Modeling of Laminar Flow Static Mixers

Accurate CFD modeling is being used by Veryst Engineering and Nordson EFD for optimizing static mixers.

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Static mixing of laminar viscous fluids has a wide range of industrial applications, especially in the pharmaceutical, biomedical, consumer product, and petrochemical industries. Yet, they are also quite difficult to model using traditional CFD methods. Veryst Engineering collaborated with Nordson EFD to find the best way to model these devices, and improve and optimize them.

Static mixers are inexpensive, accurate and can handle a wide range of fluids and mixing proportions. In many cases, the fluids to be blended are very viscous, and as molecular diffusion in laminar fluid mixing is very small, the fluids have to be mechanically mixed. This is in sharp contrast to turbulent mixing, or mixing of gases that involve significantly higher diffusion. The laminar fluid mixers analyzed in this study involve multiple elements that divide and recombine the flow, elements that invert the flow to move fluid away from the external boundary layer, and helical elements that stretch and fold the flow. A good mixing quality is obtained when the outlet of the static mixer has no concentrated volumes of either mixed materials and is overall uniform. Figure 1 shows disposable static mixers from Nordson EFD used to mix adhesives for construction, industrial and automotive bonding and repair applications.

Figure 1. Disposable static mixers.
(Photo courtesy of Nordson EFD, LLC)

Accurate CFD modeling is valuable for understanding and optimizing static mixers. However, two-phase CFD modeling by itself cannot be used due to numerical diffusion, a computational artifact that does not reflect the actual mixing process. This diffusion can be reduced with finer mesh, less stabilization, and other numerical techniques. However, numerical diffusion always dominates over the very low molecular diffusion present in static laminar fluid mixing.

CFD, Particle Tracing, and Mixing Quality

Veryst Engineering, in collaboration with Nordson EFD, developed a new modeling tool for simulating laminar static mixers. We use COMSOL Multiphysics to perform a CFD analysis of the overall mixer performance, and predict the overall flow pattern and pressure drop (Figure 2). We then use both streamline and massless particle tracing data, in separate analyses, to follow the path of fluid particles with no numerical diffusion. Figure 3 shows velocity contours at different sections of a Nordson EFD mixer, and Figure 4 shows the particle tracing at an intermediate time. Figure 4 also shows two Poincaré sections, which indicate the locations where particles cross a specific plane in the mixer. Validation of these models involved mesh convergence studies for the CFD solution, and optimal time stepping and particle density

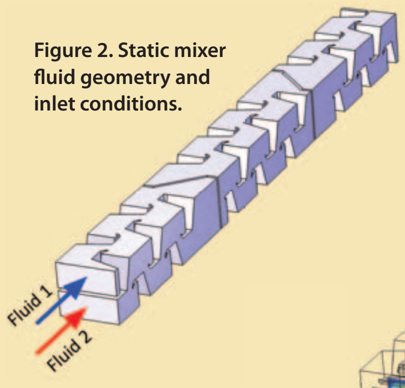

Figure 2. Static mixer fluid geometry and inlet conditions.

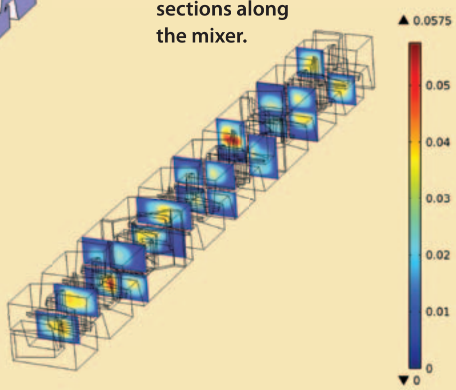

Figure 3. Velocity contours at different sections along the mixer.

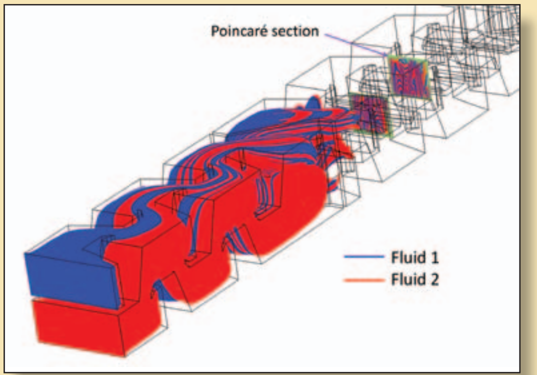

Figure 4. Particle tracing results at an intermediate time, together with a Poincaré section where good mixing is starting to occur.

