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Original Research Paper

Effect of Ventilation Modes on Production and Emission of Volatile Organic Compounds During Sewage Sludge Composting

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ABSTRACT

To investigate the relationship between ventilation modes and volatile organic compounds (VOCs) production and emission properties during sludge composting, two trials were conducted with different ventilation modes, the large ventilation rate for a short ventilation time (T1) and the small ventilation rate for a long ventilation time (T2). The VOCs were qualitatively and quantitatively monitored by gas chromatography-mass spectrometer (GC-MS). The results show that, the mass concentration of VOCs produced and emitted in the composting process of T2 is significantly higher than that of T1, the total VOC mass concentration of T1 and T2 during sewage sludge composting were 34052.0 $\mu g \cdot m^{-3}$ and 48476.6 $\mu g \cdot m^{-3}$, respectively. Total VOCs (TVOCs) emission concentration is 710.8 $\mu g \cdot m^{-3}$ and 1790.8 $\mu g \cdot m^{-3}$, respectively. Compared with the production of TVOCs, the emission of T1 and T2 were reduced by 97.9% and 97.9% respectively; the main VOCs components produced by two treatments are different, for T1, the production of olefin is the largest, accounting for 76.43% of the TVOCs. T2 produces the largest amount of oxygen-containing organic plant-based VOCs, accounting for 89.23% of the TVOCs. VOCs emission of two treatments during sewage sludge composting have the maximum concentration of oxygen-containing organic plant-based VOCs. The maximum ozone generation potential of TVOCs produced by T1 is higher than that of T2, while the maximum ozone generation potential of TVOCs emitted by T1 is lower than that of T2, in the process from produce to emission, the TVOCs maximum ozone generating potential of T1 and T2 were reduced by 99.2% and 96.1%, respectively. In order to control the secondary pollution to the environment caused by the emission of VOCs during the sludge composting, the ventilation mode of T1 is recommended.

INTRODUCTION

Secondary organic aerosol (SOA) is a very important portion in mass concentration of ambient fine particles (PM 2.5), and the volatile organic compounds (VOCs) are one of the most important precursors for SOA formation (Chen et al. 2013). Composting is widely considered to be a low-cost and environmental friendly method to manage and treat sewage sludge. However, the intense microbial activity during composting may produce and release VOCs (Shen et al. 2013). The environmental problem caused by the presence of VOCs in gaseous streams is due to the fact that many of them produce bad odours or are hazardous (Eitzer 1995). At the same time, VOCs can contribute to global warming, stratospheric ozone depletion and tropospheric ozone formation (Komilis et al. 2004). Most researchers have reported the emission and effects of VOCs during composting. Shen et al. (2012) reported that the maximum production and emission masses occurred in the mesophilic phase of composting. Kumar et al. (2011) reported that the emission rate of VOCs in the early stage of green waste composting was five times higher than in the late stage. However, ventilation mode has significant impact on production and emission of VOCs during sewage sludge composting. The objective of this work was to qualitatively and quantitatively analyse VOCs production and emission in two ventilation modes during sludge composting using gas chromatography-mass spectrometer (GC-MS) monitoring method.

MATERIALS AND METHODS

The experiment was carried out in the Bagang Municipal Sewage Sludge Treatment Plant in the city of Zhengzhou, China. The compost pile was 30×5.4×1.8m (L×W×H). Air was supplied (from bottom to top of the pile) by an air blower. The aeration strategy was auto-controlled according to the set ventilation mode. Ventilation mode of treatment 1 (T1) was large ventilation rate for a short ventilation time where ventilation rate was 0.12 $L \cdot min^{-1} \cdot kg^{-1}$. Ventilation mode of treatment 2 (T2) was the small ventilation rate for a long ventilation time, where ventilation rate was 0.08 $L \cdot min^{-1} \cdot kg^{-1}$. Total ventilation of T1 and T2 keep the same during sewage sludge composting.

Sewage sludge (SS) was taken from the Wulongkou Municipal Wastewater Treatment Plant in Zhengzhou. Mature compost and sawdust collected from the Bagang Sewage Sludge Treatment Facility were used as composting mixtures. The moisture content (MC) of sewage sludge was 79.81%, and the volatile solids (VS) content is 60.3%. Sawdust and mature compost moisture contents were 8.23%, 34.5% respectively, VS contents were 95.5% and 43.3% respectively. The mass ratio of sludge, compost, and sawdust was 10:2:1, the MC and VS of the initial composting materials were 55.2% and 52.5% respectively.

