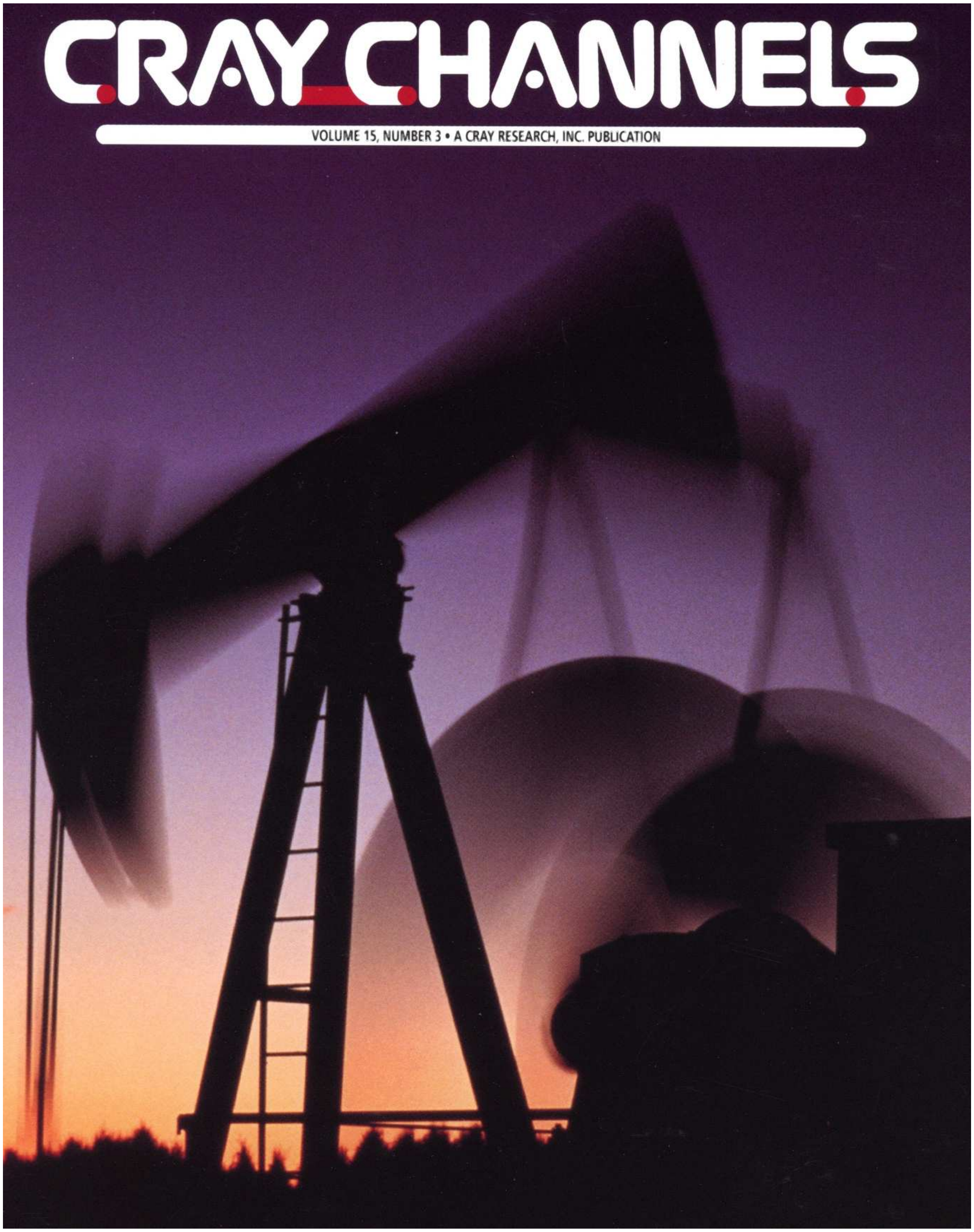
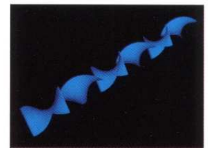
Bakker A., LaRoche R. (1993) Flow and Mixing with Kenics Static Mixers. Cray Channels, Volume 15, Number 3, page 25-28.



