Characteristics of North American Meat & Bone Meal Relevant to the Development of Non-feed Applications

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Written for presentation at the  
2006 ASABE Annual International Meeting  
Sponsored by ASABE  
Oregon Convention Center  
Portland, Oregon  
9 - 12 July 2006

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Abstract. Unmarketable animal tissues are typically processed by rendering plants, which transform them into meat & bone meal (MBM) or similar products. MBM’s traditional use as animal feed has become increasingly threatened, but MBM has potential for non-feed applications. Development of new products and processes is hindered by lack of reliable data on many of MBM’s chemical and physical properties. MBM samples as well as data on raw material and process were collected from 19 rendering facilities in the United States and Canada. A large majority of the raw material was tissue from cattle, swine and poultry. All facilities surveyed practiced continuous dry rendering; 89% of the facilities use continuous cookers and 11% use falling film evaporators. MBM is high in protein (44.6-62.8%, mfb), but this protein is poorly soluble; at pH 7 solubility ranged from 2.20 to 7.22 %. Among all samples, the particles’ median geometric mean diameter was 387 µm, and the size distribution was broad. The median density of MBM particles was 1.41 (g/ml); median density of MBM in bulk ranged from 0.50 g/ml when loose-filled to 0.68 g/ml when packed. pH values of the samples ranged from 5.89 to 7.19 and samples containing the most cattle tissue had the highest pH. Thermal diffusivity and thermal conductivity values for both loose-filled and packed MBM are reported, as well as CIE L*a*b* color values.

Keywords. Bio-based product, biomass, byproduct, characterization, meat & bone meal, rendering, feedstock, non-feed applications, materials handling, physical properties, protein solubility
**Introduction**

Since the second half of the 19th century, rendering plants have processed the majority of the unmarketable tissues from slaughtered farm animals (Burnham, 1996; Schoeff, 1985). The rendering process adds value to this material by dehydrating and stabilizing it against degradation, and by fractionating it into two primary product streams: a purified fat stream and a stream high in protein and ash. The protein and ash stream is transformed into a commodity commonly known as 'meat & bone meal' (MBM; variations on this name can indicate specific raw materials, for example ‘poultry meal’ or ‘porcine meat & bone meal’, or proximate composition, for example ‘meat meal’ when the phosphorus content is less than a specified concentration) (Association of American Feed Control Officials, 2002; National Renderers Association, 2003).

The rendering industry produces large quantities of MBM. In 2004, US renderers produced 2.1 million metric tons of bovine, porcine or mixed species MBM (Swisher, 2005) while in 2000, Canadian renderers produced 432 thousand metric tons (Canadian Food Inspection Agency, 2002). Prior to the United Kingdom’s outbreak of bovine spongiform encephalopathy (BSE) in the 1980’s, almost all MBM was utilized as a high protein ingredient in animal feed. Today, most countries do not allow MBM containing any amount of ruminant tissue to be fed to ruminant animals. In the United States, MBM with ruminant tissue is used in feed for non-ruminant farm animals (especially poultry and swine), companion animals and aquaculture species, which, with the exception of cats, have never been shown to contract BSE under normal circumstances (Matthews and Cooke, 2003; Oidtmann et al., 2003). In the European Union, MBM is banned from the feed of any animals that may become human food (Taylor and Woodgate, 2003). In the EU, MBM is now primarily either incinerated or used for its energy content in operations such as cement plants (Heilemann, 2002; Struckmann et al., 2004), or used as an ingredient in pet food.

While MBM's feed use has become increasingly restricted, growing attention has focused on the development of new, non-feed applications. Investigators have demonstrated MBM’s utility as an agent to control plant pathogens (Lazarovits et al., 1999), as a nitrogen source for the fermentative production of bio-based materials (Koller et al., 2005), as the primary ingredient in an adhesive (Park et al., 2000), as fuel for fluidized bed combustors (McDonnell et al., 2001), and as a main ingredient in a hard plastic material (Garcia et al., 2004). These and other applications have potential commercial value, but with the exception of fuel uses, most have only been implemented on a laboratory or demonstration scale.

