Investigation on dielectric barrier discharge actuator to control airflow boundary layer

Mohammadreza Ghazanchaei*, Kazimierz Adamiak, G. S. Peter Castle
Dept. of Chemical Engineering
University of Western Ontario
e-mail: mghazanc@uwo.ca*

***Abstract*— When a high voltage is applied between two electrodes, ions are produced in air and they drift from the discharge electrode to the collecting one under the Coulomb forces. These ions exchange momentum with air molecules and induce a fluid motion, called electrohydrodynamic flow (EHD). It has been proven that the glow discharge at atmospheric pressure using a dielectric barrier discharge can induce fluid flow and operate as an actuator for flow control. The plasma jet generated by a DBD actuator is able to alter the velocity inside the boundary layer and can modify the interaction between fluid and body surface without any mechanical moving parts. Such EHD phenomenon directly converts electric energy into kinetic energy with very small response time compared to the characteristic times of the fluid dynamics. There are many articles with a wide review on AC surface DBD actuators applied to airflow control. The idea of using weakly ionized gas formed at the surface of a dielectric material for producing a wall jet close to the surface of an insulator has been demonstrated by few research groups and both electrical and mechanical characteristics of surface DBD were investigated. However, because of its complicated physics, most of the investigations on DBD actuators are experimental. In the experiments it is revealed that the structure of the plasma is not exactly the same during both half cycles, and at points close to the exposed electrode negative corona discharge induces higher velocities as compared with the positive corona. Despite of this fact in the active region the experiment shows the same behavior during both positive and negative half cycles with very small fluctuation around a mean value. Several authors tried to model the whole process taking into account the chemistry of discharges in various gases. It has been shown that for a sinusoidal voltage, the discharge current consists of short pulses with large amplitude along with a low frequency current discharge of the corona type. However, the contribution of the low frequency current to the total force may be predominant in comparison with the pulse contribution because the force induced during the corona phases acts over a much larger volume and for a longer time. Although they could model the whole process, they had to increase the level of frequency up to 100 kHz in order to control the number of pulses happening during a half period of voltage. In most of existing experiments the working frequency for DBD actuators is between a few hundred hertz to a few kilo hertz. Therefore, such an approach can be useful for detailed study of some physical processes, but not as a design or optimization tool in engineering applications. Other simplified numerical studies over the DBD are not that accurate since in many of those studies the mathematical equations based on the experimental knowledge have been developed to include the net body**

force. The authors interested in engineering applications of DBD often ignore the processes in the ionization layer, what is justified due to its small thickness, generally in the order of the corona electrode radius of curvature. Besides, it must be noted that the ionic wind in the active region is mainly caused by ions drift and the electrons have negligible effect due to their small mass compared to the ion mass. Thus, in this study, first we numerically simulate DBD assuming a 2D model in order to study the ability of the discharge to actively modify low-velocity airflow along a flat plate. The investigated model involves mutual interaction between the electric field, space charge density and gas flow. A single species model including positive and negative ions has been developed in this study for AC input voltage. Since the ionic wind in this case is mainly caused by ions, the effect of the electrons in the model has been ignored. The DBD system consists of two electrodes one ! placed on the insulating surface of the plate and exposed to high voltage and the other one buried inside the dielectric material and grounded. In this configuration, the ionic wind may be able to accelerate the tangential airflow very close to the wall. In order to improve our understanding of the physical mechanisms associated with the system, velocity profiles within the boundary layer of the flat plate are presented for a free air stream velocity up to a few meters per second. The parametric study has been conducted in order to observe the effect of voltage and frequency level and geometry of the DBD on the system performance has been discussed. Effect of DBD on the mechanical drag is also studied. The results show that the EHD actuator causes drag reduction. This study could help researchers in optimization of the actuator.