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Research article

Use of compost as biological filter to remove gaseous hydrogen sulfide

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ABSTRACT

Odor pollution is very popular in developing countries. Odors can arise from many different sources, cause discomfort to expose, and also have certain effects on health. Odors can come from the anaerobic digestion of waste, from a factory's wastewater treatment system, or from manufacturing operations in industries such as seafood processing or animal feed production, tanning, and rubber processing. The composition of the odor is often diverse with many gases, mainly in low concentrations. Because it is gaseous pollution, the odor has the risk of spreading widely, the collection must be carried out in a wide range, the flow of gas to be treated is often large. In this study, one of the basic components of odors, H_2S, was of interest to be treated because of its prevalence and toxic nature. Currently, although there are many technologies to handle H_2S, the application in odor treatment still has many shortcomings. The current technologies such as adsorption and absorption are not suitable for the removal of H_2S in odor because of the low efficiency but high cost. In this study, a cheap and available commercial compost fertilizer was used for the removal of gaseous H_2S in a lab-scale biofilter. Results showed that microorganisms had an avital role in H_2S removal. The factors affecting the biological removal of H_2S were determined to be relative humidity (RH), operation time, presence of mixing/turning, and height of compost column. The high H_2S removal efficiency of 94.2% was obtained at RH of 50% and compost height of 400 mm, which is suggested for full-scale biofilter design. Under turning condition of once per two days for compost column, the biofilter system was stable at removal efficiency of over 80% during at least 12 days of operation.

Key words: Biofilter, Compost, H2S

INTRODUCTION

Air pollution is a very serious issue in many developing countries such as Vietnam. Odor pollution is one of the most popular type of air pollution which causes annoyance and uncomforting for neighbor. Odor is characterized by various bad smell compounds such as H_2S, NH_3, mercaptans, amines and other compounds at low concentration. Various methods have been developed for removal of odorous compounds such as condensation at low temperature, adsorption with activated carbon, absorption with water/acid/basic solution, incineration with/without catalyst, and biological methods [1–5]. Among these technologies, biological method was proven to be the best candidate for treatment of odorous compounds with biodegradability and low concentration [6–8]. Moreover, biological method has many advantages such as efficient and economical work for low concentrations, low installation and operation costs, low maintenance requirements, long life for the biofilter, and environmentally safe operation [3,7,9]. Biological method for gas treatment includes biofilter, biotrickling filter, bio-scrubber, and bio-membrane reactor, which are similar principles of biodegradation by microorganism, but different on design, configuration, and operation [9]. Among these, biofilter has a long history of application for odor control due to its simplicity in design and operation, high efficiency, and without secondary wastewater. Biofilter has been studies by several researcher for removal of H_2S in air [10–16]. The design and operational parameters to control the biofiltration of H_2S has been considered in the research of Yang *et al.* [10]. In the H_2S initial concentration range of 5-2650 ppm(v), the biological filtration system with filter material derived from garden waste can be up to 99.9% efficient. Biofilters, bio-scrubbers, and bio-trickling filters can be applied to remove H_2S in biogas [16]. Although biological filtration for H_2S treatment has received a lot of attention, it is very limited information about the practical application of a commercial, cheap, and popular compost in Vietnam for the treatment of H_2S. The compost market has recently increased in Vietnam

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as a result of demand increase in organic agriculture products. There are several compost brands could be found in the market with different prices, ingredients, and originality. Testing the H_2S filtration efficiency of commercial composts is expected to contribute to promoting the applicability of commercially available organic fertilizers in environmental remediation.

In this study, gaseous H_2S was removed by a biofilter system using a popular and cheap compost as biomedia. The removal efficiency of H_2S was investigated at different relative humidity, operation time, and compost height. The role of biological degradation and adsorption was also determined with and without the presence of microorganisms, respectively.

MATERIALS AND METHODS

After surveying, the compost chosen and used in this study was Dynamic Organic 3-4-3 from Japan (Figure 1) with lowest prices of 1.08 USD/kg and ingredient listed in Table 1. Based on this composition, compost appears to have sufficient organics and nutrients, which is a suitable packing material for the developing of microorganisms in the biofilter.

Before placing in the biofilter model, compost material was tested to determine its initial parameters such as humidity, density, and pH. Average results of these preliminary tests are shown in Table 2. Compost was arranged in three separate and consecutive layers by placing slightly and naturally into the biofilter model to prevent the compaction and keep its original porous structure.

