DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

OPEN-FILE REPORT
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SHEET 1 OF 2

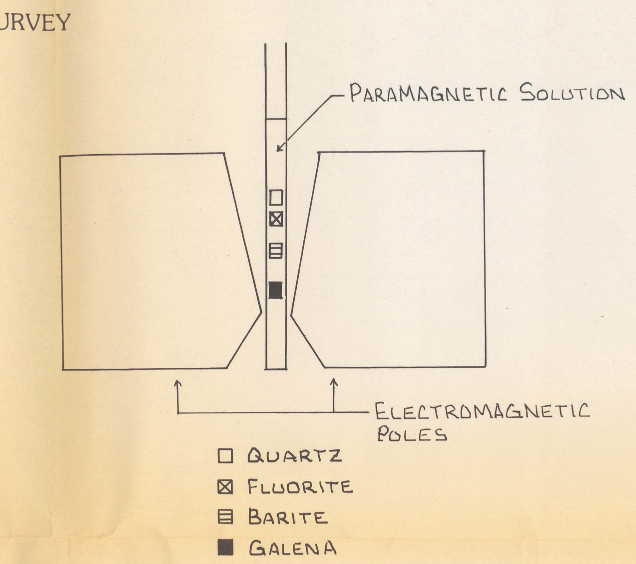

FIGURE 1.–ILLUSTRATION SHOWING THE RELATIVE HEIGHT OF SUSPENSION OF GRAINS OF QUARTZ, FLUORITE, BARITE AND GALENA IN A PARMAGNETIC SOLUTION WITHIN A MAGNETIC FIELD

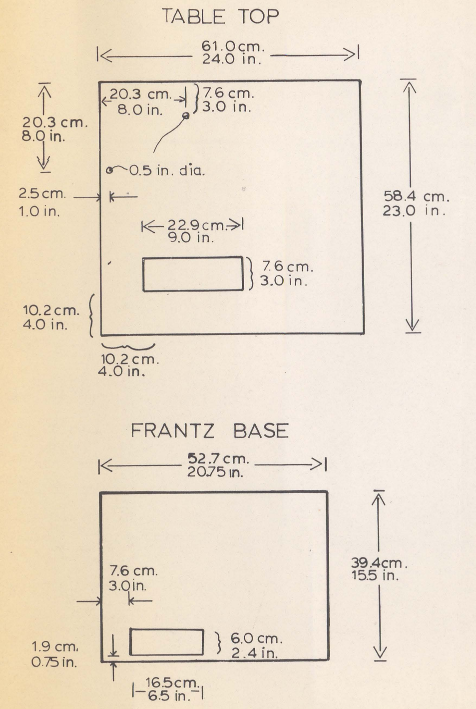

FIGURE 2.–SCALE PLANS FOR CONSTRUCTING TABLE TOP AND MODIFYING FRANTZ ISODYNAMIC SEPARATOR BASE PLATE FOR USE WITH MHS SEPARATOR

