Forward Osmosis

By Robert J. Salter

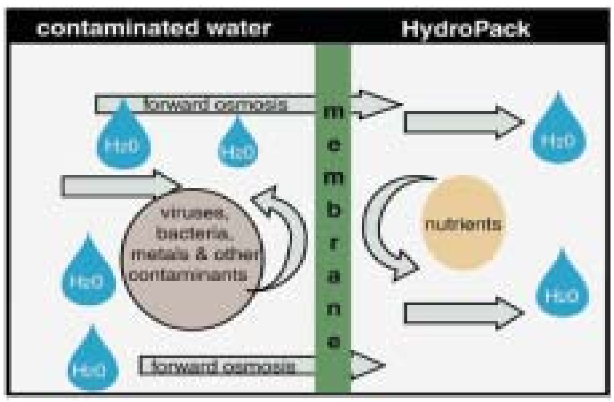
While reverse osmosis (RO) is a standard water industry purification treatment, forward osmosis (FO) is being utilized in creative ways by other market sectors.

Osmosis is the process that occurs when two different solutions contact opposite sides of a semi-permeable membrane. Everyone knows that two water-based solutions mix when they are brought into contact with no barrier between them. Even if no stirring occurs, the two solutions slowly blend due to diffusion. If a semi-permeable membrane is placed between the solutions, the tendency of the solutions to mix remains; however, the only molecule that can move through the membrane is water. Water molecules will therefore move from one solution to another to achieve maximum mixing (see Figure 1).

If apple juice and water are brought into contact, the natural tendency is for the two to mix to create dilute apple juice. If a semi-permeable membrane is placed between the water and juice, the solutions still experience the tendency to mix; however, since the juice sugars and flavors cannot pass through the membrane, the solutions mix themselves by passing all the water from the water side of the membrane into the juice. This diffusion-driven motion of water through a membrane is termed osmosis.

Thermodynamically, the strength of this mixing tendency is measured by the solution's osmotic potential or osmotic pressure. The osmotic potential is high for concentrated solutions and low for dilute solutions and is roughly proportional to the molar concentration of dissolved species. When a semi-permeable membrane separates two solutions, water always moves from the solution with the lower osmotic potential to the solution with the higher osmotic potential. Also, the greater the difference in osmotic potential, the faster water moves through the membrane.

Figure 1. Forward osmosis



It is important to note that the osmotic potential depends on the molar concentration, not the weight of dissolved species. Molar concentration is a measure of the number of molecules dissolved, not the weight of material in solution. This means 100-g/liter solution of a small molecule like table salt has a far higher osmotic potential than 100-g/liter solution of a large molecule like starch.

Table 1. Osmotic pressure fo aqueous solutions

Compound	Osmotic pressure psi (kPa)
Sea water, 3.5 percent	400 (2,800)
Fructose, 15 percent	400 (2,800)
Fructose, 6 percent	130 (900)
Human blood (normal person)	100 (700)
Sucrose, 6 percent	80 (540)
Muddy, brackish water, 1,600 TDS	20 (140)

Osmotic pressure is the pressure that must be applied to a solution to prevent a net transfer of water into the solution across a semi-permeable membrane. Table 1 shows the osmotic pressure for some compounds.

Mathematically, the rate of water crossing the membrane (Q) is roughly proportional to the membrane area (A) times the difference in the concentrations of dissolved species on the two sides of the membrane (Cn and Cw), where Cn and Cw represent the dissolved concentration in the nutrient drink and contaminated water, respectively. A mass-transfer coefficient, which is actually only a proportionality constant (K), is used to create an equation. This constant is a fairly strong function of temperature, increasing about two percent for each degree Celsius. Commonly, the constant is measured at 20°C (68°F), leading to the equivalent equations shown in Figure 2.

Figure 2.

$$Q = K_{@20°C} * 1.02^{(T-20°C)} * A * (C_N - C_W) \quad [1] \text{ or}$$

$$Q = K_{@20°C\,(=68°F)} * 1.011^{(T-68°F)} * A * (C_N - C_W)$$

The mass-transfer coefficient represents the resistances that the water encounters as it moves from the contaminated water into the membrane, then across the membrane's rejection layer and finally into the nutrient drink. The coefficient will increase if the solutions are pumped across the surface of the membrane.

