volume of hydrate can contain as much as 184 volumes of gas.

Temperature and pressure conditions that favor the formation of stable clathrate hydrates exist in depleted oil reservoirs that lie under permafrost. For example, $CO_2{\cdot}6H_2O$ forms naturally at a temperature of 0 °C and pressure of 1.22 MPa. Using this measurement, it has been calculated that the minimum thickness of continuous permafrost needed to stabilize CO_2 clathrate hydrate is only about 100 m, and the base of the permafrost is known to be considerably deeper at certain locations (e.g., about 600 m at Prudhoe Bay in Alaska). In this disposal method, the permafrost layers over the reservoirs would act as impermeable lids that would prevent dissociation of the clathrates and diffusion of the evolved gases up through pores.

Because the natural pressure and temperature conditions in suitably chosen reservoirs would favor the formation of clathrates, no additional energy would be needed, other than the energy for pumping the gases into the reservoirs. There would also be no need to drill holes into the reservoirs: instead, the holes and other infrastructure already in place (and used previously to extract the oil from the reservoirs) would henceforth be used to inject the gases into the reservoirs.

As an additional benefit, pumping of CO_2 could help to maintain the pressure necessary for extraction of oil from an adjacent reservoir that had not yet been depleted. At present, natural gas is used for this purpose. The use of CO_2 instead of natural gas would make it possible to recover more natural gas as fuel. Moreover, unlike natural gas, CO_2 does not pose an explosion hazard.

This work was done by N. Duxbury of Caltech and V. Romanovsky of the University of Alaska at Fairbanks for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-30256

Electrochemical, H_2O_2-Boosted Catalytic Oxidation System

This system offers several advantages over O_2-boosted systems.

Lyndon B. Johnson Space Center, Houston, Texas

An improved water-sterilizing aqueous-phase catalytic oxidation system (APCOS) is based partly on the electrochemical generation of hydrogen peroxide (H_2O_2). This H_2O_2-boosted system offers significant improvements over prior dissolved-oxygen water-sterilizing systems in the way in which it increases oxidation capabilities, supplies H_2O_2 when needed, reduces the total organic carbon (TOC) content of treated water to a low level, consumes less energy than prior systems do, reduces the risk of contamination, and costs less to operate. This system was developed as a variant of part of an improved waste-management subsystem of the life-support system of a spacecraft. Going beyond its original intended purpose, it offers the advantage of being able to produce H_2O_2 on demand for surface sterilization and/or decontamination: this is a major advantage inasmuch as the benign byproducts of this H_2O_2 system, unlike those of systems that utilize other chemical sterilants, place no additional burden of containment control on other spacecraft air- or water-reclamation systems.

This system produces H_2O_2 in an electrochemical/electrodialytic process that consumes only electrical energy and oxygen; that is, unlike some other systems, this system consumes no expensive chemicals. The system includes an H_2O_2 generator, an H_2O_2-pervaporation membrane, and an APCOS reactor.

Tests have verified that H_2O_2 can be easily transferred and delivered from a stream identical to that in the central compartment of an electrodialytic cell to a required process stream. Test results have also shown that at stoichiometric concentrations, H_2O_2 promotes the increased destruction of urea and of NH_3 (the chief byproduct of urea) in wastewater. Heretofore, NH_3 has been considered one of the more intractable contaminants for oxidation purposes. Data indicate that oxidation occurs at high rates at low temperatures — an important advantage in that the consumption of energy is reduced and safety increased, relative to prior oxygen-boosted systems that must operate at higher temperatures. Moreover, the ability of this system to oxygenate highly contaminated wastewater was proved by the nearly complete oxidation of 500 mg/L of acetic acid (TOC = 200 mg/L). Considered together, these data are a convincing argument for using electrochemically produced H_2O_2 to boost APCOS oxidation rates in highly contaminated wastewater.

This work was done by James R. Akse, John O. Thompson, and Leonard J. Schussel of Umpqua Research Co. for **Johnson Space Center**. *For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*
MSC-22708

Electrokinetic *In Situ* Treatment of Metal-Contaminated Soil

This is an alternative to excavation and to techniques dependent on hydraulic conductivity.

John F. Kennedy Space Center, Florida

An electrokinetic technique has been developed as a means of *in situ* remediation of soils, sludges, and sediments that are contaminated with heavy metals. Examples of common metal contaminants that can be removed by this technique include cadmium, chromium, zinc, lead, mercury, and radionuclides. Some organic contaminants can also be removed by this technique.

In the electrokinetic technique, a low-intensity direct current is applied between electrodes that have been implanted in the ground on each side of a contaminated soil mass. The electric current causes electro-osmosis and migration of ions, thereby moving aqueous-phase subsurface contaminants from one electrode to the other. The half reaction at the anode yields H^+, thereby generating an acid front that travels from the anode toward the cathode. As this acid front passes through a given location, the local increase in acidity increases the solubility of cations that were previously adsorbed on soil particles. Ions are transported towards one electrode or the other — which one depending on their respective electric charges.

