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Controlling the Composite Odour from Drying Sewage Sludge

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With economic development and an improved standard of living, the amount of domestic sewage sludge has increased annually. As an international agreement on a total ban on ocean dumping became effective in 2012, sludge has been processed with land treatment methods such as consolidation, incineration, dry fuel, carbonization and composting. This study conducted experiments for controlling composite odour emitted when drying 1,000 ton/day of sewage sludge at a drying facility to recycle sewage sludge into coal auxiliary fuel. The optimal operational condition of odour prevention facility was investigated to control odour substances emitted while drying sewage sludge. After setting the process water supply to 70 ton/day for scrubber 1, 3 and the pH of scrubber 2 to 4 by adding H_2SO_4, the facility was operated with 5 L/min of NaOCl and 49 L/min of process water, keeping scrubber 3 over pH 8.7 with NaOH and inputting 5 L/min of NaOCl and 49 L/min of process water; as a result, odour substances could be controlled stably within 144 times of composite odour level in the final outlet.

Keywords: Sewage sludge, Composite odour, Drying, Recycling.

INTRODUCTION

As part of the effort to improve water quality and prevent environmental pollution, the government established and expanded sewage treatment plants. As a result, the amount of domestic sewage sludge was 10,011 ton/day in 2014, which has increased annually [1,2]. The capacity of sewage sludge process facilities in Korea is 3,824.1 ton/day as of 2009: consolidation facilities (1,630 ton/day), incineration facilities (1,430 ton/day), drying facilities (430 ton/day), carbonization facilities (130 ton/day), mixed-incineration facilities for domestic waste (124 ton/day) and other drying, composting and worm castings facilities (80.1 ton/day) [3-5]. However, the international agreement on a total ban on ocean dumping of sewage sludge became effective starting in 2012, which led to a twofold increase in the process of land treatment methods. While landfill and incineration decreased by 23 % and 34 %, respectively, in 2013 compared to 2012, recycling, fuel and other land treatment methods increased by 19 %, 8 % and 87 %, respectively. This shows that the usefulness of recycling sewage sludge into compost and auxiliary fuel was evaluated highly. It reflects the policy for developing renewable energy using sewage sludge with the converted concept of energy recovery from the conventional process. As of July 2014, 101 sewage sludge process plants are being operated (10,187 ton/day) and 15 facilities (2,523 ton/day) are under construction (planning) for final treatment methods such as consolidation, incineration and dry co-combustion, dry fuel, drying, carbonization and composting (Table-1). As for drying, 20 extra plants have been established compared to 2012. In particular, 13 more facilities for dry fuel were installed [6,7].

Dry fuel plants currently in operation include the sludge recycling facility (2nd) in Sudokwon landfill site, which dries an average 1,000 ton/day of sewage sludge from 3 cities and provinces in the metropolitan area to produce 200-220 tons of dried sewage sludge and supply them as auxiliary fuel to the Western thermoelectric power plant.

TABLE-1
TREATMENT METHODS OF SEWAGE SLUDGE [Ref. 1] (Unit: ton/year)

Year	Landfill	Incineration	Recycling	Drying	Ocean dumping	Others	Carried-over amount	Total
2011	261,262	687,868	1,025,576	–	1,010,322	110,413	507	3,095,948
2014	692,274	815,425	2,034,811	56,839	–	51,680	3,207	3,654,236

Therefore, this study aimed to analyze the physico-chemical characteristics of sewage sludge and establish operational criteria for controlling composite odour emitted when drying sewage sludge with the direct drying method by using hot air [8].

EXPERIMENTAL

The equipment used for the experiment is capable of drying 1,000 ton/day on average. It consists of a feeding device, drying device and dry flue gas process device and odour prevention facility as shown in Fig. 1.

Being a hot-air drying rotary kiln type, the dryer can process 80 ± 5 % of sewage sludge to produce 5 ton/h of less than 20 mm homogeneous dried sludge with 10 % of moisture content. The composition and operational condition of the dryer are shown in Table-2.

