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THE USE OF MAGNETIC FLUIDS IN MASS TRANSFER PROCESSES

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Abstract. In the paper was studied the possibility of magnetic emulsions separation. These emulsions are obtained during the extraction process of oily components from waste waters, using as extractant magnetic fluids. Their stability in gravitational and magnetic field, respectively, was appreciated through the volume determination of the separated phases as well the evaluation in time of the system transparency. The influence of the magnetic field leads to a strong intensification of the separation process.

Key words: emulsion, extraction, magnetic fluid, photoresistive effect, separation, stability.

1. INTRODUCTION

A magnetic fluid (MF) consists in chemical stabilized and dispersed magnetic nanoparticles in a carrier liquid. Based on their complex characteristic given by the magnetic component (magnetite stabilized with oleic acid) and the liquid carrier where this one is dispersed (hydrocarbons, especially oil compounds), there is the possibility to use them in separation processes through extraction of oily compounds from aqueous systems. This process consists in oily component distribution between the liquid carrier of the ferrofluid and the aqueous phase. The mass transfer process is amplified thanks to the intimate contact result from the strong phases mixing. This fact leads to some emulsions formation. Their stability depends on the microdroplets size, the emulsifiers type and concentration as well as the value of system hydrophil-lipophil balance (HLB) [1].

Thanks to the strong mixing of the phases, the microdrops separation from the emulsified system can be amplified under the influence of an external magnetic field.

Besides ferrofluids, the study of monodisperse magnetic emulsions is an extremely vast and topical domain witnessing multiple preoccupations concerning their preparation [2,3] and description through optical studies, inclusively [4,5].

The magnetic attraction force $\mathbf{F_m}$ is proportional to the magnetic field gradient **gradH**, the magnetization of the ferrofluid **M(H)**, magnetic permeability μ_0 and the drops volume V_d with magnetic component content:

$$\mathbf{F_m} = \mu_0 . \text{ MgradH } . V_d \tag{1}$$

From the experimental results it is possible to establish a correlation between the values of the separation time in gravitational (τ_g) and magnetic (τ_m) field, at different values of the saturation magnetization M_s for the oily phase and different magnetic field values:

$$\frac{\tau_g}{\tau_m} = 1 + K \cdot gradB^a \cdot M_S^b \tag{2}$$

The coefficient K and the exponents a, b are specific to the used emulsion [6].

2. EXPERIMENTAL

The magnetic field was realized using permanent magnets or electromagnets. In the latter case, the magnetic field value can be modified through the agency of the supply voltage.

Thus, for a permanent ring shaped magnet (D_e= 130 mm, Di= 60 mm, H= 54 mm), the magnetic field distribution in the ring space is presented in Fig. 1, for a cross section in the middle of the cylinder (curve a) respectively in the frontal plane (on the upper and inferior side, curve b).

Greater values of the magnetic field strength are observed in the plane placed in the middle of the cylinder (6.4÷8 kA/m, curve a) in comparison with the values at the cylinder extremities (3÷4.8 kA/m, curve b) [7].

The electromagnet contains a coil made of copper wire 1.1 mm in diameter, having 1300 spires with a total resistance of 3.9Ω. The coil is connected to the power adapter (40V, 5A) which ensures an adjustable supply voltage.

Fig. 2 presents the magnetic field value (induction **B**) as a function of the supply voltage **U**, at different distances from the coil metallic core [8].

Through the direct setting between the magnet and the emulsion with MF content there is the possibility of a maximum attraction force development in the liquid layers in contact with the whole surface of the magnet (internal, external, frontal). Thus, the MF drops are submitted to an intense coalescence process obtained in a zone around the magnet body. The amount of MF retained on the magnet surface is much increased when the magnet is immersed in the aqueous medium due to the Archimedean force.

