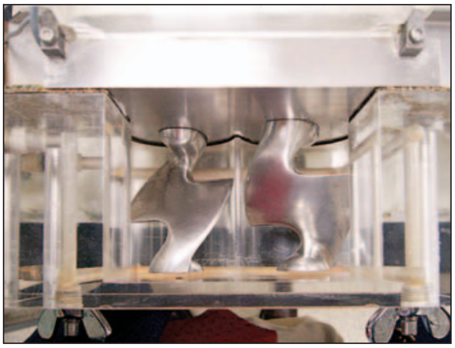
Looking Inside Dough Mixers



View of the C.W. Brabender, Inc. Farinograph® twin sigma blade mixer

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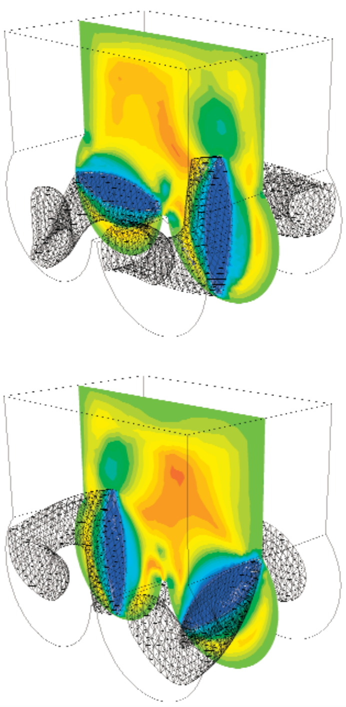

Mixing Index for Newtonian corn syrup for two mixer positions, where a value of 0 (blue) indicates pure rotation, 0.5 indicates simple shear, and 1 (red) indicates pure elongation

Wheat flour dough is a rheologically complex viscoelastic material, whose unique time-dependent properties are governed by the rate, amount, and type of deformation applied. The structure and morphology of dough also depend on the available moisture and the extent to which the dough is mixed. As a result, dough is a very dynamic and unstable material, and dough mixers have evolved into highly complex geometries that shear, stretch, and fold. In addition, they often have close wall clearances to ensure that there are no regions of ineffective mixing. Changing between mixer types, especially between batch and continuous mixers, is difficult because of the very different flow, shear, extension, and mixing profiles that characterize each one. In industry, determining mixing times and designing mixer configurations is largely done on a trial and error basis.

A more predictive approach is to calculate measures of mixing effectiveness through the use of mathematical modeling and numerical simulation. An ongoing project at the Center for Advanced Food Technology at Rutgers, The State University of New Jersey, supported by the National Research Initiative of the USDA Cooperative State Research, Education and Extension Service*, is using POLYFLOW to study the flow and mixing in typical dough mixer geometries with fluid models that range from simple Newtonian to non-linear viscoelastic [1,2]. The work featured here involves the numerical simulation of the flow and mixing in a fully filled Farinograph® mixer using the mesh superposition technique and particle tracking with a Newtonian fluid model based on a high viscosity corn syrup [3]. Future work with this geometry will focus on extending the simulations to non-Newtonian fluid models. The Farinograph is a low shear rate batch mixer with two non-intermeshing, asymmetrical sigma blades, where the fast (right) blade turns at 93 rpm counterclockwise and the slow (left) blade turns at 62 rpm clockwise. CAD STEP representations of the blade geometries were provided by C.W. Brabender Instruments, Inc., South Hackensack, New Jersey, producer of the Farinograph Mixer.

Because the blades turn at different speeds, two revolutions of the slow blade and three revolutions of the fast blade are required before there is repetition of the relative blade positions. The left (slow) blade mesh of 6232 tetrahedral elements and the right (fast) blade mesh of 6166 elements are superimposed on the bowl (41860 hexahedral elements) every 0.027 seconds, giving a total of 72 positions per blade cycle with 10° between positions for the slow blade and 15° between positions for the fast blade. The time marching flow simulation results are then used to generate particle tracking data for 10,000 massless material points initially randomly distributed throughout the flow domain, or a set of 1000 massless material points initially randomly distributed in a 1 cm^3 box. As these abstract points are tracked throughout the flow domain, the associated local flow characteristics are recorded, thus providing a spatial and temporal history of phenomena such as stretching and deformation. Random distribution is a requirement of the statistical mixing measures that are used to evaluate the particle tracking results.

The simulation results show that the differential in the speed of the two blades in the Farinograph causes an exchange of material between the blades to occur. The primary circulation pattern consists of material moving from the slow blade up toward the top of the mixer and over toward the fast blade, while the fast blade pushes material towards the slow blade near the bottom of the mixer. A slower mixing pattern is also observed where material around the blades moves from the center towards the walls and then up towards the top and back down in the center of the mixer. The zone in the center of the mixer between the two blades is shown to have excellent distributive and dispersive mixing ability with high shear rates and mixing index values [4]. The mixing index is a measure of the type of flow, with values that range from 0 for pure rotational flow to 0.5 for shear flow to 1 for pure elongational flow. A high value of the mixing index combined with a high shear stress and shear rate indicate an area in the mixer with potentially good dispersive mixing capability. That region also has fast distribution throughout both sides of the lower section of the mixer as shown by material point clusters that travel through it. In contrast, very slow mixing is seen in the area away from the region swept by the blades that is generally not filled during normal use of this mixer.

