Physical Properties of Soybean Meal[1]

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ABSTRACT

Physical properties of soybean meal, including particle size and particle size distributions, bulk density and true density, and repose angle and drain angle, were studied in the laboratory. Evaluation of particle size and particle size distributions by a standard method revealed that 70% of the particles fell into the medium and fine range (between 0.595 and 1.19 mm). Normal and log-normal particle size distribution analyses showed similar results of mean diameter by mass (0.833 and 0.786 mm, respectively). Bulk density and true density were determined by multipycnometer and loose or zero degree bed packing, respectively. Repose angle and drain angle ranged from 30.3 to 33.2° and from 26.3 to 43.7°, respectively. The statistical analysis indicated that moisture content had significant effects both on the true and bulk densities and on the repose and drain angles.

Physical properties of feed ingredients are important to design, handling, storage, and drying systems, as well as the daily operation of feed plants. Unfortunately, not much information can be found in the literature about the physical properties of soybean meal. The data presented in *Feed Manufacturing Technology III* (Appel 1985) are not sufficient. The objectives of this study were to determine the particle size and particle size distributions, bulk density and true density, and repose angle and drain angle of soybean meal and the effect of moisture content on these properties.

In soybean oil processing, the soybeans are cleaned and dehulled. They are then sent through cracking rolls, which reduce them to particles one-sixth to one-eighth the size of the beans. These fragments are graded and passed through aspirators to separate the hulls from the meats. The separated hulls are toasted and ground for animal feed. The cleaned, cracked meats pass to a conditioner-cooker that raises the temperature to ≈77°C, with a moisture content of ≈10%. The conditioned particles then are flaked using flaking rolls to a thickness of 0.005–0.010 in. The cell walls are broken down, and the surface area is increased for extraction. The flakes are extracted with a solvent, usually hexane, to remove the oil, forming a mixture called "micella." The oil is recovered from the micella and refined. The spent flakes are desolventized to remove the residual hexade. The desolventized flakes then are processed to produce meal of the desired specifications (Wright 1981).

The bulk density of a material is the mass divided by the volume of the powder bed, which includes the volume occupied by the solid plus the volume of voids. The true density is defined as the ratio of mass to the volume occupied by that mass. Therefore, the contribution to the volume made by pores or internal voids must be disregarded when measuring the true density.

The density of a material varies significantly with particle size, compaction of the material, and moisture content. Therefore, particle size and particle size distributions also must be determined.

Appel (1985) reported some physical properties of feed ingredients, including the apparent densities of solvent extracted soybean meal at: 41% protein (545–577 kg/m^3); 44% protein (561–609 kg/m^3); and 50% protein (657–673 kg/m^3). More accurate data for soybean meals at different moisture contents are needed.

The repose angle is the most commonly observed and measured angular property of granular solids. Actually, there are two different types of repose angle: one is obtained when a pile of solids is formed, and the other when it is drained. Zenz and Othmer (1960) used a rectangular experimental bin with a transparent front face and photographic recording to measure the repose angle and the drain angle. They reported that the repose angle of soybean meal was 35°, without mentioning the condition of the meal.

The angle of repose was affected by the moisture content of materials (Kanawade et al 1984, Ezeike 1988). The test results clearly indicated that the repose angles of sorghum, wheat, and maize increased with increasing moisture content (Kanawade et al 1984). The repose angle, along with specific gravity, increased as a power function of the moisture content of some seed grains (Ezeike 1988).

MATERIALS AND METHODS

One lot of solvent-extracted soybean oil meal was obtained from a Cargill oil seeds plant in Wichita, KS. The initial moisture content of the samples was ≈12%, wb. The samples were kept in a cooler before the tests.

Particle Size and Particle Size Distributions

Particle size and particle size distributions of soybean meals were determined by the sieving method with a Ro-Tap sieve shaker and a set of U.S. standard sieves (ASAE 1993).

