GLOBAL IMAGING METHOD FOR MEASURING IONIC WIND IN THE VICINITY OF THE HV POWERED ELECTRODE

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Abstract

This paper describes the measurement of the electric wind phenomenon via using Global Imaging methods. Electric wind can be described as movement of the air generated by free ions metal object (in our case electrodes) which are powered by high voltage. This physical phenomena is a vital part of the AC electrospinning technology that was developed at Technical university of Liberec. We visualize and measure electric wind velocities around vicinity of the electrode. Measurements are done with our custom build setups. Both high voltage power source system and chamber are original pieces of equipment. We substitute nanofibrous sleeve, the product of the AC electrospinning with various electrically neutral monodispersed particles. The differences in particles are mainly conductivity and polarizability. Particles are accelerated by movement of the air and then lightened by laser and recorded on high speed camera. The outputs of our measurements are vector maps that clearly describe movements of the air around electrode.

Keywords: AC nanofibers, Particle tracking velocimetry (PIV), ionic wind

1. INTRODUCTION

The Electric wind phenomenon (also known as ionic or coronal wind) that is currently researched by our group was previously described by Drews and Solovyov [1, 2]. They characterized it as a reflection of occurring electrical discharges on the electrode, which is powered by altering current (AC) power source. It is known that it is possible to use both DC (direct current) and AC power sources for generation of this phenomenon. The purpose of our research is to measure electric wind using laser based anemometry [3]. It is required to use dispersed particles with suitable diameter and electrical properties (conductivity, permittivity) as a seeding medium. Particles can be divided into two groups: polar, and non-polar. Emplacement of such chemical substances into HV electric field described by Eow [4] shows the different behavior of oil and water particles related to electrophoresis phenomenon. It is shown that DC electric field generated in small cell between two electrodes is affecting polar drop of water placed in the middle of the cell far more than non-polar surrounding made out of different oil types. Experiment shows ability to polarize a water drop which leads to movement towards electrodes or fragmentation of the drop. In the case of contact with one of the electrodes, the charge in the drop changes and movement is switched to the opposite direction. The article published by Guo [5] shows the similar experiment with cell and aqueous drop deformation. Both experiments use the same electrical intensity but they differ in the type (DC/AC) of the current making the second mentioned work closer to our own. The work done by Mhatre [6] also engages electrophoresis but it uses modified setup that is asymmetrical. One side is made of plate electrode that is grounded and the counter pin electrode is placed above with connection to AC HV source. The work shows that it is possible to cause the delay (lag) in the movement of the aqueous drop by the sinusoidal shape of the function of the field (AC) using certain frequencies. It is caused by the time required for polarization of H_2O molecules in the drop. It is also shown that during the polarity change the movement of the drop decreases but when is the function increasing and closing to the amplitudes (both negative and positive); the droplet starts to accelerate towards the pin electrode. All articles that are mentioned above describe connection between polar/non-polar fluids affected by high voltage electric fields. Such a topic is approached by our group in different manner. We are measuring ionic wind by method of laser based anemometry. This experimental setup enables us to track movement of dispersed particles with low polarity in the air and creating accurate visualization of ionic wind drafts in the vicinity of HV powered electrode. Our work aims for better understanding of this physical phenomenon that is the key factor in AC electrospinning technology [7].

2. EXPERIMENTAL SEEDING MEDIUM

Here we used various chemical substances as a seeding medium (**Table 1**). We used the inoLab 720 conductometer and Krüss BP 2100 surface tension meter to gain a complete understanding of the nature of selected liquids. Methyl Silicone was chosen as the best solution for the experiment according to its stability inside testing chamber, optical clearness, and its electrical properties.

Table 1 Physical properties of liquids used as seeding medium

In 25°C temp.	Density [g/cm^3]	Conductivity [µS/cm]	Surface tension [mN/m]	Relative permittivity
Ethylenglycol	1.11	0.9	52.8	37.0
Glycerine	1.26	0.2	68.5	47.0
H2O	1.00	4.6	75.7	80.1
Glycerine + H2O [6:1]	1.22	3.0	72.0	60.0
Methyl Silicone	0.97	0.1	38.5	2.9
Olive Oil	0.92	0.2	40.2	3.1

3. GLOBAL IMAGING METHODS

The experimental study of droplet movement in strong electric field was based on the visualization technique - Global Imaging Methods. This method is based on illumination of an investigated area using defined laser sheet and detect the moving object using CCD camera. Here we were interested of electric field impact on particles, their movement, acceleration and surface charge that cause their self-repelling.

