MEAT AND BONE MEAL INTO HIGH-ASH AND HIGH-PROTEIN STREAMS

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ABSTRACT. Meat and bone meal (MBM) is a byproduct of the rendering industry. Novel feed and non-feed applications for the protein and minerals in MBM are being developed. MBM would have improved characteristics for these applications if the bone and soft tissue-derived particles could be efficiently separated. An aspirator is a device that separates mixtures of particles based on the terminal velocity of each particle. The objective of this study was to evaluate whether an aspirator can be used to separate MBM into high-ash and high-protein fractions. It was found that the cohesive MBM particles tended to clog the hopper and aspirator column and foul the other interior surfaces of the aspirator, making continuous operation of the aspirator problematic, unless a modification was made. The results show that with this modification, and appropriate settings for feed rate and operating pressure, the aspirator produces two fractions, one that is considerably higher in ash, and one that is moderately higher in protein. Specifically, with an MBM feed rate of 8.0 g/s and an operating pressure of −116 Pa, the high-ash fraction was 52.0% ash (dry basis), compared to 34.5% ash in the unprocessed material. With a feed rate of 13.7 g/s and a pressure of −28 Pa, the high-protein fraction was 60.9% crude protein (dry basis), compared to 55.8% crude protein in the unprocessed material. The aspirator tested achieved a degree of separation that will facilitate the use of MBM in alternative applications.

Keywords. Meat and bone meal, Aspirator, Winnowing, Separation, Optimization, Cohesive solid, Powder.

MEAT AND BONE MEAL (MBM), a high-protein byproduct of the meat rendering industry, is primarily used in formulating farm animal feed (Fernando, 1992; Wang and Parsons, 1998). The outbreak of bovine spongiform encephalopathy in Europe led to new laws proscribing the use of MBM in ruminant feed in the U.S., and in any farm animal feed in the E.U. (Matthews and Cooke, 2003; Park et al., 2000; Rodehutscord et al., 2002). A looming glut of MBM has spurred the search for alternative uses (Fasl et al., 2004; Garcia et al., 2004; Park et al., 2000).

MBM is a heterogeneous mixture of particles. The particles derived from bone are high in ash, while the particles derived from soft tissues are high in protein. Additionally, some particles may be clumps containing material derived from both bone and soft tissue.

Feed formulations for some animal species could include a higher proportion of MBM, if the MBM had lower ash content. Specifically, high-ash diets are associated with increased risks of chronic renal failure in domestic cats (Hughes et al., 2002), and calcium concentrations in cat food are limited to about 1.5% (Meat and Livestock Australia, 1997). This severely limits the proportion of MBM in cat food. Some aquaculture species have been found to grow better on feed formulated with reduced-ash MBM, compared to feed with normal MBM (Stone et al., 2000). These animal species are less likely to be affected by MBM feed bans, because fish are not believed to be susceptible to BSE (Matthews and Cooke, 2003; Stone et al., 2000), and cat carcasses are not normally used in food or feed.

Many potential non-feed uses of MBM would exploit either the high protein concentration of the soft tissue particles or the high mineral concentration of the bone particles. For example, the soft tissue material might be processed to take advantage of the protein’s functional properties to produce films, adhesives, or foams (Park et al., 2000), and the bone material might be used as filler in composite materials or for its mineral content.

Efficient separation of MBM into high-protein and high-ash streams could add significant value to the commodity, especially as alternative applications emerge.

MBM is a relatively low value commodity, so the processing methods applied to it should be inexpensive, unless a very high value application is developed. The only past work on the separation of MBM involves heavy fluid separation in carbon tetrachloride (Criswell et al., 1964; Nash and Mathews, 1971) or chloroform (Mendez and Dale, 1998). Criswell and coworkers improved the efficiency of their separation method by incorporating a hydrocyclone. These methods can achieve very good separation, but because of the halogenated solvents used, they would be very expensive to use on an industrial scale.
An aspirator is a grain-cleaning device that separates particles on the basis of the particles’ terminal velocity (Al-Yahya et al., 1991; Bettge and Pomeranz, 1993). Within an aspirator, raw material is passed through a stream of air; ideally, particles with terminal velocity less than the air velocity will be sucked out of the aspirator, and particles with greater terminal velocity will fall through the air stream. Aspirators are attractive for solid-solid separations because they can process material at a high flow rate and are relatively inexpensive to operate and maintain (Flores et al., 1991; Hurburgh et al., 1996). An aspirator’s fan is its only component that is subject to maintenance or failure in normal usage (B. Kice, personal communication, 2 December 2004.). Other devices for solid-solid separations, including gravity tables and mechanical screeners, have more moving parts, and screens or decks that must be periodically replaced. Aspirators have been successfully used to process materials as diverse as soybeans (Hurburgh et al., 1996), corn fines (Al-Yahya et al., 1991), grass seed (Douglas et al., 2000), and electronics scrap (Zhang and Forssberg, 1999).

