DEVELOPMENT OF DISSIPATIVE STRUCTURES ON SURFACE OF DIELECTRIC LIQUID IN ELECTROSTATIC FIELD

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The transition of plane surface of liquid dielectric charged with the electrical charge in the electrostatic field in the periodical gofer surface of crater type deformation is researched. It was proved for the first time that the apparition of dissipative structures keeps not optical character but thermal and is not conditioned by the presence of the photo sensible semiconductor layer. It was established that the development of dissipative structures on the surface of dielectric liquid includes in itself the mechanism of initiation of germination deformations and a mechanism of multiplication of the centers of new deformations in the free volume of germination deformation.

Introduction

The thermoplastic layer of photo thermoplastic career of information (PTPCI) during the development of deformations on the local microzones with the values of sizes within the limits $(6\div25)\mu$m are behavioral as the liquid dielectric during $t\approx(0.3\div1)s$ of sensitizing (deposition of electrical charges) in the electrostatic field [1-5]. This allowed authors [6] by numerical methods to separate the development of wave shock of substance masses in the normal plane on the substrate of the sample of liquid dielectric-solid metal substrate of the development of the wave of mass transportation of substances in the radial plane [2]. Taking into consideration that the "depth" of deformations determines the value of penetrated light flux through the liquid layer, in [7] the numerical processing 3*D* of optical images 2*D* was applied. The basic idea consists in the storage of penetrated light through PTPCI in the memory of computer. The structure 3D approximated of the deformation of relief portable surface was represented by the association of each point $(\boldsymbol{x, y})$ of the image with the pseudo spatial parameter of color ($\boldsymbol{h}$). This allowed the definition of expression of some new physical value Q – the quality factor of pseudo spatial optical images.

1. Method of research and the processing of results

The method of research was elaborated in [8]. The numerical method of calculation evidentiated the non linear character of the phenomenon of apparition of the grey points $\mathbf{n_{ij}}$ (grey pixels) on the curves of histogram of optical image and the interconnection with the mechanism of development of the deformations of crater type on the free surface of PTPCI.
The model of development of the deformations elaborated in paper [1] does not explain and does not suppose the apparition of spatial structures in group or sets of groups. The elaboration of structural model that will give good results must take into consideration the factors that assure the apparition of one group with square symmetry of the deformation of crater type – "attack figure". The attack figure is multiplied into the structure of hexagonal symmetry of deformation. Taking into the consideration the possibility of the apparition "of

the crystallization of coulomb type" on the surface of some liquid dielectric media (see [9]), the computational modeling was applied. Applying special programs, the structured models were obtained that describe the process of germination and multiplication of thermoplastic deformations in group by the algorithm represented in fig. 1. On the base of computational calculations the results of theoretical researches were taken [8, 9]. The results of theoretical researches indicate that the first non stable harmonics are excited for which the deformation of hexagonal micro relief is nonvariant with respect to the rotation with 120° around the perpendicular axis on the plane of the surface of liquid.

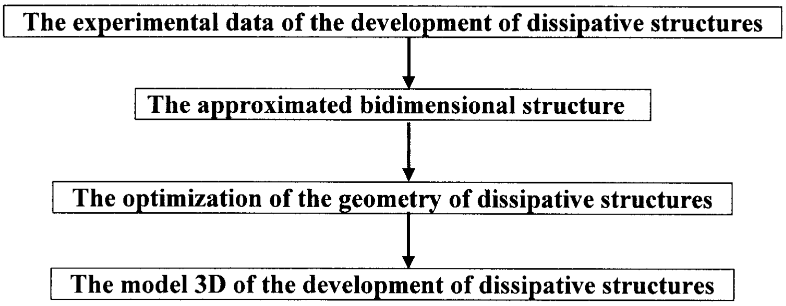


Fig. 1 The algorithm of pseudorepresentation 2D – 3D of the development of dissipative structures

