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Title:

Development of a High Gradient Magnetic Separator Using High Temperature Superconductors

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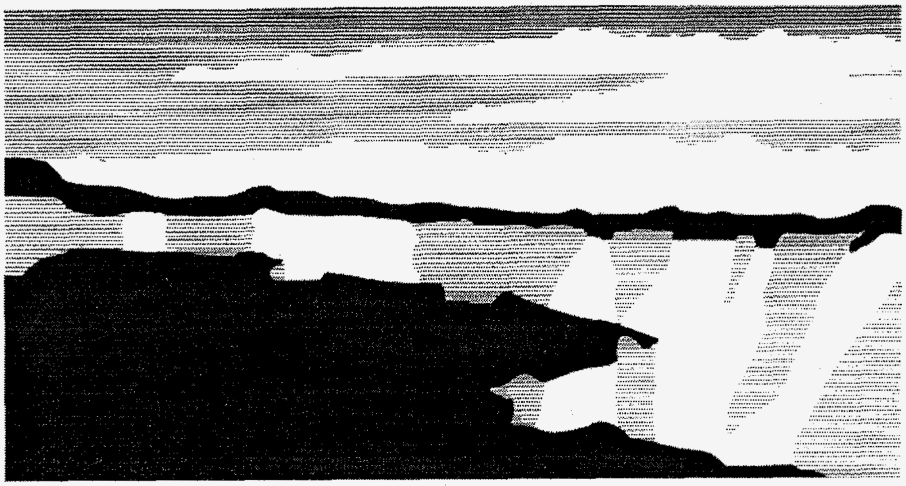

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Development of a High Gradient Magnetic Separator Using High Temperature Superconductors

F. Coyne Prenger*, David Daney, Mark Daugherty, and Dallas Hill

Abstract

This is the final report of a one-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). High-gradient magnetic separation (HGMS) is an application of superconducting magnet technology to the process of magnetic separation of solids from other solids, liquids, or gases. The production of both high magnetic fields and large field gradients using superconducting magnet technology has made it possible to separate a previously unreachable but large family of paramagnetic materials. It is possible to separate more than half of the elements in the periodic table using this method. Because HGMS is a physical separation process, no additional or mixed waste is generated. This project sought to develop a high-gradient magnetic separator using a high-temperature superconducting magnet.

1. Background and Research Objectives

High-gradient magnetic separation (HGMS) is an application of superconducting magnet technology to the process of magnetic separation of solids from other solids, liquids, or gases. The production of both high magnetic fields and large field gradients using superconducting magnet technology has made it possible to separate a previously unreachable but large family of paramagnetic materials. More than half of the elements in the periodic table have paramagnetic properties and others can be combined with magnetic seed material. This is a powerful technique that can be used to separate widely dispersed contaminants from a host material and may be the only technique available for separating material in the colloidal state. Because HGMS is a physical separation process, no additional or mixed waste is generated, which is environmentally beneficial.

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Our goal on this project was to build an HGMS system using a high-temperature superconducting (HTS) magnet. The system does not require the use of liquid helium or liquid nitrogen for cooling. A pair of high-temperature superconducting current leads are incorporated into the system to reduce the thermal load on the cryocooler. The objective was to develop a system that can be used for bench-top demonstrations of the advantages that are possible by combining HTS and HGMS technology. These advantages include potentially lower cost, higher reliability, and a more rugged system.

LANL currently has one conventional copper-coil and three low-temperature superconducting high-gradient magnetic separators. To date, more than 120 experiments have been conducted with either water-contaminant mixtures or water-soil-contaminant mixtures. The results are very promising. Tests with a clay-type soil showed a decontamination from about 1,500 pCi/g to less than 4 pCi/g with an applied magnetic field of 2 Tesla. This is close to three orders of magnitude decontamination.

Recent tests on waste water treatment have been conducted at the LANL waste treatment facility (TA-50). The influent stream can consist of isotopes of U, Pu, Am, V, Mn, Co, Y, Nb, Sr, Cs, Be, Zn, Se, Sr, Rb, and Zr. We have demonstrated, using HGMS, a contaminant reduction from about 70,000 pCi/L to less than 40 pCi/L, a reduction of more than three orders of magnitude. TA-50 currently generates about 60 tons of iron and lime sludge annually to remove actinides. Using HGMS only 0.2 tons of solid would be generated. This would reduce the volume of contaminated waste by a factor of 270. The results are shown in Figure 1.

