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# Methods for Determining the Quality of Magnetic Fluids

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**This paper presents the conversion parameter values of the magnetic properties of magnetic fluids. These values were determined for three magnetic fluid samples containing particles with diameters between 30 Å and 170 Å. The factors that may affect the value of this parameter (size of particle, magnetic properties, the presence of clusters and aggregates) are also studied. The determined values for the conversion parameter (γ) are between 0.25 and 0.76 and the determined limit value is 0.8. Because many applications require magnetic fluids with the saturation magnetization as high as possible and the viscosity as low as possible [1], it has been considered necessary to determine this parameter which describes the quality of magnetic fluids.**

**Keywords :** magnetic fluid, conversion parameter, solid phase, magnetic phase, non-magnetic layer

## 1. Introduction

The conversion parameter of the magnetic properties of magnetic fluids is a physical quantity that describes the quality of magnetic fluids [1]. It is necessary to know the optimal values of this parameter and the factors which influence this parameter in order to be able to prepare magnetic fluids of a certain quality required in practical applications. The conversion parameter of magnetic properties is defined as the ratio between the volume fractions of the magnetic phase and those of the solid phase [2]. To determine those volume fractions, different experimental methods are used. So far, few studies have been made related to the parameter (γ) and therefore new measurements were carried out using three samples of magnetic fluid and the results were compared with those obtained by other authors.

## 2. Experiments and Discussions

### 2.1. Theoretical considerations

In this paper the calculations (for the conversion parameter) have been done by processing the obtained experimental data with the equation:

$$\gamma = \varepsilon_M/\varepsilon_S \text{ or } \gamma = M_{FM}\,(\rho_S - \rho_L)/M_d\,(\rho_F - \rho_L) \qquad (1)$$

where: $M_{FM}$ - the measured values for the saturation magnetization; $\varepsilon_S$ - the solid volume fraction; $\varepsilon_M$ – the magnetic volume fraction.

2.1.1. The solid volume fraction ($\varepsilon_S$)

The solid material that was dispersed in the studied magnetic fluids has been determined by density measurements (using a pycnometer) [3]. The experimental data has been processed using the equation:

$$\varepsilon_S = (\rho_F - \rho_L)/(\rho_S - \rho_L) \qquad (2)$$

where: $\rho_L$ - density of the base fluid; $\rho_S$ - solid particle density; $\rho_F$ - magnetic fluid density.

2.1.2. The magnetic volume fraction ($\varepsilon_M$)

The studied magnetic fluids was determined through measurements of the saturation magnetization ($M_{FM}$) in strong magnetic fields (*using a magnetometer*) and in weaker magnetic fields (*using the Gouy method*) [3].

The experimental data has been processed using the equation:

$$\varepsilon_M = M_{FM}/M_d \qquad (3)$$

where: $M_{FM}$ - magnetic fluid magnetization, $M_d$ - solid particle magnetization.

(Measurements were carried out at the Institute of Complex Fluids in Timişoara and at the University of Petroşani.


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From equation (1) it has been ascertained that for obtaining a magnetic fluid with certain qualities, an optimal correlation between the solid volume fraction and the magnetic volume fraction is necessary [4].

2.1.3. Methods used to study the factors that may influence the quality of mag. fluids

By electronic microscopy measurements (carried out at Ovidius University in Constanta) the physical diameters of the particles contained in the three studied samples were determined. The magnetic diameter was determined by magnetization measurements and by calculations using the formula:

$$d_m^3 = (\gamma) d^3 \quad (4)$$

The thickness values of the particle's non-magnetic layer have been determined by processing the experimental data with three different mathematical equations.

**2.2. Determining the (γ) parameter which describes the quality of magnetic fluids**

2.2.1. The solid volume fraction ($\varepsilon_S$)

2.2.2. The magnetic volume fraction ($\varepsilon_M$)

In Figure 2 we can observe that the biggest magnetic volume fraction is for L3 sample. The L3 sample also has the biggest saturation magnetization. When the saturation magnetization value increases, the magnetic volume fraction of the studied samples also increases in a proportional manner.

