Current Issue Outline 79-2

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Washington, D.C.
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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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WATER DESALINATION

Issue Definition

Water covers three-fourths of the Earth's surface, but most of it is unfit for human consumption. The oceans and seas contain high concentrations of salt and other minerals, and inland waters such as rivers and bays may be fouled by municipal and industrial wastes and other toxic substances. In the United States we are using 360 billion gallons of water a day, triple the amount of just 30 years ago. Demands are made on our water supply by a growing population, new industrial technologies, and Federal legislation mandating clean and safe drinking water and the control of water pollution. In addition to direct human consumption and use, great amounts of water are required by power-generating stations, industrial and manufacturing plants, waste treatment processes, heating and air conditioning systems, agricultural irrigation efforts, fish hatcheries, and recreational facilities such as parks, resorts, and aquariums. The minor inconveniences of today--the request to refrain from washing your car or watering your lawn in summer--may presage the major water shortage of the future.

Since the early 1950s, the Federal Government has been actively supporting research on ways to convert seawater and brackish water into freshwater that meets the quality standards for various uses. Funded through the Water Resources Research Act of 1964 and the Saline Water Conversion Act of 1971, hundreds of research and development projects have been carried out by university research institutes, government laboratories, and the designers and manufacturers of desalination equipment.

Today, about 1,500 water desalting plants throughout the world are operational, including over 350 in the United States, each capable of producing in excess of 25,000 gallons of freshwater per day for a wide variety of uses. Some are run by local governments, electric power companies, and industrial and manufacturing plants. Others were built to provide freshwater for military bases or large aquariums in tourist complexes. In the Caribbean, desalting plants are a prerequisite for the construction of resort hotels.

Some water desalination plants are combined with electric power generation facilities where steam exhausting from the turbines is used as the heat source for the desalting process. Though no large plants have been constructed to date, very large saline water conversion operations may have a third function: recovery from the seawater of significant concentrations of minerals of commercial value, such as salt, magnesia, and potash.

Despite these efforts, desalination does not yet account for a large share of our freshwater. Although costs of equipment, maintenance, and energy are high today, current technology exists to provide plants that operate in a more efficient manner.

New materials, especially plastics of various types, offer the potential for cost savings. Estimates from the Office of Water Research and Technology of the U.S. Department of the Interior indicate that the potential market for freshwater is so great that a massive, 10-year research and development effort to make the various water desalting processes more cost effective would pay for itself in the first year of full operation.

The oil-rich nations of the Middle East have not been deterred by costs. Since 1973, these countries, especially Saudi Arabia and Kuwait, have invested heavily in water desalination, relying on United States technical expertise, because an adequate water supply is vital not only to satisfy human consumption and agriculture, but also to attract industry and enhance economic growth.

U.S. contractors, engineers, and scientific advisers also have been assisting water desalting efforts in Algeria, the Bahamas, Bahrain, Belgium, Bermuda, Egypt, Greece, Indonesia, Iran, Israel, Italy, Japan, Libya, Mexico, Morocco, Peru, and Puerto Rico. Because of the worldwide interest in desalination technology, companies from several other countries (England, France, West Germany, Israel, Italy, and Japan) also are working now to establish and maintain desalination plants throughout Africa and South America.

Desalting Technologies

The three major saline water conversion processes are membrane, distillation, and crystallization or freezing. Energy sources currently used to fuel desalination plants of various types include coal, gas, oil, electricity, steam, uranium, rubbish, and diesel engine exhaust.

Membrane Processes for Water Desalination

Membrane processes use a thin sheet or membrane to separate the dissolved salts or other matter in saline water from freshwater. Membranes are selective in that, under different conditions, they allow some substances to pass through freely while barring others.

Salt or sodium chloride is made up of electrically charged atoms (ions) of sodium and chlorine. The charge is positive for the sodium atom and negative for the chloride atom. In seawater these components of salt are dissolved, mixed with the water molecules.

If two metal electrodes connected to a direct current power source are placed in a container of seawater, a current will be generated and the charged ions will be attracted toward the electrode of the opposite charge. The sodium ions of the salt, positively charged, will be attracted to the negative electrode (the cathode), and the chloride ions, negatively charged, will be attracted to the positive electrode (the anode). If the ions pass through a membrane, such as chemically treated polystyrene or polyethylene, as they are attracted to the electrodes, desalted or freshwater is left in the chamber betwen the membranes. This is the basis of the membrane process known as electrodialysis.

A different type of membrane process is reverse osmosis. If a vessel contains seawater in one chamber and freshwater in another, separated by a semipermeable membrane, the pure water tends to flow through the membrane and dilute the saltwater; this is known as osmosis. In reverse osmosis, pressure is applied to the seawater, forcing the freshwater through the semipermeable membrane while retaining the salt. The amount of pressure needed depends on the salt concentration and to a slight extent on the water temperature.

The reverse osmosis procedure has been applied with various membrane designs. Different configurations used include a spiral wound membrane, which fits in an ordinary commercial pipe; a tubular membrane lining a half-inch diameter porous fiberglass tube; and plastic hollow fine fiber membranes. A typical sheet membrane as used in spiral wound and tubular units is a flexible plastic film 4 to 6 mils thick, made of a cellulose material treated to pass water and reject salt under pressure.

