Acta Agrophysica, 2002, 80, 55-61

EXPERIMENTAL INVESTIGATION OF A MAGNETICALLY GLIDING DISCHARGE

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Abstract. The aim of our work is to investigate a gliding discharge type reactor used for polymer treatment in which the plasma string runs between diverging electrodes. Starting in the point where the inter-electrode distance is minimal, the discharge moves along the electrodes in a channel formed by two dielectric plates spaced between 0.5 mm and 1 mm. The motion of the discharge is caused by a magnetic field of 20 mT to 140 mT that is directed perpendicularly to both the dielectric plates and the discharge current. The discharge is struck in air at pressures between 10 kPa and 100 kPa. A discharge visualisation study reveals that for these conditions the discharge is very stable. The discharge velocity and the time of discharge running in ignition-lengthening-extinction cycle are determined as a function of discharge current, magnetic field and pressure. The temperature of the gas is measured with a thermocouple inserted between the electrodes.

Keywords: gliding discharge, non-thermal plasma, non-equilibrium plasma, plasma reactor.

INTRODUCTION

In gliding discharge reactors non-equilibrium plasmas are produced that are used in technical applications in which interactions occur between the discharge and a gaseous or solid phase. These plasmas typically operate at high electrical fields and low electron densities. They offer a high selectivity and efficiency in chemical processes, but operate at limited power levels and are difficult to stabilise at high pressures.

Most often the gliding motion of the discharge is caused by a gas flow injected at the narrowest electrode gap [1-3]. In this case, the driving force acts on the discharge centre and the roots of the discharge remain attached to the electrodes while the discharge is lengthening. In this case a turbulent plasma flow is obtained. Another possibility to drive a gliding discharge is by applying a magnetic field perpendicular to the discharge current [4,5]. Then, the force acts uniformly on the entire discharge channel and its motion is very regular and easy to control.

The aim of this work is a better understanding of magnetically gliding discharges used for polymer treatment. We study behaviour of the DC gliding discharge experimentally using electrical and optical methods. Particularly, we determine velocity of discharge motion, time of discharge running in ignition-lengthening-extinction cycle and temperature of air in discharge channel.

EXPERIMENTAL SETUP

A scheme of the experimental setup is shown in Fig. 1. The gliding discharge reactor consists of two copper electrodes with a thickness of 1 mm. The electrodes form a nozzle with a smallest gap of 3 mm and a largest of 20 mm. The length of the channel is 80 mm. The electrodes are sandwiched between two glass plates, isolating the volume between the electrodes. Therefore, this area is visible and enables observation of the gliding discharge expansion. A DC magnet generates a magnetic field *B* that can be varied between 50 and 200 mT and is perpendicular to the plane of the electrodes. The discharge is powered with a current-regulated *I* high voltage source (8 kV/40 mA) obtained from 220 V/380 V three-phase-50 Hz voltage by a high-voltage transformer with a diode's rectifier and RL filter. The reactor is mounted in a vacuum chamber allowing measurements at reduced gas pressures and in different gas mixtures. The reported measurements are performed in air with the gas pressure *p* varying between 10 and 60 kPa.

A voltage divider, connected to a digital oscilloscope, is used to record the voltage across the electrodes during the discharge motion. This motion is recorded with a CCD video camera with an adjustable exposure rate between 0.1 ms and 20 ms. To eliminate the contribution of the cathode fall, the electrical field in the positive column of the discharge is derived from voltage measurements at different inter-electrode distances. The temperature of the gas is measured with a thermocouple inserted between the electrodes.