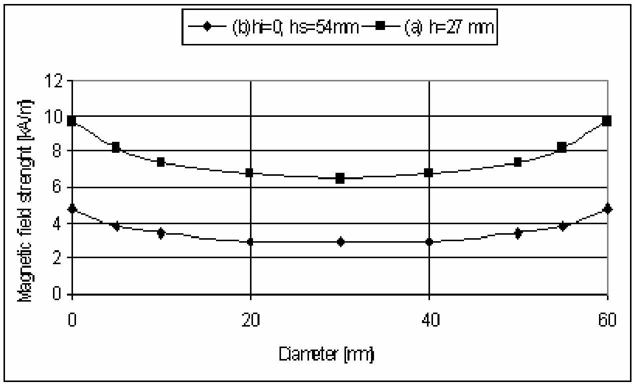


Fig. 1 – Magnetic field distribution *vs*. the diameter of the cylindrical space.

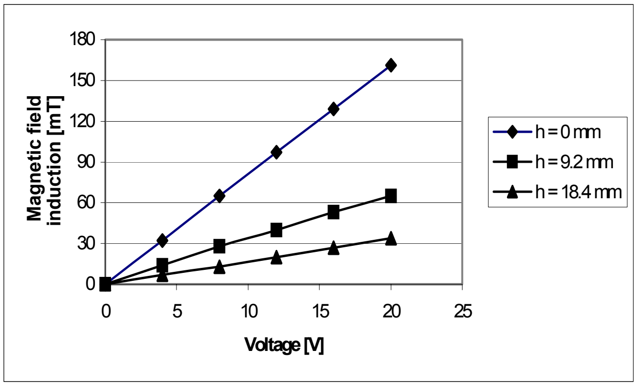


Fig. 2 – The voltage influence on magnetic field induction, at different distances.

A detailed scheme for the separator with immersed ring-shaped magnet [9] is shown in Fig. 3.

The magnet **(2)** is placed into the cylindrical body of the separator **(1)** and the ring-shaped portion is continued, to the upper side, with a bell **(3)**. The role of this one is to direct the emulsion submitted to separation to the ring-shaped area between the magnet and the separator body where it circulates descending, through the inferior frontal portion, and after that the separated aqueous phase is collected in the inner part of the bell. The ferrofluid is collected as a continuos layer **(6)** on the magnet surface and is aspirated periodically. The separated water croses the magnet inferior frontal portion and goes into the bell (route **5a**), in direct contact with the magnet inner surface, to remove all the unseparated MF drops.

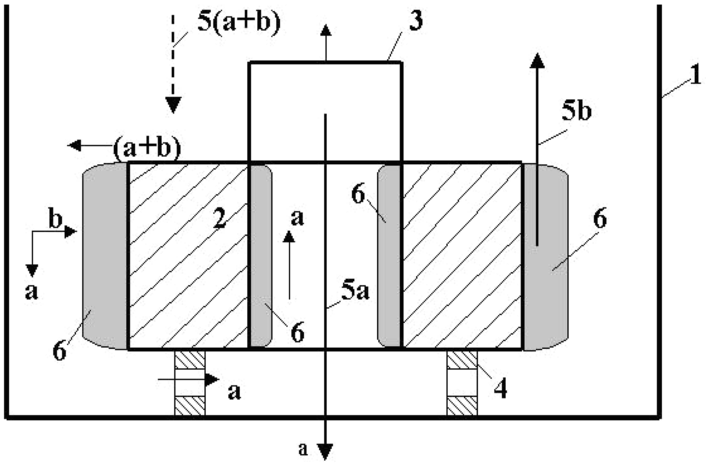


Fig. 3 – Separator for emulsions with magnetic fluid content.

To establish the separation effect of the ring-shaped magnet water with oil content (0.5÷2%) was used in which was added the proper amount of magnetic fluid so that the MF/water ratio was 1÷ 5 ml MF/1000ml water. After a strong combined mixing (mixer and recirculating pump) the emulsion was led through the separator, with various flow values. The magnetic fluid is retained around the magnet and the water with a high epuration degree is collected and analyzed.

