Review Article

A Brief Review on Emission of Gaseous Ammonia from Composting of Various Waste Materials

Gargi Palashikar, Aditi Ranade, Shanthi Veerappapillai*
Department of Biotechnology, School of Bio Sciences and Technology, VIT University, Vellore, Tamil Nadu, India.
***Corresponding author's E-mail:** shanthi.v@vit.ac.in

Accepted on: 15-04-2016; **Finalized on:** 31-05-2016.

ABSTRACT

Ammonia is a major emission during the composting process and it is known to have various adverse effects on health and the environment. Solutions of ammonia, ammonia in gaseous form, and ammonium salts have a major role in the functioning of the ecosystem. Hence, harmful ammonia emissions and utilization of ammonia by living things are areas of great research and study nowadays. The aim of this paper is to find out the average ammonia emissions during the composting process and how they can be controlled. Although ammonia is emitted from various sources, emission of ammonia from composting process is particularly taken into consideration in this paper. Various factors affect the rate of ammonia emission during various stages of the composting process of different waste materials and fertilizers. Primarily, it has been found that high temperatures and a low C:N ratio favor emission of ammonia whereas low temperatures and high C:N ratio reduce ammonia emissions. Aeration of compost pits and how it affects ammonia volatilization has been taken into consideration. This paper also has information regarding the different bacteria that grow during various stages of composting and how they should be effectively incorporated in the process.

Keywords: Ammonia emissions, composting, toxicity, metabolism, microbial diversity.

INTRODUCTION

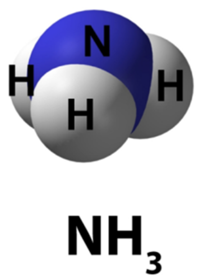

Figure 1: Structure of Ammonia

Ammonia, NH_3, is a colorless, pungent-smelling, basic gas with a specific gravity of 0.597. It is essential to the nutritional needs of terrestrial organisms, as it is an important raw ingredient for many foods and fertilizers. It is also significant in the synthesis of many pharmaceuticals. It is found in minute amounts in the atmosphere, originating from the decay of animals and plant matter rich in nitrogenous compounds. Although ammonia is known to be of great use in industry, it also has several toxic effects on plant and animal health. Ammonia has a stimulatory effect at low concentrations; however, it has an inhibitory effect as the concentration increases, or the period of exposure is prolonged. Deposition of ammonia in natural ecosystems can lead to soil acidification and eutrophication of water bodies. Moreover, it accelerates the nitrification-denitrification processes that lead to formation of nitrous oxide (N_2O), which is another greenhouse gas.

Studies involving dairy cattle present evidence that proteins that increase ammonia concentration increase the time period between calving and conception, and decrease conception rates[2].

The effect of gaseous ammonia and ammonium salts on respiration of excised barley roots, garden beet root disks, and leaf disks of spinach, sugar beets, and garden beet root mitochondria was studied. It was found that there was significant inhibition of respiratory processes in the tissues. It is suggested that the site which is most affected by the toxicity of ammonia is the electron transport chain, specifically the NADH -> NAD reaction[3] (nicotinamide adenine dinucleotide is oxidized).

The graphs in figure 1a and 1b show the effect of ammonia on metabolism in plants.

It is also important to remember that increased ammonia emissions result in a decreased content of soluble nitrogen in the soil. Compost with low soluble nitrogen content used as a fertilizer will not have adequate nitrogen for utilization by plants. Ammonia volatilization is the major cause of loss of nitrogen.

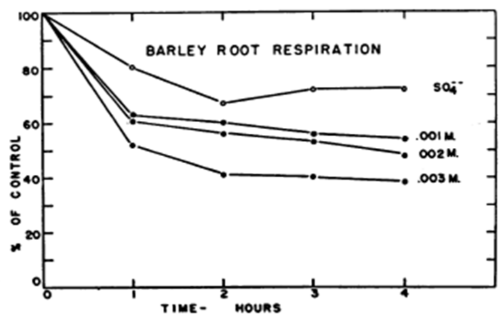

Figure 1.a: Effects of Ammonia on Metabolism of Barley Root

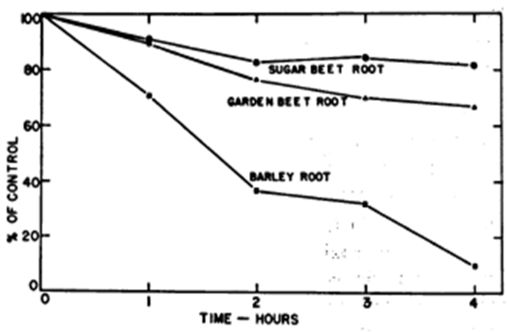

Figure 1.b: Effects of Ammonia on Metabolism of Sugar Beet Root, Garden Beet Root, and Barley Root[4]

