Influence of Gas Composition on Corona Discharge Characteristics in the High Temperature / High Pressure Electrostatic Precipitator

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1 Summary / Abstract:

The use of electrical corona discharge opens broad possibilities for effective development of electrostatic precipitators (ESPs). The object of the work is the study of the corona discharge in different gases at high temperature / high pressure (HT/HP) conditions. The studies are carried out in a HT/HP ionizer in the pure synthetic air, N_2, He and He-synthetic air and He-N_2 gas mixtures. Corona discharge characteristics are measured in electrode gaps of 10 mm and 15 mm. In the synthetic air, the corona onset voltage increases with increase of gas pressure. At constant applied voltage, the gas breakdowns take place at a lower pressure while for a higher pressure the corona discharge may not start yet. The stable corona discharge in dense He is observed at gas pressure up to P=10 MPa. For negative corona current is higher than for the positive corona. In the gas mixtures of ca. 50 Vol. % He in synthetic air or N_2, the stable corona discharge is observed at higher pressures comparative to pure gases. In helium, corona onset and operation voltages increase linearly with increase of gas pressure. The current-voltage characteristics (CVCs) can be approximated by a polynomial equation rang 2.

2 Introduction

The use of corona discharge opens broad possibilities for developments in many fields such high temperature / high pressure electrostatic precipitators, electrohydrodynamic pumps and thrusters, heat exchangers, generation of ozone, decomposition of toxic gases, etc. [1-4].

The corona discharge usually occurs when a high voltage (HV) is applied between two electrodes with substantially different radii of curvature.The charge generation and transport in the gaseous media is one of the key-points of corona discharge. The investigations of these phenomena in the air were the object of different studies [3,5-7]. Corona discharge in a point-plane electrode assembly as a function of gas pressure (P<10 MPa) and point radius 1-20 µm was investigated in [6]. The numerical modelling and simulation of corona discharge in oxygen under different conditions and electrode configuration was the topic of [3,5].

New fundamental questions appear with application of dense He gas [8,9]. Helium is used as sample carrier gas in modern analytical techniques, filling gas for discharge tubes and lasers and purge gases in semiconductor industry. The use of He at high temperature (up to 1000 °C) and pressure (up to 10 MPa) opens perspectives for helium-cooled reactors [9].

The current-voltage characteristics and charge transport in a corona discharge in He were studied at low or room temperatures. The mobility of charge carries in He strongly depends on the level of gas pressure and purification, geometry of high-voltage electrodes (HVEs) and voltage polarity [10-12]. Various forms of the self-maintained discharge that arise in He at pressure P=0,1-0,5 MPa for different corona discharge conditions are described in [13]. The data about electrical and optical characteristics of a negative corona discharge in the electrode system “needle-grid” in a He/Xe/SF_6 mixture under the pressure P=100-3000 kPa are presented in [14]. The fundamentals of microscopical theory of the corona discharge and the main mechanisms of generation and disappearance of charge and excited particles are discussed for the helium corona in [15]. The transport and Toundsen coefficients are presented for pure He and O_2 gases in [16]. The measurements were carried out in small electrode gaps and for electrode system “sharp needle – plate”. However, the corona discharge in dense gases, especially in He, in electrode gaps of 10-15 mm, is not well investigated.

In the current work the results of the study of the influence of HT/HP conditions on the corona discharge in a 10-15 mm electrode gap for different pure and mixed gases are presented. The tests were carried out with pure synthetic air, N_2 and He and in gas mixtures He-synthetic air and He-N_2. The scope of the work is the study of corona discharge characteristics and corona discharge stability, what is important for further development of effective ionizing systems for HT/HP ESPs.