From those mentioned above, further we will analyze the mechanism of initializations of periodic –spatial deformed structures for which the germination deformation $\boldsymbol{C_0}$ can initiate three centers of deformation $\boldsymbol{C_s}$ respectively only two on the selected micro zone. The experimental researches [see 10, 11] indicate that one more mechanism of initialization exists that can be observed in the samples with ultra fine liquid layers. The modification of dissipative structures can be performed in these samples from the hexapole to the octapole because the distance between $\boldsymbol{C_0}$ and $\boldsymbol{C_s}$ is greater as the radial values of the thermoplastic deformations. The modification is described by computational modeling for which C_0 can initiate on the selected microzone four centers of deformations $\boldsymbol{C_s}$, but C_s only two respectively. It was established by computational modeling that on the free surface of researched samples the structural groups (units) can exist formed of germination deformations of crater type - $\boldsymbol{C_0}$ with the approached geometrical structure (local) of satellite deformations – ($\boldsymbol{C_s}$) and the packing configuration: **$1C_0$-$2C_s$; $1C_0$-$3C_s$; $1C_0$-$4C_s$; $1C_0$-$5C_s$; $1C_0$-$6C_s$**; that are increased up to the structure with removed order of one set of groups: **$2C_0$ - $10C_s$**.

It was observed from computational modeling that in the experimental situation the sets of group can form a periodical lattice that formally can be described by structural unit of the type:

$$xC_0 \rightarrow (2x^2+x)C_s \text{ of } C_{0(x)} \rightarrow C_{s(2x^2+x)}; \text{ where } x=1, 2, \ldots \quad (1)$$

here $x=f_{(\omega)}$ is the multiplication coefficient of the centers of new deformations as the function of the increment of formation of deformation ω, thermal stable also in the electrical field.

The existence of elementary structural unit (x=1) results from relation (1) that assures the mechanism of multiplication of the centers of new deformations that correspond to the geometrical configuration of packing:

$$(1C_0 \rightarrow 3C_s) \quad (2)$$

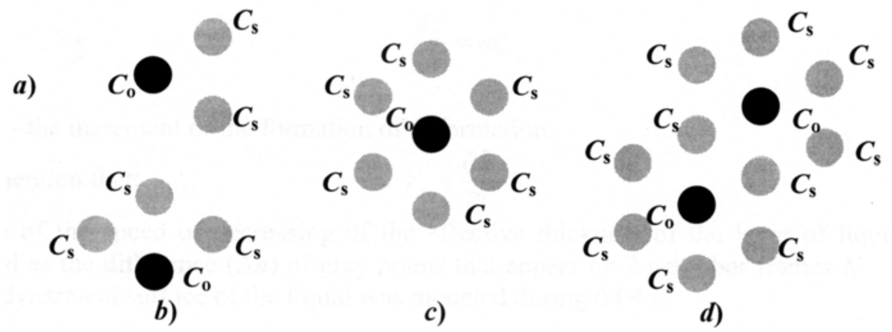


Fig. 2 Structural units induced by electrostatic field on the surface of liquid dielectric:
a) - ($1C_o – 2C_s$); b) - ($1\,C_o – 3C_s$); c) - ($1C_o – 6C_s$); d) ($1C_o – 10C_s$) $\leftrightarrow C_{o\,x} \rightarrow C_{s(2x^2+x)}$

Several examples of structural units are proposed in fig. 2 that are realized during the development of the deformation of crater type at the projection of optical images on the free surface of liquid dielectric. The model is characterized by the coefficients α, β, γ [2]. The defined structural relations are classified by the analogy with the structures for which the electrical bonds are established (chemical). So that, the mechanisms of initialization of the series of stable structures for which the intermediary states do not exist can be defined by the general relation of type: $\boldsymbol{C_o^X C_s^Y}_{XY}$, where **X,Y** is the number of harmonics (waves) totally initiated by $\boldsymbol{C_o}$. So, all geometrical forms are calculated of stable structures that can be realized in the process of formation and restructure of the deformation of the surface of liquid dielectric, researched in paper [8]: $\boldsymbol{C_o^3 C_s^2}_6$ and $\boldsymbol{C_o^4 C_s^2}_8$. The research of the mechanisms of formation of stable structure – ($\boldsymbol{C_o^4 C_s^2}_8$) formed of germination deformation and 8 satellite craters on the perimeter are outside of the objectives of the recent paper. The statistical modifications of the geometry of the structure $\boldsymbol{C_o^4 C_s^2}_8$ were emphasized in [8], but the dynamical modifications will be researched in the future papers. The limit of applicability of the model of the mechanisms of initialization of the harmonics represents the case X=Y=2 for which the stable form would be $\boldsymbol{C_o^2 C_s^2}_4$ described by relation (2) that results from the mechanism of multiplication of the centers of new thermoplastic deformations. From the evident form of relation $\boldsymbol{C_o^2 C_s^2}_4$ the dissipative structure represents a group of four thermoplastic deformation centers that are multiplied, independent of initial deformation C_0. Then the theoretical and experimental results will be synthesized by approximated numerical methods.