# Flow and mixing with Kenics static mixers



Designing optimal mixer configurations for the process industries, which rely to a great extent on common devices such as static mixers for pipeline mixing and dynamic mixers for agitated tanks, has been difficult because of limitations imposed by experimentation. Computer simulations on Cray Research systems, however, bypass some of these difficulties and give engineers new insight into mixer design.

### Static mixers

The KM inline static mixer, manufactured by Chemineer, Inc., consists of a number of elements of alternating 180° helices, as shown in Figure 1. The elements are positioned such that the leading edge of one element is perpendicular to the trailing edge of the next element. The length of each element is one-and-one-half tube diameters. This type of static mixer is used under laminar flow conditions such as mixing polymers or food products such as peanut butter and chocolate.

The High Efficiency Vortab (HEV) static mixer, also manufactured by Chemineer, Inc., consists of an array of vortex-generating tabs mounted in a pipe, as shown in Figure 2. The HEV is used both for liquid-liquid and gas-gas mixing, as in the wastewater industries or in smokestacks.

Most experimental work on static mixers has concentrated on establishing design guidelines and pressure drop correlations, and the number of investigations of the flow and the mixing mechanisms has been limited. Recent advances in computational fluid mixing (CFM) have

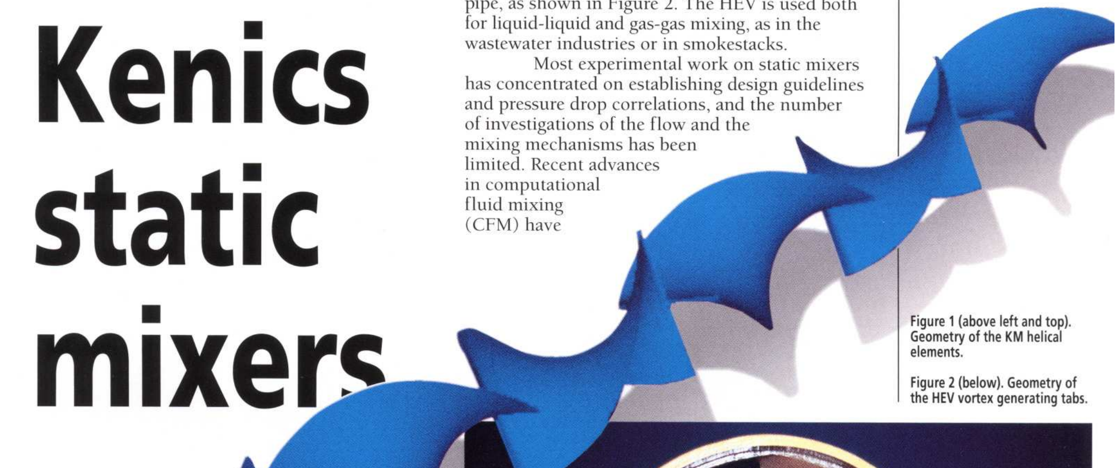
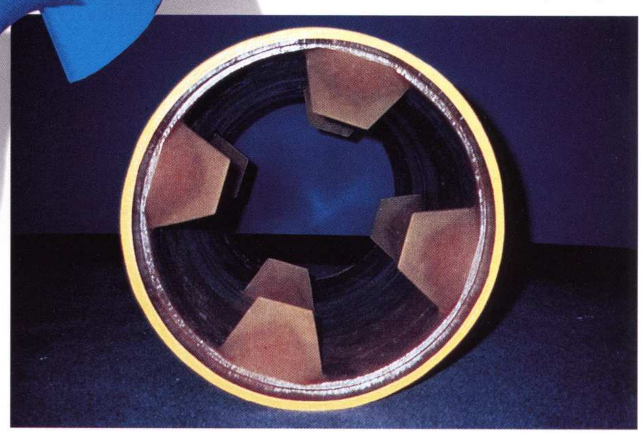


Figure 1 (above left and top). Geometry of the KM helical elements.

Figure 2 (below). Geometry of the HEV vortex generating tabs.



*André Bakker, Chemineer, Inc., Dayton, Ohio*
*Richard LaRoche, Cray Research, Inc.*

made computer simulations a useful tool in static mixer design and analysis. These simulations explore the possibilities CFM offers in the analysis of mixing and provide insight into the mixing mechanism. The FLUENT V4.21 software package from Fluent, Inc. helps analyze the static mixers' flow pattern, pressure drop, and mixing characteristics.

