Study of the changes in the flow around a cylinder caused by electroconvection

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Abstract. In this work we analyze the d.c. corona discharge between a wire-plate electrode configuration placed on the surface of an insulating cylinder. The influence of different parameters are analysed in order to characterize the discharge and to determine the best configuration to study the possibility of drag reduction of the flow acting in immersed bodies. A generalized glow regime seems the most suitable to undertake studies with this goal.

1. Introduction

The research on corona discharge when the electrodes that enabled the discharge are far away from any extraneous body has been analysed extensively. However, the knowledge of the physics of corona discharge occurring in a fluid close to an insulating surface is of interest in different engineering applications. In the mechanical engineering domain, the effect of the corona discharge on the fluid mechanics close to a limiting solid surface appears as a promising technique for flow and instabilities control. The ions injected on a fluid flow and subjected to coulombian forces will migrate from one electrode to the other exchanging momentum with the fluid particles modifying the fluid velocity field in the vecinity of the surface. Prior research work has analysed the effects of this forced electroconvection on the main flow like the one occurying on an electrostatic precipitator and other flow types like the wake downstream a cylinder with a point-to-plane electrode arrangement [1], boundary layers on flat plates with razor blade electrodes [2] and Poiseuille flows [3]. These researches show that the secondary flow caused by the exchange of momentum between injected ions and fluid particles can modify the main flow and thus it can be used as a control parameter. In view of applications leading to a drag reduction of immersed bodies some of the authors cited above have indicated a lack of knowledge of the physics of a corona discharge near an insulating surface, a problem that becomes essential to achieve optimal devices. It seems possible that in this special configuration the new surface will modify some aspects of the discharge close to the electrodes or cause the appearance of new phenomena close to the insulating surface.

Though no general theory is proposed here, it is one of the objectives of this article to report a characterization of a corona discharge occurrying close to the surface of an electrical insulating cylinder. From this we will also try to establish the conditions when forced electroconvection around a cylinder should lead to more dramatic effects.

2. Experimental study

In our study the injection of ions is obtained by a d.c. corona discharge between a wire type electrode (275 mm length) and a plane electrode of aluminum foil (25x275mm), both located on the surface of a Plexiglas cylinder and parallel to the cylinder axis. Our experimental device has been placed in a wind tunnel (0-20 m/s, 0.45 x 0.45 m rectangular cross section) with the cylinder axis normal to the main flow and horizontally placed (see figure 1). Two different H.V. sources (0-30kV,-8kV-0V) enabled to impose voltage differences between both electrodes. A current-voltage amplifier circuit using an electrometer operational amplifier with very low input bias current was used to measure the discharge passing through the electrodes. With this device we have studied the influence on the corona discharge of different parameters (voltage, diameter of the cylinder (30-40-50 mm), diameter of the wire, air velocity (0-20 m/s)). In our experiments one of the electrodes was kept at constant potential -8kV and we increased the voltage of the other between a range of 0-30kV. By doing that, the influence of any surrounding grounded object was avoided and different discharge regimes could be observed. Typical voltage-current curves are shown in figures 2 and 3 for different cylinder and wire diameters. We have tested two different arrangements: wire positive-plate negative opposed at 180 degrees (positive corona) and wire negative-plate positive opposed at 180 degrees (negative corona). These figures show that the current depends not only on electrode spacement but on electrode radius and on polarity. For large voltage difference current is higher in positive coronas and for larger radii. As electrode voltage is increased different regimes can be observed :

Spot type: (figure 4) The discharge is concentrated in some visible spots of the wire and by increasing the voltage difference they can increase in number. Some of them may ionize in a plume like type or may lead to a channel quite attached to the cylinder surface. In positive corona the border of the plate can also show a luminescence, and the discharge is noisy, while in negative coronas the luminescence is not observed and the discharge is more quiet.

