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Characterization and evaluation of the leachability of bottom ash from a mobile emergency incinerator of COVID-19 medical waste: A case study in Huoshenshan Hospital, Wuhan, China

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Keywords: COVID-19, Medical waste bottom ash, Incineration, Metals, Leachability

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Abstract

To dispose of the medical waste generated during the COVID-19 pandemic, a new type of mobile emergency incinerator (MEI) was used in Huoshenshan Hospital, Wuhan, China, and consequently, it produced a number of medical bottom ashes (MBAs). In this study, the characterization and environmental risk evaluation of these MBAs were conducted to evaluate the disposal effect of this MEI used during the pandemic. Three types of leaching tests, EN 12457–2, TCLP 1311, and HJ/T 299–2007, were compared to investigate the release behaviors of major and trace elements from these MBAs. Lack of detection of COVID-19 in MBAs showed that this mobile emergency incinerator could thoroughly eliminate the COVID-19 virus in medical wastes to avoid secondary transmission. The results indicated that the increasing usage of chlorinated disinfectants and physiological saline solutions resulted in high Cl contents in MBAs. In addition, the increasing usage of polypropylene (PP) products changed the chemical properties and compositions of MBAs, with Ca as the main element. The leachability investigation revealed that the main metals in leachates were Ca, Na and K, and the toxic heavy metals such as Zn, Pb, Cu, and Cr in MBAs were difficult to extract because of the high pH (>12) of these MBAs. This study could provide consultation for the treatment and management of MBAs produced from MEIs dealing with emergent infectious diseases such as COVID-19.

1. Introduction

Since the end of 2019, coronavirus disease 2019 (COVID-19), with multiple global epicenters, has spread rapidly causing a tremendous impact in the majority of countries and regions. To better control the outbreak, the Chinese government built several makeshift hospitals and mobile hospitals to provide more beds, better service, and treatment for more COVID-19 patients. According to a report by the China Central Television Station (CCTV), 436 medical teams with 42,632 medical staff were dispatched to support the Hubei Province in the battle against COVID-19 (China Central Television Station, 2020b). A vast number of confirmed and suspected patients were cared for in the Huoshenshan Hospital for diagnosis, and further treatment was provided by 1400 medical staff (The People’s Republic of China, 2020d). The consequent rapid increase in medical waste became a potential infectious risk and put pressure on the government.

The medical waste generation rate depends on the following factors in health care facilities: level of activity, type of department, extent of recycling and inventory control, etc. (United Nations Environment Programme, 2012). According to statistical analysis, the medical waste generation rate in China is approximately 0.7 kg bed\(^{-1}\) day\(^{-1}\) before the outbreak of COVID-19 (Yong et al., 2009). In 2018, the amount of medical waste generated in 200 large- and medium-sized cities reached 817,000 tons, 99% of which was disposed of in a timely and proper manner in China (The People’s Republic of China, 2020a). However,
more medical resources were consumed during the pandemic containment and in disease treatments in China, especially in the Hubei Province. It is estimated that the medical waste generation rate is 2.5–3.0 kg bed$^{-1}$ day$^{-1}$ in makeshift hospitals and 3.0–5.0 kg bed$^{-1}$ day$^{-1}$ in professional hospitals such as Huoshenshan Hospital during the pandemic (Yu et al., 2020; Zhang et al., 2020). The medical waste department in Wuhan city, as one of the outbreak epicenters, has faced severe challenges. The relationships between confirmed cases remained, and the amount of medical waste generated from February 24 to April 18, 2020 (the week the Huoshenshan Hospital closed) in the Hubei Province and Wuhan city is revealed in Fig. S1.

According to the WHO, medical waste was divided into the following categories: general waste (85%), infectious waste (10%), and chemical radioactive waste (5%) (United Nations Environment Programme, 2012). Improper treatment and unscientific disposal of infectious waste could pose serious viral transmission and waste of previous preventive work (United Nations Environment Programme, 2012). Although COVID-19 was classified and managed as a class B infectious disease, it was prevented and controlled as class A, namely, the highest control level via Chinese law. Hence, the medical waste and nonmedical waste generated in hospitals during the COVID-19 pandemic was classified as infectious waste by the Chinese government and must be disposed properly due to their high infectiousness (Chang et al., 2020; The People’s Republic of China, 2020c). In addition, compared to general hospitals, the legal maximum storage time for medical waste at COVID-19 professional and makeshift hospitals was regulated from 24 to 48 h to avoid potential infectious risks according to the requirements of the Chinese government (Yu et al., 2020). Therefore, 310 technical experts from 25 enterprises and institutions were sent to the Hubei Province to dispose of the generated medical waste, including 13 people from the author’s team. In their joint efforts, the disposal capability of medical waste in Wuhan City increased from 50 t d$^{-1}$ to 265.6 t d$^{-1}$ after the outbreak of COVID-19 (China Central Television Station, 2020a).

