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Feasibility Study of Low Cost Biofilter to Control Ammonia from Livestock Farms

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Abstract**—**The purpose of this study was to study the efficiency of design operation of low cost biofilters to remove ammonia gas which is the main odorous gas from livestock farms. The experiments were conducted in the pilot-scale biofilters packed with the mixture of manure fertilizer and rice husk in the ratio 80:20 at the layer barn of Kasetsart University. The results shown that the ammonia removal efficiency is more than 99% at the gas flow rates 2.0 m^3/min. The emission concentration of ammonia after biofiltration process is less than 1 ppm over the period of this study. The maximum (100%) removal efficiency was obtained in the low cost biofilters were having elimination capacities of 33,191.79 g/m^3-min. The annualized cost per volume of air treated is USD 0.0039/ 1,000 m^3 air treated**.**

Index Terms**—**ammonia gas, odor, biofiltration, biofilter, removal efficiency, elimination capacity, mass balance, farms

I. Introduction

The population of Thailand increasing rapidly causes more demand for food. Protein is one of major food groups with high demand. The major source of protein comes from animals such as meat, milk and egg. This leads to the rapid growth of livestock industry.

Rapidly growth of livestock industry makes farms enlarge the scale of business to larger operation but the area is still limited. This causes overcrowded of livestock population. Overcrowded livestock population is hard to avoid problem of unpleasant odor. Major odor from livestock farms are mainly caused by Ammonia and Hydrogen Sulfide [1].

There is the different between the definitions of odor intensity and odorous gas concentration. Odor intensity is to measure of sense of detection by nose. Odorous gas concentration is the amount of gas in the air and measured by calibrated devices in the unit of parts per million (ppm) or parts per billion (ppb).

Bad smell or unpleasant odor from livestock farms is from several hundred different substances in the air, 331 distinct odor-causing compounds in livestock manure, but the main gases that can be usually detected from livestock farms are from ammonia, hydrogen sulfide and volatile organic compounds (VOCs) [2].

Several studies showed that ammonia is an indicator of the onset of biological activity and a precursor of significant odor generation. The relationship between odor intensity and ammonia concentration are in linear [3] so in this study used odorous gas analysis method that has been proved more reliable and economical than other available methods.

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Pollution Control Department (PCD) developed the strategies to control nuisance odors from livestock farms both inside and outside barn management and also implement odorous treatment technologies. Odorous treatment technologies which have been developed to control odor problem from livestock farms in Thailand are water curtain system, plastic dome coverage and biofiltration from their effectiveness, simply, easy to implementation and maintenance, flexibility and economic to attract the farmers to apply it into their farms. The result showed that the removal efficiency are 61%, 32% and 73% respectively so the most effective odor treatment system for livestock farms is "Biofiltration" [4].

Although the experiment from PCD showed that biofiltration is the most appropriate but the efficiency can be developed more so the objective of this study aimed to study on the efficiency of developed low cost biofilter to control odor from livestock farms in Thailand.

II. Materials And Methods

A. Experimant Raw Materials

The media for this experiment was from rice husk, the agriculture residue which is regularly used in livestock farms and dry manure which is a farm waste containing nutrients such as nitrogen, phosphorus, potassium, trace nutrients and microorganisms.

B. Experimental Setup

The schematic of pilot-scale biofilter is illustrated in Fig 1. In this study, two biofilters was used. Each column made of 200 liter plastic tank of 60 cm in diameter and 100 cm in height. The biofilter media was 80% rice husk and 20% layer manure. The media was prepared before starting the experiment for 30 days. Table I showed he properties of pilot-scale bilfilter operation for this study. This experiment has been carried out in layer farm of Kasetsart university, Bangkok, Thailand.