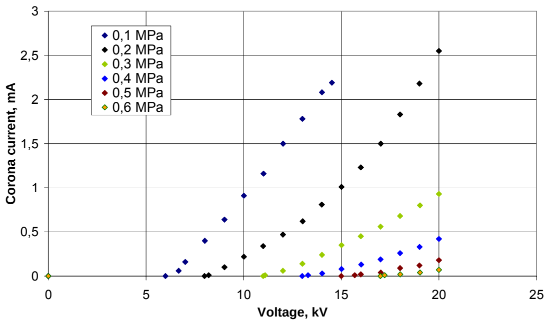
3 Test-set up

The test set-up for study of corona discharge characteristics in dense gases was developed [17]. It consisted of a grounded high pressure vessel in which a HT/HP ionizer was installed. A special high voltage isolator was developed for the tests. A high voltage rod passed through the isolator and was connected by the upper end to the output of a HV unit (Fa. Heinzinger, ±20 kV, 10 mA). At the bottom end of the rod, one or two star-shaped high voltage electrodes were installed [18]. The HV electrodes were positioned inside of a grounded electrode. The width of the electrode gap was d_1=10 mm (for 2 HVEs) and d_2=15 mm (for 1 HVE). The grounded electrode was supplied with electrically heated element which allowed the change the gas temperature T in the corona discharge zone from 20°C up to 500°C. Gas temperature was measured inside the ionizer and near the HV isolator. The gas pressure P inside of the vessel was changed from atmospheric up to 2,0 MPa (tests with hot gases). Before the measurements, gas was 5 times filled up and evacuated from the vessel. The direct (voltage increases from on-set to break-down) and in-direct (from break-down to on-set) CVCs were measured for DC positive and negative corona discharge.

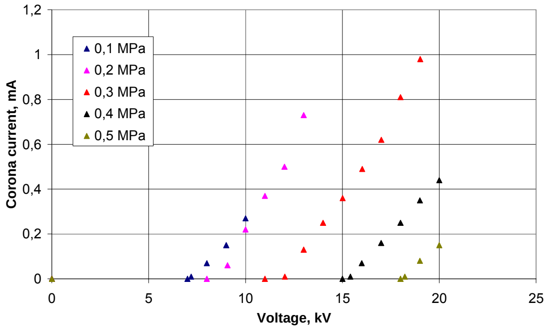
4 Results and Discussions

4.1 Measurements at atmospheric temperature

The corona discharge CVCs (Fig.1) were measured in synthetic air (79% N_2; 21% O_2). For positive voltage, the corona current was suppressed at P=0,4-0,5 MPa. For negative voltage the suppression took place at P=0,6 MPa. The on-set and break-down voltages increased with increase of gas pressure. At constant applied voltage, the gas breakdown took place at a lower pressure while for a

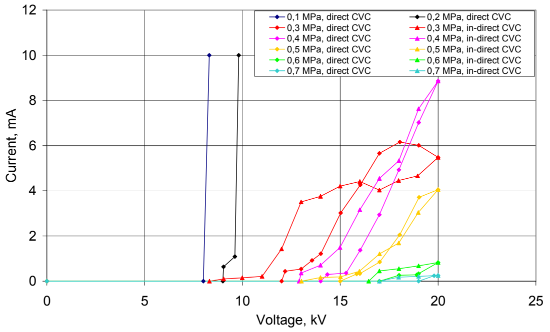


a) negative corona

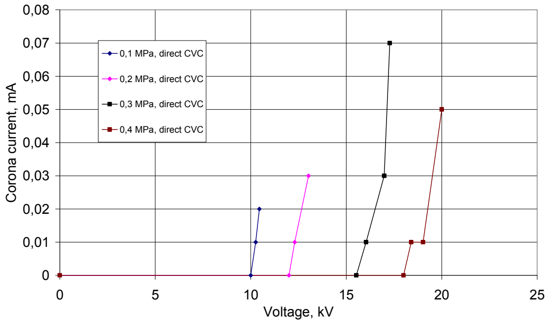


b) positive corona

Fig.1 Corona discharge CVCs in synthetic air at atmospheric temperature, d_1=10 mm



a) negative corona



b) positive corona

Fig.2 Corona discharge CVCs in N_2 at atmospheric temperature, d_1=10 mm higher pressure the corona discharge might not start yet. The higher pressure resulted in lower ion mobility and narrowed the drift region through which the ionic charge travels from the corona electrode to the grounded electrode. In order to have the same corona discharge current at high pressure, higher voltage needed to be applied.

