

*Наведено методика спектрофотометричного дослідження седиментаційної стійкості ліпідо-магнетитових суспензій (ЛМС). За допомогою вимірювання коефіцієнта пропускання проведено аналіз процесу седиментації наночастинок в суспензіях. Отримано спектри коефіцієнта пропускання для ЛМС. Визначено розміри частинок магнетиту, стабілізованих поверхнево – активною речовиною (ПАР) – моноацилглицеролом, а також концентрація ЛМС*

*Ключеві слова: магнетит, ліпідо-магнетитова суспензія (ЛМС), стабілізуюча дія, поверхнево-активна речовина (ПАР), седиментаційна стійкість, спектрофотометрія, морфологічні характеристики ЛМС, дисперсність*

*Приведена методика спектрофотометрического исследования седиментационной устойчивости липидо-магнетитовых суспензий (ЛМС). С помощью измерения коэффициента пропускания проведен анализ процесса седиментации наночастиц в суспензиях. Получены спектры коэффициента пропускания для ЛМС. Определены размеры частиц магнетита, стабилизированных поверхностно-активным веществом (ПАВ) – моноацилглицеролом, а также концентрация ЛМС*

*Ключевые слова: липидо-магнетитовая суспензия (ЛМС), стабилизирующее действие, поверхностно-активное вещество (ПАВ), седиментационная устойчивость, спектрофотометрия, морфологические характеристики ЛМС, дисперсность*

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# RESEARCH OF SEDIMENTATION STABILITY OF LIPID-MAGNETITE SUSPENSIONS BY THE METHOD OF SPECTROPHOTOMETRY

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## 1. Introduction

The study of magnetite ( $\text{FeO}\cdot\text{Fe}_2\text{O}_3$ ) and the compounds based on it, is a relevant task of modern science. Promising directions of application of magnetic materials with advanced surface include using magnetite as a vehicle for targeted delivery of drugs into defined areas of the body [1–3]. Research on the objects in vivo has shown that lipid-magnetite suspensions based on magnetite during oral introduction into a human body display biological activity valid for 3–4 hours [4, 5]. Increased concentration of iron in the body causes momentary lowering of intracranial CSF pressure, activates gastric and duodenum activities and increases urination.

Magnetite also displays antioxidant activity that contributes to the prolongation of terms of storage of fat-containing products [6].

Supplements that contain magnetite can be recommended as anti-anemic agent due to digestible ferrous iron [5].

The optimum dose of magnetite is 0.2–0.3 g per 70–80 kg of human body weight [5].

LMS possesses a unique combination of yield and the ability to significantly interact with magnetic field. Its properties are determined by the totality of the characteristics of the components that make up its composition (magnetic solid phase, dispersion medium and stabilizer), varying of which can change the physical-chemical parameters of LMS in a fairly wide range depending on the conditions of their use [4–6].

The physiological action of lipid-magnetite suspensions significantly depends on their stability over time.

That is why the study of morphological characteristics of lipid-magnetite suspensions and their sedimentation stability, and also stabilizing action of the additives of surface – active substances is a relevant and important task.

## 2. Analysis of scientific literature and the problem statement

Defining sedimentation stability of suspensions and sedimentation action of additives of surface-active substanc-

es, measuring the size of small particles and determining their concentration in emulsions, suspensions is a problem the researchers have faced for a long time and it is solved in different ways. Key methods of its solution are set forth in books and numerous articles. Thus, the papers [3] analyzed the process of kinetics of sedimentation and the stability of suspensions with super magnetic nano particles of iron oxide by methods of sedimentation and nuclear magnetic resonance (NMR). The drawbacks of this method are inaccuracy (in the case of sedimentation) and using expensive equipment (NMR). The stability of suspensions with particles of magnetite of diameter 0.3 microns was also studied by viscose metric method in combination with the method of deposition [7]. This method of analysis lacks the accuracy of measurement of the stability of suspension.

To assess the sedimentation stability of suspensions, fluorescent method is widely used [8]. However, in this context, there are limitations to this method as standard fluorescent devices present little information about morphological characteristics of suspensions.

New experimental methods of light scattering are applied [9] – scanning flow cytometer, and methods based on ellipsoidal cavity, which measure indicatrix of light scattering, allowed by one or two angles, respectively. Their disadvantage is the occurrence of differences in the intensity of lateral scattering depolarization between the suspension particles of the same size, but with varying surface charge, which leads to occurrence of errors and reduces the accuracy of the analysis.

Researchers [10] use laser methods, based on the measuring of scattered laser radiation, to characterize the morphology of highly dispersed particles. The disadvantage of this method is the dependence of measurement results on the state of particles surface in a suspension, more accurate results are obtained in the analysis of particles with smooth and even surface.

In the papers [11, 12], the concentration of particles in a suspension was determined by means of a differential mobility analyzer system (DMA), the voltage of which is the function of concentration of particles. However, the resolution of the device and the accuracy of measurement vary significantly depending on temperature and pressure.

Therefore, the problem of determining the stability of suspensions has not been fully resolved up to now, that is why the papers on the subject are regularly published.

The obvious method to solve it is the observation and measurement of particle sizes by a microscope [3, 7, 13]. Although this method is slow, its advantage is the clarity and simplicity, but it is very labor intensive and it is poorly automated. To measure nano particles, many researchers use electronic microscopes [8, 14] – bulky and expensive equipment. And in many cases, for example, in the measurement of particles in gas flows, this method is not applicable, and it is also very slow at that.