Figure 1: Dynamic Organic 3-4-3

The experimental setup is illustrated in Figure 2. The system included a gas system for H_2S generation and a biofilter for H_2S degradation. Pure and concentrate H_2S gas was created by slowly adding of Na_2S solution into H_2SO_4 solution. The concentrate H_2S flow was then diluted with clean air a certain mixing ratio to obtain the desired concentration of 30 ppm and total gas flow rate of 10 L/min before passing through biofilter. Biofilter was made of polyvinyl chloride water pipe with inner diameter of 108 mm. The concentration of H_2S gas is determined by Methylene Blue Method and titration with iodine according to Vietnam Standard (10 TCN 676-2006). The H_2S absorbent solution was prepared by dissolving 3.15 g of $CdSO_4.3H_2O$ in 500 mL of 0.5 N H_2SO_4 solution. The sampling procedure was as follows: arrange 25 mL of absorbent solution into 2 impingers connected in series, adjust the sampling rate to 100 mL/min by the flowmeter, and collect samples for 20 min. The concentration of H_2S was analyzed by absorption spectrophotometry with the following steps: extract 6 mL of sample containing H_2S, add 1 drop of p-paminodimethylaniline solution, shake well, stabilize for 10 min, and measure the absorbance at wavelength 660 nm. The results are compared with the standard series to calculate the H_2S concentration. The inlet concentration was examined regularly in order to ensure a difference of 0 – 1 ppm compared to the requirement. The H_2S removal efficiency (E, %) was determined follows the below formular, where C_{in} and C_{out} are inlet and outlet H_2S concentration, respectively.

$$E,\% = \left(1 - \frac{C_{in}}{C_{out}}\right) \times 100$$

The system's stable operating time is 2 days before performance evaluation. At each condition, the H_2S outlet concentration was analyzed 3 times, each time was 90 min apart. The results in the report are the average results. In the first experiment, compost and sterile compost were use as filter material to investigate the effect of microorganisms on the treatment efficiency. Commercial fertilizers are weighed to a specified mass, moisture treated by the addition of water to achieve the required moisture content. For the sterile compost, moisture is also added with the same method, but before that, the material is dried at 80 °C for 24 h to destroy the existing microflora. In addition, a temperature and relative humidity value of filter material were recorded in this experiment. After that, the relative humidity was changed in the range of 30−65%, the removal efficiency was monitored. To evaluate the stability of the biofiltration system and effect of stirring, experiments with long run time (25 days and 12 days, respectively) were performed. Efficiency, temperature, and compost pH are values to be observed every day. The compost height was fixed at 300 mm in the above experiments. In the final test, this value was varied from 300 to 500 mm, in order to investigate the appropriate mass of compost used for the system.

Table 1: **Ingredient of Dynamic Organic 3-4-3 compost**

Ingredient	Unit	Value	Ingredient	Unit	Value
N	%	3	S	%	0.3
P	%	4	Mg	%	0.4
K	%	3	Fe	ppm	430
Total Organic	%	40	Mn	ppm	350
C	%	20	Zn	ppm	350
Ca	%	9	Cu	ppm	30

