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Characteristics and metal leachability of incinerated sewage sludge ash and air pollution control residues from Hong Kong evaluated by different methods

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ABSTRACT

The improper disposal of incinerated sewage sludge ash (ISSA) and air pollution control residues (APCR) from sewage sludge incinerators has become an environmental concern. The physicochemical, morphological and mineralogical characteristics of ISSA and APCR from Hong Kong, and the leachability and risk of heavy metals, are presented in this paper. The results showed that a low hydraulic and pozzolanic potential was associated with the ISSA and APCR due to the presence of low contents of SiO_2, Al_2O_3 and CaO and high contents of P, S and Cl (especially for APCR). Although high concentrations of Zn and Cu (especially for ISSA) followed by Ni, Pb and As, Se were detected, a low leaching rate of these metals (especially at neutral and alkaline pH) rendered them classifiable as non-hazardous according to the U.S. EPA and Chinese national regulatory limits. The leached metals concentrations from ISSA and APCR were mainly pH dependent, and metals solubilization occurred mainly at low pH. Different leaching tests should be adopted based on the simulated different environmental conditions and exposure scenarios for assessing the leachability as contrasting results could be obtained due to the differences in complexing abilities and final pH of the leaching solutions.

1. Introduction

To properly manage the increase in sewage sludge production in Hong Kong (about 1500 tons dewatered solids/day in 2014), the Hong Kong Environmental Protection Department (EPD) has recently completed the world's largest sewage sludge incinerator which is designed to incinerate a maximum of 2000 tons of dewatered sewage sludge a day. Unfortunately this solution to the sewage sludge disposal problem creates a new, albeit lesser problem, namely the need to dispose of the incinerated sewage sludge ash (ISSA) and air pollution control residues (APCR). They are both complex anthropogenic wastes, and their improper disposal has become an environmental concern. Landfill disposal of these two wastes is inadvisable for their limited landfill capacity in Hong Kong and wasting of recoverable resources. Consequently, it is of great interest to explore appropriate re-use and resource recovery options for ISSA and APCR. As such, the important and fundamental aspects of the ISSA and APCR, such as the physical and chemical characteristics, and the leaching behavior of heavy metals should be assessed.

An overview of a typical modern fluidised bed sewage sludge mono-combustion process is given in Fig. 1. The ISSA is generally removed by a series of electrostatic precipitators, bag filters or cyclones after passing through a heat exchanger. Approximately one third of the solids content of sewage sludge consists of inorganic matters which form ISSA particles during combustion. The flue gas is then treated using a wet scrubber with alkali and activated carbon dosing to comply with emission limits. The air pollution control process produces an additional waste residue, namely APCR, which is dewatered and normally disposed of as in hazardous waste landfill.

While extensive studies have been reported on the physicochemical characteristics of ISSA (Naamane et al., 2016; Lynn et al., 2015), little work has been reported on the differences between ISSA and APCR. The ISSA can be used as filler materials due to its fineness (Lynn et al., 2016). Past studies showed the ISSA had very high absorption capacity due to its irregularly shaped, rough textured particles and porous microstructure, and thus it had good potential to be used to stabilize contaminated soils and immobilize heavy metals (Li and Poon, 2017). Furthermore, the

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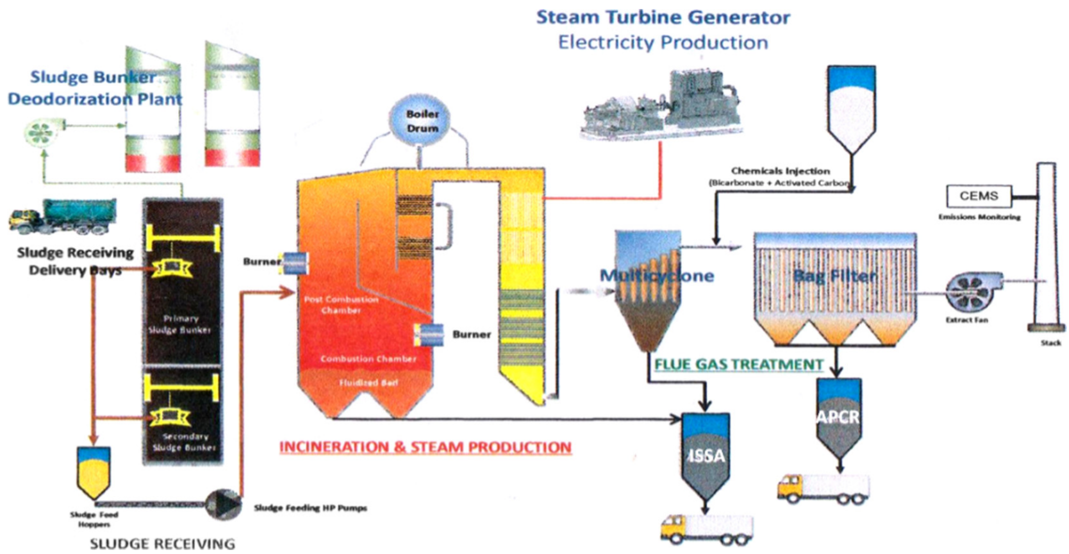

Fig. 1. Generation process of ISSA and APCR from Hong Kong sewage sludge incinerator.

