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percent), inactive payloads (23 percent), rocket bodies (16.5 percent), operational debris (12 percent), and fragmentation debris (42.5 percent). Figure 1 depicts the view of the cataloged environment as seen through the viewfinder of an imaginary 35-mm camera located over the United States at an altitude of 64,000 km. The relative congestion in low Earth orbit and the geosynchronous "rings" of communications satellites and other debris are readily apparent. Computer modeling indicates that while the cataloged objects account for about 99.93 percent of the 2 million kg of mass in orbit, they account for only 0.2 percent of the total number of objects, about 35 million. Debris between 1 mm and 1 cm in diameter are estimated to provide less than 0.03 percent of the mass but 99.67 percent of the number, with the remainder lying between 1 and 10 cm in diameter.

The primary source for debris tracking data is the SSN, which maintains orbital data on all space objects greater than approximately 10 cm in diameter through a worldwide network of radar and optical sensors. The National Aeronautics and Space Administration (NASA) has developed a suite of sensors to complement its analysis and modeling of the debris environment; these include a portable computer-driven Schmidt telescope, a 3-m-diameter liquid metal (mercury) mirror telescope, and the joint NASA/Air Force Haystack Auxiliary radar in Massachusetts. The former Soviet Union established a geographically limited counterpart to the SSN during the 1960s and tracks about two-thirds the number of objects as the SSN. Radars in Germany and Japan also observe debris.

Interest in the debris environment and the accompanying hazards presented to spacecraft has prompted research by NASA, the Department of Defense, academe, and the European, Japanese, and Russian space agencies. This research has concentrated on the characterization of the environment using sensor data, environmental forecasting using computer models, and the search for ways to prevent the creation of new debris or reduce existing debris.

Bibliography

KESSLER, D. J. "Earth Orbital Pollution." In *Beyond Space-ship Earth*, ed. E. C. Hargrove. San Francisco, 1986.

JOHNSON, N. L., and D. S. MCKNIGHT. *Artificial Space Debris*. Malabar, FL, 1987.

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DESALINATION

As the earth's population has grown and people have achieved a higher standard of living, the amount of freshwater needed worldwide has increased dramatically. In many countries, needs have strained available freshwater supplies, and have restricted economic growth and development. Historically, seawater and brackish water (called saline water) were not considered suitable for human, agricultural, or industrial use due to high salt levels. However, over the last half century the process of desalination has been established as a reliable technique for removing salts from seawater and brackish water, thus making these water resources available. Although the concept of desalination has been around for almost two thousand years, only in the last forty years has man developed the technology for desalination water treatment facilities. Three major desalination technologies have been perfected for commercial use: distillation, reverse osmosis, and electrodialysis. Ion exchange and freezing processes can also be used for desalination, but neither has shown much potential for commercial application. In general, distillation works best for desalting seawater, whereas electrodialysis and reverse osmosis are more suitable for brackish water. A major consideration in the use of desalination is its high cost, often from two to fifty times more expensive than conventional water treatment. Because desalination is inherently energy-intensive, the increases in energy costs that occurred during the 1970s have partially offset most improvements made in equipment and operating efficiencies. However, despite the substantial costs involved, the availability of desalted water can be an economic boon in many water-short areas.

Saline Water

Saline water contains significant quantities of total dissolved solids (TDS), as well as small quantities of

organic material and dissolved gases. Most of the TDS are inorganic salts, which by definition are compounds made up of positive metallic ions (calcium, sodium, ammonia) bonded to negative ions (chloride, sulfate, carbonate). These salts are quite soluble in water, and are derived from the erosion of soils on or beneath the earth's surface, and from volcanic activity, which releases hydrogen chloride, hydrogen sulfide, carbon dioxide, and so on from deep within the earth. After being dissolved in water, these materials are transported through rivers and streams to the ocean. In the oceans, the average level of TDS has been measured at 34,400 milligrams per liter (mg/l), a concentration close to 4 percent by weight. The oceans and seas make up 97 percent of the world's water supply, which is constantly recycled by evaporation and condensation to produce rain and snow.

Classification of Saline Water

For the design of desalination systems, water is divided into four classes according to salt concentration: freshwater, brackish water, seawater, and brine. Freshwater is defined as having a TDS below 1,000 mg/l, brackish water from 1,000 to 35,000 mg/l, and seawater 35,000 mg/l and above. Brine is the concentrated salt solution remaining after pure water has been removed by desalination.

