Investigation of biosolid-compost produced by high-temperature fermentation process

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Abstract. Disposal of biosolids has been paid a due attention in Taiwan owing to their increasing amounts in the recent years. As there is no special landfill for biosolids dumping in Taiwan, transformation of biosolids to compost could be one of the suitable means of disposal. The study aimed to investigate the use of high-temperature fermentation technique to produce biosolid compost and examine the quality of bio-solid compost produced. Biosolids collected from a municipal wastewater treatment plant were treated by electro-kinetics to remove heavy metals and mixed with some agricultural wastes (mushroom waste and chicken excreta) to transform into the compost by a high-temperature (130°C) fermentation process. Prior and post to fermentation, the concentration of heavy metals and pathogenic bacteria in the biosolid-compost were determined. Results indicated that concentration of Cd, Cr, Cu, Ni and Pb in the compost after fermentation was within the soil control standard of Taiwan EPA. The pathogenic bacteria such as Escherichia coli, Salmonella, and parasitic ova in the final compost were within the government criteria. Biosolid compost was then applied as a soil improvement material to compare the relative growth (with a control) of red leaf shovel within the campus premises. The plants in the plot with biosolid compost demonstrated a better growth than the same plants in the control.

1. Introduction
Recent decades have witnessed an increasing number of sewage treatment plants due to rapid industrialization and continual human population growth [1]. Taiwan has also constructed several sewage treatment plants to meet the demand of ongoing rapid development in industry and economy. Although the treated sewage has improved significantly, the amount of sewage sludge (i.e., biosolid) has also increased, leading to the issue of sludge recycling. The activated sludge process in sewage treatment plants is most commonly used because of its simplicity, high efficiency and low cost [2,3]. However, it also produces a large amount of sewage sludge. Generally, sewage sludge contains more than 90% of water and other harmful substances, such as pathogenic microorganisms including enteroviruses, parasitic eggs and pathogenic bacteria, heavy metals such as Cd, Cr, Hg and Pb etc., and refractory organics including chlorophenols, polycyclic aromatic hydrocarbons, and nitroaromatic compounds [4]. As a result, if an appropriate practice is not employed to handle sewage sludge, it may lead to several environmental, social and human health impacts [1].

The presence of organic matter and beneficial plant nutrients (C, N and P) in sewage sludge render it good soil ameliorating properties: enhanced water absorption and soil aeration [5]. However, such
sludge also contains heavy metals, pathogens and toxic organic compounds [6,7] and hence chemical analysis needs to be done prior to land application for agronomic purposes [8]. If the sewage sludge is used directly in agriculture, it may cause serious infectious diseases [9]. In contrast, it can be reused as soil improvement materials in land if properly handled and treated. The application of soil improvement materials to agriculture can address the problems of sewage sludge management and enhance agricultural productivity.

The livestock and poultry manure and some abandoned agricultural wastes contain high nutrients. In particular, the quantity of waste produced from mushroom farm in Taiwan in recent years is increasing. The research aims to develop an appropriate technology based on high temperature ($130^\circ C$) fermentation for blending of these agricultural wastes with the sewage sludge and examine the suitability of the resulting blend (soil improvement material) for application to the land.

2. Material and methods

The biosolid-compost produced by high-temperature fermentation process and approaches used during the experiment are shown in Figure 1. The compost manufacturing procedures consist of the enumeration of pathogens, detection of heavy metals, fermentation of dewatered sewage sludge and finally the land application of compost produced. Based on the above, the feasibility and safety concerns for application of biosolid compost to the soil could be scientifically addressed.

![Figure 1](image.png)

**Figure 1.** The experimental procedure.

Sewage sludge was collected from water resources recovery center of the Shigangba which is located at Shigang District, Taichung, Taiwan. The center mainly targets for the treatment of domestic sewage. There are two kinds of sewage sludge in the recovery center; original sludge having higher moisture content and dewatered sludge. The study used only dewatered sludge from dewatering unit to examine moisture content, pathogens and heavy metals. Details of the analytical methods used for pathogens and heavy metals in the sludge are shown in Table 1.
Table 1. Methods for the analysis of pathogens and heavy metals.

| Parameters | Tests/methods |
|------------|----------------|
| Pathogens |                |
| 1. *Escherichia coli* | Indole test, Brilliant Green Bile Broth test, Voges-Proskauer test, Methyl Red test |
| 2. *Salmonella* spp. | Urea broth test, Indole test, ONPG broth test, Voges-Proskauer Test, Lysine decarboxylase test (LDC), Triple sugar iron agar (TSI) test [10] |
| 3. Helminth ova | Helminth ova in the sludge mixture were separated by glass bead strike and friction using saturated sodium nitrate solution centrifugal floatation method. Ova floating on the surface of the solution were collected, observed under a microscope and enumerated |
| Heavy metals | Cd, Cr, Cu, Ni, Pb, Zn |
|             | Taiwan EPA NIEA S321.65B and ICP-OES |

Figure 2 shows the schematic diagram for manufacturing biosolid-compost. Dewatered sewage sludge, after analysis, was mixed with agricultural waste: waste mushroom and chicken excreta. The ratio of dewatered sludge to abandoned mushroom and chicken manure was 1:1.5:1.5. After heating at a high temperature of 130 °C for 2 h, the mixture was moderately heated until it was dry and soft. Then, the compost was produced after turning it up for about 7 days. The biosolid-compost was examined for pathogens and heavy metals before applying to the land. In order to observe the effect of the converted compost on plants, the biosolid-compost was used as a soil improvement material for growing landscape plant in campus. The experimental group and the control group were tested for 15 m² of red leaf shovel applying 1.2 kg biosolid-compost per m².

