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A STUDY OF THE CONDITIONS OF MAXIMUM FILTRATION EFFICIENCY FOR A HGMF - AXIAL MAGNETIC FILTER CELL WITH BOUNDED FLOW FIELD

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Abstract The theory of magnetic particles' capture on a HGMF-axial magnetic filter cell with bounded flow field is presented. The equations of particle motion for both potential and laminar flow are obtained. By analytical solving of these equations, the trajectories of particles are established. The flow velocity of the fluid suspension for the case of potential flow is set equal with the velocity averaged across the tube section for the laminar flow. Thus, it is possible to make a comparison between the capture process in laminar and potential flows. The capture time and the capture cross-section are calculated. Finally, a criterion for maximum filtration efficiency is presented.

INTRODUCTION

The HGMF magnetic filters have as principal element the ferromagnetic matrix, that it is designing by ferromagnetic wires that are magnetizated by a magnetic field applied perpendicularly to them axes[1,2]. All the models analyzed until now consider that the ferromagnetic matrix is wetted by the fluid suspension[3,4]. For practical reasons (as such anticorrosive and antierrosive protection of the ferromagnetic wires) we have analyzed, in a few previously works, a new HGMF magnetic filter cells[5,6]. For these filtration cells, the ferromagnetic wires are placed outside the flow field. In the case of axial configuration, for which the fluid suspension flows parallely to the collecting wire, the ensemble consists in a ferromagnetic wire placed outside to a cylindrical tube that bound the flow field.

The analysis is based on the particle trajectory method and has been done considering the carrier fluid viscous in relation to particles and non-viscous or viscous in relation to the inside tube wall. By analyzing the trajectories of individual particles inside the clean tube (without previous buildup), the capture cross-section and the conditions of maximum particles' recovery are determined.

TRAJECTORY EQUATIONS

We shall analyse the trajectory of a particle in the system presented in Fig.1. The cylindrical ferromagnetic wire of radius a, length L and saturation magnetisation M_s is fixed along the Oz axis and magnetised to the saturation by a magnetic field with the intensity H_0, applied along the Ox axis. The cylindrical tube with inner radius R and length L, is fixed along O'z' axis, coplanar with the Oz axis in the plane $y = 0$, at a distance d.

A spherical paramagnetic particle with radius b and magnetic susceptibility χ_p is carried by a fluid with magnetic susceptibility χ_f. We consider the particle small enough to neglect its weight and inertia.

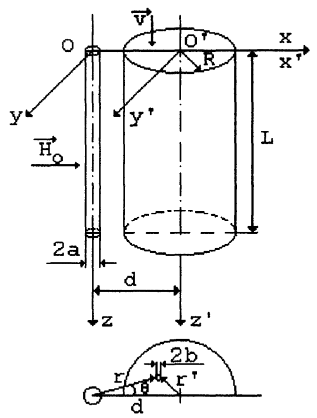


Fig.1 Schematic diagram of the system analyzed.

The magnetic force exerted on the particle has the following components expressed in cylindrical coordinates:

$$F_{Mr} = -\mu_0 V_p \chi M_s a^2 \left(\frac{M_s a^2}{r^5} + \frac{H_0}{r^3} \cos 2\theta \right) \tag{1a}$$

$$F_{Mr} = -\mu_0 V_p \chi M_s a^2 \frac{H_0}{r^3} \sin 2\theta \tag{1b}$$

$$F_{Mz} = 0 \tag{1c}$$

where $\chi = \chi_p - \chi_f$, V_p = particle volume ($= 4\pi b^3 / 3$) and $\mu_0 = 4\pi \times 10^{-7}$ H/m is the magnetic permeability of the void space. The hydrodynamic drag force on the particle has the components:

$$F_{Dr} = 6\pi\eta b \left(v_r - \frac{dr}{dt} \right) \tag{2a}$$

$$F_{D\theta} = 6\pi\eta b\left(v_\theta - r\frac{d\theta}{dt}\right) \quad (2b)$$

$$F_{Dz} = 6\pi\eta b\left(v_z - \frac{dz}{dt}\right) \quad (2c)$$

where η is the dynamic viscosity of the carrying fluid.

