



Cawangan Kedah  
Kampus Sungai Petani

Faculty of Administrative  
Science and Policy Studies

# i-SPIKE 2021

*Leading An Artificial Innovation In Knowledge, Education And Design*

## **i-SPIKE 2021 INTERNATIONAL EXHIBITION & SYMPOSIUM E-PROCEEDINGS**

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## FACILE-FABRICATED FOAMED GEOPOLYMER SPHERE FOR HEAVY METAL REMOVAL FROM WASTEWATER

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### ABSTRACT

Due to the high discharging of untreated wastewater into the environment, heavy metal pollution has been at scrutiny, and the impacts are tremendous to the environment and living organism. Therefore, it is vital to decontaminate the wastewater to prevent further ill impacts. In this work, a facile-fabricated foamed geopolymer sphere has been investigated for its heavy metal removal performance. Four different heavy metals had been selected, which were lead (Pb), cadmium (Cd), copper (Cu) and nickel (Ni). The foamed geopolymer sphere was synthesized via a simple direct-moulding method. After foaming, the density and strength of the foamed geopolymer sphere was reduced from  $1810 \text{ kg/m}^3$  to  $980 \text{ kg/m}^3$ , and from 2.2 MPa to 0.7 MPa, respectively. The foamed geopolymer sphere was able to maintain its integrity after the adsorption testing, proving that 0.7 MPa strength was sufficient. On the other hand, the heavy metal removal performance of foamed geopolymer sphere was increased substantially compared to the non-foamed geopolymer sphere. Results demonstrate that the Pb(II), Cd(II), Ni(II), and Cu(II) removal capacity of foamed geopolymer sphere was 26.77 mg/g, 26.14 mg/g, 24.69 mg/g, and 21.46, respectively, which was approximately 3-6 times increment compared to non-foamed geopolymer sphere. This improvement is attributed to the enhancement of the specific surface area and porosity of the geopolymer sphere after foaming, which subsequently improve the adsorption capacity. Furthermore, the foamed geopolymer sphere can be retrieved easily upon exhausted, which simplifies the adsorption process.

**Keywords:** Geopolymer, Foaming, Heavy metal, Adsorption, Direct-moulding

### INTRODUCTION

Due to the rapid modernization worldwide, contamination of water resources by heavy metals,

including lead (Pb), mercury (Hg), copper (Cu), nickel (Ni), cadmium (Cd), zinc (Zn), have been under scrutiny (Liu et al., 2019). The primary source of heavy metals is from the untreated wastewater. According to Sustainable Development Report 2021 (Sachs, 2021), there are about 2/3 countries in the world perform poorly in treating the wastewater, especially in the Asian countries. It is reported that in 2018, up to 87.6 % of anthropogenic wastewater in Malaysia has not received treatment.

The non-biodegradable characteristics, high toxicity level and the ability of heavy metal to bio-accumulate in living organisms and food chains results in the negative impacts fostered to the environment and human being cannot be ignored. The effects of heavy metal contamination on human are reported to be cancerogenic, teratogenic and mutagenic (Ge et al., 2014). Therefore, decontamination of heavy metals from wastewater is at utmost importance. Wastewater remediation can be done physically, chemically, or biologically, including but not limited to, adsorption, membrane filtration, advanced oxidation, precipitation (Madarang et al., 2012; Rungrodnimitchai, 2014). Among these common approaches, adsorption method is more widespread due to its effectiveness, low cost and protocol simple (Cheng et al., 2012; Gupta et al., 2012).

