

Abatement of Odor Emissions from Landfills Using Natural Effective Microorganism Enzyme

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Concentrations of ammonia (NH₃), hydrogen sulfide (H₂S) and methyl mercaptan (CH₃SH) are high in the air above landfills in Taiwan. Odors are strong and many flies are present. These factors were studied in the air above selected landfill sites where odor was considered to be a nuisance. In this study, Natural Effective Microorganisms Enzyme (NEME) was sprayed on selected sampling sites to reduce the odor, the concentration of NH₃, H₂S and CH₃SH and the number of flies in landfills. The odor levels, the concentrations of NH₃, H₂S and CH₃SH and the numbers of flies at various sampling sites before and after spraying with NEME were discussed. Results revealed that at the Tian-Wai-Tian Landfill in Ji-Long City, after NEME was sprayed, the measured odor level ranged from 190 to 552, and the reduction ratios were 99.4%. At the Yan-Pu Country Landfill, after it was spraying with NEME, the measured odor level had a mean of 1360 and the reduction ratio had a mean of 71.6%. At the Ping-Tung Municipal Landfill, after it was sprayed with NEME, the measured odor level had a mean of 602 and the reduction ratio averaged 68.1%. The reduction ratio of NH₃ from landfills averaged 72.2% and 61.1% at the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill, respectively. However, both before and after spraying with NEME, the measured H₂S and CH₃SH concentrations at both the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill were under 0.03 ppm. The reduction ratio of the number of captured flies averaged 55.0% and 39.7% at the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill, respectively.

Keywords: odor, NH₃, H₂S, CH₃SH, Natural Effective Microorganisms Enzyme (NEME)

1. Introduction

People in Taiwan have recently encountered many air pollution problems, especially those associated with bad odor (Chung et al., 2000). Over 300

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substances have been reported to have bad odors (Ikeda et al., 1980). Among these, ammonia (NH₃), hydrogen sulfide (H₂S) and methyl mercaptan (CH₃SH) are three of the nastiest. Large quantities of NH₃, H₂S and CH₃SH are generated and released from landfills, agricultural activities, traffic and industrial processes, including petrochemical refining, metallurgy, food preparation, wastewater treatment and the treatment of fuels (Eikum and Storhang, 1986; Ryer-Power, 1991; Chung et al.,

Table 1. Typical emission gases from landfills.

| Species (gaseous) | Composition (%, based on dry-gas) |
|----------------------|--------------------------------------|
| CH ₄ | 40~ 70 |
| CO ₂ | 30~ 60 |
| CO | 0~ 3 |
| N ₂ | 3~ 5 |
| O ₂ | 0~ 3 |
| H ₂ | 0~ 5 |
| H ₂ S | 0~ 2 |
| Other traces | 0~ 1 |

2000). Tables 1 and 2 present typical emission gases from landfills and typical emission gases related to trace species from landfills, respectively. Furthermore, the generation of odors is a complex process that involves several bacterial species, which produce an extensive range of volatile organic compounds in the various currently used manure storage systems. (Jun, 2000). Table 3 lists the Ambient Air Standards for odorous polluting species in Taiwan.

Ammonia is a colorless gas with a very sharp odor. It is made both by humans and by nature. It dissolves easily in water and evaporates quickly. It is commonly sold in liquid form. The quantity of ammonia generated by humans annually is almost equal to that produced by nature. Ammonia is produced naturally in soil by bacteria, decaying plants and animals, and animal wastes. Ammonia is crucial in several biological processes. Most ammonia produced in chemical factories is used to make fertilizers. The rest is used to make textiles, plastics, explosives, pulp and paper, food and beverages, household cleaning products, refrigerants, and other products. It is also used in smelling salts.

Ammonia occurs naturally, in soil, air and water. Most of the ammonia in water changes to ammonium, an odorless liquid. Ammonia and ammonium can be converted into each other in water. Ammonia is recycled naturally in the

Table 2. Typical emission gaseous trace species from landfills.

| Trace species (gaseous) | Level of concentration (mg/m ³) |
|-----------------------------------|--|
| Alcohol compounds | 2~ 2500 |
| Organic sulfide compounds | 3~ 240 |
| Halogen compounds | 1~ 2900 |
| Aromatic hydrocarbon compounds | 30~ 1900 |
| Aldehyde compounds | 0~ 200 |
| Ketone compounds | 0~ 50 |
| Alkane compounds | 20~ 4500 |
| Alkene compounds | 6~ 1100 |
| Cyclic-alkane compounds | 1~ 1000 |
| Cyclic-alkene compounds | 8~ 600 |
| Ester compounds | 0~ 1300 |
| Ether compounds | 0~ 250 |

environment as part of the nitrogen cycle. It does not last very long in the environment. Plants and bacteria rapidly take up ammonia from soil and water. Some ammonia in water and soil is altered to nitrate and nitrite by bacteria. Ammonia released to the air is rapidly removed by rain or snow or by reactions with other chemicals. Ammonia does not build up in the food chain, but is a source of nutrients for plants and bacteria.