Analysis of mass distribution data of all ground feeds and feed ingredients is based on the assumption that these distributions are logarithmic normally distributed. The size of particles shall be reported in terms of geometric mean diameter and geometric standard deviation by mass.

$$d_{gw} = \log^{-1}\left[\frac{\sum_{i=1}^{n}\left(W_i \log \bar{d}_i\right)}{\sum_{i=1}^{n} W_i}\right] \quad (1)$$

$$S_{gw} = \log^{-1}\left[\frac{\sum_{i=1}^{n} W_i\left(\log \bar{d}_i - \log d_{gw}\right)^2}{\sum_{i=1}^{n} W_i}\right]^{1/2} \quad (2)$$

where d_i = nominal sieve openings of the ith sieve (mm); d_{i+1} = nominal sieve openings in next larger than ith sieve (just above in a set) (mm); d_{gw} = geometric mean diameter by mass of sample

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(mm); $\bar{d_i}$ = geometric mean diameter of particles on ith sieve $[(mm)/(d_i \times d_{i+1})^{1/2}]$; S_{gw} = geometric standard deviation of sample estimate by mass; W_i = mass on ith sieve (g); n = number sieves + 1 (pan).

Bulk Density and True Density

The methods used by Chung and Converse (1971) were applied in this study. Bulk density was measured by gently filling a 300-ml glass beaker, scraping away the excess with a straight edge, weighing, and converting it to kg/m^3. It was loose-bed packing. True density was determined from Quantachrome multipycnometer measurements.

Repose Angle and Drain Angle

A prototype apparatus for measurement of repose angle was built in the laboratory (Fig. 1). It is similar to the device used by Kassim et al (1983) except for the size. The apparatus containing the samples was a flex-glass cylinder 50.8 cm tall with a diameter of 25.4 cm,. At its bottom, a slide gate controlled three openings with diameters of 38.1, 76.2, and 114.3 mm.

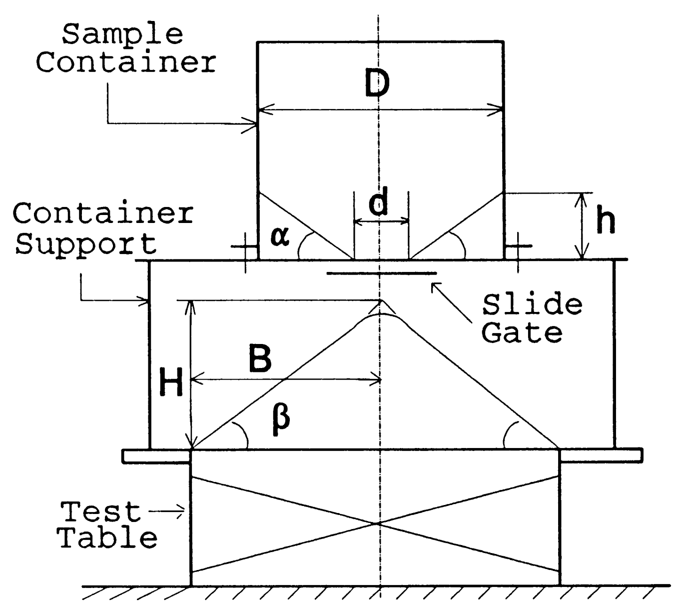

Fig. 1. Prototype for measuring repose angle (β) and drain angle (α).

A spreadsheet was placed underneath the apparatus for a pile to form when samples started to flow. As shown in Figure 1, the repose angle (β) was calculated by determining the height of the pile *(H)* and the area covered *(B* as the radius of the area it covered) on the spreadsheet. The repose angle β is:

$$\beta = \tan^{-1}\frac{H}{B} \tag{3}$$

The drain angle (α) was determined from the height of the material left in the cylinder *(h)* and the difference between the size of the flex-glass cylinder and the size of the orifice. The drain angle α is:

$$\alpha = \tan^{-1}\frac{h}{(D-d)/2} \tag{4}$$

The experiment was repeated for soybean meal at moisture contents of 10, 12, and 14% at the three orifice sizes.