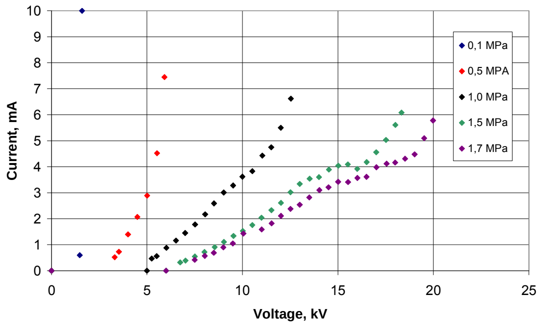
The corona discharge in N_2 (Fig.2) is more sensible for applied voltage as in the synthetic air. Small increase of voltage can result in strongly increase of corona current up to breakdown. Current for negative corona is considerably higher than for positive one. For positive voltage, the corona current was suppressed at P=0,4-0,5 MPa and for negative voltage the suppression took place at P=0,7 MPa. The increase of gas pressure stabilizes corona discharge and increases the breakdown voltage. The CVCs for negative corona (Fig.2,a) are characterized by the hysteresis loop which area decreases with increase of gas pressure.

Table 1. Gas composition (Fa. Basi)

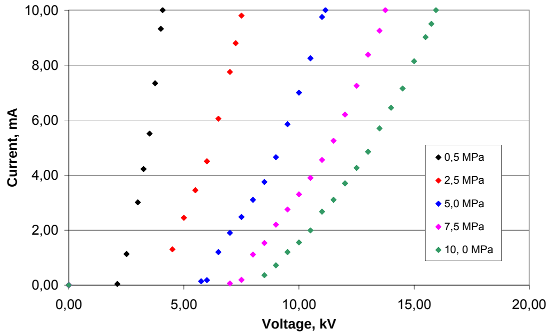
Product	**Gas**					
	He Vol.%	**N_2 ppm**	**O_2 ppm**	**C_xH_y ppm**	**CO,CO_2 ppm**	**H_2O ppm**
He 4.6	≥99,996	< 10	<3	-	-	<3
He 5.0	≥99,999	<5	<1	<0,5	<0,5	<2

The tests were carried out in He 5.0 (d_1=10 mm) and He 4.6 (d_2=15 mm) atmosphere (Table 1). The CVCs for negative corona discharge in He 5.0 and P up to 1,7 MPa are presented in Fig.3,a. In He 5.0, the positive corona discharge was characterized by rather low current. The CVCs in He 4.6 and P up to 10 MPa are presented in the Fig.3,b and Fig.3,c. One can see that for He 4.6 the stable positive and negative corona discharge exists for the tested conditions. At atmospheric pressure, the current increases abruptly. The negative corona current rapidly grows in the range of a few hundreds of volts. For negative corona discharge the operation current is much higher than for positive corona. The CVCs (Fig.3,b) in the He 4.6 can be approximated by a quadratic equation. This is in a good agreement with [19] where He corona current has a quadratic function of the drift field.

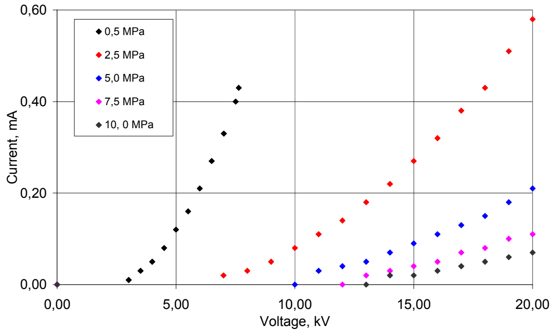
According to [10,20,21], in the corona discharge helium molecules are the dominating metastable component. The values of the mobility of charge carriers in the positive corona discharge are in accordance with the values of ions of He^+ [10]. The dominating charged particles in the external region of the corona discharge are the molecular helium ions He_2^+ [20]. In the helium negative corona the mobility of charge carriers strongly depends on gas purification. For example, for The helium gas with O_2 of the order of 100 ppm, the mobility of negative carriers is closed to the data obtained for negative O_2^- ions [10].