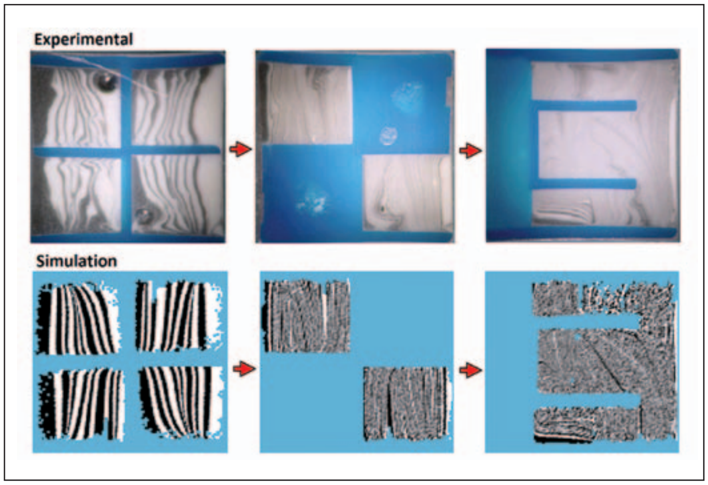

Figure 5. Comparison between experimental data and numerical mixing predictions at three sections along the first half of the mixer.

"We find that there is excellent overall agreement between experimental and simulation results..."

for the streamlines and particle tracing. At this stage, we recognized that the number of streamlines required to resolve the very thin streaks in the mixer was very large. We also found that using particle tracing in the Particle Tracing Module required significantly less computational time.

The streamline and particle tracing data is exported from COMSOL and used in a newly developed proprietary algorithm that computes two measures of mixing quality. The first is a coefficient of variation (CoV), which is a quantity that has a value of one for no mixing, and zero for perfect mixing. Here, "perfect mixing" is relative to a user-controlled length scale. The second metric is a series of cross-sectional mixer images similar to the Poincaré sections (Figure 4). These images help identify local streaks of one material that may not be clearly shown in an overall CoV analysis. The mixing images can also be stacked together to create an animation that facilitates mixing visualization.

Reliable Simulation Results

To validate this modeling tool, we compared the results to targeted mixing experiments performed by Nordson EFD involving the mixing of two epoxy materials — a black and a white compound. These materials solidify when mixed. After solidification, the mixer was sliced into about forty sections to visually assess the mixing quality.

Veryst also used streamline and particle tracing data to generate cross-sectional images comparable to the experimental results. The mixer cross-section is divided into equal sized cells that can take four states, depending on the streamlines, or particles, that intersect that cell. These values are: (i) material 1, marked as black; (ii) material 2, marked as white; (iii) well-mixed, marked as gray; and (iv) no data. Cells receive no data when they are in dead-flow zones, or recirculation zones. To reduce the amount of no-data zones, we generate particle tracing paths starting at different sections in the mixer (not just at the beginning).

Figure 5 shows a comparison between the experimental data and the numerical predictions for another Nordson EFD mixer at three different cross-sections along the first half of the mixer. The blue colored regions in the experimental data are the mixing elements. The black and white epoxies had slightly different entry angles in the experiment and in the simulation, due to the imperfect segregation of the two epoxies prior to reaching the mixing elements. This affects the distribution of black/white epoxy at different sections along the mixer. However, fluid entry angles are known to have an insignificant effect on mixing quality. We find that there is excellent overall agreement between experimental and simulation results in terms of identifying unmixed regions and fluid streaks.

Optimized Mixer Designs

The CFD simulation, particle tracing, and data processing algorithm provide a valuable tool for understanding the flow patterns inside the mixer beyond what is possible by pure experimentation. This is helping Nordson EFD optimize some of their mixer designs. Veryst Engineering and Nordson EFD are still working together on further improving the developed mixing tools, and expanding their application to other mixer geometries, mixing of significantly different fluids, and non-Newtonian fluid mixing. ■

About the Companies

Veryst Engineering, LLC

Veryst Engineering, LLC provides premium engineering services and consulting at the interface of technology and manufacturing. The Veryst Mission is "Engineering Through the Fundamentals" employing grounded knowledge of mechanics, physics, manufacturing, and computational methods to produce practical, useful results. Our consultants' backgrounds encompass teaching, extensive publications, industrial experience, and research. Veryst Engineering is a COMSOL Certified Consultant.

Nordson EFD

Nordson EFD is a leading manufacturer of precision dispensing systems that apply accurate, consistent amounts of the adhesives, sealants, lubricants and other assembly fluids used in virtually every manufacturing process. In addition to static mixers, Nordson EFD's 2K Product Line includes packaging systems and metering-mixing valves for reactive two-component adhesives and sealants, such as epoxies, urethanes, silicones and acrylics. Nordson EFD products are available through a worldwide network operating in more than 30 countries.