RESULTS AND DISCUSSIONS

Particle Size and Particle Size Distributions

Table I shows the tabulation of sieving data and calculation of log-normal particle size distribution parameters.

A plot of the weighed percentage showed a near bell shape curve. If a normal distribution was assumed, the mass mean diameter by mass d_{mm} would be calculated as:

$$d_{mm} = \frac{\sum_{i=1}^{n}(W_i d_i)}{\sum_{i=1}^{n} W_i} \tag{5}$$

where n is the number of weight fractions. Therefore, d_{mm} = (82.499/99.08) = 0.833.

All normal distributions have certain common characteristics because they have the same basic equation. If we set $z = d_i - d_{mm} / \sigma$, where σ is the standard deviation. Then,

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} \tag{6}$$

is the normalized probability distribution, where mean is zero and standard deviation is one.

Most of the time, ground feeds are assumed to be log-normally distributed. If so, using equations (1) and (2), geometric mean diameter by mass of sample (d_{gw}) and geometric standard devia-

TABLE I
Tabulation of Sieving Data and Calculation of Log-Normal Particle Size Distribution Parameters[a,b]

U.S. Sieve No.	d_i (mm)	W_i (g)	P_i (%)	ΣP_i (%<)	logd_i	$W_i$logd_i	(logd_i – logd_{gw})	W_i(logd_i – logd_{gw})^2
103	6.731							
104	4.761	10.303	10.306	99.690	–0.751	–0.228	–0.857	0.223
106	3.361	10.073	10.074	99.620	–0.602	–0.044	–0.706	0.037
108	2.381	10.963	10.972	98.650	–0.451	–0.435	–0.556	0.298
112	1.681	11.353	11.459	87.189	–0.301	–3.417	–0.405	1.866
116	1.191	20.840	21.034	66.155	–0.150	–3.135	–0.255	1.354
120	0.841	21.353	21.552	44.604	–0.000	–0.004	–0.105	0.234
130	0.595	16.123	16.273	28.331	–0.150	–2.424	–0.046	0.034
140	0.420	18.583	18.663	19.668	–0.301	–2.585	–0.197	0.332
150	0.297	16.333	16.392	13.275	–0.452	–2.863	–0.348	0.765
170	0.210	13.560	13.593	19.682	–0.603	–2.145	–0.498	0.883
100	0.149	13.370	13.401	16.281	–0.752	–2.535	–0.648	1.414
140	0.105	11.200	11.211	15.070	–0.903	–1.084	–0.798	0.765
200	0.074	12.147	12.167	12.903	–1.055	–2.264	–0.950	1.939
270	0.053	11.417	11.430	11.474	–1.203	–1.705	–1.099	1.710
Pan		1.460	1.474	0.000				
Summation		99.08	100.0			–10.341		11.853

[a] d_i = Screen opening diameter; W_i = sample weight; P_i = percentage of weight.
[b] Data in table are averages of three replicates.

tion of sample estimated by mass (S_{gw}) were calculated as:

$$d_{gw} = \log^{-1}\left[\frac{\sum_{i=1}^{n}\left(W_i \log \bar{d}_i\right)}{\sum_{i=1}^{n} W_i}\right] = \log^{-1}\left[\frac{-10.341}{99.08}\right] = 0.786mm \quad (7)$$

$$S_{gw} = \log^{-1}\left[\frac{\sum_{i=1}^{n} W_i\left(\log \bar{d}_i - \log d_{gw}\right)^2}{\sum_{i=1}^{n} W_i}\right]^{1/2} = \log^{-1}\left[\frac{11.853}{99.08}\right]^{1/2} = 2.22 \quad (8)$$

The cumulative percentage (ΣP_i) of soybean meal samples in Table I is plotted against screen size (mm) as the particle size distributions (Fig. 2).

Particle Size Groups

U.S. standard sieve no. 16 with an opening of 1.19 mm was used to separate the samples into two particle size groups: those retained on the no. 16 sieve and those that passed through. The first group was considered as coarse, and the second group was considered as medium and fine. The original samples, the coarse particle size group, and the medium and fine particle size group were designated as Size 1, Size 2, and Size 3, respectively. They were tested later to determine particle size effect.

