Behaviour of zirkoinium oxyhydrate gels under spontaneous pulsating current

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Abstract: – The pulsating character of the zirconium oxyhydrate gel properties is determined by the conformational reorganization of the matrix. The conformational instability results in the polarization change of the electrical double layers of gel particles, which manifests itself in the periodic current splashes.

Zirconium oxyhydrate gels put into the magnetic field are characterized by the great current splash, which can probably be explained by the polymerizational synchronization of the mesophaselike matrix fragments.

The mathematical model describing the linear movement of gel fragments into the electrochemical cell and gel fragment turning is given.

Key-Words: gel, zirconium oxyhydrate, mesophaselike, magnetic field, chemical potentials, electrostatic potential, membrane, conformational reorganization, synchronization.

1. Introduction

In our earlier works [1-2] the appearance of the pulsating current into the elongated oxyhydrate gel system was shown. It was proved [3] that the reason for the pulsating current appearance is the self-organizing of gel with time, to be more exact, the reasons for the pulsating current appearance are the characteristic features of the gel fragment polarization potential, the polarization potential collapse and the splash of ions into the Van der Waals forces field.

The influence of the magnetic field on liquid crystals is also widely known [4-6] (the effect of the liquid crystal molecular orientation in the force field and the flexi-effect for the spiral-shaped molecules).

Heavy metals oxyhydrate gels are mesophaselike that is why it is interesting to consider the influence of the magnetic field on the systems under study. Moreover, it is interesting to study the influence of the magnetic field on the polarization current character (gel self-organization), as it will contribute to the better understanding of the nature of polarization. It will also help to follow up the changes in gel structuring under the influence of constant force field on a particular time interval, which is of particular interest as zirconium oxyhydrate gels are evolutionary systems that are changing with time.

2. Experimental

The zirconium oxyhydrate gels were synthesized from the zirconium oxychloride salts by adding the solution of sodium hydrate (or ammonia) under pH=9.25; where the quantity of zirconium added is n = 0,00094 mol into the system.

The device for measuring the pulsating polarizing current was made of the hollow-type tube at the each end of which the round platinum electrodes (R=0.4cm) were mounted. The electrode contacts were connected to the recording device. The fresh gel was put into the hollow-type tube with the distance between the electrodes equal to 7 cm and the output resistance of the system equal to 0, which meant that the cell filled with gel shorted. The recording device measured the electric current appearing in the system with the sample frequency equal to 5 times per second. The experiment lasted for 6 hours.

The tube with the oxyhydrate gel was put into the system of constant magnets (where

field gradient of the A magnet system was equal to H_A = 900 Oe, field gradient of the B magnet system was equal to B - H_B = 600 Oe). After that the tube was mounted on the mechanical mixer (to prevent the demixing of gel system) and put into the thermostate. (T=303K).

3. Results and discussion

In the experiment the distinct from each other curves of the current splash of the zirconium oxyhydrate gel system with time were obtained. (Fig.1(a, b, c)).

a)

b)

