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.*
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