TABLE-2
OPERATIONAL CONDITION OF THE ROTARY KILN DRYER

Item	Experimental condition
Capacity (ton/h)	4.17
Experimental materials	Sewage sludge
Water content (wt %)	80 ± 5
Supply (ton/h)	4.2
Gas temperature (inlet/outlet) (°C)	800/135
Rotation speed of crusher (rpm)	100, 200, 300
Rotation speed of dryer (rpm)	0.5, 1.0, 1.5, 2.0
Characteristics	High-speed crushing, 2-step crushing, Rotary screen

Method: For the study, sewage sludge from 3 cities and provinces in the metropolitan area was analyzed for physico-chemical characteristics, caloric values and heavy metal contents. In order to set the drying condition, the rotation speeds of the dryer and crusher were adjusted and operational conditions of the odour prevention facility were changed by process.

For odour analysis, samples were collected at seven sites of the odour prevention facility as shown in Fig. 1. For analysis of proximate, the Korea Standard Leaching Procedure was followed; the physico-chemical characteristics were analyzed using ultimate analyzer, bomb calorimeter and ICP-MS. For composite odour, a 3-point comparison air dilution olfactory method was conducted. Examiners who can separate five different odours were selected and the samples were injected into one of three random bags with odourless air; the injection went in the order of 3, 10, 30, 100..... Until they could not recognize odours. Except for the best and worst examiners, three peoples results were produced as geometrical mean values. For an analysis of offensive odour substances, the samples were put in a 50 L bag and left at room temperature (25 °C) for 2 h. In order to minimize the impacts of odour occurring for the test periods of each sample, they were separated in 10L bags and GC-PFPD, HPLC and GC-MS were used to analyze odour substances.

RESULTS AND DISCUSSION

Physico-chemical characteristics of sewage sludge: To analyze the physico-chemical characteristics of sewage sludge produced from 3 cities and provinces in the metropolitan area, proximate, ultimate, caloric values and change of heavy metal contents were analyzed six times shown in Table-3.

The proximate of sewage sludge were analyzed to have 81.26 % of average water content, 12.01 % of combustible content and 6.73 % of ash content. As for the ultimate analysis, carbon was the highest with an average content of 30.61 %, followed by oxygen 15.99 %, hydrogen 5.55 %, nitrogen 4.64 % and sulfur 1.23 %.