c)
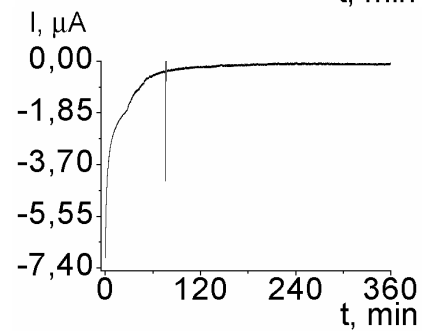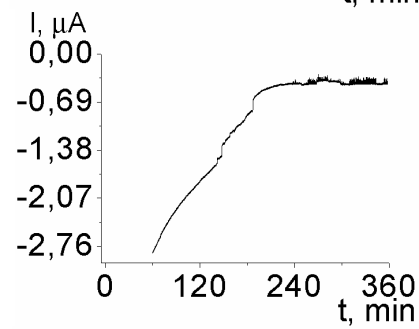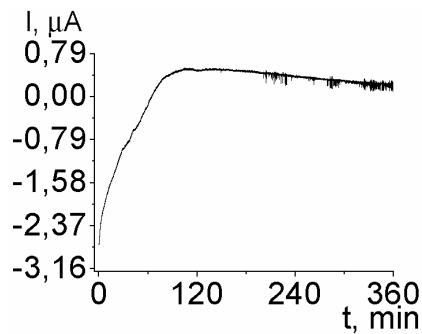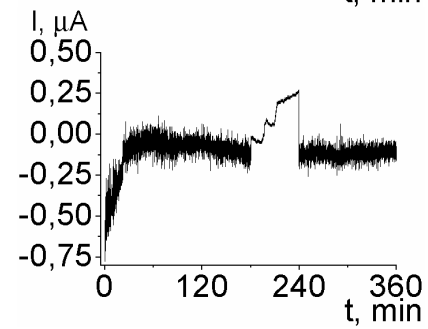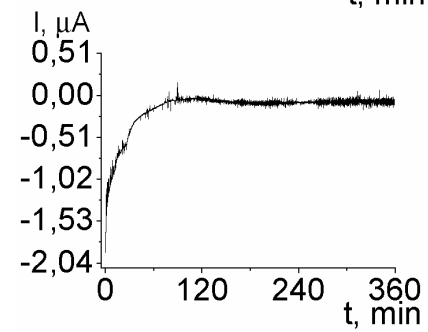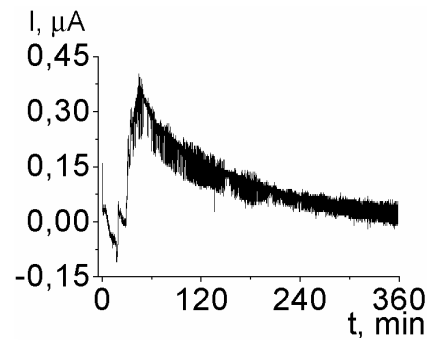
Fig. 1(a,b,c). Polarization current change of the zirconium oxyhydrate gels synthesized in three parallels.

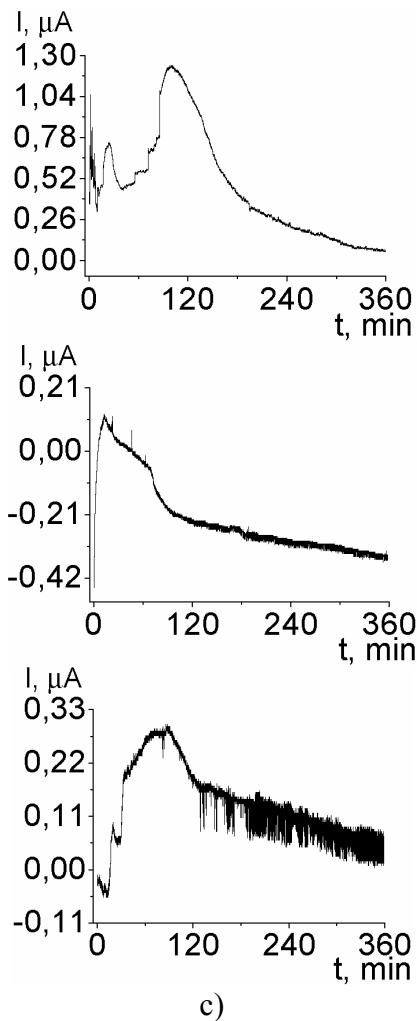*a) the gels were studied in the magnetic field with the intensity equal to 900 Oe, b) the gels were studied in magnetic field with the intensity equal to 600 Oe, c) the gels were studied with no magnetic field; the sample was synthesized under pH=9.25; the length of the tube was equal to 7 cm., the quantity of the zirconium oxyhydrate gel in the tube was n=0.00094 mol.*

The hyperbolical increase of the polarizing current has been noted for the samples put into the magnetic field of the highest intensity. The samples of the zirconium oxyhydrate gel, put into the magnetic field of the lowest intensity, have the same hyperbolical increase of the polarizing current, but after achieving the maximum value the polarizing current starts to decrease exponentially. This is accompanied by the change of the current direction, i.e. the charge exchange of the

electrodes is observed (Fig.1b). The effect of the charge exchange of the zirconium oxyhydrate gel, which was not put into the magnetic field, is expressed much stronger than in the previous two cases (Fig.1c).

To evaluate the quantity of the current splash of the zirconium oxyhydrate gel, the value ΔI microA in absolute magnitude (which is between the maximum and minimum values of the current splash given in Table 1) was calculated.

Table 1. The difference of the maximum and minimum values of the current splash in absolute magnitude.

