The research of the technological parameters effect on the shape and structure of the disperse dye flow of the inkjet printers produced in the electric field.

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Annotation. The study is devoted to the results of experimental searches of the disperse dye flows of inkjet drawn on paper in an electric field that can be used to make improvements to technology of improving the quality and the print admissible capacity of various printed materials in inkjet technology.

1. Introduction

It became necessary to save the results of calculations by recording when the first electronic computer was invented in the 50s the last century. In order to do it, people were specially taught to print received information at typewriters. It suggested the researchers and designers the idea of switching the typewrites directly to computer. And Remington-Rand Corporation invented the first printer for the computer UNIVAC (Universal Automatic Computer), named UNIPRINTER in 1953. Since then, the technologies of printing of inkjet printers, developed the last century, are not subjected to the substantial changes. Of course, the technical process is perfecting, the number of dots per inch is increasing, the quality and the speed are improving, but no significant changes in the technology of drawing ink on paper aren’t happening.

One of the important units of inkjet printer is the print head, it consists of a large number of nozzles, to which the ink leads up to. The ink is supplied to the nozzles with capillary properties and is kept from leaking out owing to the surface tension powers of its liquid components. There are special pellicate elements in one of the structures in the print head, integrated to create and draw the microscopic particles of ink on paper. There are different types of print heads, depending on the operating principle of the formed mechanism and drawing of the ink particles on the media - paper [1]:
- piezoelectric (used by companies Epson and Brother) [2];
- gas bubbles (Canon) [3];
- drop-on-demand (Hewlett-Packard) [4].

The first method of drawing the ink particles on paper is based on the physical phenomenon, which consists in the deformation of the piezoelectric element in an electric field, and in a sudden increase of pressure in the capacity for the ink and the second and third are on the effect of pressure increasing in the nozzle of the print head by pulse heating of ink above the point of its boil. The disadvantages of existing methods are: heterogeneous form (in the form of smudge) and a large spread of sizes of ink particles throwing out the print head nozzles [5]. To obtain uniform in size and shape (spherical) of ink nanosized particles a lot of researches are conducted, a large part of which is aimed at
changing structural parameters of print head, however, it has not resulted in a practical significant improvement in quality of print.

One of the effective methods of obtaining spherical in shape, homogeneous, nanosized particles is the method of the ink dispersing in an electric field [6-10]. In this method of dye drawing the sizes of spherical regular forms of ink particles have the order of units and tens of nanometers. The lower limit of particle sizes in this technology is determined by minimal sizes of dye particles, contained in the ink structure. The lower limit of the particle sizes of the particle flow is 2 ± 12 nanometers for pure liquids. In famous technologies [1-4], the volume of ink droplets is 3 : 6 pikolitres, that corresponds to the sizes of order 10^3 m, i.e. at the level of hundreds of micrometers [1]. In our case, the particle diameter of dispersed flow, measured with atomic power microscopy, amounts to 10^-6, and more times less pikoliter, therefore, the powers of medium resistance – air or any gas due to the motion of particles from the nozzle to the media are not sufficient to change their ball shape. The power of the medium resistance are reduced by reducing the relative speed (in regard to the medium entrained with flow) of the medium [11]. In the known technologies particles have the form of “smudge” [1-5]. Thus, in an area, coated with the media pikolit drops in famous technologies [5] will be placed about 10^4 or more particles produced by the proposed technology. Certainly, it will increase the admissible capacity, contrast, and quality characteristics of inkjet technology. The study is devoted to experimental research of the influence of technical parameters on the shape and structure of disperse dye flow of inkjet printers produced in the parameters of electric field of inkjet printer dispersed flow of the structure of the electric field in the area of flow formation.

