TRAJECTORY MODELING OF A MICRO PARTICLE IN MAGNETIC FIELD FOR MAGNETIC SEPARATORS APPLICATION

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Abstract

1 The paper follows the moving phenomenology of a particle in magnetic field, establishing the trajectory of a micro particle using a calculation breviary combined with a magnetic field modeling software (MagNet – Infolytica) for a specific magnetic separator configuration.

2 Introduction.

A magnetic separator is a device used to separate a mixture of fine, dry or wet materials based upon their magnetic properties. The principles governing this process are magnetism and the interaction between magnetic, gravitational, and viscosity forces. Magnetic properties of a material are based upon atomic structure and magnetic field intensity. The principles involved in the separation apparatus include: feed rate, velocity of the particles and magnetic field strength. Magnetic separation has two general applications, purification of feeds via the magnetic removal of impurities or the collection of the magnetic components from the mixture. A few examples of industrial use:

- in food industry removal of trap iron: the magnetic component is the trap iron and the non magnetic component is the food;
- in mining used too purified the feed and to collect minerals;
- in recycling process used for the separation of metal from glass and plastic.

3. Background and Theory.

Magnetic separation is a process in which two or more materials are separated from each other. The primary driving force of the separation is magnetization, however there are also other forces that act upon the particles as well. These forces are viscosity force and the gravitational force. These forces, in relation to a particle of material on the separator, are illustrated in **figure 1**.

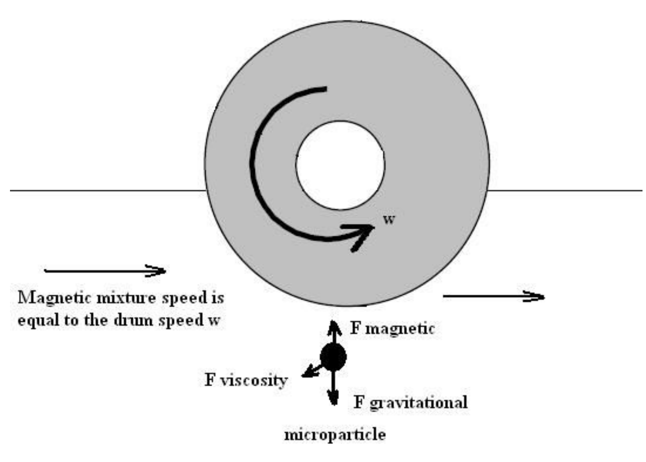


Fig. 1 *Forces exerted on a particle.*

As a particle approaches the magnetic drum it enters into the magnetic field. As the particle travels with the rotation of the magnetic drum, viscosity, gravitational, and magnetic forces are acting upon the particle. There are two possible relationships that the forces satisfy in correlation with the path of the particle:

$$F_{gravitational} + F_{viscosity} > F_{magnetic} \quad (1)$$

or

$$F_{gravitational} + F_{viscosity} < F_{magnetic} \quad (2)$$

Equation 1 describes the disengagement of the particle from the magnetic drum. In order for the particle to be released from the magnetic drum the sum of the viscosity force and a component of the gravitational force acting upon the particle must be greater than the force felt by the particle due to magnetic attraction. Note, the affect of gravity on the particle will be a function of the position of the particle in relation to the magnetic drum.

Equation 2 describes the contrasting relation. For the particle to remain in contact with the magnetic drum and to travel further as the magnetic drum rotates, the magnetic force must be greater than the sum of the viscosity force and a component of the gravitational force acting upon the particle. A better understanding of how the three forces act upon the particle may be gained through an explanation of each force in further detail.

Gravitational force is exerted on a particle as a result of gravity, which pulls the particle towards the Earth's center.

The viscosity force is exerted on a particle this force is acting on a opposite direction of the magnetic force just like a friction force due to the interactions between the mixture material in which is placed the magnetic micro particles (water and sand mixture. Viscosity and gravitational forces are easily explained, but the magnetic force due to a magnetic field requires a much more detailed explanation.

