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On New Single-Operation Magnetic Methods for Separation of Comminuted Solid-Waste Components

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Abstract

Recent increases in the price of plastics, following the trend of the oil industry, have focused attention on the problem of their recovery—similar to that of metals, glass, etc.—from industrial and municipal waste. Since plastics generally differ little in their physical properties, neither electromagnetic methods nor flotation are suitable for the purpose in hand, but specific gravity is the most promising separation parameter in spite of the relatively small differences involved. (All plastics fall within the 0.9 to 2.3 g/cm^3 range.) Single-step separation of multicomponent mixtures is feasible by means of a magnetohydrodynamic (MHD) technique based either on a constant or on a pulsating field, and also by means of magnetohydrostatic (MHS) techniques. The effectiveness of the MHD jigging method was demonstrated in experiments on a five-component mixture, carried out in a laboratory trough using a pulsating field with given periodicity. A 5-cm bed was stratified in 30 sec into fractions of sp. gr. 1.06, 1.21, 1.30, 1.37, and 1.40 g/cm^3. The main object of the study was experimental determination of the stroke of the expulsive force, in an electrolyte solution, ensuring the most effective stratification. Certain possibilities are being considered for an MHD jig separator equipped with sintered permanent magnets. Experiments were carried out which showed the feasibility of precision separation of lightweight and heavy plastics according to mass density using a MHS technique with a sensitivity up to 10^{-2} g/cm^3. The feasibility was also demonstrated of the separation of metals (copper and aluminum) and plastics (polyvinyl chloride and polystyrene) in a single process and a single operation.

INTRODUCTION

The so-called "town ore" (municipal waste), with metals, glass, wood, paper, plastics, and foodstuffs as constituents, is currently an important source of raw materials. In view of the analogy regarding the composition and form of the components, the methods used for their separation and recovery are those of conventional ore dressing, with all their advantages and drawbacks.

Separation of physically dissimilar materials involves diversified multi-operational processes; waste-treatment plants use processes based on magnetic and electric effects as well as on gravity and flotation, each process consisting of several stages. However, certain specificities of the materials, combined with possibilities inherent in new approaches, permit development of technological processes based on improved principles. Accordingly, two new magnetic processes are put forward in the present context, opening the way to a single-operation technology. The new means used in these processes permit: (a) elimination (or at least substantial reduction) of size classification by dint of their insensitiveness to this parameter; (b) reduction of the number of separation processes to one (or at least a considerable narrowing of their diversity), as well as minimization of the number of operations and stages by dint of their universality and high resolving power; and (c) preliminary determination of coordinates for all the types of particles involved (depending on their density and magnetic susceptibility), thereby providing a basis for exact determination of the process parameters.

Among the "town ore" constituents enumerated above, plastics have come to occupy a special place by virtue of their ever-increasing consumption for household uses,* mainly as packaging materials for foodstuffs. The current oil crisis has now imparted urgency to the economic problem of their recovery in the course of the general waste-reclamation cycle (*2*) and subsequent re-use [suitability for industrial re-use has been established for certain types of thermoplastics (*3*)].

In view of the special technological problem involved in their extraction, exploratory studies on a method for their classification according to composition were carried out at the U.S. Bureau of Mines (*4*).

For wastes containing substantial amounts of paper, a so-called electrodynamic separator (*5*) was proposed, consisting of a drum and a discharge electrode (operating at 35 to 50 kV), both of them earthed. The material

*In Israel its proportion is still relatively modest: 3% of the total in 1973 (*1*), but it is expected to rise to 8 to 9% by 1980, allowing for population growth.

is humidified selectively to 45 to 50%; this renders the paper conducting, in which state it is charged by the corona effect of the electrode and repulsed, whereas the dielectric properties of the hydrophobic plastics remain unchanged and they adhere to the drum. [Paper labels, stickers, etc. are removed by treatment with alkaline chemicals and with abrasives in warm water, but even then the mixture still contains not less than 4 to 7% (by weight) of contaminations.]