ISSA shares the same elemental (Si, Al, Ca and Fe) and mineral (quartz and calcite) compositions as other waste materials (Naamane et al., 2016). Therefore previously researches mainly focused on the use of ISSA as a raw material for the manufacture of bricks and concretes (Donatello and Cheeseman, 2013). It is noteworthy that the ISSA is characterized by a typically high P_2O_5 content of about 8.9–35.9% (Xu et al., 2012). Therefore, extensive studies on the possible extracting P from ISSA had been carried out (Franz, 2008). However, many heavy metals and soluble salts present in ISSA can potentially have environmental concerns (Lapa et al., 2007). Besides, the characteristics of ISSA were much more variable due to the changing degree and nature of industrial activities within the catchment area of the wastewater treatment plants (Krüger and Adam, 2015). Therefore, data and results from other studies cannot be used on ISSA generated from Hong Kong.

Recently more concerted efforts have been made to recycle ISSA. For example, phosphate recovery from ISSA was reported widely (Petzet et al., 2012). Other uses include using ISSA as sintered materials (Chen and Lin, 2009a), glass-ceramics (Park et al., 2003), cementitious materials (Husillos-Rodríguez et al., 2013), and use in soil amendments (Escudey et al., 2007) or a heavy metal adsorbent (Bouzid et al., 2008). However, these applications did not consider the use of APCR.

ISSA is often not considered as a hazardous waste due to the low leachable concentration of heavy metals, despite it has relatively high levels of certain heavy metals of potential environmental concern (Lynn et al., 2016). Since the ISSA is a waste material, attention must be paid to its environmental impact when it is reused in other applications (Fontes et al., 2004). A literature analysis shows that the ISSA typically contained high concentrations of a range of metals, including Zn, Cu, Pb, Se, As, Cr and Ni (Cyr et al., 2007; Chen and Lin, 2009b; Van de Velden et al., 2008). Toxicity is a very important hazardous property used to classify wastes. However, only few papers have been published to date regarding the toxicity of ISSA. Work published by Lapa et al. (2007) focused on both eco-toxicological and chemical methods to analyze leachates, prepared according to EN 12457-3. But the results were inconsistent and there was poor correlation between the methods used. The chemical method used in the study of Donatello et al. (2010a) followed UK's Environment Agency guidance (Environment Agency, 2015), and revealed that the major element of concern was Zn. Basically, it is the level of soluble heavy metals that is considered important rather than the total metal contents based on the U.S. EPA and Chinese national regulation. Thus, there is a need to better understand the heavy metal speciations in ISSA and APCR.

In view of the above, this study attempted to investigate the different physicochemical properties of ISSA and APCR generated from Hong Kong, and then aim to evaluate the associated leaching characteristic and hazards. Finally, the possible applications of ISSA and APCR were considered.

2. Materials and methods

2.1. Sample collection

ISSA and APCR samples from the sewage sludge incinerator in Hong Kong were obtained for this research. The incinerator adopts a fluidised bed system with combustion zone temperature maintained at above 850 °C in excess oxygen. The two samples were coned and quartered respectively until around 500 g of the materials remained which were subsequently oven dried at 105 °C.

2.2. Methods

2.2.1. Characterization tests

To measure the total heavy metals concentrations in the two waste materials, the aqua-regia digestion technique was adapted from EN 13657 (2002).

To measure the specific gravity, a water pycnometer method according to ASTM D854-14 (2014) was used.

Nitrogen adsorption–desorption measurements were carried out at 77 K using a surface area analyzer (Nova 1000e series, USA). The Brunauer-Emmett-Teller (BET) isotherms of the materials belonged to type II in the IUPAC classification. The specific surface areas of the investigated samples were evaluated using the standard BET method for nitrogen adsorption data in the range of relative pressure $p/p0$ from 0.06 to 0.3.

The chemical composition of the samples was measured by X-ray fluorescence (XRF) scan. The size distribution of the waste particles was measured using a Malvern MS3000 laser diffraction particle size analyzer in a wet mode using distilled water as a dispersing medium and sodium-pyrophosphate as a dispersing agent.