Droplets of defined size were generated using pneumatic atomizer. The nozzle enables generation of monodisperse spray. The mean droplet diameter is 5 um. Selected medium was used as material for seeding spray. Once the spray was uniformly placed in the chamber we switch on the electric field and observed the orientation and acceleration of the droplets using PIV method. The laser sheet was brought to the chamber using optical arm and the camera was fixed to the traversing unit. We supposed high speed acceleration at the beginning of the process. The process is further continuous and the droplets are moving constantly. Here we used 12 Hz sampling frequency.

The PIV system consisted of NewWave Gemini pulsed laser Nd: YAG energy of 120 mJ per pulse length of 10ns, which operates at a wavelength of 532 nm. The images were captured with Neo CMOS chip 5.5 MPixel size of 6.5 microns camera. Laser and camera system is controlled from a computer and synchronized to external TimerBox. The statistics of 400 records was processed as vector and scalar maps.

Initial tests were completed with validation measurement using different physically based method. We used hot-wire anemometry to confirm the results obtain by PIV. The investigated area of size (78 x 72) mm contained view close to charged floating point electrode. There was brought 30kV DC voltage to the electrode.

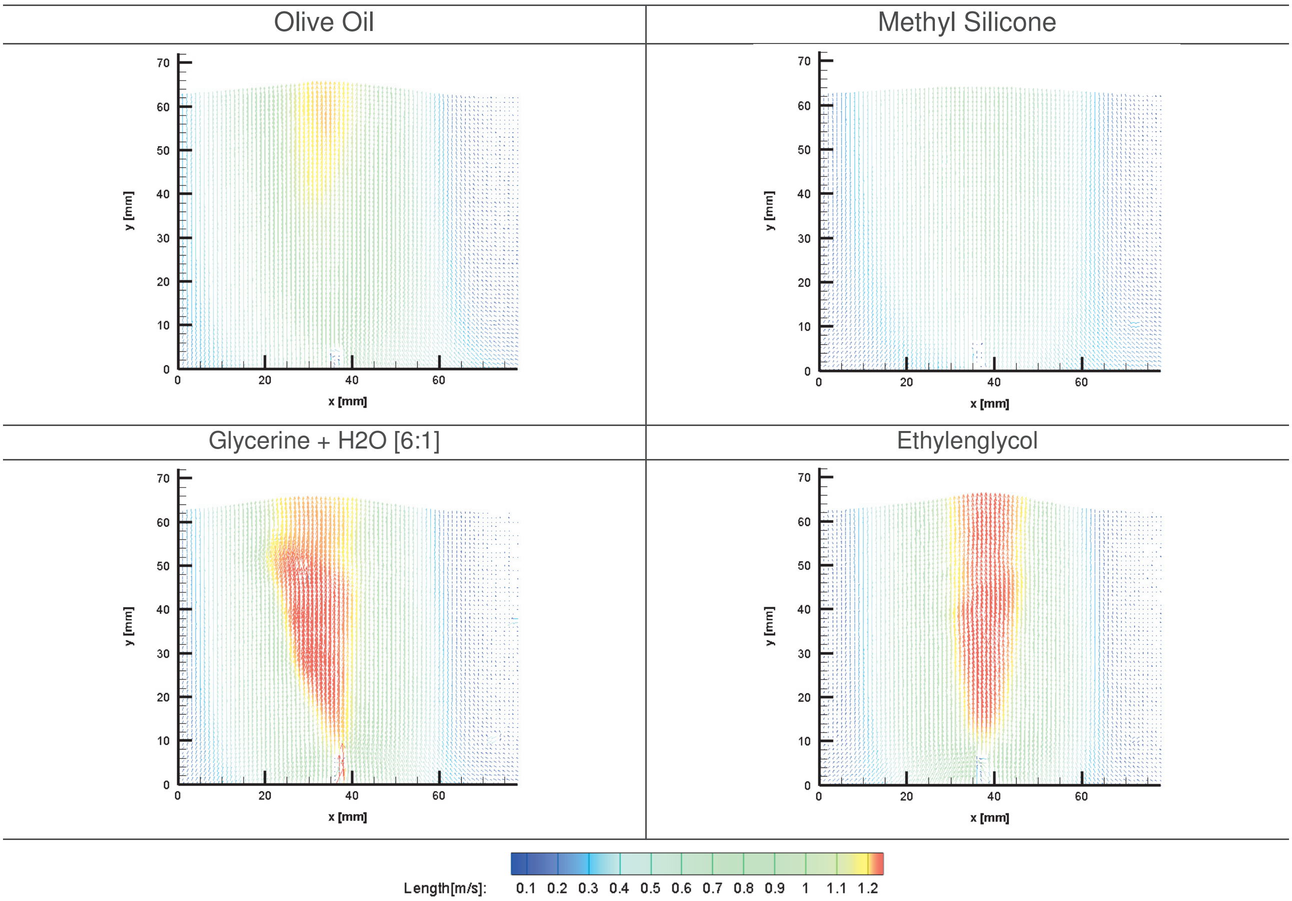

Figure 1 Vector maps of monodisperse droplet movement induced by electric field. Different particles are moving by different velocities. Mixture of Glycerine with water and Ethylenglycol are reacting more with HV field therefore generating higher speeds (red vectors)

Figure 1 shows the movement of droplet induced by electric field. The vector maps are presented as a statistic result. The initial part of the process is very fast and the droplets are accelerated and unstable. Here we separated evolution part of the process and taken in account the stable and uniform part. The differences in acting electric field on the drop motion can be also seen in summary comparing chart in **Figure 2a**. There was taken a plot horizontal line in 58mm above the tip of the electrode. **Figure 2b** shows the velocity profile in vertical line in the axis of the electrode. There are changes in velocity profiles depending on chemical character of the droplets.