Separation of glass, aluminum, alumina, and lead in simple models of magnetohydrostatic (MHS) jigs was carried out in a ferromagnetic suspension (*6*). The tests confirmed the suitability of the technique for extracting metallic and nonmetallic components from incinerator residues.

The optional methods for separating plastics from mixed wastes and for sorting them into chemical types are those based on size, shape, density, porosity, rigidity, surface properties, etc. The physical methods tried on a laboratory or pilot-plant scale are as follows: hand sorting, air classification, sink–float technique, conventional jigging, electrodynamic separation, electrostatic separation, flotation, magnetohydrodynamic (MHD) jigging, and MHS separation.

For separation of light organic from heavy inorganic components, special inertial separators were designed, operating on the basis of mass density, particle size, and elasticity (*7*). As a result of the above processes, relatively pure fractions of plastic mixtures of high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene (PS), polypropylene (PP), and polyvinyl chloride (PVC) have been obtained.

Air separation, operating on the basis of mass density, size, and shape, yields light and heavy fractions, the latter including the PVC and PS components. Further fractionation according to chemical composition is also effected on the basis of mass density, using lighter-than-water alcohol solutions and heavier-than-water calcium chloride solutions, the former being used for PP, LPDE, MDPE (middle-density polyethylene), and HDPE, and the latter for PS and PVC. (In the Bureau of Mines study, the specific gravity range of the liquids was 0.90 to 1.38 g/cm^3, the required sensitivity being of the order of 1×10^{-2} g/cm^3.) The densities of some thermoplastics are given in Table 1.

An analogous problem arises in specialized plants using glass of different types, where fractions of given chemical composition are sought by means of separation according to mass density (see Table 2).

Even with its high sensitivity, separation in liquids of given specific gravity cannot provide a technologically satisfactory solution in the case of multicomponent plastic or glass mixtures. In order to obtain several—

TABLE 1
Densities of Virgin Plastics

Type	Density (g/cm^3)	Type	Density (g/cm^3)
Polypropylene (PP)	0.90	Polystyrene (PS)	1.05–1.12
Low-density polyethylene (LDPE)	0.92–0.94	Nylon (n)	1.10–1.14
High-density polyethylene (HDPE)	0.94–0.96	Polyvinyl chloride (PVC)	1.22–1.45
Vinyl acetate (VA)	0.932		
		Teflon (T)	2.10–2.30

TABLE 2
Mass Density of Glass

Glass	Density (g/cm^3)
1. Borosilicate, low electric loss	2.13
2. 96% Silica glass, 7911	2.18
3. Borosilicate–tungsten	2.25
4. Soda lime electric lamp bulbs	2.47
5. Alumino silicate	2.53
6. Lead–alkali silicate, electrical	2.85
7. Lead–alkali silicate, high lead	4.28

say, three or four—products in a single process, a different technique is called for.

The answer was found in the form of MHD jigging and MHS separation.

MHD JIGGING

In MHD jigging the mixture of solid particles is subjected to oscillatory motion in an electrolyte bath under a periodic electromagnetic force and is stratified according to mass density. The process of MHD jigging is one of several methods of solid particle separation according to specific gravity of the solid phase in a conducting liquid (*8*).

The substance of the process consists in relating the expulsive force in the liquid not only to density but also to the electromagnetic force exerted on the latter. The body force exerted by the electrolyte under an electric and a magnetic field at right angles on a spherical particle, in a Gaussian system (*9*), is given by

$$f_{EM} = \frac{3}{2} jH \frac{\sigma_p - \sigma_m}{\sigma_p + 2\sigma_m} \qquad (1)$$

where j is the current density (in A/cm^2), H is the magnetic field (in oersteds), and σ_p and σ_m are the conductivity ($ohm^{-1}\ cm^{-1}$) of the particles and medium, respectively. Neglecting the conductivity of the particles (σ_p), Eq. (1) reduces to