Buijsman et al. (1987) showed that agricultural emissions are primarily from animal waste (chiefly from cattle, poultry, pigs and sheep) and to the use of fertilizers (mostly ammonium sulphate, ammonium nitrate, ammonia, urea and ammonium phosphate) (Buijsman et al., 1987). Battye et al. (1994) stated that the most significant source of NH₃ emissions (around 80%) in the United States is livestock waste (Battye et al., 1994).

Perrino et al. (2002) measured the atmospheric concentrations of gaseous ammonia at several traffic sites in the urban area of Rome and at an

Table 3. Ambient Air Standards for odour pollution species.

| odour pollution species | Ambient air standards (level of concentration, ppm) |
|---------------------------------------|---|
| (1) NH ₃ | 1.00 |
| (2) H ₂ S | 0.10 |
| (3) (CH ₃) ₂ S | 0.10 |
| (4) CH ₃ SH | 0.01 |

urban background site during field campaigns between the spring of 2001 and the spring of 2002 (Perrino et. al., 2002). They found that ammonia at the roadside is present in high concentrations, around five times the urban background. Furthermore, the trend in the concentration of ammonia with time is similar to that of carbon monoxide and depends on traffic emission and on the mixing of the atmosphere. In particular, the air temperature also governs the atmospheric concentration of ammonia (Perrino et. al., 2002).

Thomas et al. (2002) examined the emissions rates of ammonia (NH₃) from a fleet of 39 operational light-duty gasoline-fueled vehicles. The fleet included both light-duty passenger vehicles and light-duty trucks equipped with various emission control technologies, ranging from non-catalyst vehicles to those certified to meet the ULEV standard of California. NH₃ measurements were made using Fourier transform infrared spectroscopy and a federal test procedure (FTP) driving cycle. The FTP NH₃ emission rate for this fleet of vehicles averaged 54 mgmi⁻¹ with a range from <4 to 177 mgmi⁻¹ (Thomas et al., 2002). Thomas et al. (2002) stated that, for this fleet of vehicles, NH₃ emissions did not decline as rapidly as the regulated pollutants as the emission control technology improved. A subset of five vehicles was tested over the US06, the New York City Cycle (NYCC), and a high-speed freeway cycle for comparison with the FTP cycle. NH₃ emissions exhibited a strong dependence on the cycles, increasing with the more aggressiveness of driving

conditions. Their results indicated that NH₃ emissions during more aggressive driving conditions should be considered in developing NH₃ emission factors. The onset of NH₃ emissions typically occurred after catalyst light-off, at a time close to catalyst's reaching its equilibrium temperature. Their initial studies also showed that NH₃ emissions increased as the sulfur content of the fuel declined (Thomas et al., 2002).

Ammonia is importantly involved in aerosol processes and influences the acidity of precipitation. Until now, little information has been available on ambient NH₃ levels in large areas of the world. Carmichael et al. (2003) showed that measuring the gaseous NH₃ using IVL passive sampler technology during a pilot measurement program, as a key component of the newly established World Meteorological Organization/Global Atmospheric Watch (WMO/GAW) Urban Research Meteorology and Environment (GURME) project. They took monthly measurements of concentrations of NH₃ at 50 stations in Asia, Africa, South America, and Europe and found that median ammonia concentrations ranged from 20 ppb in Dhangadi, India, to < 1 ppb at nine stations. At 27 regional stations, the ambient ammonia levels exceeded 1 ppb (Carmichael et al., 2003). The high median NH₃ concentrations in the Indian sub-continent, Southeast and South Asia and Africa, reflect high NH₃ emissions due to agricultural activities (including fertilizer use), livestock, and the use of biofuels (such as animal dung) as domestic fuel (Carmichael et al., 2003). Carmichael et al. (2003) demonstrated that their observations reflected the spatial distributions of the emissions. Ammonia is a primary pollutant, and is emitted in large quantities near important urban and industrial centers. However, ammonia emission is in fact wide spread, reflecting the large contribution by agricultural activity (Carmichael et al., 2003).