2. Theoretical investigations.

The numerical interpretation of the process of development of the deformation emphasized the thermal character of it and the dependence on rheology. An important factor in the research of the process of initialization of the deformations represents the phenomenon of the decreasing of effective thickness of the visualized structure under the action of the pressure of electrical forces. The value of relative deformation of the surface of liquid is represented by form:

$$\frac{\Delta \xi_N}{z} \approx e^{\delta t_N} \tag{3}$$

In this case the equation of the removing of the mass of liquid in the real coordinates of the space and time is represented as:

$$\frac{d\xi}{dt} = \omega\xi \qquad (4)$$

here: $\boldsymbol{\omega}$ is the increment of the formation of deformation.

We will mention that: $V_z = \dfrac{\partial \xi}{\partial t}$

The value of the speed of decreasing of the effective thickness of the layer of liquid was determined as the difference ($\Delta \boldsymbol{n}$) of grey points that appear on 2 neighbor frames *N*. In fig. 3 the dynamical surface of the liquid was modeled during 0.04 s:

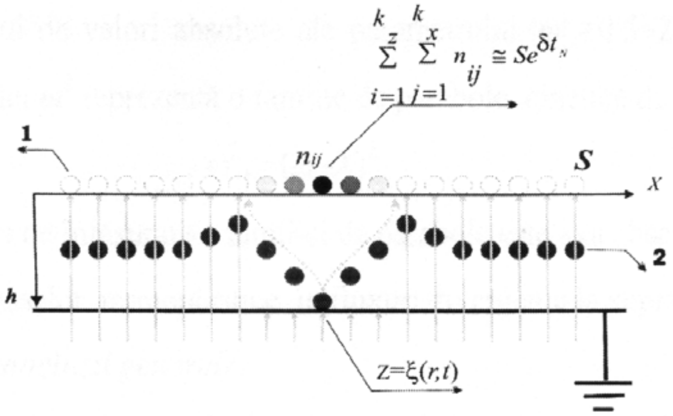


Fig. 3 The numerical representation of the development of dissipative structures: 1 – the "numerical" removing of the points of one Newtonian liquid – 2, from the dynamical surface - $\xi(\vec{r},t)$.

So in the linear approximation by the amplitude the solution of the equation of profile of dynamical surface of the liquid is defined as:

$$\xi_i = \int V dt \qquad (5)$$

The value V_z is interpreted as sum of $\boldsymbol{n_{ij}}$ bits stored in the memory of computer in the interval of time d*t*=0.04s. From the expression of the calculation of total information that is contained by optical image results:

$$S = \sum_{i,j} n_j n_i \log_2 I \qquad (6)$$

Where (*I*) is given by relation (4) and represents the gradation from white to black of each point, ($\boldsymbol{n_i}$) is the number of points from the row (*I*) and ($\boldsymbol{n_j}$) - from the column j. For I=256 (the black nuance), a point of one image will contain the information of S=8bits=1 byte (1 pixel), S has the physical meaning of maximal deformation of 8 bits of thermoplastic sample in the point of liquid surface with the real coordinate of the space $\xi(\vec{r},t) = z$. Then the stock of numerical data from the memory of computer from a base of $\boldsymbol{n_{ij}}$ bytes will describe the formation of radial deformation with the characteristic dimensions ($\boldsymbol{\lambda}$). Then the sum of $\boldsymbol{n_{ij}}$ bytes is represented as:

$$\sum_{i=1}^{k_y}\sum_{j=1}^{k_x} n_{ij} \equiv \xi_i ; \qquad \frac{1}{S}\sum_{i=1}^{k_y}\sum_{j=1}^{k_x} n_{ij} = h_i \tag{7}$$

The synthesis of numerical data and experimental ones is described by the relation of numerical calculation:

$$\frac{1}{S}\sum_{i=1}^{k_y}\sum_{j=1}^{k_x} n_{ij} \equiv \frac{\xi}{\lambda} \leq 1 \tag{8}$$