$$f_{EM} = -\frac{3}{4}jH \tag{2}$$

Over the period of action of the electromagnetic force, the expulsive force acting on a unit volume of the mixture of solid particles with density (ρ_p) in a liquid with density ρ_m is

$$f_\Sigma = (\rho_p - \rho_m)g - \frac{3}{4}jH \tag{3}$$

The stratification process under the above conditions, for instance in an aqeuous solution of NaOH, was studied on a specially designed set-up (shown schematically in Fig. 1) with a view to qualitative isolation of the basic factors involved. The test mixture comprised four types of PVC particles (mass density 1.06, 1.21, 1.30, and 1.37 g/cm^3) and one fraction of pit coal (1.40 g/cm^3). The particle size ranged from 0.5 to 3.0 mm. The examined parameters were the frequency and amplitude of the electromagnetic force, the type of stroke, and the depth of clear electrolyte over the solid bed. It was found that, using a 15 × 10 × 5 cm trough, the bed may be stratified into five layers (average thickness 2 cm) in 25 to 30 sec. The optimal type of stroke is a rectangular pulse with a duty factor of 0.4 to 0.5, the overall amplitude of the explusive force being 1.10 to 1.15 $\bar{\rho}_{mixt}$. The minimum necessary clear depth was found to be 20 to 25% of the total.

With the practicability of the method established in principle, design details may be worked out. The set-up consists of a system of channels through which the current-carrying electrolyte flows, with the stroke controlled by means of a thyristorized device. The magnet is made of a cobalt–rare earth alloy in sintered briquette form. An alloy with composition $Pr_{0.5}Sn_{0.5}Co_5$, sintered at 1100°C, has the following properties (*10*): mass density 8.22 g/cm^3, inductivity B_{is} = 1.03 T, B_r = 0.95 T, energy $(BH)_{max}$ = 22.2 MGOe, and field strength H = 8.3 kOe and H_c = 13.8 kOe. Similar magnets based on a process developed at the Reno Metallurgy Research Center (Reno, Nevada) consist of cobalt–samarium alloys with 36.7 ± 0.3% Sm (Sm_2Co_7 and $SmCo_5$). Their parameters [B_r = 0.78 T, $(BH)_{max}$ = 15.1 MGOe, μH_c = 27.4 kOe, H_c = 7.5 kOe] are sufficiently high to secure a magnetic field exceeding 5 kOe in a gap of over 5 cm (*11*).