Table 2: **Initial humidity, density and pH of the compost**

Parameter	Unit	Average value
Humidity	%	17.83
Density	g/cm^3	0.71
pH	-	7.51

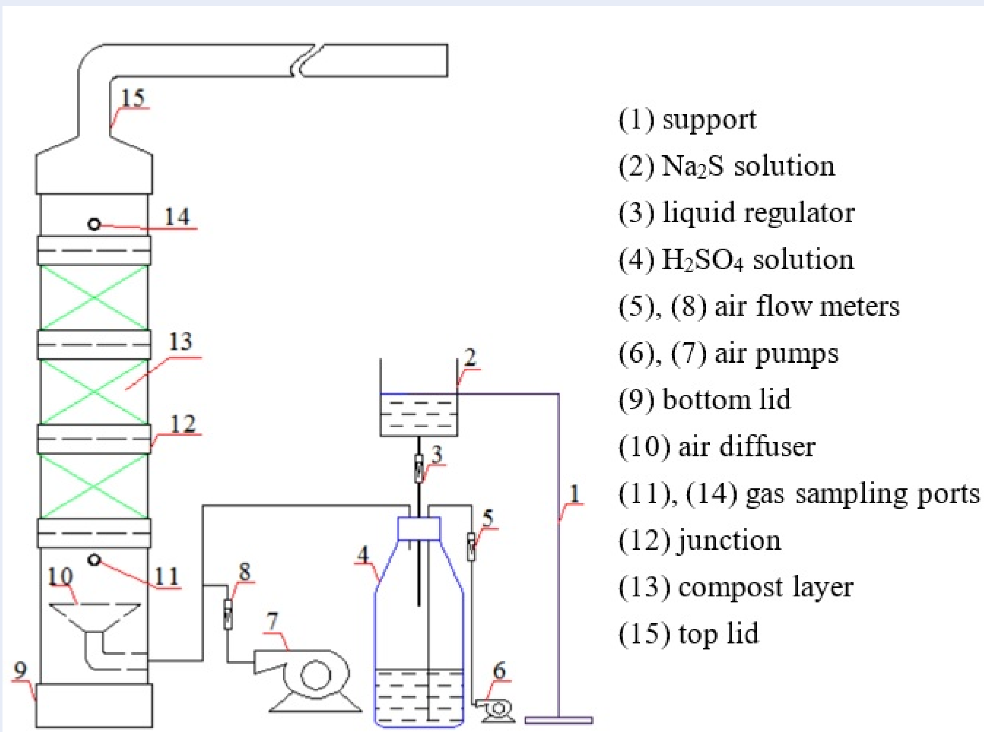

Figure 2: Biofilter system model for removal of H2S using compost

RESULT AND DISCUSSION

Effect of microorganisms

In other to clarify the role of microorganisms in the removal test, the adsorption with sterile compost and the biological degradation with original compost were conducted in this experiment. The results are presented in Table 3 at compost relative humidity (RH) of 18% and 50% with initial H_2S concentration at 30 ppm. The concentration of 30 ppm was chosen based on the design requirement of the biological treatment system for H_2S removal in Vietnam at peak concentration. At a low RH of 18%, the H_2S removal by original compost was very low at 17.8%, which was similar to that of sterile compost (13.4%). This implied that the removal ability of dry compost mostly depends on the adsorption of compost media. The removal ability of both composts significantly increased after increasing RH to 50%. However, there was a remarkable difference between the ability of original and sterile composts for H_2S removal at this high RH condition. The high removal efficiency of 82.4% by original compost, which was higher 3 times than that by sterile compost (26.5%), proven the vital role of microorganisms and its activity for H_2S removal at suitable humidity. Moreover, the lower pH value and higher temperature demonstrated more activity of microorganisms at RH of 50% as compared to that of 18%. The higher pH and temperature measured in original compost than those in sterile one further confirmed the activity of microorganisms for H_2S removal. The process of biological filtration to treat H_2S can occur in two stages (i) H_2S is adsorbed on the surface of the compost and (ii) H_2S is oxidized by the microorganisms present in the compost. The sulfur bacteria can belong to many different genera, the most commonly used being *Thiobacillus*.[17]. The decomposition process can release energy and form H_2SO_4 which lowers the pH of the compost[18].

Effect of relative humidity

As discussed above, compost humidity seems to have strong effect on the activity of microorganisms and the removal of H_2S. The effect of original compost humidity on its activity for biological removal of H_2S was investigated with RH ranged from 30 to 65%. Results in Figure 3 showed that H_2S removal efficiency increased gradually from 31.5% and reached the highest of 82.4% when RH increased from 30 to 50%. In this range, the increase of RH would enhance the microorganisms, proven by the similar increase tendency of compost temperature and pH. With further increase of RH from 50 to 65%, the removal efficiency decreases to 70.6% with similar decrease trend of compost pH and temperature. This suggests that high RH is not a favorable condition for removal of H_2S by compost, possibly due to the loss of compost porous structure and therefore the exposed biofilm under high RH condition. The mini review of Rattanapan *et al.*[18] also show that humidity is an important factor affecting the efficiency of biological filtration. However, the optimal humidity range concluded in this review is quite wide, from 20 to 60 wt% while in Ottengraf's study[19], this value ranges from 47 to 60 dry weight for compost. The difference in the results of this study with previous studies can be traced back to differences in filter media (or compost used). In addition, the moisture availability in the air stream is also an issue to be considered in biofiltration.