Recently, the potential of geopolymer as an adsorbent has been discovered (Siyal et al., 2018). Powder size geopolymer adsorbent has been commonly investigated in the related area as adsorption is dependent on the specific surface area. Nonetheless, the difficulty in retrieval and the need for supporting medium making the process complicated. Therefore, to resolve such limitations, bulk type geopolymer adsorbent is gaining interest, such as sphere, granular, and monolith (Ge et al., 2015; Siyal et al., 2018). However, bulk type adsorbent is usually accompanied with a low specific surface area that is believed to reduce the heavy metal removal effectiveness, attributed to its larger size. Therefore, in order not to compromise the removal performance of bulk type geopolymer adsorbent to a larger extent, one feasible way is to produce porous bulk type geopolymer adsorbent. By inducing porosity into the geopolymer, the specific surface area can be increased, and so will the removal performance. Therefore, this research is intended to investigate the Pb(II), Cu(II), Ni(II) and Cd(II) removal capacity of foamed geopolymer sphere that is produced via a facile method, direct-moulding instead of the suspension and solidification method.

## **MATERIALS AND METHODS**

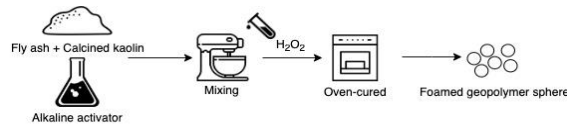
### **Materials**

Fly ash and calcined kaolin were selected as the starting material to fabricate the geopolymer sphere. For the alkaline activator, it was a mixture comprised of sodium silicate solution and 10M sodium hydroxide solution. Hydrogen peroxide (30 wt.%) was used as the foaming agent.

### **Geopolymer sphere preparation**

The foamed geopolymer sphere was synthesized via direct moulding method. The fabrication process of foamed geopolymer spheres is shown in Figure 1. Firstly, the raw materials (fly ash and calcined kaolin) were mixed with the alkaline activator. Then, H<sub>2</sub>O<sub>2</sub> was added into the slurry for the purpose of foaming. Upon completion of mixing, the spheres were cured in an oven at 60°C for 24 hours. After demolded, the geopolymer spheres were stored in a sealed

bag at room temperature until the respective testing ages. Non-foamed geopolymer sphere was prepared in the same manner, except the addition of H<sub>2</sub>O<sub>2</sub>.



**Figure 1.** Schematic diagram of the production of foamed geopolymer sphere

### Density and crushing strength

The bulk density of geopolymer spheres was measured by referring to BS EN 12390-7 (British Standards Institution, 2009). The equation was expressed in Eq. (1).

$$D = \frac{m}{V} \quad (1)$$

where.

D = Bulk density of geopolymer sphere, in kg/m<sup>3</sup>

m = mass of geopolymer sphere, in kg

V = volume of geopolymer sphere, in m<sup>3</sup>.

The crushing strength of foamed geopolymer sphere was measured by adopting the single aggregate crushing strength (Shi et al., 2019). The crushing strength of the geopolymer spheres was calculated using Eq. (2).

$$\sigma_c = \frac{2.8F_c}{\pi d_m^2} \quad (2)$$

where.

$\sigma_c$  = crushing strength of geopolymer sphere, in MPa

$F_c$  = maximum failure load, in N

$d_m$  = average diameter of geopolymer sphere, in mm<sup>2</sup>

### Batch adsorption test

The batch adsorption test was performed using the non-foamed and foamed geopolymer sphere. Firstly, the geopolymer sphere was immersed into a solution contained single type of heavy metal, which was Pb(II), Cd(II), Cu(II) and Ni(II). The concentration of heavy metal was fixed at 200 mg/L. Then, it was shaken for 48 hours at room temperature. Lastly, the geopolymer sphere was removed and the final concentration of the heavy metal was determined using an inductively coupled plasma - optical emission spectrometry (ICP-OES). The removal capacity of the geopolymer sphere can be calculated using Eq. (3).

$$q = \frac{(C_o - C_{eq})}{m} \times V \quad (3)$$

where.

q = the amount of heavy metal adsorbed, in mg/g

V = the volume of synthetic solution, in L

m = the mass of foamed geopolymer adsorbent, in g

$C_o$  = the initial concentration of heavy metal, in mg/L

$C_{eq}$  = the final or equilibrium concentration of heavy metal, in mg/L.

