COMSOL
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The fast model for ionic wind simulation

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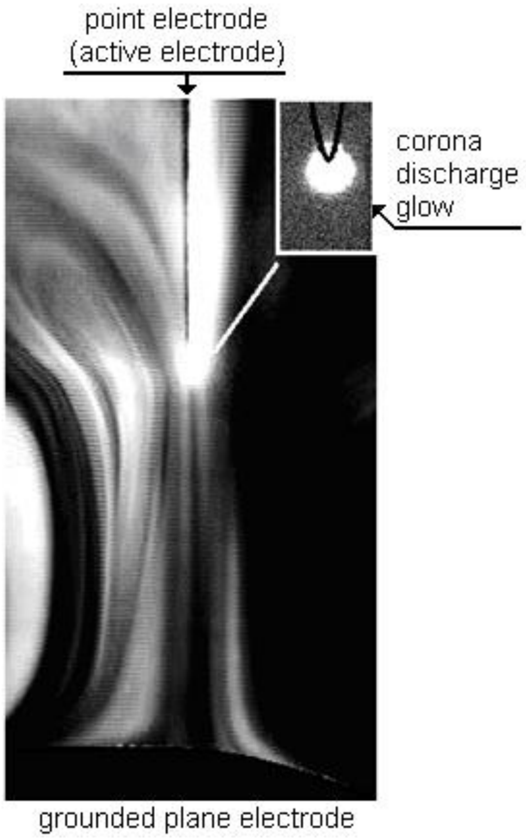
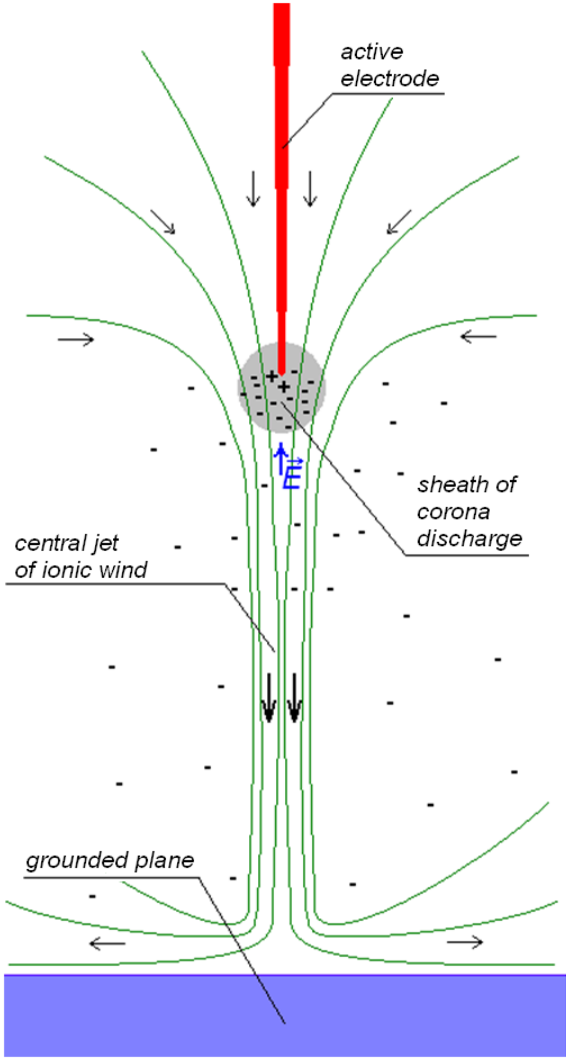
Ionic wind



Yu. Stishkov, A. Samusenko, M. Vinaykin, D. Zuev. Computer simulation of corona discharge and experimental investigation of ionic wind // Proceedings of International Symposium on Electrohydrodynamics. Sarawak (Malaysia), 2009.



Non-uniform electric field appears in systems with electrodes which curvature radii differ strongly.

If electric field intensity is high enough air ionizing and corona discharge obtain near the electrode of the lower curvature radius.

