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TRANSPORT AND ABSORPTION OF MAGNETIC PARTICLES IN A TUBE

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Abstract— **Magnetic particles have many applications such as drug delivery, biomedical imaging and waste water treatment. For designing the best system for these applications it is important to know the key parameters and how these parameters affect on the system. Particle diameter, magnetic field strength and the flow velocity are some of these parameters. In this study, we studied the influence of these parameters. It was found out that absorption rate of magnetic particles increases by increasing the coil current and particle diameter and by decreasing the Reynolds number.**

Index terms: **magnetic particle, Reynolds number, coil current, magnetic field, particle diameter.**

I. INTRODUCTION

Many applications for magnetic particles are known which include: medical diagnostics and treatments, waste water treatment, biomedical imaging, information storage, genetic engineering. For some of these applications such as drug delivery and waste water treatment it is better to simulate the particles flow first because of time and cost advantages. So, with modeling and simulating particles motion, we can consider important parameters that affects the motion, such as particles diameter, inlet velocity, geometry, magnetic field and etc.

Most of the research on magnetic particles applications such as magnetic drug targeting (MDT) is experimental. The basis of magnetic drug targeting is magnetic polarization of magnetic particles and magnetophoretic mobility when an external magnetic field is applied [1].

Here are some simulations and analytical models that

$$\vec{F} = m\frac{d\overrightarrow{u_p}}{dt} \qquad (1)$$

have been done in magnetic particles flow:

Mathieu and Martel present a model of Maxwell's coils for leading the magnetic particles [2]. They used a Y-shaped microchannel and Fe_3O_4 magnetic particles with 10.9 micrometer diameter and a Maxwell's pair coil in MRI system for generating magnetic field. They proofed that this system is possible for leading the particles in Y-shaped microchannel.

Li *et al*. demonstrated that for effective magnetic drug targeting the properties of magnetic particles and flow in the blood stream are important factors [3]. A study of deposition of magnetic particles with micrometer dimension inside a tumor was done by Rotariu *et al*. with applying external magnetic field [4] Grief *et al*. suggested a two-dimensional model for magnetic particle's targeted drug delivery [5]. Furlani *et al*. model magnetic nanoparticles in human microvasculature and studied capture of these particles for effective drug delivery [6]. Hence, choosing the optimal magnetic field strength, fluid velocity and geometry is essential to improve the efficiency of the magnetic drug targeting. In this work, we simulate the magnetic particles motion in the magnetic field to calculate the capture efficiency of magnetic particles in a tube at different magnetic field.

A. *Problem Formulation*

The magnetic particles are injected uniformly in the inlet. The fluid is assumed to be in axial direction and an external magnetic field is applied with a coil. Magnetic particles flow in a fluid with applied external magnetic field depends on many factors such as the magnetic force, drag force, buoyancy, gravity, Brownian motion and etc. In this model, we considered only magnetic force and drag force. The equation of motion of a particle in the Lagrangian frame of reference, is given by:

Where u_p is the particle velocity, and F is the total force exerting on the particles. The F in Eq. (1) includes the drag force and magnetic force:

$$F = F_m + F_D$$

Magnetic force is demonstrated by Maxwell's equations. For stationary magnetic fields we have [7]:

$$\vec{J} = \nabla \times \vec{H}$$

$$\nabla \times \vec{B} = 0$$ (4)

$$\vec{B} = \mu_0(\vec{H} + \vec{M}) = \mu_0(\vec{H} + \chi\vec{H})$$ (5)

Where J is the current density [A/m²], H is the magnetic intensity [A/m], B is the magnetic field [T], M is the particle's magnetization [A/m], μ_0 is the permeability of vacuum and χ is the magnetic susceptibility of particles.

The force exerting on a magnetic particle in a magnetic field is as below which depends on the magnetic field and magnetic field gradient.

$$\vec{F_m} = V \times \mu_0 \times \chi \times (\vec{H} \times \nabla\vec{H})$$ (6)

Where V is the volume of magnetic particle.