As a result of the long incubation, strong vitality, and unprecedented infectiousness of COVID-19, the ability to eliminate COVID-19 became the dominate factor for the selection of a medical waste treatment technology. In general, both general waste and infectious waste could be transformed into disinfected or sterile waste and recycled using different technologies, such as thermal, chemical, irradiative, and biological processes (United Nations Environment Programme, 2012). However, with the explosion of medical waste and the urgent need for treatment facilities after the COVID-19 outbreak, the Chinese government specified mobile incinerators, which could reduce the volume of medical waste by 95% after incineration and avoid the transmission risk of COVID-19 during the transport of medical waste, into the list of resources for medical waste emergency disposal (The People’s Republic of China, 2020c). Therefore, MEIs have played important roles during the pandemic for medical waste treatment (The People’s Republic of China, 2020b). Representative MEIs used in Huoshenshan Hospital are shown in Fig. S2, which was developed by the author’s team. After incineration, the medical waste weight was decreased by more than 95 wt% and turned to fly ash (FA) and bottom ash (BA). Until now, there has been little information on the characterization of COVID-19 medical bottom ashes (MBAs).

In the present study, the characteristics of MBAs from a COVID-19 medical waste emergency incinerator during the pandemic were reported for the first time. The MBAs were collected weekly from February 23 to March 15 in the Huoshenshan Hospital, Wuhan, China. The objectives of this study were to (1) investigate the characteristics of MBAs in the Huoshenshan Hospital; (2) analyze the differences in physicochemical properties and elemental composition of MBAs at various sampling intervals; and (3) evaluate the leaching toxicity of MBAs.

2. Materials and methods

2.1. MBA collection

The MEI was supplied by Anhui Guangtong Automobile Manufacturing Co., Ltd., Nanjing Normal University, and Nanjing Institute of Environmental Science, MEE. The MEI operate has been working in the Huoshenshan Hospital during the pandemic and is equipped with a main and second combustion chamber. The main combustion chamber is the space for waste incineration at 600–800 °C. It is an independent chamber surrounded by a furnace wall, grate and arch, which is the core part of the incinerator. The second combustion chamber is set behind the main combustion chamber to burn organic matter such as dioxin in the flue gas deeply at 900–1200 °C. Aviation kerosene was used as fuel during incineration because of its high calorificity, low freezing point, and zero pollution.

Three MBAs (MBA-1, MBA-2, and MBA-3) were collected on February 23, March 1, and March 8, respectively. The incombustible materials such as metals and glass accounted for approximately 9% of the bottom ash, which was separated from MBAs before further analysis. The images of the bottom ashes are shown in Fig. S3. Before MBAs were brought out of the Huoshenshan Hospital, detection of COVID-19 in MBAs was conducted using the nucleic acid-based polymerase chain reaction (PCR) assay (Orive et al., 2020) by the virus laboratory researchers to avoid COVID-19 transmission, and no COVID-19 virus was detected in the samples. The chemical reagents used during the analysis were purchased from Nanjing Chemical Reagent Co., Ltd. (China).

2.2. Characterization of MBAs

First, the samples were sieved to <3.2 mm after collection and dried at 105 °C for 24 h. The moisture content was measured after drying. The bulk density of MBA was determined according to ASTM E1109. The MBA particle size distribution was measured by a laser diffraction particle size analyzer (Mastersizer, 2000; Malvern Panalytical Ltd, UK) after dispersion treatment by ultrasonication. The MBA pH was analyzed by making a slurry in distilled water with a solid-to-liquid ratio (1:5) according to EN 15933–2012 (Asquer et al., 2019).