H, Oe	ΔI, μA		
0	1.18	0.57	0.35
600	0.49	1.84	0.99
900	13.46	3.21	6.94

H – Intensity of the magnetic field

It is clearly seen from the table that the range of the zirconium oxyhydrate gel current splashes broadens when the intensity of the magnetic field increases. It may be explained by the orientation effect of the mesophaselike gel fragments under magnetic field. As a result of the orientation effect the splash of the particles is one-directional. Meanwhile the elongated synchronized dipoles of the gel fragments, having high electrical double layers polarization, appear. The flexi-magnet ordering effect occurs less in the second case. Elongated current splashes are given in Fig.2.
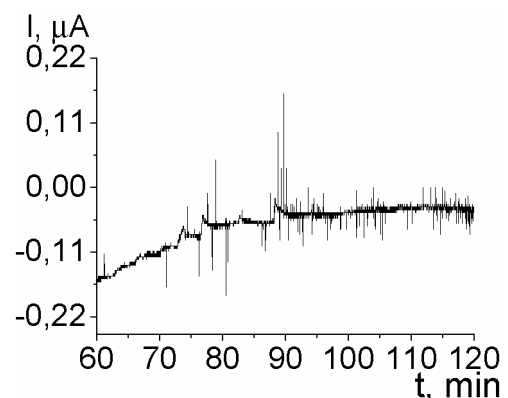

Fig. 2. Part of the experimental curve with current splashes

4. Physical explanation

Let's try to analytically describe the phenomenon of current splashes and consider the following task: let us have some gel in the colloid state and let this gel be placed into the thin flat tube. At the each end of the tube there is a round platinum electrode with the constant voltage difference between them. The chain is completed. Then, the charge fluctuation together with the gel particle movements causes the potential difference. The magnetic field self-constantly influences on gel making the charged particles move. The gel is considered to be some kind of sorbing capillary membrane.

Correspondingly, according to Fredericksburg D.A., the flows of charged particles I_+ and I_- in the absence of temperature gradient and chemical potentials will be defined by the relation:

$$I_+ = L_{11} grad\, \varphi + L_{12} grad\, P$$
$$I_- = \tilde{L}_{11} grad\, \varphi + \tilde{L}_{12} grad\, P$$

where φ is the current potential, P is the pressure, L_{11} is the conductivity coefficient for the flow of positively charged particles, L_{12} is the value of the electro-somatic flow of the positively charged particles, $\tilde{L}_{11}$ and $\tilde{L}_{12}$ are the coefficients for the negatively charged particles correspondingly.

Let $-L_{11} \neq \tilde{L}_{11}$ and $-L_{12} \neq \tilde{L}_{12}$. It can be explained by the fact that positively and negatively charged particles are presented by different substances. These substances interact with the gel media differently. Thus, charged particles undergo different attraction of the Van der Waals forces in the gel media and have different mobility in relation to the gel media.

Therefore, I_+ is not equal to I_-. This fact will cause the charge accumulation on the membranes. In our earlier works we analyzed these effects [7].

Let us consider that $\tilde{L}_{11} - \lambda = -L_{11}$ and $\tilde{L}_{12} - \zeta = -L_{12}$.

The formula for the charged particle flows may be written as:

$$I_+ = L_{11} grad\, \varphi + L_{12} grad\, P$$
$$I_- = -(L_{11} - \lambda) grad\, \varphi - (L_{12} - \xi) grad\, P \qquad (1)$$

Now let us write the continuity equation for the positively and negatively charged ions.

$$\frac{\partial n_+}{\partial t} + div \vec{j}_+ = D\Delta n_+$$
$$\frac{\partial n_-}{\partial t} + div \vec{j}_- = D\Delta n_- \qquad (2)$$

where $\vec{j}_+$ and $\vec{j}_-$ are the current densities, $D\Delta n$ - is the diffusion, D is the diffusion coefficient, Δ is the Laplace operator. It should be noted that j and I have different dimensions. That's why we divide I_+ and I_- into the sectional area, which is considered to be constant. From (1) we get the relations:

$$\vec{j}_+ = +l_{11} grad\, \varphi + l_{12} grad\, P$$
$$\vec{j}_- = -l_{11} grad\, \varphi - l_{12} grad\, P + \Lambda\, grad\, \varphi + \xi\, grad\, P \qquad (3),$$

where all the coefficients are given in relation to the sectional area.

