Magnetic Separation News, 1983, Vol. 1, pp. 37–43
0731-3632/83/0101-0037 $25.00 0

Printed in the United Kingdom

MAGNETOHYDRODYNAMICAL SEPARATION - WHATEVER HAPPENED?

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Abstract Magnetohydrodynamical separation has been developed in the eastern bloc with apparent success but has largely been ignored by western science. Here a simple, theoretical examination of the technique is undertaken and its potential for particle separation is demonstrated to a degree that poses the question- why has this technique not been fully explored in the west?

INTRODUCTION

In the 1950s Kolin[1] and Leenov and Kolin[2] regenerated interest in the previously known magnetohydrodynamical (MHD) technique of separating particulate matter of differing electrical conductivity. Subsequently, Andres and others[3-4-5] developed laboratory separators successful in the cleaning of coal fines and reported the testing of high capacity separators for the coal preparation and tin ore industries.

English language reports from the east then became scarce and western science has been slow to take up the promise offered by these works. In consequence, we decided to set aside possible practical difficulties and conduct a simple theoretical study of the capability of basic MHD separators operating in various modes. The results are encouraging and will lead to a more practical investigation.

The MHD technique is based on the fact that a particle of

conductivity σ_p in a conducting fluid of conductivity σ_f that carries a current of density $\underline{J}$ crossed with a magnetic flux density $\underline{B}$ experiences a force that is mutually perpendicular to both $\underline{J}$ and $\underline{B}$. Leenov and Kolin[2] show that the magnitude of this force on a spherical particle of volume V is $\frac{3}{4}BJV$ if $\sigma_p << \sigma_f$; is $-\frac{3}{2}BJV$ if $\sigma_p >> \sigma_f$ and is $\frac{\Delta\sigma}{2\sigma}BJV$ if $\sigma_p \simeq \sigma_f \simeq \sigma$ and $\Delta\sigma$ is $\sigma_p - \sigma_f$. Several facts immediately become clear. First, if $\underline{B}$ and $\underline{J}$ are constant over the volume of the MHD cell then the force is constant. Second, the force is dispersive for particles of different conductivity and/or different volume and third, because the force is constant it will be dispersive for particles that spend different times - the residence time t_r - in the cell and so seperate particles of different density.

PRACTICAL MODES OF OPERATION OF AN MHD CELL

To operate a basic MHD cell (see fig.1) the direction of particle

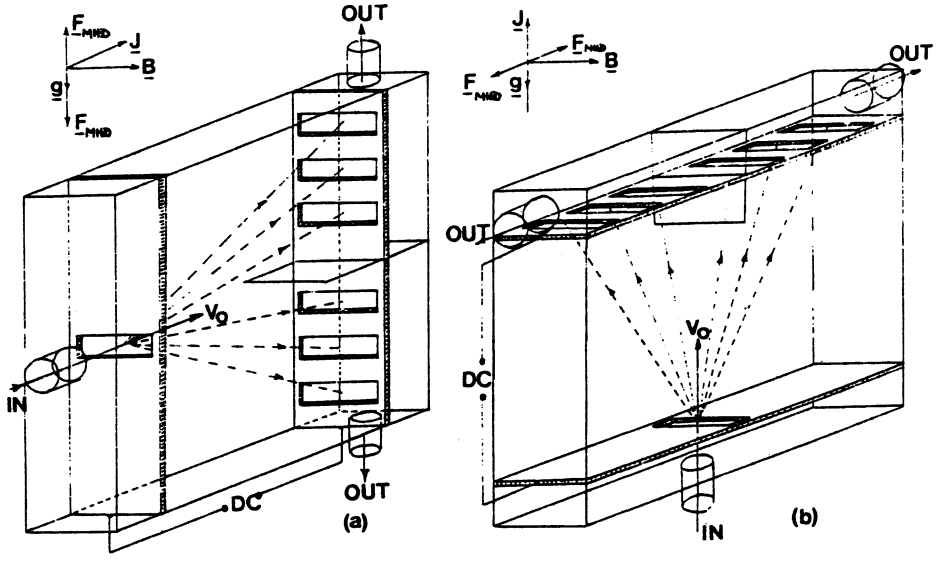

FIGURE 1 Practical operational configurations of MHD cells

deflection must be perpendicular to the initial direction of particle motion through the cell. Thus particle motion must be parallel to either $\underline{B}$ or $\underline{J}$. Practical considerations suggest that $\underline{B}$ be made parallel to a short side of the cell and that particle motion should be parallel to a long side. This maximises $\underline{B}$ and t_r. Hence the two configurations shown in fig.1 are the basic sensible options. That of fig. 1a (but in a more sophisticated form) was used by Andres et al[4-5] to clean coal fines.

