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# PARAMETRIC ANALYSIS OF THE LIQUID-PHASE OBJECT IMAGES OBTAINED BY GAS DISCHARGE VISUALIZATION METHOD

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*Analysis of the parametric methods for estimation of the liquid-phase object images obtained by the gas discharge visualization (GDV) method was done. New quantitative parameters for determination of the geometric and fractal properties of GDV-grams were offered. Modified algorithm for their calculation was presented.*

***Keywords:*** *KIRLIAN EFFECT, GAS DISCHARGE VISUALIZATION (GDV), LIQUID-PHASE OBJECT, PARAMETRIC ANALYSIS, FRACTAL.*

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## 1. INTRODUCTION

Presence of numerical diagnostic and metrological methods and techniques in modern science is explained by the variety of basic physical principles and phenomena they are based on. The gas discharge visualization (GDV) method, which found an application in medical-biological and physical-technical fields, is based on the possibility to obtain information about internal structural, topological, energetic and other properties of objects by the analysis of photo and/or video images of near-surface discharge glow in electric fields of high intensity. But GDV cannot be applied widely because of its descriptive-qualitative nature, which in the absence of precise quantitative characteristics does not allow to avoid the arbitrary interpretation of experimental results.

## 2. STATEMENT OF THE PROBLEM

The main objective of this paper is a survey of the peculiarities of GDV-gram separate quantitative parameters and analysis of their application prospects, first of all, within the context of liquid-phase objects. In the paper we propose some new parameters allowing analyze quantitative characteristics of liquid-phase objects, namely, technical, biotechnical and biological liquids in detail. Information value and independence of each parameter is defined by the method of correlation analysis of accumulated experimental data.

## 3. CLASSIFICATION OF

The image analysis consists in the study of features of single characteristics, components, fragments or separate objects in the image field. Currently the unambiguous definition of the term "image analysis" is absent in scientific literature. In our case as the image analysis we will understand the measuring aspect of photo or video data processing. Correspondingly, the image analysis will consists in the determination of certain quantitative image parameters.

Two-dimensional matrix $\|B_{ij}\|$ is a formal model of a halftone image, where $i = 1, 2, 3, \ldots, X$; $j = 1, 2, 3, \ldots, Y$; $X$, $Y$ are the image sizes, and each element is characterized by the brightness $B_{ij}$.

During digital image processing the quantization of image brightness occurs, i.e., function $B_{ij}$ takes values only from a finite number set $\mathbf{B}_{ij} = \{b_1, b_2, \ldots, b_k\}$. In our case $\mathbf{B}_{ij} = \{b_1, b_2, \ldots, b_k\}$ is $\mathbf{B}_{ij} = \{1, 2, \ldots, 225\}$. Pixel is the smallest unit of an image. It can be empty (background) or significant (that, which contains an image element).

The authors of [1] proposed to divide the whole set of GDV-gram quantitative parameters into groups, namely, integral, spectral, fractal, structural and dynamic parameters. In connection with the appearance of a new direction in this field, i.e., dynamic GDV-graphy (see [2]), it is possible to distinguish one more group of parameters.

## 4. INTEGRAL PARAMETERS

### 4.1 Area of the image flash (blackening area of the photographic plate)

The value of this parameter is calculated using the formula

$$S = \sum_{i=1}^{X} \sum_{i=1}^{Y} p_{ij},$$

where $p_{ij} = 1$ if $b_{ij} > L$ (brightness of a certain element exceeds a predefined threshold value of background brightness) or $p_{ij} = 0$ if $b_{ij} \le L$ (brightness of an element does not exceed a threshold value of background brightness); $X$, $Y$ are the sizes of the matrix $\|B_{ij}\|$.

Information value of this parameter is proved repeatedly in a number of publications [2-4]. But we have to note that this parameter depends strongly on the contact surface area and the contour line length of the studied object. And therefore use of the flash area for comparison of solid-phase objects with different geometric forms and/or sizes (that was mentioned by some authors; see, for example, [1]) significantly decreases and in some cases absolutely nullifies the information value of this parameter.