**Table 1.** Solid volume fraction $\varepsilon_S$ calculated using the equation: $\varepsilon_S = \dfrac{\rho_F - \rho_L}{\rho_S - \rho_L}$.

| Sample | $\rho_F$ (kg/m$^3$) | $\rho_S$ (kg/m$^3$) | $\rho_L$ (kg/m$^3$) | $\varepsilon_S$ $10^{-3}$ |
|---|---|---|---|---|
| $L_1$ | 815 | 5200 | 780 | 7.9185 |
| $L_2$ | 910 | 5200 | 810 | 22.779 |
| $L_3$ | 1070 | 5200 | 810 | 59.225 |

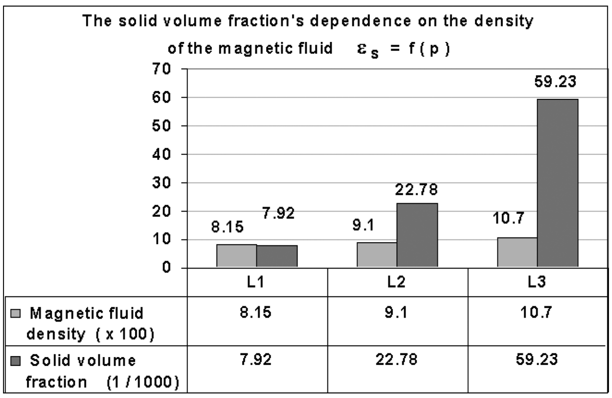



**Fig. 1.** The solid volume fraction ($\varepsilon_S$) of the studied magnetic fluids.

**Table 2.** Magnetic volume fraction ($\varepsilon_M$) calculated using the equation: $\varepsilon_M = \dfrac{M_{FM}}{M_d}$.

| Sample | $M_{FM}$ $10^3$ (A/m) | $M_d$ $10^5$ (A/m) | $\varepsilon_M$ $10^{-3}$ |
|---|---|---|---|
| $L_1$ | 2.154 | 4.46 | 4.8295 |
| $L_2$ | 6.017 | 4.46 | 13.491 |
| $L_3$ | 13.871 | 4.46 | 31.098 |

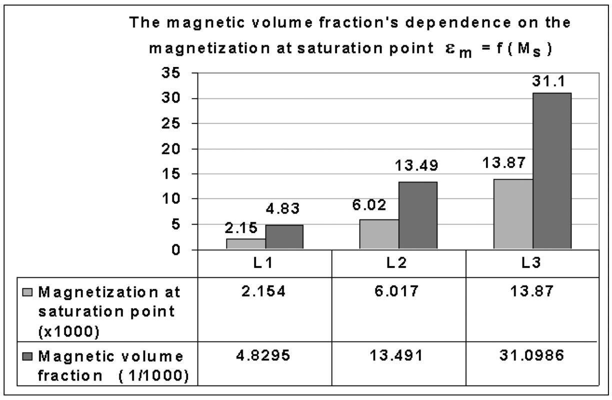



**Fig. 2.** The magnetic volume fraction ($\varepsilon_M$) of the studied magnetic fluids.

2.2.3. The conversion parameter of the magnetic properties (γ)

By comparing the values of the conversion parameter obtained for the studied samples with the values obtained by other authors, it has been ascertained that for magnetic fluids containing particles with diameters between 30 Å and 170 Å, the conversion parameter can take values between 0.25 and 0.76 [1].

**Table 3.** The conversion parameter of the magnetic properties.

L1 $0.248 < \gamma < 0.739$ L2 $0.308 < \gamma < 0.764$ L3 $0.11 < \gamma < 0.729$

$2.84 < d_m < 15.83$ (nm) $3.49 < d_m < 17.93$ (nm) $1.66 < d_m < 15.23$ (nm)

γ calculated using the equation: $\gamma = \dfrac{\varepsilon_M}{\varepsilon_S}$ and the non-magnetic fraction $\Delta\varepsilon = -\varepsilon_S - \varepsilon_M$

| Sample | $\varepsilon_M$ $10^{-3}$ | $\varepsilon_S$ $10^{-3}$ | $\gamma$ | $\Delta\varepsilon$ $10^{-3}$ |
|---|---|---|---|---|
| $L_1$ | 4.8295 | 7.9185 | 0.609 | 3.089 |
| $L_2$ | 13.491 | 22.779 | 0.592 | 9.288 |
| $L_3$ | 31.0986 | 59.2255 | 0.525 | 28.1269 |