There the MHD force was used to assist or counter gravity and these workers used a parameter α- the ratio of weight to MHD force, to determine separation. We examine the alternative configuration of fig.1b where gravity does not directly contribute to the deflection and so prefer to use, as our separation parameter, the ratio of the terminal MHD induced velocity (V_{MHD}) to the vertical particle velocity (V_{op}) - a ratio more traditional in the magnetic separation field.

PARTICLE TRAJECTORIES

If particles, mass m, radius r, are carried vertically (z-direction) upwards with a velocity V_{op} by a fluid stream of velocity V_o and enter, at time t=0, a region of horizontal (x-direction) MHD force then the vertical motion is described by $z=V_{op}t$. If Stokes' drag is applicable then the horizontal velocity imparted is

$$V_x = V_{MHD} \left(1 - \exp\left(\frac{-kt}{m}\right) \right)$$

where $k=6\pi r\eta$ and η is the viscosity of the particle-fluid mix. Thus the horizontal deflection at time t is

$$x = V_{MHD}t + V_{MHD}\frac{m}{k}\left(\exp\left(\frac{-kt}{m}\right) - 1 \right)$$

giving a trajectory.

$$x = \frac{V_{MHD}}{V_{op}} z + V_{MHD} \frac{m}{k} \left(\exp\left(\frac{-kz}{mV_{op}}\right) - 1\right) \qquad (1)$$

Here we consider particles of radii 10 to 90μm and density $2x10^3$ to $6x10^3 Kgm^{-3}$ in a fluid of viscosity $10^{-3} Nsm^{-2}$ and density $10^3 Kgm^{-3}$. Thus the second term on the RHS of Eq.(1) is negligible and the equation simply becomes

$$x = \frac{V_{MHD}}{V_{op}} z \quad \text{or} \quad x = V_{MHD}\, t_r \qquad (2)$$

If $\underline{B} \sim 1T$ and $J \sim 10^4 Am^{-2}$ then the MHD force, F_{MHD}, is approx-$3.14x10^4 r^3 N$ for non-conducting particles. Now $V_{MHD} = F_{MHD}/k$ and so ranges from $3.34x10^{-4} ms^{-1}$ ($r = 10\mu m$) to $1.35x10^{-2} ms^{-1}$ ($r = 90\mu m$). These figures can be adjusted by varying $\underline{B}$ and/or $\underline{J}$. Given a V_{MHD}, any particle deflection can then be chosen by selecting the appropriate value of V_o as this determines V_{op} which then gives t_r and thus x.

VERTICAL SPEEDS OF PARTICLES AND FLUID

In the configuration of fig. 1b particles initially travel upwards with a speed

$$V_{op} = V_o - \frac{2r^2 g}{9\eta}(\rho_p - \rho_f) \qquad (3a)$$

where g is the acceleration due to gravity and the ρ's signify densities. The limitations of this mode are clear. The value of V_o must be sufficiently high to 'lift' the heaviest particles of a mix but not so high as to cause t_r to be too low for the lightest particles. However, cell inversion allows other modes of operation for this configuration:- the particles could be allowed to sink in a stationary fluid, then

$$V_{op} = \frac{2r^2 g}{9\eta}(\rho_p - \rho_f) \qquad (3b)$$

or, the particles could be allowed to sink in a rising or falling fluid column giving

$$V_{op} = \frac{2r^2 g}{9\eta}(\rho_p - \rho_f) \mp V_o \qquad (3c)$$

where the negative alternative applies to the contra-flow mode. With the alternatives afforded by Eqs.(3) it should be possible to select the required t_r, and thus deflection, for any particle and thereby allow the separator to be 'tuned' to the problem in hand.

