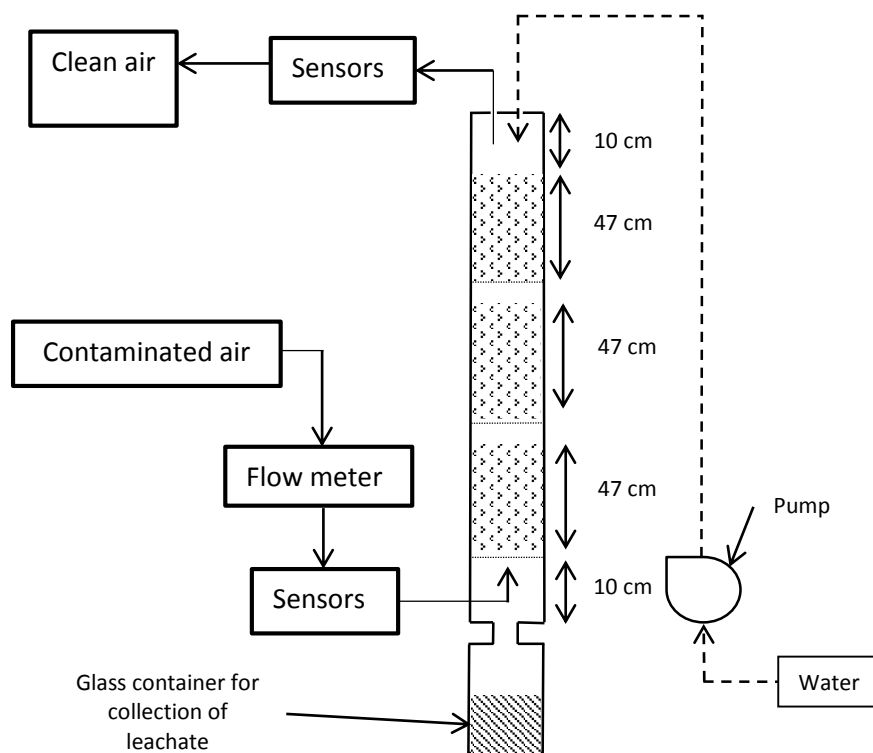
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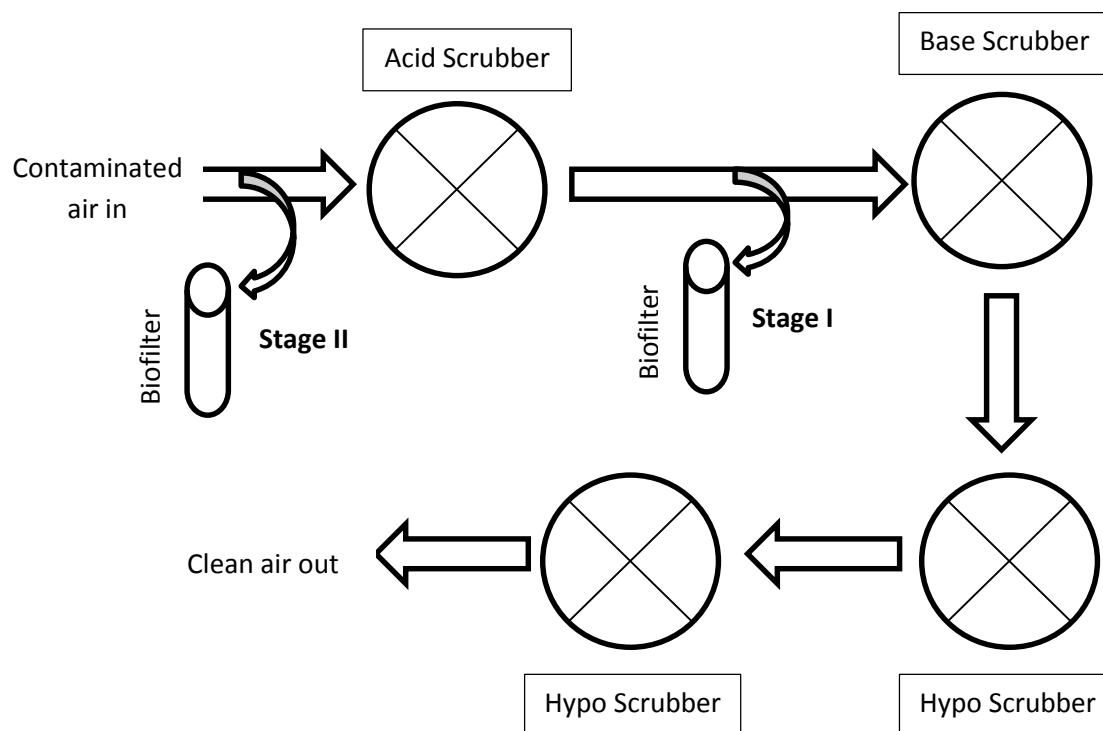
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