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Preparation and Characterization of Micro-nanoscale MSWI Ash and Their Metal Release on MSW Anaerobic Digestion

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Abstract: This paper investigates the preparation of the micro-nanoscale municipal solid waste incinerator (MSWI) ashes by using ball mills (PM 100). The physiochemical properties of MSWI ashes such as particle size, mineral compounds and metal content were further characterized by X-ray powder diffractometer (XRPD), X-ray energy dispersive spectrometer (EDS), field-emission scanning electron microscope (FE-SEM) and induced coupled plasma optical emission spectrometer (ICP-OES). In addition, titrations were carried out to obtain the potential metal release of MSWI ashes in MSW and distilled water at different pHs. Batch anaerobic digesters were also conducted to test the MSWI ash as catalyst in the co-digestion process of MSW and MSWI ashes. Results showed that micro-nanoscale size of MSWI ashes could be obtained by ball mill grinding and was verified by EDS analysis and laser particle size analyzer although some agglomeration phenomenon were found. Metals releases were found higher with pHs lower than 3. Gas accumulation in the batch anaerobic digesters also showed that suitable ratios of MSWI ash addition was found to show beneficial effects, however, higher than a critical amount of MSWI ash was found to exert a detrimental effects on anaerobic digestion.

Keywords: MSWI ash; metals; XRD; anaerobic digestion.

1. Introduction

Municipal solid waste (MSW), at present, is mostly treated by municipal solid waste incinerator (MSWI) in Taiwan. MSWI has the advantage of reducing MSW volume while gaining the energy recovery of electricity and steam. However, residues such as bottom ash and fly ash after incineration are still an environmental problem and need further treatment to avoid the secondary pollution. MSWI ashes contained complicated and hazardous materials such as dioxins, polyaromatic hydrocarbons (PAHs) and heavy metals [1-7]. They were applied in several areas such as soil amendment, backfill, aggregate and geotechnical utilization [8-19]. Using them as landfill cover is thought to be an aggressive option and is getting more acceptable if treated appropriately [20-21]. Except conventional treatment and use, creative thought was evolved to use them as catalyst or aggregate that may enhance the pollution control and civil material strength by grinding them into

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micro-nano scale size [22]. Nanoscale technology has been significantly developed in many areas such as optics, electricity, adsorption, catalyst, magnetism, transportation, disease curing, corrosive resistance and strength [22-36] including pollution abatement and remediation in environmental engineering [22,23,39]. Therefore, preparation of micro-nano scale materials is the first important step to apply them to further application. Micro-nanoscale size preparation of different materials has been developed in some methods and procedures. However, it needs to consider the specific application and thus develops the specific procedure for different purposes. Thus, dry preparation of micro-nanoscale MSWI ashes may be the premise consideration for the MSWI ash preparation and further utilization as catalyst in anaerobic digestion [20-21]. Further characterization of MSWI ashes such as metal content, mineral composition, and catalytic use added to the anaerobic digesters are the main purposes of this investigation.

2. Experimental

2.1. MSWI ashes and MSW substrate

MSWI ashes were obtained from a mass burning incinerator in central Taiwan. MSWI bottom ash was taken from the pits transported from the furnace while fly ash was obtained from the bag filter. MSWI ashes were prepared for micro-nanoscale size and also characterized with instrument for metal content, mineral, and metals release. MSW was prepared as that by Lo [20-21]. MSW containing typical organic fraction was made with office paper (30%), newspaper (35%), hay (30%), and food waste (5%). Chemical constituents of C, H, O, N etc was analyzed by elemental analyzer (elementar vario EL III) and was found to be approximately ~46, ~6, ~41, ~1.4 and ~5.6%, respectively.