The actual design of aspiration machinery varies significantly from manufacturer to manufacturer. We worked with a common design from Kice Industries (Wichita, Kansas). As the raw material flows through the aspirator column, it cascades over the edges of a series of slides. A stream of air passes through each cascade, removing the low terminal velocity particles, which are then collected in a cyclone. The airflow rate is adjusted using a butterfly valve in the exhaust duct. Rather than directly measuring air velocity, the aspirator is manufactured with an air pressure gauge, which is used to reproducibly set the static pressure within the aspirator’s duct.

In the following work, the objective was to examine the practicality and limitations of using an aspirator to process MBM into high-ash and high-protein fractions. The effects of two interacting aspirator variables (raw material feed rate and aspirator operating pressure) are studied simultaneously using a response surface method.

**MATERIALS AND METHODS**

MBM was obtained from a single manufacturing lot (Moyer Packing Co., Souderton, Pa.). A pilot-scale laboratory aspirator unit (model 6DT4, Kice Industries, Wichita Kansas) was used to process the MBM (fig. 1).

**ASPIRATOR OPERATION**

**MBM Feed Rate**

The standard hopper on the aspirator was inadequate to deliver a steady stream of MBM to the aspirator column because the highly cohesive MBM particles tended to form a stable “arch” in the hopper, preventing flow into the system. Occasionally the arch would break, allowing a large amount of MBM to flood the aspirator. We constructed a frame supporting a custom-built hopper and a vibratory feeder to deliver an adjustable, consistent flow to the aspirator (fig. 2). The hopper had an 83 mm diameter circular opening, surrounded by walls sloping upwards at $59^\circ$. It was outfitted with a vibrator (Syntron model V4RC, FMC Technologies, Houston, Texas) to agitate the material in the hopper and disrupt stable formations. Below the hopper sat a vibratory feeder (model VFM 15-1-20, Eriez, Erie, Pa.). The gap between the bottom of the hopper and the floor of the feeder tray was 25 mm. The feeder control unit was used to adjust the amplitude of the feeder vibrations. By adjusting the feeder amplitude, this setup was able to deliver MBM to the aspirator at rates of 5.6 to 30 g/s very consistently (fig. 3). Higher feed rates could be produced, if necessary, by increasing the gap between the hopper outlet and the feeder.

![Figure 1. Kice model 6DT4 laboratory aspirator unit. Material flows from the hopper (a) and down through the aspirator column (b). Low terminal velocity particles are sucked out of column into the cyclone (c). Air velocity is controlled using a butterfly valve (d) in the exhaust duct. The outlet of the exhaust duct is fitted with a cotton dust bag. For pressure measurements, a custom-made duct (e) is inserted at (f). Circles in the cross-section of the duct (g) represent positions where pressure measurements were made.](image-url)
Aspirator Operating Pressure

While the aspirator is in operation, the needle on the installed pressure gauge bounces considerably, making accurate reading difficult. To minimize the influence of this “noise” in the pressure measurements, the valve was moved through its entire range in 1° increments while measuring the pressure. A correlation between valve position and static pressure was constructed, and this correlation was used to set operating pressure in further experimental work, rather than direct reading from the pressure gauge. The exhaust bag was regularly laundered to maintain a constant resistance to airflow. It should be noted that the manufacturer installs the pressure gauge so that it reports a positive pressure when the static pressure in the aspirator duct is lower than atmospheric pressure; in this article, the signs of these pressure measurements are reversed to conform to the standard definition of gauge pressure.

