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Study of electrohydrodynamic phenomena in high temperature high pressure nitrogen

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Abstract. The study of corona discharge current-voltage characteristics (CVCs) in high temperature high pressure (HTHP) gases is an important step in development of compact HTHP electrostatic equipment. The scope of the current work was the study of corona discharge CVCs in HTHP nitrogen. Corona discharge ionizer was installed inside of a HTHP casing. Ionizer included star-shaped high voltage electrodes installed inside of a grounded tube electrode. The grounded electrode could be heated. Tests were carried out at various gas pressure and grounded electrode temperatures. The CVC-direct and CVC-indirect characteristics were measured for positive and negative polarity of applied voltage. For the same values of applied voltage, current for negative corona was higher than for positive one. The increase of gas pressure stabilized corona discharge and increased corona onset voltage. Operation of the ionizer at CVC-indirect ensured stable corona discharge. Corona discharge CVCs have shown hysteresis loop which area depended on gas pressure and temperature.

1. Introduction

Study of corona discharge and electrohydrodynamic (EHD) phenomena in HTHP gases is important for development of compact HTHP electrostatic equipment. Previous studies of corona discharge were carried out in various gases, electrode systems, applied voltage polarity, temperature and pressure. In [1] investigations were carried out in a point-to-plane electrode assembly. The scope was the study of corona discharge CVCs as a function of air pressure (<10 MPa) and point radius. The evolution of discharge parameters as a function of gas density was discussed. In [2] the simulation of a wire-cylinder-plate positive corona discharge in N₂ was performed. The results were compared with already available experimental data in air for the same electrode configuration. The study in [3] was dedicated to investigations of positive corona discharge in a point-to-plane configuration, generated in nitrogen at atmospheric pressure. It was shown that corona current decreased when the inter-electrode distance raised. Corona current increased with increase of applied voltage. In [4] tests were carried out in the ionizer which included a grounded cylinder and an axially installed wire high voltage (HV) electrode. The quartz envelope of the grounded electrode was heated. The results of the study of corona discharge characteristics for a point cathode in high pressure gas and liquid N₂ were discussed in [5]. Here the influence of electrode geometry on corona discharge CVCs was investigated. The experimental data [6] have shown that in a corona ionizer onset voltage increased with increase of gas pressure. At constant applied voltage, gas breakdowns took place at a lower gas pressure while for a higher pressure the corona discharge might not start yet.



2. Experimental set-up

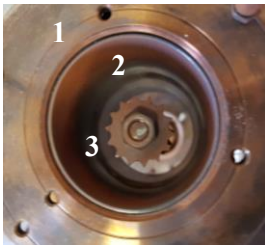


Figure 1. Ionizer:
1- support, 2 – grounded
electrode, 3- HV electrode

The scope of the current work was the study of corona discharge in the HTHP nitrogen (N_2 4.6) atmosphere. Experiments were carried using a corona discharge ionizer (Fig.1) which included a support 1 with heating element, grounded electrode 2 and two star-form HV electrodes 3 installed inside of the electrode 2 [6]. The corona ionizer was maintained inside of a HTHP casing. The set-up was equipped with corresponding measurement equipment for control of ionizer and test facility parameters.

Tests were carried out without gas flow through the casing. A high voltage power supply with maximum voltage of $U_{max}=20$ kV and maximum current of $I_{max}=10$ mA was used in the tests. The CVCs were measured at positive and negative polarity of applied voltage. The grounded electrode 2 was heated during the tests up to $T=500^\circ\text{C}$ with a single T-step change of 100°C . The gas pressure inside of the HTHP casing was step-wise changed with single P-step of 0.1 MPa. Pressure was increase up to value when it was not possible to start corona discharge at $U \leq U_{max}$. The CVC-direct characteristics were measured when the voltage was increased from $U=0$ kV up to $U \leq U_{max}$ depending on gas pressure and temperature. The CVC-indirect characteristics were measured when the voltage was reduced from $U \leq U_{max}$ to $U=0$ kV.

3. Results of experimental study

Without ionizer heating (room temperature conditions) and at $U=\text{const}$, negative polarity corona discharge was characterized by higher current than the positive corona discharge. For positive polarity it was not possible to start corona discharge at gas overpressure $P \geq 0.4$ MPa. For negative polarity this limit was $P \geq 0.7$ MPa. Increase of gas pressure stabilized corona discharge and increased corona discharge onset voltage U_0 (Fig.2). Among U_0 , measured by CVCs-direct, the corona discharge suppression voltage U_h ($I=0$ mA) was measured by the CVCs-indirect. Parameters U_0 and U_h have shown linear dependence from gas overpressure and suppression voltage U_h was $U_h < U_0$ (Fig.2). Corona discharge was more stable during the measurements of CVC-indirect than during the CVC-direct measurements.