Ions produced in corona discharge are accelerated by electric field.

Then due to elastic collisions momentum is passed from ions to neutral molecules.

Thus an air motion emerges – the "ionic wind".

A typical ionic wind stream has form of strong narrow jet which is directed from the coroning electrode to the passive opposite electrode

Applications

Electrostatic precipitator (ESP).

control of many industrial particulate emissions, including smoke from electricity-generating utilities (coal and oil fired), catalyst collection from fluidized bed catalytic cracker units in oil refineries and other.

Ionizers.

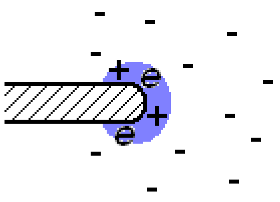
Cooling devices.

Mathematical models

“Complete” model:

drift-diffusion approximation

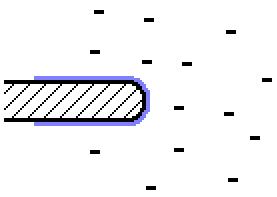
$$
\left\{
\begin{array}{lr}
\varepsilon_0 \Delta\varphi = -e\left(n_+ - n_- - n_e\right) & (1.1)\\
\rho\left[\dfrac{\partial\vec{v}}{\partial t} + \left(\vec{v}\cdot\nabla\right)\vec{v}\right] = -\nabla P + \eta\Delta\vec{v} + en_-\nabla\varphi & (1.2)\\
\left(\nabla\cdot\vec{v}\right) = 0 & (1.3)\\
\dfrac{\partial n_-}{\partial t} + \left(\nabla\cdot\left[-D_-\nabla n_- + \mu_- n_-\nabla\varphi\right]\right) = \nu_{att} n_e & (1.4)\\
\xcancel{\dfrac{\partial n_+}{\partial t} + \left(\nabla\cdot\left[-D_+\nabla n_+ - \mu_+ n_+\nabla\varphi\right]\right) = \nu_{ion} n_e} & (1.5)\\
\xcancel{\dfrac{\partial n_e}{\partial t} + \left(\nabla\cdot\left[-D_e\nabla n_e + \mu_e n_e\nabla\varphi\right]\right) = \left(\nu_{ion} - \nu_{att}\right) n_e} & (1.6)
\end{array}
\right.
$$



Corona sheath:
in bulk

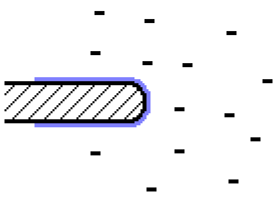
Unipolar approximation:

$$
\left\{
\begin{array}{lr}
\varepsilon_0 \Delta\varphi = en_- & (2.1)\\
\rho\left[\dfrac{\partial\vec{v}}{\partial t} + \left(\vec{v}\cdot\nabla\right)\vec{v}\right] = -\nabla P + \eta\Delta\vec{v} + en_-\nabla\varphi & (2.2)\\
\left(\nabla\cdot\vec{v}\right) = 0 & (2.3)\\
\dfrac{\partial n_-}{\partial t} + \left(\nabla\cdot\left[-D\nabla n_- + \mu n_-\nabla\varphi\right]\right) = 0 & (2.4)
\end{array}
\right.
$$



Corona sheath is described by
a boundary condition

Boundary conditions for unipolar models



In unipolar models the corona sheath is described by a boundary condition. There are several common forms.

Formula	Description	Disadvantage
$E = E_{critical}$	Fixed electric field intensity	1. Two restrictions on electric potential. 2. Corona discharge area must be predetermined.
$j_- = f(E)$	Ions' flux as a function of electric field intensity	We should measure current in experiment to define coefficient *f(E)*.

