

RESEARCH OF DIELECTRIC LIQUIDS BEHAVIOR IN INTENSE ELECTRIC FIELDS

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Abstract. There was researched the intense electric fields influence on processes which occur in dielectric liquids and in interelectrode gap, and described study of motion of particles suspended in transformer oil under the electric field action. There was established the electrodes optimal design which allows obtaining the treated liquid quality

Keywords: The electric field, dielectric liquids, electro-cleaning, electrode space, tension, sediment of particles, motion of particles

1. Introduction

The industry demand for high quantities of pure liquid and wide implementation in different industry fields of the facilities and devices for removal of solid undissolved particles from the fuels and oils by means of intense non-homogeneous electric and electrostatic fields has caused the increased interest to liquids' treating in this fields. Hence, the questions concerning the estimation of influence of these fields on the chemical composition and operating properties of treated liquids remain open and actual.

As it is known [1], till present time the researches confined to comparison of main quality parameters of liquid before and after electric treating. More perspective and informative there is the method of studying the chemical composition of liquids which are processed in electro-physical way in interelectrode gap of electric-treated facilities. For this purpose there can be used the spectroscopic research methods which allow determining the quantitative and qualitative composition of hydrocarbon mixture and the components' structure as well. As upon solving the problems concerning the influence of electric-treating device force field on behavior of dielectric liquid it is unnecessary to determine the chemical composition of mixture, there was applied the microscopic research method. As the tested medium there was used the transformer oil; the research were carried out employing the MBS-2 microscope.

2. Problem definition

The purpose of this paper is the investigation of processes which occur in dielectric liquid and within the interelectrode gap under the intense electric field action, and substantiation of optimal design of electrodes to ensure the high quality of liquid treating.

3. The investigations and publications analysis

In known papers [1–3] concerning the dielectric liquids treating the study of influence of electric field on the treated liquid has being carried out indirectly: there was monitored the purity of liquid on inlet and outlet of treating device. On base of these observations results and the fundamental physical laws there were made the conclusions regarding the processes occurring inside the cleaner. Only in the work [4] it was made the attempt with the help of magnifier to observe the processes taking place in the liquid within the interelectrode gap. It was found that in a steady mode, when the most mass of particles have precipitated on the positive electrode and the largest particles – on the bottom, the continuous movement of the smallest particles between the electrodes is observed. In this process the bulk of particles are in a state of movement in immediate proximity to negative electrodes. The particles recharge is explained by their contact with electrode and other parts.

In the most papers the process of dielectric liquid treating in intense electric fields is explained in the following way. Treated liquid moves within the interelectrode gap in parallel to electrodes' surface. The suspended in liquid particles, which have the permittivity value greater than that of liquid, displace toward to greater electric intensity side under the action of ponderomotive force of non-uniform electric field [1, 2]. In proximity to corona electrode (thin conductor or sharp needle) the particles adsorb on their surface the ions and start to move towards to precipitating electrode (plane surface and cylinder with large radius) charged unlikely. Touching the electrode and giving to it the portion of their charge the particles precipitate on this electrode due to Coulomb and adhesion forces. Such explanations of the electric treating phenomena, which are applied to electronic atomic devices and electric filters designed for gases treating where the medium does not resist to movement of charge carriers (or this resistance is slight), cannot be fully accepted to analysis of process under

consideration. As the calculations [6, 7] have shown the clean dielectric liquid in intense electric field cannot remain immobile. Movement of this liquid has the form of convective flows or "electric wind", and this fact was not taken into account at explanation of the processes occurring in the electric cleaners.

In this pa-per we show the results of experimental investigation of the processes taking place in the interelectrode gap. The observations were carried out with the help of MBS-2 microscope at direct current voltage within the range 0 to 12 kV measured on the primary winding of transformer.

Movement of particles in homogeneous electrostatic field. To study the particles behavior suspended in transformer oil there was used the open plexiglass cell with two flat steel electrodes $10 \times 100 \text{ mm}^2$ fixed in parallel to each other at distance of 7 – 8 mm.

