Treatment of $\text{H}_2\text{S}$ and $\text{NH}_3$ from wastewater using a pilot-scale tray biofilter

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Abstract. A tray biofilter was developed and tested for treatment of high volume, low concentration $\text{H}_2\text{S}$ and $\text{NH}_3$ from pig farm wastewater. The combination of 2 bed depth values (0.15 m. and 0.30 m.) and 3 EBRT values (0.6, 1.2, and 1.8 s) resulted in 6 systems for the experiment. The filter media used were compost : chopped coconut shell : dried cow manure : dried wastewater treatment plant sludge at 60:20:10:10 ratio. The treatment efficiency for $\text{H}_2\text{S}$ and $\text{NH}_3$ were in the range of 78% - 89% and 57% - 80%, respectively. Overall, the systems with higher bed depth and/or higher EBRT can treat the two gases with higher efficiency. The mass loading rates, the elimination capacity, and efficiency of this study were comparable to other studies.

1. Introduction

Hydrogen sulfide ($\text{H}_2\text{S}$) and ammonia ($\text{NH}_3$) are odorous gases found when anaerobic digestion of organic matters occurs. $\text{H}_2\text{S}$ has a typical smell of rotten eggs, and $\text{NH}_3$ has a strong and repulsive smell of animal urine. Both gases can be detected by human at low concentrations. In Thailand, one of the most significant sources of these gases in communities are livestock production, especially pig farms. The odor mostly comes from the manure and urine of pigs that were collected in the form of wastewater from the farmhouses. Levels of these gases in ambient air can cause significant odor nuisance to the people in nearby areas and may lead to their adverse health impacts – nausea, headaches, or respiratory tract irritation.

With respect to odor from the wastewater, closed-system treatment such as covered lagoons can minimize the odor while also yielding the benefit of biogas. However, $\text{H}_2\text{S}$ and $\text{NH}_3$ are still emitted into the environment via the farmhouse air ventilation system, with no treatment mechanism in place. Among several treatment techniques, compost-based biofilter can be used as a cost-effective method to treat farmhouse emission. It is suitable for low concentration gas flow and has advantages of low operating and maintenance costs [1]. Moreover, most filter media can be obtained and prepared within the farm and the spent media can subsequently be used as fertilizer. The system efficiency, however, is subjected to wide variation depending on the design parameter such as filter media types and mixture ratio, empty bed residence time (EBRT), and mass loading rate (MLR). Typical efficiency of 50-90% were reported in the literature [2, 3].

In this research, a simple tray-type biofilter was developed for treatment of high volume, low concentration $\text{H}_2\text{S}$ and $\text{NH}_3$ from pig farmhouses. This paper presents the results from the pilot-scale study focusing on the efficiency and operating conditions.
2. Methodology

2.1. System design and operation
Details of the pilot-scale tray biofilter design and operation are presented in a related paper [4] and are summarized as follow. First the design parameters were reviewed from relevant literatures and the ones that were in accordance with the research objectives were selected. The final design include a filter media box with a screen plate as the bottom of the box. The bed area was 0.4 x 0.5 m², and the box height was 0.3 m. Two values of bed depth were experimented: 0.15 and 0.30 m, which resulted in the bed volume of 0.03 and 0.06 m³, respectively. The empty bed residence time (EBRT) were selected as 0.6, 1.2, and 1.8 seconds, which were achieved by using the flow rates of 0.017-0.100 m³/s. These bed height and EBRT values were lower than most of those in the literature because they were intended to fit the tray-type configuration which is easy to operate and can handle large gas flow rate.

The combination of 2 bed depth values and 3 EBRT values resulted in 6 systems for the experiment. Each experiment was run and essential parameters were measured continuously for 14 days. New filter media was used every time the new system start its operation. The inlet and outlet concentration of H₂S and NH₃ were measured using COMBIMASS serie GA-m and Gasmet serie DX4040 portable gas analysers, respectively.

The tray biofilter system was set-up near a 300-pig housing in the farm in Suranaree University of Technology, Nakhon Ratchasima, Thailand. The average wastewater flow was 21 m³/d. The input gases were collected from a covered wastewater pit via a collection pipe system powered by a 2-HP, 1.5 kW fan with inverter for flow rate variation. The gas was considered a representative of the gas from typical pig farmhouses. The lateral pipes under the media bed were designed to evenly distribute the gas flow upward to the media bed. An automatic water spraying system was attached under the filter’s roof to control media bed moisture.

2.2. Filter media
The material type and mixing ratio of the filter media were selected based on optimum cost, ease of operation, and adequate nutrient and porosity. The selection results were compost : chopped coconut shell : dried cow manure : dried wastewater treatment plant sludge at 60:20:10:10 ratio [5]. The filter media were mixed thoroughly with added water, and kept for 2 weeks before loading into the system. The characteristics fo the filter media are shown in table 1.

Table 1. Characteristics of the filter media in this study.

| Characteristics | Individual Medium | Mixed Media |
|-----------------|-------------------|-------------|
|                 | Compost           | Chopped Coconut Shell | Dried Cow Manure | Dried WWTP Sludge | 0.56 |
| Density (g/cm³) | 0.62              | 0.05         | 0.34           | 0.66               |
| Porosity (%)    | 54.70             | 78.67        | 75.20          | 40.08              | 55.54 |
| Moisture (%)    | 17.46             | 6.58         | 2.38           | 79.78              | 71   |

3. Results and Discussion

3.1. Treatment Efficiency
Results from the operations of 6 biofilter systems were analyzed in terms of mass loading rate (MLR), elimination capacity (EC), and efficiency, and the average values were presented in table 2. For H₂S,
the treatment efficiency was in the range of 78% - 89%, with the thicker bed systems (system 1 - 3) having higher efficiency values. However, system 3 had much higher MLR and EC than system 1 and 2, so it can handle greater concentration and/or gas flow rate. Similar discussion can be made for NH3, although the difference of MLR, EC, and efficiency were less obvious. The NH3 treatment efficiency was in the range of 57% - 80%.