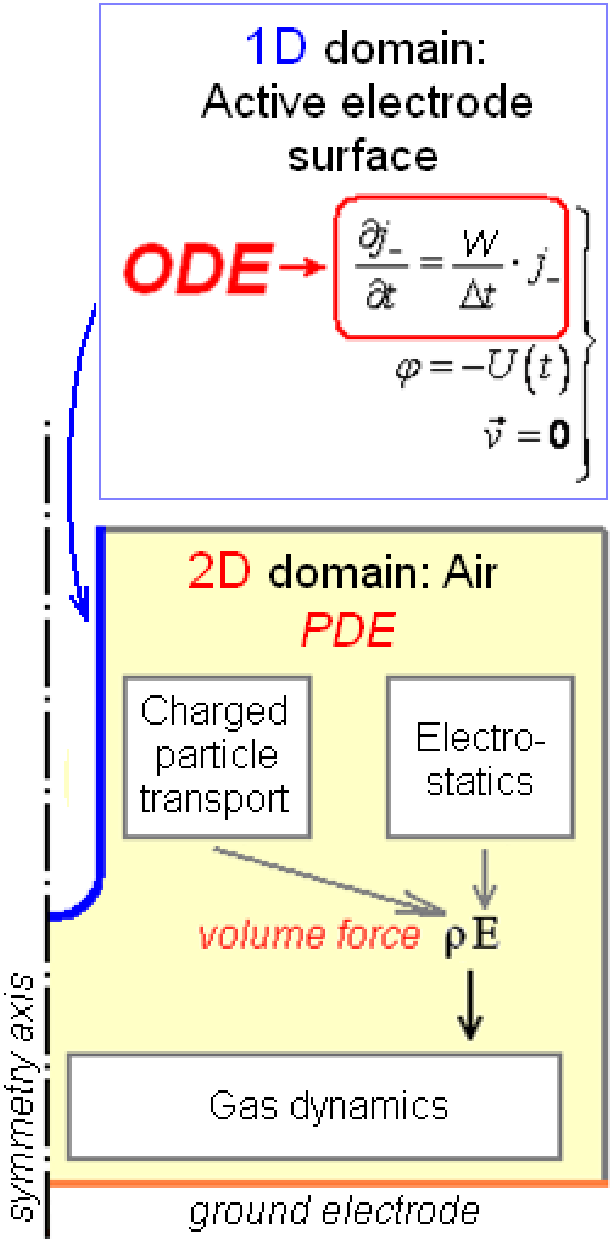
We offer boundary condition:

$$\frac{\partial j_-}{\partial t} = \frac{\gamma\left(\exp M - 1\right) - 1}{\tau} j_-$$

where:

$$M = \int_{\substack{field \\ line}} \alpha\left(E\right) ds$$

Simple (fast) model



$$
\begin{cases}
\varepsilon_0 \Delta\varphi = en_- & (2.1)\\
\rho\left[\frac{\partial\vec{v}}{\partial t} + (\vec{v}\cdot\nabla)\vec{v}\right] = -\nabla P + \eta\Delta\vec{v} + en_-\nabla\varphi & (2.2)\\
(\nabla\cdot\vec{v}) = 0 & (2.3)\\
\frac{\partial n_-}{\partial t} + \left(\nabla\cdot\left[-D\nabla n_- + \mu n_-\nabla\varphi\right]\right) = 0 & (2.4)\\
\left(\frac{\nabla\varphi}{|\nabla\varphi|}\cdot\nabla\right)M = \alpha\left(|\nabla\varphi|\right) & (2.5)
\end{cases}
$$

Used models of COMSOL Multiphysics:

(2.1): "AC/DC”: "Electrostatics"