After that we put the expressions for the current densities into the continuity equation (2) and get:

$$\begin{cases} \dfrac{\partial n_+}{\partial t} + l_{11}\Delta\varphi + l_{12}\Delta P = D\Delta n_+ \\ \dfrac{\partial n_-}{\partial t} - (l_{11} - \Lambda)\Delta\varphi - (l_{12} - \xi)\Delta P = D\Delta n_- \end{cases} \qquad (4).$$

It should be noted that the task for the potential has the form:

$$\begin{cases} \Delta\varphi = 4\pi(n_+ - n_-) \\ \varphi|_{\Gamma_1} = \varphi_0, \; \varphi|_{\Gamma_2} = \varphi_1 \end{cases} \qquad (5),$$

where Γ_1 is the left electrode where the EMF of gel maintains the constant electrostatic potential φ_0, Γ_2 is the right electrode where the EMF of gel maintains the φ_1 electrostatic potential.

If we neglect the boundary conditions, which will be discussed later in the article, and combine the systems of equations (4) and (5) we will get:

$$\begin{cases} \dfrac{\partial n_+}{\partial t} + 4\pi l_{11}(n_+ - n_-) + l_{12}\Delta P = D\Delta n_+ \\ \dfrac{\partial n_-}{\partial t} - 4\pi(l_{11} - \Lambda)(n_+ - n_-) - (l_{12} - \xi)\Delta P = D\Delta n_- \end{cases}$$

Let us consider, that the ion pressure in the liquid is equal to that in the ideal gas, and proportional to the ion concentration. Therefore, we get

$$\begin{cases} \dfrac{\partial n_+}{\partial t} + 4\pi l_{11}(n_+ - n_-) + l_{12}\Delta\left(\alpha_1 n_+ + \alpha_2 n_-\right) = D\Delta n_+ \\ \dfrac{\partial n_-}{\partial t} - 4\pi(l_{11} - \Lambda)(n_+ - n_-) - (l_{12} - \xi)\Delta\left(\alpha_1 n_+ + \alpha_2 n_-\right) = D\Delta n_- \end{cases} \quad (6),$$

where α_1, α_2 are the proportional coefficients.

5. Formal decision

The set of equations (6) is not completed as it has no initial and boundary conditions and the area for the decision to be done is not defined.

We will decide the task in one-dimensional area (x-coordinate), as the length of the dipoles is small (some micrometers) in comparison with the tube length (about 10 cm). We may consider the area to be one-dimensional and indefinite. Let us require that there are no ions on the infinity different from the ion background (as the ion background in (6) is not taken into account). So, $n_\pm \to 0$ where $x \to \pm\infty$. The same condition is suggested for the coordinate derivative: $\dfrac{\partial n_\pm}{\partial x} \to 0$ where $x \to \pm\infty$.

Time period for the decision (6): let the time period start at the moment $t = 0$ and go into infinity $t \to +\infty$. At the initial moment of time we will consider that $n_+|_{t=0} = N_0$, a $n_-|_{t=0} = N_1$, where N_0 and N_1 may not correspond due to different properties of negatively and positively charged gel particles.

Thus, the task (6) can be written as follows:

$$\begin{cases} \dfrac{\partial n_+}{\partial t} + 4\pi l_{11}(n_+ - n_-) + l_{12}\Delta\left(\alpha_1 n_+ + \alpha_2 n_-\right) = D\Delta n_+ \\ \dfrac{\partial n_-}{\partial t} - 4\pi(l_{11} - \Lambda)(n_+ - n_-) - (l_{12} - \xi)\Delta\left(\alpha_1 n_+ + \alpha_2 n_-\right) = D\Delta n_- \\ n_+|_{t=0} = N_+, \quad n_-|_{t=0} = N_-, \quad n_+|_{x\to\pm\infty} = 0, \quad n_-|_{x\to\pm\infty} = 0 \\ \left.\dfrac{\partial n_+}{\partial x}\right|_{x\to\pm\infty} = 0, \quad \left.\dfrac{\partial n_-}{\partial x}\right|_{x\to\pm\infty} = 0 \qquad x \in (-\infty; +\infty), \ t \in (0; +\infty) \end{cases} \quad (7)$$

Hereafter, not to make the calculations complex, we will take the upper two of the set of equations (7).