H₂S is a colorless gas that smells of rotten eggs. H₂S poisoning is rare, and is mainly observed in

industrial settings. Emergency physicians must be aware of the presentation and management of H₂S poisoning because recovery depends on rapid identification and treatment. Significant H₂S poisoning normally occurs by inhalation. Local irritant effects, accompanied by arrest of cellular respiration, may follow. H₂S forms complexes bond with iron in mitochondrial cytochromes, arresting aerobic metabolism in an effect similar to cyanide toxicity. As a cellular poison, H₂S impacts all organs, particularly the nervous system. The spectrum of illness depends on the concentration and duration of exposure, and high concentrations (>800 ppm) cause sudden death. Low-level H₂S exposure normally produces local eye and mucous membrane irritation, while high-level H₂S exposure rapidly produces fatal systemic toxicity. Exposures to 700-800 ppm H₂S or greater usually result in mortality.

Studies undertaken in the last decade have shown that the concentration of hydrogen sulfide varies between 5 and 200 mgm⁻³ in the air in the odorous part of the city of Izmir (Aysen Muezzinoglu, 2003), depending on the season. Clanton et al. (1999) stated that maximum concentrations of 0.05 mgm⁻³ methane thiol, 0.112 mgm⁻³ dimethylsulfide and 3.92 mgm⁻³ H₂S in air samples from a manure storage area. Clanton et al. (1999) found 20 of the sulfur-containing compounds for which they searched; however, only H₂S, carbonyl sulfide, methane thiol, dimethylsulfide, carbon disulfide and dimethyldisulfide was detected in the air samples.

Currently, the Taiwan EPA sets the ambient air standards of 1 and 0.1 ppm for NH₃ and H₂S, respectively. In a study of exhaust gas treatment, Chung et al. (1996a,b) proved the value of immobilized-cell technology, which was associated with its high removal efficiency, high removal potential, and high operational stability (Chung et al., 1996a,b). Chung et al. (2000) showed that a specific microflora (mixture of Thiobacillus

thioparus CH11 for H₂S and Nitrosomonas europaea for NH₃) was immobilized by Ca-alginate and packed inside a glass column to decompose H₂S and NH₃. The biofilter packed with co-immobilized cells was continuously supplied with H₂S and NH₃ gas mixtures in various ratios, and the removal efficiency, the removal kinetics and the pressure drop in the biofilter were monitored. Their results indicated that the efficiency remained above 95%, independently of the ratios of H₂S and NH₃ (Chung et al., 2000).

A continuous air flow enclosure method was used to measure NH₃ volatilization in a field experiment at an agricultural college in Jiangsu Province. The five treatments used application rates of 0, 100, 200 or 300 kg N ha⁻¹ for urea, in each growing season with rice straw amendment when wheat was sown, and 200 kg N ha⁻¹ without rice straw amendment. Three replicates were in a randomized block design. Ammonia volatilization was measured immediately after urea was applied in the three consecutive years from 1995 to 1997. The results indicated that N losses due to NH₃ volatilization accounted for 4-19% of the N applied during the wheat growing season and 5-11% during the rice growing season. Ammonia volatilization was significantly affected by the moisture and temperature of the soil before and after fertilizer was applied during the wheat growing season (Tian et al., 2001).

Various economic activities cause both industrial and municipal wastes to be released. The final depository of most of these wastes is a landfill site in which degradation takes place in an acidic anaerobic environment, causing odor to be emitted to the surroundings (Davoli et al., 2003; Vandergheynst et al., 1988). The observations in this work should be carefully considered in view of the difficulty in using the landfill sites in Taiwan. The comprehension of the fate of NH₃, H₂S, and CH₃SH into the atmosphere at landfills is a challenging problem that requires further

investigation.

In this work, the Natural Effective Microorganisms Enzyme (NEME) was NEME on selected sampling sites to reduce the odor level, the concentration of NH_3 , H_2S and CH_3SH and the number flies in the landfills at those sites. Then, the odor levels, the concentrations of NH_3 , H_2S and CH_3SH and the numbers of flies at various sampling sites before and after spraying NEME are discussed.