2.2. MSWI ash characterization and metals release

Micro-nano scale MSWI ashes were prepared by ball mill (PM 100). Eight gram of MSWI ashes were added with 5 mL distilled water, then, were ground by ball mill for 15 minutes. Ground MSWI ashes were put into oven with 105℃ to dry the MSWI ashes. The ground MSWI ashes were measured for particle size and element content by Field-emission scanning electron microscope (FE-SEM) and X-ray energy dispersive spectrometer (EDS) respectively. For mineral analysis, X-ray powder diffractometer (XRPD) was used to measure the compounds in the ashes. Because MSWI ashes have been applied in some areas, thus, environmental conditions such as pH was chosen to test its effect on metals release. Titrations were carried out by adding NaOH and HNO_3 for adjustment from pH 1 to 13. Bottom ash of 30 g and fly ash of 4 g with conventional and micro-nano scale size were added into 100 mL distilled water and prepared MSW respectively. At selected pH in the titration process, the MSW or distilled water were filtered for metals analysis by ICP-OES (Thermal Electron Corp.). The released metals chosen for measurement were Ca, Mg, K, Na, Cd, Cr, Cu, Ni, Pb and Zn.

2.3. MSWI ash added onto MSW anaerobic digester

In order to understand the application of MSWI ashes on biological treatment process such as co-digestion of MSW and MSWI ash, anaerobic digesters kept at ~35℃ were used to test their applicability potential. Fly ash of 0.12, 3, 6, 18 and 30 g and bottom ash of 0.6, 12, 36, 60 and 180 g with micro-nano and non-micro-nano scale MSWI ashes were added onto 600 ml bottle filled with 350 mL MSW and 150 ml seeded sludge. Gas production was recorded by gas collector with water replacement method every day. Gas generation was used to assess potential inhibitory or stimulatory effects of different MSWI ashes on MSW anaerobic digestion.

3. Results and discussion

3.1. Mineral composition

Mineral compositions of micro-nano and non-micro-nano scale MSWI ashes were measured by XRPD as can be seen in Figure 1A-D. In addition, particle size of micro-nano scale MSWI ashes can be found in Figure 2A-B. Results showed that mineral compositions have changed via ball mill grinding. Particle size of micro-nano scale MSWI ashes can be obtained through ball mill grinding. However, agglomeration phenomenon might take place as can be seen in Figure 2A-B. Metal content of MSWI ashes was measured and can be seen in Figure 3A-B (bottom ash) and Figure 4A-B (fly ash). Figure 3A and 4A showed the content of alkali metal and Figure 3B and 4B the content of heavy and trace metals. Alkali metals were found higher than that of heavy and trace metals at both bottom and fly ash.