In the case of liquid-phase objects the equality between the values of the contact surface area and the contour line length for different samples is achieved by the precise dosing of the investigated liquid using batchers. But the wetting /non wetting effect of the electrode surface (see Fig. 1) by the studied object is an important aspect which should be taken into account during the investigation.

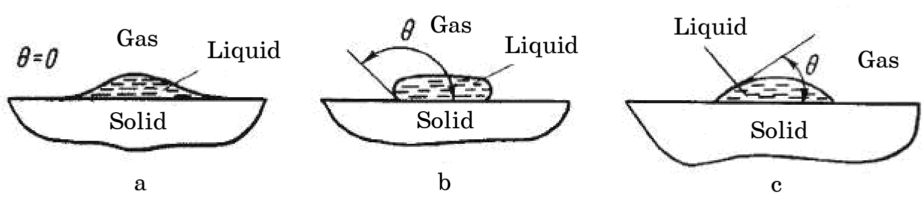


***Fig. 1*** *– Position of a water drop on the electrode surface: complete wetting (a), non wetting (b) and partial wetting (c)*

The quantitative criterion of wetting is the limiting wetting angle which is determined as

$$\cos\,\theta = (\sigma_{SG} - \sigma_{SL})/\sigma_{LG},$$

where $\sigma_{SG}$ is the surface tension on the solid/gas interface, $\sigma_{SL}$ is the surface tension on the solid/liquid interface and $\sigma_{LG}$ is the surface tension on the liquid/gas interface.

There are following degrees of wetting:

- $\cos\,\theta = 1$, $\theta = 0$ – complete wetting of the electrode surface;
- $1 > \cos\,\theta > 0$, $0 < \theta < 90°$ – partial wetting (usually $30° < \theta < 40°$);
- $\cos\,\theta = 0$, $\theta = 90°$ – non wetting (drop acquires spherical shape).

Taking into account the aforesaid and the linear dependence of the image flash area on the contact area and the contour length, it is not difficult to make the corresponding correction while analyzing liquids with different limiting wetting angles of the electrode.

### 4.2 Dispersion of the image flash area

Parameter is calculated for the series of $n$ experiments by the formula

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(S_i - \overline{S})^2,$$

where $S_i$ is the image flash area in each experiment; $\overline{S}$ is the mathematical expectation of the image flash area.

In this paper use of the dispersion value of the image flash area as a single information parameter is proposed for the first time. Up to now mentions of the dispersion of the image flash area, which can be found, for example, in [1, 2], were made only in the context of determination of the accuracy while calculating the flash area itself. Dispersion value as a single information parameter was not used. But results of the correlation analysis of the dependence of the flash area dispersion for different solvents (see Table 1) allow to establish a unique correlation between these two parameters that can be one of the assessment criteria while analyzing liquid-phase objects.

### 4.3 Perimeter length of the flash region

This is parameter which defines the length of the scanning envelope of the biggest flash spot. To obtain this parameter it is necessary to divide image into separate flash spots, determine the flash area $S$ of each spot and choose the largest one. In this case the condition $S_{max} >> S_{other}$ should hold. For direct calculation of the parameter it is possible to use different algorithms presented, for example, in [1, 5].

If confine the calculation region of the parameter by the boundaries of the largest flash spot, divide all pixels of this spot into two sorts: boundary pixels (those which border with background pixels) and internal pixels (those which border with image pixels only), the perimeter length of the flash region can be found using the following formula:

$$l = \sum_{i=1}^{X} \sum_{i=1}^{Y} p_{ij},$$

where $p_{ij} = 1$ if the indicated pixel is the boundary one or $p_{ij} = 0$ if pixel is the internal one; $X$, $Y$ are the sizes of the matrix $\|B_{ij}\|$. Modification of known [1, 5] algorithms is proposed for the first time.

Graphic example of application of the modified algorithm is presented in Fig. 2.