Environmental applications of HGMS for purification of drinking water supplies and waste water treatment also look very promising. Many contaminants can be made to associate themselves with magnetic particles seeded in the water; such associations can be brought about by surface adsorption, mechanical entrapment, coagulation, or coprecipitation. For example, Coliform bacteria, a common contaminant, tends to adhere to the surface of fine particles of iron oxide. A test conducted with water from the Charles River in Boston found that a single high-velocity pass through a magnetic separator purified the heavily polluted water almost to the standards of drinking water. Certain viruses, which are too small to be filtered, can be scavenged by iron oxide and other magnetic seeding materials and removed from water by high-gradient magnetic separation.

Applications in the utility industry include the desulfurization of coal to reduce sulfur dioxide emissions and purification of plant cooling water to reduce corrosion and impurity activation. Potential industrial applications include the removal of heavy metals and other contaminates from waste water and the purification of feed stocks and raw materials. For example, HGMS based on low-temperature superconducting magnets is used by industry to clean the kaolin clay used to manufacture coated paper. Other potential industrial applications include recovery of valuable mineral oxides such as molybdenum or tungsten oxide from the tailings left from previous extraction and the utilization of low-grade reserves such as the weakly magnetic iron mineral hematite.

2. Importance to LANL's Science and Technology Base and National R&D Needs

Los Alamos is pioneering the application of HGMS technology for soil remediation and process residue reduction of actinide contaminated materials throughout the DOE complex. This project supports Los Alamos core competencies in earth and environmental systems as well as analysis and assessment.

3. Scientific Approach and Results to Date

Currently, the HGMS technology employs low-temperature superconducting magnets to achieve magnetic field strengths in the 1.0 to 8.0 Tesla range. Although more cost effective than electromagnets, low-temperature superconducting magnets must be operated at 4K and typically require submersion in liquid helium. By using solenoidal magnets made with high-temperature superconductors at 25K, operating costs can be reduced through a reduction in refrigeration requirements. Capital costs can also be significantly reduced because the helium liquifier required for low-temperature superconducting magnets is an order of magnitude more expensive than the cryocooler required for the HTS system. In addition, the higher temperature enables the use of a conductively cooled magnet that simplifies cryostat design and results in a more field-deployable, reliable separator.

We have completed the design of the HGMS system, the fabrication of all system components, and final assembly of the magnetic separator. The design for the separator is shown in Figure 2. The magnet has been instrumented and its performance at different operating currents and temperatures has been determined. In addition, we have looked closely for any performance degradation due to thermal cycling and the mechanical loading induced by transportation. This type of data is necessary to establish the validity of the HTS magnet as an industrial component.

The rate at which material can be processed in the magnetic separator depends on the length and diameter of the matrix. For this system we selected a matrix diameter of 14 mm (0.55 inch) and a length of 76 mm (3.0 inches). A magnetic field strength of 1 Tesla over the central 2 inches of the matrix is provided by the HTS magnet. This HTS magnet is one of the most powerful produced to date and dissipates about 45 times less power than comparable magnets, which operate at dissipation levels of 1 μV/cm of conductor. The extremely low dissipation was specified to ensure that the magnet can be conductively cooled.

The internal structural supports of the system have been designed to be able to withstand dynamic transportation and handling loads in addition to the relatively modest static loads. As the size of structural support members increases the heat leak to the thermal shield and the magnet also increases, which is typical of the type of tradeoff that must be considered in the design of each component of the system.

There are two modes of operation that were considered in the thermal analysis -- cool-down and steady-state operation. For demonstrations it is desirable that the cool down time not exceed one day so a design target of 20 hours was selected. The thermal shield and the HTS magnet are cooled by a two-stage Gifford-McMahon cycle cryocooler. The upper stage cools the thermal shield and the lower stage cools the HTS magnet. The capacity of the cryocooler decreases as the temperature of each stage is lowered, and the thermal load on each stage affects the performance of the other stage.