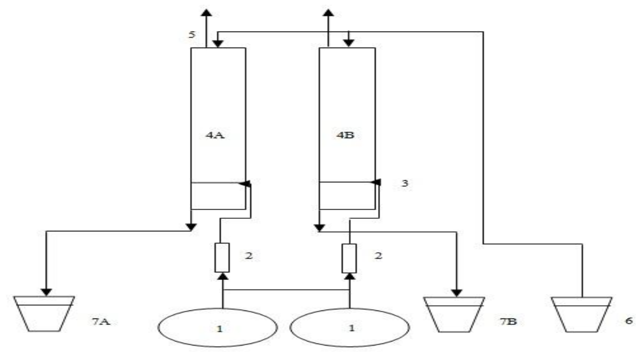


Fig. 1. Schematic Of Pilot-Scale Biofilter: (1) Air Blowers, (2) Flow Meter, (3) Gas Inlet Valve, (4) Biofilter Columns; (4A) Biofilter Column 1, (4B) Biofilter Column 2, (5) Spray Nozzle, (6) Water

Tank, (7A) Leachate Tank 1 (7B) Leachate Tank 2

TABLE I
THE PROPERTIES OF BIOFILTER OPERATION

Parameters	Experimental Operation
1. Height of biofilter media	60 cm
2. The ratio of rice husk and manure	80:20 [5]
3. Moisture content of biofilter media	40-60% [5]
4. EBRT	5 s [6]
5. pH	6.5-8.5
6. Air flow rate	2.0 m^3/min

C. *Parameter monitoring*

Ammonia gas samples were collected from the inlet and outlet and analyzed once a day in mean value. A procedure to analyze input and output ammonia gas was using Toxirae II NH_3 gas meter and Draeger gas detection tubes.

III. RESULTS AND DISCUSSIONS

Twenty-eight days after media preparation, biofilm was found in leachate water of both treatment columns.

Thirty days after media preparation, the experiment was started in the first phase; low concentration of ammonia input from layer barns for 30 days and after that started in the second phase; high concentration of ammonia input from manure collection basin for 6 days.

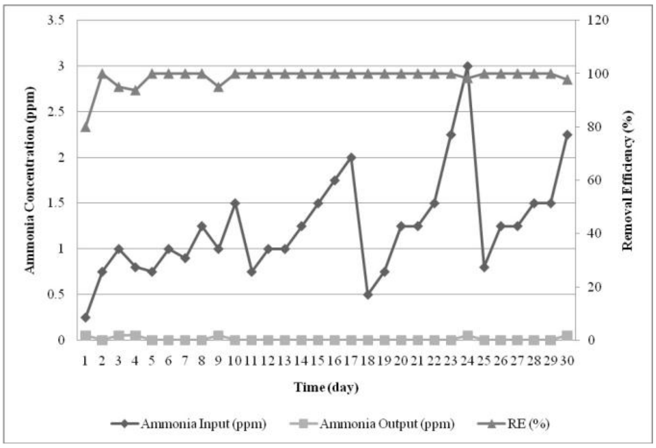
80:20 ratio of rice husk and layer manure had been applied to the treatment columns. In this experiment, 2.0 m^3/min air flow rate was used throughout the study. Periodic gas input is 2-10 min/day depended on the concentration of gas.

A. *The Efficiency Of Ammonia Removal*

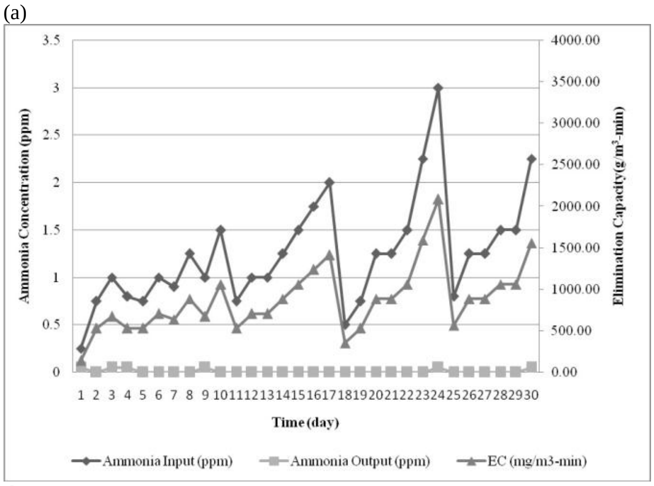
The results of ammonia removal efficiency was more than 99.9% throughout the experiment and the highest elimination capacity was 33,191.79 g/m^3-min.