The mean of the normalized length of stretch [5] calculated for material points in the Newtonian fluid case increased exponentially over time, indicating effective mixing for the majority of material points. In the area swept by the blades, the material points with the highest values of the length of stretch are generally located near the blade edges or in the area swept by the blade edges. However, material points with high length of stretch values are also found outside these zones in a more random distribution. The instantaneous efficiency, which can be thought of as the fraction of energy dissipated locally that is used to stretch a fluid element at a given instant in a purely viscous fluid [5], gives a picture of the most and least effective blade positions for applying energy to stretch rather than displace material points. The least effective blade positions are when the flattened central sections of both blades are horizontal, while the most effective mixing occurs when the flattened section of the fast blade is vertical. The mean time-averaged-efficiency [5] stays above zero while its standard deviation reduces over time, indicating that the majority of the points are continuously experiencing stretching at equivalent levels over time.

The overall result of this project has been to demonstrate the effectiveness of numerical simulation as a means to non-intrusively study the flow and mixing in a given mixer of materials with different rheological properties. The results also have established a basis of comparison between mixers with very different geometries. The simulations are providing guidance for the design of experiments that will be used to validate the findings of the simulations. Once the simulations are validated, they will be able to provide a much higher level of detail than the experimental results. The insight gained by this research has already stimulated the development of ideas by those involved on how the flow and mixing in a mixer affects the development of material structure, leading to profitable new lines of research. ■

References:

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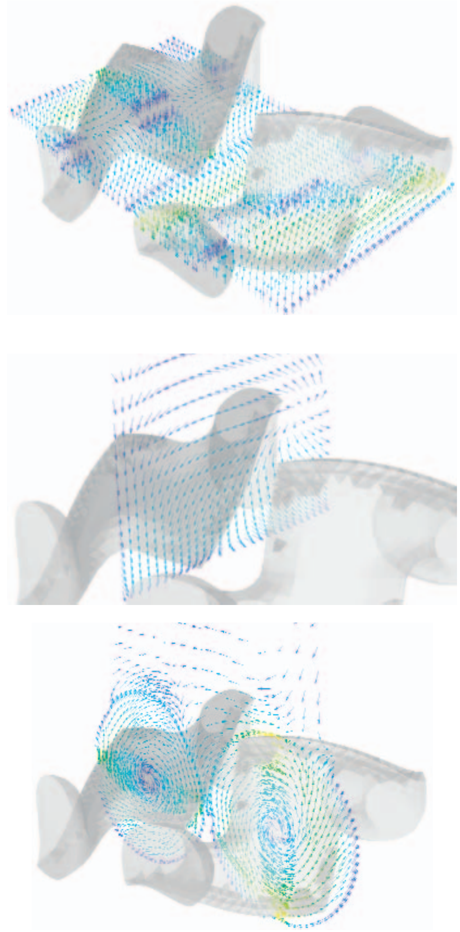
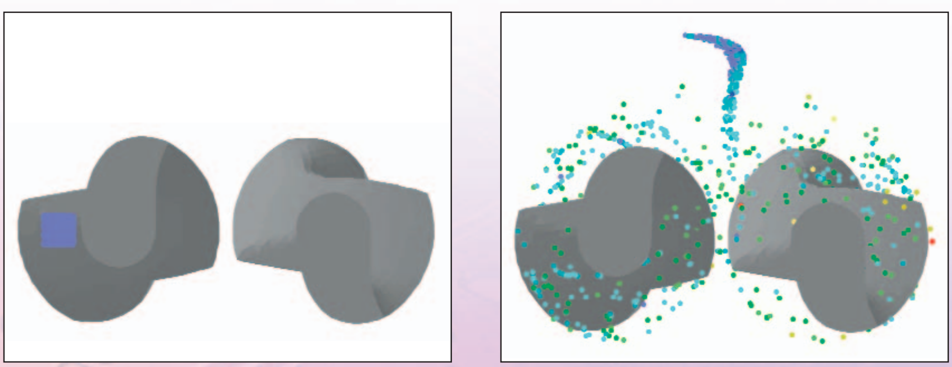
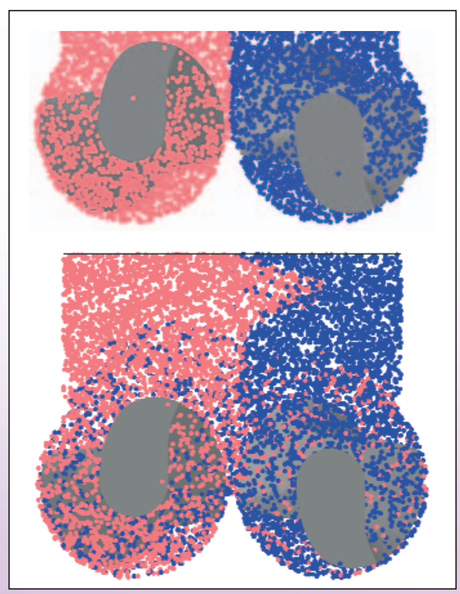


Newtonian corn syrup fluid velocity vectors for blade positions of 180° and 270° on the z=0 (top), x=0 (middle), and y=4.225 cm (bottom) planes; the vectors are all the same length and colored by the velocity magnitude



Initial (left) and final (right) positions after 3 blade cycles (6 revolutions of the slow blade and 9 revolutions of the fast blade) of 1,000 material points in the Newtonian corn syrup, colored according to the length of stretch [6]



For the Newtonian corn syrup, 3D positions of 10,000 initially randomly distributed material points (top) and after three cycles (bottom) with concentrations of 1 (red) and 0 (blue) [6]