a) negative corona, d_1=10 mm, He 5.0



b) negative corona, d_1=15 mm, He 4.6



c) positive corona, d_2=15 mm, He 4.6

Fig.3 Corona discharge CVCs in He at atmospheric temperature

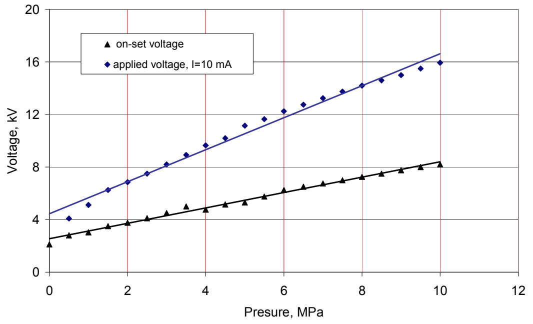
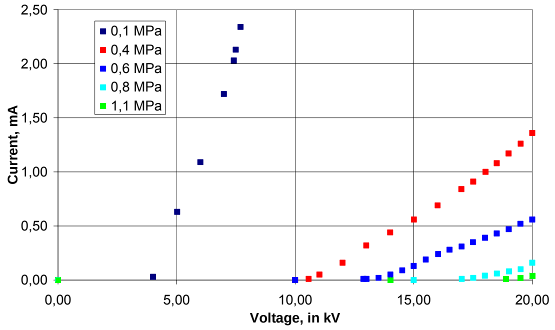


Fig.4 Dependence of the corona discharge on-set voltage and applied voltage (for I=10 mA) on the He 4.6 pressure

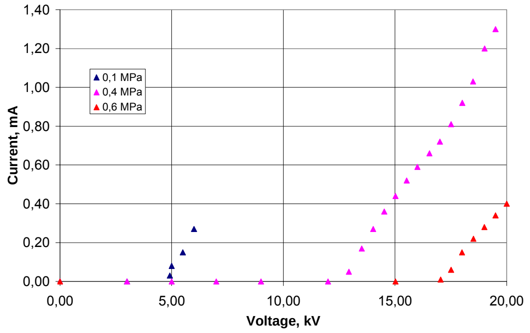
So, the possible rest gas impurities in the high pressure vessel with He 4.6 could change the corona discharge conditions in the HT/HP ionizer resulting in higher corona currents comparative to He 5.0.

A pressure increase in the discharge gap, for a given value of the electric field, reduces the ionization rate process in the ionization region. This takes place because the ionization coefficient per unit pressure diminishes. At constant corona current, the dependence of the applied voltage on gas pressure could be described by the equation $U = Apd\frac{1}{\ln(pd)+b}$, where p is gas pressure (Atm); d is electrode gap (cm); A and b are coefficients. For air the approximation is U_{op}=30(pd)+1,35 (kV).

The onset corona discharge voltage in He linearly increases with increase of gas density (Fig.4). To ensure the constant value of corona current I=10 mA, the applied voltage needs to be increased with increase of gas pressure. The increase of gas pressure improves the stability of corona discharge, increases the onset voltage and the operation range of applied voltage of the corona discharge.



a) negative corona discharge



b) positive corona discharge

Fig.5 Corona discharge CVCs in He-synthetic air gas mixture at atmospheric temperature, He Vol.% 49,21, d_1=10 mm

The experiments were carried out in gas mixtures such 10,01 Vol. % and 49,21 Vol.% of He in synthetic air and 9,94 Vol.% and 50,07 Vol.% of He in N_2. In the gas mixtures, the breakdown voltage increases gradually with increasing of pressure. At constant applied voltage, the presence of He in gas mixture increases corona current. In the synthetic air, the increase of Vol.% of helium up to Vol.% 49,21 extends the range of gas pressure when the stable corona is observed. For negative corona the extend is up to P=1,1 MPa and for positive corona the extend is up to P=0,6 MPa, correspondingly (Fig.5).

The introduction of He into N_2 increases the stability of corona discharge with increase of gas mixture pressure. The difference between the on-set and break-down voltages increases in comparison with pure N_2. The corona current for positive corona is smaller than for negative one. In He-N_2 mixture (Fig.6) width of the hysteresis loop increases with increase of the gas pressure. It maximum corresponds to pressure ca. P=1,5 MPa. In He-N_2 mixtures, the CVCs hysteresis were observed in [22] in "pins-mesh" electrodes in a unipolar corona discharge. The hysteresis loop was explained by presence of a large amount of nitrogen molecules in metastable electronic states. The area of the hysteresis loop increased with decrease of mixture pressure.