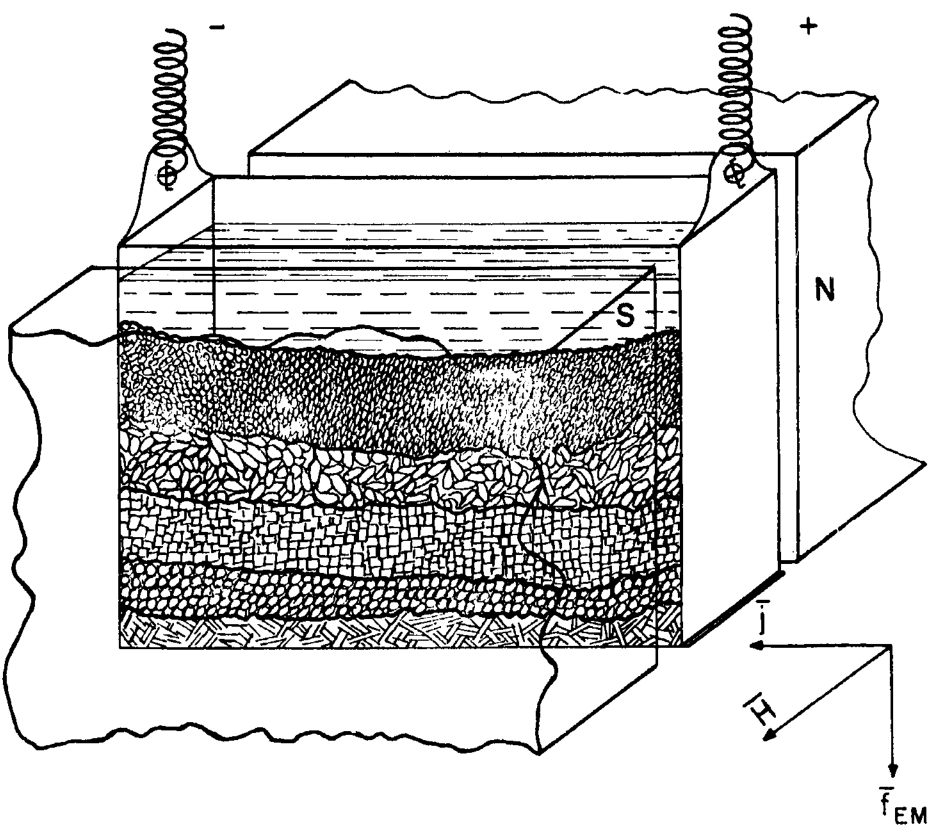

FIG. 1. MHD jigging of five-component plastic mixture.

The separator was realized accordingly in the form of a multichannel trough (Fig. 2). In order to reduce flux losses, the magnetic elements are mounted on a steel plate. Preliminary calculations showed that a two-channel separator with gabarits ($L \times B \times h = 0.5 \times 0.1 \times 0.05$ m), installed at a slight slope, achieves an output of 0.25 to 0.40 ton/hr with a 3 to 4 component mixture, depending on particle size and mass density.

The power consumption for an expulsive force of 2×10^2 dyn cm^3 (duty factor 0.5) is about 2 kW in the case of an NaCl bath ($\sigma \simeq 2 \times 10^{-1}$ ohm^{-1}cm^{-1}) and only 1 kW in the case of an alkali bath (NaOH or KOH, $\sigma \simeq 4 \times 10^{-1}$ ohm^{-1}cm^{-1}).