The chemical element compositions of MBAs were detected by X-ray fluorescence (XRF, Axios, PANalytical B.V., Netherlands). According to HJ 781–2016, the metal contents in MBA were analyzed by inductively coupled plasma–mass spectrometry (ICP–MS, NexION 300X, PerkinElmer, USA) and inductively coupled plasma optical emission spectrometer (ICP-OES, Prodigy Plus, Leeman, USA) after a strong acid digestion (PateI and Devatha, 2019). Soluble inorganic salts of MBAs were determined by ion chromatography (IC, ICS900, Thermo Dionex, USA) via NY/T 1121.16–2006 (Quina et al., 2009). The loss on ignition (LOI) was obtained by heating MBA at 600 °C for at least 6 h (HJ 1024–2019). The organic matter content of MBA was measured using the KMnO$_4$ method (Tirol-Padre and Ladha, 2004). The porosity structure parameters were investigated by an ASAP 2460 BET surface area analyzer (Micromeritics Instrument Corporation, USA). The morphologies and structures of MBAs were investigated by scanning electron microscopy (SEM, ZEISS Sigma 300, Carl Zeiss AG, Germany). The main mineralogical phases of MBA were determined by X-ray diffraction (XRD) using a D/Max 2500 v/pc instrument (Rigaku Co., Japan).

2.3. Leach test

In a previous study, EN 12457–2, TCLP 1311, and HJ/T 299–2007 were extensively applied to assess the mobility and leachability of hazardous elements (Tsakalou et al., 2018; Wang et al., 2015). To estimate the environmental risk of MBA caused by the potential emission of harmful metals, leaching tests were performed following three predefined methods (Wang et al., 2015).

In the EN 12457–2 procedure, dry MBA (5 g) and deionized water...
rpm for 24 h at 25 °C. According to TCLP 1311, extraction fluid #2 was applied. The extraction solution was prepared by diluting 5.7 mL CH₃COOH with deionized water to 1 L. Then, the dry MBA (2.5 g) and extraction solution (50 mL) were placed in a 100 mL PE centrifugal tube and vibrated at 30 rpm for 18 h at 25 °C. In the HJ/T 299–2007 procedure, 0.1 mL sulfuric-nitric acid (2:1) was diluted in 1 L deionized water to prepare the extraction solution. Then, the dry MBA (5 g) and extraction solution (50 mL) were mixed in a 100 mL PE centrifugal tube and vibrated at 30 rpm for 18 h at 25 °C. The details of the specific materials and parameters are summarized in Table S3. After vibration, the pH of the mixture was determined via a pH meter. The leachates were acquired by a 0.45-μm pore size syringe filter. The concentrations of metals in the leachates were determined using ICP.

3. Quality control

The pH, soluble inorganic salts, XRF analysis, full elements analysis, and leach tests of MBAs were repeated in triplicate in this study. The error bars denote the standard deviation about the mean of three independent measurements and were calculated by Excel (2019). The standard deviation in Tables and Figures was added. XRF analysis was conducted by PANalytical Axios at Yanqu Information Technology Co., Ltd., Hangzhou, China. The samples were sent to eceshi (www.eceshi.com) for soluble inorganic salts, BET, SEM, and XRD analysis. The quality assurance/quality control of ICP method was shown in Text S1.

3. Results and discussion

3.1. Physical and chemical characterization of MBAs

3.1.1. Primary properties

The physical parameters of the MBAs are shown in Table S4. The physical parameters of the MBAs ranged from 1.3678 to 1.4308 g cm⁻³, which are comparable to those of bottom ashes in previous reports (Huber et al., 2020). MBAs are highly alkaline with a pH level of approximately 13, which might be attributed to the presence of alkali metals and metallic compounds such as Na₂O, K₂O, CaO, MgCO₃, and Al₂O₃ (Adotey et al., 2018; Bakkali et al., 2013). The moisture contents of MBAs range from 1.07% to 1.87%, indicating that the incineration almost dried these MBAs. From Table S4, the LOI content of MBAs ranged from 2.64 to 3.15, which was comparable to the range (from 1 to 3.4) reported in previous studies (Akyildiz et al., 2017; Anjum et al., 2014; Xie et al., 2016).