The design of manufacturing processes utilizing unfamiliar materials is simplified when data are available on the normal range of critical properties (Day et al., 1993; Rosentrater et al., 1999). MBM has been well characterized in terms of its nutritional properties (Bureau et al., 2000; Hua et al., 2005; Johnson and Parsons, 1997; Lueking et al., 1996; Parsons et al., 1997) and several reports have described significant variability in these properties (Hegedus, 1984; Hendriks et al., 2002). It has been shown, however, that MBM from a single renderer is considerably more consistent (Kirby et al., 1993; Kirstein, 2003). Some renderers or protein blenders supply MBM with tightly controlled ash and protein contents by blending MBM from different sources (National Renderers Association, 2003). While many of the properties previously reported are very specific to animal nutrition (e.g., protein efficiency ratio, digestible energy, pepsin N digestibility), other properties including the proximate composition, gross energy (also known as
‘gross calorific value’ or ‘higher heating value’), and amino acid profile could be useful in the design of non-feed applications.

Other types of information, of major importance in the design of new products and processes, are not readily available. For example, there is little industry-wide information on the raw material used to produce MBM, the cooking treatment used, or geographic availability. Data on properties relevant to materials handling and product formulation is similarly scare. One recent study (Yang et al., 2005) emphasized the importance of properties such as material density and particle size distribution to the evaluation of biomass fuels; reliable data on such properties in MBM are not to be found in the scientific literature. The present study addresses these gaps in the current knowledge by gathering processing information and MBM samples from renderers across the United States and Canada. MBM characteristics, including particle size, density, thermal properties, proximate composition, protein solubility, pH, and color are investigated, as are potential correlations between these properties and the raw materials and processes used to manufacture them.

Materials and Methods

Geographic Information

US rendering facilities were identified and located by analysis of public inspection records (FDA Center for Veterinary Medicine, 2005); these records were created by the Food and Drug Administration’s Center for Veterinary Medicine by inspecting renderers, feed mills, ruminant feeders, protein blenders, pet food manufacturers, pet food salvagers, animal feed distributors and transporters, ruminant feeders, and others to determine compliance with BSE/ruminant feed regulations (FDA, 2003). Similar records for Canadian facilities were not available; many were located through the membership directory of the National Renderer’s Association (Alexandria, VA), which claims that its membership represents more than 98% of the rendering capacity in both Canada and the United States (Anonymous, 2005). Data obtained from these sources were augmented and corroborated through analysis of government reports, industrial contacts and literature (Canadian Food Inspection Agency, 2002; Pearl, 2005; Sparks Companies Inc., 1997; United States Government Accountability Office, 2005).

MBM Samples and Questionnaires

Through the Fats and Proteins Research Foundation (FPRF, Alexandria, VA) requests were made to 22 US and Canadian rendering facilities to submit 10 pounds of unblended (i.e., single batch) MBM. Sample providers were also asked to complete a detailed questionnaire (see Appendix) concerning the specifics of their rendering process, and the raw material they were processing on that day. Samples and questionnaires were assigned serial identification numbers by an intermediary at FPRF, and transferred to the researchers without revealing the source of any particular sample.

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 for analysis. Submitted samples of MBM were thoroughly homogenized and split into sub-samples by repeated cone and quartering. Sub-samples were re-homogenized prior to being analyzed.

Particle size analysis

Particle size distribution was determined by mixing samples with 1% (w/w) Zeofree 5162 (Huber Engineered Materials, Atlanta, GA) anti-caking agent and then classifying the particles with a
standard series of sieves according to ASTM D 1921-01 (ASTM International, 2001). Geometric mean diameter and geometric standard deviation of the particle size distributions were calculated using standard equations according to method ASAE S319.3 (American Society of Agricultural Engineers, 2003a).

**Density**

Loose bulk density of each sample was determined in triplicate using standard method AACC 55-10 (American Association of Cereal Chemists, 1995b), which involved pouring MBM into a cup of known volume and determining the mass. Performing the test exactly as described in the standard, however, resulted in the funnel above the test cup becoming clogged with MBM. To avoid this, MBM was added to the funnel in two smaller batches. The diameter of cup was large enough that the MBM filled the cup without ‘bridging’ or leaving any large air spaces.