Optical methods are widespread [13–15]. They are based on the measurement of the characteristics of light – scattered or absorbed by the medium that contains particles. However, these methods are far from completion, although they have been explored for a long time. One of the main reasons for this is the need to solve the inverse problem – determining the properties of particles by the results of their interaction with radiation. In this case certain difficulties arise:

1. Inverse problems are usually incorrect. Small errors in the source data lead to large errors in the obtained results.

And errors in the source data are always present because these data are the results of an experiment.

2. To reduce the errors, statistical data processing is used but it requires a large amount of computation.

Optical methods can be divided into several groups.

1. *The measurement of the form of indicatrix of the light scattered by particles.* In classical papers on the theory of diffraction [16–18], it was shown that indicatrix of the scattering of light by small particles had petal character, and the angular width of the first petal  $\phi$  depends on the ratio between the size of the particles  $r$  and the wavelength of the radiation  $\lambda$ :

$$\phi = Q(m) \frac{\lambda}{r},$$

where  $Q$  is the coefficient, which depends on a complex index of refraction of the material of particle  $m$ . The papers [19, 20] described an experimental implementation of this method. To enhance the accuracy, in the paper [20] they measured also parameters of polarization of scattered radiation.

The drawbacks of the method are the complexity of the measurement of the forms of indicatrix of scattering and the necessity to know the index of refraction  $m$ . In addition, the method cannot be applied to measure the sizes of nano particles, because the width of the first petal of indicatrix becomes very large, exceeding  $90^\circ$ , and the accuracy of measurements is significantly reduced.

*Method of dynamic light scattering.* The basis of this method is measuring fluctuations of the intensity of the scattered particles of light, caused by the Brownian motion of particles [21]. The method allows measuring the size of nano particles. It is not applicable to micro particles because they, unlike the nano particles, are deposited at the bottom of a cuvette which contains a suspension.

Disadvantages of the method are the complexity of experimental equipment that should provide for measuring very small intensities of scattered light and the inability to measure the size of micro particles.

2. *Spectrophotometric method.* The method is based on measuring the coefficient of light attenuation  $\alpha$  by a system of particles (suspension, emulsion) [22, 23]. The experiment measures the dependence of coefficient of transmission of a cuvette with particles on the wavelength of light and the analysis of this dependence. Then, in theoretical dependency  $\alpha(\lambda)$ , known from the theory of diffraction, such values of particles size  $r$ , refractive index  $m$  and index of particle concentration  $N$  are selected so that this dependence passes best through the experimental points. This presents the biggest difficulty in data processing. Each of the papers [13–15] and others, solves this problem differently.

For the most part, optical methods can be divided into two groups. The first measures the shape of indicatrix of scattering light by particles and the nature of its polarization, the second – dependence of attenuation of light by a system of particles on the wavelength. However, in the literary sources we could not find any facts of using the spectrophotometric method for the study of the morphology and sedimentation stability of lipid-magnetite suspensions. The approach to solving the problem, which is used by the authors, will be described later in this article.

The studies, described further on, belong in the second group. Using a spectrophotometer, we discarded dependency of light transmission coefficient by a cuvette, which con-

tained a lipid-magnetite suspension, containing the studied particles, on the wave length.

This work is devoted to the study of morphological characteristics of lipid-magnetite suspensions (LMS) and their sedimentation stability by the spectrophotometric method, as well as stabilizing action of the additives of surface-active substances.

### 3. The purpose and objectives of the study

The aim of this study is to develop a method of assessment of sedimentation stability of lipid-magnetite suspensions, to define the dispersibility, size of particles of magnetite, stabilized by surface active substance, as well as the concentration of suspension.

To achieve the set goal, the following tasks were solved:

- analysis of dependence of light transmission coefficient of lipid-magnetite suspension (LMS) on the wavelength and the time of the LMS exposure at different wavelengths of light and measurement of stability of suspension over time;
- defining radius of suspension particles ( $r$ ) on the basis of degree ( $q$ ) and parameter ( $\rho$ );
- determining the concentration of magnetite particles in a suspension and the analysis in the changes in the concentration of particles of magnetite in LMS over time;
- analysis of dependence of coefficient of transmission on the time of LMS exposure at different wavelengths of light and measurement of stability of suspension over time;
- defining the radius of suspension particles ( $r$ ) on the basis of degree ( $q$ ) and parameter ( $\rho$ );
- determining the concentration of magnetite particles in a suspension;
- analysis of the changes in the concentration of particles of magnetite in LMS over time.

### 4. Materials and methods of the study of sedimentation stability of lipid-magnetite suspensions

#### 4. 1. The studied substances and equipment used in the experiment

When obtaining the suspensions, we used ultra-thin magnetite, which was synthesized according to the well-known method of coprecipitation of two- and three-valent iron in an alkaline medium [24].

Synthesized magnetite is a highly dispersed black powder with particles size of 30–60 nm.

The study used sunflower refined bottled oil deodorized according to DSTU 4492:2005; corn oil, not refined DSTU GOST 8808 – 2003 “Corn oil. Technical specifications (GOST 8808 – 2000. IDT)”; soybean oil, not refined DSTU 4534:2006 “Soya oil. Technical specifications”; pig fat according to GOST 25292 – 82; beef fat GOST 1288 – 41; salomas unrefined, for margarine industry TU 9145 – 181 – 00334534 – 96, TU 15.4 – 13304871 – 005:2005; substitute of milk fat “Viola – molzhir 3” TU 15.4 – 13304871 – 005:2005, GOST R 53796 – 2010; confectionary fat “Shortening” TU U 15.4 – 00373758:022 – 2006; SAS (monoacil-glycerol) Dimodan HP.

Lipid-magnetite suspensions (LMS) were obtained by the technology [5], according to which there is a stage of peptization.