Here: (**ξ**) is the removing of the points of the liquid surface: (**λ**) is the radial dimensions of the selected micro zone at the moment t. The numerical relation (8) taking into consideration the relations (6) expresses the process of apparition of grey points **n_{ij}** on the selected micro zone, that represents a data base which is increased exponentially. From the experimental data a numerical model was developed in accordance with relation (3):

$$\sum_{i=1}^{k_z}\sum_{j=1}^{k_x} n_{ij} \cong Se^{\delta t_N} \text{ were } \delta \equiv \omega \cong \frac{1}{t_N}\ln\frac{1}{S}\sum_{i=1}^{k_z}\sum_{j=1}^{k_x} n_{ij} \text{ and } \omega_{(t)} \approx \alpha t^{-1} \tag{9}$$

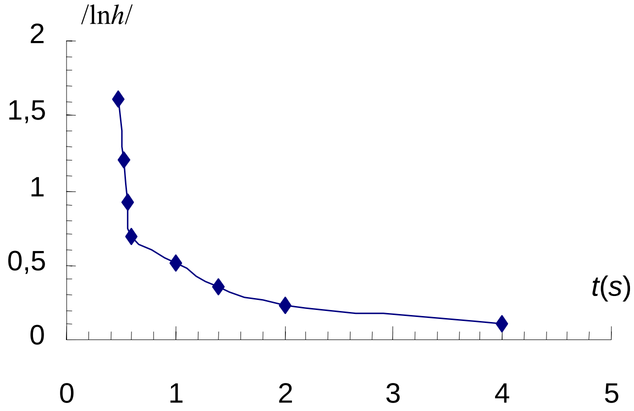
Here: **α**≤1 is the parameter that characterizes the dispersion; **δ** is interpreted as the speed (the increment **ω**) of formation of deformation.

3. The processing of experimental material

In these conditions of experiment described in paper [9] the value of increment calculated by relation (9) varies in limits **ω**=0.35÷28s^{-1}. In this segment the values: ω≈0.7÷7s^{-1} indicated in paper [2] are also included. The increasing of the values of limits (from 0.7 to 0.35 and 7 to 28 s^{-1}), with one order on the kinetic of short duration is explained by the possibilities of the modern high advanced technologies: the registration of the processes of deformation in the fluxes of diffused light through the section of the sample of thermoplastic material of the values no greater than 0.1*lx*. The increasing of the range of values of the parameter is explained also by the approximation of the calculation admitted by the authors of paper [8]. This result indicates that a group of effects of deformations of the liquid surface, characterized by the values **ω**≥7÷28 s^{-1} (II stage) up till now is not defined. The defined values in table Nr.1 are proposed for a separated crater in the conditions of experiment that assures: The characteristics of the field U_c= 5.5kV, the temperature of thermal treatment *T*= 60˚*C* of the sample with the thickness z_{tp}=2μm.

We will mention that for spatial parameter (***kh***), where $k = \frac{2\pi}{\lambda}$, in the conditions of recent experiment the range of values 1.2÷6.2 was defined that is in good accordance with the results of numerical researches (table Nr.1). The performed calculations for the conditions of regimes from the recent paper indicate that at the variation of the characteristic of the field or of the value of the temperature of thermal treatment the form of experimental shapes is saved, modifying only their shape. The peculiarities of the concreted form of one exponential dependence (see (9)) that describes the formation of one crater is proposed in fig. 4:

Table Nr. 1



$t(s)$	h	$\|lnh\|$	$\boldsymbol{kh} \equiv 2\pi(\xi/\lambda)$
0,48	0,2	1,6094	1.256
0,52	0,3	1,2039	1.884
0,56	0,4	0,9162	2.512
0,6	0,5	0,6931	3.14
1	0,6	0,5108	3.768
1,4	0,7	0,3566	4.396
2	0,8	0,2231	5.024
4	0,9	0,1053	5.652
*	1	0	6.280

Fig. 4 The logarithmical representation of pseudospatial parameter h; parameters of the curve: U_c=5.5 kV, T= 60°C, t_0=0.3 s