It is useful to transfer the expressions for the concentrations with different signs to the different parts of the equation.

$$\begin{cases} \dfrac{\partial n_+}{\partial t} + 4\pi l_{11} n_+ + (l_{12}\alpha_1 - D)\Delta n_+ = l_{12}\alpha_2 \Delta n_- + 4\pi l_{11} n_- \\ \dfrac{\partial n_-}{\partial t} + 4\pi(l_{11} - \Lambda)n_- - (l_{12} - \xi)\alpha_2 \Delta n_- - D\Delta n_- = 4\pi(l_{11} - \Lambda)n_+ + \alpha_1(l_{12} - \xi)\Delta n_+ \end{cases} \quad (8)$$

Let us introduce the designations:

$$\dfrac{\partial n_+}{\partial t} + 4\pi l_{11} n_+ + (l_{12}\alpha_1 - D)\Delta n_+ \equiv L_1[n_+],$$

$$l_{12}\alpha_2 \Delta n_- + 4\pi l_{11} n_- \equiv L_2[n_-],$$

$$\dfrac{\partial n_-}{\partial t} + 4\pi(l_{11} - \Lambda)n_- - (l_{12} - \xi)\alpha_2 \Delta n_- - D\Delta n_- \equiv L_3[n_-], \quad (9)$$

$$4\pi(l_{11} - \Lambda)n_+ + \alpha_1(l_{12} - \xi)\Delta n_+ \equiv L_4[n_+]$$

Then we get the following set of equations:
$$\begin{cases} L_1[n_+] = L_2[n_-] \\ L_3[n_-] = L_4[n_+] \end{cases}$$

Let us apply the L_1 operator to both parts of the second equation and the L_3 operator to both parts of the first equation. We will get
$$L_3 L_1[n_+] = L_3\left[L_2[n_-]\right] = L_2\left[L_3[n_-]\right] = L_2\left[L_4[n_+]\right].$$

The same type of calculations may be done for the density of the negative charges.

It should be noted that the equation we got has the second order in time and the fourth order on coordinate.

Considering the boundary conditions in the set of equations (7), we can apply the Fourier transformation.

Then, for the Fourier transform $F[n_+] = n \equiv \displaystyle\int_{-\infty}^{+\infty} n_+(x,t)\exp(ikx)\,dx$, we get:

$$\begin{aligned} &\left\{\dfrac{\partial}{\partial t} + 4\pi l_{11} - k^2(l_{12}\alpha_1 - D)\right\}\left\{\dfrac{\partial}{\partial t} - 4\pi l_{11} - k^2 l_{12}\alpha_1\right\}n = \\ &= -\left\{4\pi(\Lambda - l_{11}) - (\xi - l_{12})\alpha_2 k^2\right\}\left\{4\pi l_{11} + l_{12}\alpha_2 k^2\right\}n \end{aligned} \quad (10)$$

The solution of the equation will have the form:

$$\begin{aligned} n(k,t) = &\, C_1 \exp\left(t\left\{a_3 k^2 + \sqrt{a_1^2 - a_4 a_6 + (a_5 a_6 - a_4 a_7)k^2 + a_5 a_7 k^4}\right\}\right) + \\ &+ C_2 \exp\left(t\left\{a_3 k^2 - \sqrt{a_1^2 - a_4 a_6 + (a_5 a_6 - a_4 a_7)k^2 + a_5 a_7 k^4}\right\}\right) \end{aligned} \quad (11)$$

where the following designations are used:
$$a_1 = 4\pi l_{11}, \qquad a_2 = l_{12}\alpha_1 - D, \qquad a_3 = l_{12}\alpha_2,$$
$$a_4 = 4\pi(\Lambda - l_{11}), \qquad\qquad a_5 = (\xi - l_{12})\alpha_2,$$
$$a_6 = 4\pi l_{11}, \ a_7 = l_{12}\alpha_2.$$

The coefficients C_1 and C_2 should be determined from the initial conditions.

It should be noted that the inverse Fourier transformation is impossible to do analytically and it is necessary to make the numerical calculations.
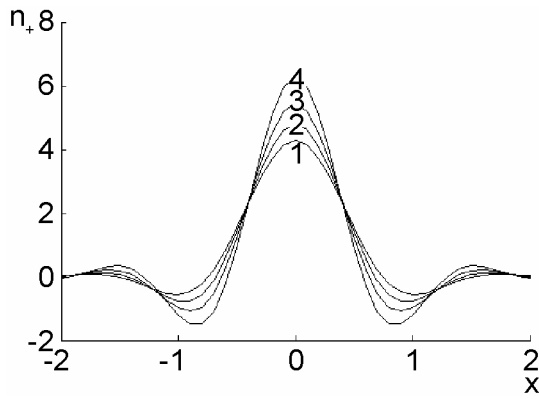
Fig. 3. Inverse Fourier transformation for the set of equations (7)