The drag force on a spherical particle is given by [8]:

$$\vec{F_D} = \frac{3}{4}\frac{\rho_f m_p}{\rho_p d_p} C_D (\vec{U_f} - \vec{U_p})\left|\vec{U_f} - \vec{U_p}\right|$$ (7)

Which is Stokes drag and ρ_f, ρ_p, m_p and d_p are, density of the fluid and particles, mass and mean diameter of particles, respectively. U_f is the fluid velocity and U_p is the particle velocity. C_D is the drag coefficient which can be obtained from the following equation that is an empirical correlation of stokes drag for larger Reynolds number:

$$C_D = \frac{24}{\mathrm{Re}_p}(1 + 0.15\,\mathrm{Re}_p^{\,0.687})$$ (8)

Where the Reynolds number of particles is defined as [9]:

$$\mathrm{Re}_p = \frac{\rho_f d_p \left|\vec{U_f} - \vec{U_p}\right|}{\mu_f}$$ (9)

Which μ_f is the fluid viscosity.

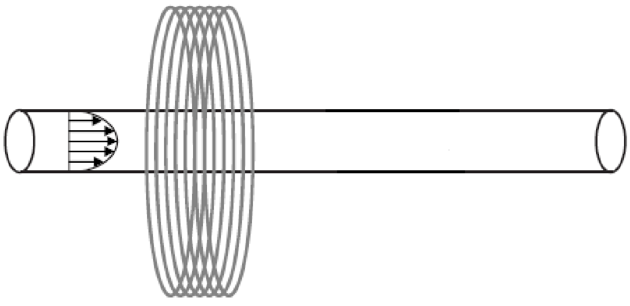

Figure 1- Schematic of geometry

Fig.1 shows the geometry of model, which consisting the coil and tube. Tube radius is 1 cm. more details of model's properties are available in Table 1. Fluid is assumed to be water. The particles relative permeability is considered 400. The absorption efficiency is defined as below:

$$\text{Absorption efficiency} = \frac{\textit{total particles} - \textit{particles traped}}{\textit{total particles}}$$

Table 1-detail of model's property

variable	value
Tube radius	.01 m
Tube length	.1 m
Coil radius	.02 m
Coil current	5 A
Number of turns in coil	250
Distance of coil from inlet	.03 m
Particle diameter	30 micron
Reynolds number	50

B. Results and Discussion

Fig.2 shows the absorption efficiency of particles as a function of coil current. The current is changing from 1 to 10 Ampere and it results to absorption efficiency between 0.2 and 1. The figure demonstrates that the absorption efficiency increases by increasing the current. If the current increases, the magnetic field would be larger, and the larger magnetic force would be applied to particles. This relation is valid up to 6 Ampere, after this value increasing the current won't change the efficiency. In this state, all the magnetic dipoles in the particle are aligned with the external field, so increasing the field cannot increase the magnetization of the particles, hence the efficiency is constant.

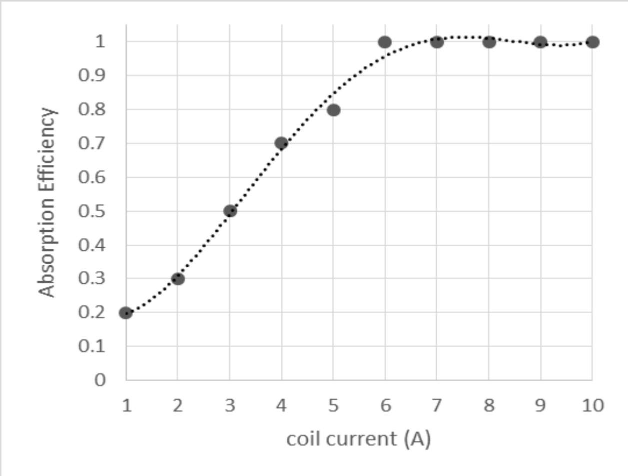

Figure 2- Absorption efficiency vs coil current- Re=50, d=30micron

Fig.3 shows the absorption efficiency as a function of Reynolds number. Reynold number is changing from 1 to 100. As Reynolds number increases the absorption efficiency decreases. Because by increasing the Reynolds number, the velocity and hence the drag force increases and a larger magnetic force is needed to overcome drag force for absorption of the particles. For Reynolds number less than 40, maximum efficiency was reached.