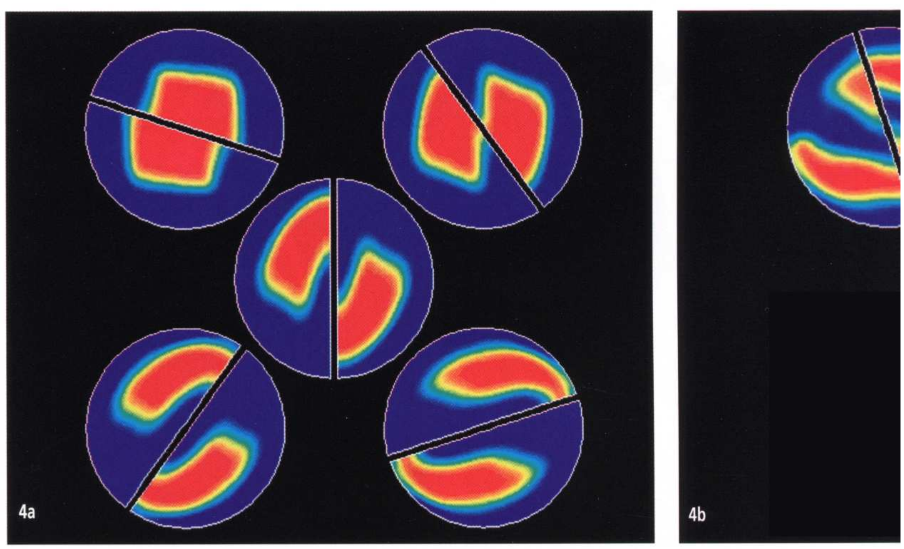
The numerical grids used to model the mixers were generated with FLUENT PreBFC V4.01 and exported to FLUENT V4.21 for the flow and mixing computations. For the laminar flow KM mixer, the model used the Reynolds number Re = 10; for the turbulent flow HEV mixer, the model used the Reynolds number Re = 100,000. For the turbulent flow conditions, the Reynolds stress model (RSM) also was used. The QUICK differencing scheme was used in all calculations.

Initial calculations were performed with 100,000 grid nodes on a Hewlett-Packard HP-750 workstation. The converged solutions were exported to the CRAY C90 system, where the grid was doubled in two directions, resulting in 400,000 nodes. Final calculations then were performed on a CRAY C90 system. These 400,000-node problems require 104 Mwords of core memory and are among the largest FLUENT problems ever run. Problems of this level of grid density are not possible on today's workstations. Typical calculation times are five and nine CPU hours on the CRAY C90 system for the KM and HEV mixers, respectively. These calculations required approximately 400 iterations with the algebraic multigrid solver option to reduce residuals to 0.001 for convergence.

There was very little difference between the flow field results at 100,000 nodes and at 400,000 nodes. Due to numerical diffusion, the species mixed too fast with the 100,000-node grid.

**Figure 3 (above). Inlet concentration of the chemical species for the KM mixer.**

**Figure 4a, 4b, 4c, (right). Concentration profiles at various intersections of the first, second, and sixth helical element (18°, 55°, 90°, 126°, 162°).**



The 400,000-node grid gave a much more accurate prediction of the mixing rate.

To evaluate the KM mixer's mixing mechanism, which consists of a series of helical mixing elements, the transport of two chemical species was calculated. Figure 3 shows the center of the inlet as 100 percent red and the outside of the inlet as 100 percent blue. The results are shown in Figure 4 as a series of raster plots. The plots show the concentration fields of the chemical species after the mixing mechanism has passed through 18°, 54°, 90°, 126°, and 162° rotation in the first, second, and sixth mixing element, respectively.

Figure 4 also shows how the red core coming from the inlet is split into two red islands, which are stretched and move outward. The blue, which was on the outside in the inlet of the element, is split in two semi-circular filaments, which are moved toward the inside of the element. Similar stretching and folding processes occur in the next elements. In the inlet of the third element, the blue species is on the inside, meaning that the concentration field has flipped inside out. This process of splitting, stretching, folding, and flipping inside out repeats itself every two elements, until the fluids are mixed. By the time the end of the sixth element is reached (Figure 4), the species concentrations are nearly uniform.