The sampling time of VOCs was at the early stage of the high temperature (5 days) when VOCs emission is the largest (Eitzer et al. 1995). The sampling points were set up within the compost pile for 50 cm and the surface of compost pile for 10 cm in the fermentation tank, representing the production and emission of VOCs during the composting process. Sampling devices were SUMMA canisters, within 24 h after sampling the samples were sent for VOC full analysis with GC-MS system (Agilent 7890 a and 7890 c gas chromatography mass spectrometry instrument).

The method of incremental reactivity puts forward the concept of VOCs incremental reactivity(IR), namely, the change of ozone concentration which is produced by adding or removing unit designated VOCs in the given mixed VOCs air, incremental reactivity is usually affected by two aspects of VOCs and NO_x, change the ratio of VOCs/NO_x to make incremental reactivity maximum and then the concept of maximum incremental reactivity (MIR) is formed.

Maximum increment reactivity (MIR) is the product of maximum incremental reactivity coefficient (MIR coefficient) and the concentration of VOCs component, and MIR coefficient can be expressed as follows (Carter et al. 1994).

$$MIR\text{coefficient} = \text{Max}[\frac{\partial \rho(O_3)}{\partial \rho(VOCs)}]$$

Among which $\rho(O_3)$ stands for atmospheric ozone concentration, ρ(VOCs) acts as atmospheric concentrations of VOCs, the partial differential part refers to the change trend of O_3 as the change of VOCs concentration, the greater the coefficient of MIR, meaning increasing the concentration of unit VOCs can produce more concentration increment of O_3, and the MIR values can response the increment of O_3 produced by VOCs components at this concentration level in current mixed gas.

RESULTS AND DISCUSSION

The concentration level of VOCs components produced and emitted during composting: VOCs produced and emitted from sludge composting process include alkanes (propane, butane, isobutene), alkenes (propylene, 1-butylene), aromatic hydrocarbons (benzene, toluene, ethyl benzene, m-xylene, p-xylene, o-xylene), oxygen-containing organic compounds (2-butanone, ethanol, acetone) (Tables 1, 2). VOCs components of two treatments produced during the compost process were different. Main VOCs components concentrations produced by T1 from high to low as: 1-butylene, acetone and ethanol, which are 26025.0μg·m^{-3}, 5173.2 μg·m^{-3}and 2319.9μg·m^{-3}, respectively, among which olefin VOCs has the maximum, accounting for 76.43% of the TVOCs. Main VOCs components concentrations produced by T1 from high to low as follows: acetone, 2-1-butylene, butanone, which are 26520.8μg·m^{-3}, 16734.8μg·m^{-3} and 4064.6μg·m^{-3}, where the maximum belongs to oxygen-containing organic plant-based VOCs, sharing 89.23% of the TVOCs.

VOCs emitted by T1 and T2 during composting have the maximum concentration in the form of oxygen-containing organic plant-based VOCs, accounted for 71.79% and 90.00% of TVOCs, respectively. The emitted concentration of VOCs components of T1 from high to low as follow: 2-butanone, ethanol and acetone, whose concentrations are 228.9μg·m^{-3}, 144.5μg·m-3 and 136.9 μg·m^{-3}, the successive order of VOCs components emitted concentration of T2 was: 2-ethyl ketone, acetone and ethanol, which is 829.7μg·m^{-3}, 613.0μg·m^{-3} and 169.1 μg·m^{-3}, respectively. The TVOCs concentration produced by T1 and T2 during composting process are 34052.0μg·m^{-3} and 48476.6 μg·m^{-3}, respectively. The total VOC emission concentrations are 710.8μg·m^{-3} and 1790.8 μg·m^{-3}, respectively. TVOCs produced and emitted in the composting process of T2 was significantly higher than that of T1.

The reactivity of VOCs components produced and emitted during composting: The concentration and reactivity analysis of VOCs produced and emitted during composting process are presented in Table 1 and Table 2, while VOCs components concentration is in the form of mass concentration μg·m^{-3}.

Table 1 and Table 3 show that VOCs components produced from T1, when compared with the method of incremental reactivity, the biggest potential of ozone generation belongs to olefin VOCs, accounting for 95.86% of the total biggest ozone generating potential, followed by the oxygen-containing organic plant-based VOCs, aromatic hydrocarbon VOCs and alkane VOCs, accounting for 3.75%, 0.32%, 0.07% of total ozone generating potential, respectively. VOCs components emitted to the surface of pile, according to the method of incremental reactivity, the biggest potential of ozone generation belongs to oxygen-containing organic plant-based

Table 1: The concentration level of every VOCs component in the internal and surface of T1.