For potential flow and laminar flow completely established inside the tube $v_r = v_\theta = 0$. For the potential flow $v_z = v_0$ and for the laminar flow v_z has a parabolic distribution given by the Hagen-Poiseuille's law, written as:

$$v_z = 2\bar{v}\frac{R^2 - r'^2}{R^2} \quad (3)$$

where $\bar{v}$ is the velocity averaged across the tube section. The relation (3) was written in a reference system attached to the tube axis. According to Fig.1, $r'^2 = r^2 + d^2 - 2rd\cos\theta$, so that (3) becomes:

$$v_z = \bar{v}\frac{2}{R^2}\left(R^2 - r^2 - d^2 + 2rd\cos\theta\right) \quad (4)$$

In the following we shall analyse apart the trajectories for the potential and laminar flows hydrodynamically equivalent to each other. The equivalence condition is considered to be $v_o = \bar{v}$.

a) The potential flow.

The equations of particle motion are:

$$-\mu_0 V_p \chi M_s a^2\left(\frac{M_s a^2}{2r^5} + \frac{H_0}{r^3}\cos 2\theta\right) + 6\pi\eta b\left(-\frac{dr}{dt}\right) = 0 \quad (5a)$$

$$-\mu_0 V_p \chi M_s a^2 \frac{H_0}{r^3} \sin 2\theta + 6\pi\eta b\left(-r\frac{d\theta}{dt}\right) = 0 \tag{5b}$$

$$6\pi\eta b\left(v_0 - \frac{dz}{dt}\right) = 0 \tag{5c}$$

The equations (5) can be written as:

$$\frac{dr_a}{dt} = -\frac{v_m}{a}\left(\frac{K}{r_a^5} + \frac{\cos 2\theta}{r_a^3}\right) \tag{6a}$$

$$r_a \frac{d\theta}{dt} = -\frac{v_m}{a}\frac{\sin 2\theta}{r_a^3} \tag{6b}$$

$$\frac{dz_a}{dt} = \frac{v_0}{a} \tag{6c}$$

where: $v_m = (2\mu_0 \chi H_0 M_s b^2 / 9\eta a)$ is the 'magnetic velocity' [1], a coefficient with the dimensions of a velocity (having also the significance of the particle terminal velocity in the (r,θ) plane under the concurrent influence of the magnetic and drag forces at $r_a = 1$ and $\theta = 0$); $K = (M_s / 2H_0)$ for $H_0 \geq (M_s / 2)$ and $K = 1$ for $H_0 < (M_s / 2)$; the subscript a denotes, here and in the following, that the corresponding parameters will be reported to the ferromagnetic wire radius, if it represents a length, or reported to the squared radius of the ferromagnetic wire if it represents a surface.

By eliminating the time in the equations (6a) and (6b)[3], one obtain the differential equation:

$$\frac{dr_a}{d\theta} = \frac{K}{r_a \sin 2\theta} + r_a \cot 2\theta \tag{7}$$

whose solution represents the equation of trajectory in the (r,θ) plane and has the form:

$$r_a^2 = C\sin 2(\theta - \alpha) \tag{8}$$

In the eqn.(8), C and α are two constants depending on r_{a_0} and θ_0 , the initial values of r_a and θ. Excepting for the case when $\sin 2\theta_0 = 0$, which, in analyzed system, corresponds to $\theta_0 = 0$, they have the expressions:

$$C = \frac{\left(r_{a_0}^4 + 2K^2 r_{a_0}^2 \cos 2\theta_0 + K\right)^{1/2}}{\sin 2\theta_0} \tag{9}$$

$$\alpha = \frac{1}{2}\arctan\frac{K\sin 2\theta_0}{r_{a_0}^4 + K\cos 2\theta_0} \tag{10}$$

