The interaction between direct current pulses and aqueous ionic solutions was investigated using electrographic recordings. The streamer distribution recorded on photographic sensor around the solution drop was analyzed by means of the fractal dimension calculation. Semi-quantitative comparison could be carried out this way for NaCl, KCl and CoCl₂.

Key word: corona discharge, complexity analysis, statistic comparison.

1. INTRODUCTION

1.1. CORONA DISCHARGE

Electrical discharges are ubiquitous in atmosphere due to the natural cloud dipoles interaction or to the artificial sources of electrical tension (especially energy transmission lines). The corona discharge is non-thermal plasma generated in open atmosphere between a thin electrode and a plate one when connected to a direct current source. Corona discharge is difficult to detect because it emits very weak radiation, mostly in the UV band (at night it is barely visible to the naked eye, though it can be imaged by UV sensitive devices) [1]. In the case of corona discharge plasma formation is taken place when Peek's condition for electric field is satisfied at the surface of corona wire. Peek's condition for wire with radius \( r_0 \) is given as:

\[
\delta = \frac{p \cdot 273}{273 + t}, \quad E_0 = 30.36 \left( 1 + \frac{0.289}{\sqrt{r_0 \delta}} \right)
\]


where $E_0$ is the electrical field strength while $p$ and $t$ are pressure and temperature. Peek's condition is found empirically [2]. Theoretically same value is found using the formalism known as Townsend avalanche.

![Typical spectrum of a corona discharge in air](image1)

Fig. 1 – Typical spectrum of a corona discharge in air [1].

The electron and ion flows from the discharge space can interact with atoms and molecules from the surrounding medium generating free radicals and, further, various peroxides. These last ones can seriously affect living tissues, so that, the corona discharge need to be considered also for biomedical applications.

![Distribution of electric field and charge density](image2)

Fig. 2 – Distribution of electric field (1-without corona discharge, 2-with corona discharge) and charge density (3) in case of wire/plane geometry; $r/0$ is the position of corona electrode and $h$ is the position of collector (after Barsoukov, 2003) [4].

A hypothesis by Akishev et al. assumes that the photoionizing radiation emitted by the positive corona discharge in air is soft X-rays generated by electron bombardment of the anode surface [3] so that the biological effects can be better understand. The distribution of the electrical field of corona discharge is provided
Electrographic images of ionic solutions

as a descriptive scheme by Barsoukov [4] (Fig. 2). The scheme of the experimental device and procedure is best presented in [5] (Fig. 3).

![Fig. 3 – The experimental scheme for corona interaction with solution droplets [5].](image)

Among the applications of the corona discharge with different media it is necessary to mention the microorganism destruction [6-8], the visualization of the human energy field [9] and the investigation of aqueous solutions [10].

1.2. THE FRACTAL DIMENSION

Three decades ago Mandelbrot conceived fractals (from the Latin fractus-irregular) as a set of forms constructed by iteration and that are characterized by infinite detail, infinite length, no slope or derivative, fractional dimension and self similarity [11]. Commonly employed to explain pattern in nature, fractals are, mathematical ways to predict the development of a growing structure, be it a plant, an animal or the universe as a whole. Many studies reported quantitative results on fractals in biology and related life sciences. [12-16].

More, the concepts derived from fractal and chaos theory are fundamental to the description and modeling of phenomena in biology, from the molecular to ecosystem levels of organization.

Traditionally, the shapes of objects have been described using Euclidean geometry but many natural objects display irregular shapes and discontinuous pattern and seem impossible to describe them rigorously or quantitatively using only Euclidean geometry. To characterize fractals, Mandelbrot used the Hausdorff dimension [17]. According to this, if a line of length $L$ is divided into equal pieces...
of length $l$, the number of partition $N$ is given by $N=L/l$; for a square of side $L$ sectioned in smaller squares of area $l^2$, the total number of pieces will be $N=L^2/l^2=(L/l)^2$ and so on. Then the dimension of any self-similar geometric form is:

$$d_f = \frac{\log N}{\log L/l}$$

The fractal dimension is a fractional quantity representing a direct measure of the relative degree of complexity and roughness of the figure, and it can never be greater than the Euclidean dimension of the space where the object is embedded.