The caloric values was averaged at 3,296 kcal/kg. When it

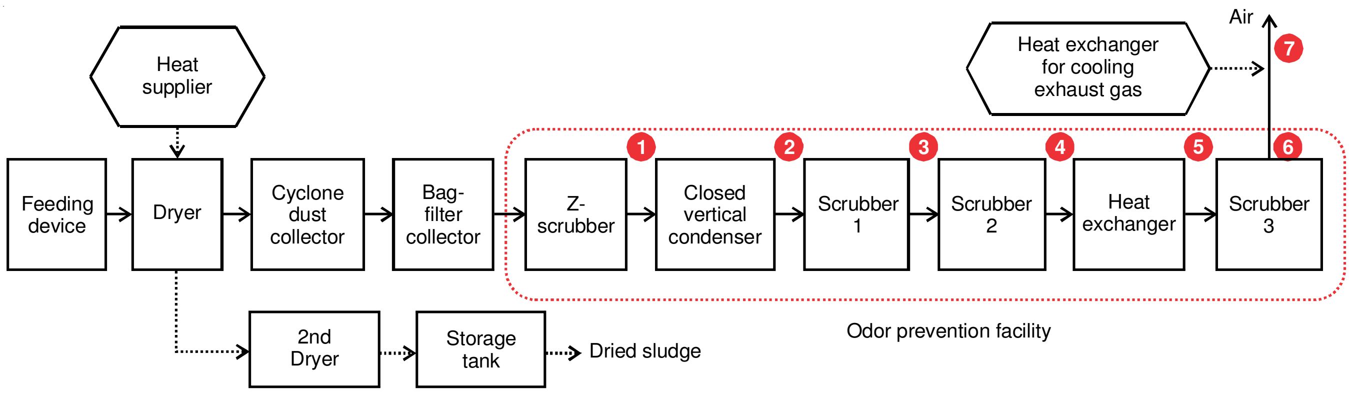

Fig. 1. Process diagram of drying sewage sludge

TABLE-3
PHYSICO-CHEMICAL CHARACTERISTICS OF SEWAGE SLUDGE

Item	Water (%)	Combustible (%)	Ash (%)	C (%)	H (%)	O (%)	N (%)	S (%)	Caloric values
Average	81.26	12.01	6.73	30.61	5.55	15.99	4.64	1.23	3,296 kcal/kg
Heavy metal leaching test (mg/L)									
Item	Cyanide	Cr^{6+}	Cu	Cd	Pb	As	Hg	Organic phosphorus	PCE
Average	0.067	0.12	0.494	n.d	0.012	n.d	n.d	n.d	n.d

came to heavy metal contents, Cd, As, Hg, organic phosphorus, perchloroethylene (PCE) and trichloroethylene (TCE) were not detected, while cyanide was 0.067 ppm, Cr^{6+} 0.12 ppm, Cu 0.494 ppm and Pb 0.012 ppm. Moreover, the characteristics of sewage sludge were studied by season: spring (Mar-Apr), summer (Jul-Aug), fall (Oct-Nov) and winter (Dec-Jan). The result of analyzing hydrogen ion concentration (pH), moisture content, chlorine content, viscosity, organic substance content and composite odour is shown in Table-4.

The pH variation by season was between a minimum 6.1 and a maximum 8.59. In general, the pH levels were slightly higher in summer compared to other seasons. This is considered to be due to the high temperature during summer partially dissociating ammonia remaining in sludge. Meanwhile, organic substance content showed significant deviation from a minimum 47.14 % to a maximum 79.74 %; spring and fall showed about 10 % higher contents than summer and winter.

Chlorine ion concentration of sewage sludge showed a significant deviation from a minimum 1.39 ppm to a maximum 89.56 ppm; it was higher in fall and winter compared to spring and summer. As a result of analyzing viscosity that shows a dispersion of sludge in the dryer, it had a huge deviation between a minimum 12.50 kg/m.s to a maximum 87.81 kg/m.s; it was lower in spring and fall, while higher in summer and winter. This is considered to be due to coagulant being used a great deal as a dewatering aid in winter, making substances with electric charges such as cation polymers in sludge cohere and preventing dehydration.

Changes of composite odour conventional drying process: To investigate the operational condition of the sewage sludge dryer using a rotary kiln dryer, the study was conducted with different rotation speeds for the crusher and dryer: the rotation speeds of 100, 200 and 300 rpm for the crusher; and 0.5, 1.0, 1.5, 2.0 rpm for the dryer. Furthermore, the temperature of the inlet was increased to 800 °C and 4.2 tons of sewage sludge were added per hour. As a result of analyzing the diameter and moisture content of dry sludge, less than 20 mm diameter of dry sludge was produced 100 % with the crusher speed of 300 rpm; which met the dry sludge fuel standard, a diameter smaller than 20 mm. When the dryer speed was 1.0 and 1.5 rpm, the standard was satisfied.

To analyze sewage composite odour produced during the sludge drying process, samples were collected at a 10 min interval after the temperature of the dryer had risen to 800 °C. As a result, the maximum odour occurred 50 min after adding sludge, which was as high as 1,000,000 times concentration. As shown in Fig. 2, from 60 min later odour reduced dramatically.