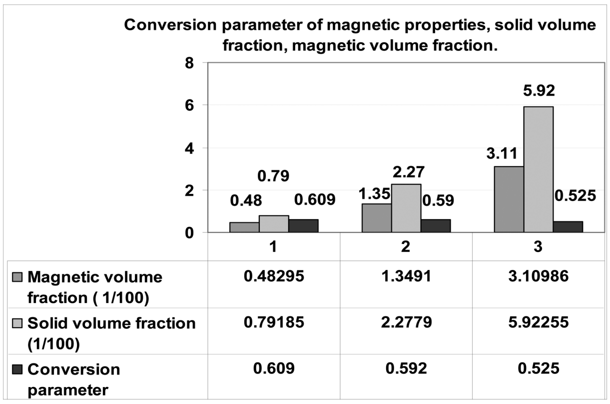
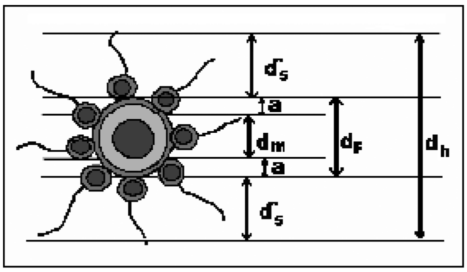



**Fig. 3.** The conversion parameter of the magnetic properties of magnetic fluids.

**Table 4.** Analysis of the size related distribution curves of the particles

| | $X_{max}$ (position of the pick in the distribution curve) | $Y_{max}$ (maximum of the distribution curve) | $d_{medium}$ physical | $\varepsilon_S$ $10^{-3}$ |
|---|---|---|---|---|
| L1 | 9,983818 | 27,092756 | 10.99 | 7.9185 |
| L2 | 8,890707 | 26,057558 | 10.51 | 22.779 |
| L3 | 6,756881 | 24,162768 | 8.70 | 59.2255 |




dm - magnetic diameter; $dm = d_F - 2a$
$d_F$ - physic diametrer; $d_F = d_h - 2\delta_s$
$d_h$ - hidro-dynamic diameter;
$d_h = dm + 2(a + \delta_s)$
$\delta_s$ - surfactant layer thickness
a - non-magnetic layer thickness

**Fig. 4.** Dimensions of the colloidal particle [5, 7, 8].

**2.3. Study of the factors which may influence the quality of magnetic fluids**

2.3.1. The conversion parameter dependency on the particle sizes

From the analysis of the distribution curves it has been ascertained that L3 sample contains more small particles which determine the growth of the solid volume fraction. In the same time, the L3 sample contains particles with diameter larger than average and this leads to a high magnetic density fraction value.

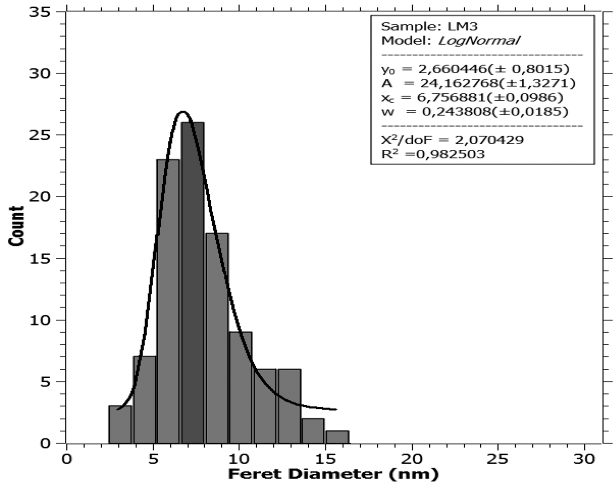



**Fig. 5.** The size related distribution curve of the particles for L3 sample.

**Table 5.** The average magnetic diameter of particles ($d_m$) is calculated using the measured physical diameter, with the equation: $d_m = \sqrt[3]{\gamma} \cdot d$

| Sample | d (physical) $10^{-9}$ (m) | $\gamma$ | $\sqrt[3]{\gamma}$ | $d_m$ (magnetic) $10^{-9}$ (m) | d-$d_m$ = 2a Non-magnetic layer |
|---|---|---|---|---|---|
| $L_1$ | 10.99 | 0.6099 | 0.848 | 9.3195 | 1.6705 |
| $L_2$ | 10.51 | 0.5922 | 0.8397 | 8.825247 | 1.684753 |
| $L_3$ | 8.7 | 0.525 | 0.8069 | 7.02003 | 1.67997 |

2.3.2. Calculating the average magnetic diameter of the particles [1]

The lowest value of the conversion parameter $\gamma$ was determined for L3 sample which has the highest density and the largest non-magnetic fraction $\Delta\varepsilon = 28.1269 \times 10^{-3}$.