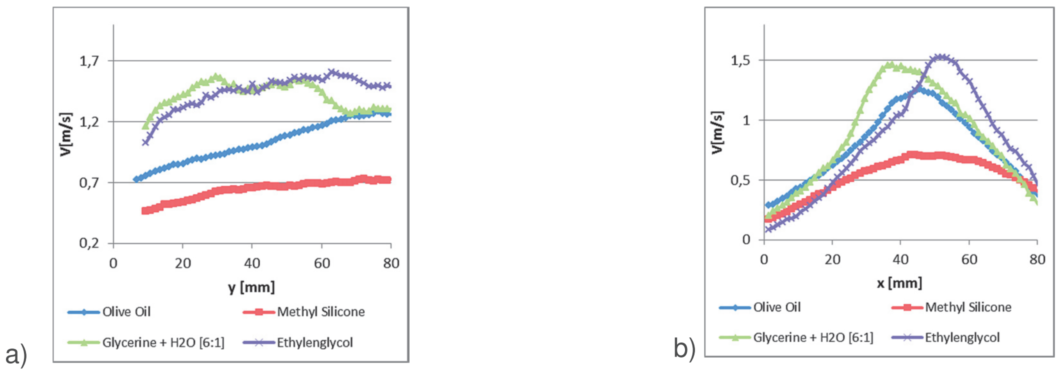

Figure 2 Profile plots of the moving droplets taken a) vertical line, b) horizontal line showing less electric interaction between Methyl Silicone and induced HV field

The polar liquids containing water as glycerin are accelerated due the oriented molecular charge and Coulombic force in-between. This effect fades if the liquid has non-polar character or is lack of water molecules. The weakest responds to the electric field force has methyl silicone. This chemical is used as transformer oil due its resistance to water, low permittivity and conductivity. Mentioned characteristics forms it's inert to the electric field force. The methyl silicone drops are accelerated due secondary existence of ionic wind. This effect is seen in **Figure 2** as a profile plot of droplet velocities.

It is clear that Methyl Silicone a solution with best behavior is chemical compound with low Relative permittivity therefore it does not react improperly with our electrode setups (no unwanted movement towards the electrode). These particles are not interacting with electric fields and they are purely driven away from the electrode by collision with negative and positive ions.

4. SIMULATION OF THE PROCES

4.1. Software

Program Comsol Multiphysics that was used for simulation of physical processes is statistically dynamical program solving problems on the basis of differential equations. Commonly it is used for creation of models and simulations in the areas of electro technology, machinery and chemistry.

4.2. Numerical model

The inner sketch program of Comsol software was used for prepared model. Enclosed rectangular space with dimensions of 3x10 mm was infused with oil drop with diameter of 0.5 mm (**Figure 3**). The data regarding air variables, dynamical viscosity and density of the drop was put in the calculations. Parameters similar to oil were inserted inside oval shape of the drop.