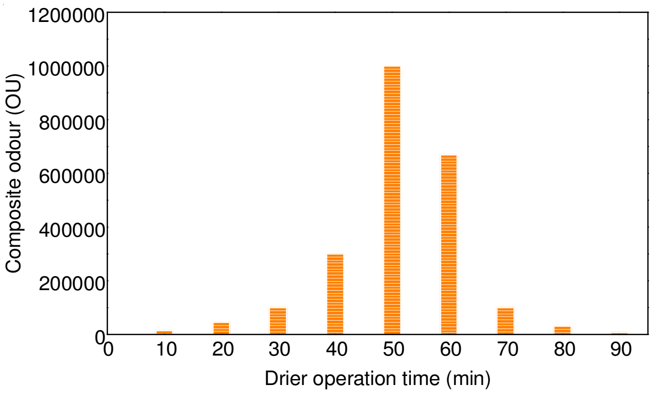

Fig. 2. Changes of composite odour according to the operation time of sludge dryer

Changes of composite odour in drying sewage sludge: The result of analyzing composite odour and offensive odour substances by process is shown in Fig. 3 and Table-5.

As shown in Fig. 3, the result of analyzing composite odour, the effect of odour reduction was shown overall; but the deviation was huge by process and even a problem of increased composite odour was detected. In particular, scrubber

TABLE-4
CHARACTERISTICS OF SEWAGE SLUDGE BY SEASON

Item	Spring	Summer	Fall	Winter	Average
pH	6.68	7.08	7.00	6.90	6.90
Organic substance content (%)	71.79	59.76	68.09	61.88	65.38
Chlorine ion content (ppm)	6.03	4.22	17.85	25.50	13.40
Viscosity (kg/m.s)	33.31	52.72	36.64	56.78	44.67
Composite odour (dilution rate)	128,355	18,906	22,155	52,545	55,490
Ammonia (ppm)	4.41	9.20	4.95	5.10	5.92
Hydrogen sulfide (ppm)	7.29	3.28	3.56	3.92	4.51
Methyl mercaptane (ppm)	9.26	4.63	5.71	6.70	6.57

TABLE-5
OFFENSIVE ODOUR SUBSTANCES IN DRYING SEWAGE SLUDGE

Test	Substance	Z-scrubber	Closed vertical condenser	Scrubber 1	Scrubber 2	Heat exchanger	Scrubber 3
S-1	Ammonia	158.82	131.250	126.510	16.258	Not detected	24.132
	Trimethylamine	0.428	0.225	0.025	0.116	Not detected	0.112
	Hydrogen sulfide	0.762	0.702	Not detected	Not detected	Not detected	0.899
	Methyl mercaptane	0.012	Not detected	0.198	0.195	0.056	Not detected
S-2	Ammonia	132.15	122.365	160.000	8.112	Not detected	21.285
	Trimethylamine	0.321	0.936	0.024	0.056	Not detected	0.155
	Hydrogen sulfide	0.425	0.264	Not detected	Not detected	Not detected	1.019
	Methyl mercaptane	0.161	Not detected	0.165	0.201	0.168	0.003

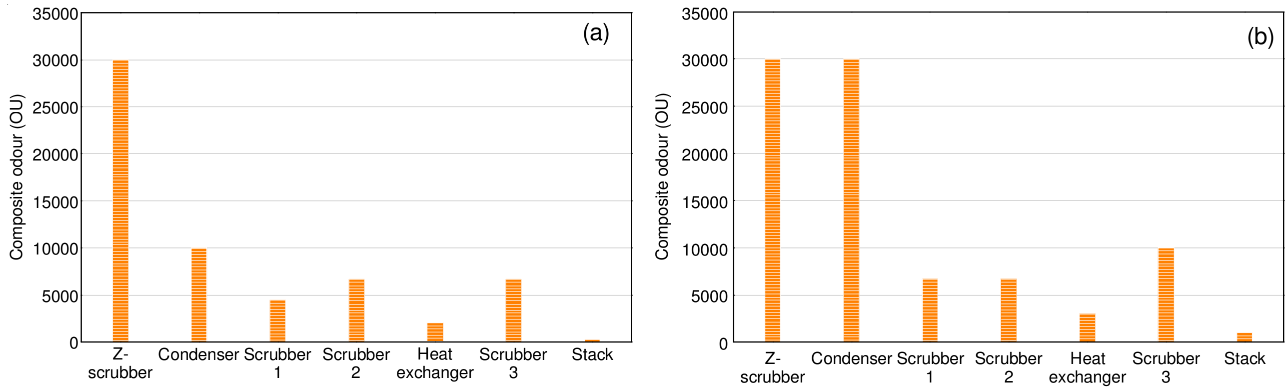

Fig. 3. Changes of composite odour in drying sewage sludge (a) sample 1, (b) sample 2