The particle trajectory will meet the inside tube surface at a point of coordinates r_{a_f} and θ_f, determined by the system of equations:

$$r_{a_f}^2 = C\sin 2(\theta_f - \alpha) \tag{11a}$$

$$r_{a_f}^2 + d_a^2 - 2r_{a_f}d_a\cos\theta_f = R_a^2 \tag{11b}$$

Since $r_{a_0} > d_a - R_a > 1$, from (10) it follows that $\alpha \approx 0$ and $C \cong \frac{{r_{a_0}}^2}{\sin 2\theta_0}$. At the same time, since d_a is not much larger than R_a , the solution of the system(11) can be approximated by:

$$r_{a_f} \approx d_a - R_a \tag{12a}$$

$$\theta_f \approx 0 \tag{12b}$$

By eliminating the time from (6b) and (6c) and taking into account (8) where $\alpha = 0$ was introduced, one gets the equation:

$$\frac{dz_a}{d\theta} = -\frac{v_0}{v_m}C^2\sin 2\theta \tag{13}$$

which, after the integration, gives the equation of trajectory in terms of z and θ.

$$z_a = \frac{v_0}{v_m}\frac{C^2}{2}\left(\cos 2\theta - \cos 2\theta_0\right) \tag{14}$$

When $\theta_0 = 0$, $\theta = 0$ all along the trajectory. In this case, it is useful to eliminate the time from the eqns.(6a) and (6c), which gives:

$$\frac{dz_a}{dr_a} = -\frac{v_0}{v_m}\frac{r_a^5}{K + r_a^2} \tag{15}$$

i.e. the differential equation describing the particle motion in the (x,y) plane. Its solution gives the particle motion in this plane:

$$z_a = -\frac{v_0}{v_m}\left[\frac{1}{4}\left(r_a^4 - r_{a_0}^4\right) - \frac{K}{2}\left(r_a^2 - r_{a_0}^2\right) + \frac{K^2}{2}\ln\frac{K + r_a^2}{K + r_{a_0}^2}\right] \tag{16}$$

We can notice that, even if the flow was considered non-viscous in relation to the tube, z_a depends on the fluid viscosity by means of v_m, since the fluid considered viscous in relation to the particle.

b) Laminar flow.

For the laminar flow, the r and θ components of the equation of motion are identical with those corresponding to the potential flow, i.e. (6a),(6b), respectively. The equation of motion in terms of z is different. After replacing v_z from (4) in (2c), one obtains:

$$\frac{dz_a}{dt} = \frac{\bar{v}}{a}\frac{2}{R_a^2}\left(R_a^2 - r_a^2 - d_a^2 + 2r_a d_a \cos\theta\right) \tag{17}$$

The trajectory equation in terms of r and θ is identical to that for potential flow.

After eliminating the time from eqns. (17) and (6b) one obtains the differential equation:

$$\frac{dz_a}{d\theta} = -\frac{\bar{v}}{v_m}\frac{2}{R_a^2}\frac{\left(R_a^2 - r_a^2 - d_a^2 + 2r_a d_a \cos\theta\right)r_a^4}{\sin 2\theta} \tag{18}$$

which describes the motion along the z-axis for the cases $\theta_0 \neq 0$. The analytical solution of eqn.(18), obtained after replacing r_a from (8) with $\alpha = 0$, is:

$$z_a = \frac{\bar{v}}{v_m}\frac{2}{R_a^2}\left[C^3 I_1(\theta) + C^2\left(d_a^2 - R_a^2\right)I_2(\theta) - 2d_a C^{5/2} I_3(\theta)\right] \tag{19}$$

where:

$$I_1(\theta) = \int_{\theta_0}^{\theta} \sin^2 2\theta d\theta = \frac{1}{2}(\theta - \theta_0) - \frac{1}{8}(\sin 4\theta - \sin 4\theta_0) \tag{20a}$$