2. Experimental

2.1 Natural Effective Microorganisms Enzyme (NEME)

This work applied the Natural Effective Microorganisms Enzyme (NEME) to reduce the odor level, the concentrations of NH_3 , H_2S and CH_3SH and the number of flies in landfills by spraying NEME over selected sampling sites as will be described in the Section 2.2 below. Natural Effective Microorganisms can secrete the NEME to reduce the odor level. NEME consists of organism and effective bacteria species, such as *Bacillus amyloliquefaciens*, *Bacillus licheniformis*, *Bacillus megaterium*, *Bacillus pumilus*, *Bacillus subtilis*. NEME has a pH value of between 4.5 and 6.5, a density between 0.9 and 1.1, and a total bacteria number $>400,000,000$ CFU/ml.

2.2 Sampling and Analysis Method Effective

Three typical landfills in Taiwan were selected to be investigated: (I) the emission levels of odor, NH_3 , H_2S and CH_3SH , and (II) the numbers of flies were examined. These three landfills were the Tian-Wai-Tian Landfill in Ji-Long City, the Yan-Pu Country Landfill in Ping-Tung Hsien, and the Ping-Tung Municipal Landfill in Ping-Tung City. Firstly, at the sampling sites at the Tian-Wai-Tian

Landfill, only odor level was examined between December 1998 and May 2000. At the sampling sites at both Yan-Pu Country Landfill and Ping-Tung Municipal Landfill, odor, the number of flies, and NH_3 , H_2S and CH_3SH levels were investigated from March to May in 1998. At each sampling site, samples were collected and investigated before and after NEME was sprayed on the landfills.

An average air suction rate of 1.5 l min^{-1} was used to obtain ammonia (NH_3), hydrogen sulfide (H_2S) and methyl mercaptan (CH_3SH) emission samples. This average flow rate was chosen based on ambient air sampling procedures applied to sampling several volatile organic compounds (VOCs) and to determining the concentration of H_2S in the air, according to NIOSH-6013.

This flow rate enabled 20 l of air (total sampling volume) to pass through the sampler during the sampling period. If a higher flow rate had been used, breakthrough of the adsorbent could endanger the sampling procedure. A lower flow rate would cause the experiment to take longer and, considering the warmth of the day, this slowness could have increased the risk of losses due to evaporation (Aysen Muezzinoglu, 2003). During the sampling hours, the temperature of the air varied between 25 and 35 $^{\circ}\text{C}$.

Vials that contain the extracts of gas chromatographic samples were covered with plastic films before they were capped. Samples and standards were maintained and all handling was performed under a hood, with strong negative pressure to prevent cross contamination (Aysen Muezzinoglu, 2003).

The collected air-samples were analyzed by gas chromatography (GC) or gas chromatograph mass spectrum analysis (GC-MS). Both a flame ionization detector (FID) and a flame photometric detector (FPD) were used to perform GC analysis.

2.3 Sensory Evaluations

Table 4. Five standard odors used in sensory evaluations.

| Name | level |
|---------------------------------|-------------|
| (A) β -phenylethy alcohol | $10^{-4.0}$ |
| (B) Methyl cyclopentenorone | $10^{-4.5}$ |
| (C) Isovaleric acid | $10^{-5.0}$ |
| (D) γ -undecalactone | $10^{-4.5}$ |
| (E) skatole | $10^{-5.0}$ |

The odor concentration was measured using a force-choice dynamic olfactometer according to the Taiwan EPA Standard Method (EPA-85-3305-09-02, 1996). Large plastic bags of with volumes of 20 l were used to collect air samples. Bags and connecting tubing in contact with odor-laden gas should be made of inert material, such as poly-tetra fluoro-ethylene (PTFE) or Tedlar, to avoid adsorption onto, or chemical reaction with, the surface of the bag. During the sampling, weather conditions, including wind direction, wind speed and temperature, were recorded. The collected samples were transported to an odor laboratory at the campus of National Ping Tung University of Science and Technology as soon as possible and analyzed within 24 hours. Qualified odor panelists were selected and those who participated in the odor testing were using the five standard odors, as shown in Table 4.

Sensory evaluations of the odor of all collected air-samples (in air-sample bag) were performed by panels of six to nine people. Panel members with normal senses of smell, were selected in advance using the olfactometer and five standard odors. Table 4 lists the five standard odors (A to E). Each panel member made a sensory evaluation of the odor of the samples, following the Taiwan EPA procedure and method (EPA-85-3305-09-02, 1996).

