acta phys. slov. 41 (1991), No. 5,6

THE CORONA DISCHARGE CURRENT IN FLOWING AIR[1)]

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The DC corona discharge of both polarities in flowing air (0.08-0.8 ms^{-1}) was investigated. A cylindrical discharge tube consisting of five identical and electrically separated sections was used. The discharge current in each section of the discharge tube was measured. A negligible effect of air flow on the the positive corona properties and the conspicuous increase of negative corona current at increasing flow velocity of air were observed. A new explanation of these effects is presented.

I. INTRODUCTION

It is typical for most industrial applications of the corona discharge, that ambient air is flowing through the corona device. But there have been relatively few studies of the corona discharge in flowing air. In these works mostly the point-to-plain configuration of electrodes was used. The gas flow direction was parallel or perpendicular, to the axis of the electrodes. Conflicting observations have been made with regard to the variation in the current in flow. At low speed regime Nygaard [1], Chalmers [2] and Farish and Davidson [3], [4] found an appreciable effect of flow on the discharge current within the range of flow velocity from 0 to 60 ms^{-1}. The increase of current at constant voltage was not higher than 30%. Also the relative decrease of the Trichel pulse frequency observed by Nygaard [1] was of the same value. According to the opinions of these authors the ions are blown downstream causing reduction in ion density and owing to this the mean current increases. Bortnikov at al. [5] made a comprehensive study of negative point-to-plain and coaxial cylinders corona in subsonic and supersonic flow. Also the influence of flow velocity on the breakdown voltage is reported. Three different effects were observed depending on the type of electrodes or on the

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1) Contribution presented at the 8th Symposium on Elementary Processes and Chemical Reactions in Low Temperature Plasma, STARÁ LESNÁ, May 23 - June 1, 1990

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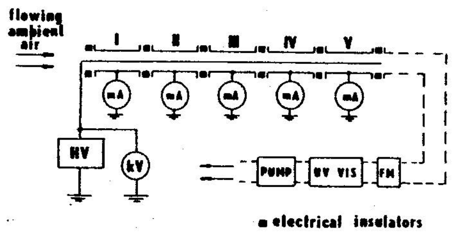

Fig. 1. Experimental apparatus.

direction of the air stream. In the case of cylindrical coaxial electrodes a conspicous increase of current at u=290ms^{-1} was registered, for all other flow velocities the current was reduced. The calculation of the electric field in the corona discharge in the presence of flow has been made by Timosin and Larionov [6].

II. EXPERIMENTAL APPARATUS

The experimental apparatus is shown in figure 1. The ambient air was driven through the discharge tube (DT), the flowmeter (FM) and the UV spectrometer (UV VIS) by the pump (PUMP). A cylindrical configuration of electrodes was used. The discharge tube consists of five identical parts. The inner electrode was for all parts every time the same, a molybdenum wire with the diameter ϕ 0.1 mm. The outer electrode of each section was a stainless cylinder with the inner diameter 15 mm and a length 0.2 m. It was constructed so that it was possible to put together a different number of discharge tube sections to enable us to measure the dependence of the ozone density in air on the discharge tube length. The discharge tube sections were connected through nylon ringlets to make possible the measurement of the discharge tube current from each section separately. The corona discharge was connected with a high voltage source TuR WPT 4,4/35-GPT 6/45 fy VEB Transformatoren und Roentgenwerk Dresden (GDR). The corona voltage was measured by a kilovoltmeter, the current from each part of the discharge tube was measured by a microampermeter. Each microampermeter was protecceted by a Zenner diode with a resistance, which are not marked on the scheme of the experimental apparatus.

The flow velocity was regulated by a valve and measured with a flowmeter. The ozone concentration in air was evaluated from the transmittance of the UV light, measured by the UV-VIS spectrometer fy SPECORD.

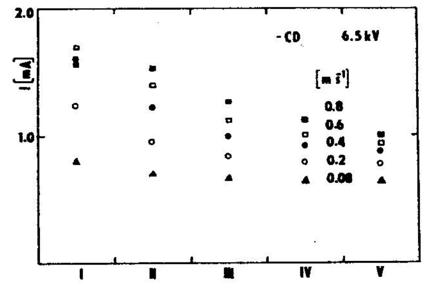

Fig. 2. Negative corona discharge current in discharge tube sections I - V at various flow velocities.