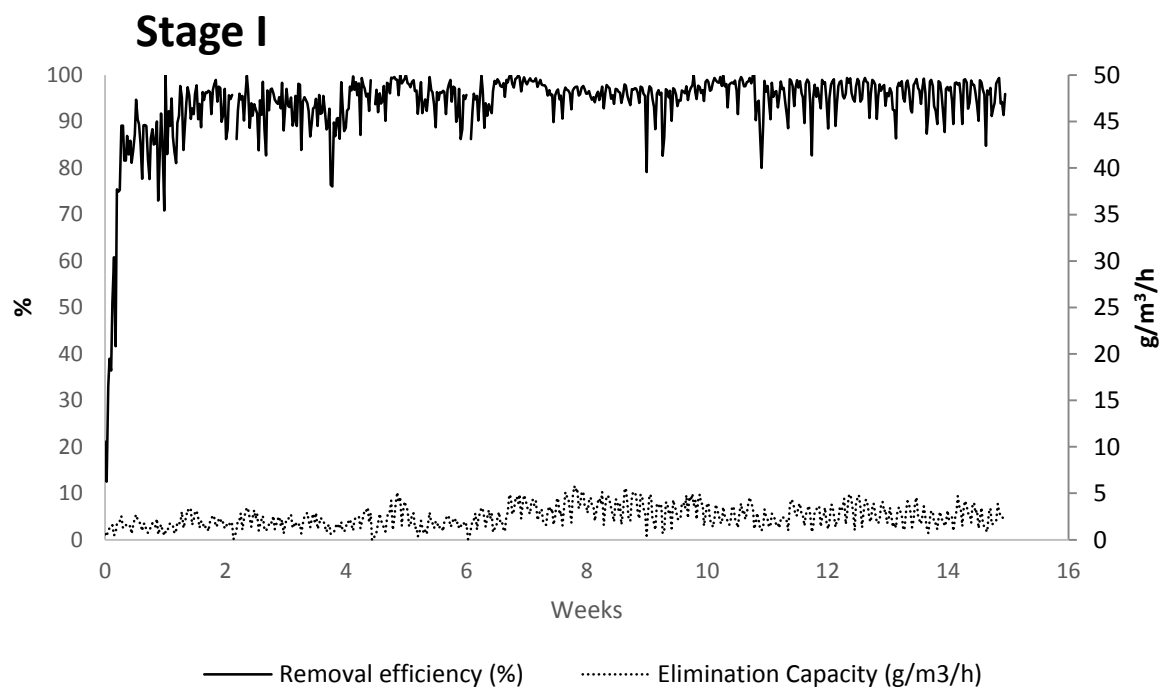
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**Figure 1:** Schematic diagram of the biofilter