2. Description of the experimental setup
Schematic section of the experimental setup is shown on the figure 1. Inside the rigid metal frame 1, made of rectangular steel profile symmetrically on two bearings fixed frame 3 providing the possibility of rotation around the horizontal axis. On the inner frame 3, fluoroplastic electrical isolation, adjustably installed metallic capillary 4 and the second electrode - working table 5. The second electrode - work-table is grounded. After installing the optimum position of the capillary required the distance between its end and the table is regulated by a screw of micromanipulator ST-3. Investigated liquid and a high potential are supplied to the capillary by fluoroplastic pipes, laid through the pipe 6, the bearing sleeve 2 and the frame profile 3. To measure power transfer of dispersed particles flow, microumometer 7 serves, through which the work-table 5 is grounded - the second electrode. Dispersed flow of liquid 8, the working table 5, and the capillary 4 are hermetically isolated from the medium, by a composite framework made of two cylindrical halves, made of transparent Plexiglas and attached to the inner frame 3 (not shown). Structure regulation of the electric field in the formation of particulate flow is performed by changing the diameter and position of the metallic disk 9 installed on the end of the capillary 4. Capillary is supplied with adjustable in the range 0 - 50 kV potential of a DC voltage source one electrode which is grounded. Power source is not shown. Capillary by fluoroplastic pipe is connected to the capacitance (capacitance is not shown) for the research liquid. Fluid consumption through the capillary is changed by changing the position of the capacity concerning to the end of the capillary or by regulation the pressure in it. The method of the change of the ink consumption through the capillary by changing the position of capacitance achieves the highest degree of accuracy, so as for regulation of pressure dropin with such precision the authors haven’t had more accurate measuring instruments and pressure gauges.

For substance dispersing with a fusing temperature above medium fluid capacity is installed directly on the capillary and heated with electromagnetic radiation or ohmic heating. In the latter case, capillary with heating device must be thoroughly electrically isolated from the installation and the insulated from the medium. At the dispersion of conductive liquids capacity must also be thoroughly electrically isolated from the casing installation.

The inner frame of the set freely rotates on bearings around a horizontal axis at 180 degrees clockwise or counterclockwise. Free rotation of the inner frame is designed for experimental evaluation of the shape and size of dispersed flow particles on its magnitude deviations on the media.
- a piece of paper pinned on the work table in the vertical plane, when you turn it in the gravitational field at 180° [7]. For the experimental evaluation of the average particle size of dispersed flow first axis is oriented vertically and the on the media - paper receive the image of section, then the system of the inner frame with fixed positions of the capillary and paper rotates at 90° and again get the image of the flow on the paper. After that, the system of inner frame rotated in the opposite direction at 180 degrees and fix the position of the center flow, and then measure the magnitude of the mixing center of the image on a sheet of paper.

3. The results of experimental searches.
New ink mark «HAMELEON» was selected for research, developed with German dyes and components have been tested at the request of the Japanese Company «Revcol» [12] National Institute for Chemistry Science, Tokio, Japan. At various installation options were researched the modes of dispersed ink flow. The ink dispersion is made with capillaries of diameter d in $3 \times 10^{-4}$, $4 \times 10^{-4}$, $4,5 \times 10^{-4}$ m on coverslips and paper, fixed on the desktop setup. Dependence of the structure and cross-sectional area of ink dispersed flow on a variety of installation options and technological conditions of the process was determined by the images of dispersed flows received on paper or the cover glass. The researches were conducted at variable: the level of ink in the reservoir concerning the end of the capillary, the capillary drive position, the distance between the electrodes for different diameter disks, fixed on the capillary.

At optimal technological regimes liquid ink cone elongates from capillary and, with the top facing down, which begins with dispersed flow at corresponding to its potential, as shown in the photographs shown in figure 2.

Fluid consumption through the capillary is changed by way of capacity position changing concerning to the end of capillary dispersion or by adjusting the pressure in it. Searchers were conducted at liquid levels above the end of the capillary in the range $0 \pm 0,01$ m, i.e. at zero, an excess (100 Pa) and negative (100 Pa) pressures in the working volume. At zero level of the
liquid under an electric field from the end of the capillary is extended drop in a cone shape. When the potential increases frequency of breakdown drops from the end of the capillary rises and subsequently is transformed into a continuous thin stream of fluid starting at the top of the cone. The increase of potential up to $500 \div 1000$ V leads to rupture of the jet and the formation of non-uniform cross section of the conical section of the dispersed flow, and in the center is still very thin stream of fluid. The further growth of potential leads to the disintegration of the central stream, and dispersed flow becomes uniform. The photo 2 shows stationary finely divided stream of jet printer ink for the set modes of dispersion.

![Image](image.png)

**Figure 2.** The photo of steady dispersed flow from the top of inverted cone, jet printer ink.

At a potential up to $5 kV$, depending on the distance between the electrodes, there is a uniform dispersion of particulate flow, with a cone on top of the capillary.

The optimal value of the potential steady dispersed flow depends on the distances between the electrodes, the structure of the electric field at the end of the capillary (in the formation zone of dispersed flow) and the properties of the fluid. When the values of the capillary potential are more than $5 kV$, cone at the end of the capillary disappears and the dispersion process becomes unstable regime. An unstable dispersion is initially in the form of two streams, then with the growth of the potential number of dispersed flows is increased to four, as shown in figure 3. Figure 3 shows images of cross sections of flow depending on the capacity of the capillary at a constant distance between the electrodes. In our opinion, the instability of dispersed flow can be explained by the potential growth and by not a sufficient flow of fluid through the capillary, resulting in a lack of fluids - a charge media is the destabilization of dispersed flows.