We have designed and tested components of an HTS current lead to minimize the heat leak to the HTS magnet. The design of the current lead is shown in Figure 3. A key component of the lead is a composite heat pipe, made of conducting and non-conducting materials, which functions as a thermal intercept. The heat pipe transferred 35 watts with a 2.7 K temperature difference, which gives a thermal conductance significantly higher than designs, which rely on thermal conduction through solids. The heat pipe thermal intercept successfully withstood 8,000 volts without breakdown while carrying a thermal load of 15 watts, greatly exceeding its performance targets of 1,000 volts electrical isolation with a 5 watt thermal load. This heat pipe has been incorporated into the HTS current lead.

The complexity and cost of the vessel, insulation, thermal shielding, and refrigeration are considerably reduced by the higher operating temperatures made possible with the use of the HTS magnet. The resulting design is smaller and lighter than a similar device made with low-temperature superconducting magnets. This may be particularly advantageous in soil remediation applications where separation units are envisioned that will be moved from site to site as required. In addition, the refrigeration power consumption is an order of magnitude smaller for the HTS magnet system. The refrigerator reliability is also significantly higher, which is an important consideration in commercial systems. These advantages must be weighed against the cost of the HTS magnet, which is currently higher than a comparable low temperature superconducting magnet. Recent advances in HTS conductor manufacturing capabilities are, however, driving the cost of HTS magnets down, which will enable them to compete for the magnetic separation market.

Publications

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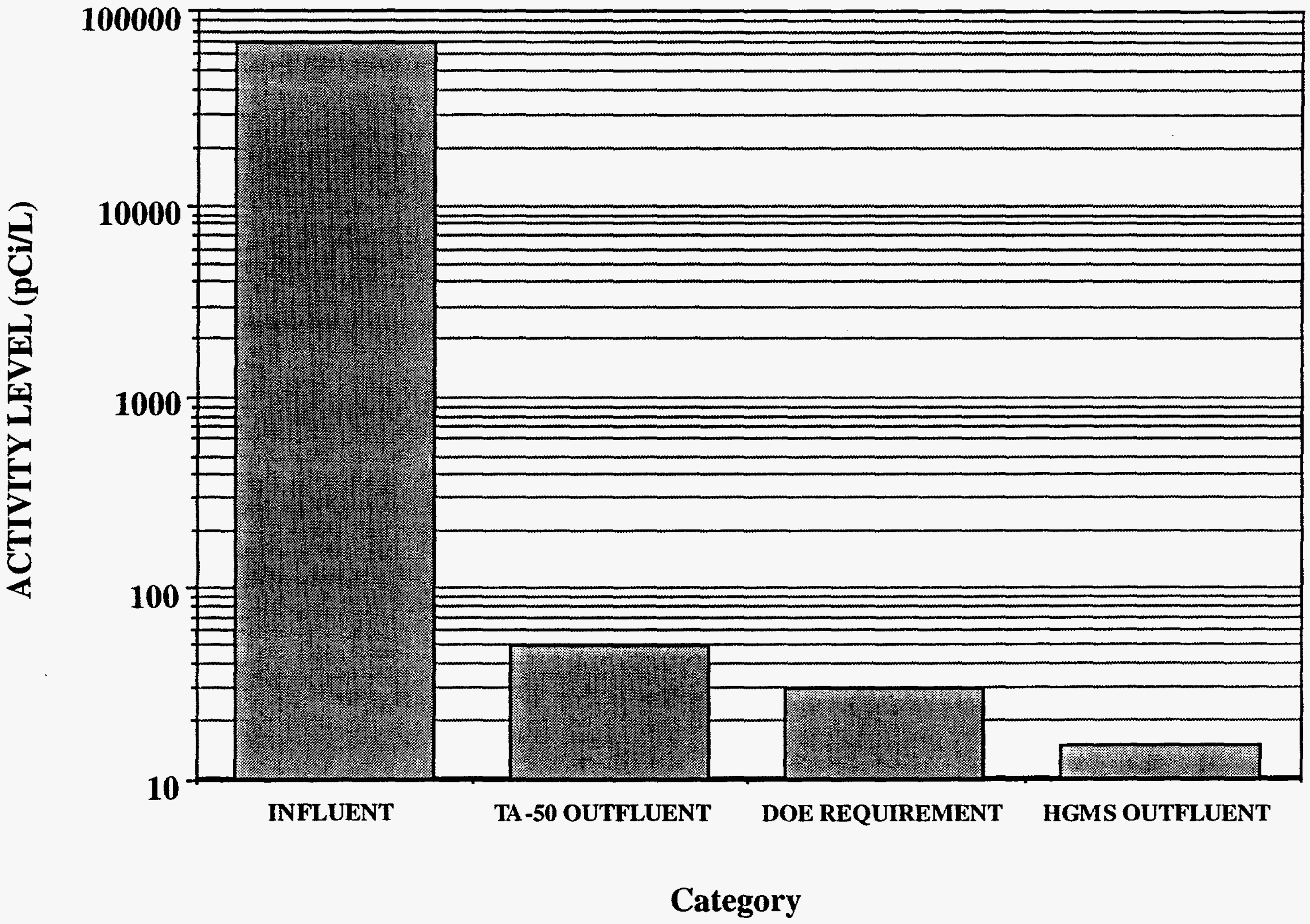

