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# Biostabilization assessment of MSW co-disposed with MSWI fly ash in anaerobic bioreactors

H.M. Lo[a,*], M.H. Liu[a], T.Y. Pai[a], W.F. Liu[b], C.Y. Lin[c], S.C. Wang[a], C.J. Banks[d], C.H. Hung[e], C.F. Chiang[f], K.C. Lin[g], P.H. Chen[a], J.K. Chen[a], H.Y. Chiu[a], M.H. Su[e], T.A. Kurniawan[a], K.C. Wu[a], C.Y. Hsieh[a], H.S. Hsu[a]

[a] Department of Environmental Engineering and Management, Chaoyang University of Technology, 168, Jifong East Road, Wufong, Taichung County, Taiwan, ROC
[b] Department of Electrical Engineering of Feng Chia University, Taichung 407, Taiwan, ROC
[c] Department of Soil and Water Conservation, National Chung Hsing University, Taichung 402, Taiwan, ROC
[d] Department of civil engineering and the Environment, Southampton University, University Road, Southampton SO17 1BJ, UK
[e] Department of Environmental Engineering, National Chung Hsing University, Taichung 402, Taiwan, ROC
[f] Department of Health Risk Management, China Medical University, No. 91 Hsueh-Shih Road, Taichung 40402, Taiwan, ROC
[g] Department of Occupational Safety and Health, Chung Shan Medical University, 110, Sec. 1, Jiangguo North Road, Taichung 402, Taiwan, ROC

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ABSTRACT

Municipal solid waste incinerator (MSWI) fly ash has been examined for possible use as landfill interim cover. For this aim, three anaerobic bioreactors, 1.2 m high and 0.2 m in diameter, were used to assess the co-digestion or co-disposal performance of MSW and MSWI fly ash. Two bioreactors contained ratios of 10 and 20 g fly ash per liter of MSW (or 0.2 and 0.4 g g$^{-1}$ VS, that is, 0.2 and 0.4 g fly ash per gram volatile solids (VS) of MSW). The remaining bioreactor was used as control, without fly ash addition. The results showed that gas production rate was enhanced by the appropriate addition of MSWI fly ash, with a rate of ∼6.5 l day$^{-1}$ kg$^{-1}$ VS at peak production in the ash-added bioreactors, compared to ∼4 l day$^{-1}$ kg$^{-1}$ VS in control. Conductivity, alkali metals and VS in leachate were higher in the fly ash-added bioreactors compared to control. The results show that MSW decomposition was maintained throughout at near-neutral pH and might be improved by release of alkali and trace metals from fly ash. Heavy metals exerted no inhibitory effect on MSW digestion in all three bioreactors. These phenomena indicate that proper amounts of MSWI fly ash, co-disposed or co-digested with MSW, could facilitate bacterial activity, digestion efficiency and gas production rates.



## 1. Introduction

Municipal solid waste (MSW) is disposed of as landfilling in many countries, including Taiwan. It is also a possible renewable energy source due to its potential methane recovery [1,2]. However, owing to difficulties in finding appropriate landfill sites in Taiwan, municipal solid waste incinerators (MSWI) have been chosen as an effective alternative to treat MSW. It has been found that MSWI could reduce MSW volume by up to 90% and weight by up to 75% [3], while gaining the beneficial recovery of electricity and steam. However, residues generated from MSWI remain an environmental concern, needing further treatment to prevent secondary pollution.

MSWI bottom ash has been used as industrial aggregate, soil amendment, backfill, and landfill cover [4–6]. MSWI bottom ash has been treated by mono landfill or used as landfill cover accounting for mostly treatment and disposal and a suitable added ratio of MSWI bottom ash to MSW has been found to be beneficial to MSW anaerobic digestion, through improved acids neutral capacity and increased gas production [7]. In addition, alkalinity in the bottom ash has been shown to assist anaerobic digestion of the organic fraction of MSW [8].