Air Velocity

Air velocity was determined by the insertion of rectangular duct (W 7.30 × H 9.84 × L 91.44 cm) between the aspirator column and the cyclone (fig. 1, e and f). A pitot tube (model 400, Dwyer Instruments, Michigan City, Ind.) was inserted into the duct, 61 cm from the upstream end, to measure static and total pressure. Measurements of static pressure and total pressure were taken at five positions in the duct (fig. 1g) and averaged.

Experimental Design and Analysis

Our experiments were set up as a central composite, response surface design (fig. 4) (Montgomery, 2001). The independent variables were MBM feed rate and aspirator operating pressure. Useful ranges for these variables were determined through preliminary experiments (data not reported). The experiments were performed in two blocks, the first block containing the “box” points and half of the center points in the design, and the second block containing the axial points and the remainder of the center points. The design was replicated, which required a total of 28 experimental runs. Minitab 14 (Minitab, Inc., State College, Pa.) software was used for statistical analysis of our results. Regression models that fit the data well, without the inclusion of insignificant terms (p > 0.05), were selected. The residuals
from each regression model were examined to ensure that none of the assumptions of the analysis were violated.

**PROXIMATE ANALYSIS**

Moisture, ash, and fat were determined using standard protocols (ASTM, 1994, 1996). Crude protein was estimated as the balance of the material that is not moisture, ash, or fat (animal tissue has negligible carbohydrates).

**SEPARATION PERFORMANCE**

There is no universal scale for the performance of a separation process. The goal of the separation may differ depending on the application of the separated material. There are trade-offs between ash content of the high-ash stream, protein content of the high-protein stream, and flow rate of each stream. We designed a relationship between these different goals to use in the optimization, which we defined as:

\[
\text{Separation effectiveness (\%) = } \frac{(m_{C} \times C_{p,C}) + (m_{A} \times C_{p,A})}{m_{C} + m_{A}}
\]

where

- \(m_{C}\) = solid mass flow rate from the cyclone (g/s)
- \(m_{A}\) = solid mass flow rate from the aspirator column (g/s)
- \(C_{p,C}\) = crude protein in the cyclone fraction (% d.b.)
- \(C_{p,A}\) = ash in the aspirator column fraction (% d.b.).

**RESULTS AND DISCUSSION**

The operator of this type of aspirator adjusts the exhaust valve to control the air velocity in the aspirator column, but the operator has no direct measurement of air velocity. To establish the relationship between the operator control (the exhaust valve) and the air velocity, a long duct (fig. 1e) was temporarily inserted between the aspirator column and the cyclone (fig. 1f). The static and velocity pressure measurements taken with this additional duct in place allowed calculation of the air velocity in the short duct if the additional duct were not there. The calculations take into account the pressure loss due to the additional duct. Measurements were taken with the exhaust valve in a range of positions. The results (fig. 5) show a non-linear relationship between valve position and air velocity in the duct. Air velocity at any specific position in the aspirator column is directly proportional to the air velocity in the duct; we did not attempt to directly measure air velocity within the column because the column’s complex shape and six air inlets make it difficult to study.

Although air velocity is closely tied to the principle on which the aspirator operates, the remaining results are presented in terms of static air pressure in the short duct of the aspirator, because this is the value that the aspirator operator will typically have available.

The proximate composition of the MBM was determined to be 4% moisture as-is, 55.8% crude protein, dry basis (d.b.), 34.5% ash (d.b.), and 9.7% fat (d.b.), which are all within the typical range for MBM (Pearl, 2004).

Aspirator processing separated the MBM into two fractions with easily observable differences. The fraction collected in the cyclone consisted of smaller particles, most of which were brown and pliable, suggesting that they were derived from soft tissue. The fraction that dropped through the aspirator column consisted of larger particles, many of which were very hard and white, suggesting they were bone-derived. The degree of difference between the fractions, and their relative amounts, clearly varied depending on the pressure setting and the raw material feed rate. Using a central composite experimental design, the effects of these two operator-controlled variables were investigated simultaneously. From this experiment, regression models were built that relate the variables to various metrics of separation (table 1).

