Treatment of H_2S and 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 H_2S and 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 H_2S and 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 *(*H_2S*)* and ammonia *(*NH_3) are odorous gases found when anaerobic digestion of organic matters occurs. H_2S has a typical smell of rotten eggs, and 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, H_2S and 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 H_2S and 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 reveiwed 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 m^2, 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 m^3, 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 m^3/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 H_2S and NH_3 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 m^3/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.

The microorganism in the filter media was measured by the aerobic plate count method along the operation period. It was in the range of 3.60×10^8 - 6.30×10^8 CFU/g, with the average of 5.76×10^8 CFU/g. The levels were within the recommended range of 10^6 - 10^{10} CFU/g for biofilters [1, 6].

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	
Density (g/cm^3)	0.62	0.05	0.34	0.66	0.56
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

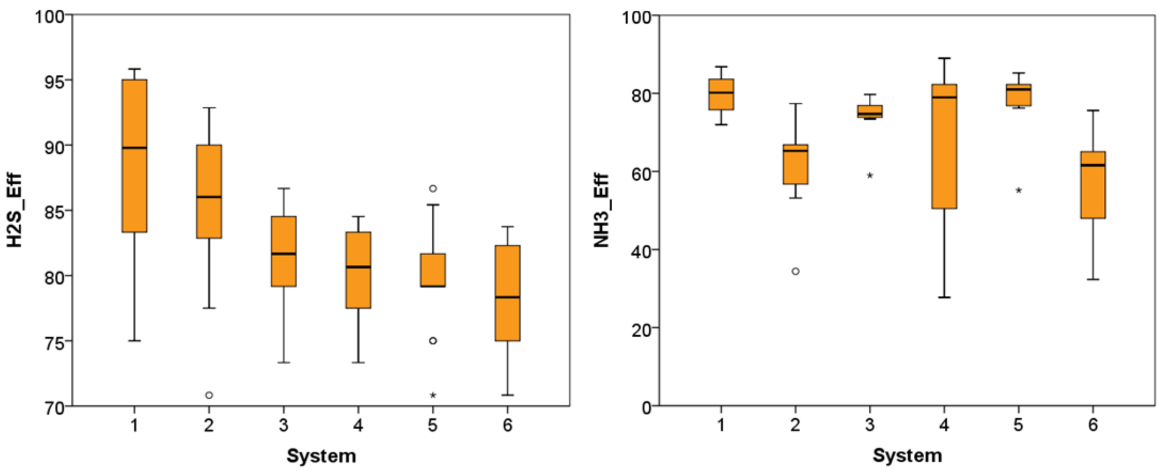
3.1. Treatment Efficiency

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 H_2S, 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 gass flow rate. Similar discussion can be made for NH_3, although the difference of MLR, EC, and efficiency were less obvious. The NH_3 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 (m^3/s)	Filtration Velocity (m/s)	H_2S			NH_3		
					MLR (g/m^3.hr)	EC (g/m^3.hr)	Eff. (%)	MLR (g/m^3.hr)	EC (g/m^3.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 occational low values. For H_2S, system 1 has considerably higher efficiency than the others, and all systems have approximately the same distribution shapes. For NH_3, 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 H_2S, 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 NH_3, 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.

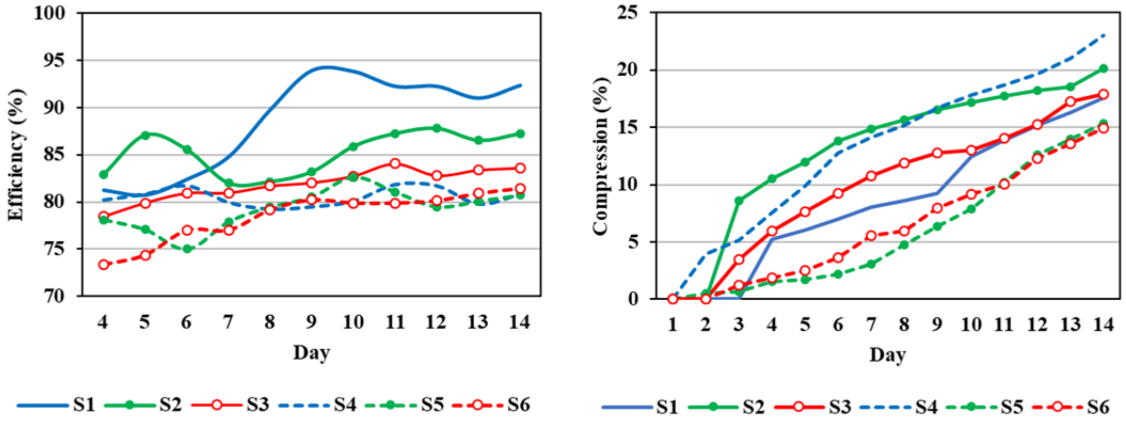


(a) (b)

Figure 1. Box plots of treatment efficiency of the 6 systems: (a) H_2S and (b) NH_3.

3.2. Operating Conditions

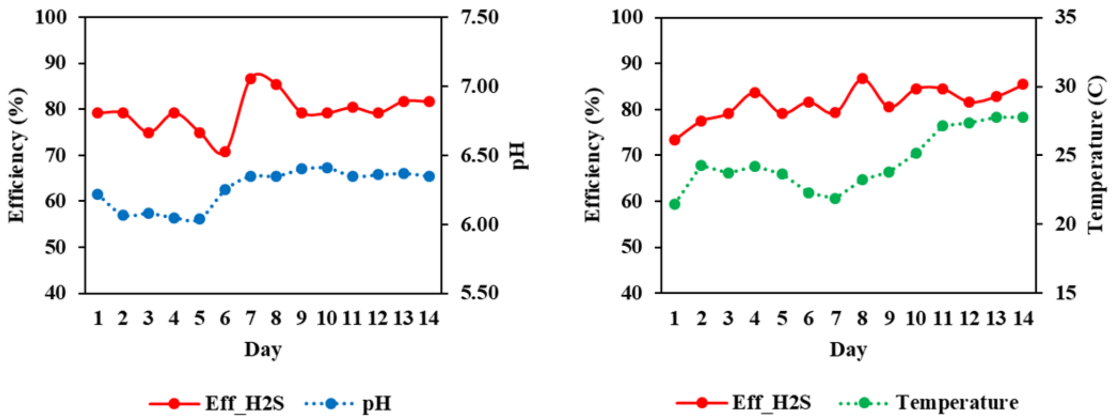
The 4-day moving average efficiency plot of the systems' efficiency during operations are shown in figure 2(a). The efficiency values fluctuated during the first few days but became more stable during the latter part of the operation. Again the systems with high bed depth showed higher efficiency. On 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.



(a) (b)

Figure 2. Time series plots of: (a) H_2S efficiency levels (4-day moving average) and (b) filter bed compression.

Correlation analysis was performed on treatment efficiency and essential factos, namely pH, temperature, and moisture, using Spearman's rank correlation coefficient *(*r_s*)*. It was found that the H_2S 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 controled and have little variations over the operation period.



(a) (b)

Figure 3. Correlation of H_2S treatment efficiency and other factors: (a) pH in system 5 and (b) temperature in system 3.

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 promissing 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_2S	[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_2S 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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