$$I_2(\theta) = \int_{\theta_0}^{\theta} \sin 2\theta d\theta = -\frac{1}{2}(\cos 2\theta - \cos 2\theta_0) \tag{20b}$$

$$\begin{aligned} I_3(\theta) &= \int_{\theta_0}^{\theta} \cos\theta(\sin 2\theta)^{3/2} d\theta = \\ &= \frac{3}{16}\arctan\frac{(1-\tan\theta_0)\sqrt{2\tan\theta} - (1-\tan\theta)\sqrt{2\tan\theta_0}}{(1-\tan\theta)(1-\tan\theta_0) + 2\sqrt{\tan\theta\tan\theta_0}} + \\ &+ \frac{3}{32}\ln\frac{\left(1+\tan\theta+\sqrt{2\tan\theta}\right)\left(1+\tan\theta_0-\sqrt{2\tan\theta_0}\right)}{\left(1+\tan\theta-\sqrt{2\tan\theta}\right)\left(1+\tan\theta_0+\sqrt{2\tan\theta_0}\right)} + \\ &+ \cos^2\theta\sqrt{\frac{\tan\theta}{2}}\left(\frac{1}{4} - \cos^2\theta\right) - \cos^2\theta_0\sqrt{\frac{\tan\theta_0}{2}}\left(\frac{1}{4} - \cos^2\theta_0\right) \end{aligned} \tag{20c}$$

One can notice that for the analyzed model, the analytical solution of the equation (18) is exact and unique for the whole cross section of the flow field, as compared to the approximate solutions dependent on the place around the ferromagnetic wire, obtained in [4] and [7] for analogous problems.

For the cases when $\theta_0 = 0$, θ remains null all along trajectory and it is useful to eliminate the time from eqns. (17) and (6a), which gives:

$$\frac{dz_a}{dr_a} = \frac{\bar{v}}{v_m}\frac{2}{R_a^2}\frac{\left[(r_a - d_a)^2 - R_a^2\right]r_a^5}{K + r_a^2} \tag{21}$$

The solution of this differential equation represents the equation of particle trajectory in the (x,y) plane under the condition of laminar flow. It is:

$$z_a = \frac{\bar{v}}{v_m}\frac{2}{R_a^2}\left[\left(d_a^2 - R_a^2\right)J_1(r_a) - 2d_aJ_2(r_a) + J_3(r_a)\right] \tag{22}$$

where

$$\begin{aligned} J_1(r_a) &= \int_{r_{a0}}^{r_a}\frac{r_a^5}{K + r_a^2}dr_a = \frac{1}{4}\left(r_a^4 - r_{a0}^4\right) - \frac{K}{2}\left(r_a^2 - r_{a0}^2\right) + \\ &+ \frac{K^2}{2}\ln\frac{K + r_a^2}{K + r_{a0}^2} \end{aligned} \tag{23a}$$

$$\begin{aligned} J_2(r_a) &= \int_{r_{a0}}^{r_a}\frac{r_a^6}{K + r_a^2}dr_a = \frac{1}{5}\left(r_a^5 - r_{a0}^5\right) - \frac{K}{3}\left(r_a^3 - r_{a0}^3\right) + \\ &+ K^2\left(r_a - r_{a0}\right) - K^{5/2}\left(\arctan\frac{r_a}{\sqrt{K}} - \arctan\frac{r_{a0}}{\sqrt{K}}\right) \end{aligned} \tag{23b}$$

$$\begin{aligned} J_3(r_a) &= \int_{r_{a0}}^{r_a}\frac{r_a^7}{K + r_a^2}dr_a = \frac{1}{6}\left(r_a^6 - r_{a0}^6\right) - \frac{K}{4}\left(r_a^4 - r_{a0}^4\right) + \\ &+ \frac{K^2}{2}\left(r_a^2 - r_{a0}^2\right) - \frac{K^3}{2}\ln\frac{K + r_a^2}{K + r_{a0}^2} \end{aligned} \tag{23c}$$

We remark once again the exactness and uniqueness of the solution of equation (21), as compared to those obtained for similar problems in the models analyzed in [4] and [7].