At high salinities reverse osmosis uses less energy than electrodialysis, and the equipment required is relatively simple. Primary problems include membrane product water flux decline, maintaining salt rejection efficiency, and scale and fouling prevention and control.

Distillation Processes for Water Desalination

Distillation involves heating saline water until a part of the water vaporizes and leaves a concentrated salt solution behind. The vapor is then cooled and condensed into freshwater. Most distillation processes in current use are based on the principle that water boils at progressively lower temperatures when it is subjected to progressively lower pressures. As a result, distillation processes are usually set up in several stages or "effects" which operate at successively lower pressures and temperatures in order to maximize the total water produced for the amount of energy supplied.

In multistage flash distillation, seawater is heated to a temperature between 180° and 200° F and then passed into the first stage, which consists of a chamber where the pressure has been lowered sufficiently to cause part of the incoming heated seawater to vaporize instantly or "flash." The vapor rises to the top of the chamber, where it is condensed into freshwater as it comes in contact with a condensing coil or tube bundle that contains cool seawater on its way to the heater. The seawater that did not vaporize (now lower in temperature with a higher salt concentration) passes into another stage operating at a lower pressure, and the cycle repeats with each successive stage. By using cool seawater to condense the vapor in each stage, less energy from an external source is required to heat the seawater to the initial temperature at the first stage as it has acquired the heat energy from the vapor during the condensation processes. This increases the efficiency of the unit.

Solar humidification is a distillation process that requires a minimal expenditure for energy. The apparatus is similar to a greenhouse. The Sun's rays pass through the glass roof of the solar still, and the solar energy is absorbed by the black bottom surface of the pan of seawater beneath the glass. Thus, the water is heated, and vapor rises, condensing into freshwater when it meets the cooler surface of the glass roof. The condensate runs down into collecting troughs at the base of the glass roof. The system depends on the availability and intensity of the Sun's rays and yields only a small quantity of freshwater per unit area--about 1 pint of water per day for each square foot of water surface.

Crystallization (Freezing) Processes for Water Desalination

When seawater is frozen, ice crystals of pure water are formed. These can be separated from the brine or salty waste water and than melted to produce freshwater. In general, freezing processes are not yet commercially available, and additional research, development, and demonstrations are needed.

The most highly successful crystallization process is called vacuum freezing-vapor compression. This involves flash vaporization of water at low pressure (and thus at low temperature), which removes heat from the seawater and causes ice crystals to form in the brine.

Another major process type is termed secondary refrigerant freezing. This process uses a hydrocarbon coolant such as butane to remove heat from the water and cause partial freezing. Plans to import large quantities of liquefied natural gas raised the possibility of using seawater as the source of the heat required to vaporize the gas for commercial use. This would produce large quantities of cold seawater that could be used to feed freezing-desalination plants. Cost and energy savings would be significant, because the feed water would be readily available and colder than normal.

Economic Factors

Of the plants constructed in the 1970's throughout the world, membrane processes for desalination outnumbered distillation processes two to one. The most popular membrane process was reverse osmosis; the most used distillation process was multistage flash. The choice is governed by many factors: cost, amount of freshwater needed, type of feed water, type and amount of energy available, and concentration of dissolved sales and other contaminants in the feed water. In general, the greater the concentration of salts and other matter in the water, the greater the costs of desalting equipment and energy consumed. This is particularly applicable to membrane processes.

A 1978 survey released by the Office of Water Research and Technology compared several desalination processes on these factors. At the present state of technology, distillation processes are the most economical choice for seawater desalination. If freezing processes were to be fully developed through a major research and development effort, they could replace distillation at a lower cost and hold about 39 percent of the desalination market by the year 2000. The membrane processes are expensive, but show the greatest potential for cost reduction if research on new materials is continued. By the year 2000, these are expected to constitute the majority of plants and supply 60 percent of the market.

Membrane processes appear to have the most potential for desalination of seawater and industrial waste water that is free of toxicants and pollutants. Freezing processes should be best for waters contaminated by industrial and manufacturing effluents.

Current Research

Federal test facilities are maintained in Roswell, N.Mex., and Wrightsville Beach, N.C. Additional laboratories are maintained by university research centers and desalination engineering and equipment manufacturing companies, where equipment, temperature, energy, and feed water problems are undergoing continuing analysis and experimentation. Current efforts focus on:

--types of membrane materials and membrane designs

--the use of higher temperatures for more efficient reverse osmosis desalination while trying to control corrosion inside pumps and tubing and scale (mineral deposits) on the membrane surfaces

--pretreatment of seawater by chemical, mechanical, or thermal means to remove solids that clog filters and form scale

--determination of the most efficient desalination process for the different types of saline water: seawater; municipal waste water; thermally polluted water from electric powerplants; and water containing heavy metals, inorganic chemicals, dissolved solids, pathogenic organisms, and industrial contaminants.

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