When the ionizer grounded electrode was heated up to $T=400^\circ\text{C}$, the onset voltage U_{0-400} and the suppression voltage U_{h-400} practically linearly increased with increase of gas pressure and $U_{h-400} < U_{0-400}$ (Fig.2). The value of the onset voltage U_{0-400} (heating of the grounded electrode 2) was lower than corresponding value of $U_{0-\text{no heating}}$ (room temperature conditions).

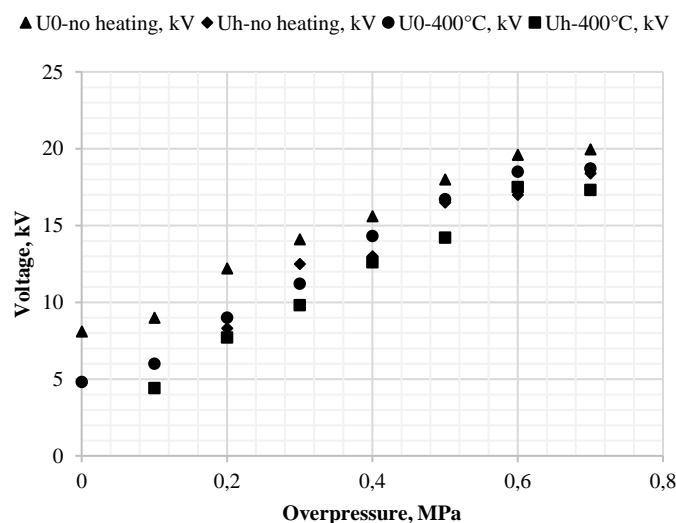


Figure 2. Negative corona discharge onset and suppression voltages for various gas overpressure

The CVCs hysteresis was observed for corona discharge in the pressurised nitrogen (Fig.3). The CVCs were measured for various values of gas overpressure inside of the HTHP casing when the grounded electrode of the ionizer was heated up to temperature of $T=400^{\circ}\text{C}$. At atmospheric pressure inside of the HTHP casing, only CVC-direct was measured (I-direct). At gas overpressure $P=0.1-0.7$ MPa, both CVCs-direct and CVCs-indirect were measured. In the Fig.3, for example, I-direct3 and I-indirect3 are corona currents measured at overpressure $P=0.3$ MPa. In comparison with CVCs-direct, during the measurement of CVCs-indirect characteristics, corona currents were measured at voltages U which were $U_h < U < U_0$. The increase of grounded electrode temperature up to $T=500^{\circ}\text{C}$ increased the area of the hysteresis loop and enhanced gas circulation inside of HTHP casing.

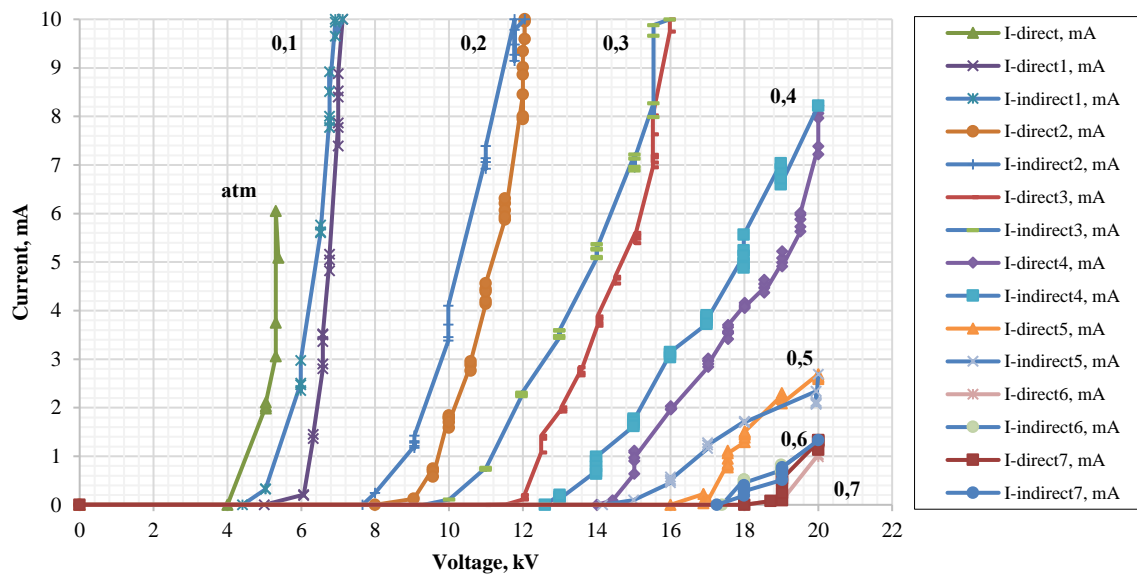


Figure 3. Corona discharge current-voltage characteristics, negative polarity of applied voltage, $T=400^{\circ}\text{C}$, “atm” – atmospheric pressure, “0.1-0.7” - gas overpressure (MPa) inside of HTHP casing

