Increasing Flow Rates in Water Purification Systems

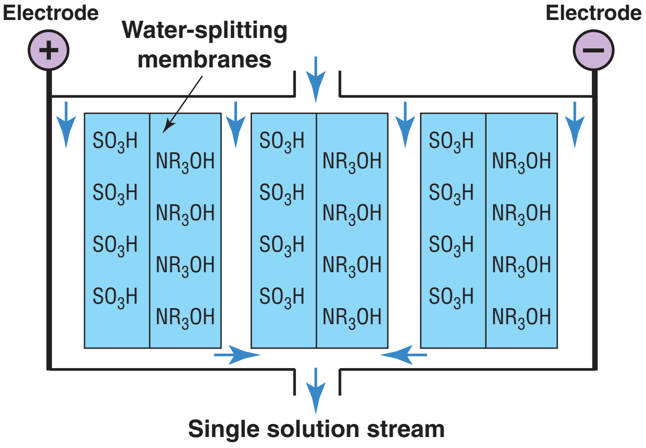
By Eric Nyberg

Providing satisfactory flow rates is a key challenge for residential water purification systems that reduce total dissolved solids (TDS). Drinking water use is particularly great in the mornings and evenings and users can quickly empty their point of use (POU) tank and still need more water. At pressures less than three bar (45 psi), which is the large majority of the world, refilling the tank will take several hours with conventional POU system's 'real-time' flow rates (the rate at which the water treatment devices produce water). A new purification technology tackles flow problems at the source by providing real-time flow rates which are 10 times greater than those of traditional TDS reduction systems. This greatly reduces consumer reliance on booster pumps and large storage tanks, in many cases allowing the elimination of the storage tank.

A manufacturer has developed a new drinking water system which delivers water at much greater flow rates using its proprietary technology. The first applicable patent, "Electrochemically Assisted Ion Exchange," was granted in 1998 (USP 5,788,826) and describes novel devices for removing ions from solution. These devices are simple: they comprise cells that include replaceable cartridges built with a special type of ion exchange membrane called a 'water-splitting membrane.' The first product drinking water system includes two cells, sediment and carbon prefilters, a flow sensor and a trademarked adjustable module to provide a continuous supply of water in a home or small business.

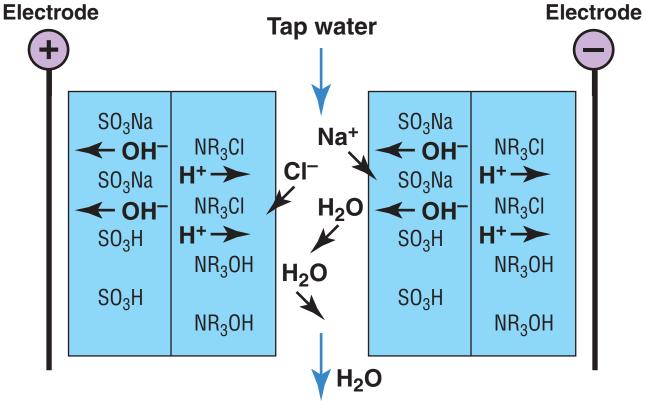
Figure 1 illustrates the basic device. Feed water enters the inlet at the top of the figure, flows between the water-splitting membranes and exits at the outlet at the bottom of the figure. As seen here, water-splitting membranes comprise two layers: cation exchange material (e.g. strong acid, P-SO_3H) secured to an anion exchange material (e.g. quaternary ammonium, P-NR_3OH). Water-splitting membranes are well known and are used for the production of acid and base chemicals from simple salts in industrial processes. These water-splitting membranes were developed by the company specifically for use in their devices.

Figure 1. Deionization apparatus



The deionization step for removing sodium chloride from the solution is shown in Figure 2. This is the classic ion exchange process in which the cation and anion exchange materials are in the acid and base forms, respectively, at the outset. In this process, however, a voltage is applied during the deionization step to accelerate ion removal (ions move faster in the electric field), allowing an increase in flow rates.