In order to apply Box Counting method the image plane is divided into small square grids each of edge length $\varepsilon$.

![Fig. 4 – The box counting algorithm.](image)

Counting the number $N(\varepsilon)$ of occupied squares one again obtains a measure for the contour length since the number $N(\varepsilon)$ of squares intersected by the curve is roughly proportional to the number of steps $N$ needed to cover the contour. Starting with the smallest $\varepsilon$ scale, the grid-length $\varepsilon$ is increased successively up to a certain number of pixels depending of the size of the picture. In a graphical representation $y=Ax+B$, where $x=\log N(\varepsilon)$ and $y=\log \varepsilon$ one obtains the fractal dimension for a self-similarity structure as the slope of the graph, $A$, while the ordinate cut is the fractal measure, $B$. Standard deviation are given in each case.
2. MATERIAL AND METHOD

Electronic device able to generate direct current pulses with controlled amplitude, duration and polarity was designed and assembled in our laboratory. Photosensitive support (paper and film) was used to record the electrographic images obtained following the interaction of the corona discharge with aqueous ionic solution droplets. Ionic solutions 1 M (NaCl, KCl, CoCl₂) freshly prepared in distilled water have been investigated. Twenty recordings for every solution have been done.

Specialized soft (HarFa) for the fractal dimension calculation on the basis of box-counting algorithm was utilized.

3. RESULTS AND DISCUSSION

In Figures 5–7 the electrographic recordings obtained for some droplets of NaCl, KCl and CoCl₂ are given.

![Fig. 5 – Electrographic image for the NaCl aqueous solution.](image)

In all three cases positive polarity was chosen, unique pulses have been applied, the pulse amplitude was equal to 15 kV and its duration was equal to 0.5 ms.

One can see numerous streamers with non-uniform disposition around the ionic solution drop whatever the metal ion is. Some qualitative distinct features can be seen to a deeper visual investigation:
– in the case of NaCl solution, the blackening of the streamer traces on the photosensitive paper is relatively slight and the traces are relatively straight lines;
– in the case of KCl solution the blackening is the stronger and the streamer traces are waived;
– in the case of the CoCl₂ solution the bifurcations of the streamers are more frequent than in the previous two situations.

The semi-quantitative approach of their image complexity, by means of the fractal dimension, was carried out following the box-counting algorithm. Average values, standard deviations and correlation coefficients using a convenient soft (commercially available) have been calculated. The results are given in Table I.

Fig. 6 – Electrographic image for the KCl aqueous solution.

Fig. 7 – Electrographic image for the CoCl₂ aqueous solution.
Table I
Fractal dimension of the investigated solutions (average values for 20 measurements)

<table>
<thead>
<tr>
<th></th>
<th>Fractal dimension</th>
<th>Fractal measure</th>
<th>Standard deviation</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>1.1567</td>
<td>7.2345</td>
<td>0.000031</td>
<td>0.9896</td>
</tr>
<tr>
<td>KCl</td>
<td>1.1723</td>
<td>7.0653</td>
<td>0.000051</td>
<td>0.9879</td>
</tr>
<tr>
<td>CoCl₂</td>
<td>1.2134</td>
<td>6.9812</td>
<td>0.000058</td>
<td>0.9912</td>
</tr>
</tbody>
</table>

The main result is the increase of the fractal dimension to the increase of the streamer image complexity, i.e. from NaCl to CoCl₂. A proportional dependence on the atomic number of the metal ion can be shaped (Fig. 8).

4. CONCLUSION

The electrographic recordings of the results of the interaction of corona discharges with some ionic solutions are bearing the hallmark of the metal ion nature. The fractal dimension evaluation, carried out with high accuracy (standard deviation less than 0.0001 and correlation coefficient higher than 0.98) has distinct average values for the three ions analyzed in aqueous solutions of their chloride salts.

REFERENCES