2 downstream in the first test and heat exchanger downstream in the second test had no reduction effect at all. As for scrubber 3, the reduction efficiency of composite odour decreased by 1 notch. Offensive odour substances also had the same results as shown in Table-5.

The condenser downstream in the second experiment showed a rapid increase of trimethylamine with low minimum threshold value and substances such as hydrogen sulfide and methylmercaptan rather increased going through dehumidification top to scrubber 3.

Such results are led to when improper chemicals were used by the process or circulating water was not replaced appropriately. This experiment tried to increase the efficiency of the odour prevention facility through proper input of liquid chemicals and replacement of circulating water; odour substances were removed by getting rid of alkali odour first and then neutral and acid odour simultaneously.

Alkali odour changes by pH adjustment in scrubber 2: For analysis of alkali odour emissions in scrubber 2 downstream, the pH of scrubber 2 was changed 2-8 times in order to control alkali odour. As a result, alkali odour was not produced when the pH was below 4 in both the first and second tests. With a pH over 6, the emissions increased to 12-45 ppm (Table-6).

TABLE-6
ALKALI ODOUR CHANGES IN SCRUBBER 2 DOWNSTREAM ACCORDING TO pH ADJUSTMENT

pH	Concentration of wet scrubber downstream (ppm)			
	Sample-1		Sample-2	
	Ammonia	Trimethylamine	Ammonia	Trimethylamine
2	n.d	n.d	n.d	n.d
4	n.d	n.d	n.d	n.d
6	12.8	1.9	11.3	0.9
8	46.9	3.7	44.8	2.8

Changes of composite odour by NaOCl adjustment: To lower overall composite odour by maximizing the efficiency of NaOCl and increasing the reduction efficiency of neutral odour, especially acetaldehyde, the experiment changed sodium hypochlorite to 0-6 L/min with the condition of pH 4. As a result, offensive odour substances and composite odour reduced when only sulphuric acid was added in the outlet of scrubber 2 during the first and second tests as shown in Table-7. It was revealed that adding NaOCl to not only scrubber 3 but also scrubber 2 significantly increased the reduction; the more NaOCl, the better the effect.

Sodium hypochlorite was used to control acid and neutral odour. Throughout the experiment, the pH of scrubber 2 and scrubber 3 were fixed to 4 and 8.7, respectively. After analyzing optimal input of NaOCl and changing it from 0 to 6 L/min, the reduction effect was confirmed through scrubber 3 outlet result as shown in Table-8.

As shown in Tables 7 and 8, device analysis results in both the first and second show that the more NaOCl, the better the odour reduction effect while the composite odour analysis also had a similar result. As for composite odour, however, it rather increased with the same amount of NaOCl (6 L/min) due to chemical odour. It was evaluated that the most proper NaOCl input was 5 L/min.

Changes of composite odour by process water supply: To analyze changes of composite odour by circulating water in the odour prevention facility, scrubber 2 was fixed to pH 4 and sodium hypochlorite input to 5 L/min; by changing process water from 7 to 63 L/min, the composite odour of scrubber 2 downstream was analyzed. As a result, water supply of less than 10 L/min had the same composite odour; from 10 to 50 L/min, the more water, the less the composite odour qualitatively. 60 L/min of water supply showed a more rapid increase in composite odour than 50 L/min; which was due to excessive

TABLE-7
ODOUR REDUCTION EFFECT BY INPUT OF SODIUM HYPOCHLORITE INPUT (pH = 4)