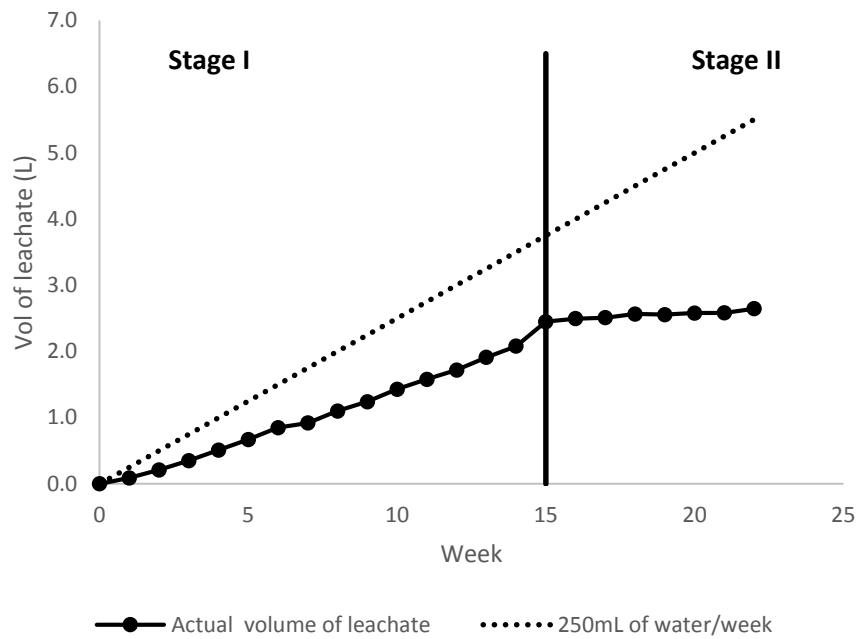


**Figure 2:** Schematic diagram of chemical odour control setup at Subiaco WWTP

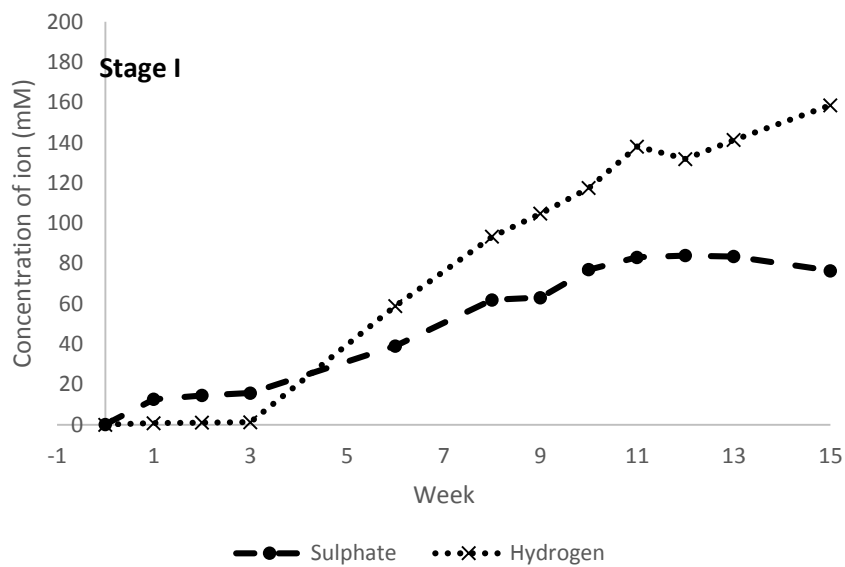


**Figure 3:** Removal of H<sub>2</sub>S