Mixing Moves Osmosis Technology Forward

U.S. soldiers get drinking water via the first forward-osmosis membrane, made possible by high-shear mixing

By Doug Cohen, Charles Ross & Son Co.

CAPT. DAVE EATON COMMANDED A SIX-MAN Air Force unit during the recent invasion of Iraq. A few weeks after the invasion was launched, his unit took part in a joint operation with Army Rangers to capture an airfield in western Iraq. The operation was successful, and when the Rangers departed, Eaton's Air Force team stayed behind to secure the desert airfield and wait for more supplies.

When the supply plane failed to appear, the team realized it would not be receiving a delivery any time soon. The soldiers would have to hold the airfield and fend for themselves. Among other challenges and threats, Eaton knew his men would soon face a critical shortage of drinking water in the blistering desert heat. His solution was to supplement the small amount of water they had with their own urine.

He explained the plan to his team. "The guys looked at me sideways," Eaton says. They didn't know that he had brought along a new filtration device developed by Hydration Technologies (HTI), Albany, Ore.

The soldiers urinated into a common container into which Eaton tossed a sealed plastic sack that resembles a medical IV bag. As the soldiers watched, the bag spontaneously filled as water migrated through the walls — leaving impurities and poisons behind. They repeated this process for two weeks and held the airfield until follow-on forces arrived. The HTI filter was crucial to the unit's survival, Eaton says. "And [the water] tasted great!"

Figure 1. A soldier puts an HTI X-Pack filter into a puddle. The membrane bag will fill with clean water via forward osmosis.

Membrane makes it possible

Many filtration and purification technologies are available today, but virtually all of them suffer from a familiar set of disadvantages. Most require energy and mechanical parts to force liquid through a filter — and energy is often in short supply during a crisis. Many such systems are complex and demand special training. Others require components that are delicate, not designed for rugged use, or too heavy to be considered portable.

Virtually all mechanical filters capture impurities and eventually clog. Ultrafine filters — those that are designed to reject pathogens and extremely small impurities — clog quickly when filtering turbid water.

One alternative to mechanical filtration is chemical purification. But chemical treatments require precise dosages and exposure times, and can leave an unpleasant taste. They are also ineffective against threats such as chemical poisons, heavy metals and even some microorganisms. Another critical disadvantage is that many chemical treatments are ineffective at purifying water that is extremely cloudy or turbid.

The one filtration concept that is free of all of these disadvantages is forward osmosis (FO). (See sidebar: "Forward Osmosis: How it Works.")

"The forward-osmosis concept has been around for years," says Robert Salter, CEO of HTI. "In theory, it looked like the perfect alternative to energy-reliant technologies — mainly because it is so simple."

In Hydration Technology's FO filtration system, water diffuses into the bag when a generic sport-drink powder is in contact with the inner, clean side of the membrane. The process is spontaneous. It requires no energy, no moving parts and no special expertise. It won't clog in even the most turbid water (up to 1,000 Nephelometric Turbidity Units), because dirty water is not being driven by hydraulic pressure into the filter material. Instead, clean water is bein *drawn through* the filter osmotically (Figure 1).

Keith Lampi, cofounder and COO for HTI, says, “The FO concept was elegant, but the key to making an FO filter work was the membrane. FO filtration was a terrific idea, but it just wasn’t practical until we discovered how to create a hydrophilic membrane that works efficiently. With previous membrane materials developed by our researchers and many others, water diffused too slowly into the bag.”

Lampi adds, “Another critical issue is the consistency of the membrane and the size of the pores that reject impurities. Filtering out dirt particles and other large impurities is easy. Our goal was to develop a membrane that would reliably reject the impurities that present the most serious threats, including bacteria, viruses and common microorganisms.”

Triple-shaft mixer to the rescue

After a long development period, the HTI team was close to success, but needed a mixer that could create the membrane material and meet consistency and cost-efficiency goals. The multistep process first requires aggressive cellulose grinding, followed by continued dispersion and dissolution as numerous other ingredients are added to a casting solution.

“We knew that a single-shaft mixer — even one equipped with multiple disperser blades — could not handle the job. So, my first impulse was to test a dual-shaft mixer,” says Steve Peterson, P.E., and senior project engineer for HTI. “In my experience, I have found that dual-shaft mixers are generally fast, versatile and cost-efficient.”

But in this case, tests using a conventional dual-shaft mixer in an open vessel produced unsatisfactory results. The process took six hours to produce an inadequate final dispersion. Looking for an alternative, the HTI engineering team scheduled a test at the Ross Test & Development Center in Hauppauge, N.Y.

After shipping raw materials to the lab, the HTI team simulated their process on a Ross VersaMix, a triple-shaft mixer that combines a slow-speed anchor agitator with a high-speed disperser and a rotor/stator high-shear mixer.

FORWARD OSMOSIS: HOW IT WORKS

When dirty or contaminated water contacts one side of HTI's semipermeable membrane while a concentrated sports-drink powder or syrup contacts the other side, clean water immediately begins to migrate through the membrane. This is forward osmosis (FO) at work (Figure 2). Acting as a molecular sieve, the HTI membrane allows water to pass into the interior of the bag, while rejecting a variety of organic and inorganic impurities.