A new membrane

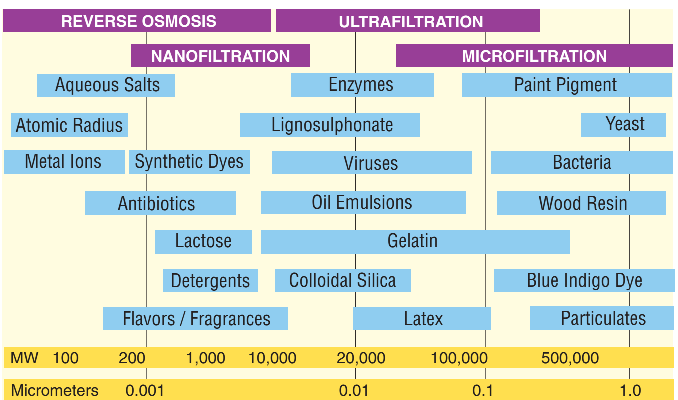
A manmade version of naturally occurring membranes has been developed by casting thin sheets of a water-absorbent cellulose-based plastic. Several characteristics have been optimized to produce superior performance (see Figure 3).

• *Selectivity*. With a nominal pore size of three to five angstroms, the new forward osmosis membrane is highly selective. The size of bacteria range from 2,000 to over 500,000 Å. The smallest viruses are 50 to 1,000 Å. To put this in perspective, if this new membrane's pore is compared to the size of a dime, then a bacteria would be larger than a two-car garage.

• *Composition*. Made from cotton-derived, cellulose-ester plastics, these FO membranes have the advantage of being extremely water absorbent, which allows water to easily diffuse through them. Common RO membranes that have the same selectivity are far more water repellent.

• *Structure*. Since osmosis is a diffusion-based process, water transfer rates through the membrane tend to be slow. An important method for improving water transfer rates is to make the selective part of the membrane as thin as possible. Diffusion through a microfiltration (MF) membrane is much faster than that through an FO membrane, which produces membranes with a very thin (10 micron) FO membrane on top of an MF membrane. Mechanical strength is provided by embedding the MF membrane in a fabric backing.

Figure 3. Filtration ranges



Osmosis versus chemicals

Chemical treatment of contaminated water with chlorine or iodine is a common and very cheap method of making potable water. Its wide use, however, is not always appropriate. Few people realize that chlorine and iodine are often ineffective if the water being treated is cloudy or muddy, nor do they realize that many harmful microorganisms are not readily killed by chemicals. In addition, chemical treatment alone does not remove mud from the water and leaves an unpleasant taste.

Microbiological testing of the membrane

Osmotic filters produce a clarified, microbiologically safe, pleasant-tasting nutrient drink. The following table and description summarize some of the testing of these filters.

The products are placed in a water suspension of *Klebsiella* and *E.coli* for up to 24 hours. At the end of the testing, the number of bacteria colony forming units surrounding the product was 400,000,000 *Klebsiella* (coliform) and 900,000,000 *E.coli* per 100 ml, but no detected bacteria in the nutrient drink.

Independent lab tests indicated no detectable passage of biological pathogens. In fact, even viral DNA fragments will not pass through. The 0.4- to 1.0-micron pigment ink is the same size as common parasites. No passage was detected. *E. coli* is a bacteria strain. Even with 100 million per milliliter, none were detected in the drink. The M 13 and MS2 bacteriophages are viruses that infect bacteria. No viruses were detected even with one billion per milliliter on the outside. DNA strands are from the M 13 phage. Besides viruses, bacteria and parasites, FO membranes offer substantial protection against hydrocarbons, pesticides and heavy metals.

Nutrient drink from osmotic filters

Osmotic filters are unlike other filters in that they produce a nutrient drink rather than simple water. This makes them inappropriate for producing cooking or hygiene water; however, the drinks produced are a superior source of water, calories and electrolytes for active people in areas where safe water is not available.

A wide range of nutrient formulations is available with special formulations including low sodium, severe dehydration and more. Customized mixes can be created and individual flavor additives are available from the manufacturer so that users can formulate their own drink mix with the addition of a sweetener.

Microbiological safety

The potability of the drink produced is ensured by three measures:

• The membrane used is designed to allow water to pass while blocking the transfer of sugars and salts. The smallest biological species virtually never permeate the membrane.

• Since it is impossible to maintain sterile conditions in the field and the filters contain a sugared nutrient drink, the manufacturer takes steps to inhibit microbiological growth in the filters. To stop the growth of bacteria such as *Klebsiella*, staph and *E.coli*, the pH of the drinks is kept as acidic as citrus juices. A mix of food-grade benzoate and sorbate preservatives are also added to inhibit the growth of yeasts and molds.

• An intermittent sanitation step is also advised for reusable elements, which is easily performed by soaking the device in either metabisulfite or bleach solutions.