The LMS, obtained in this way, with magnetite as a dispersion phase and vegetable or animal fats as a dispersion medium, have high stability in the gravitational and magnetic fields.

The study of stability and concentration of suspensions, morphological features of particles was carried out using spectrophotometry (spectrometer Spekol 11).

#### 4. 2. Method of determining stability, dispersibility and concentration of lipid-magnetite suspensions

The essence of the method consists in the analysis of spectrum of attenuation of a suspension with nanoparticles. The dependence of transmission coefficient  $T$  of a cuvette with suspension, on the wavelength  $\lambda$  of optical radiation that passes through the cuvette, is measured. The Beer-Lambert-Bouguer law underlies the spectrophotometric method of the analysis:

$$I = I_0 e^{-\alpha l}, \quad (1)$$

where  $I_0$  is the intensity of the incident light,  $I$  is the intensity of light that passed through a cuvette,  $l$  is the thickness of the layer of suspension in the cuvette (1.0 cm),  $\alpha$  is the light attenuation coefficient.

Transmission coefficient  $T$  is determined by the formula:

$$T = \frac{I}{I_0}, \quad (2)$$

where  $I_0$  is the intensity of the incident light,  $I$  is the intensity of light that passed through the cuvette,  $T$  is the transmission coefficient, un.sh.

Attenuation coefficient  $\alpha$  is associated with the transmission coefficient  $T$  by the following formula:

$$\alpha = -\frac{\ln T}{l}, \quad (3)$$

where  $l$  is the thickness of the layer of suspension in a cuvette (1.0 cm),  $T$  is the transmission coefficient, un.sh.

Typical view of the experimental dependence  $\alpha(\lambda)$  for corn-magnetite suspension is in Table 2 and Fig. 3. In this case  $\alpha_i$  and  $\lambda_i$  were defined by the formulas (4), (5):

$$\alpha_i = -\ln(T_i/100)/l, \quad (4)$$

$$\lambda_i = \lambda_0/n_0, \quad (5)$$

where  $\lambda_0$  is the wavelength in the air,  $\mu\text{m}$  (nm),  $\lambda_i$  is the wavelength in fat (oil),  $\mu\text{m}$  (nm),  $l$  is the dimension parameter (thickness) of cuvette (1 cm or  $10^{-2}$  m),  $T$  is the transmission coefficient, %,  $n_0=1,47$  is the index of refraction of the dispersed medium (corn oil), determined experimentally.

It is known from the theory of light scattering on small particles [25, 26] that the dependence  $\alpha(\lambda)$  is described well by power function

$$\alpha(\lambda) = \frac{A}{\lambda^q}, \quad (6)$$

where  $A$  is the coefficient that does not depend on the wavelength,  $q$  is the exponent whose value depends on the ratio between particles size  $r$ ,  $\mu\text{m}$ , (nm) and the wavelength of light  $\lambda$ , microns (nm).

To find  $q$ , take the logarithm of the equation (6):  $\ln \alpha = \ln A - q \ln \lambda$ .

Results of the calculation of  $\ln \alpha_i$  and  $\ln \lambda_i$  and the diagram of dependency are in Table 3 and in Fig. 4:  $\ln \alpha_i = f(\ln \lambda_i)$ .

Tangent of an angle (angle is approximately  $60^\circ$ ) of curve slope in Fig. 4 corresponds to  $q$  and equals 1,657, i. e.  $q = 1.657$ . The value of  $A$  is derived from  $\ln A$ , which is the section of the coordinates axis, cut from the curve in Fig. 4:  $\ln A = 1,12$ . Hence,  $A$  equals 44.8.

The parameters  $A$  and  $q$  in the equation (6) were also calculated by the method of least squares:

$$A = 44,8, q = 1,657.$$

From the theory of light scattering it is also known that the attenuation coefficient is determined by the formula (7)

$$\alpha = \pi r^2 N Q(\rho, m), \tag{7}$$

where  $N$  is the concentration of particles in suspension,  $\text{cm}^{-3}$ ,  $r$  is the particles size,  $\mu\text{m}$  (nm),  $Q$  is the factor of the effectiveness of the light flux attenuation,  $\rho = 2\pi r/\lambda$  is the dimension parameter,  $m = n - i\kappa$  is the comprehensive index of refraction,  $n$  is the refraction index,  $\kappa$  is the absorption indicator  $i = \sqrt{-1}$  is the imaginary unit.

Having defined the exponent  $q$  (Fig. 4) by the experimental data, one can find the parameter  $\rho$ . This can be done using the theoretical curve (Fig. 5). Fig. 5 shows by a solid line the theoretical curve of dependence (7)  $q = f(\rho)$ , which was calculated for magnetite with complex refraction index  $m = 2 - 0,04i$ . This is its table-valued index of refraction relative to the air. As the particles were placed in corn oil with refraction index  $n_0 = 1.47$ , then when calculating the value  $Q$ , we used the value of refraction of the particles relative to this medium  $m/n_0 = 1,36 - 0,027i$ . It follows from the theoretical curve (Fig. 5) that the value of the exponent  $q = 1.657$  corresponds to the value of the parameter  $\rho = 0,483$ .

This formula shows that part of the energy is removed from the light stream by the particles contained in a suspension. The particles can both absorb and dissipate the light. If in this situation the laws of geometric optics were true, this part would equal  $\pi r^2 N$ , which is the area of the cross-section of all the particles in the incident light. Since the sizes of the particles equal a wavelength of light, the effective cross-section depends on the ratio  $r/\lambda$ .

An amendment to this is given by the factor  $Q$ . Its value depends on the parameter of  $\rho$  and a complex index of refraction of particles  $m$ .