The pressure drop across the elements was calculated with the correlation proposed in the Kenics design guides. The predicted pressure drop was within 10 percent of the experimentally found pressure drop.

Figure 5 shows particle streaklines behind one of the HEV turbulent mixer's tabs. The streaklines show a strong circulation flow in the wake of the tab. The vortex, attached to the wall of the tube and not to the tabs, lies parallel with the tab and then bends to a longitudinal vortex with a center close to the tip of the tabs.

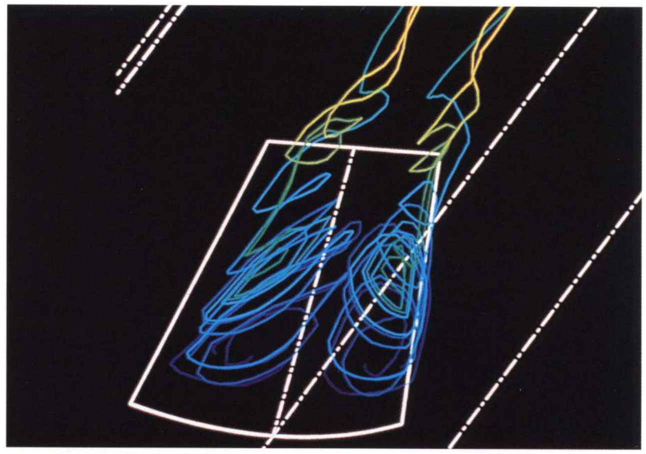
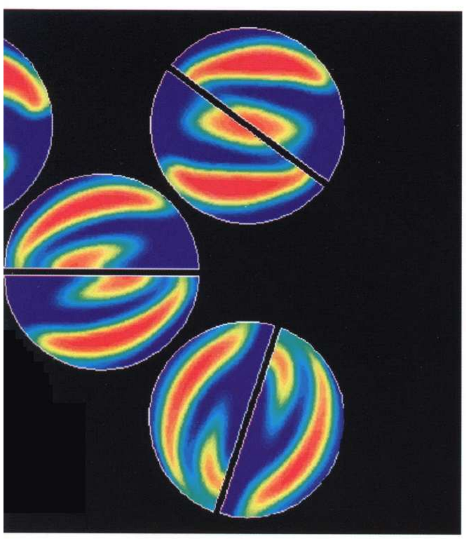


Figure 5 (above). Particle streaklines in the wake of the tab.

W. J. Gretta, in his master's thesis, "An Experimental Study of the Fluid Mixing Effects and Flow Structure due to a Surface Mounted Passive Vortex Generating Device," investigated the flow pattern as generated by the tabs using a combination of hot wire anemometry, hydrogen bubble visualization, and dye visualization.[1] Figure 6 shows the flow pattern according to Gretta. He discovered that the tabs not only generate a pair of counterrotating, longitudinal vortices but shed hairpin vortices as well. The smaller hairpin vortices move downstream with the larger longitudinal vortices.

The generation of these hairpin vortices is a transient process. Since the current model does not take time-dependent effects into account, these vortices could not be modeled explicitly. However,



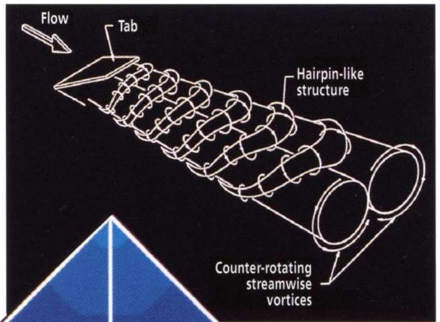



Figure 6 (right). The flow field behind the HEV tabs according to Gretta.

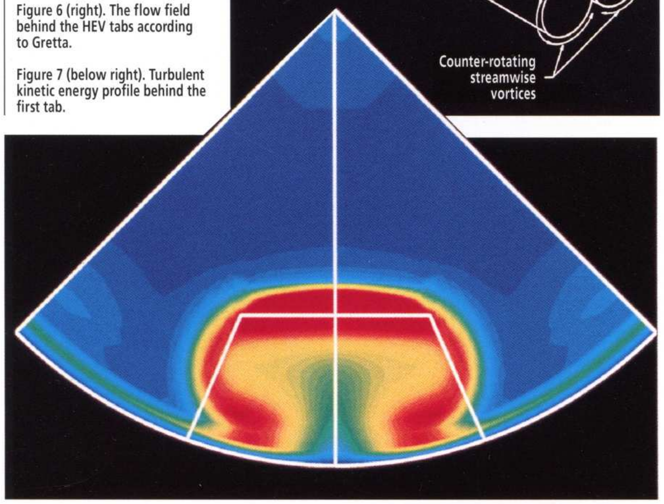


Figure 7 (below right). Turbulent kinetic energy profile behind the first tab.

