Optimization of Artificial Diffusion Stabilization Techniques and Corresponding Mesh Density Distribution in Drift Dominated Transport of Diluted Species

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Abstract

Several types of artificial diffusions are provided in COMSOL Multiphysics to stabilize the convection and diffusion problems such as charge transport. These techniques add artificial diffusion terms in the equation to make the convergence much easier to achieve. If the artificial diffusion term (not necessarily physical) is effective, it significantly accelerates the simulations by eliminating the need for mesh refinement. This paper investigates the performance of different consistent stabilization techniques in a three-carrier streamer continuum model, which is utilized to account for the charge generation, recombination, and transport mechanisms. The governing equations that contain the physics to model streamer development in liquids are based on drift-dominated charge continuity equations for positive ion, negative ion, and electron charge densities, coupled through the Gauss' law. The thermal diffusion equation is included to model temperature variations and gas formation in the liquid. The mobility dependencies on electric field intensity and temperature have been taken into account. The model is implemented in both 2D axisymmetric and 3D geometries. Several streamline diffusions (anisotropic, Upwind Petrov-Galerkin, Galerkin least-squares) and Crosswind diffusions are applied to stabilize the charge continuity and thermal diffusion equations. These techniques are compared when used either alone or in combination, with different tuning parameters. The streamer modeling results show that the artificial diffusion techniques can save great amounts of simulation time and computational capacity if used appropriately. In particular, COMSOL 3.5a streamline diffusion techniques are quite effective in charge transport problem and cannot be avoided due to convergence issues. In COMSOL 4.3, however, the crosswind diffusion is much more robust and can replace the streamline diffusion. In addition, since local element size can be used in determining the crosswind diffusion tuning parameter, the 3D problem can converge much easier and faster. In terms of accuracy, the artificial diffusion tuning parameters must be minimized or be avoided if possible. In other words, there is usually a tradeoff between reducing the tuning parameters and required mesh size to reach the convergence and accurate results. The simulation results, simulation times, and the required mesh density distributions for different applied artificial diffusion techniques are presented and discussed in detail. To overcome nonphysical off-axis instabilities, we tested several dense meshes. It turned out that only refining the mesh around the needle tip is not sufficient to solve the problem as for example shown in Figure 1 for a box with an

excessively dense mesh. Figure 2 shows that with different element size distribution, we have successfully removed off-axis instability (Figure 1); instead, an axial high-speed streamer branch evolves from the initial ionized volume. In general, our numerical experiments show that a big jump in element size distribution over space may cause a numerical positive feedback effect and form nonphysical branching especially when the electric field is extremely divergent. Such big jumps create small numerical perturbations that grow due to a streamline diffusion accumulative effect in our model. Figures 3 and 4 compare different cases of element size change over space and spatial disturbances that they may produce.

Reference

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Figures used in the abstract

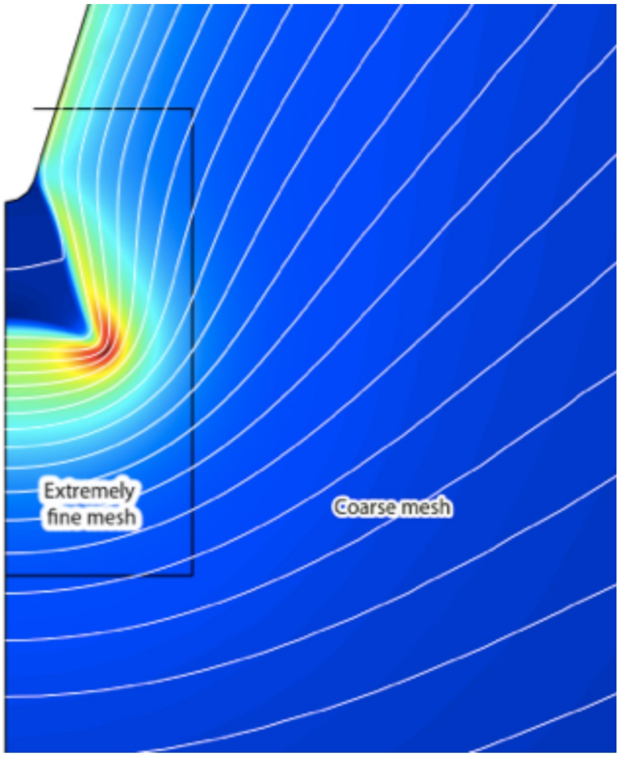

Figure 1: Off-axis branching in a positive streamer formed by a positive impulse with 200 kV and 1 ns rise-time still appears even with an extremely fine mesh around the needle.