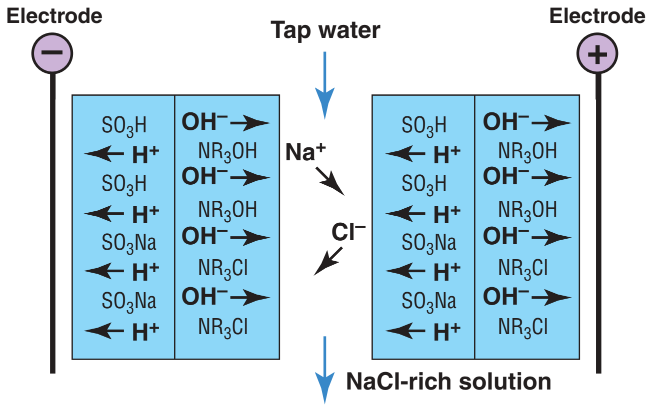
Figure 2. Deionization process



When the system's capacity for ions is exhausted, a second step, regeneration, is required (Figure 3). This step is initiated by reversing the voltage polarity, and preferably also the flow direction. At the boundary between the cation and anion exchange layers, water splits into its component ions acid (H^+) and hydroxide (OH^-), which migrate through the ion exchange layers toward the electrode having opposite polarity. Hydrogen ion (H^+) replaces sodium in the cation exchange layer and hydroxide ion (OH^-) replaces chloride in the anion exchange layer. Sodium chloride 'waste' is concentrated in the solution exiting the device and the water-splitting membranes are returned to the condition necessary for another deionization cycle.

This new technology is often confused with electrodeionization (EDI), an interesting method for producing ultrapure water. The EDI device is constructed with alternating cation and anion exchange membrane layers to form product and waste channels, rather than employing water-splitting membranes. EDI is a continuous, electrodialysis process comprising ion exchange beads in the product water chambers, in sharp contrast to the new batch ion exchange process. EDI systems are plate-and-frame systems which do not comprise replaceable cartridges and the feed water for EDI must be substantially pretreated (virtually free of hard ions and of low TDS).

Figure 3. Regeneration process



Benefits of the technology

Drinking water typically comprises only 0.1 percent contaminants and 99.9 percent pure water. The new system extracts the bulk of these contaminants while the 99.9 percent of water passes between the ion exchange membranes. Three characteristics of this new technology stand out for POU drinking water applications in the developing world. First, the cartridges exhibit a low pressure drop, only one bar (15 psi) at two liters/minute. Second, as water pressure decreases, thereby decreasing flow rates, TDS reduction improves. Third, as feed water TDS is reduced, water recovery increases.

In contrast, crossflow membrane processes such as reverse osmosis (RO) operate in a fundamentally different manner. The RO membrane process reduces TDS by squeezing water through tiny holes in a semi-permeable membrane to produce 'permeate'—a time consuming process. As a result, decreasing water pressure provides poorer TDS reduction and water recovery and reduces real-time flow rates to the point of requiring booster pumps.

Real-time flow rates and tanks

POU drinking water system users worldwide desire faucet flow rates of at least one liter (L)/minute, and more often two L/minute. When the real-time flow rate of a system is too low, storage tanks are required to collect the water and deliver it at the desired rate. Figure 4 shows real-time flow rates versus pressure for the new unit and a typical reverse osmosis POU system. For an eight-liter storage tank (two gallons), a flow rate of 0.25 L/minute will refill the tank in 32 minutes. The system provides this flow rate at only 0.3 bar (a roof-top tank), while a reverse osmosis system requires approximately five bar to achieve this real-time rate. At 1.5 bar, the system would provide one L/minute, enough for some users to consider eliminating the tank altogether.

Reduced pressure improves TDS reduction

Ion exchange processes such as the new system provide better TDS reduction as water pressure decreases. Low pressures reduce flow rates, thereby increasing the time for the water-splitting membrane to extract contaminants. This is a silver lining for people who must live with low water pressure. Figure 5 shows the effect of flow rate on TDS reduction for the drinking water system treating four liters of 800 ppm water. Crossflow membrane processes exhibit the opposite effect: at low pressure, less water permeates the tiny membrane holes while the rate of contaminant passage stays relatively constant. The result is that as water pressure decreases, crossflow membrane processes provide poorer TDS reduction.