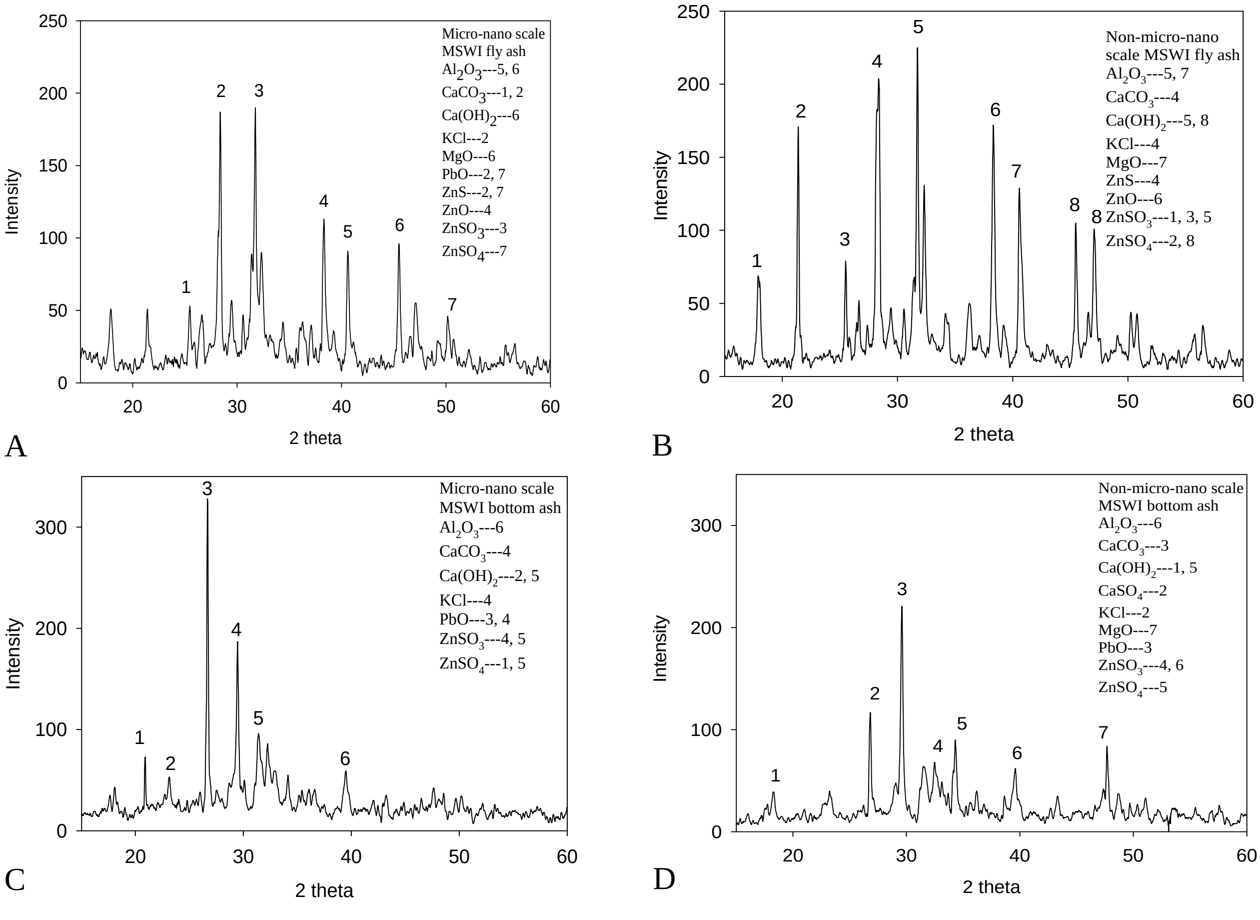
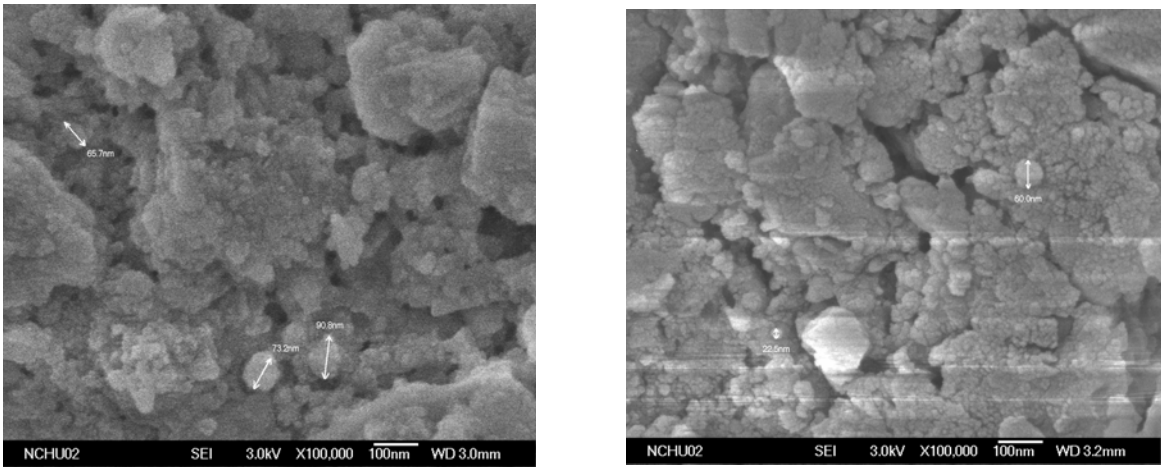


Figure 1. The mineral composition of micro-nano scale (1A), non- micro-nano scale (1B) MSWI fly ash, micro-nano scale (1C), non- micro-nano scale (1D) MSWI bottom ash.



A B

Figure2. Scanning diagram of micro-nano scale MSWI fly ash (2A) and micro-nano scale MSWI bottom ash (2B).