Bulk Density and True Density

The changes in true density and bulk density associated with the change in moisture content for soybean meals are presented graphically in Figures 3 and 4, respectively. Generally, both bulk density and true density decreased as the moisture content increased. This might be explained by particle expansion and surface characteristic changes after sufficient water was absorbed.

The regression equations for this relationship for soybean meals are:

$$\text{Size 1: } \rho_T = 1{,}366.8 - 2.425x \quad (9)$$
$$\text{Size 2: } \rho_T = 1{,}488.8 - 13.125x \quad (10)$$
$$\text{Size 3: } \rho_T = 1{,}484.9 - 11.425x \quad (11)$$

where ρ_T is the true density (kg/m^3) and x is % moisture content (wb). Standard deviations from regression for Sizes 1, 2, and 3 were 1.35, 12.53, and 14.32, respectively. Correlation coefficients between true density and moisture content for Sizes 1, 2, and 3 were 0.96, 0.90, and 0.84, respectively.

The regression equations for bulk density with moisture content are:

$$\text{Size 1: } \rho_B = 893.6 - 16.55x \quad (12)$$
$$\text{Size 2: } \rho_B = 677.8 - 7.85x \quad (13)$$
$$\text{Size 3: } \rho_B = 825.7 - 15.73x \quad (14)$$

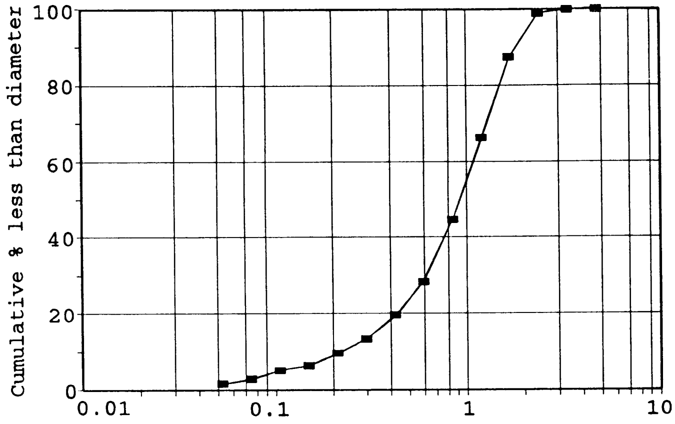

Fig. 2. Commutative weight particle size distributions.

where ρ_B is the bulk density (kg/m^3) and x is % moisture content (wb). Standard deviations from regression for Sizes 1, 2, and 3 were 19.11, 8.49, and 10.66, respectively. Correlation coefficients between the bulk density and the moisture content for Sizes 1, 2, and 3 were 0.86, 0.87, and 0.95, respectively.

The tests showed that fine particles tended to have higher bulk densities than did coarse particles. The effect of particle sizes on bulk density was significant ($P < 0.01$). The least significant difference (LSD) test at the 5% level of significance showed that the bulk density of Size 2 was significantly lower than those of the other two size groups, mainly because of more void space; the differences in bulk densities between Sizes 1 and 3 were not significant. The effect of particle size on true density was not significant ($P > 0.01$). Also, moisture contents had significant effects on both true densities ($P < 0.01$) and bulk densities ($P < 0.01$). The details of statistical analysis were reported by Wang (1994).

Repose Angle and Drain Angle

Test results for repose angle and drain angle are shown in Table II. The repose angle range was 30.3–33.2°. The LSD test at a 5% level of significance showed that the repose angle obtained at 14% moisture content was significantly higher than those at 10 and 12% moisture content. The orifice size had no significant effect ($P > 0.01$) on the repose angle, but the effect of moisture was significant ($P < 0.01$). The results from this study are lower than those from Zenz and Othmer (1960), who reported a repose angle of 35°.