Tapped bulk density of each sample type was determined in at least triplicate using an Autotap (Quantachrome Instruments, Boynton Beach, FL) set to deliver 3000 taps to each sample. These data were used to compute the Hausner ratio, the ratio of a material’s tapped bulk density to its loose bulk density (Grey and Beddow, 1969), for each sample.

Apparent material density, which is the average density of individual particles including closed pores, was determined using a helium pycnometer (AccuPyc 1330, Micromeritics, Norcross, GA). Before testing, samples were dehydrated to a constant mass, at 70 °C, under approximately 100 kPa (gauge) vacuum. Three sub-samples from each sample were obtained, and the density of each of these sub-samples was determined three times and averaged.

**Thermal Properties**

Material was allowed to free flow into 50 mL polypropylene centrifuge tubes via a standard bushel tester funnel (Seedburo Equipment Co., Chicago, IL). Compacted samples were produced by tapping on the laboratory bench by hand 20 times in a consistent manner. Thermal conductivity and diffusivity were determined, on both loose-filled as well as compacted samples, with a thermal properties meter (KD2, Decagon Devices, Pullman, WA), which utilized the line heat-source probe, maximum slope technique (Baghe-Khandan et al., 1981; Wang and Hayakawa, 1993).

**Proximate Analysis**

Lipid content was determined by Soxhlet extraction with hexane according to ASTM D 3495-83 (ASTM International, 1994). Moisture content determinations were performed by dehydrating 2g samples at 70 °C, under approximately 100 kPa (gauge) vacuum, to constant mass, which typically took 24 hours. The relatively low drying temperature in both the lipid and moisture analyses was chosen to minimize error due to vaporization of free fatty acids. Ash determination was performed by overnight incineration of 2 g samples in ceramic crucibles in a 600 °C muffle furnace.

Nitrogen content in samples was determined using an automated analyzer (model FP-2000, Leco Corporation, St. Joseph, MI). Because the sample size used in this analysis was only 50 mg, 5g samples were finely milled in a freezer mill (model 6800, Spex Centriprep Inc., Metuchen, NJ) and homogenized before drawing out sub-samples for nitrogen determination. A nitrogen to protein conversion factor of 6.45 was calculated based on recently published amino acid analyses of 12 North American MBM samples (Adedokun and Adeola, 2005). The computation of this conversion factor assumes that half the measured quantities glutamic acid and aspartic acid represent glutamine and asparagine residues that have deamidated during hydrolysis.
Three to five repetitions of each proximate composition analysis were performed.

**Protein Solubility**

Protein solubility was determined using a well-validated and widely-used method developed for commodity proteins such as soy protein concentrate or spray dried whey (Morr et al., 1985). Under carefully defined conditions 500 mg of sample protein were stirred in a solution of 0.1 M NaCl for one hour, at pH 7. After centrifugation, the dissolved protein concentration was determined; the bicinchoninic acid assay (Walker, 1996) was used rather than the recommended biuret assay. The percent solubility was calculated as the mass of protein dissolved, divided by the mass of protein in the original sample. Duplicate analyses were performed on each sample.

**pH**

The methodology used for pH determination was adapted from standard methods for pH in flour and meat (American Association of Cereal Chemists, 1995a; Food Safety and Inspection Service, 1993). Briefly, 5 g sample material was stirred into 50 mL of ultrapure water that had recently been boiled to eliminate dissolved CO₂. The solid material was allowed to settle momentarily and then the pH was measured using a calibrated pH meter. Triplicate analyses were performed on each sample.

**Color Analysis**

Images of MBM samples were produced by photographing them in a controlled and standardized manner. Specifically, duplicate samples were prepared by filling large Petri dishes (150 x 15 mm) with MBM and smoothing the surface with a straightedge. Photographs were taken with a Nikon D-70 camera, 60 mm lens, 1/60 sec F8 aperture, under studio lighting. A test shoot was performed to establish in-camera white balance. The resulting 16-bit TIFF images were analyzed using Photoshop CS (Adobe Systems Inc., San Jose, CA). A template layer superimposed on each image specified five color sampling locations, arranged in a cross pattern; at each location, a 5 by 5 pixel color sample was measured and the CIE L*a*b* color space coordinates were recorded.