The concentration of an ammonia solution determines its toxicity: a solution of ammonia, 5–10% by weight (<5.62 mol/L) is considered "dilute" whereas "concentrated" solutions are usually >25% by weight. A 25% solution has a density of 0.907 g/cm^3, and a solution that has a lower density will be more concentrated[5]. According to the European Union, the classification of ammonia solutions is as follows:

Agricultural residues, including crop straws, are added to soil as nutrients after composting. This process is responsible for a large amount of ammonia release. Fertile soils and sea water are also abundant in ammonium salts. The majority of living organisms cannot take up atmospheric nitrogen (N_2) directly. Hence, it is converted into ammonia via the nitrogen fixation cycle, which is carried out by microorganisms in the soil, such as *Rhizobium*, by decomposition of nitrogenous waste[7].

Common Sources of Ammonia

Ammonia is a toxic waste product of animal metabolism. Industrial effluents are another source of release of ammonia into the environment. Ammonia emission occurs during the first week of aerobic composting during the thermophilic phase. This is followed by steady emissions near the end of the composting process[8].

The emission of ammonia from the above-mentioned sources has become a source of increasing concern over the past several years. The global industrial production of ammonia for 2012 was anticipated to be 198,000,000 tons[9], a 35% increase over the estimated 2006 global output of 146,500,000 tons[10].

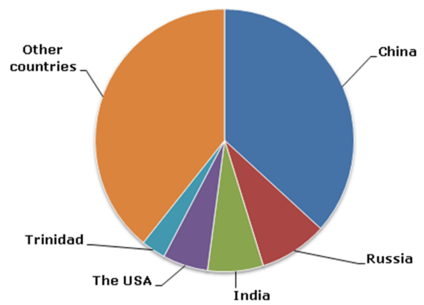

Figure 3: Forecast for the Years 2014-2018 of Global Ammonia Emissions[11]

Microbial Diversity in Compost

There was a maximum increase in microbial population in the early stages of composting, depending upon the initial substrate concentration and environmental conditions. The population of mesophilic bacteria was found to be between 1.7-2.84 x 10^9 cfu/g. Thermophilic bacteria were found to be maximum between days 11 to 32 of composting, between 10^8 to 10^7 cfu/g. The population of mesophilic bacteria stabilized between 10^6 to 10^5 cfu/g during the cooling and maturation phase, which was between days 33-40 of composting[12].

Of the colonies isolated, 84.8% were Gram positive while the remaining (15.2%) were Gram negative. The results showed that Firmicutes, specifically *Bacillus* sp., *Terribacillus* sp., and *Lysinibacillus* sp. were the majority of the bacteria found in the compost. Other genera found were *Staphylococcus, Serratia, Klebsiella, Enterobacter.* However, these bacteria were destroyed by the heat generated during the composting process, and later on, the compost was found to be free of these genera. For the first time, the genera *Kocuria, Microbacterium, Acidovorax, and Teribacillus* were reported in the microbial population of the composting pit.

Inoculation of *Pediococcus acidilactici* TM14 strain of bacteria into compost raw material in the beginning of the process was found to produce a high lactic acid concentration in the early stages. When TM14 was not inoculated, high levels of acetic acid were produced, which proved to be harmful to indigenous microorganisms that promote composting. Further, growth of TM14 promote the growth of fungi which have the ability to decompose organic matter by enhancing the growth of thermophilic bacteria[13].

Factors Affecting Ammonia Emissions

A large number of experiments have been carried out by scientists and researchers to find out the extent of ammonia emissions during composting of different wastes. The results of these experiments show which types of waste, of what compositions, emit the least amount of ammonia on composting. The maximum amount of ammonia emissions were observed from livestock waste and fertilizers which contributed to about 50% ammonia emissions globally, and 80% of ammonia emissions in Asia[14].

Key factors that control ammonia emission during composting are: pH, temperature, moisture content, aeration rate, and carbon-to-nitrogen ratio[15]. The optimum pH range for control of ammonia emissions is found to be 5.5 to 9[16]. Temperature, on the other hand, directly affects ammonia emissions[17]. That means that increase in temperature increases the ammonia volatilization, and accordingly, emissions in warm areas are observed to be higher than emissions in cooler climates. Ammonia emissions in dry conditions are higher, but overall nitrogen losses in moist conditions are higher. This is a result of nitrogen losses through leaching pathways[18].