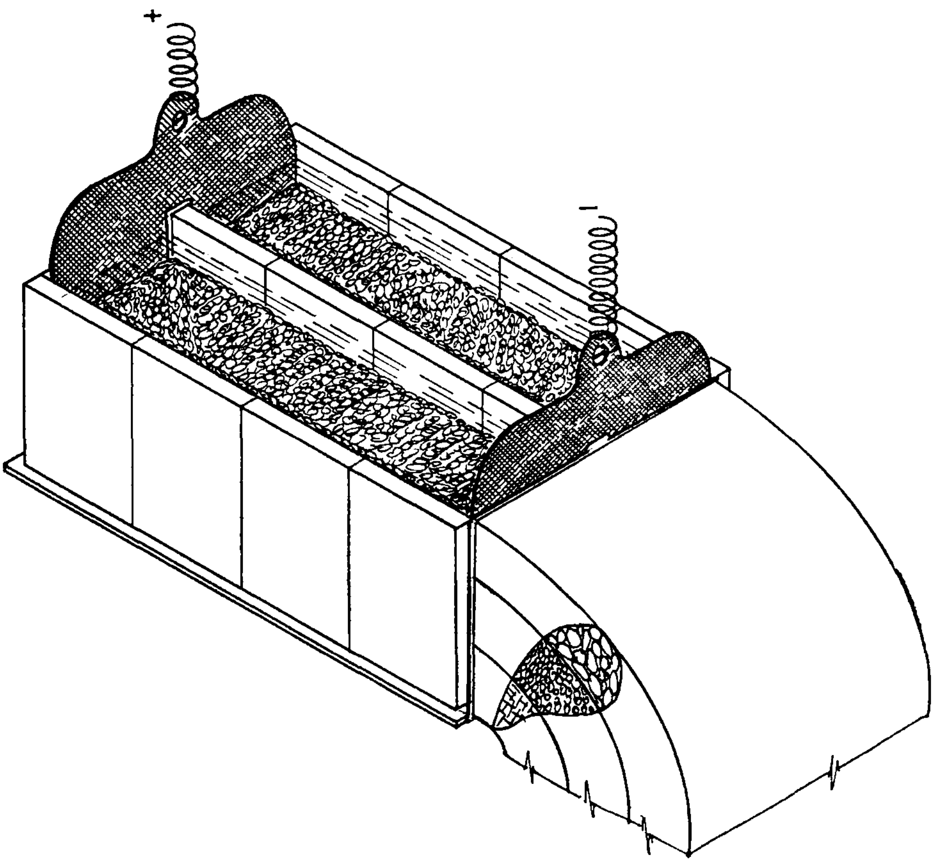

FIG. 2. Two-channel MHD jig for separation of solid plastic particles.

MHS SEPARATION

An alternative technique whereby a mixture of solid plastic particles may be separated according to specific gravity in a magnetic field is MHS separation. MHS separation is based on the interaction of a magnetic liquid (solution or suspension) and a nonhomogeneous magnetic field.

The appropriate choice of the magnetic field distribution permits creation in a magnetic liquid of technological conditions for obtaining several fractions of solid particles in a single pass.

The additional expulsive force in a magnetic liquid (*12*) is given by

$$f_M = (\chi_m - \chi_p)H \operatorname{grad} H \tag{4}$$

By appropriate choice of the pole profile of the magnet and modification of the electromagnet current, it is possible to obtain the desired number of fractions differentiated according to density.

Experiments regarding the possibility of separation of plastics according to density were carried out on a specially designed set-up (see Fig. 3), with a view to assessing the suitability of the MHS technique for fine differentiation of several types of plastics in a single pass. Figure 4 shows a test tube with five such types in the magnetic field of a wedge-shaped air gap. The corresponding densities are 0.96, 1.04, 1.05, 1.11, and 1.13 g/cm^3. Each particle is located at the equilibrium level of its density (*14*). These levels correspond to the radii at which the following Archimedean force equality holds:

$$(\rho_p - \rho_m)g = (\chi_m - \chi_p)H \operatorname{grad} H \tag{5}$$

For the field in the wedge, the magnetic force is given by (*13*)

$$f_m = A^2R^{-3}(\chi_m - \chi_p) \tag{6}$$

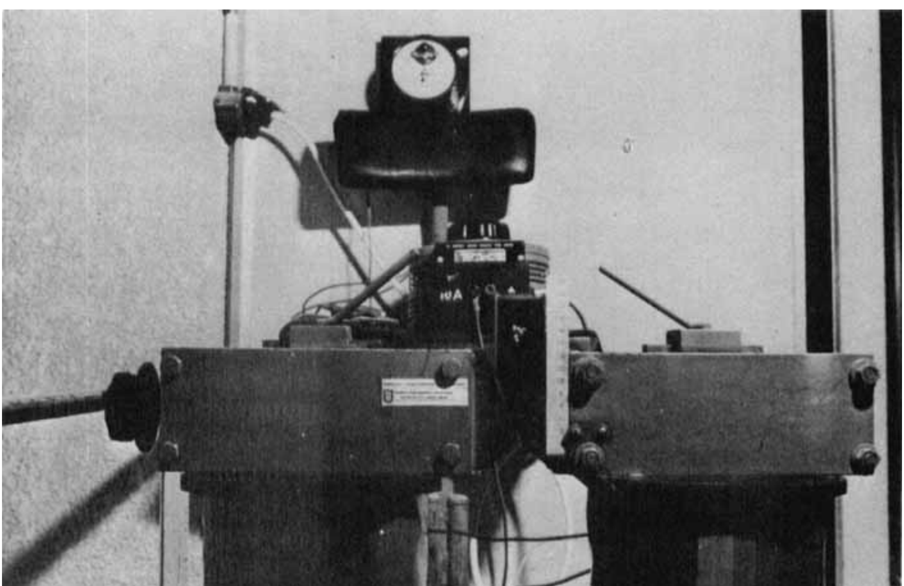

FIG. 3. Experimental set-up for MHS separation of solid plastic particles.