Upon switched-on electric current the natural contamination particles (dust, organic impurities) suspended in the oil slowly move in various directions. The microscope light ray causes their ordered movement towards to light source (the light convection of liquid). Connecting the electrodes to high-voltage source for sub-second stops any displacement, and then the particles began to move again. The interelectrode gap according to this movement character can be divided into five zones clearly expressed at large concentration of particles and strong fields. In zone 2 there is observed the accumulation of volume charge due to electrode collected in immediate proximity. The particles are moving mainly along the electrode. When the volume charge reaches the final value, the 2-nd zone layer bends forming several projections (fig. 1). The projections rapidly (1-3 m/s) move through zone 3 towards to electrode and form the channels to which the nearest to them layers locating in zone 2 move.

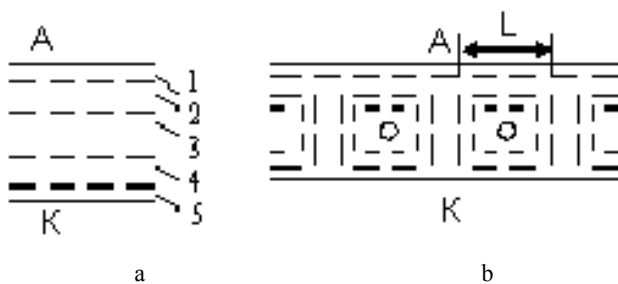


Fig. 1. Liquid flow movement in intense homogeneous electric field: a – the particle in interelectrode gap with characteristic zones 1–5; b – trajectory of directions in interelectrode gap; A, K – the electrodes; L – convective flow cell length

While approaching to electrode the flow distributes in zone 4, the movement slows and the recharging process occurs. The liquid layer locating in zone 3 separates two unlikely charged layers and haven't the own clearly expressed movement. Its individual particles are taken in by convective flow in zones 2 and 4. Under the condition of smooth and clean electrode surfaces the place of forming the projection moving to unlikely charged electrode is the function that in its turn gives the

possibility of distributing the accumulated volume charge. The convective flow cavity length L is equal to 0.7 – 2 of inerelectrode gap. The projections on the electrode surface, large particle or fiber adherent to electrode can serve as the site of the volume charges continuous outflow from zone 2.

Especially important to note that the particles taking part in electric convection don't approach to electrode at distance smaller than 0.2 – 0.5 mm. At small concentration of particles in near-electrode layers 1 and 5 any movement is not observed using the microscope with 56x magnification. It is possible that the charges transfer between the electrodes and the volume charge accumulation zones 2 and 4 is performed by the ions.

At voltage of 6 kV and concentration of 100 particles per 1 mm^3 in zones 1 and 5 there appear the particles which don't already take part in electric convection but rapidly displace from electrode 2 and backwards. The frequency of these displacements is equal to ten cycles per second approximately. On the positive electrode the particles deposit as a rather thin layer. The individual current-conducting particles which have no the oxide dielectric film on their surface are recharged after contact with electrode. The received charge approaches to final value. Such particles move with high velocity (up to 10 cm/s) along the force lines and don't take part in convective motion.

In the oil containing the rather small number of particles (max. 1 particle per 20 cm^3) and under the voltage of 2 – 3 kV the dividing of interelectrode space into zones doesn't occur. The particles slowly (0.2 – 3 mm/s) move from electrode to another one along the own trajectories which often have the crooked form. To register the contact of particles with electrodes was not observed as they moved out the visual field of microscope.

In experiments with the electrodes coated with the epoxy resin and polyethylene layers there are observed the effects similar to described above, but the occurred with less intensity. In paper [3] there is described the idea of treating the liquid containing the particles pre-charged in the homogeneous field created by the electrodes coated with dielectric material. The examination of this idea was performed in the following way. On the tip of glass rod there were placed several particles, then after the contact of these particles with the electrode during several seconds they were introduced into liquid locating within the interelectrode gap (a voltage between the electrodes was 6 kV). After losing touch with the rod the particles under the mutual repulsion force rapidly moved in different directions and then took part in common movement of particles which already were in the interelectrode gap.

Thus, on the base of our experiments and the experiments of other investigators as well it is possible to make a conclusion that the complete treatment of dielectric liquids in homogeneous electrostatic fields is impossible.

Movement of particles in nonhomogeneous electrostatic field. In papers [1, 2, 4] there given the

results of experiments concerning the using of nonhomogeneous fields for dielectric liquids treatment. We have obtained the new data concerning the processes occurring within the interelectrode gap. For experiments one flat electrode was replaced by the needle electrode (fig. 2).