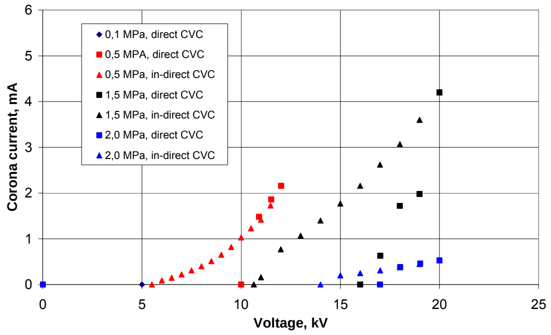
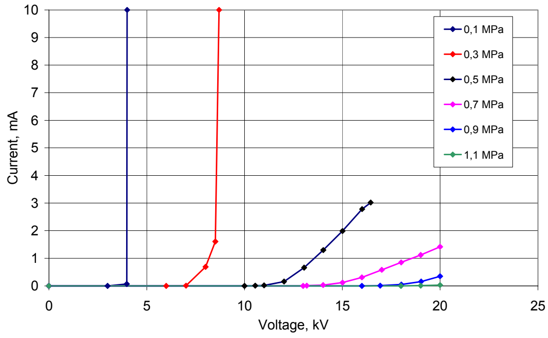


Fig.6 Corona discharge CVC in He-N_2 gas mixture at atmospheric temperature, negative polarity, He Vol.% 50,07, d_1=10 mm

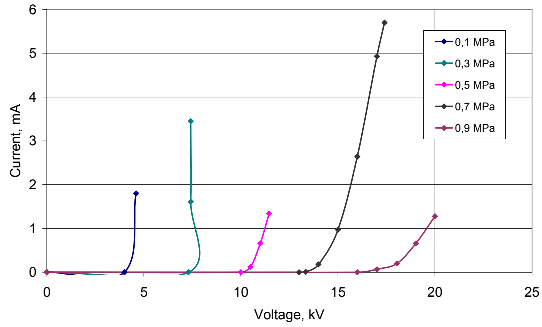
4.2 Measurements at high temperatures

The experiments were carried out at different gas pressures and temperatures which were changed with an interval of 100°C from atmospheric conditions up to T=500°C. The electrode gap in the ionizer was d_1=10 mm.

The CVCs for the synthetic air at T=500°C are presented in the Fig.7. At constant pressure, the increase of gas temperature extends the operation conditions when the stable corona discharge takes place. The extension of gas pressure is up to 1,1 MPa for negative corona and up to 0,9 MPa for positive corona. These results are in a good agreement with theory of gaseous discharge phenomena [1-3].



a) negative corona



b) positive corona

Fig. 7 Corona discharge CVCs in the synthetic air, d_1=10 mm, T= 500°C

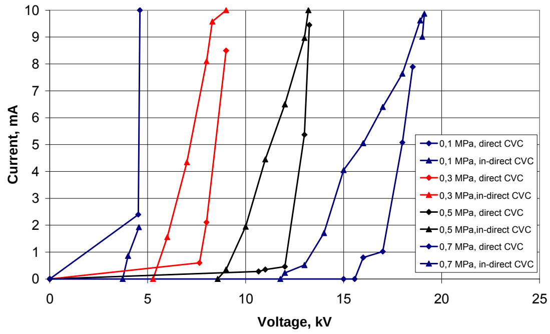


Fig. 8 Corona discharge CVCs in the N_2, negative polarity, T=500 °C

The measurements in the N_2 show that the negative corona discharge stabilises itself at gas pressure P>0,3 MPa. The upper value of gas pressure is 0,8 MPa (Fig.8).