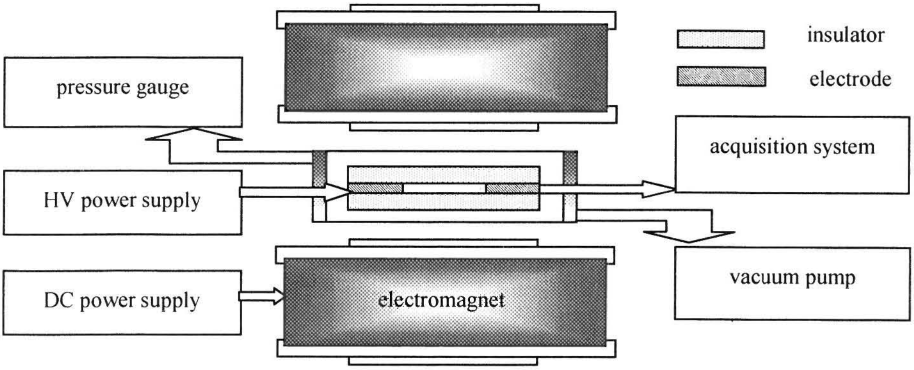
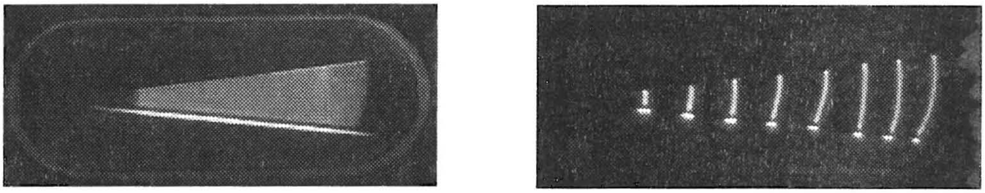


Fig. 1. Experimental setup.

GLIDING DISCHARGE BEHAVIOUR

When high voltage is applied to the electrodes, the strong electric field creates a discharge at the narrowest gap between the electrodes. Then, due to the effect of the Lorentz force produced by discharge current and external magnetic field, the plasma string is swept through the inter-electrode volume (Fig. 2). Because the discharge resistance increases at quasi-constant current, the arc voltage progressively increases until it attains the breakdown voltage of the narrowest gap and a new discharge appears, short-circuiting the first discharge that extinguishes. The voltage decreases very quickly corresponding to short discharge (Fig. 3). Such a way, the discharge is periodically submitted to ignition-lengthening-extinction cycles and power supply is operating between a no-load voltage regime and short-circuit regime. Nevertheless, the discharge behaviour is very stable in large operating conditions such as current, pressure and magnetic field appropriate for geometrical conditions such as electrode thickness and width of an angle.



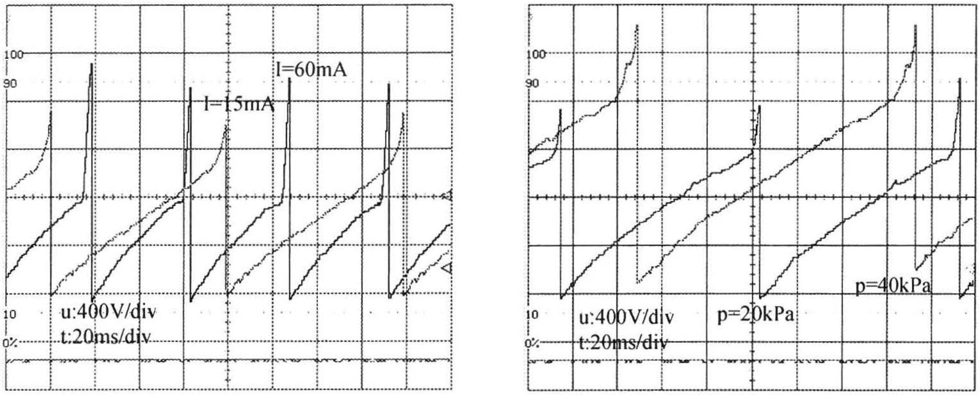
a) Exposure time: $t_{exp} = 40$ ms

b) Exposure time: $t_{exp} = 1$ ms; $\Delta t = 5$ ms

Fig. 2. View of a gliding discharge.

Figure 3 gives the voltage waveforms for two different currents (Fig. 3a) and two different pressures (Fig. 3b). The linear voltage rise corresponds with the discharge moving between the electrodes. It is interesting to notice that for gliding discharge moving by gas flow the voltage rise is exponential [3]. It seems that the forces acting on the discharge are the origin of this difference. In case of magnetically gliding discharge, the Lorentz force acts on the whole discharge whereas gas flow acts on the discharge centre.

Because for specified conditions the electric field is constant [6], the voltage rise represents the discharge length. Thus, from the nozzle dimensions and the voltage waveforms, we can determine the discharge velocity. The sudden voltage increase corresponds to the discharge extinction. Two situations are possible. The first is observed for long electrode channel and appropriate conditions when the discharge extinguishes between the electrodes. For example these cases are presented in Fig. 3 for $I = 60$ mA and $p = 20$ kPa. In the second case the discharge is reached to the end of the electrodes where the discharge roots stay attached and the length increases. It is presented in Fig. 3 for $I = 15$ mA and $p = 40$ kPa. To take these effects into account, the discharge velocity inter electrode gap and the time between re-ignition and extinction of discharge are determined as functions of current, magnetic field and pressure.



a) $p = 20$ kPa, $B = 100$ mT

b) $I = 20$ mA, $B = 100$ mT

Fig. 3. Voltage waveforms of gliding air discharge.