The aspirator drop-through stream always had significantly higher ash content than the cyclone stream, presumably because many bone-derived particles have high terminal
Table 1. Regression equations relating aspirator variables to metrics of separation. NS indicates that a particular term was not included the model because it was insignificant ($\alpha = 0.05$).

$$\hat{y} = \text{Constant} + \beta_1 \text{pressure} + \beta_2 \text{feed} + \beta_3 \text{pressure}^2 + \beta_4 \text{pressure} \cdot \text{feed}$$

<table>
<thead>
<tr>
<th>Metric</th>
<th>Constant</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\beta_3$</th>
<th>$\beta_4$</th>
<th>$R^2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% ash in aspirator drop-through stream</td>
<td>37.56</td>
<td>-0.23</td>
<td>-0.40</td>
<td>-0.001</td>
<td>NS</td>
<td>84.2</td>
</tr>
<tr>
<td>% crude protein in cyclone stream</td>
<td>60.87</td>
<td>0.03</td>
<td>0.01</td>
<td>NS</td>
<td>NS</td>
<td>72.3</td>
</tr>
<tr>
<td>Separation effectiveness</td>
<td>48.36</td>
<td>-0.31</td>
<td>-1.02</td>
<td>-0.002</td>
<td>-0.008</td>
<td>89.1</td>
</tr>
</tbody>
</table>

Figure 6. Contour visualization of regression for ash (% d.b.) in the aspirator drop-through stream.

Figure 7. Contour visualization of regression for crude protein (% d.b.) in the cyclone stream.

Figure 8. Contour visualization of regression for separation effectiveness (%).

Both operating pressure and feed rate had highly significant effects on the ash content of this stream. A combination of slow feed rate (8.0 g/s) and low operating pressure (~116 Pa, gauge) produced the highest observed ash content, 52.0% (d.b.), along with a significantly reduced protein content, 42.9% (d.b.). Figure 6 illustrates the quadratic and interacting effects of the variables on ash content of the aspirator drop-through stream.

Protein concentration in the cyclone stream was found to be primarily a function of pressure (fig. 7). Low pressures increased the proportion of small bone-derived particles that were sucked into the cyclone, diluting the protein concentration of this stream. The highest protein concentration observed (60.9% d.b.) resulted from a low feed rate (8.0 g/s) and high operating pressure (~28 Pa). The improvement in the cyclone material protein content was small but significant compared to the unprocessed material (55.8% d.b.). However, its ash content (24.8% d.b.) was far less compared to the unprocessed material (34.5% d.b.).

The results presented up to this point neglect an important aspect of the aspirator’s performance: the mass flow rates of the two product streams. This is important because, for example, a certain combination of settings may produce a very pure protein stream, but at an extremely low rate. Separation effectiveness aggregates the two product mass flow rates and their purities into a single quantity. Our results (fig. 8) demonstrate how such a measure can be useful in the optimization of aspirator variables. The region that produces the highest separation effectiveness is not congruent with either the region that produces the highest ash concentration in the aspirator stream or the region that produces the highest protein concentration in the cyclone stream. The region of greatest separation effectiveness represents a compromise between competing goals.

The highest observed separation effectiveness (58.1%) was produced by using a feed rate of 5.6 g/s and an operating pressure of ~79.6 Pa. Under these conditions, 84.6% of the processed material was collected in the cyclone and the remainder was collected beneath the aspirator column. Minitab’s Response Optimizer was used to locate the maximum value for the separation effectiveness response surface. This maximum corresponded to a feed rate of 5.6 g/s, an operating pressure of ~91.7 Pa, and a predicted separation effectiveness of 59.1%.

**Conclusions**

The aspirator used in this study can process MBM, if allowances are made for MBM’s cohesive properties. It can be effective in separating MBM into high-ash and high-protein streams. The degree of separation achieved is adequate to produce lower ash fractions for specific feed applications. The degree of separation achieved may or may not be adequate for other, more functional applications of the separated MBM.

The operator-controlled variables (feed rate and air velocity) interact with one another, and their optimum settings cannot easily be determined through one-factor-at-a-
time experimentation. Designed experiments, such as the type used in this work, are effective in studying the variables simultaneously and determining approximate locations of optimum operating conditions.

Significant challenges remain, including prevention of aspirator surface fouling, and further improvement of separation effectiveness.

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REFERENCES


