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Development of Integrated High-gravity-electrodeionization (HiG-EDI) Technology for CO_2 Capture, Waste Stabilization and Wastewater Reclamation

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ABSTRACT

A two stages process integration of high-gravity (Higee) rotating packed bed (RPB) and resin wafer electrodeionization (RW-EDI) technology was developed for CO_2 mineralization, waste utilization and water reclamation. To stabilize and upgrade the properties of the municipal solid waste incineration fly ash (MSWI FA), accelerated carbonation was performed to convert calcium-bearing species into calcium carbonates via a Higee RPB. The direct and indirect carbonation process were consecutively operated via a RPB while the leachate (water washing liquid) from MSWI FA carbonation with high content of chloride ions was reclaimed via a RW-EDI process. In this study, the carbonation conversion of MSWI FA in direct carbonation using Higee process was evaluated along with CO_2 capture capacity, $CaCO_3$ formation and energy consumption. Several key factors including rotating packed bed and liquid-to-solid ratio (LSR) were evaluated through experimental design. In addition, the energy consumption and productivity of MSWI FA leachate using RW-EDI was evaluated. Results indicate that the carbonation conversion was increased as raising the rotating speed and lower LSR. The maximal carbonation conversion of 89.81 % was found at rotating speed of 1000 rpm and LSR of 10. To remove the residual calcium ions in the leachate, the indirect carbonation was conducted in a RPB. The outlet CO_2 concentration, pH value, calcium ions concentration and conductivity of leachate were decreased as over reaction time. The maximal CO_2 capture efficiency was found at the reaction time of 5 minutes. Furthermore, the results show that the relationship between energy consumption and productivity of MSWI FA leachate treatment via RW-EDI was negative correlation. The energy consumption of RW-EDI for MSWI FA leachate treatment was found to be 1.49–3.61 kWh/m^3 with productivity of 12.82–17.09 L/hr/m^2. It suggested that the integrated HiG-EDI system offers the potential for an abundant source of CO_2 capture, MSWI FA stabilization and fresh water from FA leachate treatment, which should be viewed as a crucial component in the portfolio of CO_2 capture, waste stabilization and water reclamation.

Keywords: High-gravity rotating packed bed, Resin wafer electrodeionization, municipal solid waste incineration fly ash, CO_2 mineralization, water reclamation

NONMENCLATURE

Abbreviations

High-gravity	Higee
Rotating packed bed	RPB
Resin wafer electrodeionization	RW-EDI
Municipal solid waste incineration fly ash	MSWI FA
Liquid-to-solid ratio	LSR

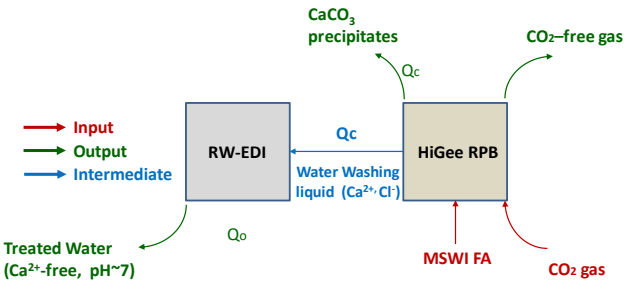

Fig 1 Process integration of Higee RPB and RW-EDI (HiG-EDI)

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1. INTRODUCTION

Numerous industrial solid wastes, such as iron/steel slag, fly /bottom ash, and byproduct lime, could be used as the feedstock for the high-gravity carbonation process (Lopez et al., 2018). High-gravity carbonation process is a promising technology for flue gas CO_2 capture, wastewater neutralization, and product utilization. The high CO_2 removal efficiency was achieved at a short retention time at ambient pressure and temperature, where the alkaline solid wastes can be carbonated and mineralized with CO_2 converting to calcium carbonate ($CaCO_3$) (Pan et al., 2017).

To improve conventional EDI technology, engineers of Argonne National Laboratory have replaced the loose ion exchange resin beads with a resin wafer, which is composed of the original loose ion exchange resins immobilized and molded into a porous, solid matrix, thereby forming resin wafer electrodeionization (RW-EDI). RW-EDI can improve ionic mobility and also allows local pH control, which has been successfully applied to different process including recycling of cooling water in power plants, production and recovery of organic acids, desalination of impaired water and CO_2 capture (Pan et al., 2018).