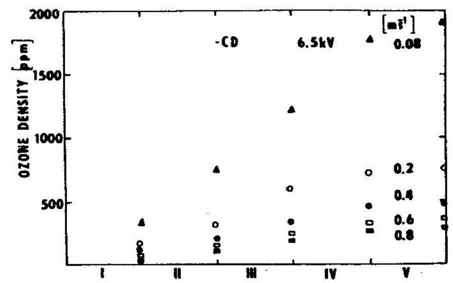

Fig. 3. The ozone density in air at the end of each section I - V for various flow velocities of negative polarity.

III. EXPERIMENTAL RESULTS

The air flow velocity within the interval 0.08-0.8 ms^{-1} has no effect on the corona onset voltage. The corona discharge was started simultaneously in all sections of the discharge tube. The value of the onset corona voltage was practically the same for both polarities and this was in good agreement with the theoretical value 4.16 kV.

The effect of air flow on the discharge current was different for the positive and the negative polarity. The ozone concentration in air is higher in the case of the negative corona discharge. The ozone concentration in air was increasing when the flow velocity was reduced for both polarities.

Negative corona discharge

The discharge current for the applied voltage 6.5 kV in each section of the discharge tube for various velocities within the range 0.08-0.8 ms^{-1} is shown in figure 2. It can be seen that the discharge current considerably depends on the flow velocity. At higher flow velocities an enhancement of current in each section was registered. The absolute values of the discharge current in each section were reduced down the stream of the air flow. The difference between the discharge current in two neighbouring sections is also decreasing with the number of the discharge tube sections.

The dependence of the ozone density in air on the discharge tube length can be seen in figure 3. The ozone concentration in air grows monotonously, nearly linearly, with the discharge tube length. As it was said above the smaller velocities are more effective for the ozone production in air.

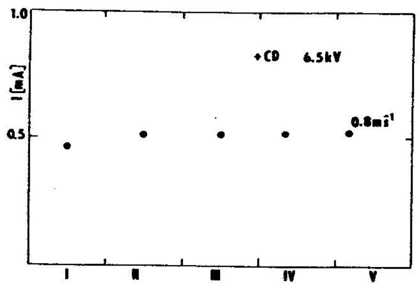

Fig. 4. Positive corona discharge current in discharge tube sections I - V at the flow velocity $u = 0.8$ ms^{-1}.

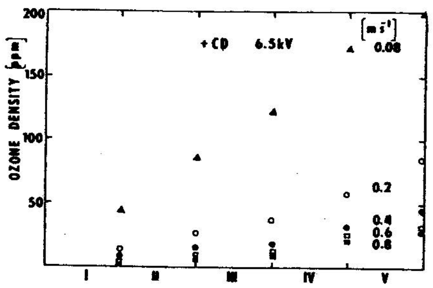

Fig. 5. The ozone density in air at the end of each section I - V for various flow velocities of positive polarity.

Positive corona discharge

The discharge current for the applied voltage 6.5 kV in each section of the discharge tube for the flow velocity u=0.8 ms^{-1} can be seen in figure 4. The flow of air has practically no effect on the discharge current. In the first section the discharge current is slightly lower when compared with other sections of the discharge tube, where the discharge current is approximately the same. For another flow velocities the current in each section is the same as that observed at the flow velocity 0.8 ms^{-1}, the values are equal with the accuracy of $\pm 5\%$.

The dependence of the ozone concentration in air on the discharge tube length is qualitatively the same as in the case of negative polarity. But the absolute values of the ozone density in air for the corresponding flow velocity are approximately one order lower compared with the negative polarity, as it can be seen in figure 5.

IV. DISCUSSION

From the experimental results shown in figure 2 there follows a significant influence of the air flow velocity on the negative corona discharge current. The enhancement of the flow velocity caused the increase of the discharge current in each section of the discharge tube. The most significant increase was observed in the first section, the lowest in the last. The apparent tendency of currents to one limit value is evident from figure 2.