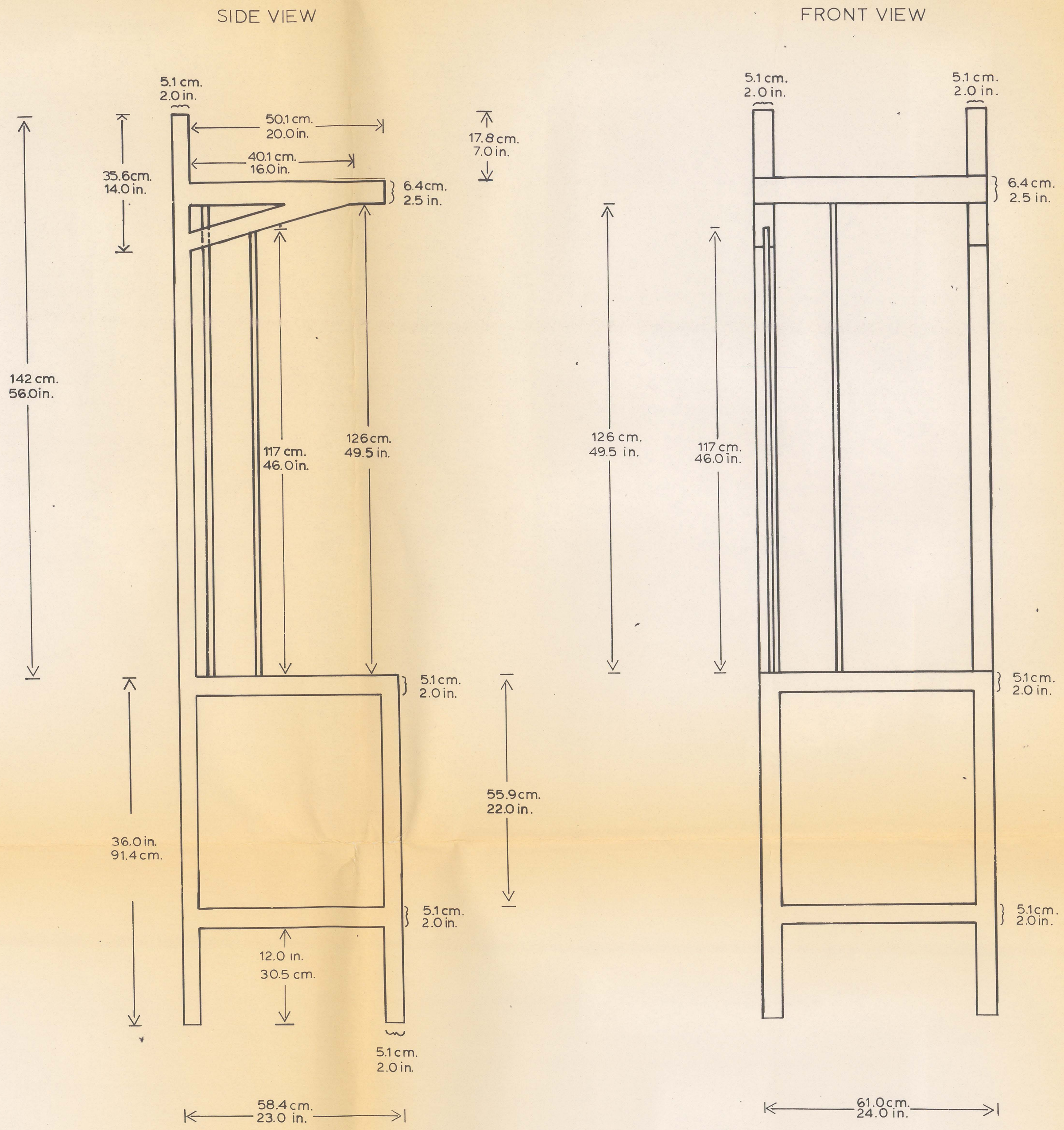

FIGURE 3.–SCALE PLANS FOR CONSTRUCTING MOUNTING TABLE FOR MHS SEPARATOR

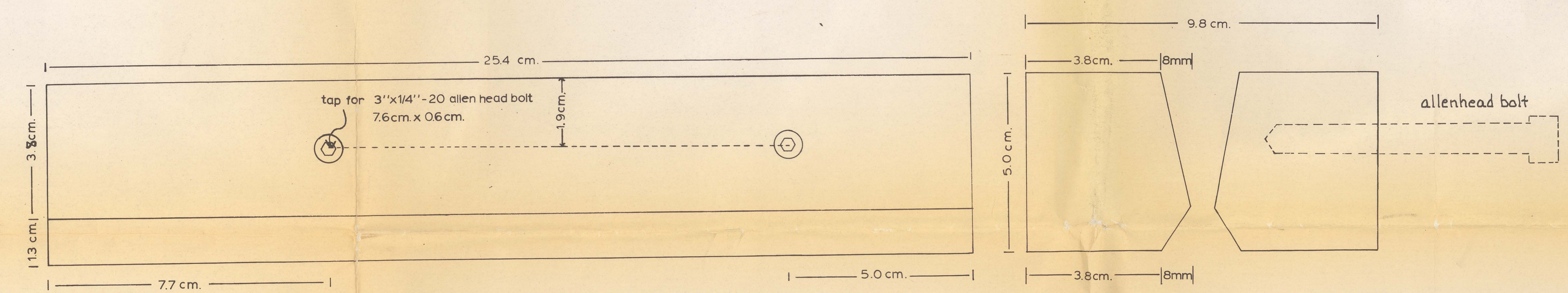

FIGURE 4.–SCALE PLAN OF MODIFIED POLE PIECES USED FOR MHS SEPARATOR

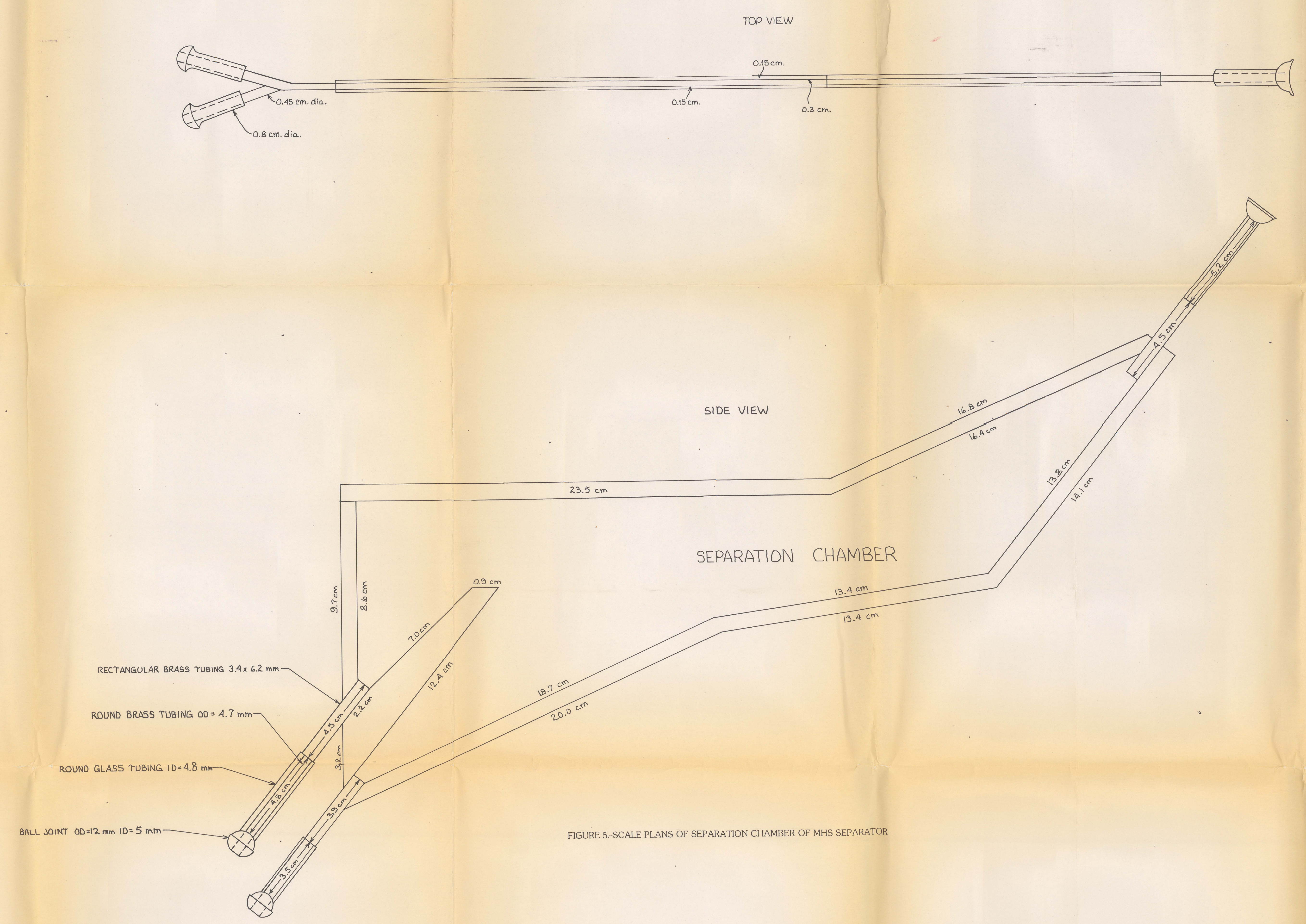

FIGURE 5.–SCALE PLANS OF SEPARATION CHAMBER OF MHS SEPARATOR

Introduction

This report presents plans for the construction of a laboratory-scale magnetohydrostatic (MHS) separator, designed, constructed, and tested as a possible alternative or supplementary mineral separation technique to heavy liquids.

