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Survival at Sea

by Joseph Alper

Just before sunrise on Tuesday, April 28, 1789, the crew of Her Majesty's Ship *Bounty* did the unthinkable—they mutinied. The rebels, led by Master's Mate Fletcher Christian, seized Captain William Bligh and 18 loyal sailors, forced them into a 23-foot launch, and cast them adrift in the Pacific Ocean somewhere west of Tahiti. For sustenance, the men had 150 pounds of bread and 16 pieces of pork in their open boat. There were also 28 gallons of water, six quarts of run, and six bottles of wine: 118 liters of fluid that would have to last the 48-day, 3600-mile voyage the crew would make to Timor, a Dutch colony in the Indian Ocean. It was there that Bligh could arrange for transport back to England and justice.

With no map but the one in his memory, and only a quadrant and compass to keep him on course, the captain ordered his men to row due west toward the tiny island of Tofua. There, Bligh hoped to find food and water. A breeze enabled the crew to raise the launch's small sails, and the boat reached the island late that night. Bligh sent a band of men ashore the next morning, but they returned with only a few quarts of rainwater taken from depressions in rocks. Dinner that afternoon was a morsel of bread and some wine. Twenty coconuts gathered later that day were added to the boat's stores.

The next day, Bligh sent a group of men ashore to search for natives from whom he might obtain supplies. The search party found natives; but instead of getting food and water, the men were attacked. They ran for the boat while John Norton, the quarter-master, struggled to cast off the stern line. About 200 natives began pulling on the line; Norton was knocked to the ground and stoned to death. The crew cut the stern line and began rowing frantically as the islanders hurled huge stones at the launch. Under cover of darkness, Bligh and his men escaped.

Despite this setback, the captain was determined to bring his men safely to Timor. There might be other islands where the people would be less hostile, but Bligh knew that the food and water on board the boat would have to be rationed carefully if the crew were to have a chance of making it to those refuges. Each man agreed to live on “One Ounce of Bread per day and One Jill (118 mL, about one-half cup) of Water.” The stringent rations guaranteed that the crew would become quite hungry in the coming days, but starvation was the least of their worries. The body can go for up to two months without food *provided* there is enough fresh water to drink—and one jill a day was not nearly enough.

The amount of water the human body needs to survive depends on many factors. The body excretes water through the lungs (exhale onto a mirror, and you can see that each breath contains a small amount of water) as well as through urine, sweat, and feces. The total water loss can easily exceed 2.5 L per day under normal conditions.

Replenishing water lost by the body is imperative, for one of the most critical tasks the body undertakes every minute of every day is maintaining the volume of blood that circulates throughout the body. As the body loses water, the volume of blood decreases. With even the slightest drop, it becomes more difficult for the heart to pump blood—and the oxygen and nutrients it contains—to the brain and other parts of the body. “And if the volume drops below a critical value, you die. It’s that simple,” says Dr. Bernard Elser, professor of medicine at the University of Miami’s Jackson Memorial Medical Center Center in Florida. Dr. Elser has treated many castaways, mostly refugees who fled Cuba and Haiti in rickety boats and spent days, even weeks, adrift at sea while trying to reach the Florida coast.

Without any water at all, an average person can stay alive 12 days — if they aren’t sweating heavily. A half-liter of fresh water a day can double the survival time, and a liter a day will provide almost unlimited survival. Unless, of course, you are sweating in the hot sun all day.

An osmotic problem

“Water, water, everywhere, Nor any drop to drink,” lamented the Ancient Mariner. Samuel Coleridge’s mythical seaman knew quite well the irony that faces every sailor lost at sea without a supply of fresh water. Water is abundant, but salt water won’t suffice. In fact, drinking seawater hastens death, rather than postpones it. The reason is that salt water causes water to flow from cells into the blood stream by means of a process called *osmosis.*

The membranes surrounding cells are semipermeable, meaning they allow some particles to pass through but not others. If such a membrane separates two aqueous solutions, one with a higher concentration of particles (for example, salt) than the other, water will flow from the less concentrated solution to the more concentrated solution until the two solutions come to equilibrium (see Figure 1).

