DOCTORAL THESIS

Co-composing of sewage sludge with coal fly ash

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Co-Composting of Sewage Sludge with Coal Fly Ash

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Abstract

Composting is becoming a more acceptable and economical method of treating sewage sludge especially for cities with a high population density, such as Hong Kong. However, the major drawback of sewage sludge composting is the high heavy metal content in the end-product, especially for the sewage sludge derived from industrial activities. It is therefore the aim of the present study to develop a cost-effective technique using coal fly ash amendment for sewage sludge composting, which can reduce the availability of heavy metals in the composting products, and improve the decomposition activity during fly ash-sludge composting through microbiological approaches.

The first phase of the present study aims to evaluate the feasibility of using two different alkaline materials, i.e., coal fly ash and lime, as co-composting materials for sewage sludge. Sewage sludge was mixed with sawdust at 2:1 w/w (fresh weight basis) to achieve a C/N ratio of 25. Coal fly ash was amended with the sewage sludge and sawdust mixtures at 0%, 10%, 25%, and 35% w/w (dry weight basis), while amendment rates for lime were 0%, 0.63%, 1.0%, and 1.63% w/w (dry weight basis). The mixtures were composted for 100 days in a laboratory batch composting system and samples were removed periodically for the evaluation of nutrient transformations, maturation, and metal availability.

Addition of coal fly ash at an amendment rate of $\geq$ 25% caused a significant decrease in the water-soluble and DTPA-extractable Cu, Mn, Ni, Pb, and Zn contents during the composting process. Sludge compost receiving a lime amendment rate of $\geq$ 1.0% also decreased the water-soluble and DTPA-extractable metal contents, but was less effective than that of coal fly ash. Coal fly ash and lime amendment resulted in a low decomposition activity due to their alkalinity as indicated by the decrease in cumulative weight loss along the composting period, but significant decreases were only observed at sludge compost having 35% fly ash and 1.63% lime amendment. An increase in coal fly ash or lime amendment resulted in a significant reduction in soluble NH_4-N, NO_3-N, and PO_4-P contents at the end of the composting period as compared to the control. In spite of the reduction in microbial decomposition caused by the alkaline amendment, all treatments reached maturation after 63 days of composting as indicated from the C/N ratio and cress seed germination test results, except for 35% fly ash amendment.

Any adverse effects due to coal fly ash or lime amendment on the decomposition process during sewage sludge composting would rule out their use as co-composting materials. Therefore, biological parameters including respiratory activity, microbial populations (thermophilic and mesophilic bacteria, actinomycetes, and fungi), and enzyme activities (dehydrogenase, alkaline phosphatase, β-glucosidase, and urease) were monitored during alkaline material-amended sludge composting to elucidate their effects on biological activities. Adverse effects of coal fly ash and lime on biological parameters were generally restricted to the early stage of thermophilic phase. Addition of $\leq$ 25% coal fly ash and < 1.0% lime could be co-composted with sewage sludge without exerting a significant inhibition on the growth of bacteria, and the activities of ß-glucosidase, alkaline phosphatase, and dehydrogenase at the end of composting. This, together with the higher effectiveness in reducing available heavy metal contents without any extension of the maturation period, supported the use of 25% fly ash as an appropriate amendment rate for sewage sludge composting.

Since 25% fly ash amendment exerted adverse effects on the decomposition process at the thermophilic phase of sewage sludge composting, the second phase of the study was to adopt a microbiological approach to improve the composting process. Isolation and identification of thermophilic bacteria from sludge compost with or without ash amendment was conducted according to the Biolog identification tests. *Bacillus* species including *B. brevis, B. coagulans, B. circulans, B. sphaericus, B. subtilis, B. licheniformis, B. thermoglucosidasius,* and *B. stearothermophilus* were identified and only one Gram-negative thermophile was tentatively identified as *Thermus spp*. among all isolates. *B. brevis* was the most dominant species of thermophilic bacteria in sludge or ash-sludge compost which accounted for more than 70% of total thermophilic bacterial population during thermophilic phase. Ash amendment at 25% decreased the population density and species diversity of thermophilic bacteria in sludge compost because of the high pH and salinity. Nevertheless, *B. brevis* still maintained as the most dominant species during the ash-sludge composting process.

