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Life-cycle environmental and cost impacts of reusing fly ash

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ABSTRACT

Municipal solid waste incinerator (MSWI) fly ash, which includes residues collected from semidry scrubbers and bag filters, is a common hazardous waste that is difficult to recycle. We evaluate a novel application of the reuse of MSWI fly ash as a substitute alkali reagent in the Waelz process at an electric arc furnace (EAF) ash recycling plant because of its economical and environmental benefits. Life-cycle assessment and cost-benefit analysis were used to compare the application with other alternatives, namely, disposal in landfill after stabilization/solidification, reuse as part of raw material in a cement kiln, and reuse as part of aggregates in brick. Data from field experiments which were performed at a commercial EAF ash recycling plant in Taiwan were used for the evaluation. Our results show that the proposed application has the lowest environmental impact because the ZnO recycling of EAF ash is environmental friendly for reducing the excavation of zinc ore. In terms of economy, the higher sale price of the resulting cement product offers the best benefit among different applications in this research. After integration of environmental and economic effects, the application was still superior to the three alternatives. Although stabilization/solidification and subsequent disposal of MSWI fly ash is common practice, the scarcity of landfill sites and its volume leads to risks associated with operation of incinerators. Thus, finding multiple approaches to recycling of MSWI fly ash is necessary. This study provides a potential option for the recycling of MSWI fly ash and presents its environmental and economic benefits in management of fly ash from MSWIs.

1. Introduction

Awareness of the harmful residues from the incineration of municipal solid waste (MSW) has increased in recent years. Many researchers have discussed the characteristics of and treatment methods for fly ash and bottom ash (Chang et al., 2009; Hyks et al., 2009; Lo and Liao, 2007; Nowak et al., 2012; Yang et al., 2015). A simplified term, municipal solid waste incinerator (MSWI) fly ash, is used in this study to include all boiler fly ash, scrubber residues, and filter ash, since they are generally collected and combined in one fly-ash storage and treatment system in incineration plants. MSWI fly ash is a hazardous waste, as it contains toxic substances such as dioxins and furans and heavy metals such as zinc and lead. In Taiwan, the majority of MSWI fly ash (280,000 t per year) is landfilled after stabilization/solidification (Lo and Liao, 2007; TWEPA, 2013). In addition to stabilization/solidification, which only reduces the leaching of heavy metals, there are other means to remove heavy metals and to destroy dioxins and furans, namely, extraction/separation and thermal treatment (Kubonova et al., 2013; Quina et al., 2008; Rani et al., 2008; Saikia et al., 2007; Samoladab and Zabaniotoua, 2014). However, stabilization/solidification is the most common and cost effective means for complying with local regulations. The risk of long-term leaching from the solidified matrix and the limited volume of available landfills has motivated researchers to explore various extensive methods of safe recycling (Hyks et al., 2009). Accordingly, this research aims to compare potential reuse methods of MSWI fly ash with the traditional landfill disposal for informed decision.

MSWI fly ash has recycling potential, as it contains large amounts of calcium, silicon, and aluminum, which can be utilized in the manufacture of cement, aggregates, and bricks (Chang et al., 2009). However, chloride salts, is also one of the major reaction products of MSWI fly ash from lime injection scrubbers, which neutralizes acidic gases of flue gas during incineration. This product prevents direct reuse from construction material due to chloride corrosion. Therefore, MSWI fly ash, in general, should be pretreated by washing with water to reduce chloride concentrations below tolerable levels depending on the final recycling steps.

A novel application which utilized the significant amount of calcium in MSWI fly ash as substitute alkali for the Waelz process was proposed at an electric arc furnace (EAF) ash recycling plant in Taiwan. This process includes a heated rotary kiln that recycles

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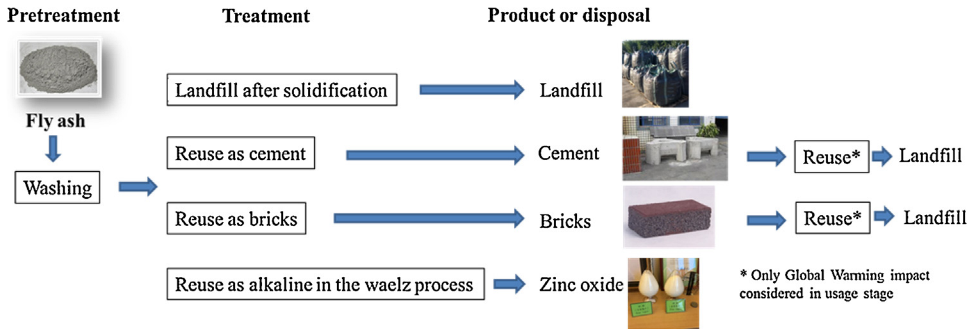

Fig. 1. Scope of LCA of reuse of MSWI fly ash for all scenarios.

