Predicting the Fluidity of Corn Flour/Water Systems[1]

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ABSTRACT

Volume fraction versus fluidity curves and packing fractions can be used to characterize differences in the fluidities of slurries made with various corn flours and water. The data used to generate such fluidity curves and packing fractions also were used to develop a fluidity prediction plot. This plot allowed us to predict the amount of water per gram of dry corn flour required to produce a dispersion with a desired fluidity. A corn flour blending equation was also developed, specifying the proportions of two or more corn flours to be blended into a flour having a desired packing fraction. The corn flour blending equation and the fluidity prediction plot can be used together to allow corn millers to create blended corn flours that have predictable fluidity when mixed with water.

Corn flour is widely used in batters. One of its major roles is the control of fluidity in those systems. However, because corn flours differ widely in their ability to influence fluidity, it has not been heretofore possible to predict the fluidity that will result when a corn flour is mixed with water to form a slurry or batter. As a result, companies that use corn flours in their batters and breaded products have been faced with the constant problem of maintaining product uniformity.

There are limited data in the literature to suggest what properties of corn flour affect the fluidity of corn flour/water systems. Foehse and Hoseney (1988) recently studied the factors that affect the fluidity of corn flour/water systems and concluded that different corn flours had different volume fraction versus fluidity curves and different packing fractions.

The objective of this study was to extend the research of Foehse and Hoseney (1988) to develop a method to predict the fluidity of corn flour/water systems.

MATERIALS AND METHODS

Corn meal and corn flour were obtained from a commercial dry corn miller.

Fluidity and Packing Fraction Measurement

The methods used to measure the fluidity and the packing fractions of corn flour/water slurries were as described by Foehse and Hoseney (1988).

Statistical Plotting Procedure

An SAS/GRAPH computer graphics program (Council and Helwig 1981) was used to fit linear regression lines to the fluidity data and produce the fluidity prediction plot.

Experimental Design for Corn Flour Blending Experiment

A design for a three-component mixture problem was used in a corn flour blending experiment (Fig. 1) (Snee 1971). The basic experimental design consisted of running each of 10 blends twice. Each point on the design predetermined a blend of three corn flours to be used in each run. Thus, the proportions of the three stock corn flours in each blend varied from run to run. The data were analyzed by Statistical Analysis System (SAS, Cary, NC) using the GLM procedure.

RESULTS AND DISCUSSION

Predicting Fluidity

Previous work (Foehse and Hoseney 1988) demonstrated that the position of a volume fraction versus fluidity curve along the volume fraction axis is characteristic of a corn flour. The data indicated that the major factors affecting the position of such a curve are particle size, particle size distribution, and the amount of damaged starch in the flour. Because the position of the volume fraction versus fluidity curve and the position of the packing fraction for a corn flour appeared to be related, we thought that the packing fraction might be used to predict the fluidity of a slurry made with the flour.

It appeared logical that the position of the packing fraction of a corn flour along the volume fraction axis would also be a function of the particle size, particle size distribution, and the amount of damaged starch in the flour. It followed that as water was added to a packed system, the particles would become mobile and flow would begin. That flow could be measured with the Bostwick consistometer, and a volume fraction versus fluidity curve could be generated to describe it.

The concentration of the slurries used to make a volume fraction versus fluidity curve could be expressed in milliliters of water per gram of dry material. This way of expressing concentration (ml water/g dry material) enabled us to plot slurry concentration at a given fluidity as a function of the packing fraction. An excellent linear relationship ($r = -0.95$) existed between ml water/g dry material at a fluidity of 10 cm and the packing fraction for 30 corn

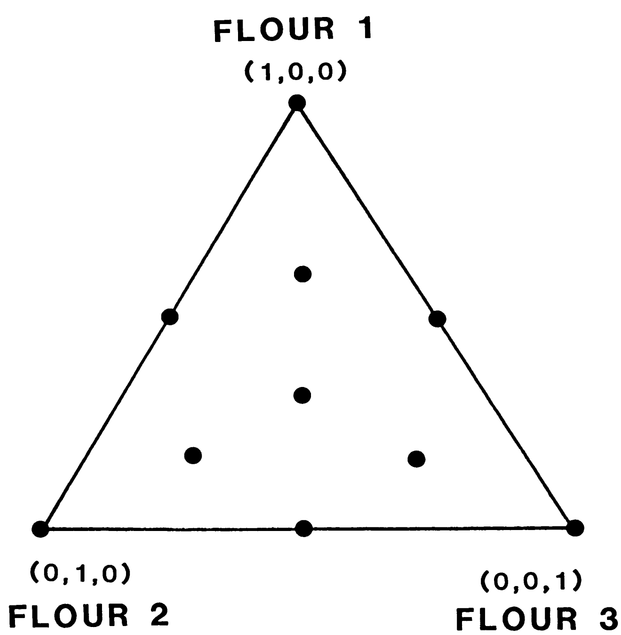

Fig. 1. Design for corn flour blending experiment.

