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Factors contributing to the poor bulk behavior of meat and bone meal and methods for improving these behaviors ☆

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Abstract

Meat and bone meal (MBM), a product of the rendering industry, is a potential feedstock for numerous bio-based applications. Design of processing equipment for MBM is difficult due to MBM's bulk behaviors; it flows less easily than many other granular materials, and it tends to foul the surfaces of processing equipment. This study examines the major factors contributing to MBM's poor bulk behavior, including moisture content, fat content, particle size distribution and temperature, and the relative importance of these factors. Potential methods for improving MBM's bulk properties, including use of an anti-caking agent, dehydration, fat extraction, milling and refrigeration are also studied. The effects of these factors were determined by a standard laboratory measurement, the Hausner ratio, as well as by the rate of surface-fouling and dust generation using a pilot-scale aspirator. In contrast to past studies with other granular materials, moisture content was shown to have an insignificant effect on MBM's bulk behavior. The results, however, show that MBM fat content is a major determinant of the bulk behavior of the MBM. Reduction of fat content resulted in major changes in MBM's bulk behavior, by all measures used. Less dramatic changes were achieved through refrigeration to solidify the fat and/or treatment with an anti-caking agent.
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1. Introduction

Meat and bone meal (MBM) is a commodity produced by the rendering of fat from unmarketable animal tissues. It comprises mainly chopped, dehydrated and partially defatted bones and offal (Garcia et al., 2006). Since the emergence of bovine spongiform encephalopathy, use of meat and bone meal in animal feed has been progressively restricted (Rodehutscord et al., 2002; Thiry et al., 2004). A looming glut of MBM has motivated efforts to develop new applications for MBM (Chaala and Roy, 2003; Conesa et al., 2003; Garcia et al., 2004; Park et al., 2000). MBM, however, can be challenging to process from a material handling perspective. It is a somewhat cohesive granular material. This cohesiveness complicates the design of equipment and processes to handle MBM. A recent study on air classification of MBM found that poor flow properties and surface-fouling were obstacles to the processing, storage and transport of MBM (Garcia et al., 2005). These problems necessitated equipment modification, use of processing equipment below its normal capacity, and a high proportion of downtime to clean fouled surfaces of the equipment.

The bulk behavior of granular materials, such as MBM, determines the special accommodations necessary to process them. The interrelated properties of bulk flow,

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fluidization behavior, and caking and dusting tendencies must be considered in the design of hoppers, conveyors, mixers, mills and other unit operations (Holdich, 2002). These properties depend on the intrinsic properties of the individual particles, and on their environment and history.

Other than properties intrinsic to the particles, moisture is most often cited as influencing the bulk behavior of a granular material. Increasing moisture content has been recognized to inhibit bulk flow and fluidization, reduce dustiness and promote caking (Pilpel, 1970; Plinke et al., 1994). These effects have been observed with a diverse range of materials including glass beads, titanium dioxide, sugar, flour and gypsum (Carr, 1970; Harnby et al., 1987; Plinke et al., 1994; Teunou et al., 1995). These effects all arise from increased inter-particle cohesion induced by moisture. Moisture can promote cohesion by multiple mechanisms, depending on the nature of the particle involved, and on the temperature, moisture and compaction applied to the particles over time (Adhikari et al., 2001; Ozkan et al., 2002).

Generally the flowability of a granular material improves with increasing particle size (Abdullah and Geldart, 1999; Teunou et al., 1995). For larger particles, the forces of gravity and inertia are large compared to the inter-particle forces, giving rise to low structural strength of the powder. Consequently, larger particles have an individual mobility that tends to result in "free flow" characteristics (Forsyth et al., 2002).

MBM is fairly fatty and has a slight, palpable greasiness or tackiness. Little information is available on the influence of fat content on the bulk behavior of granular materials. It has been found that increasing fat inhibits the release of airborne dust (Heber, 2002) and fat has been used effectively as an additive to reduce the dustiness of animal feed (Gore et al., 1986). One group (Wakiyama et al., 1992) found that fat content promoted caking of granular materials, especially when tested at temperatures above the melting point of the fat.

The present study identifies factors responsible for MBM's poor material handling properties, and evaluates potential treatments to improve these properties.

2. Methods

2.1. Sample preparation

Moyer Packing Co. (Souderton, PA) donated the MBM used in this study, which all came from a single manufacturing lot. Individual MBM particles vary widely in size and composition and the particle types have a strong tendency to spontaneously segregate, so care was required to obtain small, representative samples. A 20 kg sample of MBM was thoroughly homogenized and split into 600 g sub-samples by repeated cone and quartering. Except when noted otherwise, each sub-sample was conditioned for a minimum of four days prior to use by storing in a controlled temperature and relative humidity (RH) environment. An RH of 73.7% (±0.1, $n = 80$) was maintained using a standardized method (ASTM International, 2003) involving storage of the samples in glass desiccators over saturated solutions of sodium chloride. The samples were stirred daily to promote equilibration with the surrounding air, and the desiccators were stored in a 30 °C incubator (average $T = 30.6$ °C, ±0.03, $n = 80$). Preliminary experiments determined that this amount of incubation time was adequate for the MBM to equilibrate with the atmosphere surrounding it.

Samples treated with a temperature other than 30 °C were equilibrated at 30 °C as described above, and then hermetically sealed in a container with little headspace, and incubated at the final temperature. Milled samples were mixed approximately 1:1 with crushed dry ice, prior to being fed through a Wiley mill (Model 1, Arthur H. Thomas, Philadelphia, PA) fitted with a 1 mm outlet screen, and then equilibrated. Reduced fat MBM samples were produced by dehydrating MBM overnight and then extracting four times with hexane (1 mL/g MBM) and filtering through Whatman #1 (Whatman Inc., Florham Park, NJ) filter paper. The resulting MBM had a significantly reduced fat content (1.3% dry basis) compared to the unextracted MBM (9.1% dry basis). The anti-caking agents Zeofree 5162 (synthetic silicon dioxide) and Zeolex 7A (synthetic sodium aluminosilicate) were obtained from Huber Engineered Materials (Atlanta, GA).

2.2. Moisture adsorption isotherms

Samples of about 2 g MBM were dried in a 70 °C vacuum oven for 36 h and accurately weighed. Dry samples were sealed in chambers with constant relative humidity atmospheres. The equilibration chambers were set up according to ASTM E 104-02 (ASTM International, 2003) and consisted of small, hermetic boxes containing saturated salt solutions and a perforated plastic plate to suspend the sample above the salt solution. The solutions of LiCl, CH_3COOK, $MgCl_2$, K_2CO_3, NaBr, KI, NaCl, and KCl stored at 30 °C (±0.5 °C) equilibrate with the headspace air resulting in a RH of 11.3%, 21.6%, 32.4%, 43.2%, 56.0%, 67.9%, 75.1%, and 83.6%, respectively. The samples were removed from the chambers and weighed after incubating for 10–11 days (preliminary experiments determined the samples reached a constant mass after about four days). Moisture adsorption isotherms were determined in quadruplicate.

2.3. Bulk behavior testing

All testing was performed in a randomized order. The Hausner ratio is the ratio of a material's tapped bulk density to its loose bulk density (Grey and Beddow, 1969). Loose bulk density of each sample type was determined in triplicate using a standardized method (American Association of Cereal Chemists, 1995), slightly modified to work for MBM. Briefly, the hopper of a Winchester Bushel Weight Tester (Burrow's Equipment Co., Evanston, IL) is