## RESULTS AND DISCUSSION

### Bulk density and crushing strength

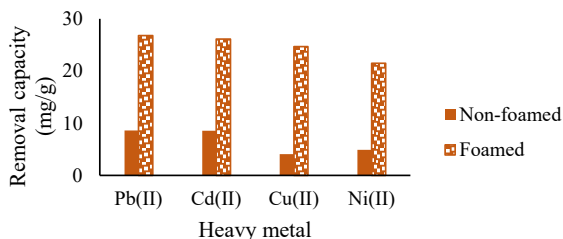
Table 1 tabulates the bulk density and crushing strength of non-foamed and foamed geopolymer sphere. It is observed that the bulk density and crushing strength of geopolymer sphere were significantly reduced after foaming. The reduction is attributed to the formation of pores within the sphere after foaming. Similar outcomes had been reported by Novais et al. (2016). The bulk density of foamed geopolymer sphere was found to be 980 kg/m<sup>3</sup>, which was approximately 45.9 % lower than the non-foamed geopolymer sphere, 1810 kg/m<sup>3</sup>. On the other hand, the crushing strength of foamed geopolymer sphere was 0.7 MPa, which was 68.2% compared to the non-foamed geopolymer sphere (2.2 MPa). The strength of a sintered ceramic water treatment filter was reported to be 0.9 – 1.7 MPa (Luukkonen et al., 2020). Nonetheless, the foamed geopolymer sphere was able to maintain its integrity after the batch adsorption testing, suggesting that 0.7 MPa strength was sufficient.

Table 1. Bulk density and crushing strength

| Geopolymer sphere | Bulk density (kg/m <sup>3</sup> ) | Crushing strength (MPa) |
|-------------------|-----------------------------------|-------------------------|
| Non-foamed        | 1810                              | 2.2                     |
| Foamed            | 980                               | 0.7                     |

### Heavy metal uptake

The Pb(II), Cd(II), Cu(II) and Ni(II) removal capacity of geopolymer spheres are illustrated in Figure 2. It is observed that regardless the type of heavy metals, the removal capacity of foamed geopolymer sphere was significantly higher compared to non-foamed geopolymer sphere. The Pb(II), Cd(II), Cu(II), and Ni(II) removal capacity of non-foamed geopolymer sphere was 8.60 mg/g, 8.57 mg/g, 4.09 mg/g, and 4.89 respectively. On the contrary, the Pb(II), Cd(II), Cu(II), and Ni(II) removal capacity of foamed geopolymer sphere was 26.77 mg/g, 26.14 mg/g, 24.69 mg/g, and 21.46 mg/g, respectively. The improvement in the uptake capacity was about 3 times for Pb(II) and Cd(II), 6 times for Cu(II) and 4 times for Ni(II). The increment is attributed to the more binding sites were provided after foaming. Furthermore, the mass of the foamed geopolymer sphere was reduced. This verifies that foaming can improve the heavy metal removal performance of the geopolymer sphere, and direct-moulding method was feasible approach to produce foamed geopolymer sphere. In addition, the complexity of the process was reduced as post-separation of the foamed geopolymer sphere from the solution can done effortlessly.



**Figure 2.** Heavy metal removal capacity of geopolymer sphere

## CONCLUSION

Through the investigation, it is observed that the removal capacity of geopolymer sphere on Pb(II), Cd(II), Cu(II), and Ni(II) was significantly enhanced after foaming, proving that foaming can improve the specific surface area of an bulk type adsorbent. On the other hand, although the crushing strength of foamed geopolymer sphere dropped to 0.7 MPa, it was sufficient as it was able to maintain its integrity after the adsorption process. In addition, the foamed geopolymer sphere can be synthesized using waste streams or industrial by-products, and the direct-moulding method reduces the usage of additional chemicals as in the suspension and solidification method, making it more environmentally friendly. Therefore, it is concluded that this facile-fabricated foamed geopolymer sphere is a potential alternative adsorbent material.

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