	Production Concent-rations/ µg·m⁻³	Emission Concent-rations/ µg·m⁻³	K^{OH} (VOCs)	Equivalent Propylene concent-rations (production) /µg·m⁻³	Equivalent Propylene concentrations (emission) /µg·m⁻³	MIR Coefficients	MIR values (production) /µg·m⁻³	MIR values (emittion) /µg·m⁻³	Activity reduced proportion of every compost
Propylene	0	0	26.3	0	0	11.66	0	0	-
1-butylene	26025.0	39.6	31.4	31071.7	47.3	9.73	253223.3	385.3	99.8%
Acetone	5173.2	136.9	0.17	33.4	0.9	0.56	2897.0	76.7	97.3%
2-butanone	185.4	228.9	1.22	8.6	10.6	4.02	745.3	920.2	-23.4%
Benzene	24.9	10.6	1.22	1.2	0.5	0.72	17.9	7.6	57.4%
Methylbenzene	112.1	12.1	5.63	24.0	2.6	4.00	448.4	48.4	89.2%
Ethylbenzene	15.7	5.5	7.0	4.2	1.5	3.04	47.7	16.7	65.0%
M-xylene	17.7	6.3	23.1	15.5	5.5	7.80	138.1	49.1	64.4%
P-xylene	16.5	4.0	14.3	9.0	2.2	7.80	128.7	31.2	75.8%
O-xylene	9.7	4.2	13.6	5.0	2.2	7.64	74.1	32.1	56.7%
Dimethylmethane	0	85.1	1.09	0	3.5	0.49	0	41.7	-
Butane	78.3	21.1	2.36	7.0	1.9	1.15	90.0	24.3	73.1%
Iso-butane	73.6	12.0	2.12	5.9	1.0	1.23	90.5	14.8	83.7%
Ethyl alcohol	2319.9	144.5	3.2	282.3	17.6	2.70	6263.7	390.2	93.8%
TVOCs	34052.0	710.8	-	31467.8	97.1	-	264164.8	2038.2	99.2%

Table 2: The reactivity of every VOCs component in the internal and surface of T2.

	Production Concent-rations/ µg·m⁻³	Emission Concent-rations/ µg·m⁻³	K^{OH} (VOCs)	Equivalent Propylene concent-rations (production) /µg·m⁻³	Equivalent Propylene concentrations (emission) /µg·m⁻³	MIR Coefficients	MIR values (production) /µg·m⁻³	MIR values (emittion) /µg·m⁻³	Activity reduced proportion of every compost
Propylene	739.9	0	26.3	739.9	-	11.66	8627.2	0	100%
1-butylene	4064.6	72.2	31.4	4852.8	86.2	9.73	39548.6	702.5	98.2%
Acetone	26520.8	613.0	0.17	171.4	4.0	0.56	14851.6	343.3	97.7%
2-butanone	16734.8	829.7	1.22	776.3	38.5	4.02	67273.9	3335.4	95.0%
Benzene	17.1	9.6	1.22	0.8	0.4	0.72	12.3	6.9	43.9%
Methylbenzene	25.8	9.3	5.63	5.5	2.0	4.00	103.2	37.2	64.0%
Ethylbenzene	12.0	4.8	7.0	3.2	1.3	3.04	36.5	14.6	60.0%
M-xylene	10.3	5.6	23.1	9.0	4.9	7.80	80.3	43.7	45.6%
P-xylene	8.2	3.8	14.3	4.5	2.1	7.80	64.0	29.6	53.7%
O-xylene	8.2	3.9	13.6	4.2	2.0	7.64	62.6	29.8	52.4%
Dimethylmethane	139.8	47.9	1.09	5.8	2.0	0.49	68.5	23.5	65.7%
Butane	171.5	12.9	2.36	15.4	1.2	1.15	197.2	14.8	92.5%
Iso-butane	23.6	9.0	2.12	1.9	0.7	1.23	29.0	11.1	61.9%
Ethyl alcohol	0	169.1	3.2	0	20.6	2.70	0	456.6	-
TVOCs	48476.6	1790.8	-	6590.8	165.8	-	130955.0	5048.9	96.1%

VOCs, accounting for 68.05% of the total ozone generating biggest potential, followed by olefin VOCs, aromatic hydrocarbon VOCs and alkane VOCs, sharing 18.90%, 9.09%, 3.96% of total ozone generating potential, respectively.

VOCs components produced from the T2, when compared with the method of incremental reactivity, the biggest potential of ozone generation belongs to oxygen-containing organic plant-based VOCs, accounting for 62.71% of the total biggest ozone generating potential, followed by olefin VOCs, aromatic hydrocarbon VOCs and alkane VOCs, sharing 36.79%, 00.27% and 0.23%, respectively. VOCs components emitted to the surface of pile, according to the method of incremental reactivity, the biggest potential of ozone generation belongs to oxygen-containing organic plant-based VOCs, accounting for 81.90% of the total ozone generating biggest potential, followed by olefin VOCs, aromatic hydrocarbon VOCs and alkane VOCs, sharing 18.90%, 9.09% and 3.96% of total ozone generating potential, respectively.