Several investigations have also been presented in the co-composting or co-digestion of coal ashes with sludge or organic materials. Coal fly ash co-digested or co-composted with sewage sludge was investigated by Fang et al. [9,10]. In addition, co-composting of pulp and paper mill fly ash with wastewater sludge was reported by Hackett et al. [11]. Co-composting of organic materials such as chicken feces, urea, manure and food garbage with inorganic substances including coal ash and volcanic ash was also presented by Suzuki et al. [12]. Generally, the quality of compost was assessed by its C/N ratio, total P, $P_2O_5$ and microbial population [13]. Comprehensive report of non-coal ashes utilization was

* Corresponding author. Tel.: +886 4 23323000x4469; fax: +886 4 23742365.
*E-mail address:* hmlo@cyut.edu.tw (H.M. Lo).

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described by Ribbing [14]. These utilizations include forest spreading, construction, cement replacement, and as a liner cover for landfills and mine tailings. In addition, utilization of MSWI bottom ash with MSW in co-disposal or co-digestion process is reported. Co-landfilling of proper MSW bottom ash with MSW [15] and co-digestion of suitable MSW bottom ash with OFMSW [7] were reported to be beneficial to the MSW digestion.

MSWI fly ash has been used in some aspects of applications including soil amendment, aggregate and effective adsorbent [16–18]. However, there are few investigations regarding the co-disposal or co-digestion of MSWI fly ash with MSW, as MSWI fly ash has been considered an environmental hazard, needing further appropriate treatment and disposal. Thus, co-disposing or co-digesting MSWI fly ash with MSW is a testing challenge requiring theoretical, experimental and field investigations to obtain clear baseline data.

This study aims to investigate the effects of MSWI fly ash co-digested or co-disposed with MSW, on the decomposition of MSW via laboratory-scale anaerobic bioreactors, with particular attention to digestion performance and biostabilization.

## 2. Materials and methods

### 2.1. Composition of synthetic MSW

The synthetic MSW comprised of 35% office paper, 30% newspaper, 30% hay and 5% potato, on a dry weight basis, as described by Lo [7], and was typical of organic fraction of MSW (OFMSW). Each MSW fraction was oven-dried in advance to be water-free. They were shredded, cut into <5 mm pieces and further blended with distilled water to produce the final MSW substrate with total solids (TS) of ∼6% and volatile solids (VS) of ∼5%. This rather higher water content of MSW seemed to differ from a real MSW of ∼50% VS (dry weight basis) with a moisture content of around 35%. However, the chemical percentage composition of the synthetic refuse for C, H, O, N and others was typical and was approximately 46, 6, 41, 1.4 and 5.6%, respectively. Although OFMSW has higher C and N content than that of real MSW. C/N ratio of 32.86 of OFMSW was similar to 39.68 of real MSW suitable for digestion and composting (C/N = 25). This set up of experimentation attempted to reduce the unwanted materials such as heavy metals and interferences from real MSW complexity. In addition, higher water content may help the microbial attack and quicker biodegradation in a shorter period.

Selected alkali and heavy metal content of MSW are listed in Table 1. The MSW substrates were stored in plastic containers in a freezer for experimental use.

### 2.2. MSWI fly ash

MSWI fly ash was obtained from a mass-burning incinerator in central Taiwan. The physical composition of receiving MSW contained paper and cardboard (30.63%), textile (6.52%), leaves, straw and wood (3.61%), domestic food (19.22%), plastics (24.05%), metals (2.86%), glasses (4.23%), stone and sand diameter >5 mm (3.35%), and others (5.53%), respectively. In addition, the chemical constituents of MSW covered water content (50.77%), ash (9.69%) and combustible (39.54%). Major element of C (20.91%), H (2.89%), O (15.10%), N (0.3%), S (0.20%) and Cl (0.14%) were also measured within the combustible.