in stage I of the experiment

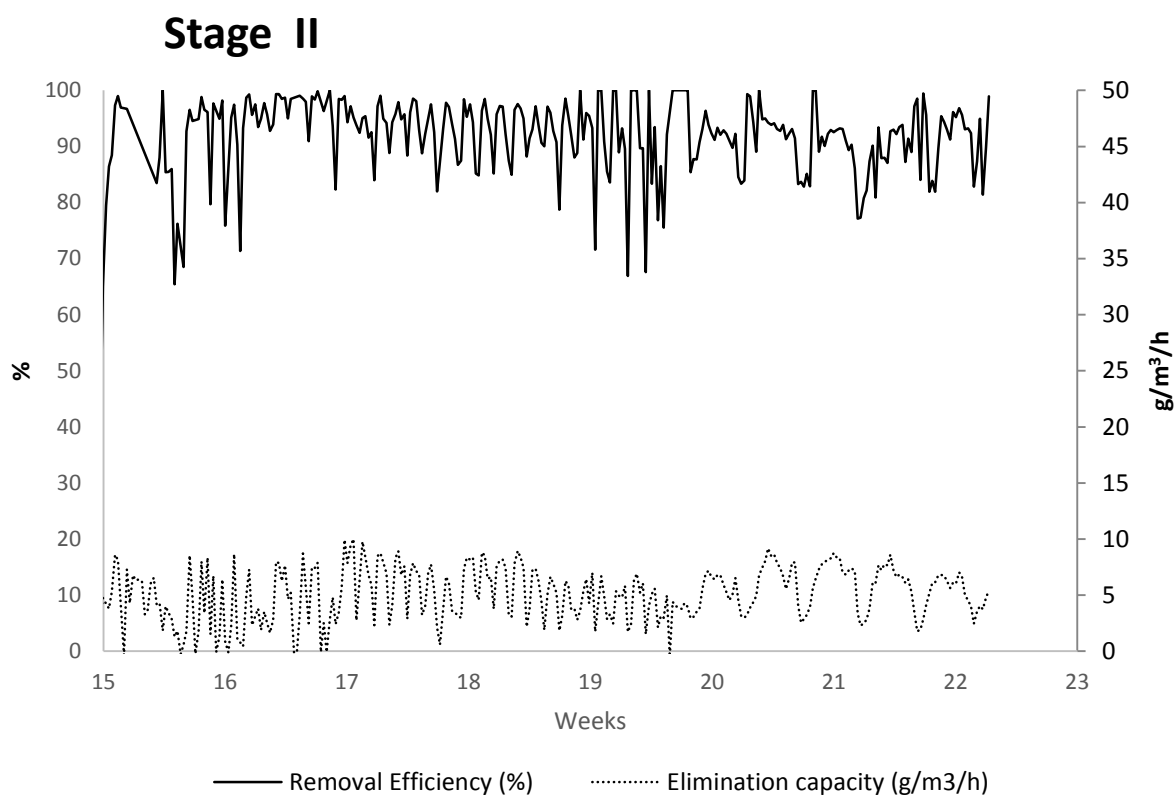




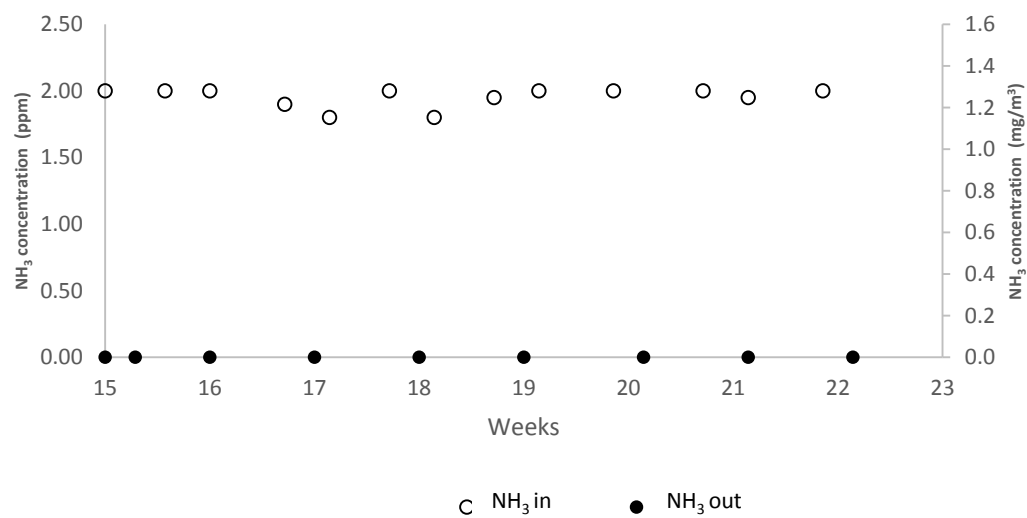
**Figure 4:** Volume of water added to biofilter and the volume of leachate produced