Fig.2 presents apart four trajectories for each of the two flow modes. The four sets of initial conditions are the same for the two cases, namely in the O'x'y'z' reference system (Fig.1), $r_0' = R$, $\theta_0' = 0$; $\pi/4$; $\pi/2$; $3\pi/4$. The characteristic parameters are $R_a = 6$; $d_a = 8$; K = 0.8 and $v_m / \bar{v}$ = 31.94. One can remark

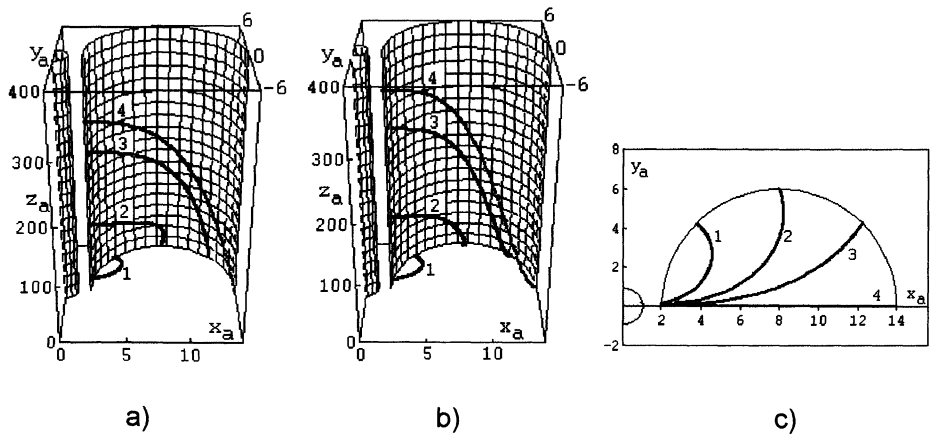


Fig.2 Trajectories in potential and laminar flow: (a) potential flow trajectories; (b) laminar flow trajectories; (c) trajectory projections in the (r , θ) plane. The initial conditions are the same for the two namely in the $O'x'y'z'$ reference system: $r_0' = R$ and $\theta_0' = \pi/4$ (curve 1), $\theta_0' = \pi/2$ (2), $\theta_0' = 3\pi/4$ (3), $\theta_0' = 0$ (4).

the coincidence of the trajectories' projection on the (r,θ) plane for the two cases and the fact that the approximate solutions of the system (11) are very closed to its real solutions (Fig.2c). The trajectories are different along the z-axis, with particular significance for z_f, the zs coordinate of the cross point of the trajectories with the inner tube surface. One can notice that the capture length for the potential flow is every time smaller than for laminar flow, which contradicts the result of the analyses of the model given in [4]. Accordingly, the capture cross-section associated to a given filtering cell is different for the two flow modes.

The analytical solutions (19) and (22) have as characteristic parameter the ratio $\bar{v}/v_m$, as compared to the ratio P_0/P_m used in [7] to describe another magnetic capture system, also based on the axial HGMS configuration. In this last ratio, P_0 stands for the pressure difference in the tube of the length L, and $P_m = (8\mu_0 \chi H_0 M_s L_a b^2 / 9a^2)$ is the coefficient with the dimensions of the pressure, whence its name of 'magnetic pressure coefficient'. Using the ratio $\bar{v}/v_m$ implies the dependence of the z_a coordinate of the viscosity of the carrying fluid, through v_m. In our analysis, we are interested in the particle capture condition for a given $\bar{v}$, irrespective of the condition in which this velocity was obtained.