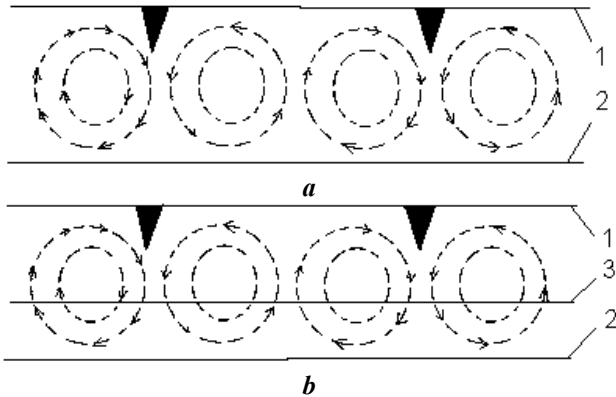


Fig. 2. Liquid flow movement in intense nonhomogeneous electric field: a – with smooth precipitating electrode; b – precipitating electrode coated with foam rubber; 1 – needle (corona) electrode; 2 – flat (precipitating) electrode; 3 – foam rubber

In this case there were observed the steady flows with velocity achieving the value of 3 – 6 m/s. On the negative electrode the particles didn't precipitate almost. On the positive sharp end there was precipitating of thin layer of particles during some time period. Long fibers were sticking to some needles. It took place by the following reason. In case of the negatively charged electrode the electrons from its tips transfer to particles and liquid. These charged particles move to flat electrode. In case of the positive electrode the electrons transfer to electrode from the impurity particles and liquid. During this process the long non-conducting particle orientating along the force lines during the touching with electrode gives it the electrons and recharges in contact point.

Thus, Coulomb force repulsing the particle from the electrode is smaller than gravity force acting due to high nonuniformity of the spike electric field. Therefore, the long particles are held on the needle electrode.

Due to corona discharge the needle electrode emits to liquid the larger discharge coinciding with the needle electrode charge in sign (independently on its polarity) and tending to precipitate on the flat electrode. The process of precipitating and holding the particles against the precipitating electrode surface is considered below.

In experiments there was used the transformer oil with concentration of 100 – 300 particles per 1 mm³. Fused corundum M5 and M7, dust-like silica sand and metallic particles obtained during the surfaces lapping were added to natural contamination (dust, oxidation products, etc.).

Precipitation of dielectric particles on non-insulated smooth flat electrode. At voltage of 10 kV and distance of 3 mm between the needle ends and flat electrode (fig. 2a) the particles precipitated on the electrode as the layers

against each spike in a form of circle. The thickest layer was observed in the circle center (just against the spike). As far as moving from the circle center the layer of particles becomes thinner. If to add into oil the greater amount of contamination the precipitation amount increase too, and the bridge is created between the spike and electrode. Moving away the electrode or decreasing the voltage leads to destruction of bridge and later to destruction of precipitation. The particles clusters were coming off the circle periphery and were removing by the liquid flow. Decreasing the voltage to 6 – 7 kV caused the precipitation parts destruction. At voltage of 2 kV and distance between the electrodes 8 mm the entire deposition was destroyed and transformed to suspended state. The further increase of voltage was accompanied by the particles precipitating. For example, even at voltage of 10 – 12 kV not less than 15 – 20 % of particles were in the oil in suspended state.

It was found that the particles near the spike collect the charge which is greater than the charge of liquid having the same volume. Thus, the greater the amount of particles in the liquid the greater charge is transferred from corona electrode. The particles precipitated on the electrode are discharged. To hold them it is necessary to ensure the charges gain from corona electrode. These charges are carried by the liquid flows from the electrodes. Precipitation of particles on the electrode leads to decrease of their concentration in liquid and decrease of charges gain from corona electrode. Furthermore, the precipitated particles cover the precipitating electrode that leads decrease of charges emission from the corona-forming electrode. The deposit will give to electrode the greater amount of charges than receive from the corona-forming electrode. As a result Coulomb force will reduce sticking the deposit to electrode; the electrode will begin to destruct increasing the particles concentration in liquid. In such way there is created dynamic equilibrium between the precipitated particles and the particles suspended in treated liquid.