***Table 1*** – *Results of the correlation analysis of the dependence of the GDV-gram flash area dispersion for different solvents*

| | $H_2O$ | NaCl (0,9% aqueous sol./physiological sol.) | NaCl (1% aqueous solution) | NaCl (2% aqueous solution) | KCl (1% aqueous solution) | KCl (2% aqueous solution) | KOH (1% aqueous solution) | KOH (1% aqueous solution) | $NH_4Cl$ (2% aqueous solution) | $NH_3$ (25 % aqueous sol./ammonia water) | $C_{12}H_{22}CaO_{14}$ (1% aqueous solution) | $C_6H_{12}O_6$ (1% aqueous solution) | $C_6H_{12}O_6$ (5 % aqueous solution) | $KNO_3$ (5% aqueous solution) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | – | 0,67 | 0,64 | 0,59 | 0,51 | 0,49 | 0,59 | 0,59 | 0,5 | 0,32 | 0,54 | 0,81 | 0,19 | 0,17 |
| NaCl (0,9% aqueous solution/ physiological sol.) | 0,67 | – | 0,78 | 0,62 | 0,61 | 0,6 | 0,51 | 0,51 | 0,45 | 0,31 | 0,27 | 0,72 | 0,21 | 0,39 |
| NaCl (1% aqueous solution) | 0,64 | 0,78 | – | 0,64 | 0,61 | 0,59 | 0,48 | 0,61 | 0,5 | 0,33 | 0,29 | 0,61 | -0,01 | -0,21 |
| NaCl (2% aqueous solution) | 0,59 | 0,62 | 0,64 | – | 0,55 | 0,68 | 0,51 | 0,48 | 0,61 | 0,29 | 0,51 | 0,54 | 0,21 | 0,09 |
| KCl (1% aqueous solution) | 0,51 | 0,61 | 0,61 | 0,55 | – | 0,68 | 0,52 | 0,61 | 0,51 | 0,3 | 0,47 | 0,6 | -0,3 | -0,14 |
| KCl (2% aqueous solution) | 0,49 | 0,6 | 0,59 | 0,68 | 0,68 | – | 0,54 | 0,49 | 0,59 | 0,33 | 0,4 | 0,49 | 0,45 | 0,23 |
| KOH (1% aqueous solution) | 0,59 | 0,51 | 0,48 | 0,51 | 0,52 | 0,54 | – | 0,41 | 0,49 | 0,29 | 0,37 | 0,55 | -0,13 | -0,25 |
| $NH_4Cl$ (1% aqueous solution) | 0,59 | 0,51 | 0,61 | 0,48 | 0,61 | 0,49 | 0,41 | – | 0,53 | 0,27 | 0,44 | 0,31 | 0,01 | 0,01 |
| $NH_4Cl$ (2% aqueous solution) | 0,5 | 0,45 | 0,5 | 0,61 | 0,51 | 0,59 | 0,49 | 0,53 | – | 0,3 | 0,43 | 0,41 | -0,09 | 0,09 |
| $NH_3$ (25% aqueous solution/ ammonia water) | 0,32 | 0,31 | 0,33 | 0,29 | 0,3 | 0,33 | 0,29 | 0,27 | 0,3 | – | 0,21 | 0,71 | 0,21 | 0,11 |
| $C_{12}H_{22}CaO_{14}$ (1% aqueous sol.) | 0,54 | 0,27 | 0,29 | 0,51 | 0,47 | 0,4 | 0,37 | 0,44 | 0,43 | 0,21 | – | 0,64 | 0,17 | -0,22 |
| $C_6H_{12}O_6$ (1% aqueous solution) | 0,81 | 0,72 | 0,61 | 0,54 | 0,6 | 0,49 | 0,55 | 0,31 | 0,41 | 0,71 | 0,64 | – | -0,15 | 0,23 |
| $C_6H_{12}O_6$ (5% aqueous solution) | 0,19 | 0,21 | -0,01 | 0,21 | -0,3 | 0,45 | -0,13 | 0,01 | -0,09 | 0,21 | 0,17 | -0,15 | – | -0,24 |
| $KNO_3$ (5% aqueous solution) | 0,17 | 0,39 | -0,21 | 0,09 | -0,14 | 0,23 | -0,25 | 0,01 | 0,09 | 0,11 | -0,22 | 0,23 | -0,24 | – |