Compost raw materials from different sources show different rates of ammonia emission. For example, sewage sludge shows the highest loss of ammonia. Following that, the next highest emissions of ammonia are seen from food waste, and then poultry and pig manure[24]. This can be explained by the difference in biodegradability of the raw materials. There is a large fraction of easily decomposable materials in green and food waste. However, sewage waste contains more recalcitrant compounds as a result of previous biological treatment.

Aeration is one of the most important factors that affect ammonia volatilization. Initially, it does not show any significant effect. However, in later stages of composting, increase in ammonia volatilization is directly linked with increased aeration[19]. Emissions of carbon dioxide as well as ammonia in systems under aerobic conditions were higher than those from untreated solid waste, or waste under anaerobic conditions. Therefore, practices which limit oxygen in the system should be employed, such as coverage and compaction.

Turning and forced aeration are methods of actively aerating the pile, supplying oxygen to the microorganisms and enhancing degradation. Both methods lead to increased nitrogen loss through ammonia emission. Aeration also stimulates the production of carbon dioxide from carbon in the pile. As the conversion of carbon to carbon dioxide is an exothermic reaction, the temperature of the compost pile increases.

In the range of temperatures in the thermophilic stage, emissions of ammonia are found to be over 10%, whereas temperatures in the mesophilic range prevent or reduce nitrogen loss through ammonia volatilization. Covering and compaction are two mechanisms through which temperatures in the mesophilic range can be achieved.

Periodical turning of the compost pile reduces stratification and decreases the formation of anaerobic pockets and oxygen gradients. In anaerobic pockets, the formation of methane (CH_4) and nitrous oxide (N_2O) is favored. These are both greenhouse gases, and have other harmful effects on humans and plants as well. N_2O is produced through both nitrification and denitrification. CH_4 is produced mainly in the initial stages of composting while carbon sources are still readily available in the raw material.

In this stage, high biological activity and warm temperatures are promoted.

Turning could result in the release of methane directly into the atmosphere, eliminating the possibility of oxidation before it reaches the surface.

The C:N ratio affects ammonia volatilization to a large extent. Carbon binds to nitrogen and makes it unavailable for ammonification.

This way the release of ammonia is reduced. So higher C:N ratio is preferred in order to minimize the loss of ammonia to the environment[20].

It has been found that addition of carbon-containing compounds, such as sawdust, leads to 10% reduction in ammonia volatilization[21].

In a study done by Chandna (2013), it was observed that organic carbon decreased, while nitrogen, phosphorous, and potassium content increased over time. After 40-50 days, the C:N ratio was observed to be stabilized at 11:1. However, it must be considered that higher concentrations of carbon in the raw material would increase CO_2 emissions. The addition of certain bulking agents and additives to change the C:N ratio can reduce emissions of ammonia as well as minimize emissions of carbon dioxide. Strategies such as turning and compaction can also be employed to reduce emission of greenhouse gases, as explained above.

Ammonia volatilization during the simple composting process (28 days) showed higher NH_3 emission from the substrate with low C:N ratio (11.5 kg/Mg dry matter) than that with additional straw (7.5 kg/Mg dry matter)[22]. These amounts of NH3 volatilized corresponded to approximately 57% of total N for the substrate with low C:N ratio (CN20) and 46% for the substrate with high C:N ratio (CN26). Hence extra straw reduced N loss by approximately 10% during the 28 days of simple composting[23].

Addition of certain strains of bacteria was found to reduce ammonia emissions. For example, NTB (nitrogen turnover bacterial) agent such as ammonifiers, nitrobacteria, and *Azotobacter* consortium were added to pig manure and wheat straw mixtures. The lowest nitrogen losses, highest degradation of organic matter, and greatest increase in total nitrogen content was found with inoculation of 1% NTB agent only when added at the beginning of composting[24].

Another strain of bacteria that was found to reduce ammonia emissions during composting was *Bacillus* sp. TAT105, a thermophilic bacteria with high ammonium tolerance. A laboratory scale composting process with swine feces, when inoculated with the bacterium, showed reduced ammonia losses by 22%[25].

Applications

By finding out the sources of ammonia emission, and the factors affecting the emission of ammonia, we can reduce ammonia emissions. This will help in reducing the amount of toxic gases in the atmosphere. Ammonia is known to cause many respiratory infections such as scratchy throat, chest tightness, cough, etc. Eye irritation and dyspnea are also symptoms of exposure to gaseous ammonia.