Two particular effects are observed and consist in attachment of discharge roots at the narrowest gap or between the electrodes, often at its ends. The first effect is observed for large current or high pressure. For these conditions the temperature of cathode root is high and important force is needed to move the discharge. This force can be obtained by large magnetic field. The second effect results, most often, from thermal conditions of dielectric plates. Especially, for slow discharge motion the conductive path is formed on dielectric plate and discharge stay in this path. This effect can also result from power supply. In order to avoid the difficulties encountered in reactor operating, the parameters of power supply, the functioning and geometrical parameters must be correlated.

DISCHARGE MOTION PARAMETERS AND TEMPERATURE

The discharge velocity is determined basing on linear part of voltage waveform and a dimensions of reactor. Similar results are obtained using a photodiode signals [5]. In Fig. 4 the velocity is plotted as current function for different pressures, and a nearly linear relationship is fund. The relationship between discharge velocity and magnetic field is linear too (Fig. 5). It is not surprising because the Lorentz force acting on the discharge is proportional to I×B. On the other hand, the temperature rises with current, having an effect on physical discharge properties. However, this effect seems to have slight influence on velocity. As shown in Fig. 4 the velocity decreases with increasing pressure. It can be explained, qualitatively at least, on the basis of a simple force balance acting on the discharge. Generally, Lorentz force and gas-dynamic drag acting in the opposite direction govern discharge motion. The drag force depends strongly on viscosity, gas density and velocity and it seems to be the main reason for strong influence of pressure on discharge velocity.

The time of discharge running in ignition-lengthening-extinction cycle is a basic parameter, which determines the efficiency of a gliding reactor. This time can be easy control changing current, pressure or magnetic field (Figs. 6 and 7).

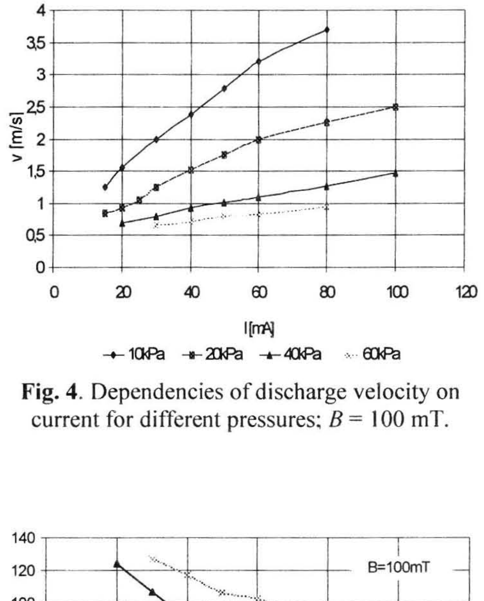


Fig. 4. Dependencies of discharge velocity on current for different pressures; $B = 100$ mT.

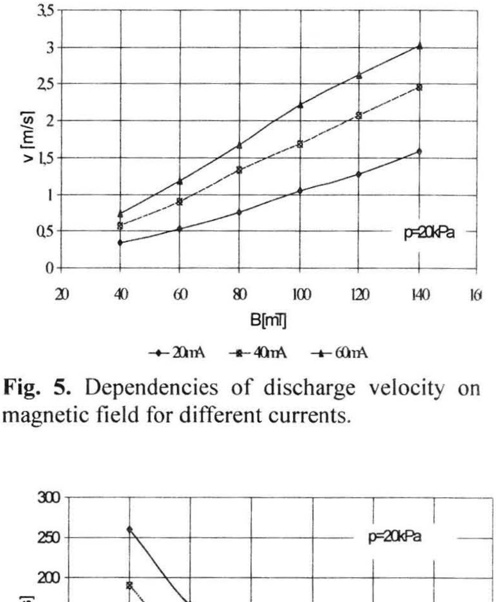


Fig. 5. Dependencies of discharge velocity on magnetic field for different currents.