The particle size distributions of MBAs are shown in Fig. S4. According to previous studies, the particle size of ash could be influenced by the composition of medical waste and the process operating parameters of the incinerator, such as temperature and residence time (Chang and Wey, 2006; Sukandar et al., 2006). In this research, a finer particle size of bottom ash was observed. More than 90% (by volume) of MBA-1 particles were smaller than 225.0 μm, more than 50% had a size lower than 20.6 μm and more than 10% was smaller than 2.2 μm. The atmospheric environment could be polluted by small particles of ash (<10 μm). Therefore, during the disposition of MBAs, appropriate respiratory protection procedures needed to be conducted.

3.1.2. XRF test

The XRF results were normalized to 100% and are shown in Fig. 1, and the details of the others are listed in Table S5 in the Appendix. The results revealed that the major elements were CaO (53.62–62.18%), followed by SiO₂ (10.45–15.35%), MgO (7.54–9.47%), Cl (4.31–5.66%), and Al₂O₃ (3.65–5.83%) in the MBAs. Other compounds, such as Na₂O, TiO₂, Fe₂O₃, P₂O₅, K₂O, SO₃, and ZnO, were also found in low quantities (<5%). The bottom ashes also contain a small number of trace elements (0.19–0.29%).

3.1.3. The metal concentrations of MBAs

The minor element contents of MBAs are shown in Table S6. The results revealed that the elements with concentration <1 g kg⁻¹ in MBAs include Ba, As, Cu, Mn, Sr and Pb. Some toxic heavy metals in MBAs were also detected, including Cr, Ni, Co, and V. Some metals, such as As, Co, Ag, and Li, which were undetected in the XRF test, were found by ICP–MS after digestion. The content variation could be attributed to the component differences of medical wastes from different treatment batches.

3.1.4. The total water-soluble salt and anion contents of MBAs

The results of total water-soluble salt ions are shown in Table S7. The results indicate that the Cl⁻ content in MBAs is higher than that in other anions, which was in agreement with the chemical composition tested by XRF (Suda et al., 2016). Therefore, the total water-soluble salt was mainly related to the content of Cl⁻. In addition, there was no significant...
difference in the contents of NO$_2^-$, Br$^-$ and NO$_3^-$ among the three MBAs.

3.2. Mineralogical and morphological characterization of MBA

3.2.1. SEM and BET test

The surface microstructure of MBAs was examined by SEM at a microscopic level, and SEM images of MBAs are presented in Fig. S5. It is clear that the particulate sizes of MBAs agree with the particle size distribution analysis in Fig. S4. Some loose structures could also be observed, which could be enriched in heavy metals. As shown in Table S8, the BET surface area and pore volume of MBAs were 3.29–7.98 m$^2$ g$^{-1}$ and 0.0143–0.0205 cm$^3$ g$^{-1}$, respectively. In previous studies, the BET surface area of medical bottom ashes ranged from 2.28 to 8.01 m$^2$ g$^{-1}$, and the pore volume varied from 0.02 to 0.029 cm$^3$ g$^{-1}$ (Ni et al., 2013, 2017; Vavva et al., 2020). This indicates that there were no clear differences between the MBAs produced by the MEI and those bottom ashes previously reported.

3.2.2. XRD test

The XRD patterns of MBAs are depicted in Fig. 2. Calcite (CaCO$_3$) and calcite magnesian ((Mg$_{0.064}$Ca$_{0.936}$)CO$_3$) were found to be the main crystalline compounds of MBAs. This was consistent with the finding of high Ca by XRF analysis. The presence of calcite magnesian and quartz (SiO$_2$) also agreed with the detection of MgO and SiO$_2$ in the XRF analysis. Previous studies reported that quartz, identified as the peak phase of geopolymer crystals, occurred in the range of 20–30 with in-tensities ranging from 1200–180 (Abdullah et al., 2017). The presence of NaCl was consistent with the detection of NaO and Cl in the XRF analysis. In addition, the concentrations of other elements were too low to be detected by XRD analysis.

3.3. Leaching results

The results of the EN 12457–2(a), TCLP 1311(b), and HJ/T 299–2007(c) tests for MBAs are illustrated Fig. 3, and the full content is listed in Table S9 and Table S10 in the Appendix. From Table S9, it was observed that the pH value of MBAs-TCLP was lower than those of MBAS-EN and MBAS-HJ/T, which was likely due to the lower initial pH of the extraction solution and higher liquid-solid ratio in the TCLP 1311 method. The results showed that light metals such as Ca, Na and K were dominant in the three MBA leachates. The extraction efficiencies of some metals, such as Ca, Al, and Sr, in MBAs-TCLP were higher than those in MBAS-EN and MBAS-HJ/T. However, elements including Ag, As, Cd, Co, Mn, Ni, and V were undetected in the leachate.

