Charging of mm-sized spheres on top of a surface dielectric barrier discharge

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Abstract: In this paper, we investigated the charging of mm-sized spherical particles by low-temperature atmospheric pressure plasma. The interaction of spheres from different materials and of different sizes with a plasma generated by a dielectric coplanar surface barrier discharge (DCSBD) at different inclination angles has been investigated. It could be shown that the acceleration of spheres is reduced due to plasma treatment, which may indicate the charging of the spheres and their interaction with the plasma environment.

Keywords: plasma, dielectric coplanar surface barrier discharge, charging of particles.

1. Introduction

One of the recent directions of research in the field of plasma physics is the study of the interaction of solid materials and powders with low-temperature atmospheric-pressure plasmas for technological application. Low-temperature plasmas are widely used in plasma medicine, for destroying cancer cells [1], agro-industry [2], for disinfecting water and residual gases, for treating the surface of various materials and in nanotechnology [3]. Compared to the plasma of low-pressure gas discharges (e.g. dc- or-rf glow discharge), the region of free charge carriers (electrons and ions) in the case of atmospheric gas discharges is very limited due to the high gas density. Hence, the investigation of surface charging of substrates (particles) by atmospheric pressure plasma is a very interesting task. In the absence of electron emission from the particle surface, it is negatively charged due to the lower mobility of positive ions and resembles an electric probe at floating potential, since the electron and ion fluxes are balanced. Therefore, common probe theories in this case are widely used to estimate the particle charge [4]. Often the simplest model of the orbital motion limit theory [5, 6] is mostly used. However, in the present case the use of the OML theory may not be justified due to the weakening of the orbital motion of ions at low ion temperatures, as well as due to an increase in gas pressure resulting in short lifetimes of charge carriers [7].

In this study the charging and interaction of mm-sized spheres in a dielectric coplanar surface barrier discharge plasma has been investigated. In particular, an experimental comparison of the motion of particles of different sizes and made of different materials on the surface of the DCSBD with and without an ignited plasma was studied.

2. Experimental setup

The effect of a surface dielectric barrier discharge at atmospheric pressure on the spheres is investigated using the DCSBD RPS400 (ROPLASS, CZ) setup. The electrode system of the DCSBD is arranged as follows: two systems of parallel tape electrodes (width 1.6 mm, thickness 0.3 mm, length 210 mm) made of silver were built into 96% alumina. The thickness of the ceramic layer between the surface and the electrodes was 0.4 mm. The distance between the electrodes is 1 mm.

The trajectories of the rolling spheres were recorded using a high-speed MotionProY4 camera. The position of the spheres was tracked using the Motion Studio software supplied by the manufacturer. Afterwards the accelerations were calculated utilizing the high temporal and spatial resolution of the particle positions.

Three types of spheres were used in the experiments: stainless steel, zirconium (IV) oxide spheres (ZrO_2) and plastic spheres made of polyoxymethylene (POM). The diameters of the spheres were 2 mm and 5 mm, respectively.

3. Conducting experiments

Investigation of the interaction of spherical substrates (as a model systems for seeds) with the plasma of the DCSBD was carried out by rolling the spheres of different materials and different diameters over the surface of the DCSBD at different angles of inclination from 5 degrees to 20 degrees in steps of 5 degrees with and without ignited plasma. Thus, it is possible to draw conclusions regarding the interaction of the spheres with the plasma of the DCSBD by comparing the behavior and trajectories of them when the plasma is ignited or switched off. Furthermore, the acceleration of the spheres without plasma was calculated by the mechanics of an inclined plane:

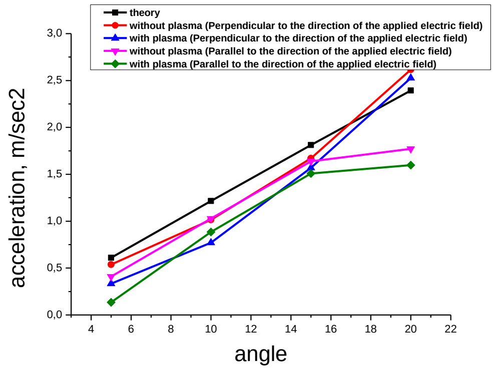
$$a = g\frac{\sin \propto}{1+\frac{I}{m\,R^2}},$$

where α is the angle of inclination, m is the mass of the sphere, R is the radius of the sphere, and I is the moment of inertia.