It is remarkable that with the increasing of sensitizing time of the liquid layers, the breaking of the straight becomes more clearly expressed. The moment of the apparition of the deformation of crater type can be determined for every characteristics of field. Using the data of the values of the pseudospatial parameter (***kh***) from table Nr.1 we can model mathematically the possible values of $\boldsymbol{\lambda}$ for the values $\boldsymbol{\xi}$ possible in the given experiment. The numeric model of the process of multiplication of the centers of new deformations on the different layers of viscous liquid (it was admitted $\xi_i \equiv z$), confirms the validity of the physical model proposed in [9]. The value of radial dimensions of the characteristic deformation, installed in the process of germination of the centers of new deformations of crater type is proposed in table Nr. 2:

Table Nr. 2

$\boldsymbol{t}^*$(s)	$\boldsymbol{h}(ur)$	$\lambda \geq \frac{2\pi\xi_i}{kh}$ (μm)		
		ξ_1=0.5μm	ξ_1=1μm	ξ_1=2 μm
0.48	0.2	2.5	5	10
1	0.6	0.8	1.6	3.3
2	0.8	0.6	1.2	2.5
4	0.9	0.5	1.1	2.2
**	1	0.5	1	2

Here t^* is the time of sensitizing that depends on the parameters of registration regime; $\xi_i \equiv z$ the maximal value of spatial parameter; $\boldsymbol{z}$ is the thickness of liquid layer; h is the value of pseudospatial parameter.

The values of the parameter $\boldsymbol{t}^*$ from table Nr. 2 are valid for the characteristic of the field $\boldsymbol{U}_c$=5÷6.5 kV and $\boldsymbol{T}$=60-80°C, on the thermoplastic layers with the thickness of $1<z\leq 2\mu$m (over the value ξ_3). The data of numerical calculation from table Nr. 2 show the dynamical parameters of periodical restructure of the deformation on the viscous liquid surface. The obtained results as the dependence of the value $\boldsymbol{t}^*>>\boldsymbol{t}_0$=0.3$s$, on the viscous layers with z=2μm, indicate a spectrum of values of (λ) from 10÷25μm which are included in the spectrum of values indicated in the physical model of the process of germination of the centers of spatial deformations (see [2]). Comparing the results for different maximal values $\xi_i \equiv z$ from table Nr.2 we can make the conclusion that the smallest values $\boldsymbol{\lambda}$ on the surface of PTPCI and respectively a higher resolution of registered optical images can be obtained on the layers of thicknesses of ≈0.5μm. An evident result represents the definition of the values of parameter (λ) at the maximal value of the pseudo spatial parameter h=1 (the row marked with ** from table Nr. 2). This obtained result by numerical method thoroughly corresponds to the obtained values from the experimental researches.

The kinetic of the development of the deformation processes and germination of the centers of new deformations on the dynamical surface of the liquid (see [3]) can be followed from the dispersion shapes from the graphical representation – fig. 5. We will mention here that the function $\boldsymbol{\omega^2}$ describes the law of dispersion of the system in the absence of one interferential raster, defined from experimental measurements with the step $\boldsymbol{\Delta h}$=0.15 and the time of delay of the moment of apparition of effects of deformation in the electrostatic sample – 0.3s, the field U_c=5.5kV, according to the experimental data from table Nr. 3:

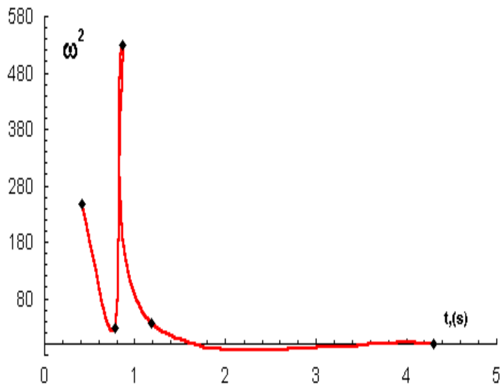


Table Nr. 3

N•0.04s	0.3+t_i(s)	$\|\Delta h\|$	h	$\|\omega\|$	kh	ω^2
1-3	0.42	0.15	0.15	15.8	0.95	249
3-12	0.78	0.15	0.3	5.2	1.9	27
12-14	0,86	0.15	0.45	23.7	2.8	529
14-22	1.18	0.15	0.6	6	3.8	36
22-100	4.3	0.15	0.45	0.4	2.8	0.16

Fig. 5 The law of dispersion $\boldsymbol{\omega^2}$ during the sensitizing of the dielectric of liquid.