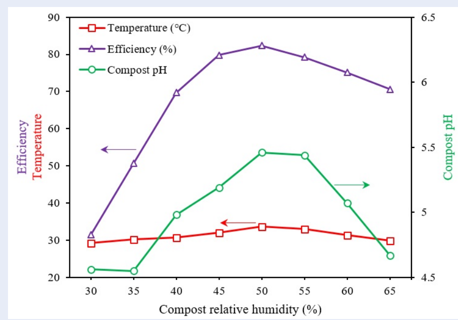

Figure 3: Effect of compost humidity

Stability test and effect of mixing

Compost was added with water to optimum RH of 50% and tested with H_2S removal for 25 days. The long-term performance of the biofilter model with fixed bed compost is illustrated in Figure 4 for removal efficiency, pH, and temperature. As observed in Figure 4, the highest removal efficiency was obtained on the first day and decrease in later days, when it took 2 to 3 days to stabilize the microorganism community development. From day 3^{rd} to 15^{th} day, the system was stable with efficiency of over 80%. After 15^{th} day, the removal efficiency decreased and was only 68.2% after 25 days of operation. Similar trend in pH and temperature change was also observed, proving the decrease of biological activity and its effect on the removal efficiency of H_2S. Possible reason could be the compaction of compost layer under high humidity condition for long time of operation. On the other hand, the decomposition of H_2S as discussed above is capable of forming H_2SO_4 under sufficient humidity conditions, creating an acidic environment that affects microbial activity[18].

Table 3: H_2S removal by original and sterile composts

RH	Parameter	Compost	Sterile compost
18%	Efficiency (%)	17.80	13.40
	pH	6.31	6.50
	Temperature (°C)	28.50	27.83
50%	Efficiency (%)	82.40	26.50
	pH	5.46	4.58
	Temperature (°C)	33.67	27.17

In order to maintain the porous structure of compost media, the compost layers were turned once per two days during 12 days of the experiment. The result is presented in Figure 5, where the removal efficiency and temperature were relatively stable at values of 80% and 32.5 °C, respectively. The pH value in this case tends to be stable, which is different from the condition without stirring the filter material. The cause maybe due to the periodic stirring to help the compost have uniform moisture, not have accumulate moisture locally, limiting the oxidation of S^0 to SO_4^{2-} [18]. This suggested the significance of compost porous structure as well as the homogeneous moisture and composition of compost during the biological degradation of H_2S by microorganism activity. Similar findings were recorded in the report of Morgan-Sagastume *et al.* [20] when the H_2S initial concentration was 100 ppm, the experiment with stirring the filter material gave a higher H_2S degradation efficiency, above 90%.

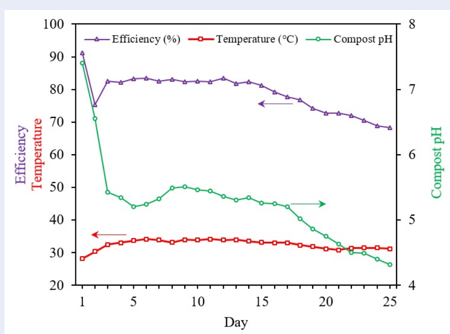

Figure 4: Stability test, fixed condition

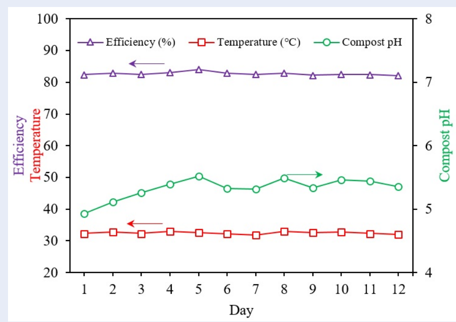

Figure 5: Stability test, turn once per two days

Effect of compost height

Under fixed gas flowrate, the height of compost will affect the retention time of gas in compost layer. Increase of compost height provides more compost media for gas treatment but results in higher pressure drop. The effect of compost height on the removal of H_2S was investigated in range of 300 to 500 mm compost height. Result displayed in Figure 6 showed that the removal efficiency increased with the increase of compost height, which was most effective in range of 300 to 400 mm where efficiency increased from 87.8 to 94.2%. However, further increase from 400 to 500 mm only resulted in a slightly increase of 4.2% efficiency. Therefore, 300 to 400 mm is suggested as a suitable compost height for biofilter design using this kind of compost. Most studies have shown that increasing the volume of the filter material while the gas flow velocity is kept constant (or increasing the empty bed residence time - EBRT) improves the biofiltration efficiency [21,22]. However, the degree of influence as well as the appropriate EBRT is also dependent on other factors such as pollutant concentration and biodegradability [6].

