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A NEW SPIN ON REACTOR DESIGN

Refined rotor-stator system has the potential to boost chemical process intensification efforts

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The process intensification movement afoot in manufacturing industries has the goal of generating products in a more concise environment that is safer, cleaner, and less expensive. In chemical production, this means reducing the footprint of chemical plants while increasing the efficiency of converting reactants into products. One focal point is the design of new types of continuous reactors to replace less efficient stirred-tank batch reactors, the longtime workhorses of the chemical industry.

One such reactor is the Spinning Tube-in-Tube (STT) system being developed by Camarillo, Calif.-based Holl Technologies. Designed by mechanical engineer and company founder Richard A. Holl, the STT reactor has taken the Couette reactor principle--in which one cylinder (a rotor) turns inside a second cylinder (a stator)--to the next level by incorporating modifications that make production-scale reaction chemistry possible, according to Stanley A. Sojka, Holl Technologies senior vice president and chief operating officer.

"STT is a diffusional chemical reaction system developed to close the gap between lagging engineering research in reactor design and the growing pressure for cleaner and more efficient chemical processing," Sojka said. The STT design and an overview of its initial performance in pilot-scale tests were presented by Sojka during a talk in late June at the 6th Annual Green Chemistry & Engineering Conference in Washington, D.C.

Rotor-stators have an annular gap of about 5 mm or more between the outside wall of the rotor and the inside wall of the stator. While the rotor is rapidly spinning, liquids, solids, or gases enter the annular space where they encounter shear forces that can create mixtures, pastes, slurries, or emulsions, depending on the machine's design.

Conventional rotor-stators are widely used to incorporate additives in

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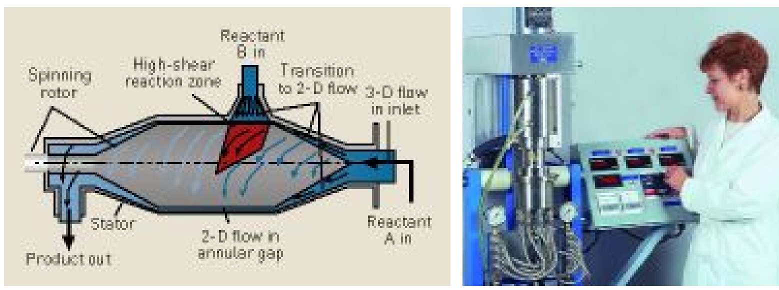
food processing; for the production of paints, inks, and coatings; in the deagglomeration of solids for the production of pharmaceuticals, foods, and composite materials; and in premixing chemicals for further reaction. However, little has been known about the potential of rotor-stator devices to carry out complete reaction chemistry. Other continuous reactors being used in process intensification efforts are integrated reactor-heat exchangers (HEX reactors), spinning-disk reactors, and chip-based microreactors (C&EN, March 4, page 36).

Key to the STT reactor's design is being able to precisely control the fluid dynamics of the reaction stream to achieve nearly instantaneous and complete molecular-scale mixing of the reactants, Sojka explained. This is accomplished in part by reducing the annular gap to a width between 0.25 and 1.5 mm, significantly less than in conventional rotor-stators. The smaller gap effectively reduces a three-dimensional volume-based flow to a two-dimensional area-based flow, he said.



GOING FOR A SPIN **Holl Technologies' Spinning Tube-in-Tube (rotor-stator) reactor generates a high-shear zone where reactants achieve molecular-scale mixing, allowing reactions to occur nearly instantaneously. The heat-exchange unit (not shown in schematic) lines the outside wall of the stator. A 400-lb-per-week pilot-scale unit is shown at right.** HOLL TECHNOLOGIES PHOTO

AS THE ROTOR SPINS at several thousand rpm, 2-D reactant films can be sheared against each other in the annular space to create a centimeters-long zone where uniform molecular-scale diffusion occurs, allowing rapid mass transfer and essentially quantitative formation of product. The ability to control the high shear rate under laminar conditions and thus the degree of mixing depends on the fixed annular gap, the rotor velocity, and the viscosity of the reactants. Outside this optimal level, turbulent flow with so-called Taylor vortices occurs, Sojka noted, which provides insufficient mixing for reactions to take place.

The reactors are made from stainless steel or corrosion-resistant Hastelloy and can operate at temperatures up to 300 °C and pressures up to 400 atm, Sojka said. Reactor sizes vary from desktop-sized units with pounds-per-day capacity to units that are about 15 feet long and can process more than 1 ton of product per hour. Since the annular gap size and shear rate can be scaled linearly, he added, there is no need for standard scale-up operations for the larger reactors, which can provide great savings in time and cost.

Most chemistry conducted on an industrial scale that requires high reaction rates and tight thermal control can be carried out in an STT reactor, Sojka noted, as can the types of processing carried out by conventional rotor-stators. The unique mixing regime means that many reactions can be run without a solvent or a catalyst, he said.

The reactor is designed as a module that can be used in series with other reactors for multiple-step processes and in a parallel array for high-volume production. Individual modules can be taken off-line and bypassed for maintenance or repairs without having to shut down operations.

The bane of engineers is dealing with rotating equipment, Sojka added, which generally results in high maintenance costs for bearings and mechanical seals. The STT reactor compensates for that, he said, by using specially designed bearing systems, canned motors, and magnetic drives. Another concern in reactor design is dissipating the high heat generated by rapid exothermic reactions. A proprietary heat-transfer system was designed for the STT reactor that allows control of the temperature to within 1 °C during operation.

Asked to comment on the new reactor, Andrew Green, technical director of BHRSolutions, Cranfield, England, a business that provides process intensification equipment and services for the chemical industry, says the reactor looks promising for intensification of very fast reactions. It appears to provide sufficient residence time for the reactants in the reaction zone, he noted, and seriously addresses the important issue of removing heat. "The machinery design has been given a lot of thought," Green adds.

HOLL TECHNOLOGIES is in the initial stages of licensing STT reactors and has five clients involved in pilot tests. Four of the clients are operating through a cooperative agreement with R. C. Costello & Assoc., Redondo Beach, Calif., an engineering firm that specializes in process intensification.

One of Costello's clients is Akzo Nobel, which is testing a 400-lb-per-week STT reactor to make a new wood-treatment chemical. Initial runs earlier this month to produce the chemical at a company site in Axis, Ala., went very well, although all the data have not been thoroughly analyzed, according to John R. Blunk, an Akzo Nobel technical manager.

"We were pleasantly surprised that what we theoretically predicted matched the performance of the reactor," Blunk says. "Molecules aren't going to react unless they can get close together. And one thing we can say about the Holl reactor is that you probably can't get a better degree of mixing."

Blunk acknowledges that starting up a new process gave Akzo Nobel engineers the flexibility to try the new reactor, but he thinks that implementing something new like the STT reactor for broad use will take time. "Chemical engineers are comfortable with stirred pots, so in trying to change that you are running up against tradition," Blunk said. "But once the reactor generates some success and reputation, it should help advance process intensification efforts."

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