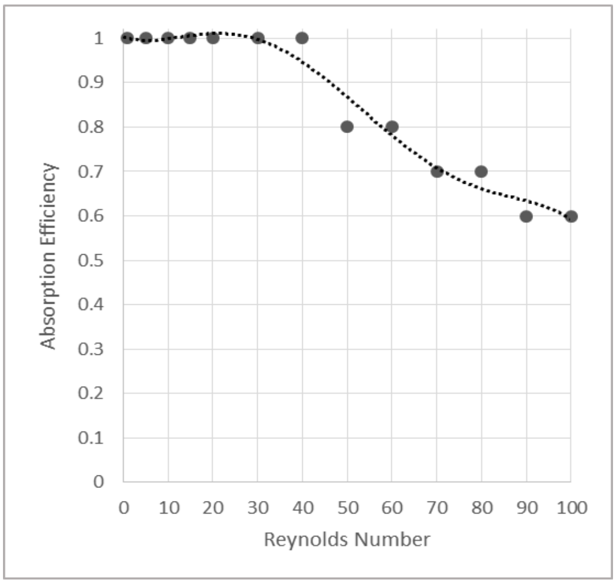

Figure 3- Absorption efficiency vs Reynolds number- d=30micron, I=5A

Fig.4 shows the absorption efficiency as a function of particle diameter. The particle diameter is changing from 1 to 100 micrometer. It shows that by increasing the particle diameter, the absorption efficiency increases. Because increasing the particle diameter increases the magnetic force relative to the drag force, so larger particles are more likely to be magnetically trapped. When particle get larger, the dipole moment get larger and it results in increasing absorption of particles.

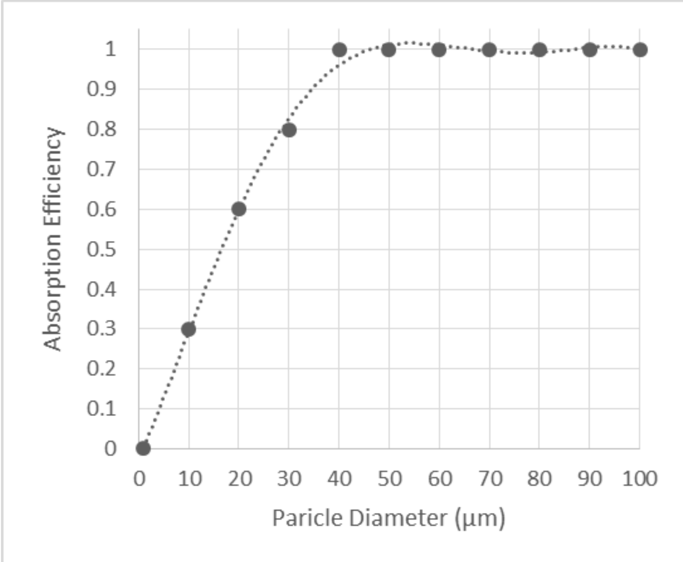

Figure 4- Absorption efficiency vs particle diameter- Re=50, I=5A

II. Conclusion

The magnetic particles absorption efficiency under an applied magnetic field depends on many factors such as particle diameter, Reynolds number, magnetic field strength, geometry. In this model the effect of these parameters were studied. By increasing the coil current, the magnetic field of the coil and as a result the magnetic force exerting on the particles will increases. So absorption efficiency increases. The maximum efficiency is achieved in 6 Ampere. By increasing the Reynolds number the velocity and therefore the absorption efficiency decreases. Because when Reynolds number increases, the velocity increases and it results in larger drag force and decreases trapped particles. At last, by increasing particle diameter the absorption efficiency increases. So the particle diameter is another parameter that influence the absorption. By understanding the key parameters and their influences on the absorption, one can make a better system for trapping and leading the particles.

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