Magnetic Soret effect in a hydrocarbon based colloid containing surfacted Mn–Zn ferrite particles

E. Blums[a,*], S. Odenbach[b], A. Mezulis[a], M. Maiorov[a]

[a]*Institute of Physics, University of Latvia, Salaspils-1, LV-2169, Latvia*
[b]*Center of Applied Spacetechnology and Microgravity (ZARM), University of Bremen, Bremen, Germany*

Abstract

The Soret effect has been investigated in a hydrocarbon based magnetic fluid containing surfacted $Mn_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles with a magnetic volume concentration of 2.3%. The magnetic fluid fills up a vertical diffusion column which consists of a flat vertical channel between two walls and two reservoirs at the ends of the channel. One wall of the channel is being heated while the another one is cooled, maintaining a temperature gradient over the channel's width that leads to separation of particles due to the Soret effect as well as the convective flow in the channel. The combination of the two mentioned effects brings up a measurable change of the concentration of magnetic particles in both reservoirs. The results have been obtained for uniform magnetic fields, aligned parallelly and normally to the temperature gradient respectively, by measuring the concentration of magnetic particles in the reservoirs. Obtained results are in good qualitative agreement with thermodiffusion column theory, published earlier (E. Blums, J. Magn. Magn. Mater. 149 (1995) 111). © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Soret effect; Soret coefficient; Thermal diffusion; Thermodiffusion column

1. Experimental setup

Measurements have been performed by means of a thermodiffusion column. The column (see Fig. 1) consists of a flat vertical channel and two reservoirs at the ends. The whole system is filled with fluid. To establish a temperature gradient over the channel's width, one wall of the channel is being heated while the other one is cooled. The colloid is being separated across the channel due to a particle transfer caused by the temperature gradient between the channel's walls, and due to the vertical convective flow, directed up in proximity of the warm wall as well as directed down in proximity of the cold wall of the channel. The combination of these two mass transfer effects causes a change of the concentration of magnetic particles in both reservoirs, being detected to proceed with time.

The detection of the concentration of magnetic particles was realized by means of inductivity measurements of two coils placed in the reservoirs. The inductance L of each coil, which changes by changing the concentration of magnetic particles in

*Corresponding author: Tel.: + 371-2-944664; fax: + 371-7-901214.

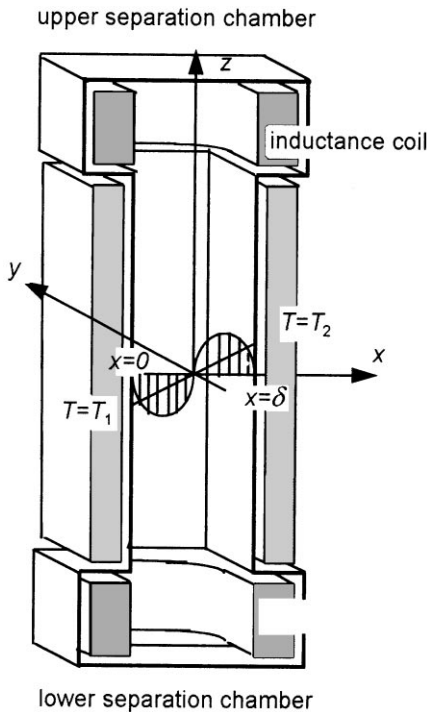*E-mail address:* eblums@sal.lv, elmars@blums.lza.lv (E. Blums)

upper separation chamber
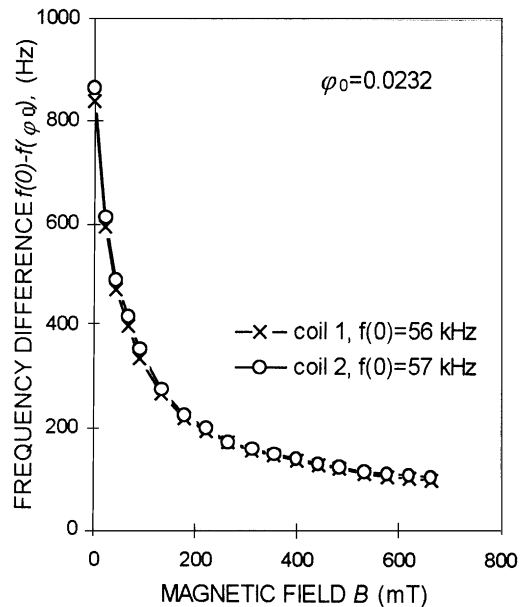

Fig. 1. The sketch of the column.

Fig. 2. The difference of the resonance frequencies of an LC oscillator with magnetic fluid $f(\varphi_0)$ and with nonmagnetic solvent $f(0)$ as a function of the strength of an external uniform magnetic field B.

the selective reservoir, can be found out by measuring the resonance frequency f of the LC circuit according to the Thompson formula. Hence the resonance frequencies f of the LC circuits are being detected as a function of time during the diffusion experiment, one receives a time-dependent information on the concentration of magnetic particles.

2. Measurements of the concentration of magnetic particles

To use the described method of concentration measurements, it is necessary to calibrate this measuring system, i.e., to find out the dependence of the frequency f from the concentration of magnetic particles for each reservoir. In this context one comes across the fact that the application of a magnetic field induces important changes in the frequency-concentration dependence, related to the sensitivity of this measuring method. This fact is clearly predicted by theory since the magnetic

permeability of the fluid μ, which influences the inductance L of the coil, varies with the intensity of the magnetic field, $\mu = \mu(H)$. Moreover, the frequency-concentration characteristics depend also on temperature since $\mu = \mu(T)$.

