European Cells and Materials Vol. 3. Suppl. 2, 2002 (pages 142-145) ISSN 1473-2262

COLLOIDAL – CHEMICAL LAWS OF INTERACTIONS OF MAGNETIC FLUID PARTICLES WITH SURFACES OF NATURAL FIBERS

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INTRODUCTION: The interaction of magnetic fluids (MF) with an extraneous phase (including particles, fiber and tissue) can break the aggregation stability of a magnetic phase and cause sedimentation. Coagulation of magnetic fluid particles on a surface of an extraneous phase occurs spontaneously, that is at the expense of power resources of the system. The contact of natural fibers and tissues with magnetic fluids allows the coating of their surface with magnetic layers and gives them magnetic properties. Our investigations [1-3] are devoted to study this phenomenon. The preparation of metal particle films and strings from polymeric materials is possible by introducing particles of these metals in a polymeric phase during the stage of fiber formation. This method cannot be applied to fibers of natural origin, as the thermal or chemical influence on them will result in their irreversible destruction. The modification of a surface by coagulation [4,5] allows creating biologically compatible magnetic strings and filters based on these strings.

MATERIALS: MF were prepared by the peptization method, using various types of stabilization.

Table 1. MF characteristics.

MF	ρ ·10^{-3} kg/m^3	Ñ, (%)	D_1· 10 ^{9} m	D_2· 10 ^{9} m
1	1,11	11, 4	12	60
2	1,17	14, 3	12	200

MF	S_S · 10^{-3} m^2/kg	η · 10 ^{3} Pa · c	B, G	B_S · 10 ^{3} G · m^3/kg
1	96	7	102	92
2	100	16	94	81

r – Density of MF; C – concentration of a magnetic phase (mass); D_1, D_2 – diameters of magnetic particles without or with the thickness of a stabilizing surfactant or polymer layer; S_S – specific surface of magnetic particles; h – viscosity of MF; B – magnetic properties of MF; B_S – specific magnetic properties of MF.

MF_1 contained spherical magnetite particles (Fe_3O_4) stabilized in aqueous medium by the anionic surfactant sodium oleate (70 g/l). MF_2 contained spherical γ–Fe_2O_3 particles stabilized in aqueous medium by the polymer dextran (200 g/l). The MF choice is based on the fact that MF_1 is widely used in laboratory and industrial investigations, and that MF_2 is of interest in biology and medicine (Table 1). The chosen natural fibers and their properties are given in Table 2.

Table 2. Fiber characteristics.

Natural fiber	Albumen	ρ · 10^{-3} kg / m^3	S_S· 10^{-3} m^2/ kg
Wool	Keratin	1300	950
Catgut	Collagen	1440	700

r – Density of MF; S_S – specific surface of fibers.

METHODS: The basic physico-chemical parameters of the colloidal systems were analyzed as follows. The *density* of magnetic fluids and natural fibers was determined with a picnometer. The *concentration* of particles was determined gravimetrically. The *size and specific surface* of the magnetic particles were examined by means of line ultramicroscopic and photon-correlation spectrometer (Malvern model 4300, England). The *specific surface* of natural fibers was determined by adsorption of nitrogen by the BET method. The *viscosity* of magnetic colloids was determined with a scanning rotational rheometer Low - Shear 30. The *magnetic properties* were investigated with a ferrograph 1.033 (FRG). The *sedimentation stability* of prepared magnetic colloids was investigated in a centrifuge at 6000 rpm for 1h. The *electrostatic surface properties* of magnetic fluids and natural fibers were investigated by electrophoresis and electroosmosis, using a background electrolyte of 0.013 Ì KCl solution and correcting the ðÍ with 0.027 Ì HCl and 0.0178 Ì KOH. The investigation of MF particle coagulation on the surface of natural fibers was carried out optically with a photocolorimeter KFK – 2 after direct contact of the magnetic fluids (1.0 kg/m^3) with fibers.

The aggregation stability of MF with positively and negatively charged particles at a pH between 6 to 8 and with or without electrolytes was investigated. The binding kinetics was investigated with or without electrolytes, using different amounts of fibers with modified or unmodified surfaces. For the initiation of slow MF coagulation, 0.05 M HCl and NaOH solutions were used. The surface modifiers for the fibers were anionic surfactants (sodium dodecylbenzensulphonate (sulphonol), sodium carboxymethylcellulose (Na–CMC)) and cationic surfactants (dodecylammonium chloride (DACl), dodecyl dimethyl benzene ammonium chloride (cathamine)).