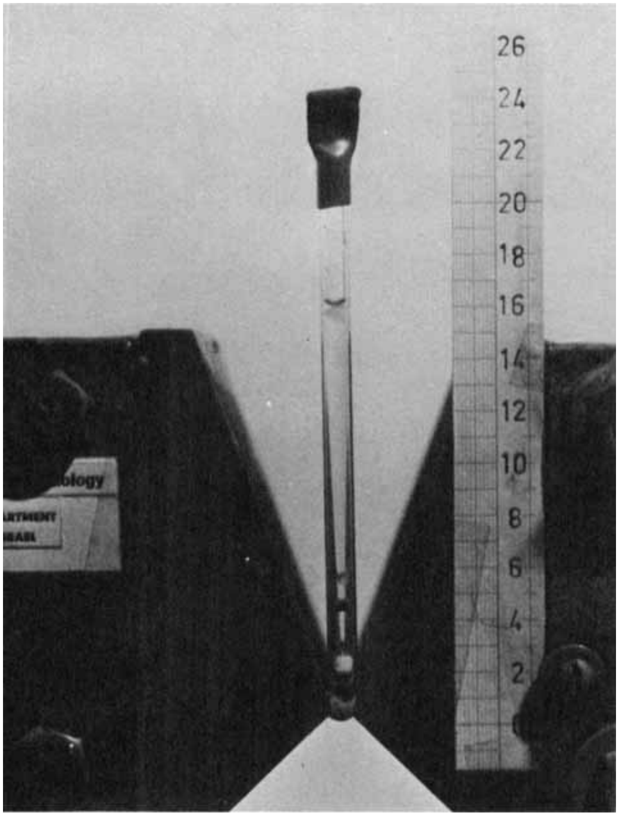

FIG. 4. Stratification of five types of plastics by MHS technique.

where R is the distance of the particle center from the apex of the wedge (i.e., the vertical coordinate of the particle), and A is a constant of the magnet, depending on its induction and on the wedge angle, $A = H \times R$.

A solid particle in a magnetic liquid polarized by a nonhomogeneous (in this case wedge-shaped) field is at equilibrium at the point where its weight equals the expulsive force. By Eqs. (5) and (6) we have

$$(\rho_p - \rho_m)g = (\chi_m - \chi_p)A^2R^{-3} \tag{7}$$

whereby the vertical coordinate is

$$R = \left[\frac{(\chi_m - \chi_p)A^2}{(\rho_p - \rho_m)g}\right]^{1/3} \tag{8}$$

For the lower layers, located within the range of influence of the magnetic field with reverse gradient (see Figs. 4–7), the equilibrium condition reads

$$(\rho_p - \rho_m)g = (\chi_m - \chi_p)\left[\frac{A_1^2}{R_1^3} - \frac{A_2^2}{R_2^3}\right] \tag{9}$$

where A_1 and A_2 are the respective parameters of the upper and lower fields, and R_1 and R_2 are the coordinates with respect to the respective apices.

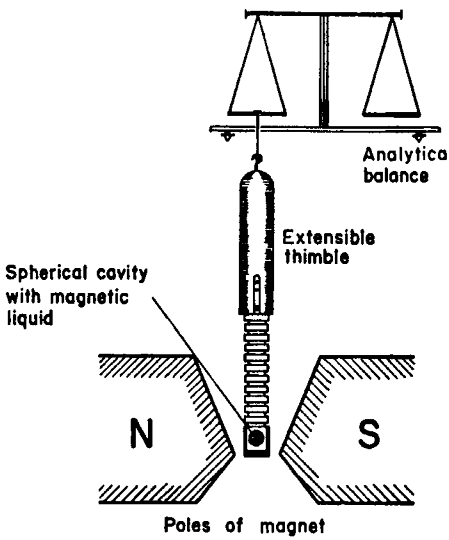

FIG. 5. Set-up for measuring the magnetic force.