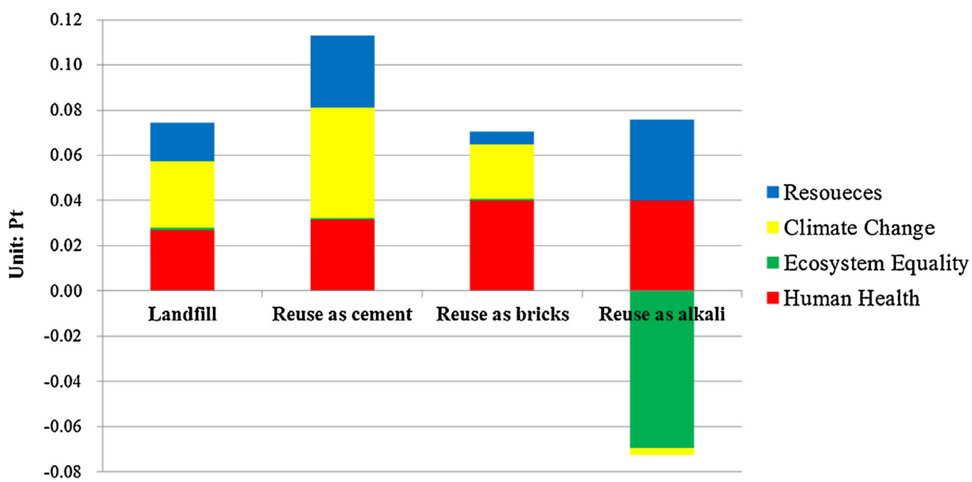

Fig. 2. Comparison of environmental impact of all scenarios.

abundant zinc oxides from EAF ash under an acidic or a basic atmosphere. Here, alkali lime and coke are necessary additives (Hung et al., 2012; Suetens et al., 2014; Tsai et al., 2014). Except for the advantage to reduce the consumption of fresh lime in Waelz process, the characteristics of MSWI fly ash are slightly similar to those of EAF ash. Therefore, co-treatment of MSWI fly ash under certain mixing ratios would not significantly change the final product properties of zinc oxides in the Waelz process, as already measured and proven by the previous field experiments (Quina et al., 2008). MSWI fly ash even has a dilution effect on toxic substances such as dioxins and furans, while co-treated EAF ash is more severe on concentration.

Although field experiments in Taiwan have proven the technical feasibility of using water-washed MSWI fly ash as an alkali substitute at a commercial EAF ash recycling plant, complete life-cycle assessment (LCA) should still confirm its potential environmental impact, as few studies have discussed it (e.g. Boesch et al., 2014; Fruergaard et al., 2010). This study therefore applied LCA to assess such environmental impact, including energy consumption, resource depletion, and pollutant emission (Leme et al., 2014). Cost-benefit analysis (CBA) was also performed to estimate the net present value (NPV) and to find an approach to the reuse of MSWI fly ash with minimum environmental impact and relatively acceptable benefit to the economy. The main scenario, reusing MSWI ash as alkali in the Waelz process, was compared with three alternatives, namely, 1) disposal in a landfill after stabilization/solidification, 2) reuse as part of raw material in cement kiln, 3) reuse as part of aggregates in brick. A more comprehensive evaluation could be accomplished while applying our results to a more broad scope including risk assessment for health and ecosystems in future studies.

2. Methodology

This study applied LCA and CBA to evaluate four scenarios for the disposal or reuse of MSWI fly ash in terms of environmental impact and economic benefits. The latest software for LCA, SimaPro 8.0, and model IMPACT 2002+ (Jolliet et al., 2003) was utilized to measure the environmental impact. For CBA, the NPV was adopted to define the economic values of different scenarios. The boundary for evaluation included in situ pretreatment, vehicle transportation, off-site reuse treatment, and final product use (if any) or disposal. The functional unit was one tonne of MSWI fly ash disposed of or reused, including its benefits from final product sale if applicable. Operating data from a refuse incineration plant in Taipei City, Taiwan was collected which plant was equipped with facilities for water washing of MSWI fly ash and stabilization/solidification, as well as sampling data from field experiments at a commercial EAF ash recycling plant. Complementary parameters and reference information were searched in the literature. Because of the varied possible uses of the cement product and bricks, this study referred to an environmental product declaration (EPD) of a fly ash brick to estimate the usage-stage impact (CALSTAR PRODUCTS^{TM}, 2016). The EPD document based on constructing a wall includes a complete LCA of bricks with a function unit of one modular brick (3 5/8 × 2 ¼ × 7 5/8 inches) plus associated mortar (mortar joints assumed to be 3/8 inches wide, and run the full depth of the brick). Accordingly, the environmental impacts of mortar (composed of sand: lime: cement = 6:1:1) and bricks were converted to the function unit of Scenario 2 and Scenario 3. However, as the varied possible uses of products may lead to variety of environmental burdens, only the impact of Global Warming was considered. Detail inventory can be found in the Supplementary materials.