RESULTS AND DISCUSSION: The MF – fiber interactions take place within 5 days (Fig. 1 and 2) and can be explained by good particle stabilization by the surfactants and polymers. The coagulation of highly dispersed magnetic particles on a firm surface is shown in two processes: direct interaction of MF particles with points on a surface and interaction of MF particles with particles and their aggregates fixed on a surface. These processes proceed simultaneously, but at various speeds. The degree of fiber coating can be predetermined by regulating the two involved processes. The MF cooperates with all macrophases, but to different extents. The initial ratio of cooperating phase surfaces determined in parameter q is very important:

$$q = S_{1S} \cdot m_1 / S_{2S} \cdot m_2 \quad (1)$$

where S_{1S}, S_{2S} are the values of specific surfaces of magnetic particles and fibers (m^2/kg), m_1, m_2 are the masses of the magnetic phase and fibers (kg).

The coagulation kinetics depends on the mass of the entered fiber at constant concentrations of MF (Figure 1).

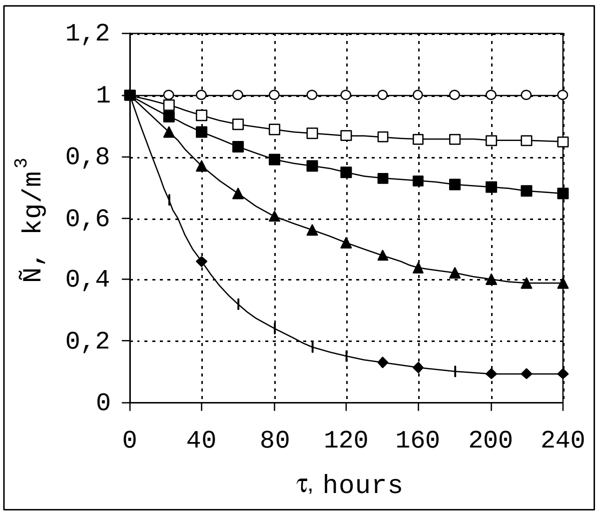

Fig. 1. Kinetics of particles MF_1 coagulation on a fiber (wool) at various q:
without added electrolyte
with added electrolyte
MF_1 with electrolyte in contact to a fiber
q = 0.02; q = 0.10; q = 0.20

The surface condition of the fiber is also very important (Figure 2). The process proceeds most effectively when cationic surfactants (DACl and cathamine) are present.

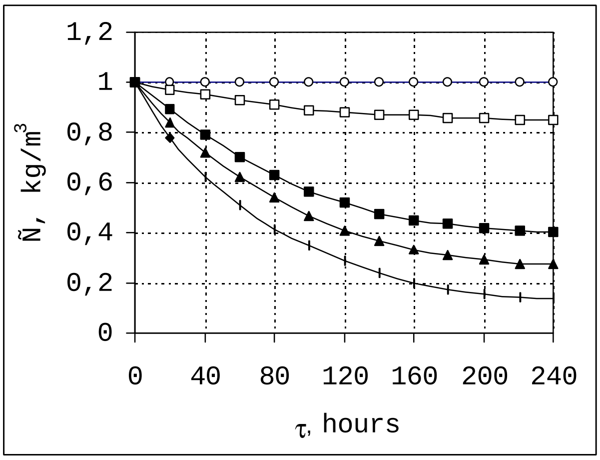

Fig. 2. Kinetics of particles MF_1 coagulation on a fiber (wool) at q = 0.10:
without added electrolyte
with added electrolyte
MF1 with electrolyte in contact to a fiber
in contact with a fiber modified by DACl
in contact with a fiber modified by cathamine

It proves to be true by dependences of quantity fixed on fibers magnetic coagulum from equilibrium concentration of a magnetic phase in solutions MF, achieved to time of the termination of process (Figures 3 and 4). They look like curves leaving on a plateau, with the further rise upwards, that testifies to formation on a surface of fibers mono- and polylayers of magnetic particles structures.