The magnetic field produced by the magnet is the means for the exertion of a magnetic force on a substance. The magnetic field is the area surrounding a magnet that is marked by a detectable magnetic force in every part of the region. Magnetic fields can be produced in two ways: as a result of the movement of electrically charged particles, such as a current in a wire. Or due to the elementary particles of a substance, which have an intrinsic magnetic field surrounding them. In other words, the latter result explains that a particle's magnetic field strength is a basic characteristic of the particle itself. The ability of a compound to be held or repelled by a magnetic field depends on the susceptibility of the compound. Susceptibility is a material property that refers to how easily a compound is magnetized. Susceptibility may be broken down into three different categories: diamagnetic, paramagnetic and ferromagnetic. Diamagnetic substances are weakly repelled by a magnetic field. This slight repulsion is due to the fact that the electron spins of the compounds are all paired giving a net spin of zero. Paramagnetic substances will have some electrons with unpaired spins, which will result in the material being weakly attracted to a magnetic field. Lastly, ferromagnetic substances are strongly attracted to a magnetic field, resulting from the alignment of unpaired electron spins.

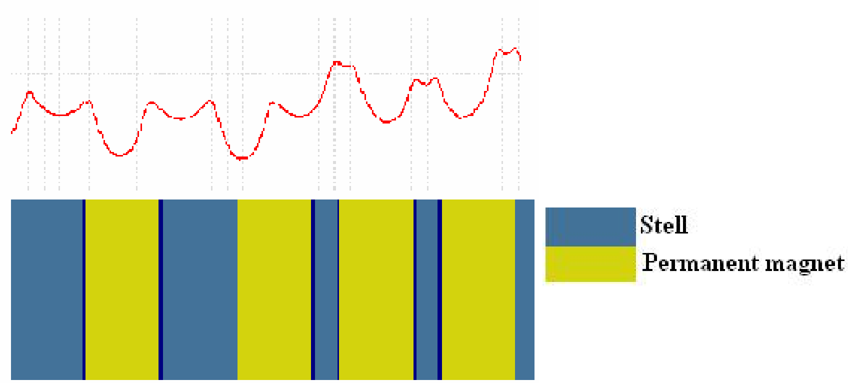


Fig. 2 *Magnetic field distribution and relative field strength of the magnetic separator.*

It must be recognized that in addition to the susceptibility of a particular substance, the intensity of the magnetic field has an effect on the magnetization of a compound. The magnet associated with the magnetic separator has two strengths, as shown in **figure 2**. In accordance with the figure, the right side of the magnet contains a 3:1 magnet to steel ratio by width and is considered to be the strong side, with a field measuring to be approximately 220 mT. The left side is considered the weak side with a 1:1 ratio of magnet to steel by width and has a field strength of approximately 160 mT. The north-to-north and south-to-south configuration normally causes repulsion between magnets however; the steel placed between the magnets causes the fields to be redirected, making the steel "slices" the effective poles instead of the magnets.

4. Trajectory modeling.

The paper follows the moving phenomenology of a particle in magnetic field for some specific geometry of magnetic separator. We have made studies regarding the separation of the hematite and magnetite micro particles from sands used in the glass industry, especially types of sand used for crystal glass production. Specific modeling of the magnetic field was made for a specific rotational magnetic separator with permanent magnets using performing software "Magnet 2D-3D"Infolytica.

The particles were characterized dimensional and have been measured the magnetic proprieties, using this data with the modeling software it was determined the magnetic field force components of the particle. With the results we were able to estimate and illustrate the particle trajectories using a breviary and specific subprogram. The results obtained with the modeling software are the base of conception and final design for a magnetic separator.

The following stages were made to make the optimal rotational magnetic separator:

- The magnetic characterization of micro particles
- Creation of a calculation breviary
- Modeling the structure of field for different configurations
- Choosing optimal configuration
- Experimental model realization

5. Magnetic characterization of micro particles.

It has been made a magnetic separation of the micro particles out of sand probes using a magnetic separator with big intensity; it was used tree types of sand for separation. The separated material was analyzed chemically using the diffract meter, in the separated magnetic material it was found materials like magnetite Fe_3O_4 and hematite Fe_2O_3.