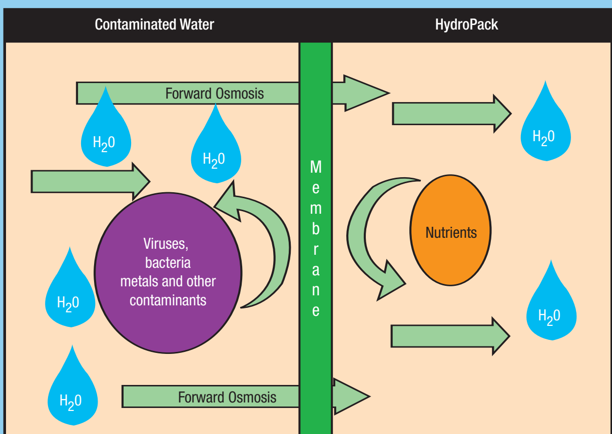

Figure 2. Forward osmosis allows clean water to pass through the membrane, while viruses, bacteria and other contaminants are left out.

The HTI membrane is a rugged composite. An ultrathin (10 μ) FO layer is sandwiched with a microfilter and a fabric backing, which provides strength. With pores measuring 5 Å (0.0005 μ) in diameter, the FO layer successfully filters *E. coli* bacteria, anthrax spores, viruses, heavy metals, suspended particles and other health threats.

Forward osmosis is normally a very slow process since it is not driven by hydraulic pressure. The HTI membrane allows water to pass at a much higher rate (as high as 1 L/hr in some of the personal hydration systems) because the FO layer is so thin. Also, since it is made from cotton-derived, cellulose-ester plastics, the FO layer is extremely hydrophilic. This allows water to pass through easily, accelerating the filtration process.

Hydration Technologies' X-Pack (Figure 3) is the first FO filter to be commercialized. The success of the membrane is due to the combination of ultra-small and highly consistent porosity with a high pass-through rate.

Figure 3. Water spontaneously diffuses into HTI's X-Pack when a generic sport-drink powder is in contact with the inner, clean side of the membrane. It requires no energy and no moving parts.

The rotor/stator agitator on the triple-shaft mixer creates more intense shear than that created by a dual-shaft mixer. It also provides more versatility. Each agitator is independently controlled, and each offers a range of capabilities that complements the other two agitators, which significantly extends the overall range of the mixer. (See sidebar: "Triple-Shaft Mixer Anatomy.")

Ross' triple-shaft mixer is a closed-batch system; most applications include vacuum and thermal control with hot oil, water or steam circulating in a jacket surrounding the mix vessel. The vacuum proved unnecessary for HTI's application, but thermal control was important because the cellulose acetate polymer is heat-sensitive. When it overheats, it melts and forms a smeary plastic. Since the system is closed, very little solvent was lost due to evaporation during the mixing cycle.

Success tastes great

The triple-shaft mixer quickly breaks down the cellulose acetate polymer and disperses it into the casting solution, along with the other ingredients.

The rotor/stator mixer is especially well-suited for the first phase of the HTI application. The process takes a long time in a dual-shaft mixer because polymer pellets bounce off the teeth of a high-speed disperser blade. The rotor/stator mixer, on the other hand, draws them into the high-shear zone and doesn't let them escape until they are broken apart. Meanwhile, the disperser and anchor agitators maintain energetic flow, which ensures a high degree of batch homogeneity.

Also vital to the HTI application, vigorous flow helps carry heat away from the high-shear zone and disperse it evenly throughout the vessel. This helps protect the heat-sensitive polymer while allowing for an increased shear rate.

The rotor/stator mixer can be fitted with a variety of stators, which provides a great deal of flexibility in matching the mixer configuration to the application (*CP*, April, p. 31).

"With a dual-shaft mixer, the initial phase produced 'gel balls' that resisted wetting out and dispersion," Peterson says. "But with the triple-shaft mixer — thanks to the intense shear that the rotor/stator mixer applies — the gel balls dissipate very quickly. At that point in the cycle, we turn off the high-shear mixer and proceed with only the high-speed disperser and the anchor agitator." The batch was complete in two hours, compared with the six-hour cycle that a dual-shaft mixer required.

Today, HTI operates with a 40-gal. VersaMix in full-scale production, while a 2-gal. model supports a vigorous R&D program. Anticipating the need for multiple process lines before long, the company plans to follow up its success on the battlefield with applications in other industries, including homeland security, international relief and development, and the maritime industries. **CP**

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TRIPLE-SHAFT MIXER ANATOMY

The Ross VersaMix is a triple-shaft mixer that includes a slow-speed anchor agitator and two high-speed devices: a rotor/stator high-shear mixer and a high-speed disperser (Figure 4). The anchor sweeps the vessel wall and bottom, constantly removing material that would otherwise impede heat transfer. As it turns, it also stimulates radial and axial mass flow to promote thorough batch turnover.

Figure 4. This unit combines a three-wing anchor with scraper, a two-blade, high-speed disperser, and a rotor/stator high-shear mixer. It also features a dished cover with angled ports for adding solvent.

The rotor/stator high-shear mixer applies intense shear and generates moderate flow. The high-speed disperser, shown here with a sawtooth blade, applies moderate shear and generates substantially greater flow. All three agitators are independently controlled with electronic variable-speed drives and monitored with instrumentation.

For demanding applications, the triple-shaft mixer offers a broad range of capabilities. This includes the ability to apply extremely intense shear with the rotor/stator mixer, while maintaining vigorous flow with the other two agitators.

With independent controls, the two high-speed agitators are often used selectively during a series of mixing phases. This allows the operator to choose the right combination of agitators and tip speeds for each phase, depending on key process variables, such as shear requirements, heat thresholds and batch viscosity.