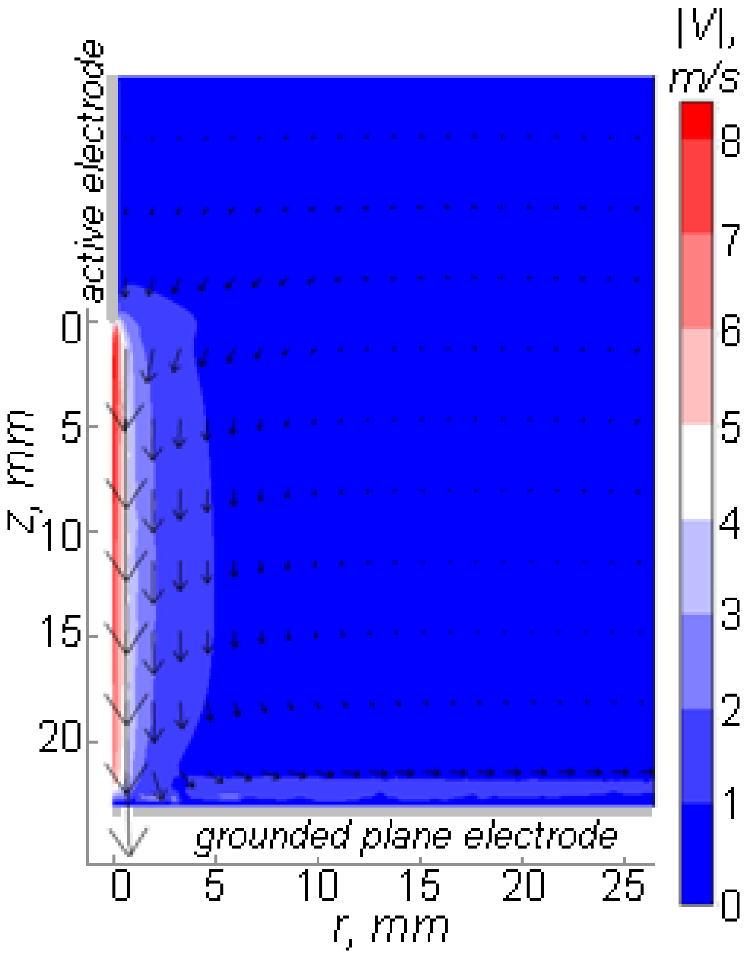
(2.2)-(2.3): "Fluid flow”: "Laminar flow"

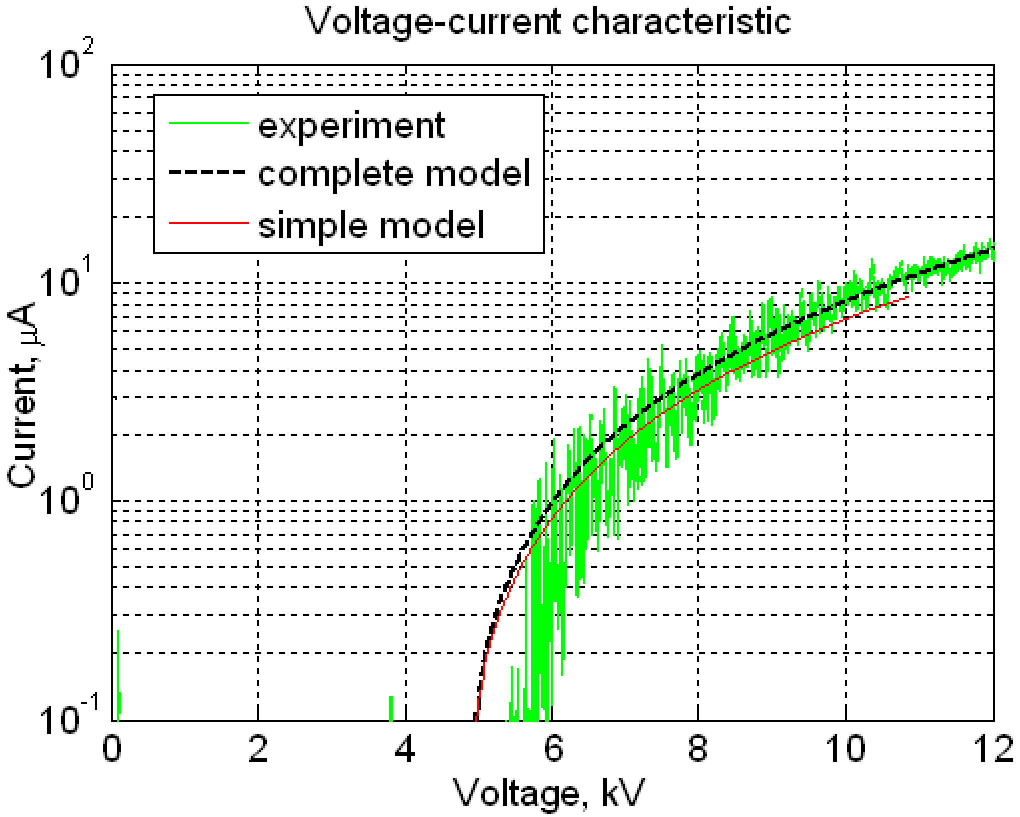
(2.4): "Plasma”: "Drift-diffusion"