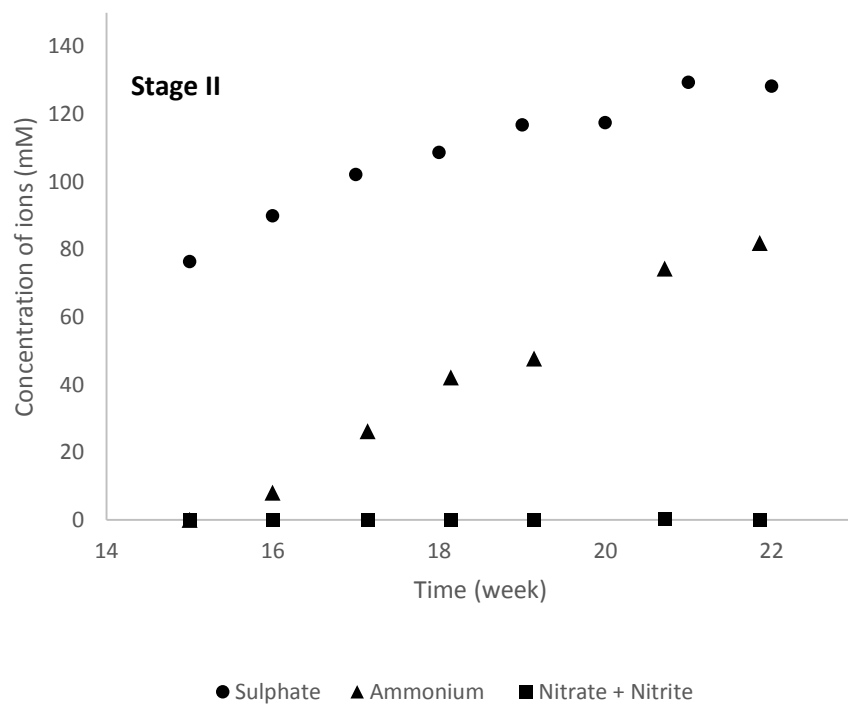
**Figure 5:** Sulphate and hydrogen ion concentration in leachate



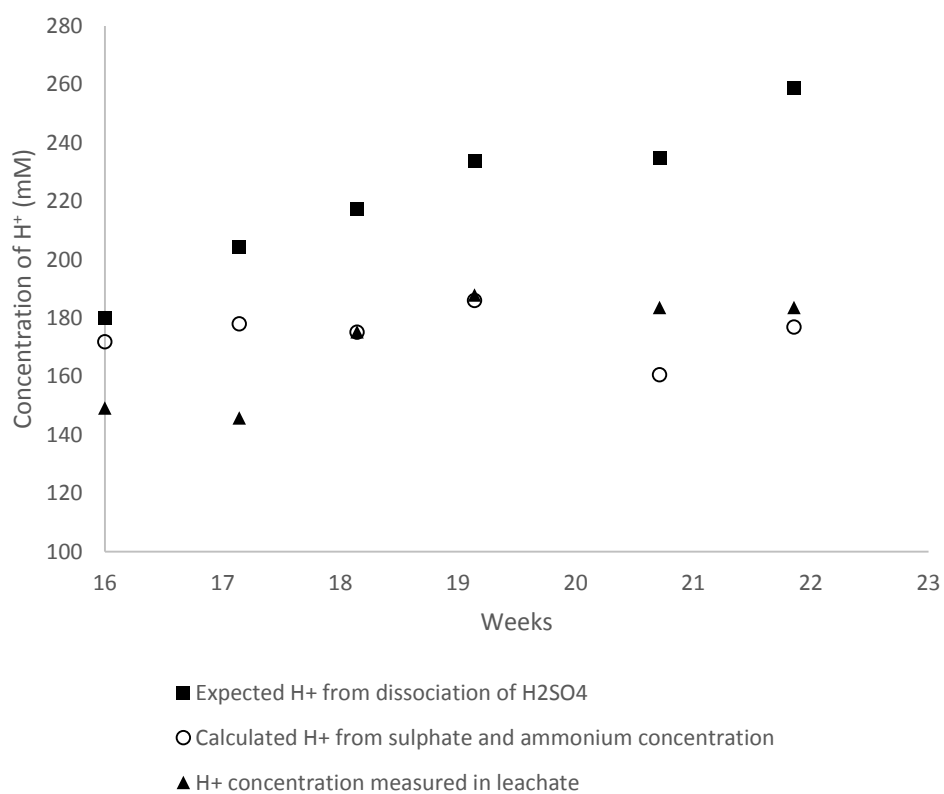
**Figure 6:** Removal of H<sub>2</sub>S in stage II of the experiment