TYPICAL TRAJECTORIES

Fig 2a shows trajectories, calculated using Eqs. (2) and (3a), of non-conducting particles, density $3\times10^{3}\mathrm{Kgm}^{-3}$, of varying radii given a BJ of $10^{4}\mathrm{TAm}^{-2}$ and a V_o of $5\times10^{-2}\mathrm{ms}^{-1}$. Dispersion of particles of different size is substantial and increases as r increases. It should afford the geometric splitting of the mix into different output channels according to size. If the dispersion of the 10 and 30μm particles is inadequate then they could be collected initially in the same output channel and then recycled with a $V_o = 10^{-2}\mathrm{ms}^{-1}$, say, resulting in the dotted trajectories of fig. 2a.

Also important is the dispersion of particles of a mix by virtue of density difference. Fig. 2b shows trajectories for 50μm particles of similar σ_p but of varying density when carried upward by a fluid with $V_o = 0.03\mathrm{ms}^{-1}$. The degree of dispersion is again seen to be substantial and increases with density.

Figs. 2a and 2b can also be used to visualise dispersion by difference in σ_p; as in all cases the deflection for particles with $\sigma_p >> \sigma_f$ are twice those shown and in the opposite direction.

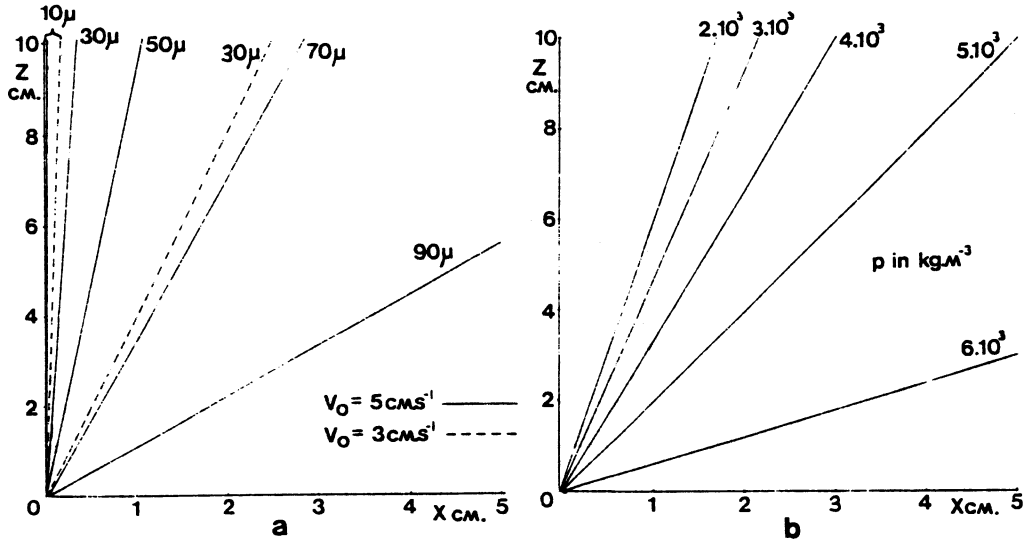

FIGURE 2 Examples of trajectories of particles (a) of the same density ($3x10^3 Kgm^{-3}$) but of different radii and (b) of the same radius (50μm) but of different density.

CONCLUSIONS

These simple calculations serve to demonstrate the potential power of MHD separation techniques and cause one to wonder why MHD separation has not been persued more vigorously in the west. Perhaps the answer lies in the possible practical difficulties involved: vortex motion of the fluid; transport of particles through charged plates; collision processes when trajectories cross; heating of the electrolyte; chemical evolution of the electrolyte and gaseous release etc. etc..... The list can be as daunting as the prospects are exciting. But if the difficulties have largely been overcome in the east, then why not in the west?

REFERENCES

1. A. Kolin, Science, 117, 134 (1953)
2. D. Leenov and A. Kolin, J.Chem. Phys,22(4), 683 (1954)
3. U. Ts. Andres, L.S. Polak and S.I. Syrovatskii, Soviet Physics- Technical Physics 8 (3), 193 (1963)
4. U.Ts. Andres and V.A. Kinareevskii, Koks Khim, No. 3, 12,(1965)
5. U. Andres, Min. Sci. Engng, 7 (2), 99, (1975)