(2.5): "Coefficient form PDE interface”

Simple (fast) and complete models: comparison

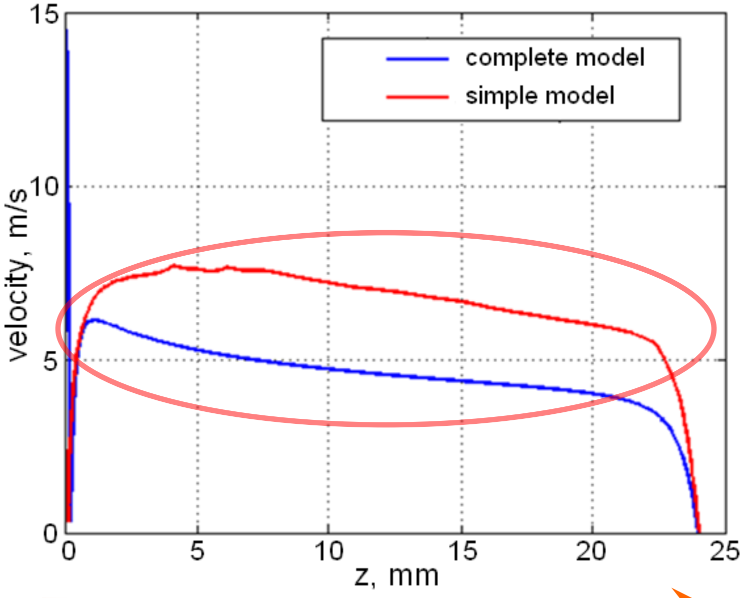
Ionic wind flow (simple model)