When calculating, the shape of a particle is considered to be spherical. Real particles, of course, have irregular shape. But at their chaotic positioning in space, results of calculations for spherical particles coincide rather well with the results of the experiment.

The formulas for the calculation of the effective attenuation coefficient  $Q$  is well known in the theory of light scattering [16, 17].

It follows from the combination of equations (6) and (7) that

$$q = \frac{\rho}{Q(\rho, m)} \frac{\partial Q(\rho, m)}{\partial \rho}, \tag{8}$$

where  $q$  is the exponent value, in our case it equals 1.657,  $Q$  is the effective light flux attenuation coefficient,

$\rho = 2\pi r/\lambda$  is the dimensional parameter,  $r$  is the particles size,  $\mu\text{m}$  (nm),  $\lambda$  is the wavelength of light in fat (oil), micron (nm),  $m = n - i\kappa$  is the comprehensive index of refraction,  $n$  is the refraction index,  $\kappa$  is the absorption indicator  $i = \sqrt{-1}$  is the imaginary unit.

This equation links the values  $q$  and  $\rho$ . Particle radius  $r$  can be found from the ratio  $\rho = 2\pi r/\lambda$ . In this case, the value of light wave length in the medium of corn is used. We take the average value of a wavelength in the studied range:

$$\lambda_{cp} = \frac{\lambda_{max} + \lambda_{min}}{2} = 0,503 \mu\text{m},$$

where  $\lambda_{max}$  is the maximum wavelength in fat (oil), micron (nm),  $\lambda_{min}$  is the minimum wavelength in fat (oil),  $\lambda_{cp}$  is the average wavelength in fat (oil), micron (nm), then

$$r = \frac{\rho \lambda_{cp}}{2\pi} = 0,039 \mu\text{m}, d = 2r = 0,078 \mu\text{m}.$$

Knowing the size of the particles, one can use the formula (9) to find their concentration in a suspension:

$$N = \frac{\alpha}{\pi r^2 Q(\rho, m)}, \tag{9}$$

where  $N$  is the concentration of particles in suspension,  $\text{cm}^{-3}$ ,  $r$  is the particles size,  $\mu\text{m}$  (nm),  $Q$  is the effective light flux attenuation coefficient,  $\rho = 2\pi r/\lambda$  is the dimension parameter,  $m = n - i\kappa$  is the comprehensive index of refraction,  $n$  is the refraction index,  $\kappa$  is the absorption indicator  $i = \sqrt{-1}$  is the imaginary unit,  $\alpha$  is the effective attenuation coefficient.

### 5. Results of research of sedimentation stability and morphological characteristics of LMS

Results of the measurement of the coefficient of transmittance ( $T$ , %) depending on the wavelength of light ( $\lambda$ , nm) over time (the ratio  $\text{Fe}_3\text{O}_4:\text{SAS} = 0.05:0.70$  mass %) are in Tables 1, 2 and in Fig. 1–4.

Table 1

Results of measurement of the coefficient of transmittance ( $T$ , %) depending on the wavelength of light ( $\lambda$ , nm) over time for corn-magnetite suspension

$\lambda$ , nm	Transmittance coefficient $T$ , %					$\Delta T$ , %
	Exposure time of suspension $\tau$ , hours					
	0	0,5	1,0	24,0	48,0	
500	0,3	0,4	0,6	0,7	0,8	62,5
550	2,0	2,1	2,3	2,5	3,6	44,4
600	4,2	4,4	4,4	4,8	6,4	34,4
650	6,1	7,1	7,4	7,5	9,6	36,5
700	8,3	9,6	10,2	10,7	13,1	36,6
750	10,8	12,0	12,6	13,3	16,7	35,3
800	13,1	14,2	15,5	16,9	20,0	34,5
850	16,0	16,7	18,6	20,3	25,9	38,2

The typical view of the experimental dependence  $\alpha(\lambda)$  for corn-magnetite suspension is in Table 2 and in Fig. 3. In this case  $\alpha_i$  and  $\lambda_i$  were defined by the formulas (4, 5)  $n_0 = 1,47$  is the refraction index of dispersed medium (corn oil), determined experimentally.

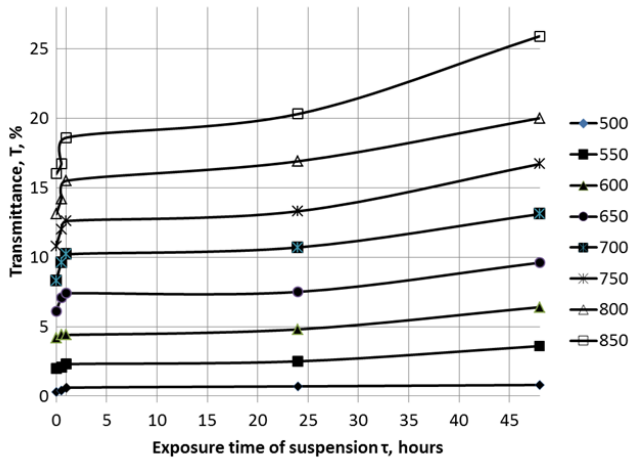


Fig. 1. Dependence of coefficient of transmittance (T, %) on the wavelength of light  $\lambda$  (nm) over time for corn-magnetite suspension