1.1 Low concentration of ammonia gas input

The operation was set up under the designed parameters. The flow rate of low cost biofilter was 2.0 m^3/min. The concentration of ammonia from the layer barn varied from the condition of ammonia production from the barn each day. During the experiment, the amount of ammonia fed into low cost biofilter columns fluctuated in the range of 0.25-3.00 ppm. The system was stable and the removal efficiency was more than 80% since the first day of the experiment and more than 99% overall this experiment. The results showed that the operation with air flow rate 2.0 m^3/min can be used for ammonia removal efficiently as shown in Fig 2(a)-(b).



(a)

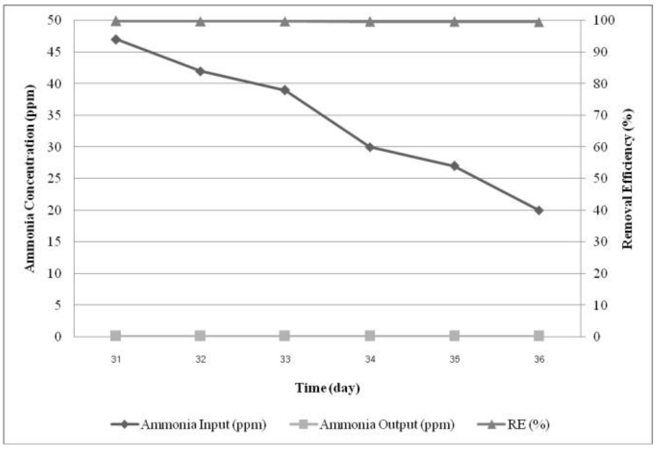


(b)

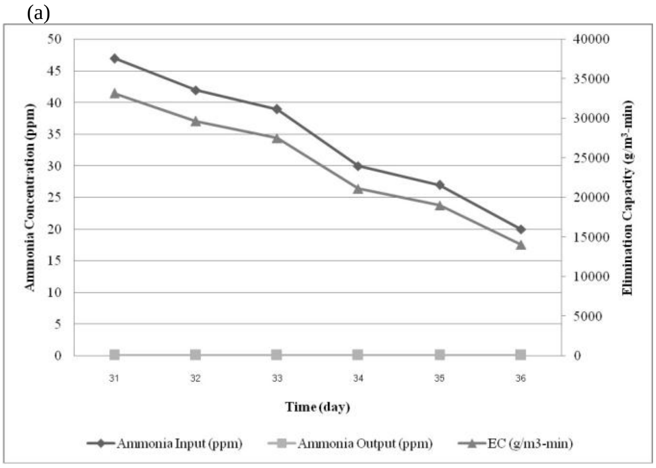
Fig. 2. Relationship Between Ammonia Input, Ammonia Output, With (A) Removal Efficiency (B) Elimination Capacity (Low Concentration Of Ammonia Input)

1.2 High Concentration Of Ammonia Input

The flow rate of low cost biofilter was 2.0 m^3/min. The concentration of ammonia from the manure tank varied from the condition of ammonia each day. During the experiment, the amount of ammonia fed into low cost biofilter columns fluctuated in the range of 20.0-47.0 ppm. The system was stable and the removal efficiency was more than 99% since the first day of the experiment and overall this experiment as shown in Fig 3(a)-(b).



(a)



(b)

Fig. 3. Relationship Between Ammonia Input, Ammonia Output, With (A) Removal Efficiency (B) Elimination Capacity (High Concentration Of Ammonia Input)

B. Nitrogen Mass Balance In Treatment Columns

Mass balance can be used for evaluation of biofilter performance quantitatively from entered and leaved gases and by leachate. Ammonia can be removed or transformed by nitrifying bacteria. In the first step, nitritation, ammonia is oxidized to nitrite by *Nitrosomonas spp*. and in the second step, nitratation, nitrite is oxidized to nitrate by *Nitrobacter spp*. Denitrification is assumed to be as the environment in biofilters is aerobic.

To measure for nitrogen mass balance, the assumption was made as follow;

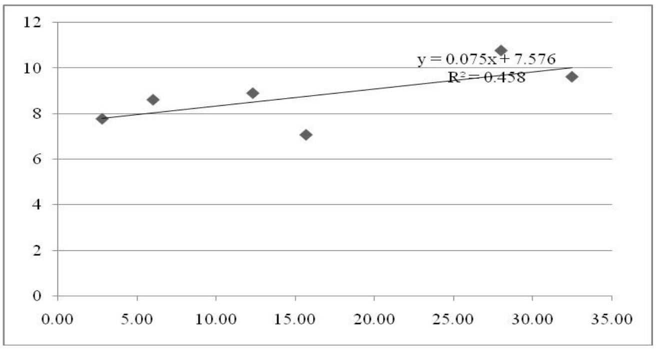
- Biofilter operation was in a stationary water phase and in steady state condition.
- Leachate from biofilters is equal to water input.
- No ammonia was produced in the biofilters.