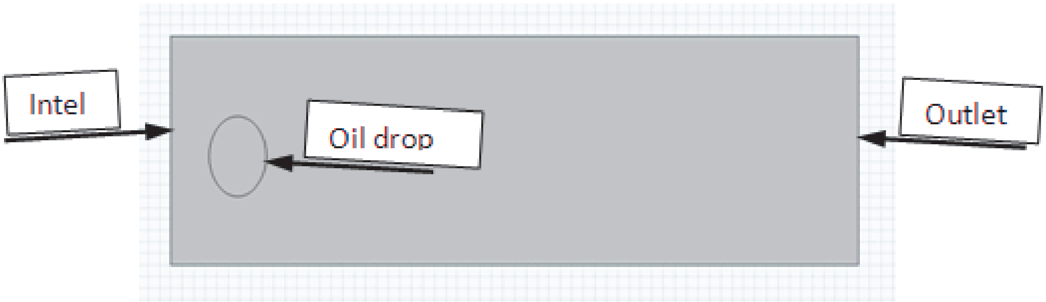

Figure 3 Geometry with boundary conditions defined in Comsol Multiphysics

The mesh with finite elements with triangular shapes was inserted to all parts of the geometry. The area around the drop was thickened for the purpose of higher quality mesh. The correctness of the mash was checked for easier and faster calculations. The final model included 10016 elements and 322 boundary elements (**Figure 4**).

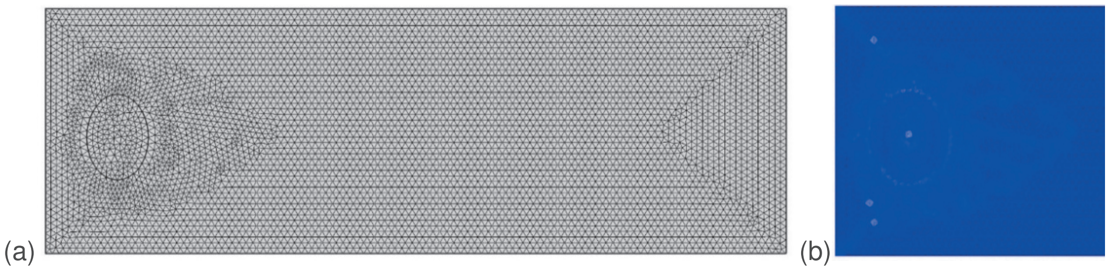

Figure 4 Tetragonal mesh (a) followed with detailed picture (b) of the vicinity of the drop

The permittivity of oil and air were defined with cross-reference to established input definition. For the purpose of solving this problem, the Maxwell equations of the electromagnetic field were introduced at the boundaries of the model. Boundary conditions were added to the model. One for the input of the electric potential (30 kV) was added to the top edge, other with zero potential to the bottom edge of the model. The movement of the oil drop was secured by adding other physical property for the flux. Left side of the defined space was enhanced by input boundary condition. Established parameters of the air were inserted on the boundaries of the model and input/output conditions were set (**Figure 5**)

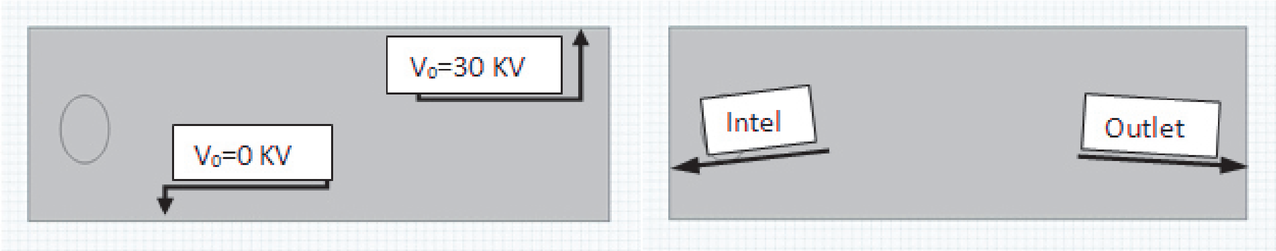

Figure 5 Boundary conditions for the input and output of electrical potential and flux ranging from zero voltage to 30 kV

The oil drop moved in the area with established electric potential of 30 kV as shown by the results. **Figure 6** shows the recording of the drop movement in electric field. The drop is encircled by field lines and dragged out of the area from initial point of the simulation creating flux channel that can be observed in **Figure 7**.

