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Predicting cone-in-cone blender efficiencies from key material properties

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Abstract

Blending of powders and granular materials is a critical unit operation in many industries, yet the ability to predict blending effectiveness lags well behind our ability to create new and novel blenders. As a result of this, production plants must rely on vendor blending tests conducted on small scale model blenders to determine if their specific material will work in the proposed blender design. Once these blending tests are conducted, engineers must then use past experience and conservative design practices to scale-up to full scale units at process flow rates.

The difficulty in predicting blending efficiencies arises from the fact that blending performance depends on basic material properties, blender geometry, blender flow rates, and blender operation parameters. These effects are convoluted during blending operation. Successful scale-up would require understanding how to separate the influence of these four effects. If this could be accomplished, blender performance could be determined by measuring simple material properties, predicting blender velocity profiles, and computing blender efficiencies from predicted velocity patterns. This method would allow separation of factors affecting blender performance and provide a means of reliable scale-up using simple material properties and specified blenders geometries.

This paper presents a methodology of predicting blender performance in simple in-bin blenders using easily measured material properties. It discusses blender optimization and determines the influence of gas pressure gradients on blender flow and operation. The specific blender analyzed is the cone-in-cone blender and the analysis suggests that blender performance depends on wall friction parameters for conditions where input concentration fluctuations occupy much of the blender volume. However, blending action appears to be independent of friction angle for conditions where there are many concentration fluctuations within a blender volume. The analysis also shows that gas pressure gradients can lead to stagnant region formation.

Keywords: Mass flow; Mixing; Residence time distributions; Powders; Solid mechanics

1. Introduction

Acceptable blending of powder and granular materials requires three things. First, all material within the blender must be in motion during blender operation. Second, a distribution of material residence times must exist within the blender. Third, the blending shear and velocity profiles must result in mixing on a scale smaller than the size of the final product sample.

It is obvious from these three criteria that the specific motion in a given blender configuration determines the extent of blending caused by the process equipment. In fact, if flow profiles in any given blender were known, then they could be used to compute residence time distributions for the given blender configuration. These residence time distribution functions could then be used to evaluate blender performance.

Blending of powder material can be accomplished by imposing a velocity profile across a given piece of process equipment resulting in a distribution of residence times within the blender. For example, in well designed mechanical blenders all of the material in the blender is in motion during operation. In these blenders the velocity flow field is complex, resulting in particle flow paths that cross multiple times before exiting the blender. Since all particle flow paths do not travel the same distance before exiting the blender and individual particle velocities are different, the complex flow paths result in a residence time distribution function. Ideally, adjacent particles in a blender would have very different flow paths causing significant inter-particle mixing and produce wide residence time distribution functions. However, real blenders always shear

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material, often producing local zones which possess different trajectories and result in mixing down to the scale of local shear zones produced during the mixing processes. These local shear zones are caused by flow around paddles or screw flights and, when combined with the dynamic material trajectories, produce the overall blending in any given blender. In fact, the velocities in any given blender are due to shear or dynamic effects that move groups of particles around. Thus, to understand blending as a unit operation, one must be able to estimate the velocity profiles in both dynamic and shear flows. Every blender will have a combination of these velocity types. The main premise of this work is that material properties can be used along with specific blender geometries to predict blending velocity profiles. These velocity profiles can then be used to compute the expected blender residence time distribution functions and finally estimate the blender performance. This approach de-convolutes the effects of material properties, blender geometry, and blender operation parameters, making scale-up possible.

This approach is presented for the simple case of in-bin blenders such as the cone-in-cone. The dynamic material trajectories in this style blender occur only during blender filling as material free falls into the blender and distributes on the resulting pile. Most of the blending occurring in this type of blender results from shear velocity profiles caused by the specific blender geometry. The cone-in-cone blender will be used as an example to show how to de-convolute the effects of blender performance, material properties, blender geometry, and blender operation parameters and provide a methodology for blender scale-up. This blender will also be analyzed relative to the three criteria outlined above.