CAPTURE CROSS-SECTION

The differential equation (6b) with (8) enables the calculation of the time necessary for a particle to be captured on the inner surface of the tube which bounded the flow field:

$$T_c = \int_{\theta_0}^{\theta_f} \left(\frac{dt}{d\theta}\right) d\theta = \frac{a}{v_m} \frac{{r_{a_0}}^4}{\sin^2 2\theta_0} \begin{bmatrix} \sin(\theta_0 + \theta_f - 2\alpha)\sin(\theta_0 - \theta_f) + \\ + \frac{1}{2}\sin^2 2\alpha \ln\left(\frac{\tan\theta_0}{\tan\theta_f}\right) \end{bmatrix} \tag{24}$$

where θ_f, α and C has been previously evaluated. As it has presented above, we can set θ_f, $\alpha \approx 0$ and $C \approx \frac{{r_{a_0}}^2}{\sin 2\theta_0}$, and thus (24) becomes:

$$T_c \cong \frac{a}{4v_m} \frac{r_{a_0}^4}{\cos^2 \theta_0} \tag{25}$$

In the following we shall analyze the capture condition for the potential and laminar flows taking into account the equivalence $v_o = \overline{v}$. This condition is that the capture time must be less than the traveling time of the particle in magnetically active space.

The traveling time can be written as:

- *potential flow:*

$$T_p = \frac{L}{\overline{v}} \tag{26a}$$

- *laminar flow:*

$$T_\ell = \frac{L}{\overline{v}'} \tag{27}$$

where $\overline{v}'$ is the velocity averaged across the particle's trajectory and that it is a function of initial coordinates. If we consider that the most severe capture condition is for the particle entering in magnetically active space through the point situated diametrically opposed to the ferromagnetic wire, $\overline{v}'$ for this particle is:

$$\overline{v}' = \frac{1}{R}\int_0^R v_z(r)\mathrm{d}r = \frac{4}{3}\overline{v} \tag{28}$$

Eqn.(27) becomes:

$$T_\ell = \frac{3}{4}\frac{L}{\overline{v}} \tag{26b}$$

The capture conditions will be:

- *for potential flow*

$$T_c \leq T_p \;\Rightarrow\; \frac{r_{a0}^2}{\cos\theta_0} \leq 2\sqrt{\frac{L}{a}\frac{v_m}{\overline{v}}} \tag{29a}$$

- *for laminar flow*

$$T_c \leq T_\ell \;\Rightarrow\; \frac{r_{a0}^2}{\cos\theta_0} \leq \frac{3}{2}\sqrt{\frac{L}{a}\frac{v_m}{\overline{v}}} \tag{29b}$$

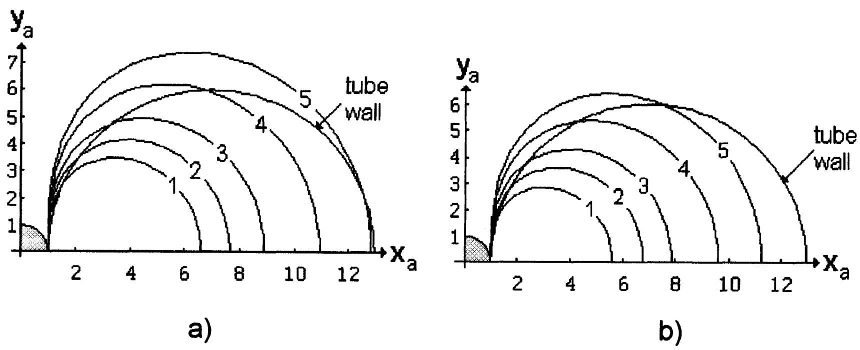


Fig.3 Capture cross-sections for the following conditions: $R_a = 6$, $d_a = 7$ and L= 20, $\frac{v_m}{\overline{v}}$=10 (curve 1), L= 50, $\frac{v_m}{\overline{v}}$=10 (2), L= 100, $\frac{v_m}{\overline{v}}$=10 (3), L= 100, $\frac{v_m}{\overline{v}}$=25 (4), L= 100, $\frac{v_m}{\overline{v}}$=50 (5) for a) potential flow; b) laminar flow

Eqns.(29) are the capture conditions for a particle entering the magnetically active space through the cross-section of the tube of radius R and that will meet the inside surface of the tube up to the length L. These conditions can be represented as curves in the entering plane which divide this plane in two surfaces (Fig.3). The surface next to the ferromagnetic wire is called capture cross-section. All the particles which entering the magnetically active space through this surface will be captured before them leave the filter cell.