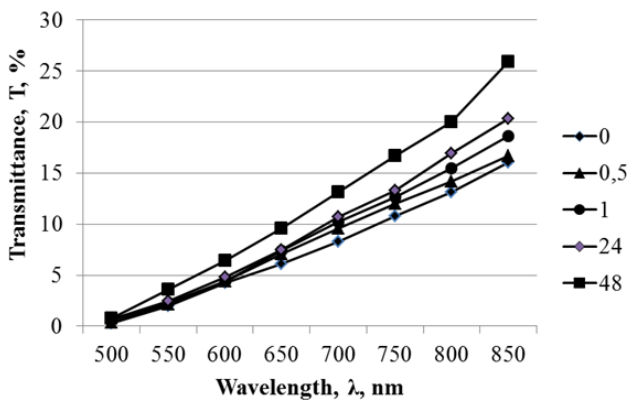


Fig. 2. Dependence of coefficient of transmittance (T, %) on exposure time of corn-magnetite suspension ( $\tau$ , hours) at different wavelengths of light ( $\lambda$  – from 500 to 850 nm)

Table 2

Results of calculation of  $\lambda_i$  and  $\alpha_i$  of suspension

$\lambda_0$ (nm) – $T_i$ (%); $T_i$ (un.sh.)	$\lambda_i$ , micron	$-\ln T_i$	$\alpha_i$ , $m^{-1}$
500 – 0,3; 0,03	0,340	5,81	581
550 – 2,0; 0,02	0,374	3,91	391
600 – 4,2; 0,042	0,408	3,17	317
650 – 6,1; 0,061	0,442	2,80	280
700 – 8,3; 0,083	0,476	2,49	249
750 – 10,8; 0,108	0,510	2,23	223
800 – 13,1; 0,131	0,544	2,03	203
850 – 16,0; 0,160	0,578	1,84	184

Table 3 and Fig. 4 present the results of calculation of  $\ln \alpha_i$  and  $\ln \lambda_i$  and a diagram of dependency:  $\ln \alpha_i = f(\ln \lambda_i)$ .

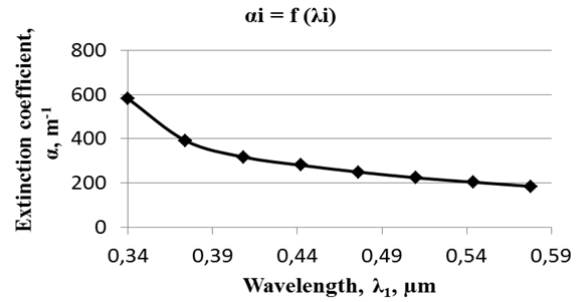


Fig. 3. Dependence of coefficient of attenuation of light ( $\alpha$ ,  $m^{-1}$ ) in corn-magnetite suspension on wavelength ( $\lambda$ ,  $\mu m$ )

Table 3

Results of calculation of  $\ln \alpha_i$  and  $\ln \lambda_i$  of suspension

$\lambda_0$ (nm)	$\lambda_i$ , $\mu m$	$-\ln \lambda_i$	$\alpha_i$ , $m^{-1}$	$\ln \alpha_i$
500	0,340	1,120	581	6,365
550	0,374	0,998	391	5,969
600	0,408	0,896	317	5,759
650	0,442	0,815	280	5,635
700	0,476	0,742	249	5,517
750	0,510	0,673	223	5,407
800	0,544	0,609	203	5,313
850	0,578	0,548	184	5,215

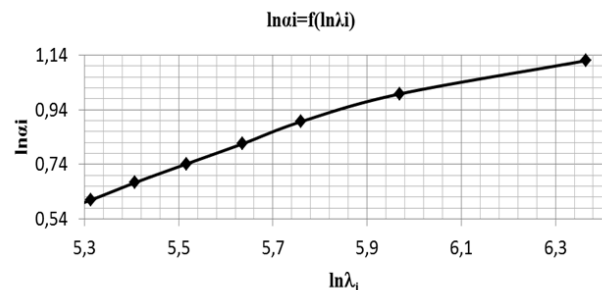


Fig. 4. Dependence of the logarithm of light extinction coefficient ( $\ln \alpha$ ) on the logarithm of the wavelength ( $\ln \lambda$ ) in corn-magnetite suspension

Tangent of an angle (angle is approximately  $60^\circ$ ) of curve slope in Fig. 4 corresponds to  $q$  and equals 1,657, i. e.  $q=1.657$ . The value of  $A$  is derived from  $\ln A$ , which is the section of the coordinates axis, cut by the curve in Fig. 4:  $\ln A=1.12$ . Hence,  $A$  equals 44.8. The parameters  $A$  and  $q$  in the equation (6) were also calculated by the method of least squares:  $A=44.8$ ,  $q=1.657$ .

Having determined an indicator of the degree of  $q$  (Fig. 4) by the experimental data, one can find the parameter  $\rho$ . This can be done by using the theoretical curve (Fig. 5). Fig. 5 shows the theoretical curve of the dependence (7)  $q=f(\rho)$ .

It follows from the theoretical curve (Fig. 5) that the value of degree  $q=1.657$  corresponds to the parameter value  $\rho=0.483$ .

The radius  $r$  of the particles was calculated by the ratio  $\rho=2\pi r/\lambda$ . In this case we used the value of the wavelength of light in the medium of corn oil. We used average wavelength in the studied range ( $\lambda$  – from 500 to 850 nm)

$$\lambda_{cp} = \frac{\lambda_{max} + \lambda_{min}}{2} = 0,503 \mu m.$$

Then

$$r = \frac{\rho \lambda_{cp}}{2\pi} = 0,039 \mu m, \quad d = 2r = 0,078 \mu m.$$

Knowing the size of the particles, we found their concentration in a suspension using the formula (9). Table 4 and Fig. 6 present the results of the study of changes in quantity (concentration) of particles in 1 cm<sup>3</sup> of suspension during 45 days.