Generalized glow: (figure 5) At higher voltage differences, for wires with the larger diameters the spots occupy almost all the wire. Then, a regime characterized by a luminescence similar to the one appearing in a glow discharge occurs, occupying the whole arc distance between both electrodes . This discharge is quite homogeneous and it extends almost all along the electrode length, and when it occurs the cylinder surface looks like supporting a thin film of ionized air. For highly intense discharge this film is simmetric from the wire and the glow does not move along it. The phenomena is noisy and the current quite stable with time. In the voltage current curves this regime appears as a large increase in the slope of the curve (see in figure 2 results close to 21 kV for configuration cylinder diam. 30 mm and wire diam. 0.9mm). The glow is more difficult to be achieved with negative coronas where the discharge is similar to the so called pulseless corona of the point-to-plane arrangement. For the larger cylinder diameters (40-50mm) it was not possible to obtain this discharge when the electrodes were opposed at 180 degrees, however when placing them on these cylinders at arc distances similar to the one of the smaller cylinder (30 mm diam.) this regime appeared once again.

Streamer type: (figure 6) This regime occurs preceded of the generalized glow regime or directly from spot type regime. It can be characterized by some points of the wire with a concentrated discharge in an arborescent shape or in filament type. In them the discharge seems to be concentrated to a small channel. This filaments could achieve the whole arc distance in the positive corona case, while in the negative corona case they can interrupt between both electrodes. By further increasing the voltage some localized sparks with sharp noises appeared and then tests were stopped.

The influence of the surrounding air velocity on the discharge corona depends on the regime considered. As air velocity was increased (0-20m/s) in the spot or streamer regime it could be observed that the number of points increases, while in the glow discharge regime it extended the lenght of the wire supporting a visible discharge. No degradation of the polymer's surface could be observed after our series of experiments.

3. Analysis of results

The generalized glow discharge regime cited above can only be explained by an electric field configuration that enables the ionization all along the arc distance. In order to have a first approach of this we have solved Laplace's equation for the electrical potential in air in a two dimensional domain neglecting the effect of the space charge. The boundary conditions considered on the electrical potential function are: a linear dependence with angular coordinate of the potential function on the cylinder surface having extreme values at the electrodes (similar to the one used in [2]), and null value at a very large radius R_∞ for any value of angular coordinate. To simplify the analysis both electrodes have been considered of the wire type. The solution of the problem can be considered as a superposition of two solutions: one corresponds to an electrode configuration $\Phi = \pm V_1$ and the other to a constant potential cylinder at $\Phi = V_2$. The potential function Φ obtained is

$$\Phi = \frac{4V_1}{\pi^2} \sum_{n=1}^{\infty} \left(\frac{a}{r}\right)^n \frac{(-1)^n - 1}{n^2} \cos(n\theta) + V_2 \frac{\ln(r/R_\infty)}{\ln(a/R_\infty)}$$

with a the cylinder radius, r and θ the radial and angular co-ordinate. From this equation the electric field E can be easily obtained as $E = -\nabla\Phi$ and figure 7 gives an image of the electric field prior to ion injection or when the space charge is very low. In this figure we can see that the electric field is very large in regions close to the surface in coincidence with the expressed above.

3.1. Effects of the discharge on the Flow Field configuration

We have undertaken a visualization of the flow field configuration with smoke injection when the wire was placed on the frontal stagnation point. Though this technique may induce to some errors due to the possibility of charging of the smoke particles it can be considered as a first approach to compare the spot or streamer regime with the generalized glow regime. From our results, like from those in [1], it is observed that the wake is largely modified and that vortex streets can be modified and controlled by electroconvection. In the spot or streamer regime, and under certain conditions, new instabilities can be observed, of the Kelvin-Helmholtz type, which do not occur in a cylinder without electroconvection or in the configuration of [1]. An analysis of the characteristics of this instability due to the shear flow could enable an indirect estimation of the velocity of the secondary flow. In the generalized glow regime the effects are much more dramatic and the filaments of the smoke tracers are perturbed in almost the whole section of the wind tunnel downstream the cylinder. The effect of the dc corona discharge in this regime are important not only because of its intensity but also because the homogeneity of the discharge occurring all along the wire that leads to a two-dimensional flow field configuration. Thus the main flow presents very distinctive characteristics given that, as it attacks the solid body it finds a slip condition.