Panel members were not permitted to eat or smoke for one hour before the session to ensure the quality of their results. Panel members were in the odor room 15 minutes before the measurements were made. They did not use perfumes, after-shave

Table 5. Preparatory test with different retention times after NEME was added in the laboratory.

| retention time | I. 8 hr odor level | II. 16 hr odor level | (I.+II.) Mean odor level |
|----------------|-----------------------------|-------------------------------|-----------------------------------|
| reactor | | | |
| A01 | 1738 | 714 | |
| A02 | 1000 | 1202 | |
| A03 | 2089 | 1445 | |
| mean | 1609 | 1154 | 1381 |
| B01 | 1000 | 615 | |
| B02 | 1881 | 1556 | |
| B03 | 736 | 546 | |
| mean | 1206 | 906 | 1056 |
| C01 | 1000 | 470 | |
| C02 | 2291 | 1000 | |
| C03 | 1000 | 666 | |
| mean | 1430 | 712 | 1071 |
| B/A (%) | 75 | 78 | 76 |
| C/A (%) | 89 | 62 | 78 |

- (1) A1, A2, A3: sampling mixtures + 50 ml DI water (to present blank condition)
- (2) B1, B2, B3 : sampling mixtures + 50 ml dilution of 5% NEME (to present 5% NEME concentration)
- (3) C1, C2, C3 : sampling mixtures + 50 ml dilution of 10% NEME (to present 10% NEME concentration)

lotions or any other fragrant essence before the session. Panel members were not allowed to attend a session if he/she had a cold, influenza or any other health problem that could affect his/her nose. No panel member tested for more than 4 hours per testing. Within the period of testing, at least two ten-minute breaks were taken for olfactory rest. In particular, the odor panels worked in a room constructed of odor-free materials and equipped with a ventilation system to prevent the build-up of odor in the room.

2.4 Preparation for the Laboratory Test

Before the spraying process, the feasible for

Table 6. Odor level at Tian-Wai-Tian Landfill in Ji-Long City (before and after NEME was sprayed).

| date | Site no. | odor | Odor level | Mean temp. | RH(%) | Pressure (mm-Hg) | Mean velocity(m/s) |
|--|----------|--------|------------|------------|---------------------|------------------|--------------------|
| before NEME was sprayed (background odor level emission from landfills) | | | | | | | |
| 1999/12/10 | #1 | 500 | 912 | 208 | 64 | 757.7 | 1.6 |
| | #2 | 1580 | | | | | |
| | #3 | 1180 | | | | | |
| | #4 | 300 | | | | | |
| | #5 | 1000 | | | | | |
| 1999/12/11 | #1 | 1316 | 1212 | 20.7 | 66 | 760.3 | 1.7 |
| | #2 | 3000 | | | | | |
| | #3 | 382 | | | | | |
| | #4 | 1000 | | | | | |
| | #5 | 300 | | | | | |
| | #6 | 208 | | | | | |
| | #7 | 2280 | | | | | |
| 2000/05/10 | #1 | 241 | 2220 | 25 | 60 | 747.3 | 1.8 |
| | #2 | 503 | | | | | |
| | #3 | 10000 | | | | | |
| | #4 | 300 | | | | | |
| | #5 | 54.8 | | | | | |
| 2000/05/11 | #1 | 75.6 | 32784 | 30 | 33 | 748.7 | 1.8 |
| | #2 | 728 | | | | | |
| | #3 | 7280 | | | | | |
| | #4 | 150878 | | | | | |
| | #5 | 4960 | | | | | |
| after NEME was sprayed (background odor level emission from landfills) | | | | | | | |
| 2000/05/20 | #1 | 44.7 | 552 | 25 | 68 | 754.8 | 1.8 |
| | #2 | 1202 | | | | | |
| | #3 | 125 | | | | | |
| | #4 | 1148 | | | | | |
| | #5 | 242 | | | | | |
| 2000/05/21 | #1 | 125 | 190 | 26 | 58 | 758.4 | 3.0 |
| | #2 | 100 | | | | | |
| | #3 | 132 | | | | | |
| | #4 | 447 | | | | | |
| | #5 | 145 | | | | | |
| Reduction ratio | | | | | 39.5 ~ 99.4% | | |

smelling dose of NEME in the field had to be evaluated. Hence, in a prior test in the laboratory, three conditions were considered: (i) Condition A: sampling mixtures + 50 ml DI water (blank condition); (ii) Condition B: sampling mixtures + 50 ml of dilute 5% NEME (5% NEME concentration); (iii) Condition C: sampling mixtures + 50 ml of dilute 10% NEME (10% NEME concentration). Each condition was repeated three times, with the times of 8hr and 16hr.