The experimental results cannot be explained by the theory based on the effect of blowing out the space charge of negative ions from the drift region. If this model is correct, then the current in the last sections should not depend on the flow velocity. The effect of the flow on the negative ion motion could be observable only

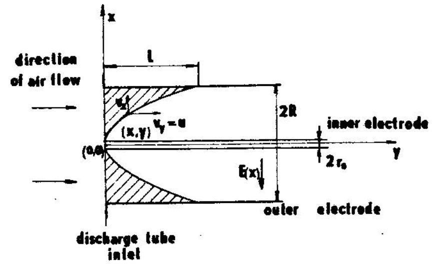

Fig. 6. The situation at the inlet of the discharge tube.

in the first section as it follows from the next consideration. Let us consider the negative ion placed in a position characterized by the coordinates (x, y) (figure 6). The motion of the ion is influenced by the electric field and air flow. The velocity in the direction of the electric field is $v(x) = E(x).b$, where $E(x)$ is the intensity of the electrid field in the distance x and b is the mean mobility of the negative ion. Suppose further that velocity in the direction of the air flow is identical with the flow velocity of neutral molecules $v(y) = u$. Let the electric field in the discharge tube be equal to the electric field in a cylindrical condenser. Then the electric field intensity $E(x)$ at the distance x is given by the formula

$$E(x) = \frac{E_0\, r_0}{x}\,, \qquad (1)$$

where E_0 is the intensity of the electric field on the surface of the central electrode and, r_0 is the radius of the inner electrode.

If we assume that all ions are created on the border of the ionization sheath, then the space must exist at the inlet of the discharge tube from which all negative ions are removed (see figure 6, hatched part). The equation of the curve dividing both regions (with and without ions) can be derived from the condition that time necessarry for the ion to reach the outer electrode due to its drift in the electric field must be the same as the transport time of the ion needed to reach the coordinate $y = L$ (see figure 6)

$$\int_{r_i}^{R} \frac{dx}{v(x)} = \int_{r_0}^{R} \frac{dx}{E(x)b} = \frac{L}{u}\,, \qquad (2)$$

where R is the radius of the outer electrode and r_i is the radius of the ionization sheath ($r_i \approx r_0$).

Table 1

u [ms^{-1}]	0.08	0.2	0.4	0.6	0.8
L [10^{-5} m]	1.8	4.5	9.0	13.5	18.1

From (2) it follows that

$$L = u\frac{R^2 - r_0^2}{2}\frac{1}{b\,E_0\,r_0}\,. \qquad (3)$$

Considering $b = 2m^2V^{-1}s{-1}$ from relation (3) the dependence L on the flow velocity u was calculated (see table 1).

It is evident that the length L is negligible in comparison with the length of the section. Therefore changes of the space charge density can hardly have an influence on the discharge current. The change of space charge distribution can be taken into account only in the first section, it means that in the next sections the distribution of ions is not influenced by the flow and according to the previous explanations [1] - [4] the current should be the same in all sections expect in the section I. This effect was not observed, so that another explanation has to be sought for.

A conspicuous effect of flow velocity on the ozone concentration was observed (see figure 3). It can be seen that ozone concentration is increasing in the flow direction. According to the theoretical consideration published in [7] the electrons and negative ions are drifting to the outer electrode. The total discharge current is the sum of electrons and negative ion currents.

In pure air only the negative ions 0^- are created by a dissociative attachment in the vicinity of the ionization sheath

$$e + O_2 \longrightarrow O^- + O\,, \qquad (4)$$

which are changed to CO_3^- ions. A small part of free electrons is attached also by three body collisions

$$e + O_2 + M \longrightarrow O_2^- + M\,. \qquad (5)$$

In air containing ozone molecules also the following dissociative attachment ef electrons to ozone molecules

$$e + O_3 = \begin{cases} O^- + O_2 & (6) \\ O_2^- + O & (7) \end{cases}$$

Table 2

DT section	I	II	III	IV	V
$u = 0.8ms^{-1}$ b [$10^{-4}m^2V^{-1}s^{-1}$]	6.32	6.16	5.11	4.51	4.03
$u = 0.08ms^{-1}$ b [$10^{-4}m^2V^{-1}s^{-1}$]	3.22	2.82	2.62	2.53	2.50

is effective. As it was proved by mass-spectrometric measurements the first reaction channel (6) is dominant [8].