4. Conclusions

This work shows that it is possible to obtain an homogeneous discharge ionizing the air in the whole distance between electrodes of the wire-plate type placed on the surface of an insulating cylinder. This kind of discharge occurs in a very thin region and the effect of an air flow on the range of velocities tested was to homogeneize the discharge. Flow visualization by smoke injection indicates that the generalized glow leads to the more dramatic effects in the wake downstream the cylinder. As a result, this regime seems to be the more convenient to study the control by electric forces of the drag of an air flow on immersed bodies.[1]

References

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[2] S. El-Khabiry, G. Colver 1997 *Physics of fluids* **9(3)** 587-599

[3] M. Malik et al 1983 *AIAA 21st Aerospace Sci. Meeting, Reno Nevada* AIAA-83-0231

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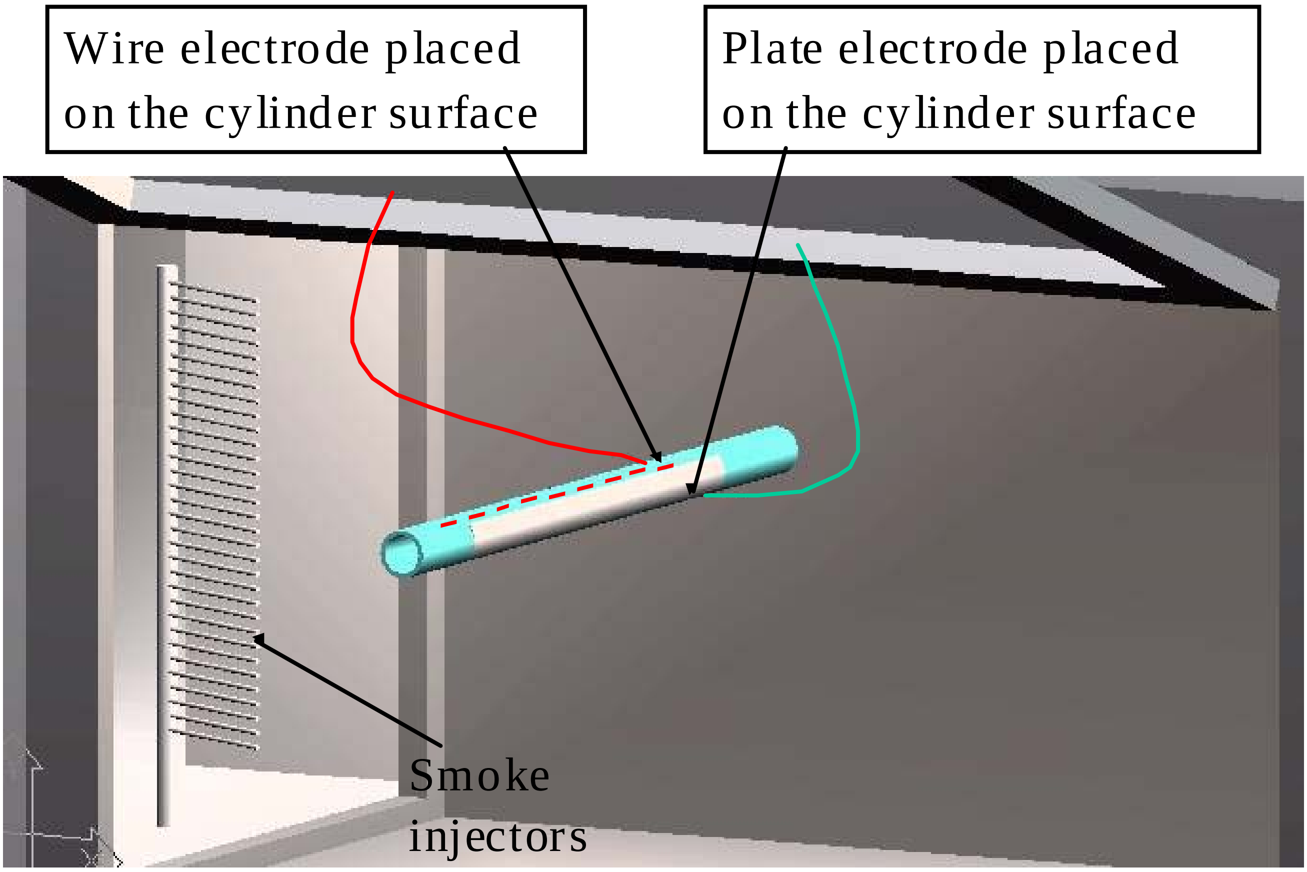

Figure 1: Experimental device: Cylinder placed on a wind tunnel (section 450x450mm)