The term magnetohydrostatic (MHS) was coined by U. Andres (1976), who did much of the original experimental work in the definition of the principles of this technique, as well as its applicability to industrial processes.

Using an MHS separator, one has the equivalent of an instantly variable heavy liquid, ranging in density between 1.4 through >9.0. Nonmagnetic minerals are affected only on the basis of their specific gravity characteristics. Somewhat magnetic minerals are affected on a combination of their specific gravity and magnetic susceptibility characteristics, making the former appear greater than, in fact, they are. Magnetic minerals are pulled out of the solution by the electromagnet.

Principle of MHS Separation

A magnetohydrostatic separator is based on the principle that when a paramagnetic solution (or ferro fluid) is placed within an inhomogeneous magnetic field, it will exhibit an apparent specific gravity directly proportional to the magnetic field strength. Thus, in the case of a container filled with a paramagnetic solution placed within a wedge-shaped airgap between the pole pieces of an electromagnet, the apparent specific gravity of the solution will be the highest in the zone of maximum constriction and will decrease progressively upward, as illustrated by the suspension levels of galena, barite, fluorite, and quartz (fig. 1).

Solutions of any number of soluble paramagnetic salts could be used in a MHS separator. The authors selected manganous chloride ($MnCl_2 \cdot 4H_2O$) because of its low toxicity, high magnetic permeability, high solubility and relatively low cost.

Using a solution concentration of 150 gm $MnCl_2 \cdot 4H_2O$ per 100 ml H_2O, a solution flow rate of 30 ml/min., and a sample feed rate of 1 gm/min., the authors routinely obtained separation with crossover of <1 percent.

MHS Separator Construction

The MHS separator is constructed around a modified Frantz Isodynamic separator, which is used to provide the required magnetic field. The modifications, which are such that the Frantz can be easily reconverted to its original purpose, consist of:

a. The cutting of a hole in the Frantz base plate as shown in figure 2 and;

b. The replacement of the standard Frantz pole pieces with modified ones shown in figure 4. The new pole pieces should be machined from the mildest available steel, preferably a magnet-grade alloy, to minimize residual magnetism.

Plans for a specialized table for mounting the MHS separator are shown in figure 3.

With the new pole pieces in place, the electromagnet is oriented in such a manner that the pole piece airgap faces upward and the long axis of the pole pieces faces forward. Subsequently, the magnet is tilted forward so that the plane formed by the tops of the pole pieces makes a 45° angle with the horizontal. A plexiglas separation chamber (fig. 5) is mounted within the airgap as shown in figure 6. It is important that the wedge-shaped splitter within the separation chamber be in line with or somewhat above the line formed by the narrowest portion of the airgap. This line indicates the plane within the paramagnetic solution above which the "lights" exit the chamber through the upper tube and below which the "heavies" are removed through the lower tube. It is also important that the separation chamber be positioned in such a manner that mineral grains entering it via the inlet tube fall vertically into progressively stronger parts of the magnetic field rather than being trapped in the back of the chamber behind the magnetic field.

Figure 7 is a schematic of the entire MHS separator (with the electromagnet omitted). A combination of light and heavy arrows indicate the portion of the separator through which the sample flows. The various components of this portion must be connected with glass tubing and ball and socket joints to permit easy passage of particulate matter. The balls and sockets are lightly coated with silicone stopcock grease to prevent leakage. The light arrows indicate the portion of the system through which solution flow occurs. These components can be interconnected with flexible tubing.

In addition to the pole pieces and separation chamber, other custom-made parts are the sample catchment funnels, the flow equalization chamber, three-way coupler, and the sample feed funnels; plans are shown in figures 8, 9, 10, and 11, respectively. The other components are the following commercially available items:

a. two (top and bottom) tanks--rectangular plastic 15 l containers;

b. two needle values--200 ml/min range;

c. liquid flow meter--100 ml/min range;

d. two plastic funnels;

e. one 250 ml gas washing bottle used as filter;

f. one one-way ball valve;

g. one 1/25th horsepower electric pump;

h. one electronic liquid level controller;

All components are secured onto the table frame and/or the two round rods using standard laboratory utility clamps.