**Results and Discussion**

**Geographic Distribution of the Rendering Industry**

There are approximately 250 rendering facilities operating in the US and 32 operating in Canada. Geographic data shows that rendering facilities are not distributed homogeneously (Figure 1); the states of Texas, Nebraska, California, and Illinois contain 28% of all the rendering plants in the US. The data available on Canadian facilities is less complete; of the 19 facilities identified, 68% were in the provinces of Ontario, Alberta or Quebec.

**General Survey Results**

The 22 requests sent out resulted in submission of 19 MBM samples accompanied by completed questionnaires (86.4% response rate). Although samples were submitted anonymously, evidence gleaned from return addresses and questionnaires indicated that the samples originated in at least 12 different cities, geographically dispersed across the US. Not all respondents answered all questions on the questionnaire, so not all the following results are based on the same number of data points. One of the MBM samples submitted was actually a
material known as ‘crax’ or ‘cracklings’, material which has not gone through the final operations of milling and screening to produce finished MBM; this sample was not subjected to the laboratory analysis but the questionnaire data associated with it was used.

Figure 1. Geographic distribution of US rendering facilities. Alaska, Hawaii and Puerto Rico not to scale. Arrows indicate location of facilities that are difficult to see on the map.

**Raw Material**

Material from cattle, swine and poultry made up the majority of the raw material processed by the renderers surveyed (Figure 2). Most MBM submitted contained material of more than one species, three of the submitted samples were all pork material, three were all cattle, and one was 99% chicken. A minority of renderers reported using any material from cervids, horses or aquatic animals; none of these species made up greater than 10% of an individual renderer’s raw material. No renderers reported including any sheep, dog, cat or other companion, fur or zoo animals. The absence of canine or feline material is supported by an FDA report, which examined a range of commercial dog food, many varieties of which contained MBM. Using a very sensitive method to identify the species of the material, they did not detect any feline, canine or equine tissue (Myers et al., 2004). The absence of ovine material is consistent with a National Renderer’s Association policy against the inclusion of sheep material; since the collection of the samples in the present study, this policy has been rescinded (Malone, 2005).
12 out of 19 respondents reported that the majority of their raw material consisted of meat animal carcasses (excluding hair, hoof, horn, blood, and contents of the gastrointestinal tract) after they had been harvested for their high value tissues at a slaughterhouse (Figure 3). Ten out of 19 renderers used at least some material from dead stock (animals that died before slaughter); five of 19 renderers had dead stock as at least 10% of their raw material. None of the renderers reported using any dead stock from non-agricultural sources such as road kill, wildlife culling, racing animals, zoos, or veterinarians. Eight out of 19 renderers had some material that consisted of meat products past their ‘sell by’ date; five out of 19 renderers had this type of material as at least 10% of their raw material. Eight out of 19 included protein recovered by the dissolved air floatation unit in the plant’s effluent stream. Eight out of 19 included some material from the processing of hides (fleshings or trim).

Figure 3. Sources of renderer’s raw material (n=19). a) slaughterhouse bones and offal, b) dead stock, c) meat products past ‘sell-by’ date, d) DAF system skimmings, e) hide fleshings, f) hide or hide trim, g) restaurant or foodservice (n=19).
**Processing Methods**

All facilities surveyed practiced continuous dry rendering; 16 of 18 facilities use continuous cookers and two of 18 use falling film evaporators. These results are consistent with reports that alternative processes, such as batch dry rendering, wet rendering and solvent extraction, are currently rare in the United States and Canada (Auvermann et al., 2004; Bisplinghoff, 1995; Prokop, 1996). The data reveal that material from different facilities has been subjected to very different time-temperature treatments (Figure 4).

![Figure 4. Reported heat treatment received by raw material in the rendering process (n=15). Data points labeled with numbers represent multiple overlapping points.](image)

**Particle Size Distribution**

MBM particle sizes are widely distributed both within and between samples. Computed geometric mean diameter for individual samples were all within the range 256-800 µm, with a median of 387 µm. Within individual samples, two distinct patterns of particle size distribution were qualitatively observed, which correlated well with calculated values for log normal geometric standard deviation. Eight of the 18 samples had clear peaks in their distribution profiles, as typified in Figure 5a, and standard deviations of less than 70% of their mean diameter; the remaining samples displayed much flatter distribution profiles, as typified by Figure 5b, and standard deviations of greater than 70% of their mean diameter. The questionnaire on rendering process specifics did not request any information on the final stages of the rendering process where crax is screened and milled into finished MBM. Anecdotal evidence, however, suggests that the flatter distribution profiles may originate at plants where screens have been removed from the normal finishing operation; the screens tend to become
blinded with fatty residue and some operators consider them an unnecessary nuisance (Hamilton, 2005).