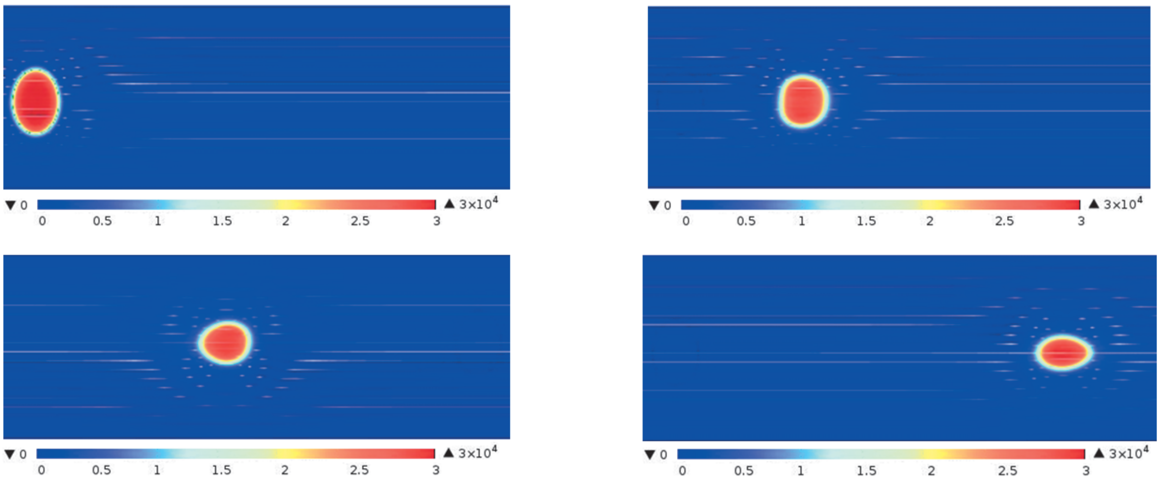

Figure 6 Movement and deformation of the drop in electric field powered by 30 kV. Red color representing high intensity of the field in the droplet

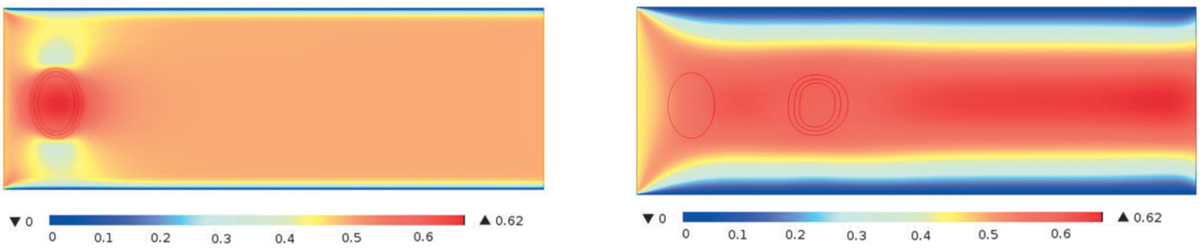

Figure 7 Movement of the drop in the created flux [m/s]. The red parth of the right picture is representing stream with highest velocity of the supposed particle transport

4.3. Results of the simulation

The geometry for purpose of determination of the movement of the oil drop was created in Comsol Multiphysics software. This movement was affected by electric potential and flux of the air. The geometry of the drop was created and placed inside rectangular space. Material constants comparable to our experiments were chosen and put inside the model. The boundary conditions that described input and output of the model were introduced to the model. Mesh used for model was enhanced and debugged for the purpose of the easier calculations. The results shown the movement of the oil drop surrounded by the air inside the space with established electric potential.

5. CONCLUSION

Here we used the Global Imaging method for the visualization of droplets in electrostatic field. The motivation of this research was to establish the effect of strong electric field on droplets generated from various chemical substances to observe and prove the character of their movement. There was assumption of strong effect on polar liquids, or liquids contenting water molecules, due prevailing Coulombic force between droplets. Here we targeted the liquid with low permittivity, conductivity, and of non-polar character that was expected to be none reacting with strong electric field. The set of experiment proved the Methyl Silicone as an inert liquid that is not following (acting) the streamlines of electric field, but is mostly affected by electric wind. These results will be further used for the visualization of ionic wind as we select the optimal liquid as a seeding medium for these experiments.

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