Table 3: Reactivity of VOCs and their percentages of TVOC reactivity.

		TVOCsmass Concent-rations/ $\mu g \cdot m^{-3}$	Alkane $\mu g \cdot m^{-3}$	Percentage / %	Olefin /$\mu g \cdot m^{-3}$	Percentage / %	Aromatic hydrocarbon /$\mu g \cdot m^{-3}$	Percentage / %	Oxyor-ganics /$\mu g \cdot m^{-3}$	Percentage / %
Production	T1	34052.0	151.9	0.45	26025.0	76.43	196.6	0.58	7678.5	22.55
	T2	48476.6	334.9	0.69	4804.5	9.91	81.6	0.17	43255.6	89.23
Emission	T1	710.8	118.2	16.63	39.6	5.57	42.7	6.01	510.3	71.79
	T2	1790.8	69.8	3.90	72.2	4.03	37.0	2.07	1611.8	90.00
Maximum	T1	264164.8	180.6	0.07	253223.3	95.86	854.9	0.32	9906	3.75
increment reactivity (production)	T2	130955	294.8	0.23	48175.8	36.79	358.9	0.27	82125.5	62.71
Maximum increment reactivity	T1	2038.2	80.7	3.96	385.3	18.90	185.2	9.09	1387	68.05
(emission)	T2	5048.9	49.4	0.98	702.5	13.91	161.8	3.20	4135.2	81.90

The maximum ozone generating potential of total VOCs produced by T1 and T2 during composting were 2038.2 $\mu g \cdot m^{-3}$ and 5048.9$\mu g \cdot m^{-3}$, respectively. The maximum ozone generation potential of TVOCs emitted are 2038.2 $\mu g \cdot m^{-3}$ 05048.9 μg·m-3, respectively. The maximum ozone generation potential of TVOCs produced by T1 is higher than T2, while the maximum ozone generation potential of TVOCs emitted by T1 is lower than that of treatment 2, in the process from the production to the emission, TVOCs maximum ozone generating potential were reduced by 99.2% and 96.1%, respectively.

CONCLUSIONS

VOCs produced and emitted from sludge composting process have 14 main components, which can be divided into four major categories such as alkane VOCs, olefin VOCs, aromatic hydrocarbon VOCs and oxygen-containing organic plant-based VOCs. TVOCs concentrations produced by T1 and T2 during sewage sludge composting were 34052.0$\mu g \cdot m^{-3}$ and 48476.6$\mu g \cdot m^{-3}$, respectively, the TVOCs emission concentrations are 710.8$\mu g \cdot m^{-3}$ and 1790.8 $\mu g \cdot m^{3}$, respectively. The TVOCs concentrations of T1 emitted during composting was significantly higher than that of T1. The maximum ozone generation potential of TVOCs produced by T1was higher than that of T2, while the maximum ozone generation potential of TVOCs emitted by T1 is lower than that of T2. In order to control the secondary pollution to the environment caused by the emission of VOCs during the sludge composting, the ventilation mode of T1 is recommended.

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REFERENCES

Carter W.P.L. 1994. Development of ozone reactivity scales for volatile organic compounds. J. Air & Waste, 44(7): 881-889.

Chen, W. T., Shao, M. and Yuan, B. 2013. Parameterization of contribution to secondary organic aerosol (SOA) formation from ambient volatile organic compounds (VOCs). Acta Scientiae Circumstantiae, 33(1): 163-172.

Eitzer, B.D. 1995. Emissions of volatile organic chemicals from municipal solid waste composting facilities. Environmental Science and Technology, 29: 896-902.

Hanajima, D., Kuroda, K. and Morishita, K. 2010. Key odor components responsible for the impact on olfactory sense during swine feces composting. Bioresource Technology, 101(7): 2306-2310.

Komilis, D. P., Ham, R. K. and Park, J. K. 2004. Emission of volatile organic compounds during composting of municipal solid wastes. Water Research, 38: 1707-1714.

Kumar, A., Alaimo, C.P., Horowitz, R., Mitloehner, F.M., Kleeman, M.J. and Green, P.G. 2011. Volatile organic compound emissions from green waste composting: Characterization and ozone formation. Atmospheric Environment, 45(10): 1841-1848.

Shen, Y.J., Chen, T.B., Gao, D. Zheng, G,D., Liu, H,T. and Yang, Q.W. 2012. Online monitoring of volatile organic compound production and emission during sewage sludge composting. Bioresource Technology, 123: 463-470.