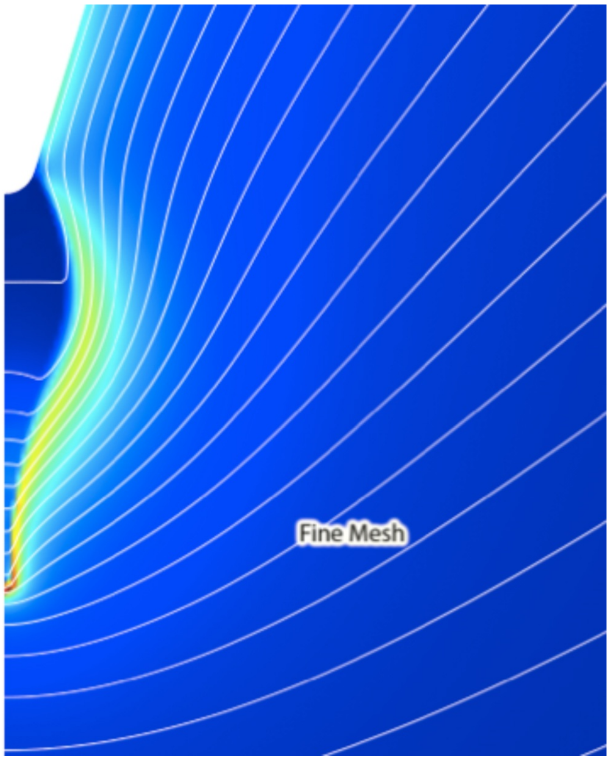

Figure 2: Off-axis branching in a positive streamer formed by a positive impulse with 200 kV and 1 ns rise-time disappears even with a fine mesh over a larger box around the needle.

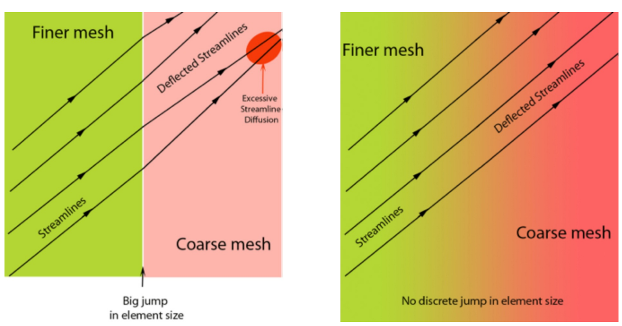

Figure 3: Left side: Critical disturbance over a big jump in element size. Such disturbances can form deflections electric field large enough to add excessive streamline diffusion, and consequently deflect the main axial steamer branch. An example of this case can be seen in the right side of Fig. 1. Excessive streamline diffusion in the off-axis (radial) direction deflects the streamer and accumulates charge off the axis of symmetry. Such big jumps in mesh density must be avoided if the non-physical "radial bump" is to be eliminated from the results. Right side: One of the possible options to minimize the effect of spatial disturbances due to element size gradient. It seems that a gradual rise in element size is the optimum approach to keep accuracy high enough on one hand and decrease the number of elements on the other hand.

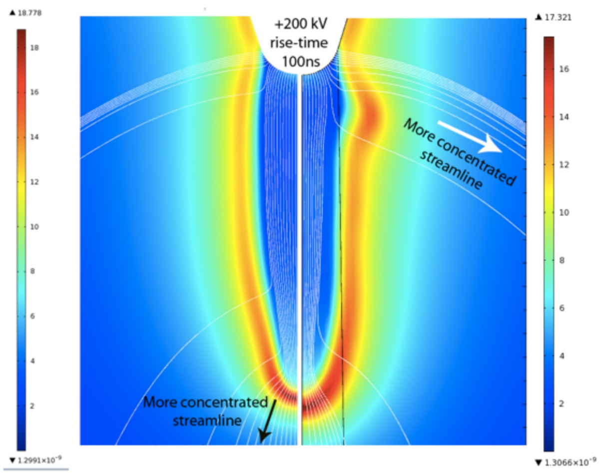

Figure 4: Non-dimensionalized electric field (Eb=1.2e7) for two different mesh element size distributions for a positive applied voltage with 200 kV peak and 100 ns rise-time at time 85 ns. The two simulations are separately computed with the left side plot having a smooth fine mesh (derived by COMSOL adapted mesh) while the right side plot has a fine mesh within 40 μm (maximum element size of 2 μm) and for the outer area beyond this box it has been freely meshed. Both streamline and crosswind diffusions are applied.