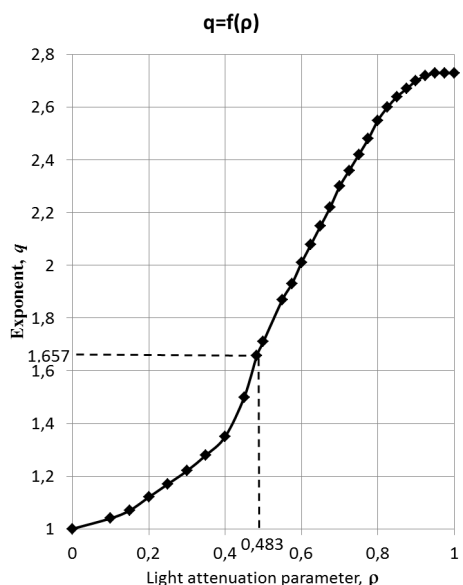


Fig. 5. Determining the size of the particles of magnetite in corn-magnetite suspension (theoretical curve)

By the experimental data given in Table 4 and Fig. 6, one may assess the sedimentation stability and dispersibility of LMS.

Number of particles in 1 cm<sup>3</sup> of corn-magnetite suspension

The number of particles of magnetite in 1 cm <sup>3</sup> of suspension	Exposure time of CMS, t, hours					
	0	0,5	1,0	24,0	48,0	1080,0
	1,33 · 10 <sup>12</sup>	1,32 · 10 <sup>12</sup>	1,30 · 10 <sup>12</sup>	1,23 · 10 <sup>12</sup>	1,13 · 10 <sup>12</sup>	1,09 · 10 <sup>12</sup>

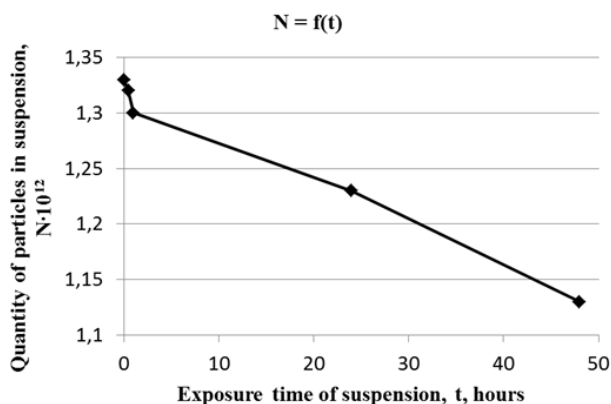


Fig. 6. Change in the concentration of particles of magnetite in corn-magnetite suspension over time

## 6. Discussion of the results of study of stability of LMS

Magnetite, synthesized by the method of chemical condensation, is a highly dispersed black powder. Earlier cytomorphological-biophysical studies of magnetite, cited by the Authors, proved its beneficial properties and positive effect on human body [5]. Therefore, when designing new forms of dietary and nutritional supplements, the most advisable as a dispersion phase in lipid suspensions is to use non-toxic and useful substance – magnetite (Fe<sub>3</sub>O<sub>4</sub>).

We received various lipid-magnetite suspensions.

The assessment of sedimentation stability of lipid-magnetite suspensions was carried out by spectrophotometric method, as well as the sizes of particles of magnetite with SAS and their concentration in suspensions were determined, for example, diameter of the particles in the corn-magnetite suspension equals 78 nm.

The analysis of Fig. 1 and Table 1 shows that over time (0–48.0 h) and with increasing wavelength (500–850 nm), a gradual increase in the coefficient of transmission is observed from 0.3 % (500 nm) up to 16.0 % (800 nm) at zero hours of suspension exposure; from 0.8 % (500 nm) to 25.9 % (800 nm) at maximum exposure time of suspension (48 hours).

In the coefficient of transmittance (ΔT, %) over time is observed at wavelengths of 500 and 550 nm (62.5 and 44.4 %), respectively. With other wavelengths, ΔT equaled about 36 %. Therefore, with regard to the accuracy of the colorimetric method of analysis for determining the stability of a suspension, it is better to recommend the wavelengths at which the accuracy of defining is higher, that is, 650–700 nm; further on, the ΔT starts to change in jumps (alternating growth and fall).

The studies have shown that all suspensions (in which corn, sunflower, soybean oils, beef and pork fats, confectionery fats and salomas were used as the dispersion medium) are sufficiently stable over time. The work studied different ratios of components of lipid-magnetite suspensions, while the best results for stability was displayed by suspensions with the ratio of Fe<sub>3</sub>O<sub>4</sub>:SAS=0,02:0,35g or 0,04:0,70 mass % and 0,025:0,35 g or 0,05:0,70 mass %. And since the study relied on medical and biological requirements, the selection was made in favour of the suspensions with the ratio Fe<sub>3</sub>O<sub>4</sub>:SAS=0,025:0,35 g or 0,05:0,70 mass %.

Table 4

the study relied on medical and biological requirements, the selection was made in favour of the suspensions with the ratio Fe<sub>3</sub>O<sub>4</sub>:SAS=0,025:0,35 g or 0,05:0,70 mass %.

We determined the concentration (the number of particles in 1 cm<sup>3</sup>) of suspension, which, for example, equals N=1,33·10<sup>12</sup> cm<sup>-3</sup> while preparation.

The decrease in the number of particles of magnetite with SAS in 1 cm<sup>3</sup> of corn-magnetite suspension was determined: over 48 hours, the concentration in 1 cm<sup>3</sup> decreased from 1,33·10<sup>12</sup> down to 1,13·10<sup>12</sup> cm<sup>-3</sup>.

The analysis of Table 4 and Fig. 6 points to the fact that the number of particles in the layer of a suspension in 0.5 hour reduces by 0.87 %, in 1.0 hour – by 2.25 %; in 24 hours – by 9.65 %, in 48 hours – by 45 % and in 45 days – by 18.17 %. The obtained data indicate partial homogeneity of particles of magnetite – the largest particles settle during the first day.