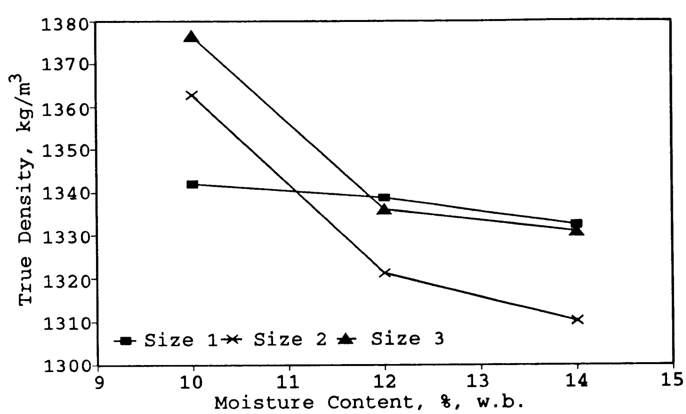

Fig. 3. True density of soybean meals at different moisture contents. Size 1: regular mixture of soybean meals; Size 2: soybean meal particles retained on U.S. no. 16 sieve; Size 3: soybean meal particles passed through U.S. no. 16 sieve.

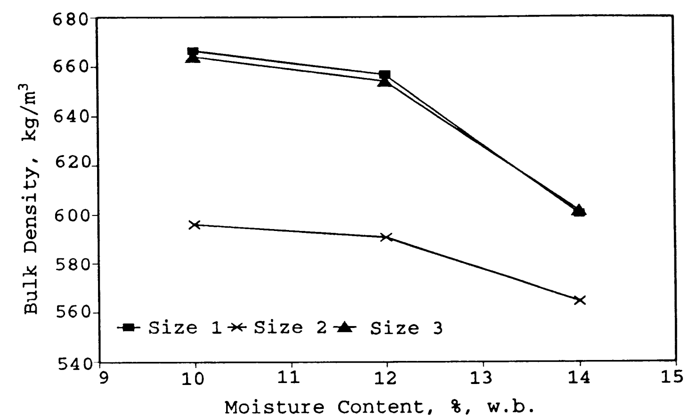

Fig. 4. Bulk density of soybean meals at different moisture contents. Size 1: regular mixture of soybean meals; Size 2: soybean meal particles retained on U.S. no. 16 sieve; Size 3: soybean meal particles passed through U.S. no. 16 sieve.

TABLE II
Repose Angle and Drain Angle of Soybean Meals at Different Moisture Contentsand Orifice Diameters

Moisture Content (% wb)	Orifice Size (in.)	Repose Angle (β, °)	Drain Angle (α, °)
10	1.5	31.3	31.9
10	3.0	30.5	29.9
10	4.5	30.6	26.3
12	1.5	30.7	40.1
12	3.0	31.1	34.6
12	4.5	30.3	30.4
14	1.5	33.2	43.7
14	3.0	32.3	35.6
14	4.5	31.6	29.2

[a] All data are the average of three replicates.

The drain angle had a wider range (26.3–43.7°). Both moisture content and orifice size had significant effects ($P < 0.01$) on drain angle, and the interaction between them was also significant ($P < 0.01$). The drain angle increased as the moisture content increased, and it decreased as the orifice size increased.

SUMMARY AND CONCLUSIONS

The particle size and particle size distributions of soybean meal were determined using the standard method provided by the ASAE (1993). The medium range (0.595–2.38 mm) included 70% of the soybean meal particles; 30% of the particles were fine (<0.595 mm). Normal and log-normal particle size distribution analyses revealed similar results for mean particle diameters by mass, which were 0.833 and 0.786 mm, respectively.

Moisture content had significant effects on both true density and bulk density. As moisture content increased, the densities decreased. Particle size had a significant effect on bulk density, but not on true density. Fine particles had a higher bulk density than coarse particles.

The moisture content had a significant effect on repose angle range (30.3–33.2°). The effect of orifice sizes tested was not statistically significant. Both moisture content and orifice size had significant effects on drain angle range (26.3–43.7°). The drain angle increased as the moisture content increased, and it decreased as the orifice size increased.

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