Magnetocaloric Pumping of Liquid Oxygen

Neither moving parts nor pulsing of the magnetic field are needed.

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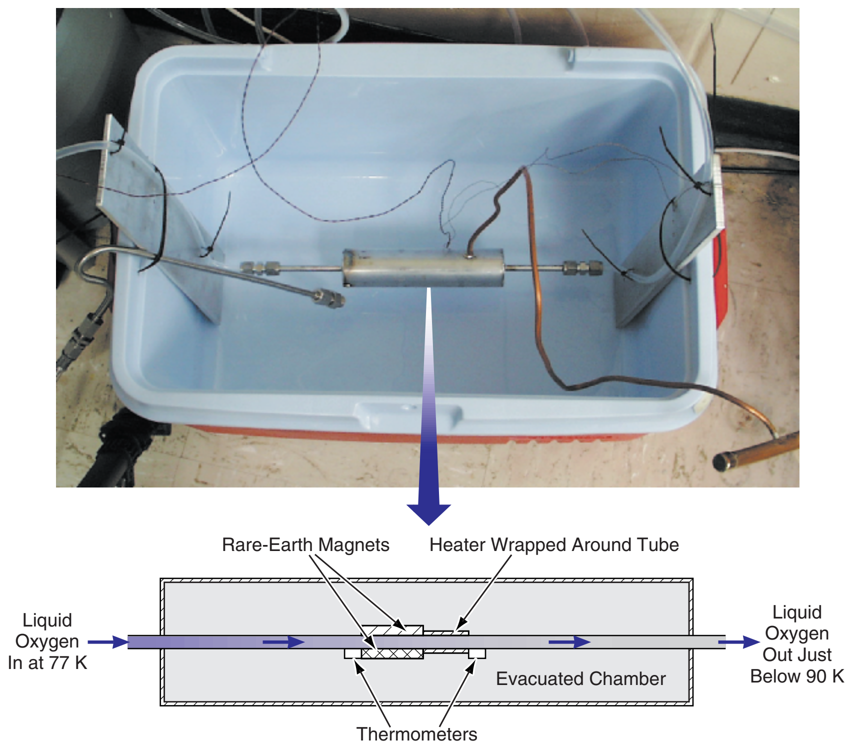
As noted in the previous article, the field-induced force density on a magnetic fluid is proportional to the magnetic susceptibility times the gradient of the magnetic field squared. The direction of the force is towards increasing magnetic field (positive gradient). Applying a magnetic field to a magnetic fluid will result in a force from all directions towards the location of peak field. Since the magnetic field is conservative and there are no magnetic monopoles, the net field-induced force on any fluid of constant susceptibly will be zero. The only manner to obtain a nonzero net field-induced force is to vary the susceptibility of the fluid. At the gas/liquid interface of liquid oxygen, the susceptibility varies drastically, and the exploitation of the resultant large net forces has been detailed in the previous article, "Pumping Liquid Oxygen With Pulsed Magnetic Fields" (KSC-12284).

An alternative method of varying the magnetic susceptibility is to vary the temperature of the fluid. The magnetic susceptibility of paramagnetic liquid oxygen obeys the Curie-Weiss law: it is inversely proportional to temperature. By applying a temperature gradient in the presence of a symmetric magnetic field, a nonzero net force results. Much of the theory of the so-called "Magnetocaloric Effect" has previously been developed for and applied to ferromagnetic fluids, or ferrofluids, but is readily applied to paramagnetic liquid oxygen.



A **Prototype Magnetocaloric Pump** for liquid oxygen has been demonstrated to produce a significant pressure rise.

The figure shows an example prototype single-stage magnetocaloric liquid-oxygen pump that has been extensively tested at Kennedy Space Center. Rare-earth permanent magnets supply a peak magnetic field of roughly 0.5 Tesla to a short length of 1/4-in. (6.4-mm) stainless-steel tubing. A heater is placed on one side of the magnets. The assembly is insulated with a vacuum jacket and placed in a bath of liquid nitrogen. The liquid oxygen enters on the left side of the magnetic field at 77 K and is warmed by the heater to just under 90 K on the right-hand side. This 13 K temperature gradient is enough to generate roughly a centimeter of pumping head.

Clearly, many improvements could be made to increase performance. Multiple stages could be juxtapositioned to increase the pumping head. Stronger magnetic field gradients (such as those produced by persistent current mode superconducting magnets) would greatly enhance the force on the fluid. Liquid oxygen at 90 K could be cooled using liquid nitrogen (instead of being warmed by a heater) or cooled by some other means to near its melting point, 54 K, to establish a larger temperature gradient.

Magnetocaloric pumping of liquid oxygen is a way to convert heat directly to motion of the fluid. Being a simple heat engine, it could, in principle, be made to approach the Carnot efficiency. It would also not require any moving parts, would not require contact with the fluid, and would not need access to the edge of the fluid. It would operate in a manner similar to a peristaltic pump.

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