## 7. Conclusions

1. The evaluation of sedimentation stability of lipid-magnetite suspensions was performed (in which corn, sunflower,

soybean oils, beef and pork fats, confectionery fats and salomas were used as dispersion medium). All suspensions are sufficiently stable over time. The best results for stability were displayed by suspensions with the ratio of  $\text{Fe}_3\text{O}_4$ : SAS=0,02:0,35 g or 0,04:0,70 mass % and 0,025:0,35 g or 0,05:0,70 mass %. We determined the size of the particles of magnetite with SAS. The diameter of the particles is 78 nm.

2. It was determined that over time (0–48.0 h) and with increasing wavelength (500–850 nm), a gradual increase in the coefficient of transmission is observed from 0.3 % (500 nm) up to 16.0 % (800 nm) at zero hours of suspension

exposure; from 0.8 % (500 nm) to 25.9 % (800 nm) at maximum exposure time of suspension (48 hours).

3. We defined the concentration of the particles of magnetite, stabilized by a surface active substance – the concentration (number of particles in  $1 \text{ cm}^3$ ) equals  $N = 1,33 \cdot 10^{12} \text{ cm}^{-3}$  during preparation of a suspension. A slight decrease in the number of particles of magnetite with SAS in  $1 \text{ cm}^3$  of suspension was observed over time: during 48 hours, the concentration in  $1 \text{ cm}^3$  decreased from  $1,33 \cdot 10^{12}$  down to  $1,13 \cdot 10^{12} \text{ cm}^{-3}$ . The concentration decreases by approximately 2.25 % per 1 hour.

## References

1. Chapa Gonzalez, C. Development of Antibody – Coated Magnetite Nanoparticles for Biomarker Immobilization [Text] / C. Chapa Gonzalez, C. A. Martínez Pérez, A. Martínez Martínez, I. Olivás Armendáriz, O. Zavala Tapia, A. Martel-Estrada, P. E. García-Casillas // *Journal of Nanomaterials*. – 2014. – P. 1–7. doi: 10.1155/2014/978284
2. Unterweger, H. Development and characterization of magnetic iron oxide nanoparticles with a cisplatin – bearing polymer coating for targeted drug delivery [Text] / H. Unterweger, R. Tietze, C. Janko, J. Zaloga, S. Lyer, N. Taccardi et al. // *International Journal of Nanomedicine*. – 2014. – Vol. 1. – P. 3659–3676. doi: 10.2147/ijn.s63433
3. Mamani, J. B. Particokinetics: computational analysis of the superparamagnetic iron oxide nanoparticles deposition process [Text] / J. B. Mamani, T. T. Sibov, C. A. Caous, Jr. E. Amaro, L. F. Gamarra // *International Journal of Nanomedicine*. – 201. – P. 2699–2712. doi: 10.2147/ijn.s30074
4. Cihanovskaja, I. V. O perspektivah ispol'zovanija magnetita v kachestve biologicheski aktivnyh dobavok [Text]: tez. dok. 2-oj mezhd. nauch.-teh. konf. / I. V. Cihanovskaja, T. A. Onoprienko, V. A. Kovalenko, V. I. Onoprienko // *Himija i tehnologija zhirov. Perspektivy razvitija maslo-zhirovoj otrasli*. – Kharkiv, NII masel i zhirov, 2009. – P. 53–54.
5. Iljuha, N. G. Tehnologija proizvodstva i pokazateli kachestva pishhevoj dobavki na osnove magnetita [Text] / N. G. Iljuha, Z. V. Barsova, V. A. Kovalenko, I. V. Cihanovskaja // *Eastern-European Journal of Enterprise Technologies*. – 2010. – Vol. 6, Issue 10 (48). – P. 32–35. – Available at: <http://journals.uran.ua/eejet/article/view/5847/5271>
6. Denysova, A. Ju. Doslidzhennja vplyvu zhyro-magnetytovoi' suspenzii' na termin zberigannja tvarynnyh zhyriv. Part 1 [Text] / A. Ju. Denysova, Y. V. Cyhanovskaja, O. B. Skorodumova, Ja. M. Goncharenko, G. O. Pryjmak, I. V. Shevchenko // *Progresyvna tehnika ta tehnologii' harchovyh vyrobnyctv, restorannogo ta gotel'nogo gospodarstv i torgivli. Ekonomichna strategija i perspektyvy rozvytku sfery torgivli ta poslug*. – Kharkiv, 2013. – P. 71–72.
7. Cho, J. Characterization of particle aggregation in a colloidal suspension of magnetite particles Original Research Article [Text] / J. Cho, S. Koo // *Journal of Industrial and Engineering Chemistry*. – 2015. – Vol. 27. – P. 218–222. doi: 10.1016/j.jiec.2014.12.038
8. Lou, W. On the Electromagnetic Scattering and Absorption of Agglomerated Small Spherical Particles [Text] / W. Lou, T. T. Charalalampopoulos // *Journal of Physics D: Applied Physics*. – 1994. – Vol. 27, Issue 11. – P. 2258–2270. doi: 10.1088/0022-3727/27/11/004
9. Xu, R. Particle Characterization: Light Scattering Methods [Text] / R. Xu. – N.Y.: Kluwer Academic Publishers, 2001. – 410 p.
10. Di Stasio, S. Feasibility of an Optical Experimental Method for the Sizing of Primary Spherules in Sub-Micron Agglomerates by Polarized Light Scattering [Text] / S. Di Stasio // *Applied Physics B: Lasers and Optics*. – 2000. – Vol. 70, Issue 4. – P. 635–643. doi: 10.1007/s003400050872
11. Mulholland, G. W. Measurement of 100 nm and 60 nm Particle Standards by Differential Mobility Analysis [Text] / G. W. Mulholland, M. K. Donnelly, Ch. R. Hadwood, S. R. Kukuck, V. A. Hackley, D. Y. H. Pui // *Journal of Research of the National Institute of Standards and Technology*. – 2006. – Vol. 111, Issue 4. – P. 257–312. doi: 10.6028/jres.111.022
12. Ivanov, L. A. Izmenenie svetovozvrashhenija ot stekljannyh mikrosharikov i progon kachestva sveto-vozvraashhajushih pokrytij [Text] / L. A. Ivanov, D. V. Kizevetter, N. N. Kiselev et al. // *Opt. zhurn.* – 2006. – Vol. 73, Issue 1. – P. 35–40.
13. Kizevetter, D. V. Odnovremennoe izmerenie razmerov i skorosti dvizhenija chastic [Text] / D. V. Kizevetter, V. I. Maljugin // *Zhurn. tehn. fiziki*. – 2009. – Vol. 79, Issue 2. – P. 90–95.
14. Ershov, A. E. Effects of Size Polydispersity on the Extinction Spectra of Colloidal Nanoparticle Aggregates [Text] / A. E. Ershov, I. L. Isaev, P. N. Semina, V. A. Marke, S. V. Karpov // *Physical Review B*. – 2012. – Vol. 85. doi: 10.1103/physrevb.85.045421
15. Karpov, S. V. Opticheskie spektry kolloidov serebra s pozicii fiziki fraktalov [Text] / S. V. Karpov, I. L. Isaev, A. P. Gavriljuk // *Kolloid. zhurn.* – 2009. – Vol. 71, Issue 3. – P. 314.
16. Van de Hulst, G. Rassejanie sveta malymi chasticami [Text] / G. Van de Hulst. – Moscow: IL, 1961. – 536 p.
17. Kerker, M. The scattering of light and other electromagnetic radiation [Text] / M. Kerker. – N.Y., London, Academic Press, 1969. – 666 p.
18. Xu, R. Particle Characterization: Light Scattering Methods [Text] / R. Xu. – N.Y.: Kluwer Academic Publishers, 2001. – 410 p.
19. Di Stasio, S. Feasibility of an Optical Experimental Method for the Sizing of Primary Spherules in Sub-Micron Agglomerates by Polarized Light Scattering [Text] / S. Di Stasio // *Applied Physics B: Lasers and Optics*. – 2000. – Vol. 70, Issue 4. – P. 635–643. doi: 10.1007/s003400050872