In Fig. 2 it is shown that the difference of the resonance frequency f between the measurements with magnetic fluid (having initial volume concentration $\varphi_0 = 2.3\%$) and with pure nonmagnetic solvent tetradecane, decreases approximately 6 times while the magnetic field is being increased from 0 to 600 mT. The sensitivity of the concentration measurement decreases in the same manner by increasing the magnetic field, limiting the maximum magnetic field strength to a finite value, after which reasonable concentration measurements become impossible.

3. Experimental results

The diffusion experiments have been carried out with the vertical diffusion column and the measuring
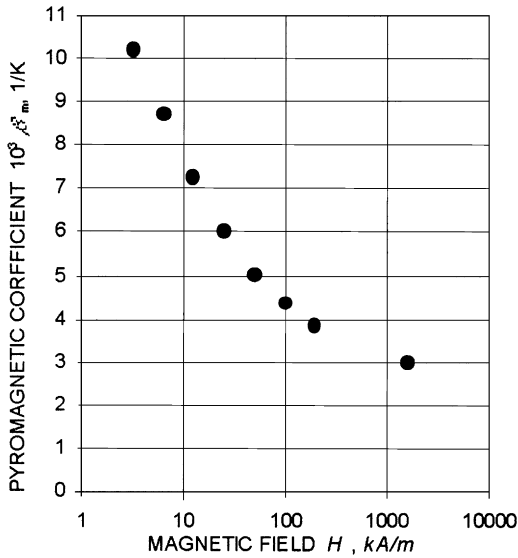
Fig. 3. Relative pyromagnetic coefficient of $Mn_{0.5}Zn_{0.5}Fe_2O_4$ particles in tetradecane, the volume fraction of particles $\varphi = 9.3\%$ ($T = 25°C$).

Fig. 4. Relative Soret effect in the presence of an uniform magnetic field, orientated in the directions $\boldsymbol{B}\perp\nabla T$ and $\boldsymbol{B}\|\nabla T$.

method, both described above, using a strongly temperature sensitive magnetic fluid containing $Mn_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles. Fig. 3 illustrates the relative pyromagnetic coefficient of the fluid, which is comparably high, increasing the thermodiffusion effect.

The Soret coefficient can be calculated from the particle separation curves $\Delta\varphi/\varphi_0 = f(t)$ by one of the two laws lettered '5/2' and '1/2' that indicates the power of the time-dependence in accordance to the following equations [1]

$$\frac{\Delta\varphi}{\varphi_0} = \frac{kGr_{\mathrm{T}}Sc}{5400}\frac{d}{l_{\mathrm{c}}}m^5\left[\left(1 - \frac{5m}{6} + \frac{10m^2}{49}\right)\right.$$
$$\left. + k\frac{Gr_{\mathrm{T}}}{Gr_{\mathrm{c}}}\left(\frac{25m^2}{63} - \frac{m^3}{4}\right)\right], \quad m = \sqrt{12\tau}, \quad (1)$$

$$\frac{\Delta\varphi}{\varphi_0} \approx 0.62\sqrt{\frac{7}{40}}\frac{l}{l_{\mathrm{c}}}k\sqrt{\tau}, \quad (2)$$

where Gr_{T} and Gr_{c} are the thermal and the concentration Grasshoff numbers, Sc is the Schmidt number, $\tau = Dt/d^2$ is the diffusion Fourier number, k is a nondimensional parameter proportional to the Soret coefficient, d is the width of the separation channel of length l and l_{c} is the equivalent length of
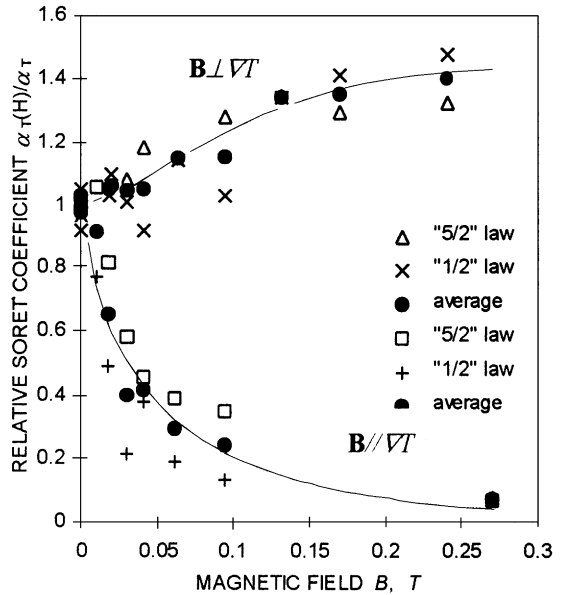
the upper and lower separation chambers. In accordance with the thermodiffusion column theory [1], the '5/2' law is allowed for the present experiment in a time range from $\tau = 0$ to $\tau = 0.0208$ whereas the '1/2' law is approximately valid from $\tau = 0.04$ to $\tau = 0.5$.

The experiments have been performed in the presence of a uniform magnetic field $\boldsymbol{B}$, applied with different strength for both orientations referring to the temperature gradient ∇T in the channel. Fig. 4 shows obtained results of the relative Soret coefficient calculated by '5/2' and '1/2' laws and their averaging. The obtained results are in good qualitative agreement with the theoretical ones published earlier [2]. Nevertheless, it has to be noted, that the measured effect of the uniform magnetic field is significantly stronger than expected from the existing theory. Obviously, in further studies the hydrodynamic theory of thermophoresis must include specific nano-scale effects (slip velocity etc.).

References

[1] E. Blums, S. Odenbach, A. Mezulis, M. Maiorov, Phys. Fluids 10 (1998) 2155.
[2] E. Blums, J. Magn. Magn. Mater. 149 (1995) 111.