The data for the parameter $\Delta U=U_0-U_h$ without and with ionizer grounded electrode heating (various gas pressure) are presented in the Fig.4 (here ΔU is “Delta U”). Without electrode heating ($\Delta U_{\text{no heating}}$), the parameter decreased with increase of gas overpressure P . For room temperature conditions, the value of $\Delta U_{\text{no heating}}$ was possible to calculate for $P \geq 0.2$ MPa. For electrode 2 temperature of $T=400^{\circ}\text{C}$, the ΔU_{400} remained rather constant with increase of gas overpressure up to $P=0.7$ MPa. This parameter was

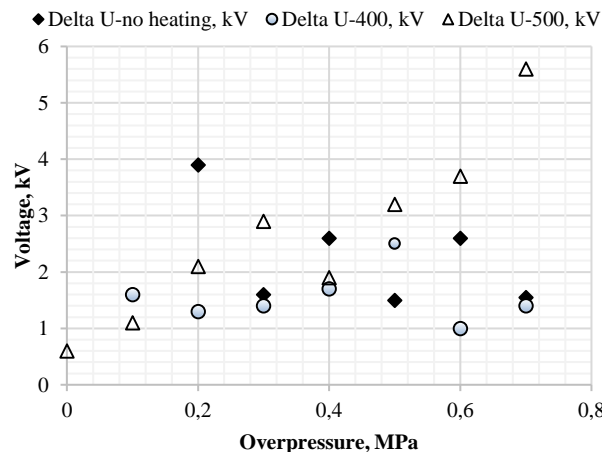


Figure 4. Parameter “Delta U” for various gas overpressure and grounded electrode temperatures

possible to calculate starting from $P=0.1$ MPa. For electrode 2 temperature of $T=500^{\circ}\text{C}$, the value of ΔU_{500} increased with increase of gas overpressure. The increase ΔU_{500} corresponded to the increase of hysteresis loop area. The increase of corona discharge power consumption P_d resulted in enhance of electric wind circulation inside of the ionizer. Gas circulation resulted in enhance of heat transfer inside of the ionizer and in increase of HTHP casing temperature. This effect was well observed during the measurement of corona discharge characteristics without heating of the ionizer grounded electrode (Fig.5). During the measurement of the CVC-direct, the growing of electrode temperature was accelerated when corona discharge power consumption increased over the value of 50 W. At the end of the measurement, the electrode 2 temperature was $T=50^{\circ}\text{C}$. During a short period of time between the CVC-direct and CVC-indirect measurements, the ionizer was operated at $U=20$ kV and $I=5.5$ mA, what resulted in increase of electrode 2 temperature up to $T=64^{\circ}\text{C}$. During the measurement of CVC-indirect, even by decrease of corona power consumption, the electrode temperature T increased up to 80°C . The growing took place when the $P_d \geq 50$ W. The temperature growing was slowed down when power consumption decreased below the value of 50 W.

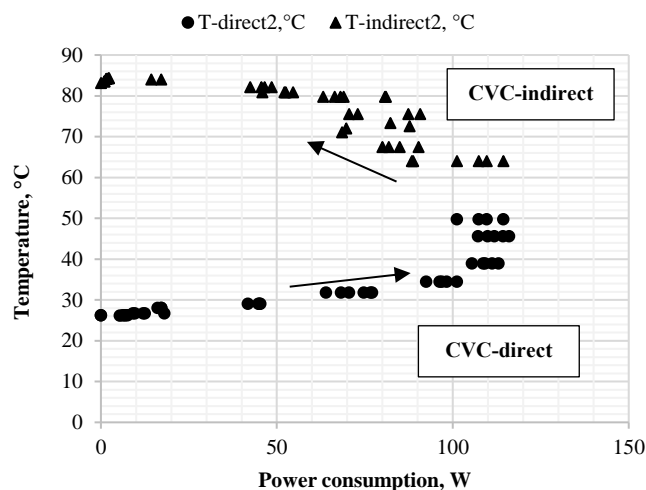


Figure 5. Dependence of grounded electrode temperature on corona discharge power consumption, no heating of grounded electrode, $P=0.2$ MPa

4. Conclusions

The direct and indirect corona discharge current voltage characteristics were measured in the HTHP nitrogen atmosphere. At $U=\text{const}$ and $P=\text{const}$, the negative corona discharge is characterized with higher currents, than the positive corona discharge. The operation of corona discharge ionizer at CVC-indirect curve ensured discharge stability with high corona currents and increased discharge power consumption. The increase of power consumption enhanced electric wind, gas circulation and heat transfer inside of the ionizer and HTHP casing. Gas temperature and pressure influenced on corona discharge characteristics hysteresis. In pressurized nitrogen at constant pressure, with increase of gas temperature the area of hysteresis loop increased.

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