C_1 *is equal to* $\exp(-k^2)$, $C_2 = 0$; $a_3 = 1/130$, $a_5a_6 - a_4a_7 = 0$, *radical expression in the exponent (11) is equal to zero; 1 is the second moment of time (t), 2 is the forth moment of time (t); 3 is the sixth moment of time (t); 4 is the eighth moment of time (t); dimensionless time (t); x is space coordinate; n_+ is the concentration of the positively charged ions; negative values of the concentration are determined by the rough regularization of the inverse Fourier transformation.*

6. Accurate solution

Let N_+ be the initial concentration of the positively charged density, and N_- be the initial concentration of the negatively charged density. The solution for the n_+ is:

$$n_+ = C_1 \exp\left(t\left\{a_3 k^2 + \sqrt{a_1^2 - a_4 a_6 + (a_5 a_6 - a_4 a_7)k^2 + a_5 a_7 k^4}\right\}\right) +$$
$$+ C_2 \exp\left(t\left\{a_3 k^2 - \sqrt{a_1^2 - a_4 a_6 + (a_5 a_6 - a_4 a_7)k^2 + a_5 a_7 k^4}\right\}\right) \quad (12)$$

For the sake of convenience we introduce the values λ_1 and λ_2, so that $n_+ = C_1 \exp(\lambda_1 t) + C_2 \exp(\lambda_2 t)$.

Then, we get the following relationship for the negatively charged ion concentration:

$$(4\pi l_{11} - k^2 l_{12}\alpha_2)n_- = (\lambda_1 + 4\pi l_{11} - k^2(l_{12}\alpha_1 - D))C_1 + (\lambda_2 + 4\pi l_{11} - k^2(l_{12}\alpha_1 - D))C_2$$

After that, we get the relationships for the constants C_1 and C_2:

$$C_1 = \frac{N_-(4\pi l_{11} - k^2 l_{12}\alpha_2) - N_+(\lambda_2 + 4\pi l_{11} - k^2(l_{12}\alpha_1 - D))}{\lambda_1 - \lambda_2},$$

$$C_2 = \frac{N_+(\lambda_1 + 4\pi l_{11} - k^2(l_{12}\alpha_1 - D)) - N_-(4\pi l_{11} - k^2 l_{12}\alpha_1)}{\lambda_1 - \lambda_2}.$$

Then, we get the relationships for the density of the negatively and positively charged particles:

$$n_+ = C_1 e^{\lambda_1 t} + C_2 e^{\lambda_2 t},$$

$$n_- = \frac{(\lambda_1 + 4\pi l_{11} - k^2(l_{12}\alpha_1 - D))}{(4\pi l_{11} - k^2 l_{12}\alpha_2)}C_1 e^{\lambda_1 t} + \frac{(\lambda_2 + 4\pi l_{11} - k^2(l_{12}\alpha_1 - D))}{(4\pi l_{11} - k^2 l_{12}\alpha_2)}C_2 e^{\lambda_2 t}$$

As we are interested in the charge difference $\delta n = n_+ - n_-$ we subtract n_- from n_+.

As a result we get

$$\delta n = \frac{(\lambda_1 + k^2 D)}{(4\pi l_{11} - k^2 l_{12}\alpha_2)}C_1 e^{\lambda_1 t} + \frac{(\lambda_2 + k^2 D)}{(4\pi l_{11} - k^2 l_{12}\alpha_2)}C_2 e^{\lambda_2 t}$$

.

Let's consider that $N_+ = 0$ and $N_- = +1$.

Then we get the relationship

$$\delta n = \left(\frac{(\lambda_1 + k^2 D)}{\lambda_1 - \lambda_2}e^{\lambda_1 t} + \frac{(\lambda_2 + k^2 D)}{\lambda_1 - \lambda_2}e^{\lambda_2 t}\right)e^{-k^2}. \quad (13)$$

The solution of the equation is given in Figure 4.

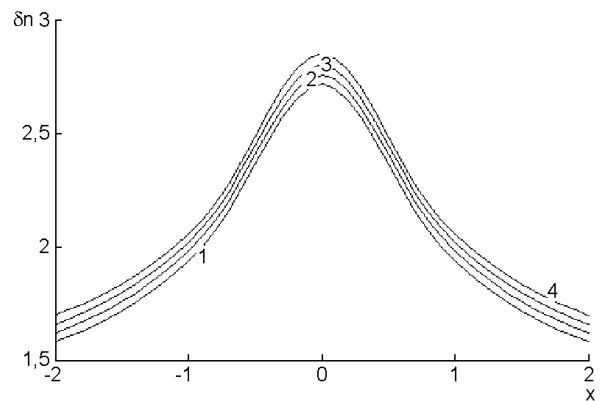

Fig. 4. Decision of equation (13),
x is the space coordinate; δn is the coordinate calculated from the equation (13), (dimensionless coordinates); 1 is the moment of time in dimensionless units 0; 2 is the moment of time equal to 0.5; 3 is the moment of time 1; 4 is the moment of time equal to 1.5.