TABLE 3
Calculated vs Experimental Magnetic Force

Vertical coordinate of sphere R (cm)	Magnetic field intensity H (kOe)	Magnetic force Calc (dyn)	Magnetic force Exptl (dyn)
7	1.0	7.0	8.2
6	1.5	17.0	18.0
5	2.0	34.0	36.0
4	2.5	63.0	68.0
3	3.0	108.0	110.0
2	4.2	266.0	281.0
1	5.7	658.0	647.0

Figure 5 shows the set-up for measuring the magnetic force acting on a spherical particle in the wedge. Instead of measuring the expulsive force, a special thimble was used with a spherical cavity filled with a magnetic liquid of known susceptibility. By means of this thimble, suspended in the field, the magnetic force may be varied along the vertical axis. Results are shown in Table 3.

Figure 6 shows the set-up used for separation of the four-component mixture. The equilibrium levels of the particles in an aqueous solution of manganese chloride are shown in Table 4.

The feasibility of simultaneous separation of nonferrous metals and

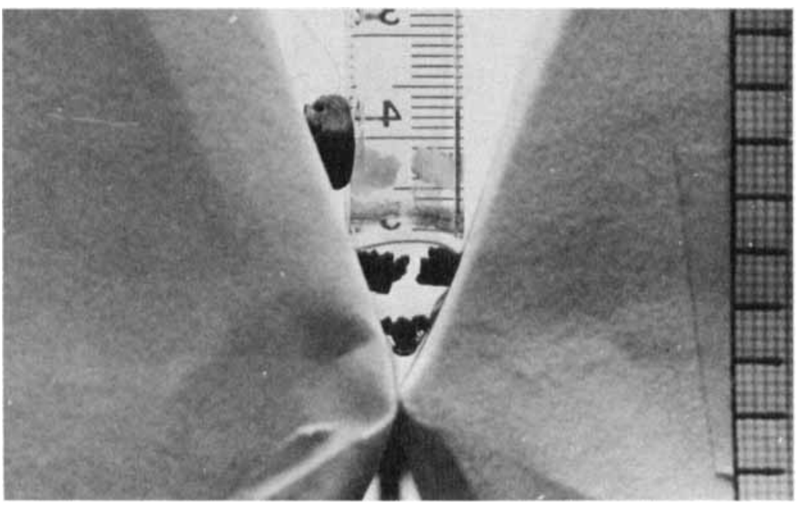

FIG. 6. Equilibrium levels of the four types of particles.

TABLE 4
Equilibrium Levels of Particles in Wedge-Shaped Gap

Materials	Mass density (g/cm^3)	Current 2 A		3.8 A		5.0 A	
		R_{calc}	R_{exptl}	R_{calc}	R_{exptl}	R_{calc}	R_{exptl}
Copper	8.0	0.10	0.0	0.57	0.47	0.75	0.67
Aluminum	2.7	1.38	1.30	1.65	1.50	1.95	1.87
Sulfur	2.0	1.72	1.80	2.30	2.30	2.65	2.68
Porous magnesite	1.7	2.13	2.20	3.15	3.20	3.40	3.48