3.4. Discussion

According to the XRF, ICP, and XRD results, Ca compounds were the main components in MBA, and their contents were much higher than those of bottom ash in a previous study (Bakkali et al., 2013; Gidarakos et al., 2009; Kougemitrou et al., 2011). The results indicated that MBA could easily form a geopolymer paste and have good mechanical properties during landfill disposal (Abdullah et al., 2017). In addition, some CaCO$_3$ was inferred to originate from medical supplies. The incinerated medical waste mainly contained disposable medical items such as protective suits, face masks, and glasses, which were made of polypropylene (PP) (Gao et al., 2012; Pechyen and Ummartyotin, 2016; Yang et al., 2007). During the production of PP, fillers, e.g., CaCO$_3$ and SiO$_2$, are usually added to enhance the stiffness and mechanical properties (Malakhov et al., 2020). After incineration, PP was burned into ash, but CaCO$_3$ and SiO$_2$ fillers remained in the ash. Therefore, SiO$_2$ was also detected by XRF and XRD tests. Because the composition of input wastes, incinerator type, and combustion temperature could affect the MBA properties, the major element components of MBAs during the COVID-19 pandemic were separate from those during the prepandemic period. The chemical compositions of MBAs were compared with those in different countries, as shown in Table S5 (Akyıldız et al., 2017; Gidarakos et al., 2009; Tsakalou et al., 2018; Tzanakos et al., 2014; Zhao et al., 2010). SiO$_2$ accounted for a large proportion of MBAs in the prepandemic incineration. However, because of the application of vast amounts of medical protective products during the pandemic, the ratio of PP products in medical wastes increased to a large extent, while the ratios of SiO$_2$ products (e.g., glass bottles) significantly declined. The mineralogical and morphological characterization of MBAs also showed the analysis of MBA composition. The agglomerated morphology formed

Fig. 2. XRD analysis of MBA-1 (a), MBA-2 (b) and MBA-3 (c).
by fine particles is consistent with a previous study, which could be consistent with lime (Tsakalou et al., 2018). Therefore, Ca compounds were the main component in the MBAs collected from the Huoshenshan Hospital.

Variations in the element contents of MBAs were found in separate incineration batches. These variations could be attributed to the large number of medical products, such as protective suits, face masks, glasses, needles, scalpels, and knives. The presence of Na and K in MBAs probably originates from medicine, physiological saline, blood-stained cotton, wound-dressing materials, and body fluid in medical waste, which has been previously reported (Bakkali et al., 2013; Shen et al., 2019). Some products in medical waste could increase the content of metals in MBAs. As the primary alloy metal compounds, Fe, Al, Ti, Mg, Ni, Mn, Cr, and Co are frequently employed in medical tools and instruments (Kougemitrou et al., 2011; Tsakalou et al., 2018; Zhao et al., 2009). The enrichment of Ba was possibly due to the consumption of contrasting agents used in radiology and glass-ceramics (Kougemitrou et al., 2011). Zn elements are widely added in food, textile materials, and medical materials used in radiology, and Cd, Cu, Pb are enriched in MBAs because they are generally applied in medicines, photographic materials, and medical tools (Shim et al., 2005). Silver nitrate was used as a sensitive substance in X-ray plates, increasing the Ag content in MBAs (Zhao et al., 2009).

Some nonmetallic elements were also contained in the MBAs. The presence of Cl was possibly caused by the body fluid associated with the protective suits, and the application of NaCl might be the source of Na (Allawzi et al., 2018). The presence of the other anions might be caused by the application of related medical chemicals.