CONCLUSIONS

The treatment of gaseous H_2S by biofilter system using low-cost compost was done in this study. The removal of H_2S treatment was found to be mainly carried out by microorganism activity in compost. The suitable condition was found to be humidity of 50% and compost height of 400 mm. The performance was stable after 2 to 3 days and turning is suggested

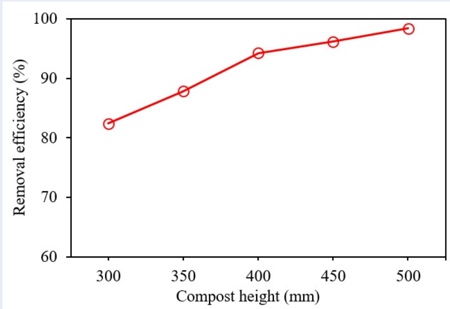

Figure 6: Effect of compost height

for stable operation in long-term operation. Future studies should focus on the comparison with other compost materials, especially on the local composts of Vietnam. The microorganism community in compost should also be determined to recognize the effective groups of microorganisms for H_2S removal. The performance of this system for actual odorous gas with multiple air pollutants (e.g., from wastewater treatment plant and solid waste transferring station) should be investigated. The operational condition (e.g., pH, oxygen, carbon sources, nutrients, and humidity, retention time, air humidity) should be optimized for obtaining the optimum condition with highest treatment performance.

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CONFLICT OF INTEREST

There is no conflict of interest regarding this manuscript.

AUTHORS' CONTRIBUTION

Nguyen Thi Le Lien and Nguyen Nhat Huy outline the research, plan the experiment, and prepare the figures.

Nguyen Duy do the experiment, collect, and compose data.

Lam Pham Thanh Hien support to do experiment and prepare equipment

Vo Thi Thanh Thuy and Le Thi Kim Phung support to process data, prepare the draft manuscript, and complete the final manuscript.

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Tạp chí Phát triển Khoa học và Công nghệ – Kĩ thuật và Công nghệ, 4(SI1):SI62-SI69

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Bài nghiên cứu

Nghiên cứu xử lý H_2S bằng quá trình lọc sinh học với phân bón hữu cơ giá rẻ

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TÓM TẮT

Mùi hôi là một vấn đề môi trường phổ biến ở các nước đang phát triển. Mùi có thể phát sinh từ nhiều nguồn khác nhau, gây sự khó chịu khi tiếp xúc và cũng có những ảnh hưởng nhất định đến sức khỏe. Mùi có thể xuất phát từ quá trình phân hủy kỵ khí rác thải, từ hệ thống xử lý nước thải của nhà máy, hoặc từ các hoạt động sản xuất của các ngành công nghiệp như chế biến thủy sản, sản xuất thức ăn gia súc, thuộc da, và chế biến cao su. Thành phần của mùi hôi thường đa dạng nhiều chất khí, chủ yếu ở nồng độ thấp. Vì là ô nhiễm dạng khí nên mùi hôi có nguy cơ phát tán rộng, việc thug om phải tiến hành ở phạm vi rộng, lưu lượng dòng khí cần xử lý thường lớn. Trong nghiên cứu này, một trong các thành phần cơ bản của mùi hôi là H_2S được quan tâm xử lý bởi sự phổ biến và tính chất độc hại của nó. Hiện tại, mặc dù có nhiều công nghệ để xử lý H_2S tuy nhiên việc ứng dụng trong xử lý mùi còn nhiều bất cập. Các công nghệ hiện tại như hấp thụ hoặc hấp phụ không thích hợp trong xử lý mùi H_2S bởi hạn chế về mặt hiệu quả và giá thành. Trong nghiên cứu này, một vật liệu giá thành thấp có sẵn trên thị trường đã được sử dụng để chuyển hóa H_2S có trong dòng khí bằng hệ thống lọc sinh học quy mô phòng thí nghiệm. Kết quả cho thấy vi sinh vật có vai trò quan trọng trong việc xử lý H_2S. Ảnh hưởng của các yếu tố vận hành như độ ẩm phân compost, thời gian vận hành, điều kiện xới trộn và chiều cao lớp phân đến quá trình chuyển hóa sinh học của khí H_2S được khảo sát. Hiệu quả xử lý H_2S đạt 94,2% được ghi nhận với các điều kiện độ ẩm phân và chiều cao lớp phân lần lượt là 50% và 400 mm. Trong điều kiện có xới trộn (2 ngày/lần), hệ thống lọc sinh học có thể hoạt động hiệu quả trong suốt 12 ngày với hiệu quả chuyển hóa H_2S duy trì trên 80%.

Từ khoá: H2S, Lọc sinh học, Phân compost

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