Due to these reactions the number of free electrons is reduced, it means that the mean mobility of the negative particles is reduced too. Therefore with increasing ozone concentration the discharge current is decreasing.

These effects are in agreement with the theory of two currents mentionend above. From this theory it follows that the change of ozone density brings about the change of the discharge current. That means the change of the ozone density induced by the flow velocity leads to the change of the discharge current. This effect is more marked in the sections closer to the discharge tube inlet. The decrease of flow velocity and the corresponding increase of ozone density have an inluence on the mean mobility of the charged particles, i.e. electrons and negative ions. These values calculated by Towsend's formula from the CV characteristics [9] for each section. They are shown in table 2 for the voltage U = 6.5 kV and the velocities u = 0.08 and 0.8 ms^{-1}.

From the calculated values it follows that for low ozone concentrations, i.e. higher flow velocities, the electron component of the current is considerable. The calculated mean mobility value $b = 6.32 \times 10^{-4}m^2V^{-1}s^{-1}$ in the first section of the flow velocity 0.8 ms^{-1} is nearly four times higher than the mobility of negative ions in air $b = 1.7 \times 10^{-4}m^2V^{-1}s^{-1}$ [10]. For higher ozone concentrations the values are calculated from the experimental results closer to the value given in [10]. Thus it can be concluded that the number of free electrons in the drift region is substantially reduced.

No influence of the flow velocity on the positive corona discharge was observed. The currents were the same in all sections although the dimensions of the space at the inlet of the discharge tube from which the ions are removed is practically the same in the case of a positive and a negative corona discharge. This is also one evidence of the discrepancy of previous theoretical explanations [1] - [4] and our experimental results. The difference in behaviour of the positive and the negative corona discharge can be explained by a different rule of the electron attachment at different polarities. In the case of a negative corona the attachment is effective in the whole drift region, whereas in the case of a positive polarity the negative ions can be found only in the Hermstein sheath [9]. So the change of the ozone concentration can have an influence on the processes of the electrons' attachment only in this sheath. The thickness of this sheath is less than the thickness of the ionization sheath. Moreover, according to the figure 5, the concentration of ozone created in the positive corona discharge is one order lower than in the case of negative polarity. The ozone can influence the processes only in the depth of the ionizing sheath of a positive corona, i.e. those which can influence only the onset corona voltage. An increase of the ozone concentration could cause an increase of the onset voltage. The mobility of charged particles in the drift region, i.e. positive ions, is not influenced by the presence of ozone molecules, as there do not arise positive ions. The small decrease of current observed in the first section cannot be explained by any of the mentioned considerations.

V. CONCLUSIONS

The negative corona discharge current in flowing air is increasing within the interval of air velocities (0.08 - 0.8) ms^{-1}. No apparent effect of air flow velocity on the positive corona current has been found. The changes of the current of the negative corona discharge cannot be explained on a basis of air stream force acting on the negative ions. The changes of the ion distribution in the drift space of the discharge are negligible, thus not important. The main reason for the observed effects are the changes of the ozone concentration in the discharge space which is influenced by the air flow velocity.

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Received October 18th, 1990
Accepted for Publication November 9th, 1990

ТОК КОРОННОГО РАЗРЯДА В ПРОТЕКАЮЩЕМ ВОЗДУХЕ

В работе исследуется постоянный ток коронного разряда обоих полярностей в потоке воздуха (0,08-0,8 м/с). Цилиндрическая разрядная труба состоит из пяти идентичных отдельных секций, разрядный ток которых измеряется отдельно. Влияние скорости потока воздуха на свойства положительной коронны показало незначительный эффект, пока что в отрицательной короне влияние скорости потока воздуха показало значительную зависимость. Приведено пояснение наблюдаемого.