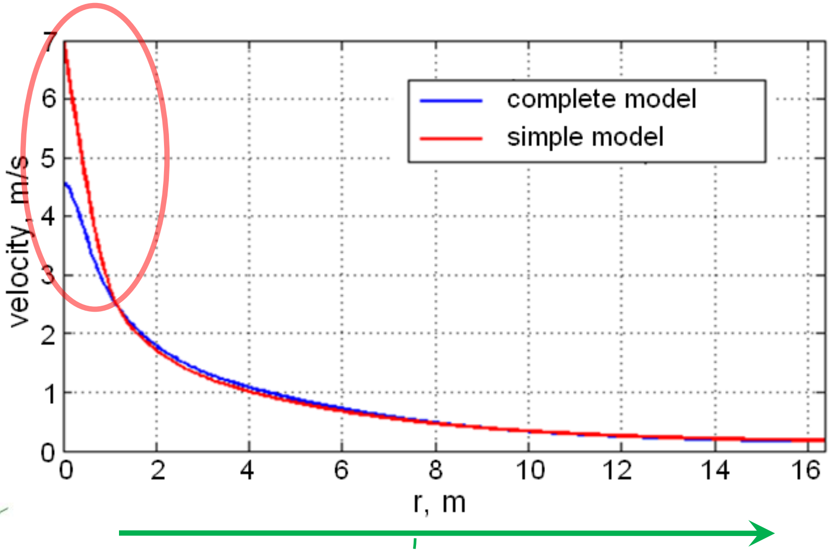


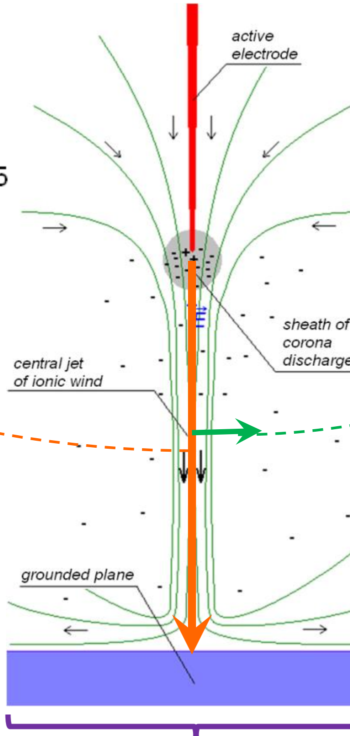


The both models are in good correspondence with experimental data

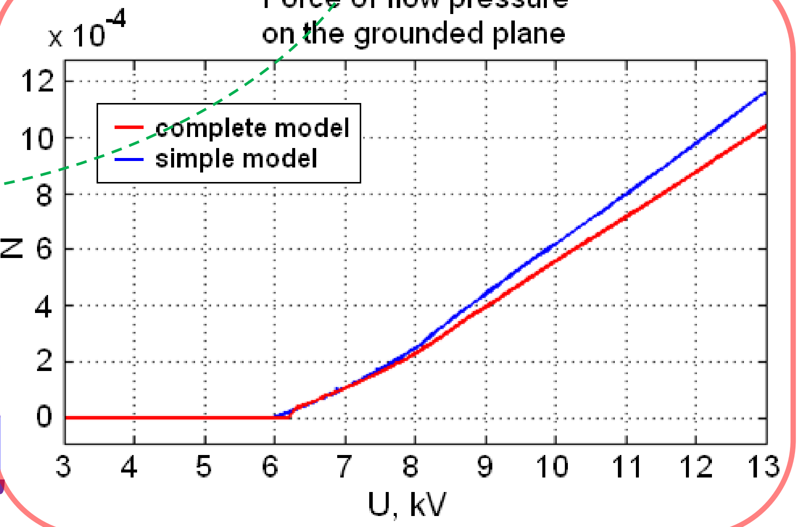
Simple (fast) and complete models: comparison







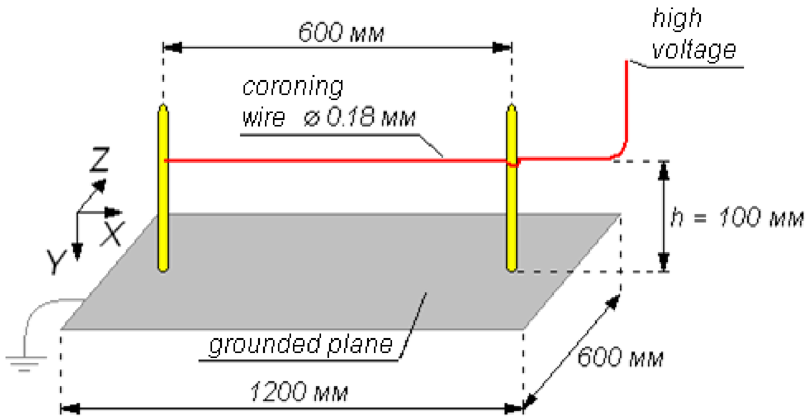
Force of flow pressure on the grounded plane



The **narrow maximum** of velocity in central jet in the simple model is more the one in the complete model (**up to 50%**).