The numerical calculation of the spatial parameter (***kh***) indicates that after **≈1*s*** from the moment of connection of corona the dimensions of characteristic deformation **λ=2πz/*kh*≅ 3*μm*** on the layers with the thickness ***z*≤2*μm***. We will have to mention that for the kinetics of short duration we can establish $\boldsymbol{\lambda_{max}=2\pi z/kh \cong 13.2\mu m}$ is confirmed by direct metrical measurements performed in the real time of registration.

From the analysis of the range of values of the pseudospatial parameter (***kh***) we can make the conclusion that for the description of the deformation phenomena of the dynamic surface of the viscous liquid we can apply the model of Newtonian liquid, for which the removing of one point of the liquid corresponds to one pixel on the matrix of numerical transformation.

The calculation of the values ($\boldsymbol{\omega}$) with relation (9) indicates the field of absolute values $|\boldsymbol{\omega}| \cong 0.5 \div 28(s^{-1})$. The law of dispersion from relation (9) is defined graphically in fig. 2. The form of the shape $\boldsymbol{\omega^2}$ is in good concordance with the result of theoretical researches and experimental ones that indicate the possibility of the discrediting of the dispersion shapes [2]. The experimental analysis on the values of the dependence generally indicates that the shape of dispersion is determined by a certain monoparametric set of shapes (fig. 5). The evident expression of the equation $\boldsymbol{\omega^2}$ that describes the set of shapes can be represented as: $\boldsymbol{\omega^2_{(X,\,t)}}=0$.

The form of experimental shape of the law of dispersion represents a set of kinetic parabolas of type:

$$\omega^2_+ = (\omega - X)^2 \qquad (10)$$

Here the sign + indicates that the shape of wrapping of the parabolic set is the axis of abscises (0,t); X characterizes the movement of the substance masses in the divergent fluxes on the surface of liquid.

4. The basic results, general conclusions

1. The basic results were obtained on the base of researching method elaborated by the authors that assured the storage as the form of one numerical data base in the memory of computer of the optical information obtained from the light beam diffused by the non homogeneities of the free surface of the sample of liquid dielectric – the rigid metal electrode.
2. The thermoplastic layer of PTPCI during the development of the deformations on the local micro zones $D\approx 6\div 25\mu$m is similar as dielectric liquid in the interval $t\approx 0.3\div 1s$, $U=5\div 7k$V, $T=58\div 80^{\circ}$C and the values of the pseudo spatial parameter (h) enclosed in the limits 0 and 0.2.
3. The type of restructure of the surface of liquid dielectric in the range of temperatures $T=58\div 90^{\circ}C$ is modified as the dependence of the time of charge with the electrical charge $t=0.3\div 10s$, at the constant value of the potential U of corona; the increasing of the value U from 5 till 7 kV contributes to the increasing of the speed of development of thermoplastic deformations and the increasing of the values of the pseudospatial parameter $\boldsymbol{h}>0.2\div 1$.
4. The increasing of the value U and the time of sensitizing assures the formation of dissipative structures both in the illuminated regions and non illuminated regions of PTPCI.
5. It was established that an optimal exposition exists for the researching in the real time of the phenomena of deformation on the surface of liquid dielectric with the values enclosed in the limits $0\div 0.33lx$.
6. On the base of the method of the chemical selective attack generally the dispersed model was elaborated of the deformation of the surface of liquid characterized by kinetic curves that form hysteresis loops, in the optimal regime of the registration of optical images.
7. The generalized geometrical model of the dissipative structures was realized by the identification of statistical coefficients:

a) α- the ratio between the dimensions of germination deformation and separated deformation that possesses the values enclosed between 1 and 0.5;

b) β- the ratio between the dimensions of crater from the volume of germination deformation and the mediated dimensions of one separated crater. The increasing of the value U leads to the increasing of the value in the limits 0.8 and 1;

c) γ- the most stable coefficient that characterizes the ratio of distances between the centers of deformations with the values enclosed in the limits 2 and 2.1.

8. The optical hybrid devices with big potential of application realized by PTPCI by the wrapping of the diffractive element on the refractive element of one diffractional grating, obtained by holographic method.
9. The mechanism of multiplication of the centers of new deformations on the surface of liquid is described by the relation $\boldsymbol{xC_o\rightarrow(2x^2+x)C_s}$, where the coefficient of multiplication (x) is functional by the increment of formation of deformations ($\boldsymbol{\omega}$).

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