Figure 5. Effect of real-time flow rate on TDS reduction

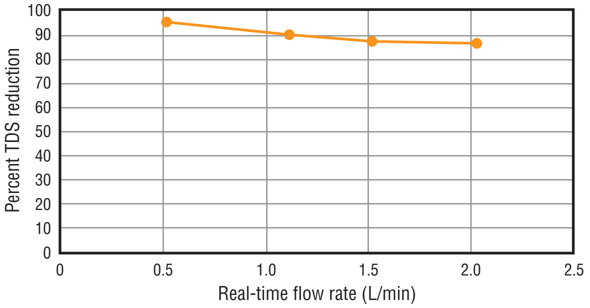
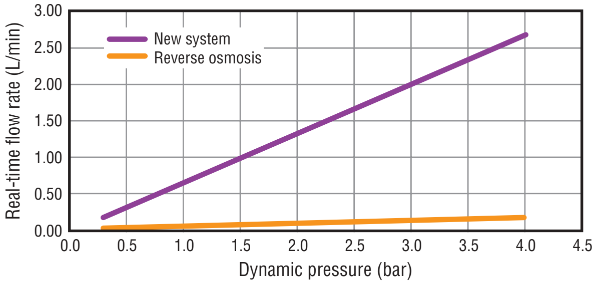


Figure 4. Effect of pressure on real-time flow rate



Excellent water recovery

The new drinking water system does consume some water during regeneration, but the volume is small. Furthermore, water recovery improves when operating on feed waters with lower TDS (Figure 6). As feed water TDS decreases, the volume of water which can be treated by the system before requiring regeneration increases because the ion exchange membrane has a fixed capacity. Since the waste volume per cycle is a constant 1.5 liters, the water wasted per cycle decreases as shown in Figure 6 (for two L/minute real-time flow rate, 85 percent reduction). Under ideal conditions, reverse osmosis systems waste four liters for each liter produced (20 percent recovery); and in actual use waste closer to 10 liters per liter produced (10 percent recovery). This wasted water is a significant and growing operating cost—approximately $30 per year at today's U.S. water rates.

Selectable taste

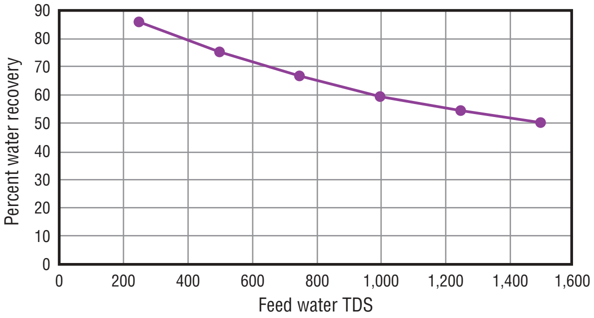
The new system offers another

unique benefit: taste control. This provides the consumer with a choice in water taste, offering similar variety to that found in bottled water. The adjustable control increases or decreases the electrical power used during the deionization step. Other TDS reduction technologies strive for maximum TDS reduction, but the key to taste is not the degree of TDS reduction, but the final TDS *concentration*. The taste feature allows the consumer to select a preferred taste with a turn of the dial. Human preferences in water flavor range from 20 ppm to 300 ppm, depending on our upbringing and individual taste. Additionally, the best TDS level for drinking water is not what one would choose for making coffee, orange juice or preparing dinner. For example, it is generally accepted that the best coffee taste is obtained with 150 ppm TDS.

Table 1: Selectivity for nitrate, nitrite and perchlorate ion extraction

Contaminant	Influent (ppm)	Reduction (percent)
TDS	430	88%
Nitrate	27	93%
Nitrite	3.1	95%
Perchlorate	0.120	96%

Figure 6. Water wasted for RO and new system products vs. feed water TDS



Selective removal of important contaminants

The primary benefit of ion exchange materials is that they exhibit selectivity for many contaminant ions. As an illustration, Table 1 shows the percent reduction for TDS, nitrate, nitrite and perchlorate ions using the new POU system at 2 L/minute. Specific ion reductions which are greater than for TDS reduction indicate selectivity for those species.

Conclusion

New technology provides several important benefits to the huge number of people living with low water pressures—people who often have the greatest need for drinking water equipment. These drinking water systems provide excellent real-time water production rates to rapidly refill small storage tanks, or eliminate them altogether and without booster pumps. Water recovery and TDS reduction are good under all conditions and significantly improve with decreasing pressure or feed water TDS. The adjustable taste control allows for personal taste adjustment and the ion exchange membranes provide selectivity for important contaminants.

About the company

Pionetics was founded in 1995 to develop and commercialize EAIE technology, branded as LINX® technology, a TDS reduction technology patented in 1998 based upon the fundamentals of electrically regenerated ion exchange. The company's first implementation of technology is the LINX 120 Drinking Water System for POU applications. For additional information, contact Pionetics at (650) 551-0250; Information@pionetics.com or online at www.pionetics.com