Disposable bags

A two-liter membrane bag that has been pre-loaded with nutrient powder is intended to fill overnight. It is placed in any available water in the evening; in the morning it contains a drink that can be immediately consumed or carried in a canteen. Each bag produces up to 20 times its weight in drink and includes a protected drink spout. These bags are discarded after use.

Reusable bags

This is a filter bag inside a sealable pouch. During use, the filter bag is loaded with a nutrient powder and the pouch is filled with unsafe water. It is then carried in a backpack or pocket until the water in the outer pouch migrates into the filter bag. After use, additional nutrient powder can be added to the filter bag and the outer pouch can be refilled to enable reuse with available water.

Stationary application filters

Spiral osmotic filter tubes for use in stationary applications utilize a nutrient syrup which is fed continuously to a filter tube which is immersed in non-potable water. The tubes are available in a range of sizes to produce from half a liter to four liters per hour of drink. The elements are designed to produce 25-50 liters of drink for every liter of nutrient syrup. Figure 4a shows how the syrup flows through the spiral filter and Figure 4b shows how the syrup flows through the membrane envelope.

Figure4a. Hiker's backpack operation step 1

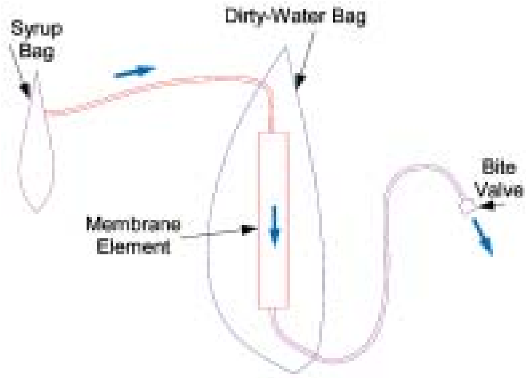


Figure4b. Hiker's backpack operation step 2

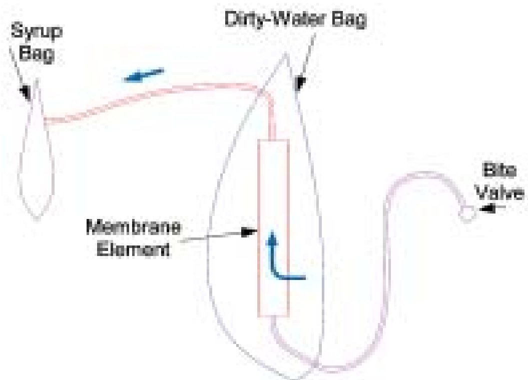
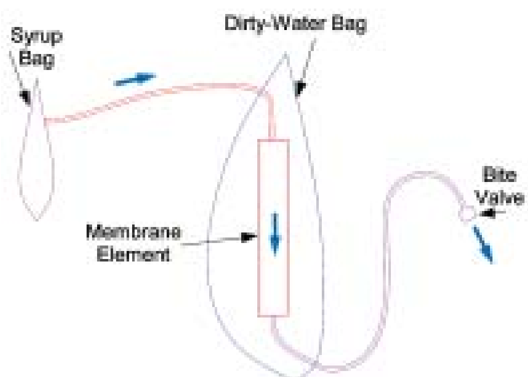


Figure4c. Hiker's backpack operation step 3



Hiker's backpack

This hydration backpack produces up to a liter per hour of dilute nutrient drink. Each has a three-liter dirty water bladder, a spiral osmotic filter tube, a nutrient reservoir (syrup bag) and a bite tube for drink delivery. The user fills the bladder with available water, connects the nutrient reservoir to the filter and can begin to drink immediately. The nutrient drink is made on demand. When loaded with water the backpack weighs 10 lbs. (4.5 kg) and a replaceable 700-g nutrient reservoir will produce approximately 15 liters of drink.

About the author

S *Robert J. Salter is President/Founder & Chairman of the Board of Hydration Technologies, Inc. (HTI). Prior to HTI, Salter founded Osmotek in 1987 to develop and commercialize innovative Direct Osmosis membrane technologies. He is the inventor and co-inventor of several company-held patents that have been granted in the U.S., Australia, Israel and Europe. Salter's management activities include patent, project and business development, contract negotiations, legal affairs and marketing. Salter received a BA in economics from City University of New York, Richmond College.*

About the company

S *Hydration Technologies Inc. (HTI) has developed a leading expertise in water filtration. With over fifteen years of research, the scientists at HTI have developed the world's first commercially viable forward osmosis membrane. This membrane has been used by NASA and the U.S. Department of Defense and is now available to the public. HTI is headquartered at 2484 Ferry St. SW, Albany, Ore. 97322-7801; telephone (541) 917-3335; fax (541) 917-3345 or visit www.hydrationtech.com*