From this topic making in the first phase of the experiment cannot be used for nitrogen mass balance calculation because the composition of media consisted of 20% chicken manure which contained uric acid and undigested proteins that are nitrogen source and can cause ammonia emission and nitrate leaching [7] that made nitrate leaching was more than ammonia gas input.

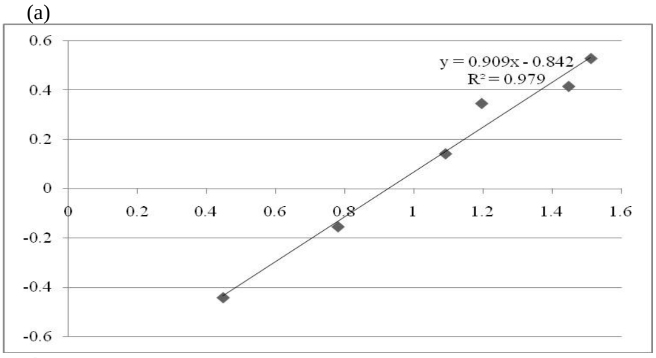
The overall nitrogen mass balance should be

$NH_3\text{-}N_{(in)} - NH_3\text{-}N_{(out)} = NO_2^-\text{-}N_{(leachate)} + NO_3^-\text{-}N_{(leachate)} + NH_3\text{-}N/NH_4^+\text{-}N_{(leachate)} + NH_3\text{-}N/NH_4^+\text{-}N_{(adsorption)} + NH_3\text{-}N/NH_4^+\text{-}N_{(biodegradation)}$

To determine nitrogen mass balance, the adsorption study was conducted in the laboratory. The media from biofilter columns was prepared as adsorbent. The media was dried at 105° C for 24 hours. The adsorption experiment was conducted by placing a series of six 250 ml conical flasks, each with 5 g adsorbent media and 250 ml of 6 concentrations of ammonia; 10 ppm, 20 ppm, 40 ppm, 60 ppm, 80 ppm and 100 ppm respectively. These flasks were placed at room temperature for 30 minutes. The graphs of adsorption isotherm were plotted as shown in Fig.4 (a)-(b).



(a)



(b)

Fig. 3. Adsorption Isotherm (A) Langmuir Adsorption Isotherm (B) Freundlich Adsorption Isotherm

The results showed that the ammonia removal was comforming more to Freundlich adsorption isotherm due to higher R^2 value (The regression coefficients).

TABLE II
NITROGEN GAS BALANCE OF BIOFILTER OPERATION

Day	Liquid phase	Leachate			Media	
	$NH_3\text{-}N_{in-out}$ (mg)	NO_2^-N (mg)	NO_3^-N (mg)	$NH_3\text{-}N$ (mg)	Adsorbed $NH_3\text{-}N$ (mg)	Biotransformed $NH_3\text{-}N$ (mg)
41	135.77	ND	0.82	13.18	90.43	31.34
42	121.29	ND	NT	14.83	80.82	25.64
43	112.61	ND	NT	19.10	75.06	18.45
44	105.10	ND	NT	16.63	70.07	18.40
45	94.55	ND	0.68	28.00	63.06	0.09
46	69.47	ND	NT	21.41	46.72	1.81

ND is not detected, NT is not tested, NH_3-N from liquid phase, and media were from calculation

From the table 4 showed that ammonia can be eliminated from media adsorption around 67.00% and 17.70% can be drained as ammonia contaminated leachate and assumed from biotransformation by bacteria 14.97%.