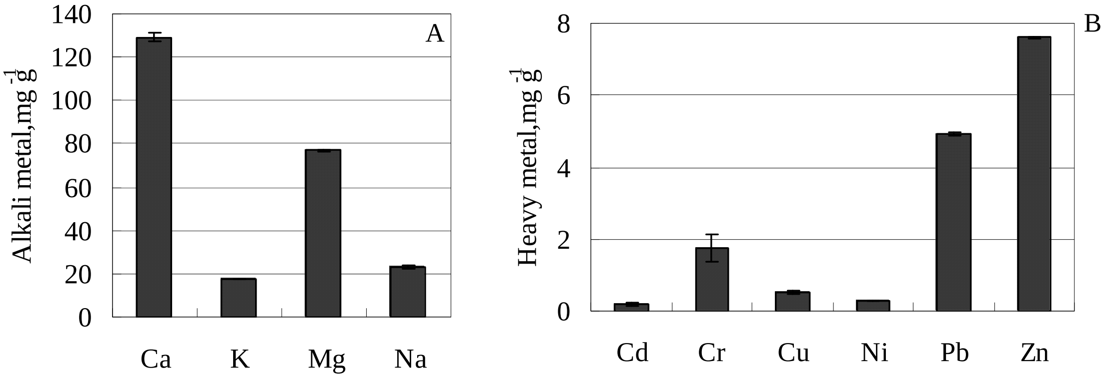


Figure 3. Metal content of bottom ash (BA).

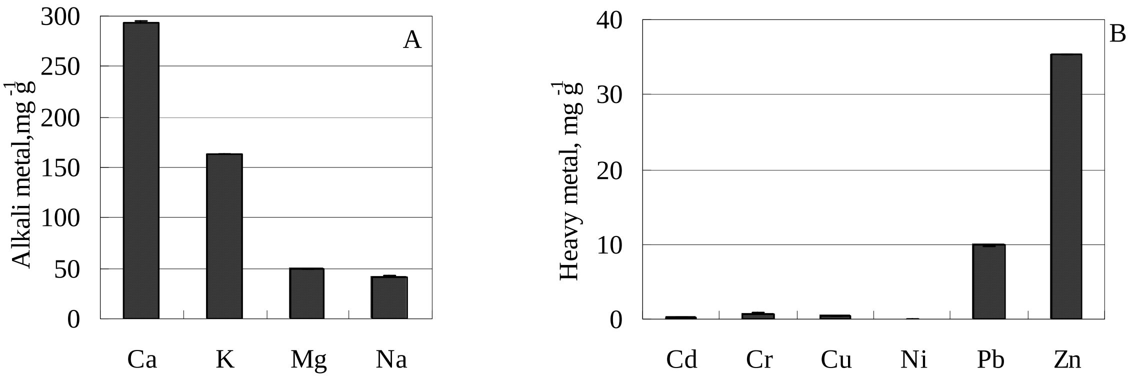


Figure 4. Metal content of MSWI fly ash (FA).

3.2. Metals release

Selected metals release of micro-nano scale and non- micro-nano scale size of MSWI ashes were measured to assess their potential application and risks when exposed to environment under different pHs. The released metals chosen for measurement were Cd, Cr, Cu, Ni, Pb and Zn. Results revealed that micro-nano scale MSWI ash had higher released levels than non-micro-nano scale one (Figure 5E-J). It was because that the MSWI ashes contained potential higher alkali metals content than heavy metals. Higher metals releases were also observed for all metals under pH 3.