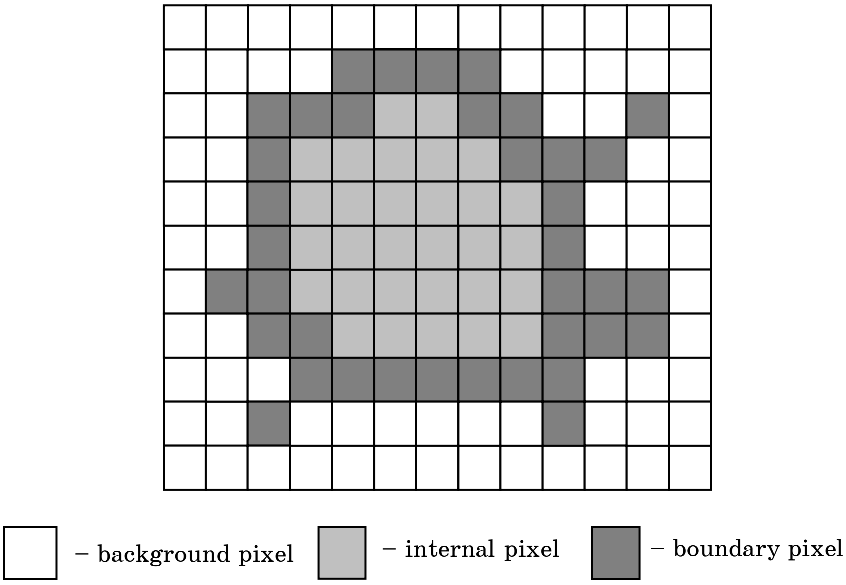


***Fig. 2** – Example of distinguishing image boundaries*

### 4.4 Flash activity coefficient

This parameter is determined as the ratio of the flash area to the area of a liquid drop projection onto the electrode surface. The last one can be found using the abovementioned algorithm of calculation the photographic image area for a drop of studied liquid directly before the GDV-analysis or by the theoretical calculations using the technique given in Ref. [6]. This is a new parameter which is proposed to be introduced for analysis of GDV-gram liquid-phase objects, for description the emission properties of the surface that can be the representation of the certain internal physical-chemical, structural, energetic and a number of other properties (for example, solution concentration, impurities in technical and biological liquids, etc.).

## 5. SPECTRAL PARAMETERS

### 5.1 Width of the brightness spectrum

This parameter is determined as the brightness difference of the brightest and the darkest flash spots (this value is usually assigned by the threshold background level) or the brightest and the darkest pixel of the image. In this case brightness of the last one is usually close to zero.

### 5.2 Integral brightness of the flash spot

To determine this parameter it is necessary to separate a one-dimensional array $\|A_i\|$ of elements from two-dimensional brightness matrix, for which $b_{ij} > L$ (brightness of a certain element exceeds a given threshold value of the background brightness). Calculation of the integral brightness is carried out by the following formula:

$$A = \frac{1}{N}\sum_{i=1}^{N} a_i,$$

where $N$ is the number of non-zero (significant) elements in array $\|A_i\|$.

We have to note that the authors of some publications (see, for example, [1]) propose to use this parameter for the whole image, not only for the flash spot. But in this case dependence of this parameter on the size of the investigated object and other factors is evident. This makes impossible the comparison of the data obtained for different sized objects or using different equipment.

## 6. FRACTAL PARAMETERS

### 6.1 Mandelbrot fractality

This is parameter that firstly was mentioned in Ref. [1] and is determined as the image perimeter ratio at different image scales. Using the algorithm proposed in the present work the value of this parameter is always equal to zero and does not contain any information. But the authors of [1] present another calculation technique of the image perimeter, namely, using array of radiuses for image envelopes. In this case deviations of the fractality index are really possible. But the fact of their information value is rather doubtful, since not certain internal properties typical for the object itself but the process of digital image obtaining and handling is the nature of these deviations.

### 6.2 Image shape coefficient

This parameter is determined as the ratio of the squared perimeter length of the flash region to the total brightness area [1]. Parameter characterizes primarily the emission properties of the surface of investigated liquid which influence the width of a “crown” round the object contours. The values of this parameter correlate strongly with the relative dielectric constant of the objects. For example, values of the correlation coefficient of the relative dielectric constant for eight substances ($N_2$, $NH_3$, $C_3H_6O$, $H_2O$, $H_2SO_4$, $CH_2O_2$, $C_2H_6O$ and physical solution) is about 0,7. The relative dielectric constant data of these liquids is taken from [7, 8].

