Parameters Impacting Columnated Granular Soil Pneumatic Seal Performance. J.R. Stewart[1] and D.L. Linne[2],
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Introduction: The ability of a column of loose granular soil to form a pneumatic seal was investigated by varying the diameter of the soil column, the effective column height, and the level of compaction in the soil. The soil column diameter was tested at three levels using pipes with inner diameters measuring 5.08, 10.16, and 15.24 centimeters (2, 4, and 6 inches). Soil was filled in each pipe to form 15, 30, and 45 centimeter (6, 12, and 18 inch) tall soil columns. Each diameter/height configuration was also tested at three levels of soil compaction, compared by calculating the bulk density of the soil with mass and volume measurements. GRC-1a simulant was used, with approximate low/medium/high bulk densities of 1.6, 1.75, and 1.9 g/cc achieved with a combination of vibration and tamping. The order of tests for a given column diameter was randomized and repeated three times.

With the top of the soil open to atmosphere at room temperature, compressed air was injected through a small diffuser at the column base with several small downward-facing holes. The number and size of these holes was scaled such that a constant total inlet orifice area to column cross sectional area ratio was maintained for each column diameter. Inlet air pressure was slowly increased via a precision regulator to preserve quasi-static equilibrium in the soil column to minimize the impact of dynamics. Air pressure was increased all the way through the static and bubbling regimes until slugging or turbulent behavior was observed in the soil to ensure that the entire static regime had been captured during data collection.

A three-factor, three-level analysis of variance (ANOVA) statistical analysis was performed on the resulting data to determine the extent to which each physical parameter impacted the soil column seal performance. It was concluded that there is statistically significant evidence that column height, and the interaction between column height and diameter impact soil seal performance. In all other cases there was insufficient data to identify a statistically significant causal relationship. Additionally, plots were generated comparing experimental data to the predictive formula developed by Ogino et al. for fluidized beds in 1993 [1]. Because this model was developed for industrial spouted fluidized beds, the accuracy of its output prior to fluidization in the static seal 'edge case' is unknown, especially considering in this application the working gas was diffused across the column base rather than being injected through a spout. Further, the fidelity of the model had not yet been tested with lunar soil simulants. Plotting the Ogino et al. model alongside test data allows for a more intuitive sense of the impact of test parameters on soil seal performance, as well as providing a quick means to further tune this predictive model for more accurate use with static seals across granular lunar soil simulants.

The model provided by Ogino et al. was further tuned using test data to determine the degree to which a spouted bed model could be applied to a slightly modified set of testing conditions: lunar soil simulants and a more diffuse, homogeneous application of pneumatic pressure. A Matlab script was created to test different values for the leading coefficient and exponents in Ogino's formula. The script swept preset ranges, then iterated with higher resolutions across narrower ranges to converge on the optimal value for each parameter. The resulting adjusted model was compared to the original, as well as test data with noticeable improvements across the entire test domain.

References: [1] Ogino, F.,Zhang, L., Maehashi. (1993). Minimum rate of spouting and peak pressure drop in spouted bed. Int. Chem. Eng. 33:2, 265-272.