This flow of water is called osmosis, and *osmolarity* is a measure of the concentration of particles in a solution. Chemists typically measure the concentration of a single chemical in units of *molarity*; when the same measurement is applied to the mixture of chemicals that contributes to osmosis, it is called osmolarity. The osmolarity of blood is normally about 300 milliosmoles, or 300 millimoles of particles per liter of blood plasma.

The osmolarity within red blood cells is also 300 milliosmoles; so, too, is the osmolarity of nerve cells, muscle cells, and all the other cells in the body. In contrast, the osmolarity of seawater is about 1000 millimoles per liter, primarily because of the high concentration of sodium ions and chloride ions. Drinking seawater will therefore increase the osmolarity of blood, which will cause water to flow from all the other cells in the body into the bloodstream. True, this increases blood volume, but there are two reasons why this is not beneficial.

First, the cells of the body begin to shrink and malfunction. As a result, muscles become weak and ache, the heart beats irregularly, the mind wanders, and so on.

Worse still, the increase in blood volume is temporary. The body works to maintain not only constant blood volume, but also the concentration of sodium and chloride ions in the bloodstream. When the concentration of sodium and chloride ions is too high, the kidneys get rid of the excess by producing more urine...and excreting more water.

Luck and planning

The *Bounty's* mutineers passed many islands during the first few weeks of their voyage, but the unpleasant experience with the natives at Tofua led Bligh to continue without stopping. Hunger was constant, and the crew was regularly doused by torrential rains. At one point, the crew endured 15 straight days of storms. These downpours made for a miserable time, but saved lives, for the crew continually replenished their freshwater supply. On May 20th, for example, the crew caught and saved 20 gallons (76 liters) of rainwater.

A brief respite came late in the afternoon on Friday, May 29, when Bligh ordered the launch to land on a tiny island off Australia's northeast coast. The crew rested for three days, eating oyster stews and digging a well for water to refill the boat's kegs. Then, after reading prayers on Sunday, Bligh ordered the crew into the launch to begin the final leg of their journey.

Finally, on June 15, Bligh and his men reached their goal. Of the 19 men who had been forced from the *Bounty*, only one failed to make it to safety. Certainly, the 18 sailors were all suffering the effects of 48 days at sea, and one, botanist David Nelson, eventually died on Timor. But good luck and steady rainfall enabled them to survive.

Modern shipwrecks

Today, sailors lost at sea do not have to depend on rainfall to keep them supplied with fresh water. William and Simonne Butler didn't, and they survived for weeks in the Pacific Ocean in a six-foot raft with little more than a fishing hook, a piece of line, a knife, and an ingenious device for turning salt water into fresh water.

The Butlers had set sail from their Florida home on April 14, 1989, on what was supposed to be an around-the-world cruise. The trip was going smoothly when suddenly, on June 15, whales crashed into their yacht *Siboney*, and the vessel immediately began sinking. They inflated the life raft and frantically threw in any supplies they could find. When the yacht sank, the Butlers had nine cans of food, two cans of crackers, a half jar of peanut butter, and about 45 liters of water. Most important, they had managed to grab a device called the Survivor-35, a hand-operated pump that reverses the process of osmosis to literally force fresh water out of seawater.

Reverse osmosis

The heart of the pump, manufactured by Recovery Engineering (St. Louis Park, MN), is a semipermeable membrane made of three different synthetic polymers: polyester, polysulfone, and polyamide. The mesh-like polyester resembles the material in a nontear envelope and acts as a sturdy support for the other membranes. Layered on top of this is the permeable polysulfone, an exceptionally smooth material that serves as a base for a thin layer of polyamide. It is the polyamide layer that is semipermeable (see Figure 2).