The properties of MBAs were influenced by the composition of medical waste. Normally, the pH value of ash is correlated with its CaO content, and MBAs are highly alkaline (Abdullah et al., 2017). The high pH value of MBAs implied that the heavy metals in MBAs were stabilized and the leached heavy metals were quite low because hydrides of most heavy metals are sparingly soluble (Allawzi et al., 2018). Some investigations demonstrated that the finer particle size of ash brought a higher environmental risk (Allawzi et al., 2018; Wu et al., 2013). Because the consumption of PP increased during the pandemic and PP products could be thoroughly incinerated easily, the particle size of MBA was finer than that of bottom ash in previous studies (Bakkali et al., 2013b; Huber et al., 2020; Tsakalou et al., 2018). Therefore, it is necessary to take tougher management steps for MBA treatment (Bakkali et al., 2013b; Huber et al., 2020; Tsakalou et al., 2018). In addition, Ca components such as CaCO$_3$ and organic matter could adsorb water from the air, which might lead to the moisture increase in MBAs (Tang et al., 2015). The LOI value could be due to the unburned carbon contained in MBAs (Lee et al., 2016). The low LOI value of MBAs means that the incineration processed in the MEI is exhaustive. All of them meet the standard (5%) in the Chinese regulation of GB 18598–2019 and could be treated in a flexible landfill.

The leachability of heavy metals in MBAs was correlated with the physical and chemical characterization of MBAs. SEM analysis indicates that MBAs have cemented and hardened structures, which probably inhibit the leachability of metals (Zhang and Zhao, 2009). In addition, Ca compounds increased the compressive strength and leachate pH value of MBAs, which are beneficial to landfill disposal (Allawzi et al., 2018). However, the pH values of leachates exceeded the legal limits (pH = 12), indicating that these MBAs have corrosive effects (Bakkali et al., 2013; Shen et al., 2019).
et al., 2013). Therefore, these MBAs must be landfilled in concrete landfills according to GB 18598–2019. In the leaching tests, light metals such as Ca, Na and K were dominant in MBA leachates because of the major components of MBAs contained CaO, Na2O, and K2O. The higher liquid-solid ratio in the EN 12457–2 and HJ/T 299–2007 methods could increase the content of some strongly soluble metals, such as Na and K, in the leachate, which could largely exist in a strong alkaline environment. However, it is difficult for a large amount of Ca to exist in strong alkaline solutions because the solubility product constant ($K_{sp}$) of Ca(OH)$_2$ is much lower than that of NaOH and KOH. Because the leachate of MBAs had strong alkalinity, only a small number of heavy metals were extracted, and most of the heavy metals were immobilized by hydroxides (Vavva et al., 2020). In addition, the formation of calcium arseate phase at higher pH immobilized arsenate and decrease its leachability (Zhang et al., 2015). The contents of heavy metals such as Zn, Pb, Ca, and Cr in the leachate were below the regulatory limit value in GB 18598–2019. The TCLP regulatory limits includes eight metals (Ag, As, Ba, Cd, Cr, Pb, Hg, and Se) and only three of them (Ba, Cr, and Pb) were detected via ICP analysis. According to TCLP analysis (Agency, 1993; Stoker and Mueller, 2006), we suggested MBAs should be treated as hazardous waste, considering its specificity.

4. Conclusion

In this research, MBAs from MEIs applied in Huoshenshan Hospital, Wuhan, China, during the COVID-19 pandemic were analyzed using various analytical methods. The MBAs collected from separate batches revealed that the main compounds were similar and some properties of MBAs vary with the incinerated waste components. The lack of detection of COVID-19 revealed that there was no COVID-19 virus in the three MBA samples. The properties of MBAs were influenced by the increased usage of PP products. Because PP products were easier to incinerate thoroughly, MBAs had a finer particle size and potential risks to landfills and the atmosphere. In addition, Ca compounds were the main components in MBA, which was different from the bottom ash of medical waste in a previous study. The XRD analysis of MBAs showed that calcite and quartz are the main crystalline compounds, and XRF and ICP tests revealed that the major element was Ca due to the addition of CaCO$_3$ during the production of PP. Due to the presence of Na and K and the increased content of Ca in MBAs, MBAs were highly alkaline, and the leachability of heavy metals was decreased. Therefore, the leached heavy metal contents (via EN 12457–2, TCLP 1311 and HJ/T 299–2007) were below the limits in GB 18598–2019. However, because the pH of MBAs exceeded the limits of waste in flexible landfills (7.0–12.0), MBAs should be landfilled in a rigid landfill according to Chinese regulations. In general, the investigation showed that MEIs could achieve the same disposal effect as commonly used fixed incinerators and that the disposal effect as commonly used fixed incinerators and that the

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.114161.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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