

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,  $\text{CO}_2\cdot 6\text{H}_2\text{O}$  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  $\text{CO}_2$  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  $\text{CO}_2$  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  $\text{CO}_2$  instead of natural gas would make it possible to recover more natural gas as fuel. Moreover, unlike natural gas,  $\text{CO}_2$  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).  
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## Electrochemical, $\text{H}_2\text{O}_2$ -Boosted Catalytic Oxidation System

**This system offers several advantages over  $\text{O}_2$ -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 ( $\text{H}_2\text{O}_2$ ). This  $\text{H}_2\text{O}_2$ -boosted system offers significant improvements over prior dissolved-oxygen water-sterilizing systems in the way in which it increases oxidation capabilities, supplies  $\text{H}_2\text{O}_2$  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  $\text{H}_2\text{O}_2$  on demand for surface sterilization and/or decontamination: this is a major advantage inasmuch as the benign byproducts of

this  $\text{H}_2\text{O}_2$  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  $\text{H}_2\text{O}_2$  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  $\text{H}_2\text{O}_2$  generator, an  $\text{H}_2\text{O}_2$ -pervaporation membrane, and an APCOS reactor.

Tests have verified that  $\text{H}_2\text{O}_2$  can be easily transferred and delivered from a stream identical to that in the central compartment of an electrochemical cell to a required process stream. Test results have also shown that at stoichiometric concentrations,  $\text{H}_2\text{O}_2$  promotes the increased destruction of urea and of  $\text{NH}_3$  (the chief byproduct of urea) in wastewater. Heretofore,  $\text{NH}_3$  has been consid-

ered 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  $\text{H}_2\text{O}_2$  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.  
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## 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 cad-

mium, 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 im-

planted 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