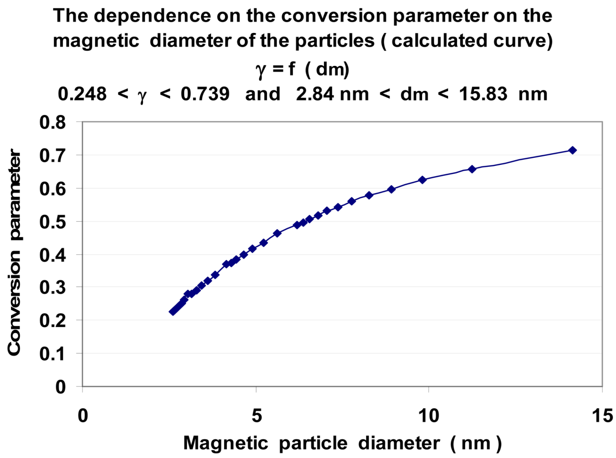



**Fig. 6.** (Color online) The conversion parameter depends on the magnetic diameter of the particle: $d_m$ (high) → μ (high) → $\varepsilon_M$ (high) → γ (high).

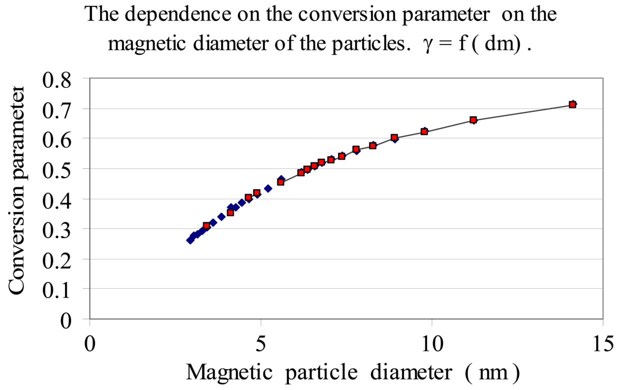



**Fig. 7.** (Color online) The curve for the calculated diameter (dm) compared with the one for the experimentally determined diameter (d'm).

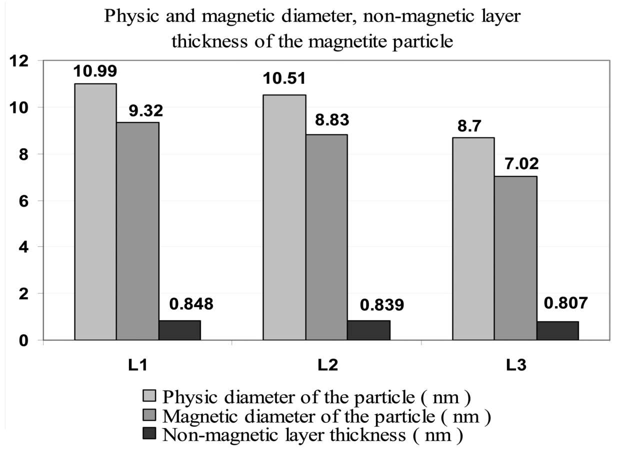



**Fig. 8.** The conversion parameter of the magnetic properties of magnetic fluids in relation to the medium dimensions of the particles in the studied samples.

2.3.3. The dependence of the conversion parameter on the magnetic diameter

Particles with a high magnetic diameter (dm) also have a high magnetic momentum (μ), a high magnetic volume fraction ($\varepsilon_M$) and as a result, a high magnetic parameter (γ) of the magnetic properties. As a result, the conversion parameter value increases when the magnetic diameter increases.

Tables 3 and 5 show that the volume fraction of the solid phase has higher values than the volume fraction of the magnetic phase $\varepsilon_S > \varepsilon_M$. From the variation of the ratio $\varepsilon_M/\varepsilon_S$ (which is less than 1, $\gamma < 1$) we find that a large fraction of the solid phase in the suspension is not magnetic [1]. $\Delta\varepsilon = \varepsilon_S - \varepsilon_M$.

2.3.4. Determining the thickness of the non-magnetic layer

The thickness values of the non-magnetic layer of particles were determined by processing the experimental data with three different mathematical equations.

For the colloidal particles of magnetite the non-magnetic layer has a thickness of: a = 0.83 nm. The existence of this non-magnetic layer involves reducing the physical diameter of the magnetic particles with a thickness equal to double the side of an elementary cell "2a = d – dm = 1.67997" [6].