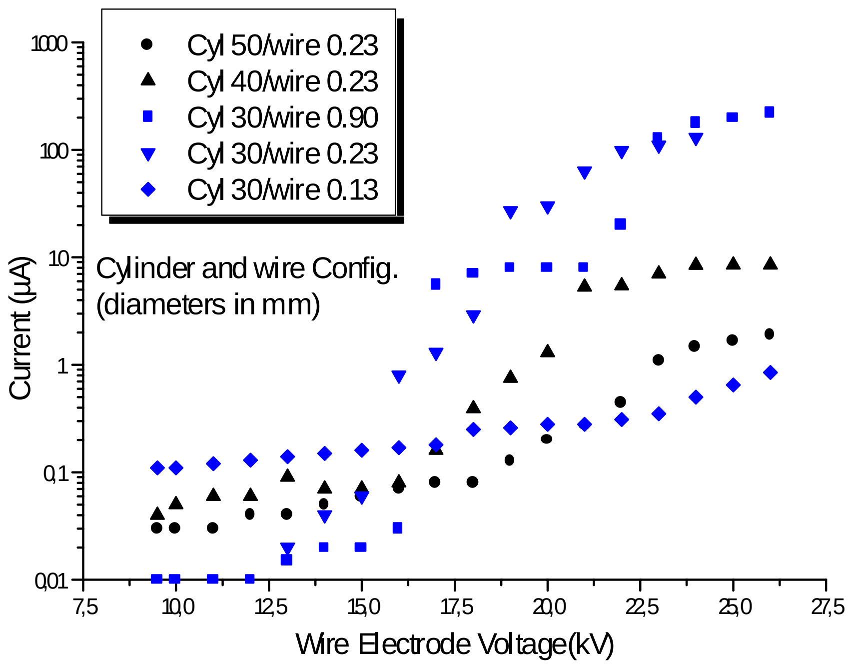

Figure 2:Positive corona- I(V)

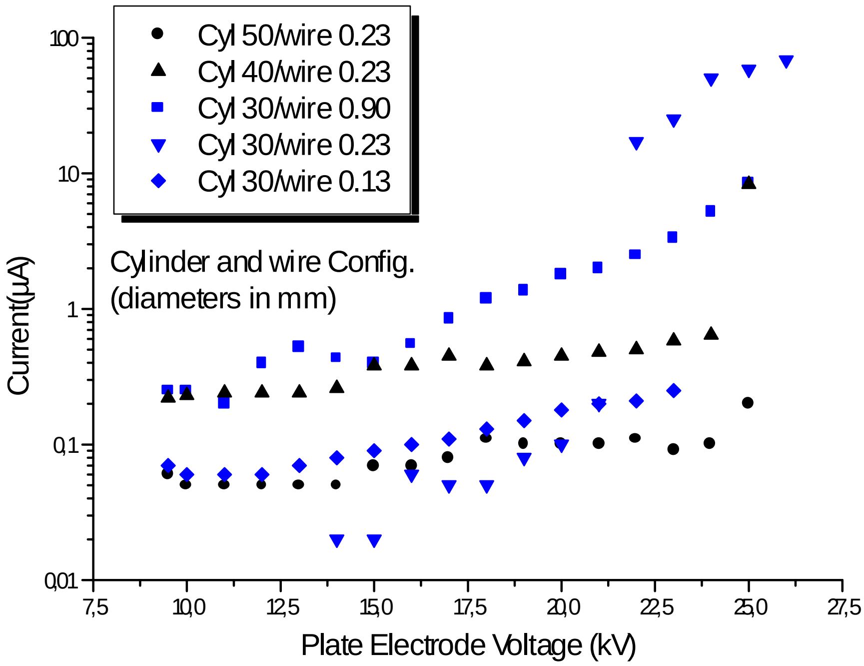

Figure 3:Negative corona-I(V)