![Figure 2. Schematic diagram for manufacturing biosolid-compost.](image)

3. Results and discussion

Water content, *Escherichia coli* and *Salmonella* in the sludge were analysed (Table 2). Water content in the untreated dewatered sludge was reduced to 84% from the original 97% after the dewatering process whereas in the biosolid-compost, it was further reduced to 81.88%. The number of *E. coli* and *Salmonella* enumerated from untreated and undehydrated sludge was higher than the regulatory standards, especially, the *E. coli* content was about 2 times higher than the standards. The main reason could be that the water recycling centre treats domestic sewage and the sewage contains not only organic substances, but also diverse groups of bacteria [11,12]. When the water content of sludge was as high as 97%, the number of *E. coli* was also high which reduced after further dehydration of the sludge. Higher number of *Salmonella* than the regulatory standards in dehydrated sludge may imply that the dehydration process can effectively reduce *E. coli* but may not have the similar effect on *Salmonella*. In addition, when the dewatered sludge was mixed with the mushroom waste and the chicken excreta to convert sludge to biosolid-compost by high-temperature fermentation at 130 °C for
2 hours, the number of pathogens in such compost complied with the regulatory standards. The number of parasite eggs which exceeded the regulatory standards in the untreated sludge (data not shown) were absent in the biosolid-compost.

Table 2. Content of water and pathogenic bacteria in sewage sludge.

| Sampling                      | pathogens         | water content | Cw<sup>a)</sup> | Cw<sup>b)</sup> | Cd<sup>c)</sup> |
|-------------------------------|-------------------|---------------|-----------------|-----------------|----------------|
| Untreated and undehydrated sludge | *Salmonella*      | 97%           | 3.0             | <0.18           | 6              |
|                               | *E. coli.*        |               |                 | 790             | 2633           |
| Dehydrated sludge             | *Salmonella*      | 84%           | 16              | 2.7             | 16.88          |
|                               | *E. coli.*        |               |                 | 17              | 10.6           |
| Fermentation                  | *Salmonella*      | 81.88%        | 18.12           | 0               | 0              |
|                               | *E. coli.*        |               |                 | 0               | 0              |

USEPA standard: *E. coli* =1000MPN/g, *Salmonella* spp. < 3 MPN/g
EU standard: *E. coli* =1000MPN/g, *Salmonella* spp. No detection
a): Percentage of dry matter contained in wet sludge (%)
b): *E. coli* content in wet sludge (MPN/10<sup>9</sup>g), *Salmonella* spp. content (MPN/g)
c): *E. coli* content in dry sludge (MPN/g), *Salmonella* spp. content (MPN/g)

Table 3 shows heavy metal concentration in sludge and bio-compost. The heavy metal content of the sludge after transposition was greatly reduced (reduction percentage ranged between 66.67 and 79.68%) complying with the heavy metal concentration standard of sewage sludge for reuse. Moreover, the heavy metal concentration in the soil applied with the bio-compost was also lower than regulatory standard of the soil (data not shown). Based on these observations, it can be concluded that there would be no safety concerns if the sludge was to be applied to the soil after high temperature fermentation with agricultural waste.

Table 3. Heavy metal concentration of sludge and bio-compost.

|                | Cd (mg/kg) | Cr (mg/kg) | Cu (mg/kg) | Ni (mg/kg) | Pb (mg/kg) | Zn (mg/kg) |
|----------------|------------|------------|------------|------------|------------|------------|
| Sludge         | 2.4        | 414        | 357        | 153        | 136        | 2130       |
| Biosolid-compost | 0.8       | 113        | 73         | 37         | 31         | 594        |
| Reduction percentage | 67       | 73         | 80         | 76         | 77         | 72         |

Biosolid-compost, produced using above technology, was applied to the land for planting red leaf shovel (Figure 3). The control group was supplied with the commercial fertilizer and the experimental group with the biosolid-compost in this study. The average plant height of the experimental group was observed 5 cm higher than that of the control group. Therefore, it can be elucidated that such biosolid-compost can be applied to soil, which is undoubtedly safe and can also promote plants growth.
4. Conclusions
Based on experiment, the following conclusions can be drawn:
1. High temperature fermentation of sludge with agricultural wastes can be used to produce biosolid compost. The pathogens and heavy metal concentration of such compost are in compliance with the prescribed standards. Therefore, there is no safety concern.
2. Applying the biosolid-compost as the soil improvement material to plants, we found even better effect than the general commercial fertilizer. In fact, the plant height and growth situation are further improved by such compost. Hence, this biosolid recovery technique may contribute addressing the issues with sewage sludge and agricultural wastes.

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