## 7. STRUCTURAL PARAMETERS

In some cases for the convenience of the digital processing, transfer and analysis of GDV-grams it is necessary to present the obtained image in the vector format instead of the bit patterned one. It can be done in several ways: to assign the envelope contour function in matrix or polynomial form (as it is proposed in [1]) or to obtain analytically the brightness distribution matrix $\|B_{ij}\|$ as a three-dimensional surface. We have to note that the first approach is the auxiliary one and it cannot be used separately since in this case a part of information contained in the initial matrix can be lost.

To describe functions obtained by any abovementioned approach the standard procedures of the probability theory, namely, mathematical expectation, dispersion and higher centered moments, are usually used.

By analogy with the information entropy, the entropy can be determined by the following formula:

$$E = k\sum_{i=1}^{X}\sum_{i=1}^{Y} b_{ij} \log_2 b_{ij},$$

and for the function defined by the whole matrix or for the separate contour matrix-function

$$E = k\sum_{i=1}^{L} l_i \log_2 l_i.$$

In both cases entropy characterizes degree of the system chaotic state.

Autocorrelation function is the characteristic of the process regularity and can be found as

$$c(u) = \frac{1}{N}\sum_{t=1}^{N-u} (x_t - \bar{x})(x_{t+u} - \bar{x}),$$

where

$$\bar{x} = \frac{1}{N}\sum_{t=1}^{N} x_t.$$

Autocorrelation function can be used both for the brightness function of the contour lines and other elements of the flash spot.

## 8. DYNAMIC PARAMETERS

### 8.1 Dynamic dispersion of the flash area

Presently, the flash area is the main information parameter of GDV-grams. As it was mentioned above, the largest number of publications is devoted to the usage of this parameter in static GDV-graphy. Relationship between the flash area parameter and many internal characteristics of objects is proved in [3, 9]. That is why one can expect certain results in investigations of the flash area time dependences. To achieve this aim we propose a new parameter – the dynamic dispersion of the flash area, which is determined as

$$\sigma(t) = \sum_{t=1}^{n} (S(t) - S_0),$$

where $S(t)$ is the value of the flash area in every time moment; $S_0$ is the value of the flash area in initial time moment.

### 8.2 Increment of the temporal increase of the flash area dynamic dispersion

This is parameter defining the growth rate of the flash area dispersion parameter which is determined by the formula

$$\delta = \ln \sigma_1 / \sigma_2,$$

where $\sigma_1$ and $\sigma_2$ are the values of the flash area dispersion in different time moments every certain preassigned time interval.

It is known that when the gas discharge appears between the electrode and the investigated object, the charge of the order of $10^{-10}$ - $10^{-12}$ C and the energy of the order of $10^{-7}$ - $10^{-9}$ J [9] are transmitted as the electron avalanche. This energy is distributed all over the volume of the studied object and leads to its partial evaporation and combustion. In static GDV-graphy when the exposition time does not exceed some seconds this effect can be neglected. But using the dynamic approach the application of the increment parameter for the analysis of the liquid-phase objects allows to determine the specific heat of evaporation (specific heat) for the studied object that can be used in the component analysis, while defining the food value, etc.

## 9. CONCLUSIONS

1. Classification and assignment of the main quantitative parameters of the GDV-gram analysis of the physical objects (in particular, liquid-phase) and the analysis of their application prospects are presented.
2. The modified algorithm of calculation of some quantitative characteristics for the determination of geometric and fractal properties of images (GDV-grams) of the liquid-phase objects is proposed.
3. New quantitative parameters for the image analysis (GDV-grams) of the liquid-phase objects are proposed.
4. It is shown that the usage of the flash area dispersion parameters, flash activity coefficient, flash area dynamic dispersion, increment of the temporal increase of the flash area dispersion allows to perform the quantitative analysis of static and dynamic GDV-grams and determine a number of characteristics of the investigated object which cannot be obtained by other physical methods.
5. Obtained results are the certain step towards the solution of the problem of information properties of physical (in particular, liquid-phase) objects.

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