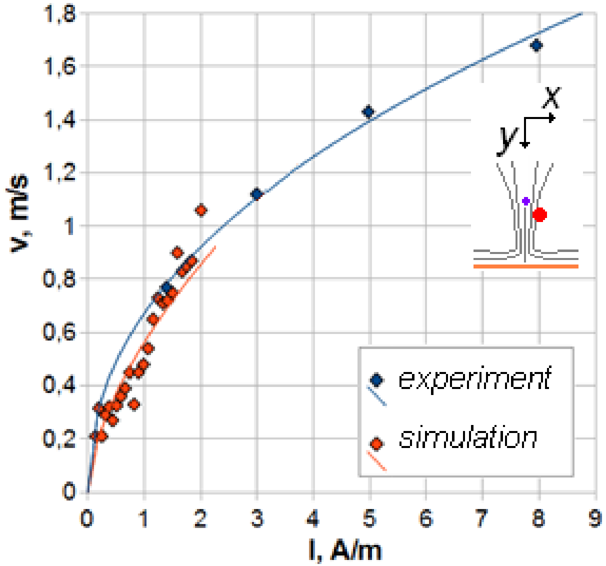
However a small portion of the flow volume passes here. Therefore **integral characteristics** (summary current, pressure on the grounded plane and other), **are in good correspondence** (about 10%).

Simple (fast) model and experiment: comparison

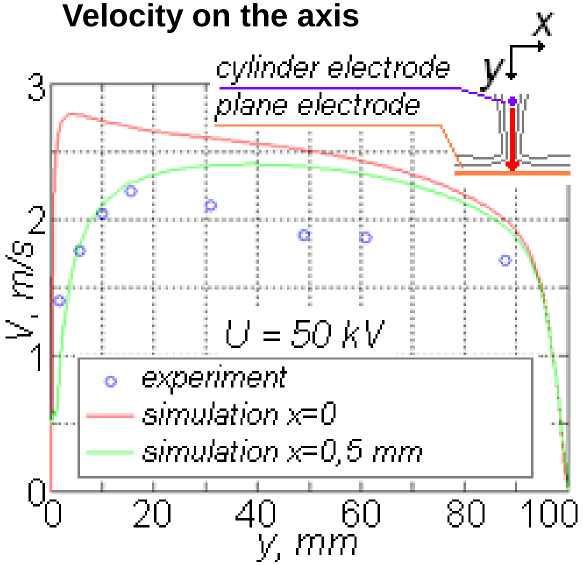


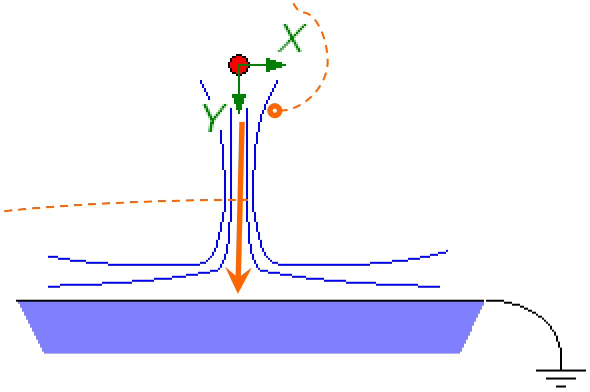
The experiment statement and results are described in: *Vereschagin I.P.* Corona discharge in the devices of electron-ion technology. Russia, Moscow: Energoatomizdat, 1985. 160 Pp. In Russian.

Dependence of air velocity on current: *y*=10 mm, *z*=10 mm.