The incineration technology has become the main treatment of municipal solid wastes due to the advantages of harmlessness, volume and waste reduction, and heat recovery. However, the MSWI FA is a hazardous wastes and forbidden to depose and utilize directly due to high heavy metals and chloride (Cl) contains. The developed technology for MSWI FA stabilization and utilization is currently an urgent issue. Several technologies for MSWI FA treatment such as cement-based solidification and stabilization, thermal plasma, and glass solidification and carbon mineralization were investigated (Lam et al., 2010). To overcome the barriers of MSWI FA stabilization and utilization, MSWI FA can be considered as a feedstock of CO_2 capture process via carbonation and mineralization due to its high alkalinity and calcium-based species components. Thus, the accelerated carbonation coupled with CO_2 and MSWI FA via an aqueous process may be successfully achieved through combining Higee technology.

2. PAPER STRUCTURE

2.1 Objectives

To evaluate the MSWI FA stabilization, CO2 capture efficiency, and water washing leachate from MSWI FA purification, an integrated process of Higee and RW-EDI was proposed. The objectives of this study include : (1) to establish high-gravity process via direct carbonation reaction for CO_2 capture, (2) to access the chloride removal performance via high-gravity process, (3) to investigate the CO_2 capture efficiency and $CaCO_3$ formation via indirect carbonation reaction, and (4) to evaluate the energy consumption and fresh water productivity from FA leachate purification via RW-EDI process.

2.2 Material and methods

In this study, the feedstock of MSWI FA was collected from an incineration plant in Taiwan. The FA samples were dried at 105°C for 48 hours then sieved under pore size of 250 μm, and the liquid agent was tap water. The process integration of Higee RPB and RW-EDI can be divied as three stages, as shown in Fig. 1. First, the FA was mixed with tap water to form FA slurry then pump into RPB for direct carbonation with CO_2 up to 40 minutes. The reaction reached to steady as the pH values declined to 6~7. Secondly, after seperating FA and liquid, the leachate was added sodium hydroxide to enhance the akalinity for indirect carbonation process up to 20 minutes. Finally, the carbonated leachate was injected into RW-EDI system for chloride removal and the fresh water was generated.

2.3 Theory/calculation

Carbonation conversion (i.e, direct carbonation with FA) was the amount of CO_2 actually captured in the dry mass of each sample compared with the theoretical extent of carbonation on the basis of the reactive-oxide content of the fresh FA, calculated by eq. 1. The theoretical CO_2 capture capacity whose calculation was based on the X-ray fluorescence result, expressed the potential CO_2 capture capacity of the FA. In contract, the actual CO_2 capture capacity was calculated by eq. 2 on the basis of thermogravimetric anaylsis.

$$\delta_{CaO}(\%)=ACO_2/ThCO_2\times100 \quad (1)$$

$$ACO_2=\Delta m_{CaCO_3}/(m_{105^oC}-\Delta m_{CaCO_3}) \quad (2)$$

The performance of indirect carbonation was evaluated via on-site CO_2 gas analyzer (PG350, Horiba, Japan). The CO_2 capture capacity can be calculated by eq. 3, which represented the total amount of CO_2 capture content at each run. The $CaCO_3$ formation was weighed directly after liquid and solid separation.

$$C_{cap}=\int_0^t (C_o-C_i)Q_g\rho_{CO_2}dt \quad (3)$$

For a cost-effectiveness water reclamation process, remaining a high energy performance in terms of productivity and energy consumption is a crucial element for minimizing economic cost. The energy consumption and productivity were chosen as key performance indicators to evaluate the RW-EDI process for desalination. Energy consumption (ψ_c , kilowatt hours per cubic meter) is the electric energy used to produce a unit of purified water, as determined by eq. 4. The productivity is considered as a function of total membrane area, which defining as the ratio of the feed processed rate to the total active cross-section membrane area, as estimated by eq. 5.

$$\psi_c(\mathrm{kWh}/m^3)=16.7\times\frac{UI}{Q_p} \quad (4)$$

$$\varphi(L/h\ m^2)=\frac{V_B}{tA} \quad (5)$$

2.4 *Results and discussion*

Fig. 2 presents the carbonation conversion under various liquid-to-solid ratio and rotating speed during the reaction time. Results indicated that the carbonation conversion increased as decreasing the LSR. The highest conversion was found at LSR of 10 and reaction time of 15 minutes. In other words, the more FA added, the more reacted agent was provided. In addition, the carbonation conversion was increased in a higher rotating speed, which indicated that the reaction can be accelerated via high centrifugal force because the mass transfer rate between liquid and gas can be enhanced.