Substance	Input of sodium hypochlorite (L/min)											
	0		2		3		4		5		6	
	S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2
Composite odour	44,814	30,000	14,422	10,000	6,694	6,694	4,481	4,481	2,080	3,000	4,481	4,481
Ammonia	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Trimethylamine	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hydrogen sulfide	1.264	0.965	0.864	0.865	0.793	0.739	0.537	0.518	0.321	0.427	0.295	0.317
Methyl mercaptane	0.032	0.027	0.017	0.019	0.010	0.012	0.009	0.009	0.006	0.005	0.003	0.004

TABLE-8
ODOUR REDUCTION EFFECT BY INPUT OF SODIUM HYPOCHLORITE (pH = 8.7)

Substance	Input of sodium hypochlorite (L/min)											
	0		2		3		4		5		6	
	S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2
Composite odour	3,000	3,000	2080	2,080	1,000	1,442	1,000	1,442	669	448	1,442	1,000
Hydrogen sulfide	0.321	0.427	0.269	0.227	0.168	0.188	0.098	0.103	0.017	0.014	0.006	0.002
Methyl mercaptane	0.008	0.005	0.008	0.006	0.007	0.006	0.003	0.003	0.000	0.000	n.d	n.d
Acetaldehyde	0.488	0.417	0.416	0.388	0.406	0.351	0.264	0.229	0.104	0.118	0.088	0.100

dilution of chemicals. As such, it was evaluated that the most proper process water supply was 50 L/min.

As for scrubber 3, composite odour in scrubber 3 downstream was analyzed by fixing the pH to 8.7 and 5 L/min of NaOCl and changing process water input from 0 to 77 L/min. As a result, the higher the water supply, the lower the composite odour and bad smells (Fig. 4). With 49 L/min of water supply, composite odour showed the lowest value. Like the efficiency increase of scrubber 2, an increase of water supply to 49 L/min in scrubber 3 led to improved efficiency of composite odour reduction, due to growth of odour solubility. The bigger increase of composite odour with over 63 L/min of water supply than 49 L/min is considered to be because of a bigger dilution rate of liquid chemicals due to excessive water supply.

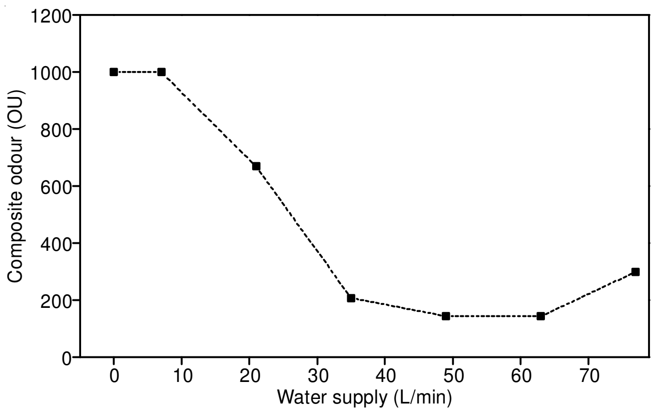

Fig. 4. Changes of composite odour by process water in scrubber 3

Optimal operational conditions for odour prevention: In order to investigate the optimal operational conditions for the odour prevention facility, changed conditions shown in Table-9 were applied to the initial conditions. In addition, composite odour and offensive odour substances from the outlet of scrubber 1 to the final outlet, which contribute to odour reduction, were analyzed and the result is shown in Table-10.

As a result, the final outlet showed stable levels of composite odour (about 144 times). Regardless of odour deviations, the optimal condition for operations was decided. By evaluating for non-digested sludge that has composite odour, it was revealed that odour reduction efficiency increased by more than 90 % compared to the composite odour of the final outlet (2,080 times).

Moreover, the offensive odour substances analysis showed a clear reduction effect of alkali odour substances and neutral aldehyde compounds that had been detected at the final outlet.

Conclusion

This study was conducted to set the optimal operational conditions for a drying and odour prevention facility based on the analysis result of the physico-chemical characteristics of sewage sludge from 3 cities and provinces in the metropolitan area.