The oceans and seas of the world are interconnected, and the composition of seawater is relatively consistent. However, in specific areas the composition of seawater can vary considerably, although the relative proportion of various chemical constituents to the chloride ion is fairly constant. Land masses, heating and cooling, ocean currents, winds, and tides can all affect the concentration of a saltwater body at any given location and time. Since desalting seawater is more expensive than desalting brackish water, seawater is used for desalination only when sufficient brackish water is not available.

Brackish water can be found in lakes, rivers, and streams, and below the earth's surface in groundwater supplies. Brackish water usually occurs naturally due to several basic processes, including (1) freshwater flowing through or over mineral deposits and dissolving them; and (2) freshwater and seawater intermixing where they interface in bays, estuaries, and/or groundwater formations. Deposits of rock salt, gypsum, and limestone develop

over time as brackish water evaporates, but then are gradually redissolved by rain to form new brackish water supplies. Human activities that produce brackish water include various domestic, industrial, and agricultural uses that generate wastewaters high in TDS. As successive use and reuse of water occurs, salinity continues to build up eventually making the water unusable.

Unlike naturally occurring saline water, domestic wastewater is not uniform in composition, and contains whatever people dispose of in sewers, from human wastes to highly potent cleaning agents and industrial chemicals. Treated domestic wastewater has been used as feedwater for desalination plants in California, most of which use the reverse osmosis process. Drainage from irrigated land is also a potential source for desalination. Agricultural drainage generally requires pretreatment to remove pesticides, herbicides, and chemicals that could adversely affect the desalination process.

Desalination Processes

The major desalination techniques in use today can be classified as either distillation or membrane processes, including reverse osmosis and electrodialysis. The choice of a process and its related costs are determined by the chemistry and physical condition of the feedwater, the production rate required, and the energy source available to power the desalination plant.

Distillation. Distillation is a simple process in which saline water is boiled, and the steam produced is collected and condensed to produce salt-free water. Salts are not vaporized and remain in the brine. For an efficient distillation process, some of the steam heat is transferred back to the salt water to improve thermal efficiency. The most widely used distillation process, multistage flash (MSF) distillation, is based on the principle that water will boil at lower temperatures when subjected to lower pressures. In the MSF process, heated seawater flows into a chamber where the pressure is just low enough to boil some of the water and flash off hot vapor. The vapor is then condensed on tubes that carry fresh, cool seawater into the system. The seawater not evaporated then moves into a second chamber, at a lower pressure,

and the process repeats. A large MSF plant may have fifty or more flash chambers. Multiple effect distillation (MED) is a modification of the MSF process in which the largest portion of pure water is produced by boiling, and it uses the steam generated in one vessel as the heat source for the next. Vapor compression (VC) systems use heat from the compression of vapor, rather than the direct exchange of heat from boiler-produced steam. Solar distillation uses the Sun's energy to evaporate saline water in large surface-area basins called solar stills. The vapors condense on the inner surface of basin covers and the runoff is collected in troughs. Inexpensive land and intense sunshine are required to make this process economically feasible.

Reverse Osmosis. Reverse osmosis (RO) uses pressure to force pure water through a special membrane, leaving the dissolved salts behind on the feedwater side of the membrane. Energy is required primarily for pressurization, and no heating or liquid-to-vapor change is necessary. Operating pressures and product water quality vary with feedwater salt concentration and the type of membrane employed. Four types of membranes are generally used: plate and frame, tubular, hollow fine fiber, and spiral. Spiral and hollow fine-fiber membranes have completely dominated the industry to date, and large installations, over 1 million gallons per day (mgd), or 3,800 cubic meters per day (m^3/d), have successfully been used to treat brackish water for many years. Other types of membranes that operate at higher pressures have been developed for seawater desalination. In some applications, seawater RO systems may be cost competitive with distillation, but for very large facilities, over 5 mgd ($19,000 \text{ m}^3/\text{d}$), distillation is more economical.

Electrodialysis. Electrodialysis (ED) is based on the fact that most dissolved minerals will dissociate into electrically charged ions. By means of two special membranes that allow the passage of only positive (cation) or only negative (anion) charged ions, and a direct current electric field, salts can be removed from saline feedwater. The two membranes are arranged in alternate layers with water passages between them, and electrodes at the top and

bottom to introduce the required electric current. After salt separation, alternate water layers contain either purified water or brine. Because of the electrical energy required, ED is normally used to purify only brackish, low salinity water (1,000–4,000 mg/l TDS). A process improvement called electrodialysis reversal (EDR) was introduced in 1972.

Besides solar stills, other renewable energy systems such as solar voltaic, wind, wave power, and geothermal have not been applied commercially for desalination. However, interest in these techniques has increased sharply in recent years, and several experimental projects are now underway.