Figure 8 (far right). Side view of the concentration field in the HEV mixer.

the hairpin vortices do show up in the CFM results as regions with a large turbulence intensity. Figure 7 shows the turbulent kinetic energy in a plane directly behind the first tab. Red denotes regions with a large turbulence intensity. This plot shows that there is a region with a large turbulence intensity surrounding the vortex, where the hairpin vortex would otherwise be found. The hairpin vortex is generated in the high shear region at the edge of the tab. In the steady-state model used here, high shear increases the production of turbulent kinetic energy.

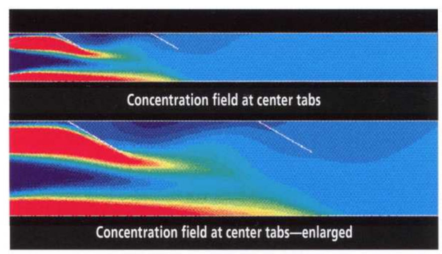
The mixing of a tracer fluid was studied to determine the HEV mixer's efficiency. The tracer fluid was injected at two positions—the center of the tube and a point in front of a tab. The total concentration of tracer fluid in the tube was 1.25 percent of the total fluid volume. Figure 8 shows the concentration field in a plane through the center of the tabs. Red denotes regions with large concentrations of tracer fluid, and blue denotes low concentration regions. The injection in front of the tab bends off when it hits the tab and is blended almost immediately in the turbulent wake of the tab. The injection in the center persists almost undisturbed until halfway between the two tabs. There, the turbulence intensity generated by the vortex is large enough to blend the material in the center. These results indicate that it is not just the longitudinal vortex which controls the blending; the hairpin vortex and random turbulence contribute significantly to the mixing.

The state of the art in CFM allows for the modeling of flows and mixing of chemical species in complex geometries such as those of static mixers. Computer simulations, though time-intensive are much faster than extensive experimentation when engineers are trying to optimize the geometry of the mixing elements for a variety of operating conditions, fluid viscosities, and equipment size.

Grid independence for the flow pattern is achieved with fewer grid nodes than for the results of the species mixing. The large-memory capability and fast processing speed of the CRAY C90 system made the 400,000-node problems possible.

With the KM helical elements, mixing occurs through a combination of flow splitting and shearing at the junctions of successive elements and a stretching and folding mechanism within the elements. The concentration field looks like it is flipped inside out after two elements: material originally at the wall is in the core, and vice versa. This makes the KM element an excellent radial mixing device, applicable in a variety of laminar mixing applications.

The HEV mixers generate a complicated vortex system, consisting of transient hairpin vortices and steady longitudinal vortices. The model correctly predicted the longitudinal vortices. The transient hairpin vortices showed up as regions of high turbulent kinetic energy. Future work will concentrate on more grid dependency studies and on comparing various alternative geometries.




### *Reference*

1. Gretta, W. J., *"An Experimental Study of the Fluid Mixing Effects and Flow Structure due to a Surface Mounted Passive Vortex Generating Device,"* master's thesis, Lehigh University, Bethlehem, Pennsylvania, 1990.

### *About the authors*

*André Bakker is principal research engineer at Chemineer, Inc. in Dayton, Ohio. He is specialized in modeling mixing problems using CFD. He holds both an engineering degree and a Ph.D. degree in applied physics from the Delft University of Technology in the Netherlands.*

*Richard LaRoche is a senior chemical engineer in the Engineering Applications Group at Cray Research, Inc., where he focuses on the application of CFD to process industry problems. He received his B.S. degree in chemical engineering from Montana State University and his M.S. and Ph.D. degrees in chemical engineering from the University of Illinois at Urbana-Champaign. He has previously held positions at Dow Chemical and Penn State University.*