Increased ammonia volatilization leads to depletion of nitrogen content in the compost, which in turn results in a reduced fertility of the manure obtained.

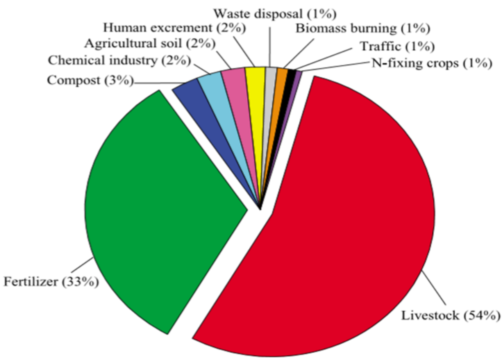

Figure 4: Source contributions (%) to ammonia emissions in China

In another study, Datta projected the upper and lower limits of ammonia emissions from subtropical crop lands in India in the year 2012 through different stages of crop growth. Initial stages of crop development (Sowing and root initiation) showed high ammonia emissions. This data can be used to compare with crops grown in compost soils that have been optimized to achieve minimum ammonia emissions.

Table 1: European Union Classification of Ammonia Solutions[6]

Concentration of ammonia by weight (w/w)	Molarity	Concentration mass/volume (m/v)	Classification
5-10%	2.87-5.62 mol/L	48.9-95.7g/L	Irritant (Xi)
10-25%	5.62-13.29 mol/L	95.7-226.3 g/L	Corrosive (C)
>25%	>13.29mol/L	>226.3 g/L	Corrosive (C) Dangerous for the environment (N)

Table 2: Ammonia Emissions during Various Stages of Composting in Subtropical Crop Land in India 2012[26]

Crop Stages	Ammonia Upper Limit (μg/m^{2}d)	Ammonia Lower Limit (μg/m^{2}d)
Sowing	33.3	57
Crown Root Initiation	15.3	29.2
Panicle Initiation	10.3	28
Grain Filling	8.7	23.9
Maturity	13.9	28.9

CONCLUSION

In order to reduce ammonia emissions from composting of various waste materials, it is necessary to increase the C:N ratio, decrease the period of aeration, reduce the time for which the system is exposed to high temperatures and maintain the desired pH levels i.e. 5.5 – 9. As the moisture content is not known to have any major effect on ammonia volatilization, nominal percentage of moisture would be sufficient to maintain normal levels of ammonia emission. However, it is essential to keep in mind that higher the C:N ratio, higher will be the production of carbon dioxide, so C:N ratio should be optimized. Keeping the compost pit covered for most period of time also helps in reducing ammonia volatilization and in turn increases soluble nitrogen content that can be used by plants. Use of nitrobacters should be promoted as it can effectively reduce ammonia emissions.

Acknowledgement: The authors thank the management of Vellore Institute of Technology, for the constant encouragement, help and support to carry out this work.

REFERENCES

1. General Chemicals; Manufacturing of Ammonia by Haber's Process; (2014) World of Chemicals; Data Research Analyst.
2. Visek W. J.; Ammonia: its Effects on Biological Systems, Metabolic Hormones, and Reproduction; (1984); Journal of Dairy Science; 67; 481-498.
3. Hubbe M. A., Nazhad M.; Composting as a Way to Convert Cellulosic Biomass and Organic Waste Into High-Value Soil Amendments: A Review; (2010); Bioresources; 5(4); 2808-2854.
4. Vines H. M., Wedding R. T.; Some Effects of Ammonia on Plant Metabolism and a possible mechanism for Ammonia Toxicity; Department of Plant Biochemistry, University of California Citrus Experiment Station, Riverside; 820-825.
5. Huang X., Song, Y. Li, M., Li J., Huo Q., Cai X., Zhu T., Hu M., Zhang H.; A High Resolution Ammonia Inventory in China; (2012); Global Biogeochemical Cycles; 26, 2012, 1-14.
6. Council Directive 67/548/EEC of 27 June 1967 on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labeling of dangerous substances; 1967; Official Journal; L196, 1-98.

7. Jiang T., Schuchardt F., Li G., Guo R., Zhao Y.; Effect of C:N Ratio, Aeration Rate and Moisture Content on Ammonia and Greenhouse Emission During the Composting; (2011); Journal of Environmental Sciences; 23, 2011, 1754-1760.