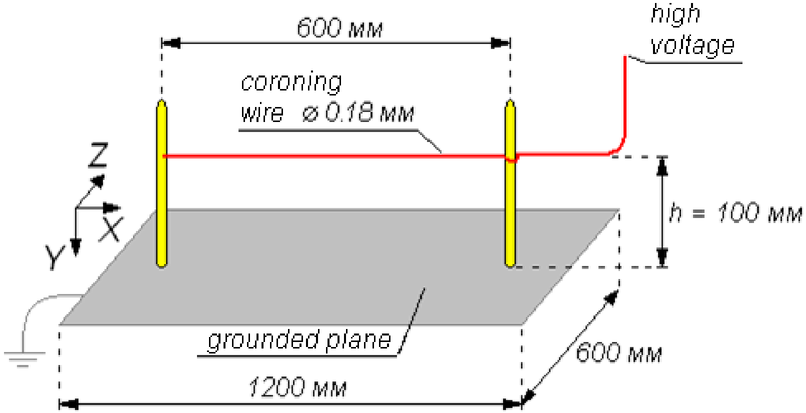


Velocity on the axis



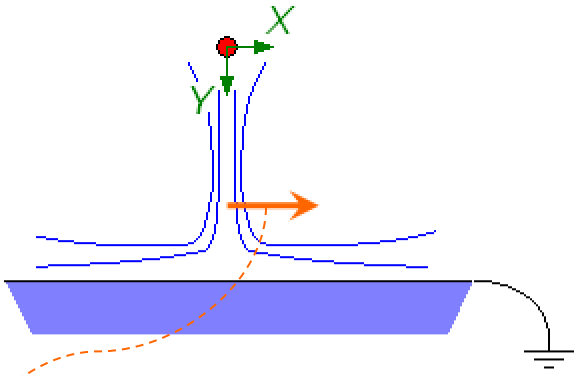


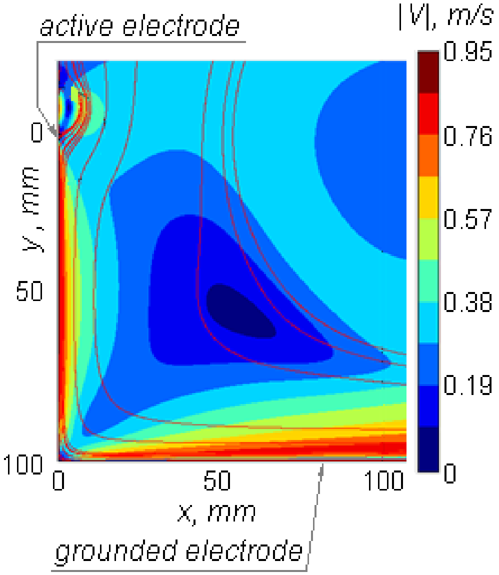
Simple (fast) model and experiment: comparison

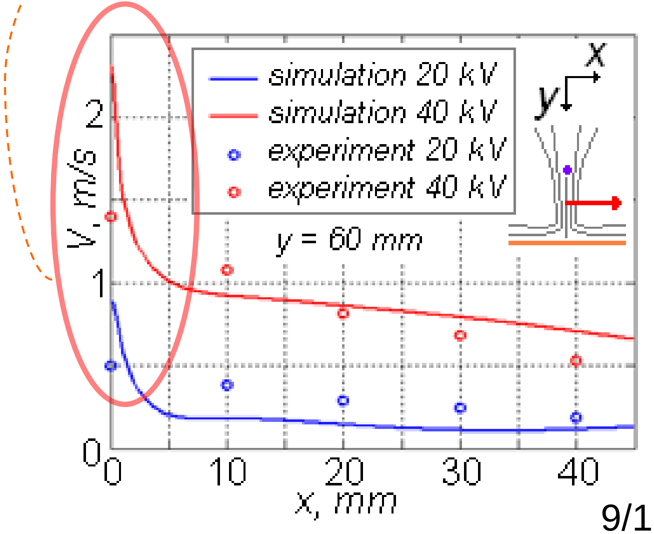


The experiment statement and results are described in: *Vereschagin I.P.* Corona discharge in the devices of electron-ion technology. Russia, Moscow: Energoatomizdat, 1985. 160 Pp. In Russian.

Transversal distribution of air velocity is in good correspondence with experiment except the narrow maximum of the central jet.







Conclusions

The offered **simplified** unipolar model of ionic wind gives results which are **close to the complete** (drift-diffusion) model results.

However the simplified (fast) model **reduces** solution **time and** used **memory** volume **up to 10 times** in comparison with the full model. This advantage is significant for 3D simulations.

The offered **new boundary condition** on the active electrodes makes the model more universal: information about voltage-current characteristic or corona area is not needed to implement the simulation.

The simulation results are in good correspondence with experimental data.