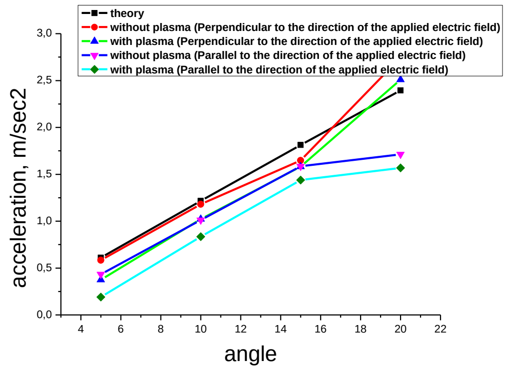
To obtain more accurate data, experiments were repeated 10 times for each angle of inclination. In addition, studies were carried out when rolling spheres in two different directions: 1) the spheres rolled along the y-component (the long side of the surface of the DCSBD), perpendicular to the direction of the applied electric field; 2) the spheres rolled along the y-component (the short side of the surface of the DCSBD), parallel to the direction of the applied electric field. A number of experiments were also carried out to investigate the interaction of spheres with the surface of the DCSBD, heated to 60°C which corresponds to the surface temperature when the plasma is ignited. These measurements were done to check for a thermal effect influencing the spheres.

4. Results and discussion

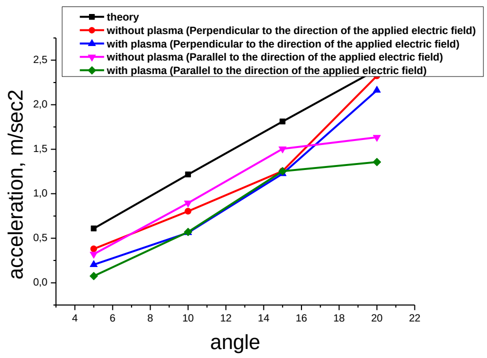
According to the data obtained by recording trajectories of rolling spheres by a high-speed camera, accelerations of the spheres were calculated. The results are shown in figure 1.



a)



b)



c)

Fig. 1. Dependence of the acceleration of particles along the surface of the DCSBD on the angle of inclination (a - results for ceramic spheres, b - for stainless steel spheres, c - for plastic spheres).

The acceleration of the spheres when the plasma is turned on is less than without plasma operation, which indicates the inhibitory nature of the plasma. This effect could also be explained by the presence of a high surface temperature during DCSBD operation (about 60°C). To exclude the thermal effect a number of experiments (not shown in figure 1)were carried out in which the spheres rolled along the surface heated to 60°C but without plasma. The results of these experiments agreed with the values of the acceleration of the spheres without plasma and a cold surface. Thus, a thermal effect can be neglected.

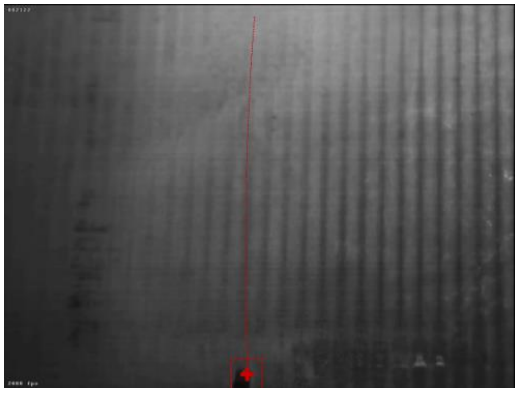


Fig. 2. The trajectory of the sphere rolling along the surface during plasma ignition (white lines - electrodes, black lines – distance between electrodes).

When a ball enters the plasma, the observed force pulls the When a sphere enters the plasma layer, the observed force pulls the sphere to the center of the plasma channel. After repulsion to one side, the sphere again moves to the center of the channel (Fig. 2), which may indicates an electrical interaction mechanism (electrostatic force) rather than a purely mechanical process.

Also during the experiments, it was observed that the sphere did not immediately penetrate into the plasma channel. This was observed in the case of experiments with a plastic sphere with a thickness of 2 mm at 5 degree angle of inclination of surface of DCSBD. If the sphere is between the ignited plasma channels, it experiences a repulsive force that pushes the sphere away from the plasma, bringing it back to the point of descent.

5. Conclusion

The acceleration of mm-sized spheres during plasma treatment in a DCSBD is decreased compared to the non-plasma case, which may indicate the inhibitory nature of the plasma. This may be due to the fact that the density of charged species above the surface of a burning DCSBD is interacting with the charged rolling spheres compared to the case of neutral air.

The acceleration of the spheres in the case when the direction of movement of the spheres was perpendicular to the electric field is greater than in the case when the direction of movement of the spheres coincides with the parallel direction of the electric field. This may be due to the fact that in the second case, the currents arising in the plasma, can inform the transfer of momentum in the direction of rolling spheres.

Acknowledgments

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6. References

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