7. Distributed membrane

Let us consider that the membrane is a distributed one, i.e. the charge adsorption will take place in many places. It means that the current magnitudes I_+ and I_- are given only for the thin layer δx. Therefore, these values should be considered not as current magnitudes but as current steps δI in the current direction. Consequently, taking into account the

continuity equations we get the analogue system of equations (4-5):

$$
\begin{cases}
\dfrac{\partial n_+}{\partial t} + l_{11}\dfrac{\partial}{\partial x}\varphi + l_{12}\dfrac{\partial}{\partial x}(\alpha_1 n_+ + \alpha_2 n_-) = D\Delta n_+ \\[2mm]
\dfrac{\partial n_-}{\partial t} - (l_{11}-\Lambda)\dfrac{\partial}{\partial x}\varphi + (l_{12}-\xi)\dfrac{\partial}{\partial x}(\alpha_1 n_+ + \alpha_2 n_-) = D\Delta n_- \\[2mm]
\dfrac{\partial^2 \varphi}{\partial x^2} = 4\pi(n_+ - n_-)
\end{cases} \quad (14)
$$

We consider the set of equations (8) in the same area as the set of equations (6).

Considering the set of equations (8) we take into account the boundary conditions that are analogous to those in (6). It should be noted that these boundary conditions enable us to make the x-coordinate Fourier transformation in infinite limits.

When the x-coordinate Fourier transformation is done we get the relationships:

$$
\begin{cases}
\dfrac{\partial F[n_+]}{\partial t} + ikl_{11}F[\varphi] + ikl_{12}(\alpha_1 F[n_+] + \alpha_2 F[n_-]) = -k^2 DF[n_+] \\[2mm]
\dfrac{\partial F[n_-]}{\partial t} - ik(l_{11}-\Lambda)F[\varphi] + ik(l_{12}-\xi)(\alpha_1 F[n_+] + \alpha_2 F[n_-]) = -k^2 DF[n_-] \\[2mm]
-k^2 F[\varphi] = 4\pi(F[n_+] - F[n_-])
\end{cases} \quad (15)
$$

For simplicity let us consider the case, when $\Lambda = 0$ and $\xi = 0$. Then we neglect the boundary conditions. After that we add to the given above set of equations its Fourier transformation in order to account for the influence of the external field.

$$
\begin{cases}
\dfrac{\partial F[n_+]}{\partial t} + ikl_{11}F[\varphi] + l_{11}F[E_0] + ikl_{12}(\alpha_1 F[n_+] + \alpha_2 F[n_-]) = -k^2 DF[n_+] \\[2mm]
\dfrac{\partial F[n_-]}{\partial t} - ikl_{11}F[\varphi] - l_{11}F[E_0] + ikl_{12}(\alpha_1 F[n_+] + \alpha_2 F[n_-]) = -k^2 DF[n_-] \\[2mm]
-k^2 F[\varphi] = 4\pi(F[n_+] - F[n_-])
\end{cases} \quad (16)
$$

Let us consider that at the initial moment of time the positive and negative ion concentrations are equal to zero.

To solve the given set of equations we add the first two sets of equations. As a result we get the following relationship:

$$
\frac{\partial(\tilde{n}_+ + \tilde{n}_-)}{\partial t} + ikl_{12}(\alpha_1 \tilde{n}_+ + \alpha_2 \tilde{n}_-) = -k^2 D(\tilde{n}_+ + \tilde{n}_-).
$$

If the coefficients α_1 and α_2 are considered to differ not much from each other, the solution for the equation is zero, i.e. $\tilde{n}_- + \tilde{n}_+ = 0$.