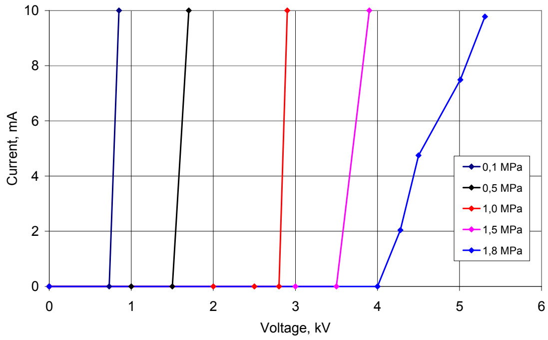
The positive corona discharge shows considerably lower currents comparative to negative corona. In hot gas and negative corona discharge, the hysteresis loop is more pronounced than at atmospheric conditions.

The width of the loop increases with increase of gas pressure. At the same applied voltage, the in-direct CVCs show considerably higher current than the direct current-voltage characteristics. Operation at in-direct CVC ensures stable corona discharge.

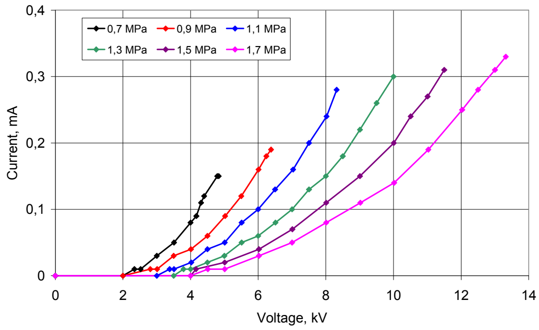
In the He 5.0 atmosphere, the increase of gas temperature decreases the stability of negative corona discharge (Fig.9,a). In the HT/HP ionizer stable corona currents (I=6-10 mA) were observed for negative corona at gas pressure P>1,8 MPa.

In comparison with gas temperature T~20°C, where it was not possible to on-set stable positive corona discharge at high pressure, at T=500°C the positive corona discharge was characterised by stable currents of I=0,15-0,3 mA (Fig.9,b). The increase of gas pressure at T=500°C extends the gap between the on-set and break-down voltage values.

The comparative curves for the negative corona CVCs for the He 5.0 gas at pressure P~2,0 MPa for different gas temperatures are presented in the Fig.10.



a) negative corona



b) positive corona

Fig. 9 Corona discharge CVCs in the He, T=500°C

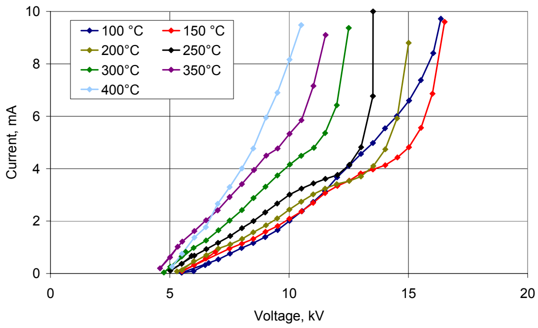


Fig.10 Influence of gas temperature on the negative corona discharge characteristics, He 5.0, P~2,0 MPa

One can see that the increase of gas temperature slightly decreases the value of corona on-set voltage. The gap between the on-set and break-down voltages narrows. With increase of gas temperature, same corona currents could be obtained at lower values of applied voltage.

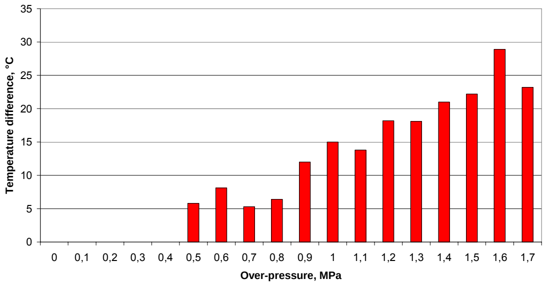


Fig.11 Difference between gas temperatures in the ionizer for different gas pressures

In a hot helium atmosphere, by on-set of corona discharge a decrease of gas temperature in the ionizer is observed. Simultaneously the temperature increases in the upper part of the vessel near the HV isolator. With increase of pressure, the difference in temperatures before and after every measurement increases (Fig.11). This could be explained by the fact that that, the electrohydrodynamic phenomena in the ionizing zone provoke the drift of gas inside of the high pressure vessel. The investigations both of these phenomena and corona discharge in the He-synthetic air and He-N_2 gas mixtures at HT/HP conditions are currently in the stage of experimental study.

5 Literature

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