**Table 2.** Mass loading rate (MLR), elimination capacity (EC), and efficiency results.

| System | Bed Depth (m.) | EBRT (s) | Flow Rate (m³/s) | Filtration Velocity (m/s) | H₂S | NH₃ |
|--------|----------------|---------|------------------|--------------------------|-----|-----|
|        |                |         |                  |                          | MLR (g/m³ hr) | EC (g/m³ hr) | Eff. (%) | MLR (g/m³ hr) | EC (g/m³ hr) | Eff. (%) |
| 1      | 0.3            | 1.8     | 0.033            | 0.17                     | 115 | 103 | 89 | 10 | 8 | 80 |
| 2      | 0.3            | 1.2     | 0.050            | 0.25                     | 185 | 156 | 85 | 17 | 10 | 61 |
| 3      | 0.3            | 0.6     | 0.100            | 0.50                     | 426 | 349 | 81 | 33 | 25 | 74 |
| 4      | 0.15           | 1.8     | 0.017            | 0.08                     | 139 | 113 | 78 | 10 | 7 | 66 |
| 5      | 0.15           | 1.2     | 0.025            | 0.13                     | 169 | 135 | 79 | 14 | 11 | 77 |
| 6      | 0.15           | 0.6     | 0.050            | 0.25                     | 428 | 338 | 80 | 23 | 14 | 57 |

Descriptive summary of the treatment efficiency results during the operation can be presented in box plots as shown in figure 1. Most plots showed distributions that are a little skewed to the left, which means there were occasional low values. For H₂S, system 1 has considerably higher efficiency than the others, and all systems have approximately the same distribution shapes. For NH₃, the differences were rather obscure. Comparison of average efficiency values among the 6 systems were carried out using Tukey’s multiple-pair comparison method [7]. For H₂S, 5 pairs were found to be significantly different – the mean efficiency value of system 1 was higher than those of system 2, 3, 4, 5 and 6. For NH₃, the mean efficiency value of system 1 was significantly higher than system 2 and 6. This suggests that the system with high bed depth and high EBRT can treat the two gases with higher efficiency.

**Figure 1.** Box plots of treatment efficiency of the 6 systems: (a) H₂S and (b) NH₃.

3.2. Operating Conditions

The 4-day moving average efficiency plot of the systems’ efficiency during operations are shown in figure 2(a). The efficiency values fluctuated during the first few days but became more stable during
the latter part of the operation. Again the systems with high bed depth showed higher efficiency. On the other hand, filter bed compression rates were quite similar for all system, 1.3% - 1.6% per day, as shown by the slopes in figure 2(b). On average, system 1 - 3 compressed 5.5 cm./day and system 4 - 6 compressed 2.7 cm./day.

Correlation analysis was performed on treatment efficiency and essential factors, namely pH, temperature, and moisture, using Spearman's rank correlation coefficient ($r_s$). It was found that the H$_2$S treatment efficiency had significant positive correlation with pH in system 5 ($r_s = 0.580$) and 6 ($r_s = 0.766$), and with temperature in system 3 ($r_s = 0.624$) (figure 3). No significant correlation was found in the case of NH$_3$. Few correlations were anticipated because the factors were controlled and have little variations over the operation period.

Table 3 shows a comparison of operating condition and results of this research with relevant studies. This research used relatively lower inlet concentration of both gases and operated at lower EBRT values. Nevertheless, the mass loading rates, the elimination capacity, and efficiency were
relatively better than other studies. Therefore, the tray-type biofilter is a promising odor treatment alternative for pig farmhouses.

Table 3. Comparison of operating condition and results with relevant literatures.

| Gas  | Reference | $C_{in}$ (mg/m$^3$) | EBRT (s) | MLR (g/m$^3$.h) | EC (g/m$^3$.hr) | Efficiency (%) |
|------|-----------|---------------------|----------|-----------------|----------------|----------------|
| H$_2$S | [3]       | 1.2-1.3             | 0.6      | -               | 2.56           | 42.2           |
|       | [8]       | 32-3,480            | 7-23     | 130             | 250            | 93-100         |
|       | [9]       | 393                 | 45       | 3-34            | 122            | 100            |
|       | [10]      | 131-1,650           | 32-51    | 0.1-13          | 8              | 45-100         |
|       | [11]      | 200-1,300           | 60       | 11.7-60         | 58             | 99             |
|      | This Research | 72-58 | 0.6-1.8 | 115-428 | 103-349 | 79-89 |
| NH$_3$ | [3]       | 7-9                 | 0.6      | -               | 14.4           | 45.8           |
|       | [6]       | 139-348             | 22.5     | 0.48 -19.06     | -              | 99             |
|       | [12]      | 43-150              | 30-60    | 54              | 52             | 96             |
|      | This Research | 4-6 | 0.6-1.8 | 10-33 | 7-25 | 57-80 |

4. Conclusion
This research yielded a pilot-scale tray biofilter which can treat H$_2$S and NH$_3$ from pig farm wastewater with 78% - 89% and 57% - 80% efficiency, respectively. The treatment efficiency corresponded to the bed depth and EBRT.

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