Capture cross-section can be obtained by following integration

- *for potential flow:*

$$S_{c_p} = 2\int_0^{r_0}\int_0^{\pi/2} r_0 dr_0 d\theta_0 = 2a^2\sqrt{\frac{L}{a}\frac{v_m}{\bar{v}}} \tag{30a}$$

- *for laminar flow:*

$$S_{c_\ell} = 2\int_0^{r_0}\int_0^{\pi/2} r_0 dr_0 d\theta_0 = \frac{3}{2}a^2\sqrt{\frac{L}{a}\frac{v_m}{\bar{v}}} \tag{30b}$$

According to (30), the capture cross-section depends on the constructive (L,a) and operational parameters (H_0 , M_s , η , b , χ - which are included in expression of the magnetic velocity) of the filter cell. By means of this variable, we can give a criterion for 100% filter efficiency: for a maximum recovery the capture cross-section must surrounds the tube cross-section(ex. curve 5 in Fig.3a)

$$S_c \geq S \Rightarrow S_c \geq \pi R^2 \tag{31}$$

By substituting (30) in (31) one obtain an inequality between constructive and operational parameters of filter cell, which represents the condition of maximum particle recovery:

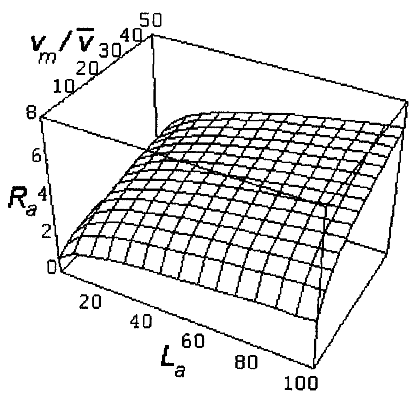
- *for potential flow:*

$$R_{a_p} \le \left(\frac{4L_a}{\pi^2}\frac{v_m}{\bar{v}}\right)^{\frac{1}{4}} \tag{32a}$$

- *for laminar flow:*

$$R_{a_\ell} \le \left(\frac{9L_a}{4\pi^2}\frac{v_m}{\bar{v}}\right)^{\frac{1}{4}} \tag{32b}$$

In designing a filtration cell or process with 100% efficiency, the condition (32) can be easily considered by using the diagram in Fig.4, which presents the



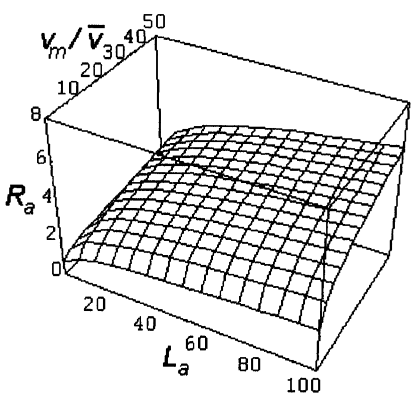


Fig.4 Dependence R_a *vs.* $\left(L_a, \frac{v_m}{\bar{v}}\right)$ for a) potential flow; b) laminar flow.

dependence R_a vs. $\left(L_a, \frac{v_m}{V}\right)$ by means of a surface separating the cell parameters' space into two zones. If the cell parameters determine a point placed above this surface the cell will work with less than 100% filtration efficiency. If the point is under this surface, the filtering efficiency is 100%.

From Fig.4, it can be noticed that the condition for maximum recovery is more restrictive for laminar flow compared with the potential flow, as we expected.