Due to the type of the sample (sand particles with magnetite and hematite particle) it was necessary to make a determination of physical proprieties like: density, mass, and volume for some different amounts of separated material (6 samples). It was necessary to choose a minimum weight for each sample so that it can be magnetically characterized using the VSM (Magnetometer with vibrant proof).

The separated magnetic material was riddled to obtain different grain sizes. The grains seizes were less than 100 μm, between 100 μm and 250 μm and more the 250 μm. The measured densities of the probes were in the range of 5.03-5.22 g/cm3, and the 6 probes weight was between 0.0161-0.06 grams.

This step was necessary to determine the magnetic and physical proprieties of the micro particle so that the material can be modeled with the Infolytica software. For the magnetic modeling software's it is weary important that the materials have the correct magnetic parameters, because it can appear solution errors up to 10-15 percents due to using different types of materials in the simulation. In the **figure 3** it appears the firs magnetization curve for two samples with different granulations.

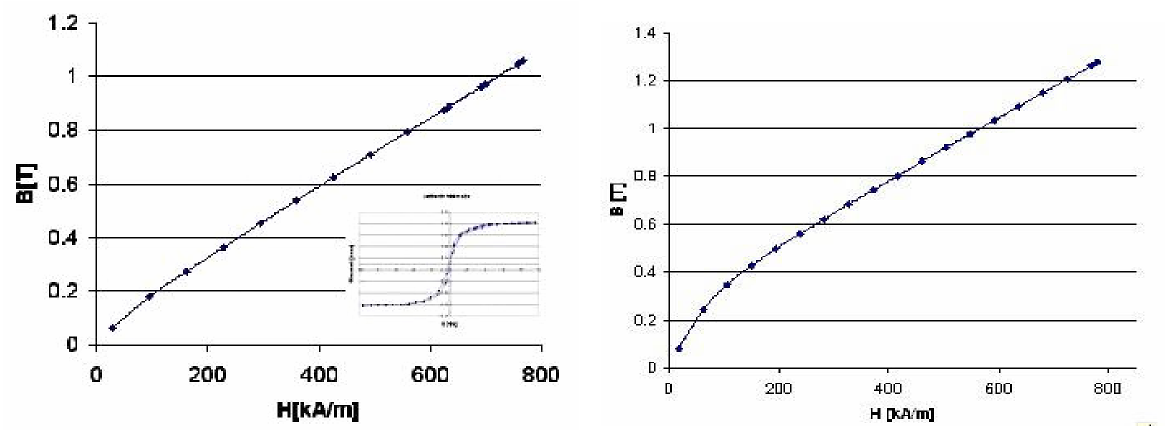


Fig. 3 *First magnetization curve for two different samples:*

a) Sample 1 with grain size less than 100 µm; b) Sample 2 with grain size more than 250 µm.

6. Creation of a calculation breviary.

The main purpose of this paper it was to determinate the trajectory of a micro particle so that the micro particle adhere in necessary time to the magnetic separator. The magnetic separator considered for the breviary it consist from a cylindrical drum with permanent magnets like ceramic ferrite in combination with iron jokes. The micro particles from the sand (the sand it is wet) it is not considered as dry sand, are flowing under the cylindrical drum which is rotating with a constant speed, the flowing speed of the sand must be equal to the speed of the cylindrical drum. This way there is a length were the micro particle is in rest regarding to the rotating cylindrical drum, and it ca be made a static magnetic modeling.

