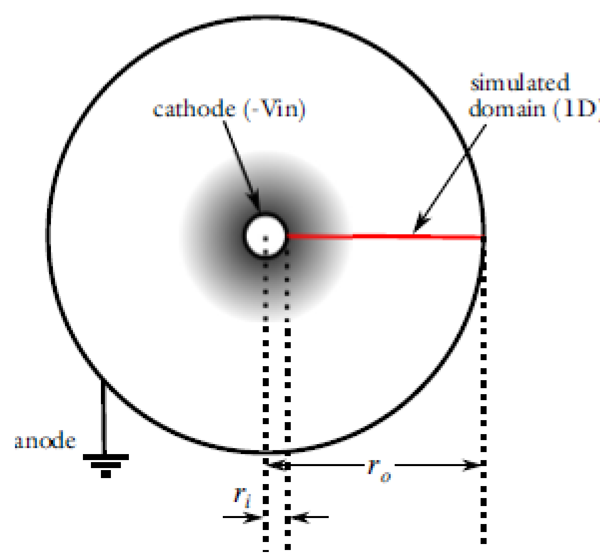
Expanding the Study of Plasma Discharge Conditions with Computational and Experimental Models

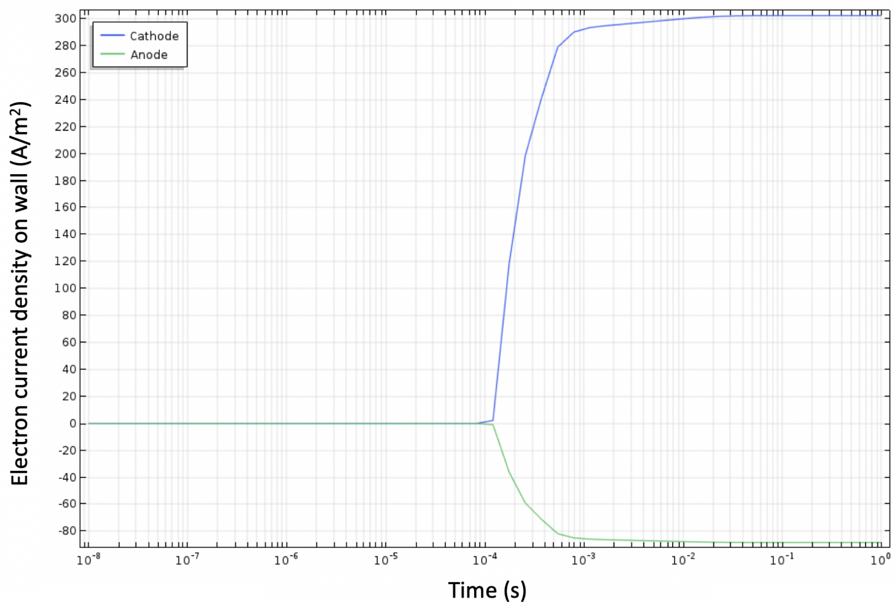
Project Synopsis:

The purpose of this project is to study plasma discharge conditions that can lead to the production of different chemical species for atmospheric pressure applications, for contexts such as the biomedical or space fields. Corona discharges are very useful for creating non-equilibrium chemical reactions because these discharges are stable and easy to use in a wide array of gases and pressures. Specifically, we will be working with DC (Direct Current) corona discharge at atmospheric pressure, while also investigating these conditions with or without a magnetic field, as magnetized corona discharge is not yet a well-documented study. We will investigate such conditions using both the tabletop corona discharge setup and a computer simulated physics environment, in an application called COMSOL, then compare results.

Plasma discharges can produce a wide variety of radiation types and particle species, such as UV radiation, negatively charged electrons, and positive or negative ions. In turn, these plasma conditions can lead to the production of chemical species. Studying the array of different discharge compositions based on varying discharge parameters can be very useful as many of these different species can be applied in a wide range of scientific disciplines and contexts. In the case of a biomedical context, non-equilibrium atmospheric pressure plasma (NEAPP) is a cost-effective and non-destructive approach to sterilization (e.g. bacterial contamination) and has much potential in the realm of wound therapy and cancer treatment [1]. Ions created by corona discharge can also be used for gas diagnostics, such as detecting and measuring gas contaminants; this is very useful in situations for which such contamination is a concern--like spacecraft [2]. The model we intend to create will help significantly in experimental progress. It will assist in being able to describe the chemical reactions taking place, easily change the parameters of the experiment, and compare the varying parameters and observe their relations. The COMSOL software suite has all the necessary functions and capabilities to create such a model.