Table 5 presents the prior to test with different retention times after NEME was added in the laboratory.

Based on the results of Table 5, the feasible dose of NEME in the field was obtained as follows.

Use a total reactor volume of 200 l (in the mixing tank).

- (i) Add 100 l about half of the volume of water to the mixing tank.

Table 7. Odor level at Yan-Pu Country Landfill in Pingtung City (before and after NEME was sprayed).

| Yan-Pu Country Landfill | | | | | |
|--------------------------------|-------------|-------------|-------------|-------------|-------------|
| date | P1 | P2 | P3 | P4 | Mean |
| before NEME was sprayed | | | | | |
| 1998/03/03 | 7360 | 5500 | 5500 | 10000 | 7090 |
| 1998/03/05 | 2460 | 4840 | 3000 | 3000 | 3330 |
| 1998/03/06 | 5560 | 5170 | 4950 | 4050 | 4930 |
| 1998/03/10 | 3000 | 74 | 170 | 4840 | 2020 |
| 1998/03/12 | 3000 | 5170 | 4300 | 5460 | 4480 |
| 1998/03/19 | 13740 | 5830 | 5010 | 3000 | 6900 |
| mean | 5853 | 4431 | 3822 | 5058 | 4790 |
| after NEME was sprayed | | | | | |
| 1998/05/15 | 2280 | 1840 | 1730 | 1730 | 1900 |
| 1998/05/16 | 550 | 550 | 670 | 1730 | 875 |
| 1998/05/19 | 144 | 100 | 55 | 208 | 127 |
| 1998/05/22 | 1000 | 7400 | 3820 | 1730 | 3490 |
| 1998/05/23 | 670 | 380 | 300 | 300 | 413 |
| mean | 929 | 2054 | 1315 | 1140 | 1360 |

- (ii) Add 1.6 l of sugar-mixtures and 1.6 l of NEME into the mixing tank.
- (iii) Add water to reach an exact volume of 200 l in the mixing tank.
- (iv) Wait for at least one hour before the spraying process.
- (v) Sprays about 15 m³/day on each sampling site.

3. Results and Discussion

3.1 Odor Level Emitted from Landfills

Table 6 indicates that the measured odor level at the Tian-Wai-Tian Landfill in Ji-Long City ranged from 912 to 32784 before NEME was sprayed. The results imply that an increase in the mean temperature of the ambient increases the mean level of the odor. However, the results also show that a decrease in the ambient mean relative humidity tends to increase in the mean level of the odor at the Tian-Wai-Tian Landfill. The atmospheric pressure and mean wind speed seem to

be unrelated to the mean level of odor at the Tian-Wai-Tian Landfill. After NEME was sprayed, the measured odor level at the Tian-Wai-Tian Landfill in Ji-Long City ranged from 190 to 552. The reduction ratios were between 39.5% and 99.4%.

Table 7 shows that the measured odor level ranged from 2020 to 7090 with a mean of 4790 at the Yan-Pu Country Landfill, before NEME was sprayed. After NEME was sprayed, the measured odor level ranged from 127 to 3490 with a mean of 1360. The mean reduction ratio was 71.6%.

Table 8 shows that the measured odor level ranged from 1760 to 2050 with a mean of 1890 at the Ping-Tung Municipal Landfill, before NEME was sprayed. After NEME was sprayed, the measured odor level ranged from 123 to 998 with a mean of 602. The mean reduction ratio was 68.1%.