Figure 5. Particle size distribution in MBM. Two distinct patterns are observed, a) a relatively narrow distribution, and b) a much broader distribution.

Density

Bulk MBM consolidates significantly when disturbed (Table 1); the median loose fill bulk density was 0.50 g/mL, while after extensive tapping the median bulk density increased to 0.68 g/mL. Strong positive correlations ($\alpha < 0.001$) were found between ash content and both bulk and material densities. These correlations are consistent with earlier observations (Mendez and Dale, 1998) that rendered bone particles are denser than rendered soft tissue particles.

The Hausner ratio of a particulate material is known to correlate well with the material’s fluidization behavior (Geldart et al., 1984). Of the MBM samples tested, 11% had Hausner ratios indicating that they would behave as easy to fluidize Group A powders (Hausner ratio $> 1.4$), 5% as difficult to fluidize Group C powders (HR $< 1.25$), and the remaining 84% as transitional Group AC powders.

Table 1. Observed range of values for several of MBM’s physical and chemical properties (n=18).

<table>
<thead>
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<th>Property</th>
<th>Minimum</th>
<th>Median</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>True Protein (%., mfb)</td>
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<td>56.6</td>
<td>62.8</td>
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<tr>
<td>Lipid (%., mfb)</td>
<td>8.9</td>
<td>12.2</td>
<td>16.0</td>
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<td>Ash (%., mfb)</td>
<td>20.7</td>
<td>25.3</td>
<td>39.9</td>
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<tr>
<td>Moisture (%., as received)</td>
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<td>5.7</td>
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<tr>
<td>pH</td>
<td>5.89</td>
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<td>7.19</td>
</tr>
<tr>
<td>protein solubility (%)</td>
<td>2.2</td>
<td>5.4</td>
<td>7.2</td>
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<tr>
<td>bulk density (g/mL)</td>
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Thermal Properties

Thermal conductivity and diffusivity at 22.5 (±0.3) °C were determined for MBM samples at both low and high bulk densities (Table 1). The thermal conductivities of samples at their lowest stable bulk density all fell in a tight range, 0.05-0.06 W/(m°C); after compacting the samples with 20 standard taps, the conductivities increased and covered a larger range, 0.07-0.11 W/(m°C). These results are consistent with previous reports of the thermal conductivity of powders increasing along with bulk density (MacCarthy, 1985; Muramatsu et al., 2005).

The thermal diffusivities the samples at low density fell in the range 0.150-0.187 mm²/s, while at high density they fell in the range 0.107-0.137 mm²/s.

Proximate Analysis

The proximate composition of the MBM samples studied varied substantially from source to source (Table 1), consistent with the findings of previous studies. The use of unblended MBM in the present research exaggerates the variability of MBM’s proximate composition. It is standard practice for renderers to blend batches of MBM in order achieve a specified proximate composition (Anonymous, 2003; Kirstein, 2003).

The percentage of cattle tissue in the raw material had a significant positive correlation (α=0.023) with the ash content of the finished MBM. No other correlations between raw material species and proximate composition were observed.

Protein Solubility

The samples’ protein solubility at pH 7 ranged from 2.20 to 7.22 % with a median value of 5.35 %. These results indicate that MBM protein is much less soluble than commodity proteins such as soy protein isolate, whey protein concentrate or sodium caseinate (Morr et al., 1985).