Due to the high contents of Cu and Zn in the sludge, attempts were made to isolate Cu- and Zn-tolerant thermophilic bacteria, and inoculate their cultures in 25% fly ash-amended sludge compost in order to accelerate the decomposition activity. Three Cu- and Zn-tolerant *Bacillus* species, i.e., *B. brevis, B. coagulans,* and *B. licheniformis,* were isolated. The cultures of these bacilli were inoculated into ash-sludge mixture in aqueous phase and incubated for 10 days. All the three bacilli were able to decompose the organic matter more quickly as compared to the control receiving no inoculation, while no significant difference was noted among the three bacilli at an inoculation size of 10^7 CFU g^{-1} dry sludge.

In addition to the isolated Cu- and Zn-tolerant thermophilic bacteria, a commercial decomposter and a recycled sludge compost were used as seeding materials in the composting of 25% ash-amended sludge. Inoculation of the commercial decomposter (0.6% dry weight basis) and bacterial culture (10^7 CFU g^{-1} dry sludge) with milk powder as a substrate (1.8% dry weight basis) could improve the decomposition activity by more than 10% as compared to the control without any additives according to the results of CO_2 evolution and cumulative weight loss. Therefore, the isolated metal-tolerant *Bacillus* species were as efficient as the commercial decomposter to accelerate the decomposition activity during ash-amended sludge composting. Ash-sludge compost inoculated with 15% (dry weight basis) of recycled compost showed a slightly but insignificantly lower decomposition activity than those inoculated with bacterial culture and the commercial decomposter with milk powder. This may be due to the lower degradable organic matter in the recycled compost. Hence, the lower operation cost but an acceptable decomposition efficiency makes recycled compost a promising additive for ash-amended sludge composting.

The present study demonstrates that amendment of 25% coal fly ash in sewage sludge composting is an appropriate option in reducing the availability of heavy metals from sludge compost without affecting the maturation of the end-product. The low effective reduction of available metal contents and the high level of nitrogen loss in lime treatments render lime less attractive than coal fly ash as a co-composting material for sewage sludge. Addition of 15% recycled sludge compost can improve the decomposition activity of 25% ash-amended sludge composting. This co-composting strategy will provide a cost-effective means to produce a high quality of sludge compost, but requires further field tests and plant growth experiments for validation.

Table of Contents

		Page
Section III.	System Improvement of the Co-Composting Process of Sewage Sludge with Coal Fly Ash	
Chapter 6.	Effect of Coal Fly Ash on Thermophilic Bacteria When Co-Composting Sewage Sludge with Coal Fly Ash	159
6.1	Introduction	159
6.2	Materials and methods	160
6.2.1	Enumeration and isolation	160
6.2.2	Biolog identification tests	161
6.3	Results and discussion	162
6.3.1	Identification of thermophilic bacteria	162
6.3.2	Effect of fly ash on *Bacillus* species	168
6.4	Conclusions	173
Chapter 7.	Digestion Activity of Cu- and Zn-tolerant Thermophilic Bacteria Isolated from Ash-Amended Sewage Sludge Compost	174
7.1	Introduction	174
7.2	Materials and methods	176
7.2.1	Isolation and identification of tolerant thermophilic bacteria	176
7.2.2	Digestion test of isolated *Bacillus* strains	177
7.2.3	Statistical analysis	179
7.3	Results and discussion	180
7.3.1	Isolation of Cu- and Zn-tolerant species	180
7.3.2	Digestion activity of isolated *Bacillus* strains in ash-sludge mixture	183
7.4	Conclusions	199
Chapter 8.	Seeding Effect on Sewage Sludge Composting with Coal Fly Ash	200
8.1	Introduction	200
8.2	Materials and methods	201