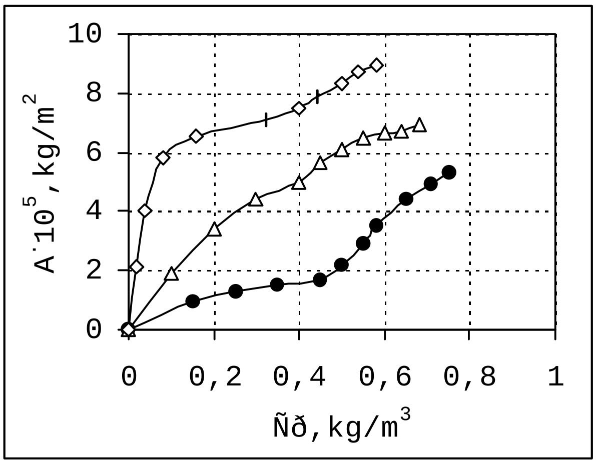

Fig. 3. Amount of magnetic coagulum A from MF1 fixed on a fiber (wool) at different equilibrium concentrations Cp.

We received similar results using catgut (data not shown).
The presented results will allow choosing the conditions to fine-tune a fiber coating with mono- or multi-layers of magnetic particles.

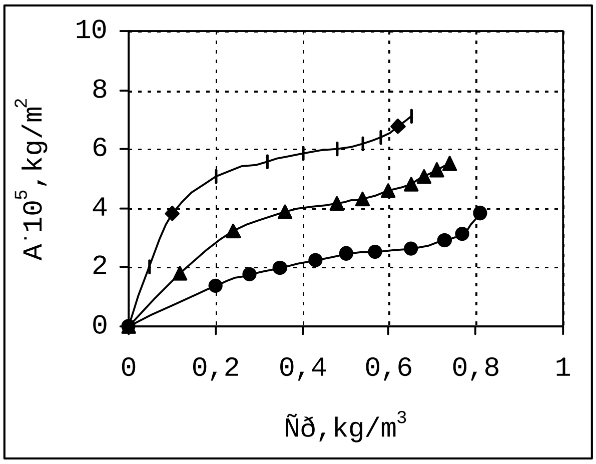

Fig. 4. Amount of magnetic coagulum A from MF_2 fixed on a fiber (wool) at different equilibrium concentrations Cp.

ðèãå fiber; fiber modified with:

DACl; cathamine;

sulphonol; Na-CMC.

The aggregation stability of a magnetic fluid is disturbed near a fiber. The level of this process is determined by experimental conditions such as ðÍ. Driving forces of interaction between MF particles and a fiber are the differences of superficial forces at the borders between "particle of a magnetic phase - medium" and "surface of a fiber - medium". The electrostatic surface properties of magnetic fluid particles and fibers depend on the pH, as shown with zeta-potential measurements (Figures 5 and 6).

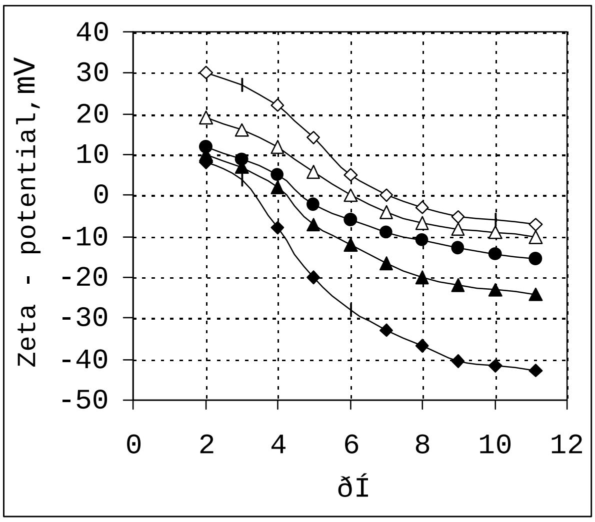

Fig. 5. Change of zeta - potential of a natural fiber (wool) with ðÍ.

In the investigated range of ðÍ 6 to 8, particles MF_1 are charged negatively and MF_2 are charged positively, whereas the fibers are charged negatively. To achieve higher coagulation rates for particles MF_1 on fibers, it was thus necessary to reduce the negative charge. This was achieved by preliminary modification of their surface with DACl or cathamine. Similarly, an increase of positive charge on the MF_2 particles by treatment with sulphonol or Na–CMC led to increased coagulation on the fibers.