The result of analyzing the physico-chemical characteristics is as follows: pH was 6.1-8.5 and moisture content was 72.1-84.2 %, which were high in spring and winter in general; chlorine concentration (Cl^-) was 1.39-89.56 ppm and the concentration was usually higher in fall and winter; viscosity was 12.50-87.81 kg/m.s and higher in summer and winter; and organic substance content was 47.14-79.74 % and showed significant deviations by season. Composite odour had huge deviations of between 698 and 180,000 times, hugely affected according to organic substance contents and the odour strength of sewage sludge was the highest in spring.

TABLE-9
OPERATIONAL CONDITIONS BY ODOUR PREVENTION

Operational condition	pH (H_2SO_4)		pH (NaOH)		NaOCl (ton/day)		Condition of water supply (ton/day)	
	Before	After	Before	After	Before	After	Before	After
Scrubber 2	4-5	4	–		–	–	100	140
Scrubber 3	–		8.5-9	8.7	8	14	160	140

TABLE-10
CONCENTRATION CHANGES OF COMPOSITE ODOUR AND OFFENSIVE ODOUR SUBSTANCES BY ODOUR PREVENTION FACILITY

Substance	Z-scrubber	Vertical condenser	Scrubber 1	Scrubber 2	Heat exchanger	Scrubber 3
Composite odour	100,000	66,943	44,813	1,000	1,000	144
Ammonia (ppm)	148.69	110.32	24.36	n.d	n.d	n.d
Trimethylamine (ppm)	1.264	0.826	0.428	n.d	n.d	n.d
Hydrogen sulfide (ppm)	3.415	1.264	0.806	0.168	0.142	0.001
Methyl mercaptane (ppm)	0.074	0.032	0.019	0.007	0.003	n.d
Acetaldehyde (ppm)	3.698	2.487	1.643	0.406	0.447	0.096

When drying sewage sludge with the hot-air drying technique, the optimal operational conditions of the drying facility were as follows: 300 rpm of crusher rotation speed, 1.0-1.5 rpm of dryer rotation speed and the initial temperature rise of dryer was maintained at 800 °C stably after 15 h. 90 min of optimal drying time satisfied the standard concentration of below 10 % of moisture content for dry sludge.

In addition, when it comes to the relationship between the physico-chemical characteristics of sewage sludge and moisture content of dry sludge, no correlation was found in hydrogen ion concentration (pH), chlorine ion (Cl^-) concentration, sludge moisture content or organic substance content. On the other hand, viscosity showed an almost similar pattern to dry sludge moisture content, being considered to be the most important factor for the drying process.

For an analysis of composite odour produced during the drying process of sewage sludge, exhaust gas was sampled by increasing dryer temperature from 100 to 900 °C. As a result, it was a maximum of 44,814 times until the temperature increased to 350 °C and continuously increased to high concentrations of more than 600,000 times at temperatures between 400 and 600 °C; from 650 °C, it decreased gradually and reached slightly over 10,000 times at 900 °C. As for a rotary kiln-type dryer, dry sludge is produced within 90 min after the temperature rising of dryer (800 °C) is completed. As a result of sampling and comparing composite odour at 10 min intervals during the sludge drying process, the maximum odour was emitted 50 min after the sludge was input, which was as high as 1,000,000 times the level; after 60 min, it dramatically decreased.

The optimal operational conditions of the odour prevention facility were investigated to control odour substances emitted while drying sewage sludge. After setting the process water supply to 70 ton/day for scrubber 1, 3 and the pH of scrubber 2 to 4 by adding H_2SO_4, the facility was operated with 5 L/min of NaOCl (7.2 ton/day) and 49 L/min of process water (70 ton/day), keeping scrubber 3 over pH 8.7 with NaOH and inputting 5 L/min of NaOCl (7.2 ton/day) and 49 L/min of process water (70 ton/day); as a result, odour substances could be controlled stably within 144 times of composite odour level in the final outlet.

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