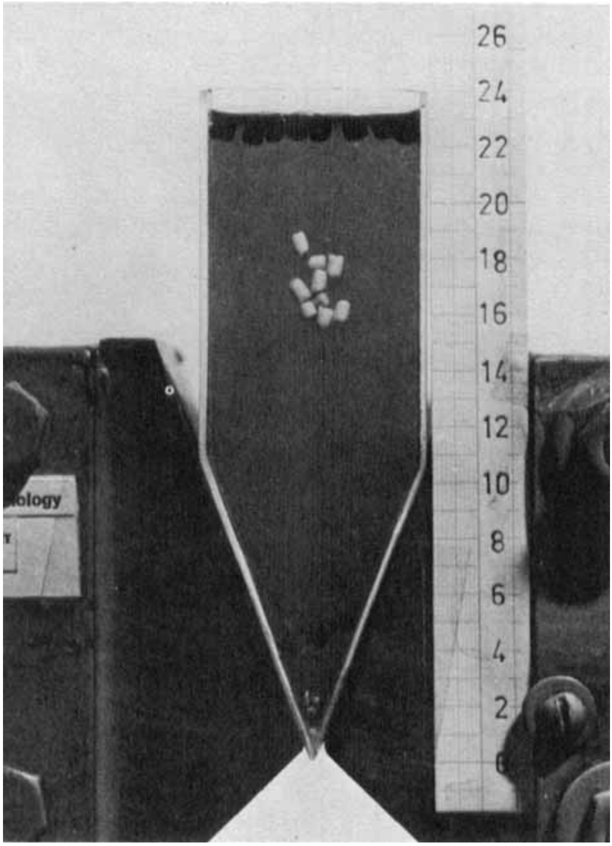

FIG. 7. Simultaneous separation of nonferrous metals and plastics.

plastics is illustrated in Fig. 7. The fractions obtained consisted of copper, aluminum, PVC, and PS. Suitable separators may thus be designed according to the principle described above.

SUMMARY

The feasibility of MHD jigging for recovery of classified plastics from unincinerated municipal waste was demonstrated using sintered magnets and NaCl or alkalies as electrolyte.

Another interesting possibility of fine separation of plastics according

to mass density was demonstrated by the MHS technique. A special separator based on this principle is feasible.

An important distinctive feature of the processes is the possibility of calculating their design elements and the high resolving power of the separators.

REFERENCES

1. *Report of Subcommittee on Solid Waste Pollution*, Israel National Committee on Biosphere and Environment, Jerusalem, 1973.
2. *Recovery and Utilization of Municipal Solid Waste*, Solid Waste Management Office, U.S. Environmental Protection Agency, Washington, D.C., 1971.
3. J. Shramm and R. Blanchard, *The Use of CPE as a Compatibilizer for Reclamation of Waste Plastic Materials*, Technical Service and Development, Plastic Department, Dow Chemical Co., Plaquemine, Louisiana, 1972.
4. J. L. Holman et al., *Processing the Plastics from Urban Refuse*. U.S. Bureau of Mines, Technical Progress Report (TRP 50), 1972.
5. M. R. Grubbs and K. H. Ivey, *Recovering Plastics from Urban Refuse by Electrodynamic Techniques*, U.S. Bureau of Mines, Technical Progress Report (TRP 63), 1972.
6. S. E. Khalafalla and G. W. Reimers "Separating Nonferrous Metals in Incinerator Residue," *Separ. Sci.*, *8*, 161–178 (1973).
7. J. S. Wiley, "Some Specialized Equipment Used in European Compact Systems," *Compost Sci.*, *4*, 7–10 (1963).
8. U. C. Andres and V. Kinareevskii, "Stratification of Grain Layer under Periodic Electromagnetic Expulsion, *Tr. Inst. Goryuchikh Iskopaemykh*, *23*, 37–42 (1965).
9. D. Leenov and A. Kolin, "Theory of Electromagnetophoresis, *J. Chem. Phys.*, *22*, 4 (1959).
10. J. Gould, *Cobalt Alloy Permanent Magnets*, Centre d'information du Cobalt, Brussels, 1971.
11. J. Walkiewicz et al., *Preparation of Samarium–Cobalt Permanent Magnets*, U.S. Bureau of Mines, Report of Investigation N7784, 1973.
12. U. C. Andres et al., "MHS Separation," *Zh. Prikl. Mekh. Tekhn. Fiz.*, *3*, 158–162 (1966).
13. U. C. Andres, "Foundations of Magnetohydrodynamic and Magnetohydrostatic Separation of Minerals," Synopsis of Doctoral Thesis, Institute of Steel and Alloys, Moscow, 1972.
14. I. J. Lin and U. Andres, "Separation of Comminuted Mixed Plastic Waste in Magnetic Fields, E_3–E_{12}," in 5th Scientific Conference of the Israel Ecological Society, Tel-Aviv, May 8, 1974.

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