Earlier research has consistently found that MBM processed at lower temperatures has greater amino acid bioavailability (Batterham et al., 1986; Johnson et al., 1998; Kondos and McClymont, 1972; Wang and Parsons, 1998). This phenomenon apparently is not due to greater protein

<table>
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<tr>
<th></th>
<th>loose fill</th>
<th>packed – 3000 taps</th>
<th>Hausner ratio</th>
<th>apparent material density (g/mL)</th>
<th>thermal conductivity (W/(m°C))</th>
<th>thermal diffusivity (mm²/s)</th>
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<td>thermal conductivity (W/(m°C))</td>
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<td>0.187</td>
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<tr>
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<td>0.120</td>
<td>0.137</td>
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<td>L*</td>
<td>25.6</td>
<td>51.2</td>
<td>69.9</td>
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<tr>
<td>a*</td>
<td>13.4</td>
<td>22.1</td>
<td>26.5</td>
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<tr>
<td>b*</td>
<td>25.2</td>
<td>38.9</td>
<td>57.0</td>
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solubility; the present study found no correlation between processing parameters such as ‘peak cooker temperature’ and protein solubility (Figure 6).

![Figure 6. Peak temperature applied to raw material in the rendering process versus the solubility of the resulting MBM protein at pH 7 (n=15)](image)

**pH**

pH values of the samples ranged from 5.89 to 7.19 with a median value of 6.30. The samples with the 4 highest pH values were the samples with the 4 highest concentrations of cattle tissue.

**Color**

All 18 samples of MBM received could be described as brown or tan, but significant color differences between samples are easily observable (Table 1); in appearance the samples ranged from dark brown (similar to coffee grounds) to tan (similar to pale beach sand).

**Conclusions**

Data from the present research should assist engineers in evaluating whether MBM could be used in their product or process. This work has shown that differences in raw material and rendering processes result in considerable variation in the physical properties of the MBM produced. Any process designed to utilize MBM will have to accommodate this variation.

Misconceptions about the raw material composition may have prevented MBM’s past utilization in non-feed applications. The survey results of this show that very little, if any, MBM is made from material such as euthanized pets, road kill, or zoo animals. The geographic study shows that MBM is produced in close proximity to most major manufacturing centers.
There are still significant hurdles to the adoption of MBM as a feedstock for bio-based products. Many potential applications are ruled out by the potential for prion contamination of the material. It should be noted, however, that BSE has been diagnosed in a total of four Canadian-born cows (Canadian Food Inspection Agency, 2005) and one US-born cow (Animal and Plant Health Inspection Service 2005); no cases have been found in Mexico (OIE, 2005). Thus, the chances of BSE contamination in North American MBM are extremely limited (Cohen et al., 2003).

**Acknowledgements**

Lorelie Bumanlag, Paul Pierlott, John Phillips, and Brian Coll provided valuable technical assistance in completion of this research.

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Appendix

Questionnaire Given to Renderers

When answering these questions, just consider the raw material that was rendered today to produce the MBM sample you are providing. Don’t consider anything that went into separate processes (feathers-> feather meal; restaurant grease-> recycled restaurant grease).

The animal species in our raw material today is approximately:  (your best estimate – based on amount of material, not based on number of animals)


Pearl, G. G. personal communication. 7 March 2005.


<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Bone %</th>
<th>Offal %</th>
<th>Whole Animal %</th>
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<td>Cattle</td>
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<td>Deer/Elk</td>
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<tr>
<td>Horse</td>
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<tr>
<td>Dog/Cat/Pet</td>
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<tr>
<td>Fish</td>
<td></td>
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<tr>
<td>Other</td>
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</tbody>
</table>

Of this raw material, what % is: (your best estimate)

- ____ % Dissolved air floatation grease and solids
- ____ % Hide fleshings; species %________; ________
- ____ % Hides and trim; species %________; ________
- ____ % out-dated meat products; species %________; ________
- ____ % restaurant or food service waste
- ____ % dead stock

If there is dead stock in your material, where did it come from?

- ____ % farm/ranch
- ____ % dairy
- ____ % feedlot
- ____ % veterinarian
- ____ % horse owners
- ____ % zoo
- ____ % wildlife managers
- ____ % hunters
- ____ % roadkill
- ____ % other (if so, what? _____________________)

Is your rendering process continuous, batch, or falling-film evaporator? If other, please describe.

Is your rendering process dry (the steam does not come in direct contact with the raw material)?

How long does the raw material remain in the cooker? (specify average or minimum residence time)

What is the peak temperature of the material in the cooker? _____ Exit temperature? _____

What date was this MBM sample produced on?

Do you add anything to the MBM (for example to dilute excess protein)?

Do you currently exclude any SRMs from the material you process? If so, please list those SRMs removed.