MHS Separator Operation

Before introduction of a sample into the separator certain sample preparation steps are necessary:

1. A sample rich in clays should be washed to remove most of them. Clays will flocculate in the solution and clog the system.

2. All samples should be sieved to ensure that the largest grains are somewhat smaller than the smallest opening within the mineral flow path. In that the smallest opening is approximately 3 mm, a L9-mesh sieve (2-mm apertures) can be used.

3. Strongly magnetic minerals (magnetite, ilmenite, maghenite, etc.) should be removed from the sample using a hand magnet to prevent excessive build-up within the separation chamber.

This MHS separator can be operated with or without accompanying solution flow. Solution flow speeds up the separation process but somewhat reduces separation precision. The drop in precision is the result of the complexity of motion occurring within the separation chamber, specifically the movement of the grain relative to the fluid and of the fluid relative to the chamber walls. At higher solution flow rates, grain configuration and grain size become important factors in determining whether the grain goes into the light or heavy fraction. Turbulent flow within the separation chamber occurs as a result of high flow rated and tends to force light minerals into areas of high solution specific gravity.

If the separator is operated without solution flow, the sample is introduced into the open sample funnel via a vibrator-mounted hopper attached to the rod above the funnel. The sample feed rate is governed by a variable rheostat controlling the vibrator.

Upon leaving the sample feed funnel, the sample material drops vertically through the three-way coupler, into the vertical portion of the separation chamber and sinks until the various mineral component reach the level, in the solution, having an equivalent apparent specific gravity. The nonmagnetic/light mineral fraction then slides along a series of closely spaced stratified layers parallel to the line delineated by the maximum airgap constriction, above the splitter and through the upper line into catchment separatory funnel. The less magnetic and nonmagnetic/heavy (at this amperage) mineral fraction drops to the bottom of the separation chamber and is saltated via the lower exhaust tube into a catchment separatory funnel. The grains of the magnetic fraction become attached to the chamber walls along the maximum airgap constriction and are retained within the chamber until the electromagnet is turned off.

The light- and heavy-mineral fractions can now be drained into the filter paper-lined funnels, and the magnetic fraction recovered by turning off the electromagnet and catching the material in the "heavies" catchment separatory funnel. The sample material in the filter funnels can be washed with water and dried on a hot plate. The separator can be cleaned between samples by fully opening the fluid flow control needle valve for some time, and removing any mineral grains that might get flushed down into the catchment separatory funnels. A more vigorous flushing can be obtained by opening both catchment separatory funnel stopcocks. Cleanliness can be completely ensured by draining and refilling that portion of the system between the sample feed funnel and the tops of the catchment separatory funnels.

If the separator is operated with solution flow, the sample is introduced directly into the partly filled sample feed funnel and thoroughly wetted with solution using a wash bottle. The funnel is capped with a soft rubber stopper equipped with an overflow line leading into the top storage tank. The top tank stopcock and sample feed rate valve are then opened and the desired solution flow rate is established by adjusting the solution flow rate valve. The sample feed rate valve is closed momentarily and sample flow is established by opening the stopcock at the bottom of the sample feed funnel and simultaneously adjusting the sample feed rate needle valve until the desired rate of sample flow is established. The back pressure of the solution flowing up into the sample feed funnel permits one to establish and maintain a uniform sample flow rate over a wide range. The sample material follows the same pathway as described above for the static solution mode of operation. The solution, starting at the top storage tank (fig. 7), flows through the sample feed rate needle valve, the separation chamber, the two catchment separatory funnel overflow lines, the flow equalization chamber, solution flow rate control valve, flow meter, and into the bottom storage tank. Here the solution accumulates until it reaches a preset level, at which point the electronic liquid level controller activates a pump to force the solution through a filter (adapted gas washing bottle), and a one-way valve back into the top storage tank. This flow is continuous as long as the separator is in operation.

Reference Cited

Andres, U., 1976, Magnetohydrodynamic and magnetohydrostatic methods of mineral separation: John Wiley and Sons, New York, 224 p.

CONSTRUCTION PLANS AND OPERATING INSTRUCTIONS FOR A LABORATORY-SCALE MAGNETOHYDROSTATIC (MHS) MINERAL SEPARATOR

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