Using the magnetic modeling software we have determined the magnetic attraction force acted upon the micro particle from the magnetic cylindrical drum. To calculate and illustrate the trajectory of the micro particle it was necessary in the breviary the calculation of the forces witch are acted upon the micro particle and these are the gravity force Fg, the friction force Fv due to viscosities, and the magnetic force Fm. The main condition that the micro particle adhere to the cylindrical drum is that magnetic force has to be greater than the sum of al other forces acted on the particle.

$$Fm > Fg + Fv \text{ , where}$$

- Fg is the gravitational force: $Fg = m \cdot g$,

m is the mass of the particle, g is the gravitational acceleration.

- Fv is the viscosity force: $Fv = 6 \cdot \pi \cdot r \cdot \eta \cdot v$,

where r is the radius of the particle, η is the dynamic viscosity of the liquid and v is the velocity of the micro particle.

- Fm is the magnetic force due to the magnetic field acted upon the micro particle calculated with the magnetic modeling software MagNet from Infolytica.

Knowing these tree forces, it can be calculated with simple physic formulas the speed and acceleration of the particle at every time steps until the particle adhere to the magnetic separator. With the calculated data is very simple to illustrate a trajectory of the micro particle. In the **figure 4** is illustrated the schematics of the rotational magnetic separator.

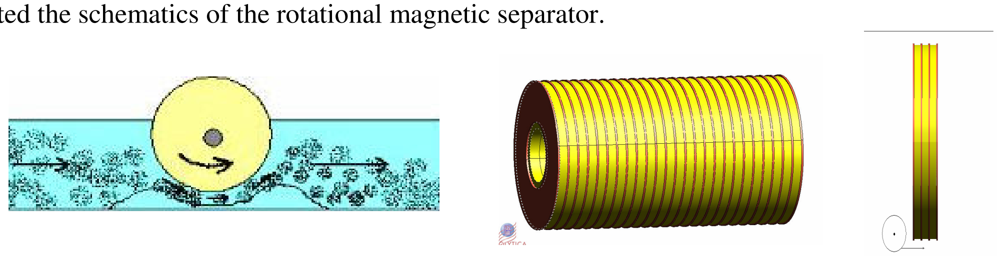
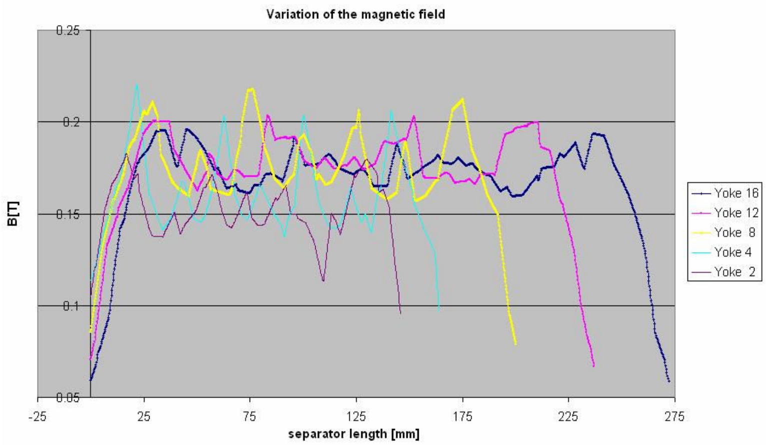


Fig. 4 Cylindrical m*agnetic separator.*

7. Modeling the structure of magnetic field with a performing software Magnet-Infolytica.

After choosing a specific set up for the magnetic separator according the calculation breviary there were made different simulation to obtain the most efficient structure of the separator, dimensioning of elements, permanent magnets and yokes depending of the force exerted on micro particles. According to the magnetic modeling for different yoke sizes, the biggest value of the attraction force was obtained for a yoke with 8 mm thickness. In the **figure 5** it is illustrated the variation of the induction for different sizes of the joke. The biggest value of the induction it is achieved for a yoke with 8 mm, the value of the induction are calculated with the modeling software a distance of 6 mm from the cylindrical drum.