Upon arrival at the electrodes, the ionic contaminants can be allowed to become deposited on the electrodes or can be extracted to a recovery system. Surfactants and other reagents can be introduced at the electrodes to enhance rates of removal of contaminants. Placements of electrodes and concentrations and rates of pumping of reagents can be adjusted to maximize efficiency.

The basic concept of electrokinetic treatment of soil is not new. What is new here are some of the details of application and the utilization of this technique as an alternative to other techniques (e.g., flushing or bioremediation) that are not suitable for treating soils of low hydraulic conductivity. Another novel aspect is the use of this technique as a less expensive alternative to excavation: The cost advantage over excavation is especially large in settings in which contaminated soil lies near and/or under industrial buildings and therefore excavation would be made even more expensive by the need to prevent damage to numerous underground pipes and cables.

This work was done by Jacqueline Quinn of **Kennedy Space Center** *and Christian A. Clausen III, Cherie Geiger, and Debra Reinhart of the University of Central Florida. Further information is contained in a TSP (see page 1).*
KSC-12265

Pumping Liquid Oxygen by Use of Pulsed Magnetic Fields

No moving parts are in contact with the oxygen.

John F. Kennedy Space Center, Florida

An effort is underway to develop a method of pumping small amounts of liquid oxygen by use of pulsed magnetic fields. This development is motivated by a desire to reduce corrosion and hazards of explosion and combustion by eliminating all moving pump parts in contact with the pumped oxygen.

The method exploits the known paramagnetism of liquid oxygen. Since they both behave similarly, the existing theory of ferrofluids (liquids with colloidally suspended magnetic particles) is directly applicable to paramagnetic liquid oxygen. In general, the force density of the paramagnetic interaction is proportional to the magnetic susceptibility multiplied by the gradient of the square of the magnitude of the magnetic field. The local force is in the direction of intensifying magnetic field. In the case of liquid oxygen, the magnetic susceptibility is large enough that a strong magnetic-field gradient can lift the liquid in normal Earth gravitation.

Simple pumps were built to demonstrate the feasibility of the method. Each pump included a 1/4-in. (≈6.4-mm) poly(tetrafluoroethylene) tube, wrapped with several hundred turns of wire. The tube was partially immersed in liquid nitrogen (atmospheric-pressure boiling temperature 77 K), positioned so that the coil was just above the liquid-nitrogen surface. Gaseous oxygen (atmospheric-pressure condensation temperature 90 K) was bled into the tube, wherein it condensed to form liquid oxygen. The coil was connected to and energized by a pulse circuit as described below. The cooling of the coil by virtue of its proximity to the liquid nitrogen reduces the electrical resistance of the wire significantly, thereby increasing the magnetic field that could be generated by applying a given potential to the coil.

The solenoid coil was subjected to a current pulse through a high-power insulated gate bipolar transistor (IGBT). A typical coil configuration consisted of 1,900 turns of 18-gauge wire, resulting in a solenoid length of 8.3 cm with an approximate resistance of 1/2 ohm at 77 K. Thirty-ampere current pulses of several tenths of a second to 1-s durations, activated the solenoid, while the level of the liquid oxygen (LOX) column was measured. A typical magnetic field of about 0.9 T, accelerated the 36-cm LOX column upward, several centimeters, to just past the top of the solenoid. The dynamics of the LOX column are especially sensitive to starting position near the ends of the solenoid because of the large gradients in the magnetic field. Variations in starting distance of as little as 1 mm can result in 2 or more centimeter variations in maximum displacement of the column.

Part of this work involved the development of a numerical model describing the solenoid electrical circuit and magnetic field characteristics, as well as the LOX dynamics. This model has been shown to agree reasonably well with the experimental data, and like all useful models, it provides a means of carrying out additional experiments by varying many of the system parameters on a computer. The solenoid drive circuit portion of the model simulates a wide pulse, moderate current using an IGBT (as described above), as well as a short pulse, high current using a charged capacitor. Multiple solenoids with synchronized delayed current pulses were also simulated, suggesting that multiple stage solenoid coils could theoretically propel LOX to any desired distance.

In Earth's gravity, the maximum distance a LOX column can be propelled using a single solenoid, is probably limited to a few inches, dependent upon the size of the column, the specifics of the solenoid, and the available current and voltage. However, in reduced gravitational environments, such as on Mars or in Space, there may be a need to transport small amounts of liquid oxygen and in these lower gravitational fields, significant transport should be possible. An active area of ongoing research is finding a way to produce LOX from the Martian atmosphere. From a reliability standpoint, it may be advantageous to use a pumping system, which requires no moving parts, rather than a mechanical pump that would be more prone to failure.

This work was done by Robert Youngquist, John Lane, Christopher Immer, and James Simpson of Dynacs, Inc., for **Kennedy Space Center.** *For further information, please call the SERTTC Industry Liaison at the Kennedy Space Center Technology Transfer Office, (321) 867-8130.*
KSC-12284