It was collected from air pollution control devices, such as the semi-dry scrubber with $Ca(OH)_2$ as flushing reagent and bag filter for ash filtration. Final control of flue gas was sprayed with powder carbon for dioxin and hazardous gas removal. Then, flue gas was induced by fans to emit into the atmosphere by a stack (with three steel pipes inside) of ∼120 m high. Fly ash settled from semi-dry scrubber and bag filter was conveyed to the ash pit. Fly ash was taken from the ash pit with plastic bag for experiment. The MSWI was operated at temperature range 850–1050 °C. Selected metal levels of MSWI fly ash are also listed in Table 1 [19–27].

### 2.3. Anaerobic bioreactor

Three bioreactors were employed to examine the effects of MSWI fly ash addition on MSW anaerobic digestion. Each anaerobic bioreactor was 1.2 m high and 0.2 m in diameter, with a working volume of ∼34 l (Fig. 1). One bioreactor was used as control. It contained a mixture of 22 l synthetic MSW substrate (TS 6%; VS 5%) and 12 l anaerobic sludge seeding (TS 3%; VS 2.5%;) from the sludge anaerobic digester at Fu-Tian municipal wastewater treatment plant located at central Taiwan. This plant collects ∼ 50,000–55,000 CMD waste water and adopts aerobic biological treatment process with activated sludge method (HRT, 6 h). Settled sludge from first (HRT, 1.5 h) and secondary sedimentation tank (HRT, 4 h) is sent to gravity thickener (HRT, >12 h) and then the anaerobic digester (SRT, 30 days) for anaerobic digestion. The digested sludge are then dewatered by pressure filtration. Dewatered sludge (75% water content) is landfilled or reused in agricultural purpose. After secondary sedimentation tank, the effluent is treated with 10% NaOCl in a disinfection tank for 20 min and discharged. Digested sludge in the anaerobic digester was collected in 20-l plastic bottles and was settled in laboratory to obtain a VS of ∼2.5% (anaerobic sludge seeding) and immediately mixed with MSW to conduct the experiment. The combined VS of MSW and anaerobic sludge seeding was measured and calculated to be 4.12%. The leachate had a pH, alkalinity, COD and volatile acids of ∼7.7, ∼208 mg $l^{-1}$, ∼4734 mg $l^{-1}$ and ∼83 mg $l^{-1}$, respectively. The two fly ash-added bioreactors also contained ∼34 l of MSW substrate and anaerobic sludge seeding, the same as the control, but with a further addition of two weight ratios, corresponding to 10 and 20 g $l^{-1}$, respectively (10 and 20 g fly ash per liter MSW or 0.2 and 0.4 g $g^{-1}$ VS).

The three bioreactors were arranged in four layers. In the control bioreactor, each layer contained 8.5 l of the mixture of MSW substrate and anaerobic sludge seeding. In the ash-added bioreactors, each layer contained 6.5 l of the mixture of MSW substrate and anaerobic sludge seeding, with a cover of a 2-l mixture of MSW and anaerobic sludge seeding blended with the designated MSWI fly ash weight ($22 \times 10/4 = 55$ and $22 \times 20/4 = 110$ g for each layer, respectively), simulating co-digestion of MSW and MSWI fly ash for the potential application to landfill-cover practice (Fig. 1). The three arrangements, including control and two fly ash addition ratios, corresponded to 0, 10 and 20 g $l^{-1}$, respectively. Leachate from the three bioreactors was recirculated by peristaltic pumps at a volume of 100 ml $day^{-1}$. Leachate recirculation was operated carefully to avoid the digesters disturbance. To measure operational parameters for assessment of MSW biostabilization, 100 ml leachate was sampled daily or weekly. The three anaerobic bioreactors were placed in a homeostatic oven, maintained at ∼35 °C, suitable for anaerobic digestion.

### 2.4. Parameter analyses

The parameters chosen for bioreactor performance assessment (pH, conductivity, alkalinity, chemical oxygen demand (COD), volatile solids (VS), volatile acids (VAs), selected metals, etc.) were assessed from 100 ml leachate samples, taken daily or weekly. pH and conductivity were measured with pH and conductivity meter. Gas production was collected from the exit of anaerobic bioreactors with pipes connected to plastic bottle by using water replacement method every day. Alkali metals, heavy metals and other ions, such