3.2 Levels of NH₃, H₂S and CH₃SH Emitted from Landfills

Table 9 shows that the measured NH₃

Table 8. Odor level at Ping-Tung Municipal Landfill in Pingtung City (before and after NEME was sprayed).

| Ping-Tung Municipal Landfill | | | | | |
|-------------------------------------|-----------|-----------|-----------|-----------|-------------|
| date | P1 | P2 | P3 | P4 | Mean |
| before NEME was sprayed | | | | | |
| 1998/05/05 | 1730 | 1440 | 2090 | 1930 | 1800 |
| 1998/05/06 | 1630 | 3000 | 1730 | 1840 | 2050 |
| 1998/05/08 | 1840 | 1840 | 1730 | 1870 | 1820 |
| 1998/05/11 | 2080 | 1550 | 1320 | 2080 | 1760 |
| 1998/05/13 | 3000 | 1730 | 1440 | 1870 | 2010 |
| mean | 2056 | 1912 | 1662 | 1918 | 1890 |
| after NEME was sprayed | | | | | |
| 1998/05/25 | 193 | 71 | 173 | 55 | 123 |
| 1998/05/27 | 1870 | 1000 | 300 | 820 | 998 |
| 1998/05/29 | 241 | 786 | 208 | 548 | 446 |
| 1998/05/30 | 241 | 405 | 1600 | 367 | 654 |
| 1998/05/31 | 199 | 2190 | 219 | 548 | 790 |
| mean | 549 | 890 | 500 | 468 | 602 |

Table 9. Mean NH₃ concentration level emitted from various sampling Landfills in Taiwan (before and after NEME was sprayed).

| date | Site (samples number, n) | Level (ppm) | |
|---|------------------------------------|--------------------|--------------|
| | | Range | Mean |
| before NEME was sprayed | | | |
| NH₃ (ppm) | | | |
| 1998/03/03~1998/03/19 | Yan-Pu Country Landfill (n=6) | 0.05~ 3.94 | 1.58 |
| 1998/05/05~1998/05/13 | Ping-Tung Municipal Landfill (n=5) | 0.36~ 5.4 | 1.85 |
| after NEME was sprayed | | | |
| NH₃ (ppm) | | | |
| 1998/05/15~1998/05/23 | Yan-Pu Country Landfill (n=6) | 0.25~ 0.93 | 0.44 |
| 1998/05/25~1998/05/31 | Ping-Tung Municipal Landfill (n=5) | 0.57~ 0.83 | 0.72 |
| Reduction Ratios of NH₃ | | | |
| Yan-Pu Country Landfill | | | 72.2% |
| Ping-Tung Municipal Landfill | | | 61.1% |

concentration at the Yan-Pu Country Landfill ranged from 0.05 to 3.94 ppm with a mean of 1.58 ppm before NEME was sprayed. Table 9 also indicates that the measured NH₃ concentration at the Ping-Tung Municipal Landfill ranged from 0.36 to 5.4 ppm and with a mean 1.85 ppm.

Table 9 shows that the measured NH₃ concentration at the Yan-Pu Country Landfill ranged from 0.25 to 0.93 ppm with a mean of 0.44 ppm after NEME was sprayed. Table 9 also shows that the measured NH₃ concentration at the Ping-Tung Municipal Landfill ranged from 0.57 to

Table 10. Mean H₂S and CH₃SH concentration level emitted from various sampling Landfills in Taiwan. (before and after NEME was sprayed).

| date | Site (samples number, n) | Level (ppm) | |
|--------------------------------|------------------------------------|-------------|--------|
| | | Range | Mean |
| before NEME was sprayed | | | |
| H₂S (ppm) | | | |
| 1998/03/03~1998/03/19 | Yan-Pu Country Landfill (n=6) | < 0.03 | < 0.03 |
| 1998/05/05~1998/05/13 | Ping-Tung Municipal Landfill (n=5) | < 0.03 | < 0.03 |
| after NEME was sprayed | | | |
| H₂S (ppm) | | | |
| 1998/05/15~1998/05/23 | Yan-Pu Country Landfill (n=6) | < 0.03 | < 0.03 |
| 1998/05/25~1998/05/31 | Ping-Tung Municipal Landfill (n=5) | < 0.03 | < 0.03 |
| before NEME was sprayed | | | |
| CH₃SH (ppm) | | | |
| 1998/03/03~1998/03/19 | Yan-Pu Country Landfill (n=6) | < 0.03 | < 0.03 |
| 1998/05/05~1998/05/13 | Ping-Tung Municipal Landfill (n=5) | < 0.03 | < 0.03 |
| after NEME was sprayed | | | |
| CH₃SH (ppm) | | | |
| 1998/05/15~1998/05/23 | Yan-Pu Country Landfill (n=6) | < 0.03 | < 0.03 |
| 1998/05/25~1998/05/31 | Ping-Tung Municipal Landfill (n=5) | < 0.03 | < 0.03 |

0.83 ppm with a mean of 0.72 ppm. The mean reduction ratios were 72.2% and 61.1% at the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill, respectively.