8. Wang J., Hu Z., Xu X. Jiang X., Zheng B., Liu X., Pan X.; Emissions of ammonia and greenhouse gases during combined pre-composting and vermicomposting of duck manure; (2014); Waste Management (Elsevier); 34, 2014, 1546-1552.

9. Market Study Ammonia; (2012); Ceresana

10. Appl M.; Ammonia; (2006); Ullmann's Encyclopedia of industrial Chemistry; 10.

11. Ammonia: 2014 World Market Outlook and Forecast up to 2018; (2014); Research and Markets; 521.

12. Chandna P., Nain L., Singh S., Kuhad R.C.; Assessment of Bacterial Diversity During Composting of Agricultural Byproducts; BMC Microbiology; 2013, 13.

13. Tran Q.N.M., Mimoto H., Nakasaki K.; Inoculation of lactic acid bacterium accelerates organic matter degradation during composting; (2015); International Biodeterioration and Biodegradation; 104, 2015, 377-383.

14. Velasco-Velasco J., Parkinson R., Kuri V.; Ammonia Emissions During Vermicomposting of Sheep Manure; (2011); Bioresource Technology; 102, 2011, 10959-10964.

15. Paoli L., Bensperi R., Pannunzi D. P., Corsini A., Loppi S.; Biological Effect of Ammonia released from a Composting Plant Associated with Lichens; (2014); Environmental Science and Pollution Research (Springer); 21, 2014, 5861-5872.

16. Wang J., Hu Z, Xu X., Jiang X, Zheng B., Liu X., Kardol X .P. P.; Environmental Assessment of Home Composting; (2010); Resources, Conservation, and Recycling (Elsevier); 54, 2010, 893-904.

17. Ermolae E., Sundberg C., Pell M. Jonsson H.; Greenhouse Gas Emissions from Home Composting in Practice; Bioresource Technology (Elsevier); 151, 2014, 174-182.

18. Guillermo Pardo, Raul Moral, Eduardo Aguilera, Agustin Del Prado; Gaseous Emissions from Management of Solid Waste: a Systematic Review; (2015); Global Change Biology; 21, 2015, 1313-1327.

19. Hao X., Benke M., Larney F. J., McAllister T. A.; Greenhouse Gas Emissions When Composting Manure from Cattle Fed Wheat Dried Distillers' with Solubles; (2011); Nutrient Cycling in Agroecosystems (Springer); 89, 2011, 105-114.

20. Asadollahfardi G., Asadi M., Youssefi M., Elyasi S., Mirmohammadi M.; Experimental and Mathematical Study on Ammonia Emission from Kahrizak Landfill and Composting Plants, Tehran, Iran; Journal of Material Cycles & Waste Management (Springer); 10.

21. Maulini-Duran C., Artola A., Font X., Sanchez A.; A Systematic Study of the Gaseous Emissions from Biosolid Composting: Raw Sludge Versus Anaerobically Digested Sludge; (2013); Bioresource Technology; 147, 2013, 43-51.

22. Li Y., Li W., Liu B., Wang K., Su C., Wu C.; Ammonia Emissions and Biodegradation of Organic Carbon during Sewage Sludge Composting with Different Extra Carbon Sources; (2013); International Biodeterioration & Biodegradation (Elsevier); 85, 2013, 624-630.

23. Anderson D. P., Beard C. W., Hanson R. P.; The Adverse Effects of ammonia on Chickens Including Resistance to Infection with Newcastle Disease Virus; Department of Veterinary Science, University of Wisconsin, Madison, Wisconsin; 369.

24. Jiang J., Liu X, Huang Y., Huang H.; Inoculation with Nitrogen Turnover Bacterial Agent Appropriately Increasing Nitrogen and Promoting Maturity in Pig Manure Composting; Waste Management; 39, 2015, 78-85.

25. Kuroda K., Waki M., Yasuda T., Fukumoto Y., Tanaka A., Nakasaki K.; Utilization of *Bacillus* sp. Strain TAT105 as a Biological Additive to Reduce Ammonia Emissions during Composting of Swine Feces; Bioscience, Biotechnology, and Biochemistry; 79(10), 2015, 1702-1711.

26. Datta A., Sharma S.K., Harit R.C., Kumar V., Mandal T.K., Pathak H.; Ammonia Emission from Subtropical Crop Land Area in India; Asia-Pacific Journal of Atmospheric Sciences; 48(3), (2012), 275-281.

Source of Support: Nil, **Conflict of Interest:** None.