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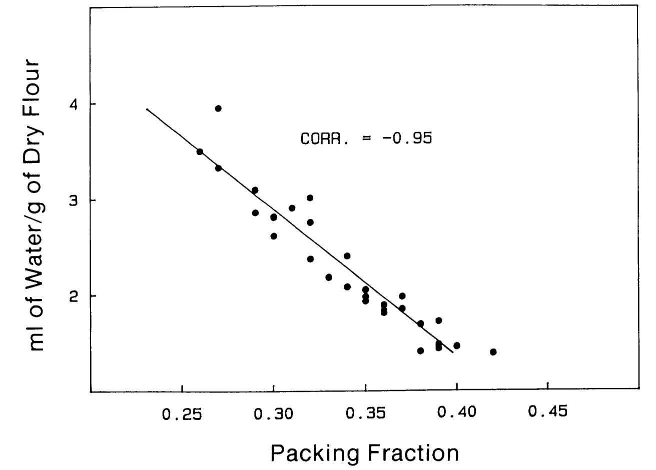

Fig. 2. Relationship between slurry concentration (ml of water/g dry corn flour) and packing fraction at a fluidity of 10 cm.

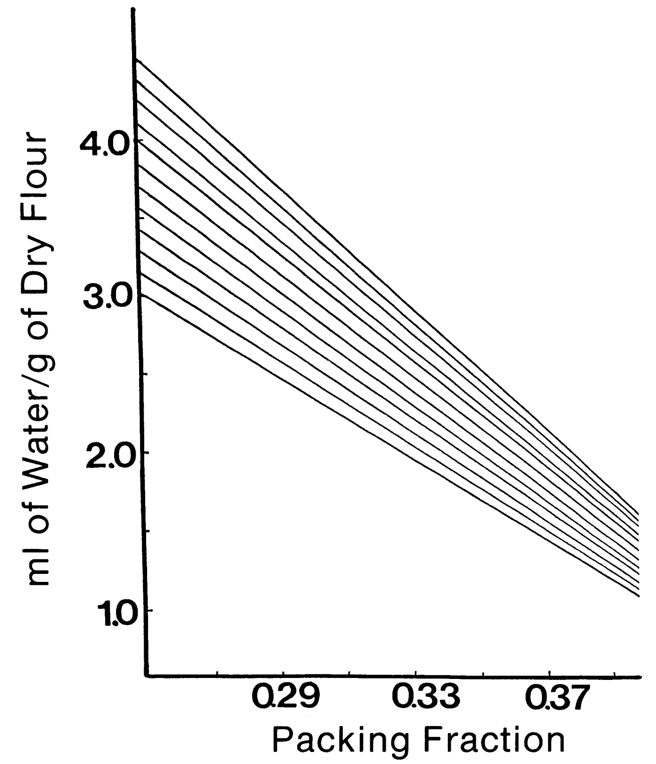

Fig. 3. Fluidity prediction plot. Fluidities represented by the lines decrease from 24 to 2 cm (by increments of 2 cm) from the top to the bottom of the plot. The equation for the lines is $Y = (\mathrm{PF} - 0.48)m$, where Y = ml of water/g of dry flour, PF = packing fraction, and m = slope. The slopes of the lines are 2 cm = −13.038, 4 cm = −13.611, 6 cm = −14.177, 8 cm = −14.769, 10 cm = −15.355, 12 cm = −15.934, 14 cm = −16.557, 16 cm = −17.203, 18 cm = −17.695, 20 cm = −18.290, 22 cm = −18.871, and 24 cm = −19.466.

flour samples (Fig. 2). This plot allowed us to predict the amount of water per gram of dry flour required to produce a slurry with a fluidity of 10 cm.

The plot was expanded to include fluidity prediction lines ranging from 2 to 24 cm (Fig. 3). Data used to make the plot came from 30 samples, including defatted corn flours, hard endosperm corn flours, corn flour fractions, and corn flour blends (Foehse and Hoseney 1988). The fluidity prediction plot is important, because it allows us to predict the fluidity that will result when water is added to any corn flour.

Predicting the Packing Fraction of Blended Corn Flours

As shown above, the packing fraction of a corn flour can be used to predict the amount of water needed to produce a corn flour slurry having a desired fluidity. The next step was to determine whether we could blend corn flours with different packing fractions and predict the packing fraction of the blend. Results of this experiment indicated that a linear model could predict the packing fraction of a blend of corn flours very well ($R^2 = 0.976$).

It appears that if one has k corn flours with known packing fractions given by $PF_1, PF_2, \ldots, PF_k$, and if one mixes $100(P_i)\%$ of flour (i), $i = 1, 2, \ldots, k$, to make a blend, the packing fraction for the blend is $PF_b = P_1(PF_1) + P_2(PF_2) + \ldots + P_k(PF_k)$, $(P_1 + P_2 + \ldots + P_k = 1)$.

This blending equation can be used to determine the proportions when more than two corn flours are to be blended. However, for blends of three or more corn flours, more than one combination of blending proportions can be used to obtain a desired packing fraction. In such cases, the best combination of blending proportions can be selected, based on the available quantity or cost of each corn flour.

The blending equation did not work well for predicting blending proportions to obtain a corn flour with a desired packing fraction when the samples to be blended were relatively monodispersed. When a flour fraction with large particles and a flour fraction with small particles were blended in the proportions given by the blending equation, the resulting packing fraction was higher than predicted. This was consistent with the system being more fluid than desired. This effect was attributed to the polydispersity of particle sizes in the blended corn flour (Jeffrey and Acrivos 1976). The small particles occupied the voids between the large particles, so the packed system retained less water than it would have if the particle size had been more uniform. A packed system that retains less water has a higher packing fraction than a packed system that retains more water. Results of this experiment suggest that although the blending equation works well for blending whole flours that are polydisperse, it does not work well for monodispersed fractions separated from flours.

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