Table 10 shows that the measured H₂S concentration at both the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill were under 0.03 ppm both before and after NEME was sprayed. Similarly, Table 10 shows that the measured CH₃SH concentration at both the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill were under 0.03 ppm both before and after NEME was sprayed. This measured value is below the California Ambient Air Quality Standard (CAAQS) for hydrogen sulfide. The current California Ambient Air Quality Standard (CAAQS) for hydrogen sulfide is 0.03 ppm (30 ppb, 42 µg/m³) for one hour.

3.3 Flies Captured at Landfills

Table 11 presents the numbers of captured flies on sticky plates at different sampling landfills in this study. Before NEME was sprayed, the number of captured flies at the Yan-Pu Country Landfill ranged from 289 to 884 flies/m²-hr with a mean of 547 flies/m²-hr. Before NEME was sprayed, the number of captured flies at the Ping-Tung Municipal Landfill ranged from 15 to 271 flies/m²-hr with a mean of 131 flies/m²-hr. After NEME was sprayed, the number of captured flies at the Yan-Pu Country Landfill ranged from 121 to 496 flies/m²-hr with a mean of 246 flies/m²-hr. Before NEME was sprayed, the number of captured flies at the Ping-Tung Municipal Landfill ranged from 21 to 175 flies/m²-hr with a mean of 79 flies/m²-hr. The mean reduction ratios were 55.0% and 39.7% at the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill, respectively.

3.4 Summary and Future Works

Table 11. Numbers of captured flies on sticky plates at various sampling landfills (before and after NEME was sprayed).

| date | Site (samples number, n) | Numbers (flies/m ² -hr) | | |
|--|------------------------------------|------------------------------------|----------|-----|
| | | Range | Mean | |
| before NEME was sprayed | | | | |
| 1998/03/03~1998/03/19 | Yan-Pu Country Landfill (n=6) | | 289~ 884 | 547 |
| | #1 | 520 | | |
| | #2 | 408 | | |
| | #3 | 603 | | |
| | #4 | 289 | | |
| | #5 | 884 | | |
| 1998/05/05~1998/05/13 | Ping-Tung Municipal Landfill (n=4) | | 15~ 271 | 131 |
| | #1 | 181 | | |
| | #2 | 271 | | |
| | #3 | 56 | | |
| 1998/05/15~1998/05/23 | Yan-Pu Country Landfill (n=6) | | 121~ 496 | 246 |
| | #1 | 496 | | |
| | #2 | 196 | | |
| | #3 | 121 | | |
| | #4 | 256 | | |
| | #5 | 225 | | |
| 1998/05/25~1998/05/31 | Ping-Tung Municipal Landfill (n=4) | | 21~ 175 | 79 |
| | #1 | 175 | | |
| | #2 | 68 | | |
| | #3 | 52 | | |
| Reduction ratios of numbers of captured flies | | | | |
| Yan-Pu Country Landfill | | 55.0% | | |
| Ping-Tung Municipal Landfill | | 39.7% | | |

The measured odor level at the Tian-Wai-Tian Landfill in Ji-Long City, ranged from 190 to 552 after NEME was sprayed, yielding reduction ratios of between 39.5% and 99.4%. At the Yan-Pu Country Landfill, after NEME was sprayed, the measured odor level ranged from 127 to 3490 with a mean of 1360, and the mean reduction ratio was 71.6%. At the Ping-Tung Municipal Landfill, the measured odor level ranged from 123 to 998 with a mean of 602 after NEME was sprayed, and the mean reduction ratio was 68.1%. The mean reduction ratios of NH₃ from landfills were 72.2% and 61.1% at the Yan-Pu Country Landfill and the

Ping-Tung Municipal Landfill, respectively. Furthermore, before and after NEME was sprayed, the measured H₂S and CH₃SH concentrations at both the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill were under 0.03 ppm. The mean reduction ratios of the number of captured flies landfills were 55.0% and 39.7% at the Yan-Pu Country Landfill and the Ping-Tung Municipal Landfill, respectively.

The different values and different trends of emitted NH₃, H₂S, and CH₃SH with time, at the selected sampling landfill sites may not suffice to enable the importance of landfills emissions in

determining the amounts of emitted NH_3 , H_2S and CH_3SH levels to be deduced. More information can be inferred by comparing the results of future investigations at levels with the background place.

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