Polyamides are a family of polymers that include all proteins and a host of synthetic materials, such as nylon and Kevlar, used to make bullet-proof vests. In this case, the polyamide contains carboxylic acid side chains that project out from the surface of the polymer, resembling tiny hairs growing from skin. The carboxylic acid groups (with formula COO^-) serve to repel any negatively charged ions, such as chloride (Cl^-), that might try to cross the membrane. As a result, no positive ions will pass either, because both an anion and a cation have to pass to maintain charge balance on both sides of the membrane. Thus, the membrane will allow water to pass, but not salts.

Normally, if fresh water and sea-water were on opposite sides of this membrane, osmosis would cause water to flow from the freshwater to the seawater side, in an attempt to reach equilibrium. However, it is possible to stop or even reverse osmosis by applying pressure to the seawater.

The osmotic pressure of seawater is about 27 atmospheres, so to remove any useful amount of fresh water from seawater requires applying at least twice that much pressure to the membrane. If you have ever pumped up a high-pressure bicycle tire you probably found it tough going as the tire got full, but that is a mere five atmospheres. To directly pump seawater through an osmosis membrane you'd have to produce ten times as much pressure as needed to pump up a bicycle tire. This would be difficult for the strongest athlete—impossible for one adrift at sea, weakened by hunger, thirst, and exposure to the hot sun.

Dick Hembree, vice president of Recovery Engineering, recognized that about 90 percent of the energy used to pressurize the membrane is wasted, because only 10 percent of the seawater going in comes out as fresh water. By recycling the remaining water back to the pump itself, he reasoned, it should be possible to capture that wasted energy and reduce the amount of force that a person would need to operate the device.

In fact, that's just how the Survivor-35 operates. With about the same effort needed to work a bicycle pump, the device produces five liters (11 pints) of fresh water an hour, more than enough to meet the needs of all the men in Captain Bligh's group.

With little worry about running out of fresh water, the Butlers were able to concentrate on catching fish. They grew quite adept at it, and though they steadily lost weight, they were in fairly good health when the Costa Rican Coast Guard finally rescued them after 66 days.

CAPTIONS

Figure 1. When water is added to a U-shaped tube that is divided by a semipermeable membrane (A), the water can pass freely through the membrane, and the height of the water on the left side equals that on the right. If a chemical that cannot pass through the membranes, such as sodium chloride (white dots in B), is added to the right side, the water will flow from left to right. The difference in heights, h, is an indication of the osmotic pressure. A pump can be used to apply external pressure to the right side (C). If the pressure is great enough and the membrane is strong enough, the osmotic flow of water can be reversed, producing pure water on the left from salt water on the right. The pressure required

to purify seawater is much greater than a person can produce with a simple pump like the one shown.

Back home in Florida, William and Simonne Butler pose with their valuable water purifier. When the Butler's 40-foot sailboat was attacked and sunk by whales 1,200 miles off Costa Rica, they survived 66 days in a life raft by eating raw fish and drinking fresh water from the reverse-osmosis purifier. They each needed about 2.5 liters of fresh water per day which the Survivor-35 produced with about 40 minutes of hand pumping.

Figure 2. The heart of the Survivor-35 pump is a clever mechanism that helps pump itself. When you press down on the operating handle you push a piston that pressurizes some seawater (1) and forces it into the cylinder that contains the reverse osmosis membrane. (In this illustration, pressurized seawater is shown in dark blue, unpressurized seawater in medium blue, and pure water in light blue.) Some of the water is forced through the membrane (2) but the dissolved ions are blocked. The result is a small stream of pure water (3). Most of the seawater leaves the reverse osmosis cylinder without flowing through the membrane (4). In traditional reverse osmosis devices this water is discarded, but in the Survivor-35 it is returned to the pump where its pressure is recycled. The return water flows through an open slide valve (5) and is directed to the *back* of the original piston (6). This way much of the pressure that you worked hard to produce at the front of the piston returns to help push the

BIOGRAPHY

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