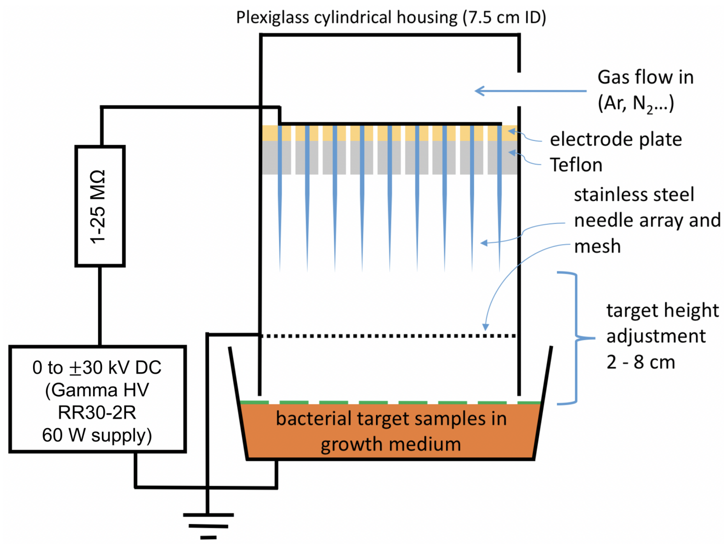
The cross-section of a coaxial configuration of an atmospheric pressure corona discharge model is shown in Fig. 1. The purpose of this model is to simulate the ionization of the neutral gas at atmospheric pressure (Argon [Ar] in this simulation) as well as the movement of the energized particles (Ar+ and electrons) when the negative electric potential is applied to the inner conductor with the outer perimeter being grounded. As the negative voltage is applied to the cathode, the electrons are accelerated towards the anode, leaving behind a dense collection of positively charged gas near the cathode. While the negative potential increases, the ions collide at a greater rate causing them to create even more electrons, which in turn increases the current and generates a positive feedback loop. In order to prevent this positive feedback loop from continuing indefinitely, once the ion current becomes notably large an RC circuit is put in series with the system to reduce the cathode negative potential, such that an equilibrium is reached with generated charged particles. After running the simulation, we can analyze the output (Fig. 2). Figure 2 is a graph of the electron current density on the electrodes vs time which is showing the initiation of breakdown of neutral Ar and the growth of discharge current until saturation is achieved.



This model allows us to describe much of the phenomena with plasma chemistry. We can create collision and surface reactions with many different predefined neutral gases in COMSOL such as: helium, neon, krypton, etc. Additionally, after the simulation we will be able to study what chemistry results from the given plasma and neutral gas concentrations. This shows that COMSOL has the potential to build an accurate and efficient model of the pre-built apparatus.

Project Description:

This project will be investigated and compared in two significant ways: experimentally and computationally. In COMSOL I will focus on a 2D study of a discharge between a single high-voltage needle tip and a grounded electrode, with the results being able to be extended into 3D by assuming azimuthal symmetry. After completing the model and simulation I would then move onto adding multiple needle tips, variable flow rate and composition of discharge gases (e.g. argon, air, helium). Air is useful for the relevant plasma chemistry such as reactive oxygen and nitrogen species (RONS) generation, and helium can be used in certain clinical applications like tooth bleaching [1]. In both cases of the experiment I will study the various plasma species and their properties that will be created from changing the parameters of the experiment. These include the change in discharge voltage and current and the spacing between the needle, the ground electrode, and the magnetic field, which will be horizontal with respect to the vertical orientation of the needle(s) and electric field. With our base apparatus already built (Fig. 3), all we need to do is add additional magnets with modifiable positions outside of the chamber to create the magnetic field (which expands on the work being done in our lab by current Space Grant fellow Matthew Isada). This magnetic field may cause a change in the corona discharge's temperature and plasma electron density, which will allow us to study even more varied chemical species created by such reactions. Considering we will be analyzing a wide array of boundary conditions and results thereof, we will use LabVIEW - software created for data acquisition, instrument control, and test automation - to control and monitor the experimental variables and output the data and measurements. Integrated with LabVIEW is an interface for OceanView, a spectrometer software package that will help us view the spectroscopic emission lines of the various plasma discharge species that will be produced. We will also use our Kron Chronos 1.4 high speed camera to capture any change in the morphology of the plasma discharge to be correlated with the time evolution of the spectroscopic data. After numerous experiments and tests with the 2D and 3D study I would then proceed to build a Computer-Aided Design (CAD) model of the experimental apparatus using SolidWorks, importing it into COMSOL and simulating it with various parameters in plasma discharge conditions. Ultimately, the combined experimental/computational effort will give us better insight into the DC corona plasma discharge conditions that lead to the generation of particular chemical species for the wide range of applications mentioned.



Project Timeline:
-*May 2020*: 2D COMSOL model should be finished, start comparing results with the experiment.
-*June 2020*: Start experimenting with the magnetic field and create a 3D axi-symmetric model to coincide with it. Prepare apparatus for upgrade with mass flow controller for gas composition adjustment.) Install high sensitivity ammeter for experimental discharge current measurements.
-*July 2020*: Expand COMSOL model to include gas composition and flow variables; compare to experiment. Submit abstract to American Physical Society Division of Plasma Physics.
-*August 2020*: Correlate plasma spectroscopic and high speed imaging results with COMSOL output to draw conclusions about magnetized DC corona discharge conditions and resulting plasma chemistry.

Project Budget:
-*High voltage probe*: $250 Fluke model 80k-40 (amazon.com)
-*Current meter*: $895 Keithley model 2100 multimeter (Bell Electronics NW).
-*Mass flow controller*: $1176 Omega model FMA5528A (omega.com)

References:

[1] G. Y. Park, S. J. Park, M. Y. Choi, I. G. Koo, et al. “Atmospheric-pressure plasma sources for biomedical applications” *Plasma Sources Science and Technology*, **21**(4), 043001. https://doi.org/10.1088/0963-0252/21/4/043001

[2] M. Goldman, A. Goldman and R. S. Sigmond “The corona discharge, its properties and specific uses”, *Pure & Appl. Chem* **57**, 1353-1362 (1985)