Thanks to the black colour of the MF and to the discoloured tendency as a result of magnetic component separation, the separation degree was estimated through the photoresistive effect **(ΔR)** of the aqueous phase that leaves the plant ($\Delta R = R_0 - R$; R_0, R – the initial and momentary value of the photoresistive effect) [10].

For samples preparation was used ferrofluid based on magnetite stabilized with oleic acid and dispersed in oil, with an initial value of the saturation magnetization M_S = 20 kA/m, density 1100 kg/m^3 and the dynamic viscosity 5.2 mPa.s (20°C).

The emulsions whose stability in gravitational and magnetic field was studied contain water, oil based MF with or without emulsifiers. The emulsifying process was realized under strong stirring ($\mathrm{Re} = 5\cdot 10^4 \div 10^5$) using a vessel with vertical baffles and a stirrer with two series of perforate palettes. The preparation time was 30 minutes. The stirring system was characterized by the criterial equation (Eu, Re-Euler and Reynolds numbers):

$$Eu = 81.3 \cdot \mathrm{Re}^{-0.35} \tag{3}$$

3. RESULTS AND DISCUSSION

On the basis of the initial ferrofluid (M_S = 20 kA/m) mixing with the oil phase from the aqueous system diluted magnetic fluid was obtained. Through magnetic separation, at different specific flows, using the separator described in Fig. 3, preepurated water samples were obtained. For these ones we measured the photoresistive effect and the organic loading expressed by the CCO-Cr (oxygen chemical consumption) parameter. The experiments were done at magnetic field gradient $|\text{grad } B|$ = 6.9 T/m.

Fig. 4 presents the dependence between the photoresistive relative value (ΔR/R) and the separation specific flow defined as the liquid volume separated in time, in the separator flow section.

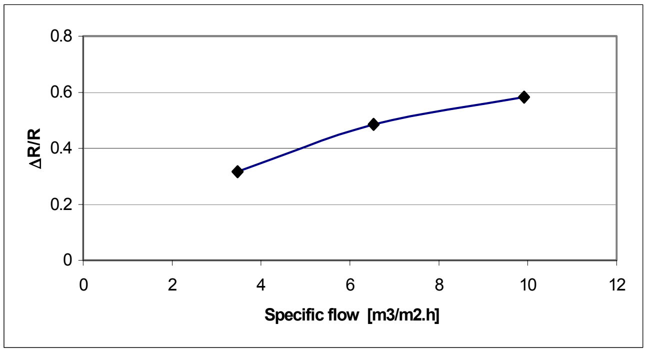


Fig. 4 – The photoresistive relative value *vs*. specific flow.

From the photoresistive experimental values the oily phase concentrations in the preepurated water samples were established. Based on these results we calculated the remove efficiencies (the ratio between the separated oil fraction and the one existent initially in water) of the organic magnetic phase after the wastewater passed through the separator (Table 1).

Table 1

The final concentrations of organic phase and the separation efficiencies

Specific flow, m^3/m^2. h	ΔR/R	Organic phase concentration, ml oil/1000 ml water		Separation efficiency, %
		initial	final	
3.47	0.316	20	0.67	96.6
6.53	0.485		1.30	93.5
9.92	0.583		1.75	91.2

It was found that the specific flow increasing leads to a less efficient separation of the organic component from the system. This conclusion is proved both by the photoresistance value increasing due to less emulsion transparency (MF presence) and the remove efficiency decreasing.