![Image](image.png)

**Figure 3.** Dynamics of changes in cross section and the structure of ink dispersed flow of inkjet printers, depending on the capacity of dispersion.
The main interest for researches is the stationary mode of dispersion when the dispersion of sizes and density and distribution of particles in the stream of flow are minimal. Optimization of modes of ink dispersed flow in the process is done by studying - volt-ampere characteristics of dispersed liquid flows and the dependence of the cross sections structure: the potential of the dispersion, the distance between the electrodes, the structure of the electric field in the area of the stream formation, consumption of substances and their physical properties.

Figure 4 shows the volt-ampere characteristics for different levels of ink in a reservoir above the end of the capillary (because of absence of accurate data on the of the ink density in the paper gives the height of the level of ink above of the end of the capillary instead of hydrostatic pressure).

During the researches the level of dye over the end of the capillary was changed in the range from $-10^{-2}$ to $+10^{-2}$ m. As we can see from the figure the increase in level of ink over the end of the capillary does not affect the curves of volt-ampere characteristic of the dispersed flow to a potential value equal to 7 kV and at potentials more than 7 kV there is a discrepancy of curves by increasing flow instability and current oscillations of transfer. As It’s known from experimental data at negative values of differential pressure (level), the potential of dispersion increases with increasing its value. With the growth of a negative differential pressure, the potential of dispersion increases, in our opinion, owing to the growth of work done with electric field at the capillary rise of ink in the tube to the point of disintegration of the jet. Therefore, the potential growth does not increase the current transfer with dispersed flow. Maximum current transfer of dispersed flow reaches at the zero level drop of ink in the reservoir concerning the point of dispersion. The dependence of flow structure on: the potential dispersion of the ink and the height of their level over the end of the capillary are shown in figure 5. Figure 5 shows how a cross section structure of flow and density of its particles over the cross section when the altitude level and the potential of disintegration change.

![Figure 4.](image)

**Figure 4.** The effect of the level h2 dye in the reservoir above the end of the capillary on current-voltage characteristic of dispersed flow ($\Diamond - 10^{-2}$m, $\Box - 7 \times 10^{-3}$m, $\Delta - 5 \times 10^{-3}$m, $\times - 3 \times 10^{-3}$m, $\otimes - 2 \times 10^{-3}$m, $\odot - 10^{-3}$m, $+ 3 \times 10^{-3}$m, $\times - 5 \times 10^{-3}$m, $\otimes - 7 \times 10^{-3}$m).

When the ink level over the end of the capillary is zero, the homogeneous dispersion flows are observed up to 4 kV, then the density of particles in the cross section of dispersed flow becomes non-
uniform and as a result of it a dark spot is in the center of image. The increase in the potential up to 5kV and more results in an unstable mode of dispersion, increasing the area of dark spot, and its displacement from the center. With further increase in potential spots become darker, and dispersed flow splits into two or more.

**Figure 5.** Dynamics of change in flow structure depending on the level of ink over the end of the capillary (in the figure some errors are caused by errors: the holding time of flow and installation of dispersion capacity, but the overall figure of the process is clearly seen, as noted in the literature [6]).

Increasing of the ink level over the end of the capillary in the range from 0 to – 10 m results in a shift of the unstable dispersion toward lower potentials. And when the ink level equal to 10 m it’s impossible to find the sustainable mode of dispersion, due to the large consumption of it. Apparently, caused by that charges do not have time to drain to the entire stream and in the middle
of flow is the stream of fluid, which is either not charged or not charged up to the required capacity to divide. This phenomenon may be caused by the contents of the different components in the ink, as result of it the regime of stable dispersion for one component may coincide with the unstable mode dispersion of the other component.

If we analyze the current-voltage characteristics shown in figure 4 and the data in figure 5, we’ll see that increasing of the ink level over the end of the capillary does not resulting in significant change of the current, while the flow consumption through the capillary increases. This can be explained by the fact that the charges do not flock on the entire flow of ink and that’s why the central part of the flow is keen on peripheral due to electrical forces in a form of very thin trickle what we see on the stream and as the result of it the darkening is observed in the center flow.