Precipitation of conducting particles on non-insulated smooth flat electrode. In this experiment the dielectric particles were in the oil in a small amount (5-10 particles per 1 mm³) and moved in "electric wind" flow. The conducting particles (cast iron and bronze particles 3 – 15 μm) were quickly displacing from the corona-forming electrode to precipitating one and backwards along the force lines with the velocities by 3 – 6 times greater than the velocity in "electric wind" flow. They freely were moving in the opposite direction regarding the liquid flow. Deposit on the flat electrode was slight. Most likely that these particles are the dielectric ones and the particles with the surface coated with the dielectric oxide film. In case of adding the dielectric particles into oil the metallic particles were precipitated on the flat electrode together with above mentioned particles. The greater amount of dielectric particles was added into liquid the greater amount of metallic particles precipitated on the electrode. It can be explained by assumption that the dielectric particles

conserved their charge upon the contact with flat electrode.

Precipitation of particles on insulated smooth flat electrode. The dielectric particles were precipitating on insulated electrode coated with polyethylene film with the same intensity as in case of non-insulated electrode. However, in case of non-insulated electrode the deposit layer was thinner. This is explained by the fact that the metallic particle upon its participating on particle participated previously quickly transfers its charge to this particle and is taken away by the liquid flow as it is not held by Coulomb force.

In all cases the particles precipitation on the smooth flat electrode even after multiple influence of electric field maximum 15 – 20 % of total amount of particles remain in the liquid in suspended state. Our data correspond to experimental results by other authors [1, 4].

Thus, it was found in experimental way that the full treatment of dielectric liquids in nonhomogeneous electric fields with the smooth surface of participating electrodes is impossible.

Precipitation of particles on flat electrode coated with the porous dielectric. The participating electrode (fig. 2.b) is coated with the 5 mm thickness foam rubber layer. Distance between the needles and the foam rubber is 3 mm. In the gap between the needle and flat electrodes as well as in case of smooth electrode the liquid moves along the detected trajectories. However, these trajectories differ from the above mentioned trajectories by the fact that the liquid flow is divided into two parts while approaching to flat electrode. The flow part turns to needle electrode and doesn't contact with to precipitating electrode coating. Another part of flow enters to dielectric coating pores. In the pores the flow velocity decreases, hydrodynamic effect reduces, and the particles precipitating from the oil on the coating pores surface occurs. Passing through the coating pores the liquid purified from the particles joins with the first part of the flow and moves to needle electrode. The participated particles penetrate to depth of 3 – 4 mm. Maximum amount of particles participates against the electrode spike. The liquid treating on the electrode with the porous coating occurs significantly faster than on the smooth electrode. Significantly smaller amount of particles remains in suspended state. In case of strongly contaminated output liquid the particles fully clog the pores against the electrode spike. The further participation of particles in this place becomes more difficult due to hydrodynamic effects (hydraulic resistance of the foam rubber and the particles taking away increases).

4. Conclusions

1. Precipitation of conducting particles is possible on the insulated electrode only.
2. Precipitation of dielectric particles is possible on both the non-insulated electrode and insulated one.
3. Conducting and dielectric particles containing in the liquid can participate on both the non-insulated

electrode and insulated one. In last case the participation occurs under the stipulation that the amount of conducting particles is smaller than the amount of dielectric ones. Relationship between the particles depends on their dispersiveness and the properties of dielectric particles.

4. The previous electrization of the particles prior to supply into interelectrode gap doesn't change the participation process.
5. The full treatment of liquids in intense homogeneous electric fields and in nonhomogeneous fields with the smooth precipitating electrodes is impossible.
6. The best treatment of liquids in nonhomogeneous fields with the participating electrode coated with the porous dielectric.

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ИССЛЕДОВАНИЕ ПОВЕДЕНИЯ ДИЭЛЕКТРИЧЕСКИХ ЖИДКОСТЕЙ В СИЛЬНЫХ ЭЛЕКТРИЧЕСКИХ ПОЛЯХ

Резюме. Исследовано влияние сильных электрических полей на процессы, которые происходят в диэлектрических жидкостях и в пространстве между электродами, описано наблюдения за движением взвешенных в трансформаторном масле частиц под действием сил электрического поля. Установлена оптимальная конструкция электродов, которая позволяет получать наивысшее качество очищенной жидкости

Ключевые слова: Электрическое поле, диэлектрические жидкости, электроочистка, межэлектродное пространство, напряжение, осаждение частиц, движение частиц