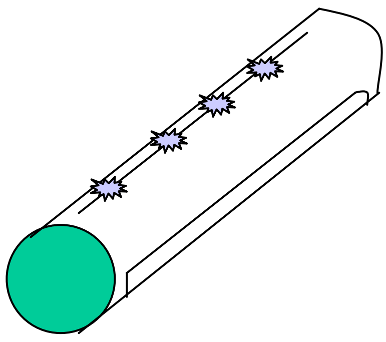

Figure 4: Spot type discharge

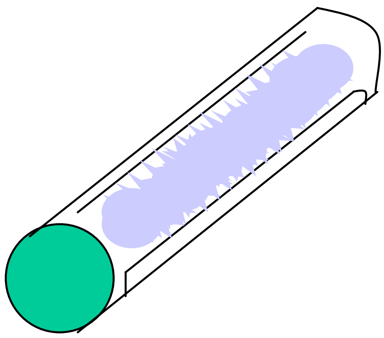

Figure 5: Generalized glow discharge

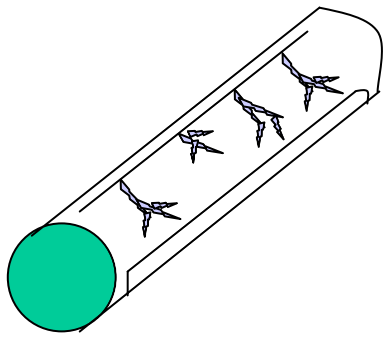

Figure 6: Streamer type discharge

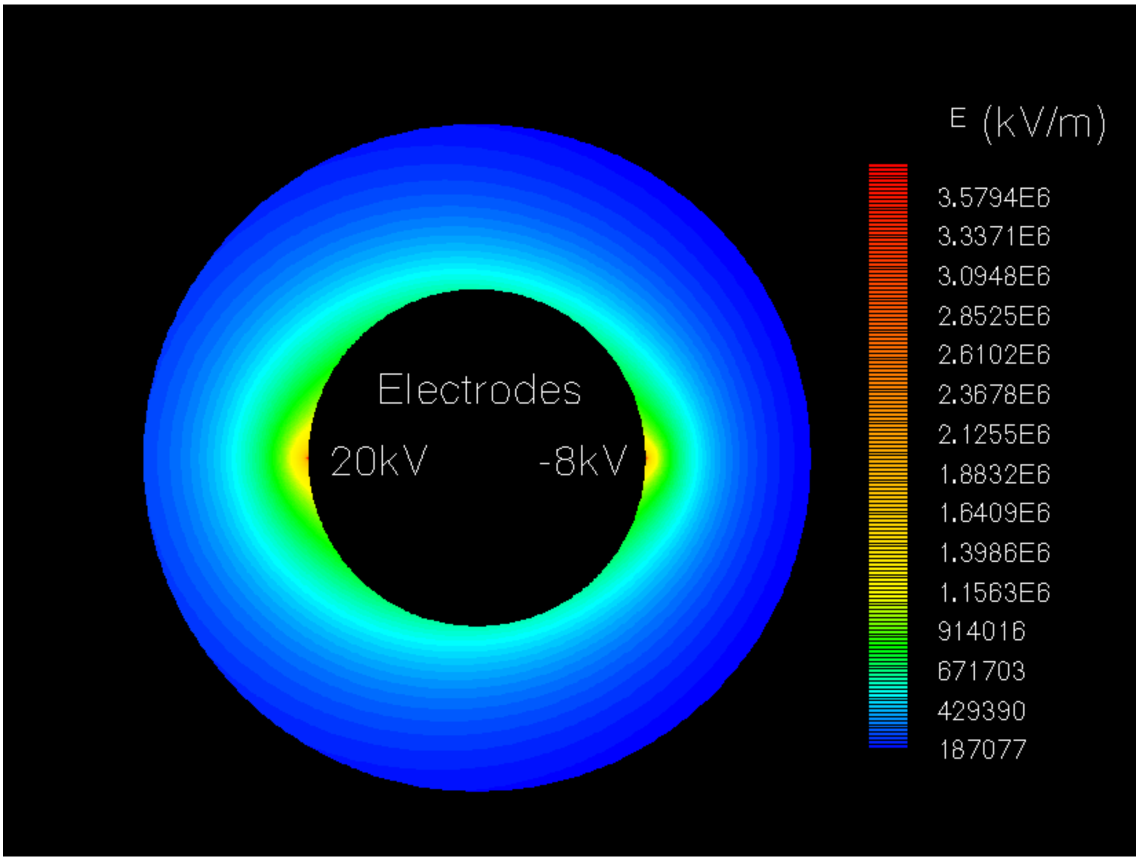

Figure 7: Electric field configuration for a cylinder with a 30 mm diameter