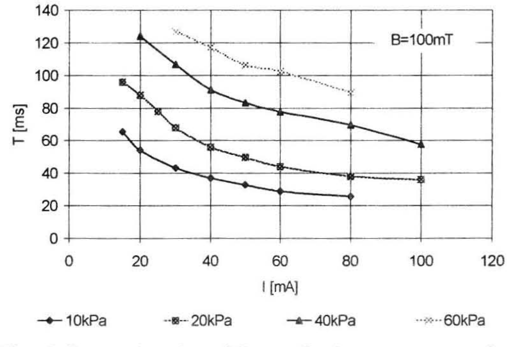


Fig. 6. Dependencies of the cycle time on current for different pressures.

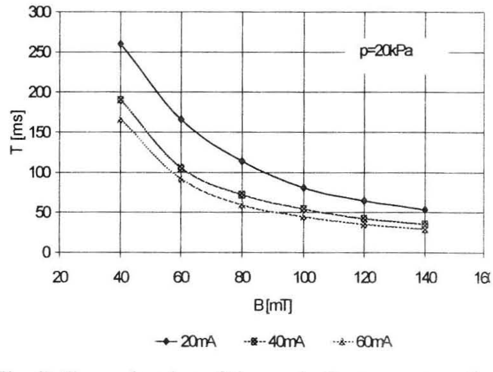


Fig. 7. Dependencies of the cycle time on magnetic field for different currents.

There is some additional remark, which should be made with the determining parameters such as discharge voltage, electric field and velocity. These parameters depend on air temperature in the channel. The steady state temperature is reached after several minutes and the experimental data measured at time differ from one another. The typical temperature rise in reactor channel is shown in Fig. 8. The time to arrive at the steady state temperature depends on discharge velocity. On the other hand, the velocity influences the heat transfer from the discharge, thus the steady state temperature. We suppose that it can explain the dependence of steady temperature on magnetic field observed experimentally.

In Fig. 9 the steady state temperature is plotted as current function, and linear relationship is found.

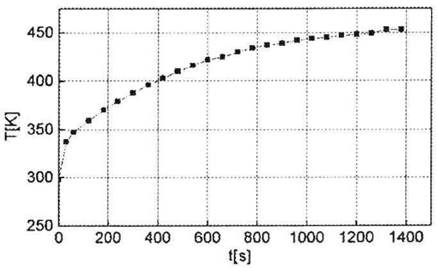


Fig. 8. Temperature rise in reactor channel; $I = 20$ mA, $p = 10$ kPa, $B = 50$ mT.

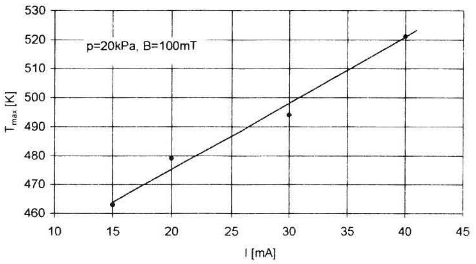


Fig. 9. Dependence of steady state temperature on discharge current.

CONCLUSIONS

A gliding discharge type reactor used for polymer treatment is investigated. The study reveals that the discharge is very stable and its motion is easy to control. The discharge velocity and the time of discharge running in ignition-lengthening-extinction cycle are determined as a function of discharge current, magnetic field and pressure. The dependence of electric parameters on temperature is discussed and the rise of this temperature is shown. The linear relationship between steady state temperature and current is found.

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BADANIA EKSPERYMENTALNE WYŁADOWANIA ŚLIZGAJĄCEGO W POLU MAGNETYCZNYM

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Streszczenie. W pracy przedstawiono wyniki badań eksperymentalnych reaktora z wyładowaniem ślizgającym stosowanego do obróbki polimerów. kanał wyładowczy formowany jest przez płaskie elektrody umieszczone miedzy płytkami dielektrycznymi o odległości od 0,5 do 1 mm. Elektromagnes prądu stałego wytwarza w obszarze wyładowania pole magnetyczne o indukcji regulowanej od 20 mT do 140 mT. Prezentowane są wyniki badań wyładowania w powietrzu o ciśnieniu od 10 kPa do 100 kPa. Natężenie pola elektrycznego oraz prędkość przemieszczania się wyładowania zależą od natężenia prądu, ciśnienia i pola magnetycznego.

Słowa kluczowe: wyładowanie ślizgające, plazma nietermiczna, plazma nierównowagowa, reaktor plazmowy.