Figure 9 shows that for all the studied samples, between

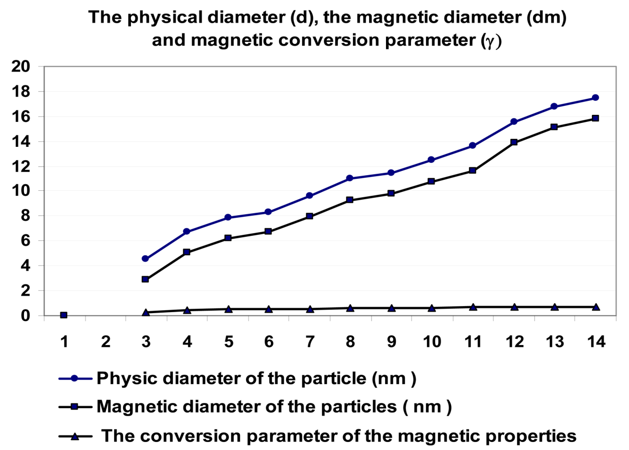



**Fig. 9.** (Color online) The difference between the diameters (d – dm) = 2a is constant.

**Table 6.** Thickness of the non-magnetic layer of particles (a) calculated with :

$$a = 0.5d(1-\sqrt[3]{\gamma}) \qquad a' = 0.5d_m\left(\frac{1}{\sqrt[3]{\gamma}} - 1\right) = 0.5d_m\left[\left(\frac{\varepsilon_S}{\varepsilon_M}\right)^{\frac{1}{3}} - 1\right] \qquad a'' = 0.5(d - d_m)$$

| Sample | d (physical) $10^{-9}$(m) | $d_m$ (magnetic) $10^{-9}$(m) | $\sqrt[3]{\gamma}$ | a $10^{-9}$(m) | a' $10^{-9}$(m) | a" $10^{-9}$(m) |
|---|---|---|---|---|---|---|
| $L_1$ | 10.99 | 9.3195 | 0.848 | 0.83524 | 0.8396 | 0.83524 |
| $L_2$ | 10.51 | 8.8284 | 0.8397 | 0.83554 | 0.8409 | 0.8408 |
| $L_3$ | 8.70 | 7.02 | 0.8069 | 0.83998 | 0.8394 | 0.83998 |

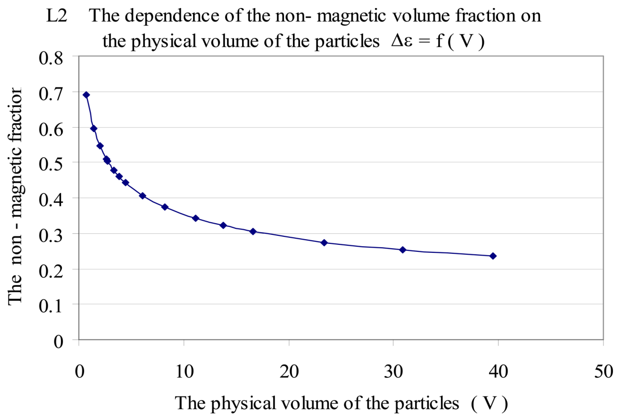



**Fig. 10.** (Color online) As the volume increases, the non-magnetic volume fraction decreases and the small particles have a higher non-magnetic fraction.

the physical and magnetic diameter there is a constant difference, regardless of the particle size.

## 3. Conclusion

1. The calculated values of the conversion parameter ($\gamma$) for the three studied samples are contained in a wide range: ($L_1$) $0.248 < \gamma < 0.739$; ($L_2$) $0.308 < \gamma < 0.764$ and ($L_3$) $0.11 < \gamma < 0.729$ and are in good concordance with the values given by other authors in their works (between 0.3 and 0.8). [1, 3, 4]

2. Because the volume fraction of the solid phase has greater values than the volume fraction of the magnetic phase $\varepsilon_S > \varepsilon_M$, the conversion factor is smaller than 1 ($\gamma < 1$). This means that a significant fraction of the solid phase in suspension $\Delta\varepsilon = \varepsilon_S - \varepsilon_M$ is not magnetic [1]. The smallest value of the conversion parameter has been determined for the sample which has the highest density and the largest non-magnetic fraction.

3. Magnetic fluids have a better quality when the conversion parameter has a larger value (the maximum calculated value is 0.8). This is possible if the fluid contains particles with high magnetic diameter that do not form clusters and aggregates. The conversion parameter value increases if the magnetic diameter increases.

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