Then,

$$
\begin{cases}
\dfrac{\partial F[n_+]}{\partial t} + ikl_{11}F[\varphi] + l_{11}F[E_0] = -k^2 DF[n_+] \\[2mm]
-k^2 F[\varphi] = 8\pi F[n_+]
\end{cases}
$$

or

$$
\frac{\partial F[n_+]}{\partial t} - \frac{il_{11}}{k}F[n_+] + l_{11}F[E_0] = -k^2 DF[n_+] \quad (17)
$$

Making calculations in the common coordinates we get:

$$
\frac{\partial n_+(x,t)}{\partial t} + A\int n_+(x,t)dx + E_0(x,t) = D\frac{\partial^2 n_+(x,t)}{\partial x^2}.
$$

Now we solve the equation concerning the derivative with time and get the integral equation that has the form:

$$
n_+ = -E_0 t - A\int_0^t \frac{d\tau}{\sqrt{4\pi D(t-\tau)}}\int_{-\infty}^{+\infty}\exp\left(-\frac{(x-s)^2}{4D(t-\tau)}\right)ds\int n_+(s,\tau)ds \quad (18)
$$

Let's make some numerical approximations for the solution of this equation:

The zero solution has the form: $n_+^{(0)} = -E_0 t$

The first solution has the form: $n_+^{(1)} = -E_0 t + AE_0 tx$.

It should be noted that the first approximation is odd. In view of the relationship $n_- + n_+ = 0$, the charge in the capillary will linearly increase with time correspondingly increasing the potential of the capillary. The magnetic field of the potential will be oriented against the external field, which will make the current position of the capillary unstable and it will strive to turn against the magnetic field. Considering the capillary turn occurs in seconds, we can suppose that the magnetic field depends on time in discrete steps: $E_0(x,t) = E_0 sign(\sin(\omega t))$, where the value ω will be determined by the unstable equilibrium state of the capillary.

Correspondingly, the densities will change: under zero-order approximation the density will have the form $E_0 = E_0 \arcsin(\sin(\omega t))/\omega$, under first approximation the density will have the form - $n_+^{(1)} = (-E_0 + AE_0 x)\arcsin(\sin(\omega t))/\omega$.

How will the frequency of oscillation be determined then? Roughly, it will be determined from the relationship: $I\ddot{\varphi} = -2E_0^2 Tl\sin\varphi$, where I is the inertia moment of the gel capillary, E_0 is the electric field created in the capillary, T it the period time of the turn, l is the part of the asymmetric capillary which acts as the arm of force. Consequently, the frequency of oscillation will

be determined by: $\Omega^2 = \dfrac{2E_0^2 Tl}{I}$, or taking into account the dependence of period on the frequency of oscillation: $\Omega^3 = \dfrac{4\pi E_0^2 l}{I}$. The non-linear equation should be made to determine the exact values.
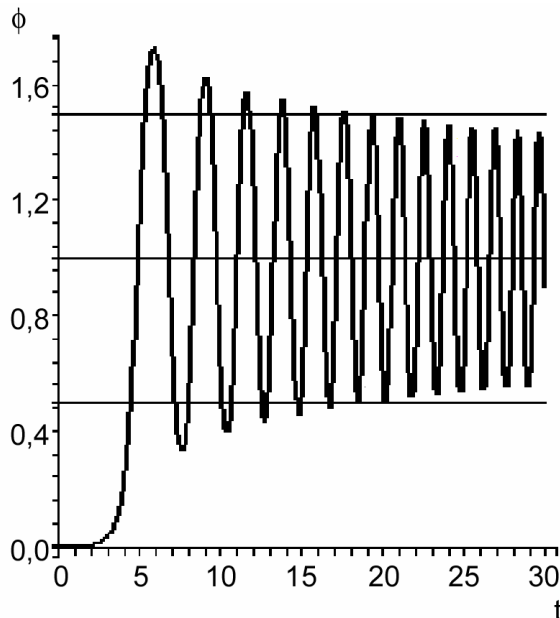

Fig. 5. Change of the dipole turn angle with time

$I\ddot{\varphi} = -2E_0^2 tl \sin\varphi$ *(the angle is calculated in pi radian units), t is the dimensionless time. The decision is based on the consumption that the deviation from the normal position at the initial moment of time is equal to 0.01radian, and the velocity is equal to zero.*

The drift of the dipole in the external field will take place in the following manner: the "inverted" dipole will for some time drift in the field till the accumulated charge of its polarized part "resolves". After that the backward movement may start if the oxyhydrate dipole and the polymer membrane do not become polymer-linked.

8. Conclusion

The pulsating character of the zirconium oxyhydrate gel properties is determined by the conformational reorganization of the matrix. The conformational instability results in the polarization change of the electrical double layers of gel particles, which manifests itself in the periodic current splashes.

Zirconium oxyhydrate gels put into the magnetic field are characterized by the great current splash, which can probably be explained by the polymerizational synchronization of the mesophaselike matrix fragments.

The mathematical model describing the linear movement of gel fragments into the electrochemical cell and their turning is given.

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