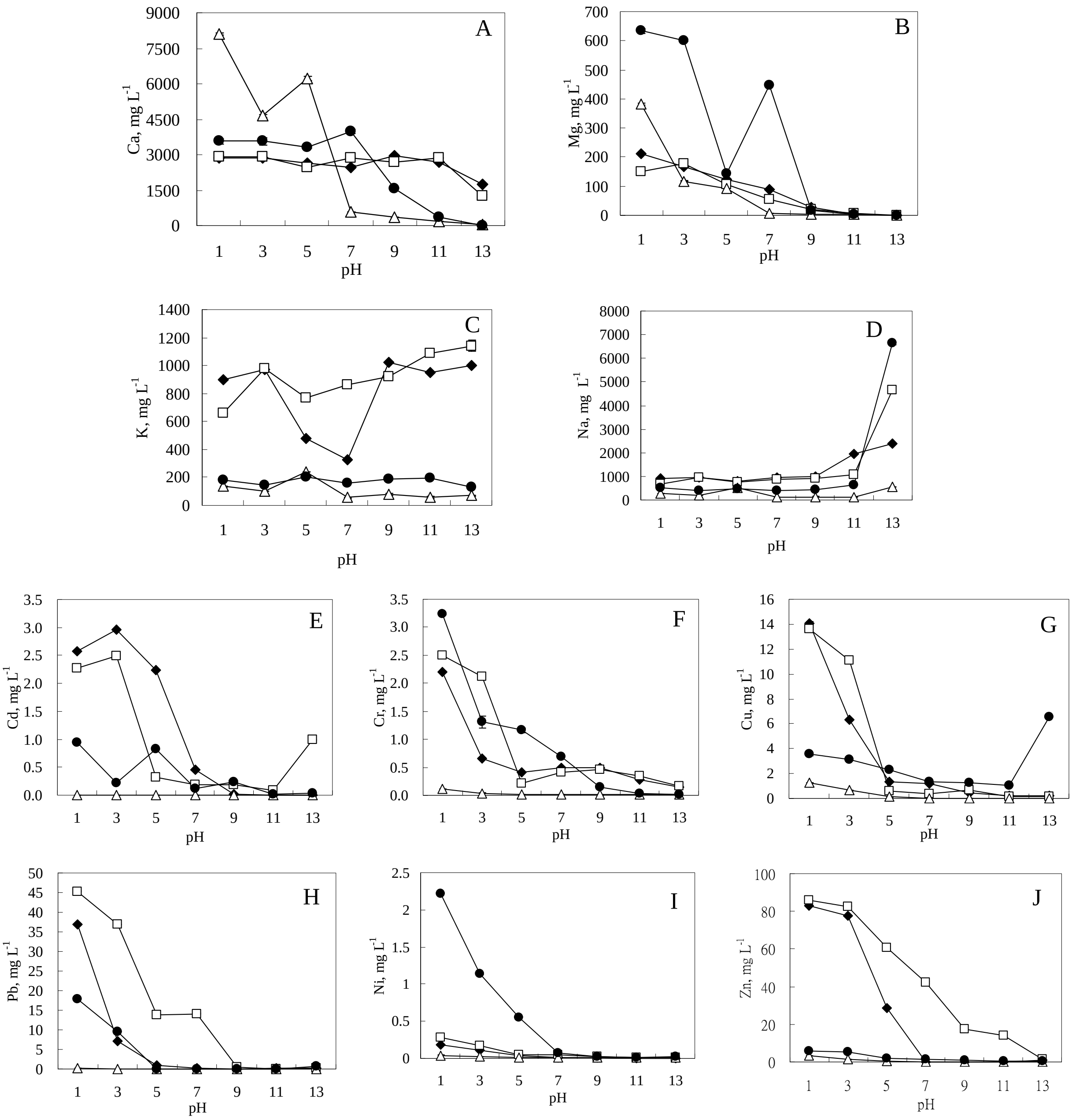


Figure 5. The alkali and heavy metal releases of 4 g MSWI fly ash (◆fly ash and □micro-nanoscale fly ash) and 30 g MSWI bottom ash (△bottom ash and ●micro-nanoscale bottom ash) exposed with 100 mL MSW substrate at different pHs

3.3. MSWI ash addition on anaerobic digestion

The gas accumulation in the anaerobic digestion process showed that some MSWI fly ash addition had the potential to inhibit the gas production particularly on the added amount higher than 30 g both in the micro-nano scale and non-micro-nano scale. Micro-nano scale and non-micro-nano scale size of 6 g fly ash addition seemed to show a same slight gas enhancement compared to other fly ash additions (Figure 6). Fly ash added bioreactors revealed that gas production appeared to show the similar trend for both micro-nano scale and non- micro-nano scale addition. 12, 36 and 60 g of micro-nano scale MSWI bottom ash added bioreactors showed the increased gas production compared to other added ones while 36, 60 and 120 g of non-micro-nano scale MSWI bottom ash added bioreactors exerted the enhancement of gas production and showed a slight higher gas production than the 12, 36 and 60 g micro-nano scale MSWI bottom ash added ones (Figure 6). Micro-nano scale MSWI bottom ash added onto bioreactors might be more agglomerated than the non-micro-nano scale one resulting less potential nutrients of dissolved metal levels for anaerobic digestion. These phenomena were thought that suitable released metals levels might be beneficial to the MSW anaerobic digestion. The extent of stimulation or inhibition depended on the metals concentration, microbial community, pH and the carbon source content.