Fig. 3 (a) shows the performance of $CaCO_3$ formation, CO_2 capture capacity and anions of leachate during indirect carbonation. Results indicate that the $CaCO_3$ formation and CO_2 capture capacity were enhanced as more NaOH addition, which can be attributed to more alkalinity from NaOH solution and more Ca^{2+} can be reacted to carbonate ions then converting to $CaCO_3$. Fig 3(b) presents the performance of energy consumption, anion removal and productivity for FA leachate treatment via RW-EDI. The energy consumption of RW-EDI for MSWI FA leachate treatment was found to be 1.49–3.61 kWh/m^3 with productivity of 12.82–17.09 L/hr/m^2.

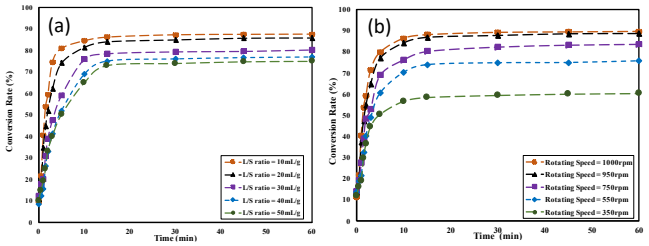

Fig 2 The carbonation conversion under various (a) LSR (b) rotating speed.

2.5 *Conclusions*

This present study suggested that the integrated HiG-EDI system offers the potential for an abundant source of CO2 capture, MSWI FA stabilization and fresh water from FA leachate treatment, which should be viewed as a crucial component in the portfolio of CO_2 capture, waste stabilization and water reclamation.

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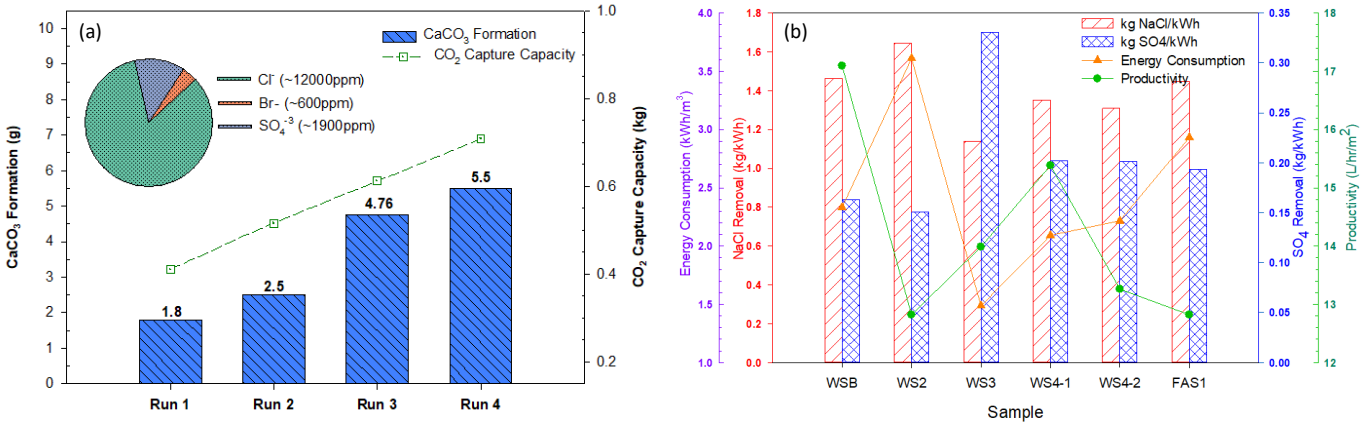

Fig 3 (a) Performance of $CaCO_3$ formation, CO_2 capture capacity and anions of leachate during indirect carbonation; (b) Performance of energy consumption, anion removal and productivity for FA leachate treatment via RW-EDI.

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