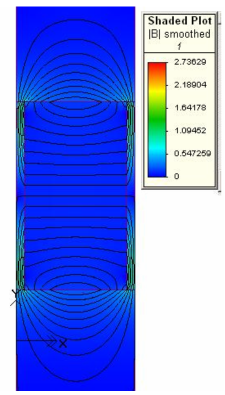
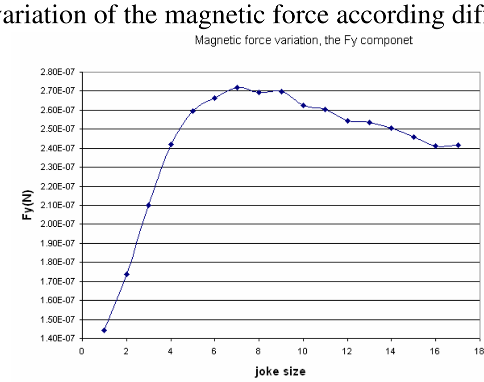


Fig. 5 *Magnetic field variation.* **Fig 6.** *Magnetic field distribution.*

In **figure 6** it is illustrated the magnetic field distribution in a 2D modeling solution with the smallest yoke size. The main problem using the modeling software is due to the very small size of the particle, it can accord very big errors when the force is calculated, and this problem is due to the mesh size used for the modeling structure. It is necessary to use a very small mesh size in the area of the micro particle which will lead to more calculation time for the computer. In **figure 7** it is illustrated variation of the magnetic force according different sizes of the yokes.



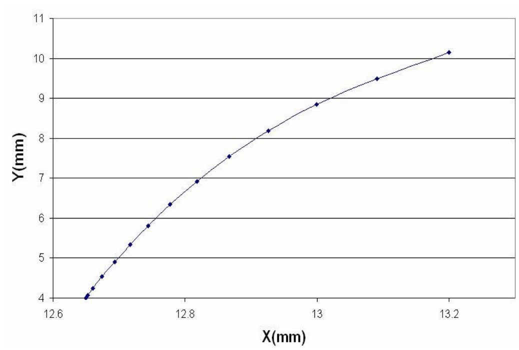


Fig. 7 *Magnetic force variation.* **Fig. 8** *Trajectory of a micro particle.*

In **figure 8** it is illustrated the trajectory of a micro particle in the magnetic field of the cylindrical drum using the created breviary calculation and the magnetic modeling results, the micro particle it is situated according **figure 4**, in the middle of cylindrical permanent magnet.

Even if the attraction force is the highest for some yoke dimensions, the best optimal configuration for the magnetic separator is to choose a structure with a high gradient of the magnetic field structure which was demonstrated in the two different experimental models with different yoke sizes. Using a very small yoke size will lead to a high gradient field which is necessary to attract the very small particles, even if the permanent magnets have a very low working point, when using larger yoke sizes according to the magnetic modeling and the calculation breviary it will attract the particles with larger sizes. I is very important when realizing a simulation with a magnetic modeling software to know some more than the basics of magnetic theory.

8. Experimental results.

Probe type	Weight [mg]	Concentration [mg/100ml]	Atomic iron concentration in 100 ml
Initial sand probe	251.9	0.5114	0.20301
After the first magnetic separation	252.4	0.2882	0.11418
After the second magnetic separation	250.5	0.1631	0.06538
The collected sand by the separator	251.5	1.0368	0.41223

After analyzing the different types of probes with the diffract meter we can take the following conclusion that wee need at least two magnetic separator mounted in series for this type of magnetic separator with cylindrical drum: one with a large thickness of yoke to separate from the sand the particles with large dimensions and a magnetic separator with very small yoke thickness to separate the very small particles.

Fig. 9 *Experimental model of the rotational magnetic separator with permanent magnets (with ceramic ferrite)*

9. Conclusions:

- The values of the inductions measured with gauss meter are corresponding to predeterminations
- In the present stage of the work, the attempts of separate were made in dry and wet environment, obtaining satisfactory results
- The mathematical modeling, with the help of conceived calculation breviary, proves the experimental model capacity of realized magnetic separator to attract the magnetite and hematite micro particles from an amount of quartz sand (especially in the wet environment).

10. References:

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