C. The Cost Of Low Cost Biofilter [8]

The cost of full-scale biofilter consists of capital cost, annual operation and maintenance cost, and media replacement cost (every 5 years)

From this study, the calculation for full-scale biofilter was proposed as below;

Q = 300,000 – 450,000 m^3/hr for standard livestock barns in Thailand, EBRT = 5 s, open-bed dimension = 20 x 40 x 1 m

Capital costs

1. Initial site preparation costs

1.1 Volume of media bed = Q x EBRT

V = 450,000 (m^3/hr) x 5 (S) x 1 (hr)/3,600 (s)

V = 625 m^3

1.2 Assuming a 20% safety factor:

V safety = V x 1.2 = 625(m^3) x 1.2 = 750 m^3

1.3 Assume another 0.305 m for gravel bed height:

Volume of gravel is 0.305 (m) x 20 (m) x 40 (m) = 244 m^3

1.4 Volume to be excavated = media volume + gravel volume = 750 (m^3) + 244 (m^3) = 994 m^3

1.5 Excavation (includes equipment, labor, overhead/profit) and off-site disposal (assume non-hazardous and 10-nule roundship) = USD 3/ m^3

1.6 Total cost for site preparation = USD 3/m^3 x 994 (m^3) = USD 2,982

2. Media costs

2.1 The cost of rice husk in Thailand is USD 4/m^3 so the media cost is 750 (m^3) x USD 6/m^3 = USD 4,500

2.2 Labor cost = USD 0.3/m^3 = USD 0.3/m^3 x 994 (m^3) = USD 298.2

Total capital cost = USD 2,982 + USD 4,500 + USD 298.2 = USD 7,780.2 (USD 389.01/year)

Annual operation and maintenance cost

1. Water consumption

Assuming inlet air from process stream is 50% saturated, it is estimated that 525.00 m^3/week will be used. Assumed cost of water is USD 0.5/m^3.

Water consumption is 525.00 m^3/week x 52 week x USD 0.5/m^3 = USD 13,650.00/year

2. Labor (USD 0.91/day)

Annual cost of labor = USD 0.91/day x 365 days/year = USD 332.15/ year

Total yearly operating costs = USD 13,650.00 + USD 332.15 = USD 13,982.15

Media replacement costs (every 5 years)

1. Media removal cost

Excavation, transportation, and disposal = USD 0.15/m^3

Volume to be excavated = 750 m^3

Total cost for media removal = 750 (m^3) x USD 0.15/m^3 = USD 112.5

2. New media addition

Assuming new media costs is USD 4/m^3,

Media cost = USD 6 /m^3 x 750 m^3 = USD 4,500

Labor cost for media installation = USD 0.3/m^3 = USD 0.3/m^3 x 750 (m^3) = USD 225

Total media replacement cost (every 5 years) = USD 112.5 + 4,500 + 225 = USD 4,837.5 (USD 967.5/year)

Annualized costs = USD 389.01+ USD 13,982.15+ USD 967.50 = USD 15,338.66/year

Other cost estimates

1. Investment costs per unit volume

Capital costs/volume of biofilter bed

USD 7,780.2/750 (m^3) = USD 10.37/m^3 of biofilter bed

2. Investment costs per flow rate

Capital costs/flow rate

USD 7,780.2/450,000 (m^3/hr) = USD 0.017/m^3hr^{-1}

3. Operating costs per volume of air treated

Operating costs per 1000 m^3 of air treated

In one year, 3,942 million cubic meters of air will be treated at a flow rate of 450,000 m^3/hr

USD 13,982.15/3,942 x 10^3 (m^3) = USD 0.0035 per 1,000 m^3 air treated

4. Annualized costs per volume of air treated

Annualized costs per 1,000 m^3 of air treated

In one year, 3,942 million cubic meters of air will be treated at a flow rate of 450,000 m^3/hr

USD 15,338.66/3,942 x 10^3 (m^3) = USD 0.0039 per 1,000 m^3 air treated

IV. CONCLUSION

The removal efficiency as more than 99% when input both low and high concentration of ammonia. From nitrogen mass balance showed that the mechanism in biofilters was media adsorption 67.00%, 17.70% can be drained as ammonia contaminated leachate and assumed biotransformation by bacteria 14.97%. The leachate from the system should be treated before drain into the environment due to still high ammonia concentration.

In conclusion, the deigned low cost biofilter from rice husk and compost is suitable for livestock farms in Thailand. Ammonia gas can be removed efficiency, 99% ammonia removal. The annualized cost per volume of air treated is USD 0.0039/ 1,000 m^3 air treated.

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