Figure 1. Results of HGMS treatment of TA-50 waste water. Influent is initial untreated condition, TA-50 outfluent shows results acheived with current technology, DOE requirements is the future DOE standard, and HGMS outfluent is the result obtained with HGMS.

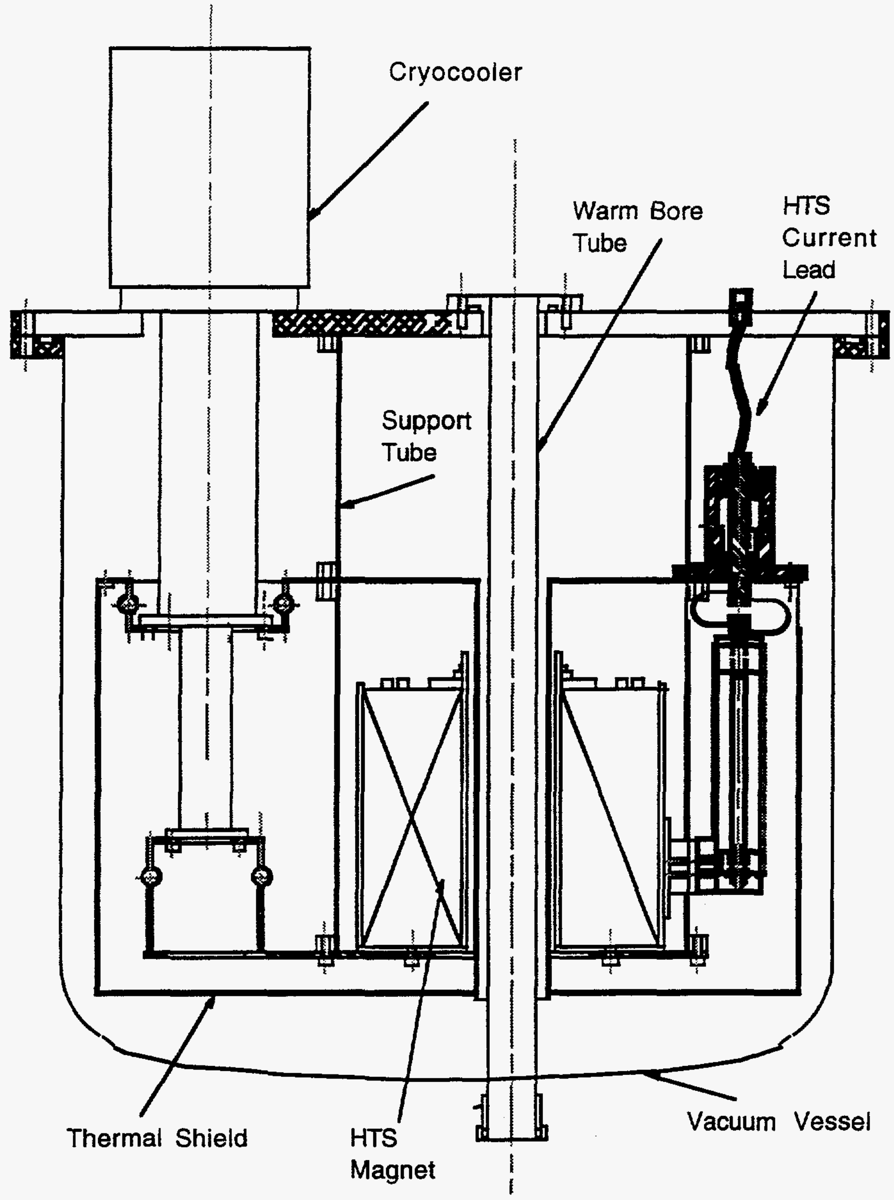

Figure 2. High Gradient Magnetic Separator.

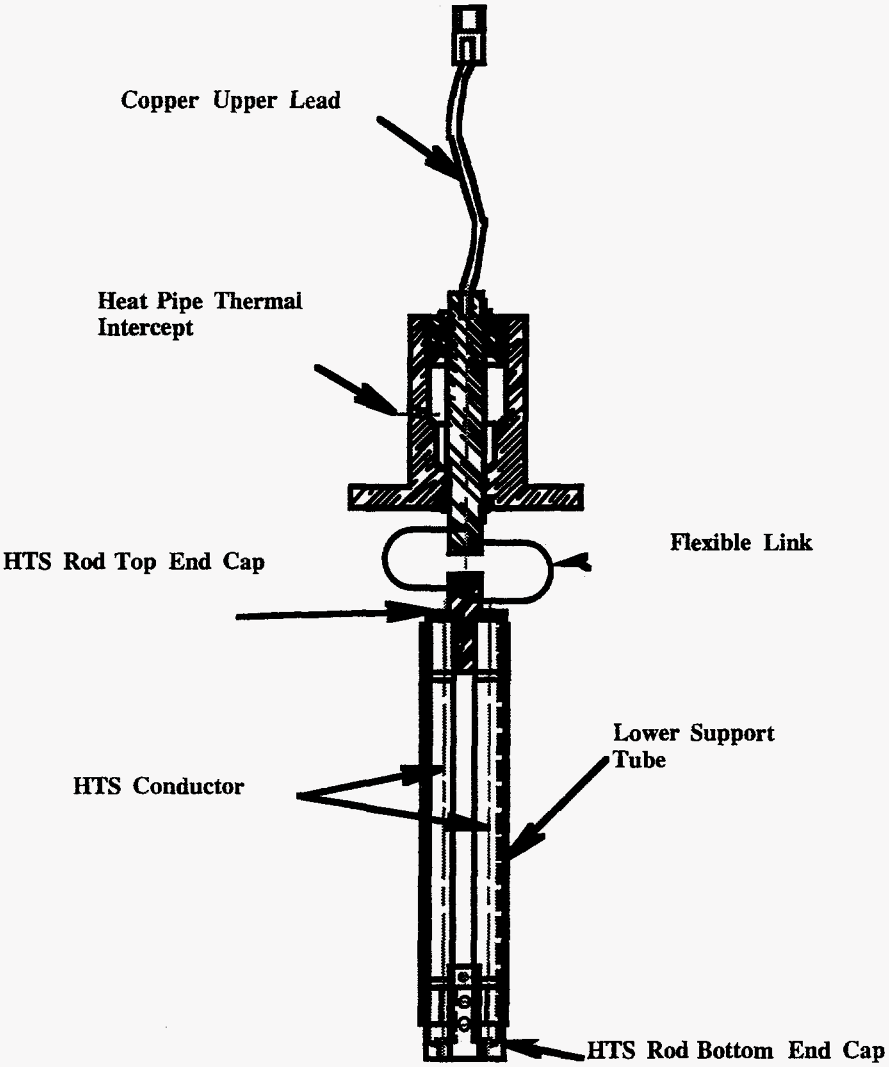

Figure 3. HTS Current Lead Assembly.