**Figure 7:** Removal of NH<sub>3</sub> in stage II of the experiment



**Figure 8:** Sulphate, ammonium and nitrate concentration in leachate during stage II.



**Figure 9:** Hydrogen ion balance in leachate during stage II

**Table 1:** Gradient of moisture and ions in the biofilter during stage I

		Top section	Middle section	Bottom Section
Moisture content	g / g*	1.21	1.27	0.99
pH		5.34	4.95	3.67
SO <sub>4</sub> <sup>2-</sup> concentration	mM	1.46	1.79	4.23

\* g/g refers to grams of water per gram of supporting medium

**Table 2:** Gradient of pH and ion concentrations at the end of stage II

		Top section	Middle section	Bottom Section	Leachate
Moisture content		1.31	1.18	0.89	-
pH		4.63	3.39	1.51	0.90
SO <sub>4</sub> <sup>2-</sup> concentration	mM	1.45	3.75	10.96	128.38
NH <sub>4</sub> <sup>+</sup> concentration	mM	0.00	0.00	1.2	81.90

**Table 3:** Summary of results of biofilter using three sections and only one section

	All three section	One section only
Average H <sub>2</sub> S concentration of inlet air	31.86 ppm (0.04 g/m <sup>3</sup> )	30.98 ppm (0.04 g/m <sup>3</sup> )
Average NH <sub>3</sub> concentration of inlet air	1.94 ppm (1.35 mg/m <sup>3</sup> )	1.96 ppm (1.36 mg/m <sup>3</sup> )
Volume of reactor	0.025 m <sup>3</sup>	0.0083 m <sup>3</sup>
Inlet Flow rate	0.05 m <sup>3</sup> /min	0.05 m <sup>3</sup> /min
EBRT	27.98 s	9.33 s
Mass Loading Rate for H <sub>2</sub> S	5.37 g of S/m <sup>3</sup> /hr.	15.66 g of S/m <sup>3</sup> /hr.
Mass Loading Rate for NH <sub>3</sub>	0.14 mg of N/m <sup>3</sup> /hr.	0.43 mg of N/m <sup>3</sup> /hr.
Removal Efficiency for H <sub>2</sub> S	91.96 %	90.24 %
Removal Efficiency for NH <sub>3</sub>	100 %	100 %

**Table 4:** Summary of cost savings in converting from chemical scrubber to a biofilter

Savings from non-use of reagents				
Reagent	Amount of reagent used	Reagent cost		Savings per year
Acid	40 L/day	\$0.40/L		\$5,840
Caustic	200 L/day	\$0.50/L		\$36,500
Savings from electricity consumption				
	Power	Electricity cost per unit	Usage	Savings per year
Pump	11 kW	\$0.18 /kWh <sup>a</sup>	20 h/day	\$14,454
		Total savings per year		\$56, 794

<sup>a</sup>[58]