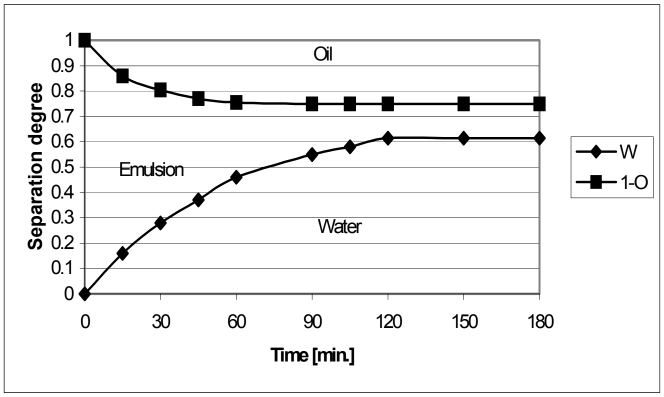
The stability of the emulsions obtained as a result of the mixing that accompanied the mass transfer processes was studied through determination of the phases volume separated in time: aqueous phase fraction (W) and the oily phase fraction (O) which coexists with the emulsion (E), respectively. The stability diagrams were designed through representation, in parallels, of the time dependence for W and 1-O parameters. From the comparative study of these diagrams the estimation of the emulsion stability is possible as well the specification of the less stable phase.

Thus, for the emulsion with 70% water and 30% oil based magnetic fluid (M_S = 4 kA/m), the modification of the separation degree in time, in gravitational and magnetic field, respectively, is shown in Fig. 5 a, b [6].

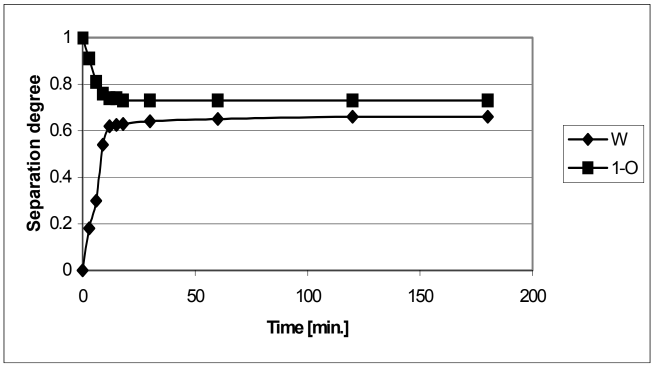
Through the emulsion placement in magnetic field (described in Fig. 1) the acceleration of the phases separation process is observed: at the final value of the aqueous phase separation efficiency (90%) obtained after 135 minutes in gravitational field, it arrives in 12 minutes in magnetic field.

For the same emulsion, the time dependence of the R/R_0 ratio is presented in Fig. 6.

In this case, it is observed too that the separation process is accelerated by the magnetic field presence and the process amplification is proportional to the gradient of the magnetic induction.



a



b

Fig. 5a, b – The separation degree variation in time: a) – gravitational field; b) – magnetic field.

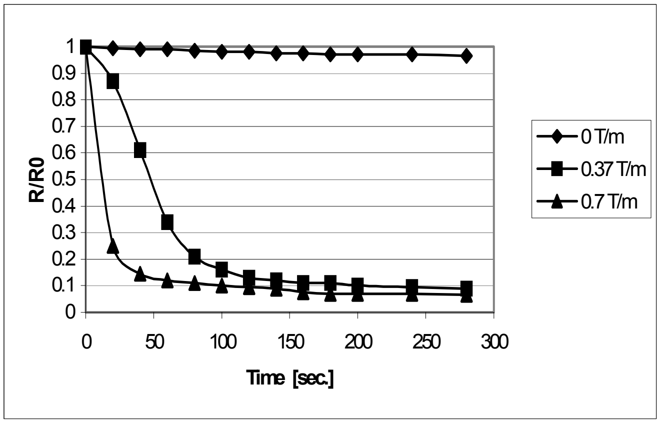


Fig. 6 – Ratio R/R_0 as a function of time, at different values of the gradient of magnetic induction

4. CONCLUSIONS

The separator with immersed magnet allows the fast separation of the magnetic oily component with efficiencies higher than 95%, with the possibility of oily phase and ferrofluid recovery.

Magnetic fluid specific consumption can be decreased to 0.1÷0.2 kgMF/kg oily component

The separation efficiency of the emulsions with magnetic fluid content is increased by the magnetic field action. This amplification is proportional to the magnetic field gradient and the magnetic component concentration.

The opto-electrical method is adequate to evaluate the separation process efficiency of magnetic emulsions due to its precision and rapidity.

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