Disposal of By-Products. Desalination processes produce two resultant streams. One is the product stream, which has a low level of TDS, and the other is the brine (or reject) stream, which has a higher level of dissolved salts than either the feedwater or the product water. The brine must be disposed of in an environmentally acceptable manner. For facilities located close to the ocean, disposal does not generally pose a problem, but it can be a serious problem for inland locations. The most common disposal methods include evaporation by solar (or conventional) thermal means, injection into saline groundwater zones, and pumping into a saline water source.

History of Desalination

Progress has been rapid in the field of desalination. In 1967, the worldwide installed capacity was only about 250 mgd ($946,000 \text{ m}^3/\text{d}$), and distillation was the most widely used process for the desalination of both brackish water and seawater. ED had enjoyed some commercial success in brackish water desalination with several installations in North America and the Middle East, but RO was still in the developmental stage. By 1972, the worldwide installed capacity had doubled to about 500 mgd ($1,890,000 \text{ m}^3/\text{d}$). Distillation still dominated both brackish water and seawater desalination, but ED and RO were beginning to make significant advances into brackish water applications. By 1980, the worldwide installed capacity had again doubled to over 1 billion gpd ($3,780,000 \text{ m}^3/\text{d}$), and although distillation was still more prevalent, economic constraints were beginning to restrict its use

almost exclusively to seawater. ED and RO were being used more for desalination of brackish waters due to lower costs. In the early 1990s, over 7,500 desalination units with a total capacity of 3.7 billion gpd (14 million m³/d) had been installed worldwide or were under contract. The main market for desalination used specifically to produce drinking water has been the water-short Middle East. In the United States and Europe, desalination has been selected primarily to treat industrial water sources. However, population expansion in Florida and drought conditions in California are creating interest in desalination to enhance potable water supplies there. The cost of desalinated water has largely eliminated its use for normal crop irrigation.

The U.S. Army Corps of Engineers developed considerable expertise in design and construction of desalinization plants during the 1970s when the United States provided construction support to Saudi Arabia. Corps desalinization projects included large treatment systems suitable for cities and towns, as well as small units required by military troops in the field. The large plants employ the MSF distillation process and have performed well over the years, even, for example, when threatened by the oil spill that occurred during Operation Desert Storm (1990). The smaller units were used by all three branches of the armed services during Desert Storm, and are based on the RO desalinization process. The larger Corps desalination plants were constructed in Saudi Arabia and include a 1.67 mgd MSF distillation unit at Jeddah Naval Base, and a 2.0 mgd MSF distillation unit at Jabil Naval Base, both installed in the 1970s. Smaller systems include multiple 10,000 gpd RO units deployed at various locations in Saudi Arabia during Desert Storm (1990–1991), and several 2,000 gpd RO units installed at An Shas Air Force Base, Egypt, in the 1970s.

Bibliography

- BUROS, O. K. *U.S.A.I.D Desalination Manual*. Washington, DC, 1980.
- . *The Desalting ABCs*. Topsfield, MA, 1990.
- EUBANK, F. C. *Corps Accomplishments in Desalination*. Washington, DC, 1993.
- HOWE, E. D. *Fundamentals of Desalination*. New York, 1974.

ORTEOUS, A., ed. *Desalination Technology*. New York, 1983.

SPIEGLER, K. S., ed. *Principles of Desalination*, 2nd ed. San Diego, CA, 1980.

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DESERTIFICATION

See Land Degradation and Desertification

DIAGENESIS

Diagenesis is the sum of physical, inorganic chemical and biochemical changes in a sedimentary deposit after its initial accumulation, excluding metamorphism (see METAMORPHIC PROCESSES). The boundary between diagenesis and metamorphism is not well defined. A key diagenetic change is the conversion of sediments into sedimentary rocks (see SEDIMENTS AND SEDIMENTARY ROCKS, CHEMICAL AND ORGANIC; SEDIMENTS AND SEDIMENTARY ROCKS, TERRIGENOUS). It therefore is the link between sand and sandstone, mud and shale, carbonate sediment and limestone. Diagenesis involves, among other things: (1) compaction; (2) addition of new material; (3) removal of material, and transformation of material by (4) change of mineral phase; or (5) replacement of one mineral phase by another (see MINERALS, NONSILICATE, and MINERALS, SILICATES).

The addition of new material raises questions as to where the material came from and how it spread through the sediment. The removal of material creates new pore spaces and may provide the substance of cements for some other sites of precipitation, millimeters or kilometers away. Thus the addition and removal of material are closely allied to the contrasting processes of dissolution and precipitation. Removed material may be the source of the cement. For example, the degree to which cal-