CONCLUSIONS

The axial HGMF filtration cell with bound flow field analyzed in this work presents certain obvious practical advantages: anticorrosive and antierosive protection of the ferromagnetic matrix, a 100% filtration efficiency, the possibility to choose the optimum constructive and operational parameters for reaching this efficiency. The optimisation of the filtration efficiency consists in choosing the constructive and operational parameters which ensure the capture of the particles entering the magnetically active space up to the length of the cell tube. We defined the capture cross-section as the surface of all points (r_{a_0}, θ_0) for which the capture is ensured. Based on this parameter, we introduced a criterion for choosing the filtration cell parameters which ensure the maximum efficiency in the cell operation. As a main, this criterion establishes that the filtration cell works under the conditions of 100% recovery then the capture cross-section exceeds the cross-section of the cell tube. As a result of laminar velocity field produced by viscous interaction with the boundary walls, the condition for 100% recovery is more restrictive for laminar flow than the potential flow.

The HGMF magnetic filtering cell with the axial configuration analyzed in this paper is adequate to many real situations. The optimization method presented here enables the design of filtration cells with bound flow field under the condition of maximum efficiency.

REFERENCES

1. J.H.P. Watson, *J. Appl. Phys.,* **44** (1973) 4209-4213.
2. J.A. Oberteuffer, *IEEE Trans. Magn.,* **MAG-10** (1974) 223-229.
3. S. Uchiyama, S. Kondo, M. Takayasu and I. Eguchi, *IEEE Trans. Magn.,* **MAG-12** (1976) 895-900.
4. R.R. Birss, R. Gerber, M.R. Parker and T.J. Sheerer, *IEEE Trans. Magn.,* **MAG-14** (1978) 1165-1169.
5. N. Rezlescu, V. Murariu, O. Rotariu and V. Badescu, *Powd. Tech.,* **83** (1995) 259-264.
6. V.Badescu, O.Rotariu, V. Murariu and N. Rezlescu, *Intern. J. Appl. Electromagn and Mech.*, **9** (1996) 1-11.
7. R. Gerber, *J. Phys. D: Appl. Phys.,* **11** (1978) 2119-2128.

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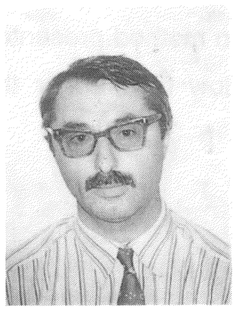
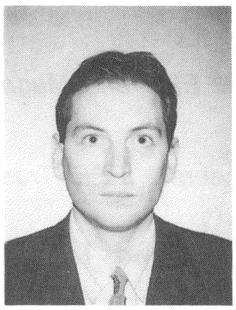
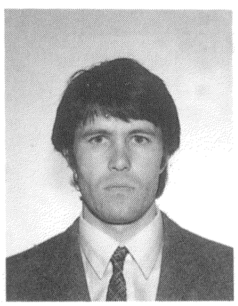
Keywords: Magnetic separation, laminar flow, capture cross-section, recovery efficiency



Vasile Badescu: for biography see *Magn. Electr. Sep.* **6** (1995), 151



Vasile Murariu was born in 1968 and graduated in physics from the University of Iasi, Romania, in 1993. After graduation he joined the Institute of Technical Physics. Mr. Murariu is presently preparing his Ph.d. thesis on magnetic separation and filtration, particularly in axial configuration. He is an author of five papers and his interest include magnetic separation and computational physics.



Ovidiu Rotariu was born in 1968 and graduated from Faculty of Physics of the University of Iasi, Romania, in 1968. He is presently a research officer in the Magnetic Separation Laboratory, the Institute of Technical Physics, Iasi. Mr. Rotariu is an author of five papers and is presently preparing his Ph.d. disertation. His main field of interest is ferrohydrodynamics of granular materials.

Nicolae Rezlescu: for biography see *Magn. Electr. Sep.* **6** (1995), 151