When the level of ink drops from the end of the capillary in the range from 0 to \(-10^{-2}\) m ink consumption is reduced through the capillary and electrical charges have time to flow down, that’s explains the uniformity of the structure of the flow cross-section even at non-stationary mode dispersion.

In this case, up to 4.5 kV, we observe a steady mode dispersion, and then decay of the flow into multiple parts. This figure also shows that an increase of ink consumption the cone base radius of flow is growing, as the consumption is increases with the growth of level altitude (in the figure the consumption is increasing from bottom to top).

Figure 6 shows the results of researches of the effect of capacity dispersion on the ink consumption at different levels of ink over the end of the capillary. By increasing the capacity of the capillary and the ink level from 0 to \(35 \times 10^{-3}\) m, within the error of measurement of time and changes in level, consumption increases linearly, as can be seen from the figures 6 and 7.

The maximum potential value, for which a dispersion is observed above is limited with phenomenon of the breakdown.

![Figure 7. Potential effect of dispersion on the flow U G ink at different levels of h2 ink in the reservoir above the end of the capillary (one division is \(10^{-5}\) liters, \(\Diamond - 0\text{m, } \Box - 3\times10^{-3}\text{m, } \Delta - 5\times10^{-3}\text{m, } \times - 7\times10^{-3}\text{m, } \times - 10^{-3}\text{m, } \bigcirc - 15\times10^{-3}\text{m, } + - 25 \times10^{-3}\text{m, } \bigcirc - 35 \times10^{-3}\text{m})]

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The next stage is devoted to the research of distance effect between the electrodes on the current-voltage characteristics and the structure of dispersed flows. Figure 9 shows current-voltage characteristics for different distances between the electrodes. With increasing potential strength of the current grows polynomially.

![Current-Voltage Characteristics](image)

**Figure 8.** The effect of the dye level in a reservoir above the end of the capillary on its consumption at different dispersion potentials (■ - 3kV, ■ - 4kV, ▲ - 5kV).

The increase of the distance between the electrodes in the range of $5 \times 10^{-3}$m to $10^{-2}$m brings to a polynomial growth of the current. As can be seen from the graph when the distance between the electrodes increases the offset of curves voltage characteristics is observed toward higher potentials, as the potential formation of a stable dispersion flow is shifted to the right. When the distance between the electrodes $3 \times 10^{-3}$ m the area of minimum cross section of the base of the free cone flow is $0.5024 \times 10^{-6}$ m$^2$, and at a distance of $10^{-2}$ m area the base flow is equal to $6.1575 \times 10^{-6}$ m$^2$ With increasing of distance between the electrodes the diameter of the conical flow base grows linearly, as well as the potential beginning of disintegration.

Figure 10 shows the cross-sectional area of dispersed flows from the distance $h$ between the electrodes at the altitude of the ink over the end of the capillary is zero. The size and shape of dispersed flow can be changed by adjusting the structure of the electric field or by the influence of a magnetic field in the flux of particles to the second electrode. For all cases of free dispersed flow in a steady state the cross section of basis are coincided in the form to the ideal circles. More homogeneous dispersed flows in the cross section are observed from the apex of ink cone in the modes of the beginning of the jet decay formed at the end of the capillary. With further grow capacity of capillary increases the consumption of ink through the capillary, as evidenced by higher saturation flux images on the media paper or a slide in unit time. At this mode, the experimentally determined dependence of the ink on the time of change in change of the rate level in the reservoir at different potentials of the
capillary, and as a reservoir used gostirovann vessel with a capacity of 1 milliliter and scale divisions of 100 units, i.e. with the scale of $10^{-5}$ liters/division.

![Figure 9](image)

**Figure 9.** The dependence of current-voltage characteristics of dispersed ink flow of jet printers at distance $h_1$ between the electrodes (■ - $5\times10^{-3}$m, ▲ - $7\times10^{-3}$m, × - $9\times10^{-3}$m, · - $10^{-2}$m).

![Figure 10](image)

**Figure 10.** Dynamics of changes in cross-sectional area and the structure of dispersed ink flows on the second electrode, depending on the capacity of the capillary at different distances between the electrodes.

4. **Conclusion**

On the basis of numerous experimental searches are shown that the structure of the dispersed ink flow of jet printers and their dispersion mode in electric field depends on: the installation options, the potential dispersion, the ink consumption through the capillary and its electrical conductivity. During the research the optimal mode dispersion at different installation options and the modes of uniform on
section of stationary dispersed flow are set. This technology can be successfully used for drawing of ink films on basis of nanopowder CIGS semiconductor for producing of flexible (roll) solar energy converters, in ink and 3D printers.

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