20. Kizevetter, D. V. Odnovremennoe izmerenie razmerov i skorosti dvizheniya chastic [Text] / D. V. Kizevetter, V. I. Maljugin // Zhurn. tehn. fiziki. – 2009. – Vol. 79, Issue 2. – P. 90–95.
21. Papok, I. M. Using the dynamic light-scattering method for the analysis of a blood-serum model solution [Text] / I. M. Papok et al. // Moscow Univ. Phys. Bull. – 2012. – Vol. 67, Issue 5. – P. 452–456.
22. Patent. na korisnu model' № 54284, MPK S 01 G 49/00. Sposib otrimannja magnetitu [Text] / Iljuha M. G., Cihanov'ska I. V., Barsova Z. V., Timofeeva V. P., Vedernikova I. O. – opubl. 10.11.2010. Bjul. № 21. – 4 p.
23. Klenin, V. I. Harakteristicheskie funkcii svetorassejaniya dispersnyh chastic [Tekst] / V. I. Klenin, S. Ju. Shhegolev, V. I. Lavrushin. – Saratov: Izd-vo SGU, 1977. – 176 p.
24. Klenin, V. I. Praktikum po kolloidnoj himii [Tekst] / V. I. Klenin. – Moscow: Sol', 1996. – 56 p.

*Розроблено модель утворення піноемультсійної системи. Визначено шляхи регулювання міцності міжфазних адсорбційних шарів. Експериментально підтверджено, що для створення піноемультсійної системи необхідно використовувати білки молока та три низькомолекулярні поверхнево-активні речовини з високим і низьким гідрофільно-ліпофільним балансом. За реалізації даних принципів одержано піноемультсію, яка володіє високою піноутворюючою здатністю, стійкістю піни та механічною міцністю*

*Ключові слова: міжфазний адсорбційний шар, гранична напруга зсуву, збита емульсія, піноутворююча здатність*

*Разработана модель образования пеноэмульсионной системы. Определены пути регулирования прочности межфазных адсорбционных слоев. Экспериментально подтверждено, что для создания пеноэмульсионной системы необходимо использовать белки молока и три низкомолекулярные поверхностно-активные вещества с высоким и низким гидрофильно-липофильным балансом. При реализации данных принципов получена пеноэмульсия, которая обладает высокой пенообразующей способностью, устойчивостью пены и механической прочностью*

*Ключевые слова: межфазный адсорбционный слой, предельное напряжение сдвига, пенообразующая способность*

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# DEVELOPING A MODEL OF THE FOAM EMULSION SYSTEM AND CONFIRMING THE ROLE OF THE YIELD STRESS SHEAR OF INTERFACIAL ADSORPTION LAYERS TO PROVIDE ITS FORMATION AND STABILITY

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## 1. Introduction

In recent years, the process of Ukraine's European integration as a factor of socioeconomic development of the state

has a significant impact on all activities of the industrial sector and trade, including the food industry and restaurant business. It affects primarily the requirements for food products, which must comply with the Ukrainian and European