2. Cone-in-cone blenders

A cone-in-cone blender consists of a bin with a hopper that comprises two independent conical hopper sections as shown in Fig. 1. One conical hopper section is inserted inside the other to

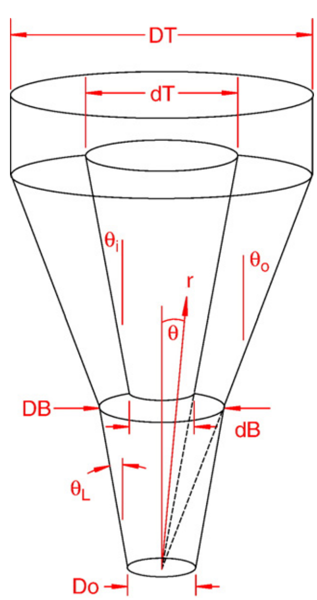

Fig. 1. Schematic of typical cone-in-cone geometry.

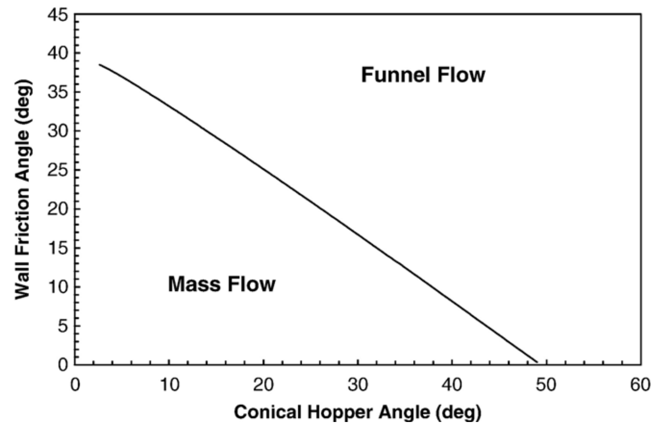

Fig. 2. Typical mass flow funnel flow limit for effective internal friction angle of 50°.

form an interior conical hopper and an annular flow channel. Material flows through both the inner conical hopper and the annular region during blending operation. The vertical section above the cone-in-cone is designed large enough to provide a mixing zone but is usually limited to a height equivalent to twice the diameter. Distribution chutes at the top of the blender spread the input flow stream across the blender cross section thus helping reduce possible segregation during blender filling. There is a conical hopper below the cone-in-cone section. The velocity profile across the cone-in-cone section combines with the velocity profile in the lower cone to yield a combined velocity profile responsible for axial blending in the in-bin blender. Material exiting this blender usually flows through some form of feeder to down stream process equipment. The cone-in-cone blender mixes well in the axial direction but provides only a small mixing capability in the radial direction. Hence, the feeder below the cone-in-cone provides radial mixing that is lacking from this style blender.

3. Mass flow in cone-in-cone blenders

The cone-in-cone hopper is a type of mass flow hopper. The interior cone and the lower cone are designed so the hopper slope angle is compatible with standard mass flow criteria. Simply stated, mass flow is a condition that produces significant material movement in the entire process equipment as material passes through or discharges from it (BMHB [1]). There are no stagnant regions in a mass flow bin. However, depending on the hopper shape and wall friction angle, a significant velocity profile can exist in a mass flow bin creating a residence time distribution. This property has been used successfully to create mass flow blenders (Ebert et al. [2], Johanson [3]).

The radial stress theory has been successfully used to compute the velocity in conical hoppers as well as to predict the mass flow limit. This theory will be extended to cone-in-cone hoppers as outlined below. These theories predict a relationship between the conical hopper half angle and the friction angle that is compatible with radial stress conditions. Fig. 2 shows the calculated relationship between conical hopper angle and wall friction angle based on the radial stress theory (Jenike and