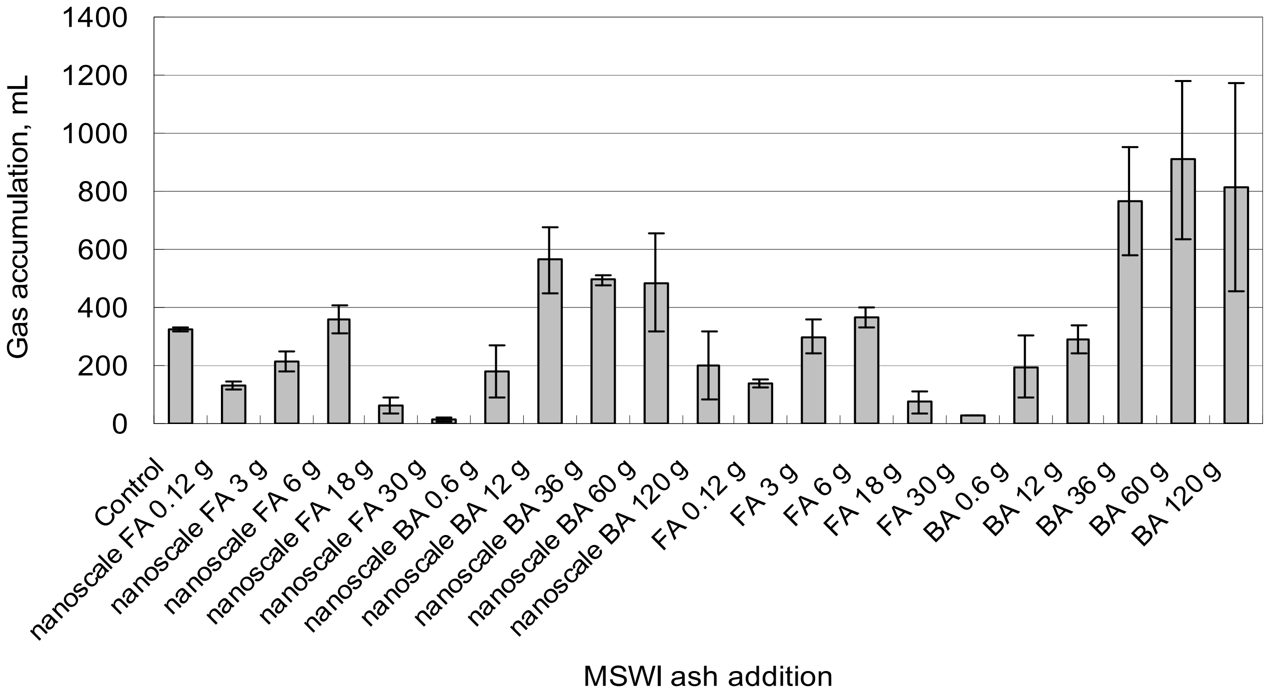


Figure 6. Gas accumulation of MSW substrate with different MSWI bottom and fly ash

4. Conclusions

Micro-nano scale MSWI ashes were prepared by ball mill grinding. Further, it was characterized for metal content, mineral composition, by instrumental analysis such as XRD, EDS and ICP. Anaerobic bioreactors for MSW digestion were used to test its potential application in biological treatment process. Results showed that micro-nano scale MSWI ashes can be obtained by ball mill grinding. Some mineral compositions were changed through the grinding process. MSWI ash addition on the effects of MSW digestion also showed that adequate ratios of MSWI bottom ash were found to enhance gas production than several addition ratios of MSWI fly ash.

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