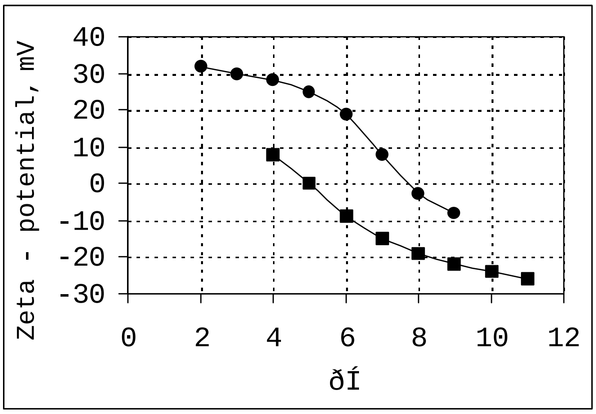

Fig. 6. Zeta - potential of a MF at different ðÍ's. MF_1; MF_2.

The difference between the zeta-potential of fibers and MF particles was thus increased during neutralization, as seen by the process of coagulation.

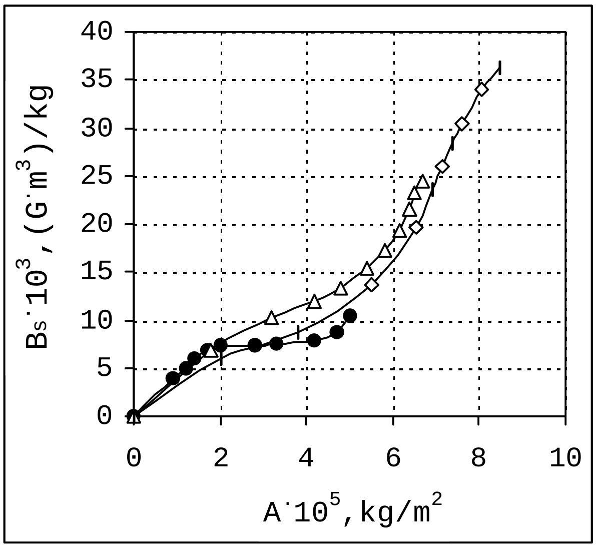

Fig. 7. Dependence of magnetic properties of a fiber B_S (wool) on the amount of magnetic coagulum A after contact with MF_1.

The magnetic properties of the fibers changed considerably depending on the way of treating the surfaces with surfactants (Figures 7 and 8). Cationic surfactant pretreated fibers (DACl or cathamine) show increased adsorption of MF_1

particles stabilized with sodium oleate (Figure 7). A similar effect is seen between fibers and dextran-stabilized MF_2 particles (Figure 8).

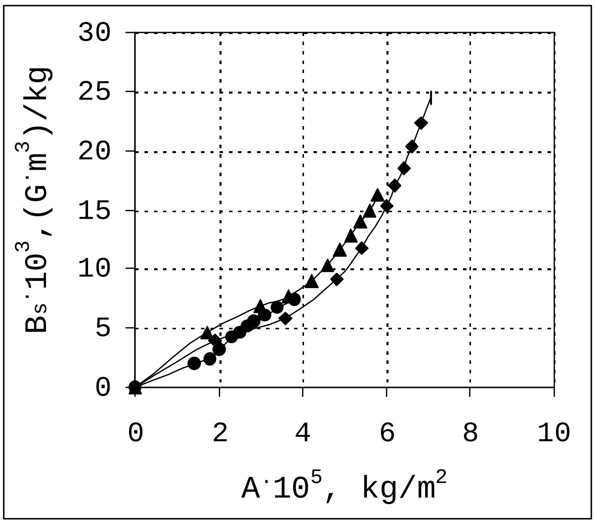

Fig. 8. Dependence of magnetic properties of a fiber B_S (wool) on the amount of magnetic coagulum A after contact with MF_2 .

We observed a sharp increase of the magnetic fiber properties after modifying them with the anionic surfactants sulfonol and Na-CMC. The difference between the electrostatic surface forces in the system "magnetic fluid – fiber" is the basis of process coagulation. A future direction is the investigation of influence of temperature and stirring on coagulation kinetics. Our work is the basis for the coating of fiber surfaces with magnetic particles.

CONCLUSIONS: The coagulation process depends on the fiber quantity and its surface properties. Modification of the fiber surfaces with surfactants changes their electrostatic properties, which is a precondition for the effective formation of layers of magnetic particles. The magnetic fiber coating initially is modest, but increases considerably after preliminary treatment with surfactants.

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