# Supplementary Data A

## Experimental Methodology

## Bulk and tapped densities

Bulk and tapped density measurements assess the mass and volume relationships of powdered or granular material, both in their initial and compacted states, respectively (Amidon et al. 2017). Tapped density experiments reveal the maximum achievable density through packing. Changes in bulk and tapped density measurements can be influenced by the cohesive properties of particles (Deb et al. 2018) and can be affected by the shape and size of the material (Amidon et al. 2017). Given the irregular and angular characteristics of volcanic ash (Table 1), it is important to note that not all interstitial spaces between particles are eliminated. In this study, we determined the bulk and tapped density of dry samples to characterize their cohesivity before the introduction of water, following the methodology outlined in the United States Pharmacopeia from 2015.

Bulk density () was obtained by pouring 100 g of the volcanic material into a 250 mL cylinder and levelling it as needed. The unsettled volume was measured, and bulk density was calculated using Equation 1. This procedure was repeated three times for each sample.

[1]

*= mass (g)*

*= unsettled apparent volume (mL)*

To calculate tapped density, the cylinder was tapped at a rate of 150 taps per minute, with volume measurements taken every minute until it reached a stable level. The tapped density () is calculated from the unsettled apparent volume and the final tapped volume, Eq. 2), where is *mass (g),* is the *unsettled apparent volume (mL) and i*s thefinal *tapped volume (mL)* (Moondra et al*.* 2018).

[2]

*= mass (g)*

*= final tapped volume (mL)* (Moondra *et al.* 2018)

Important parameters for understanding flowability behaviours can be calculated from the bulk and tapped density results. The Carr's Index (CI; Eq. 3) and Hausner Ratio (HR; Eq. 4) serve as indicators of a material's flowability and interparticulate behaviours (Hausner, 1981) and are valuable tools for assessing a material's ability to fluidize and flow (see Table 1). Carr's Index assesses a material's strength and compressibility (Moondra et al. 2018), while the Hausner Ratio gauges the packing density of the material and its susceptibility to compaction from external forces (Yu and Hall, 1994; Abdullah and Geldart, 1999). A low Hausner Ratio suggests better flowability.

[3]

[4]

**Table 1** Correlation between Carr’s Compressibility Index, the Hausner Ratio, and flowability characteristics. From (Gorle and Chopade, 2020).

|  |  |  |
| --- | --- | --- |
| CI | HR | Flowability |
| ≤10 | 1.00 – 1.11 | Excellent |
| 11 – 15 | 1.12 – 1.18 | Good |
| 16 – 20 | 1.19 – 1.25 | Fair |
| 21 – 25 | 1.26 – 1.34 | Passable |
| 26 – 31 | 1.35 – 1.45 | Poor |
| 32 – 37 | 1.46 – 1.59 | Very Poor |
| > 38 | >1.60 | Very Very Poor |

## Angle of repose

This method involves determining the Static Angle of Repose (SAoR) to assess the flowability of a material (Al-Hashemi and Al-Amoudi, 2018). The SAoR is related to the static friction coefficient and angle of internal friction of a material and the results of Angle of Repose analysis can be used to understand the flowability of the material (Table 2).

**Table 2.** Flowability assessment using angle of repose results (Beakawi Al-Hashemi & Baghabra Al-Amoudi, 2018).

|  |  |
| --- | --- |
| Flowability | Angle of Repose (°) |
| Very free flowing | <30 |
| Free flowing | 30 - 38 |
| Fair to passable flow | 38 - 45 |
| Cohesive | 45 - 55 |
| Very Cohesive (non-flowing) | >55 |

To determine the SAoR, 100 g of material was released from a funnel held 3.5 cm over a circular platform with an average diameter of 8.5 cm. The height of the cone formed by the material is measured and the angle of repose is calculated using Equation 5 (Jan et al. 2015). Where the material does not release freely from the funnel, it is lightly agitated to facilitate release. Where the height of the cone reaches the base of the funnel, the funnel was moved incrementally to accommodate the growing cone. This process is repeated three times.

[5]

*= height (mm)*

*= base diameter (mm)*

A funnel on a metal holder

Description automatically generated

*Figure 1 SAoR method set-up.*