Influence of Gas Mixture Composition on the Current Voltage Characteristics of a Compact Corona Discharge Ionizer

A. Bologa, K. Woletz, H.-J. Gehrmann, D. Stapf
Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

Abstract - The work is focused on the study of the influence of gas mixture pressure on the current voltage characteristics (CVC) of a compact corona discharge ionizer, being measured at room temperature conditions. The compact ionizer includes grounded tube electrode, high voltage (HV) rod with star-form electrodes, as well as HV insulator. The ionizer is installed inside a high pressure tube casing. The "direct" (by increase of applied voltage) and "indirect" (by decrease of applied voltage) CVCs are measured at positive and negative polarity of applied voltage. The hysteresis of corona discharge CVCs is observed in CO_2:He and in CO_2:He:N_2 gas mixtures. The temporal evolution shows the decrease of corona discharge power consumption at the beginning of the measurements. Then, the corona discharge power consumption is stabilized at rather constant level. At constant gas pressure and applied voltage, the power consumption of negative corona discharge varies with gas composition. For the positive corona discharge, the power consumption remains rather stable both in CO_2:He and in CO_2:He:N_2 gas mixtures.

Dr. Andrei Bologa, andrei.bologa@kit.edu
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I. INTRODUCTION

The use of compact corona discharge ionizers opens large possibilities in the development of new equipment and prospective technologies.

The scope of the study is to investigate the CO_2 conversion phenomena in non-thermal plasma of a DC corona discharge.

In the framework of the defined scope, the current work is focused on the design of a compact corona discharge ionizer and on the study of the influence of gas mixture composition, namely CO_2:He and CO_2:He:N_2, gas temperature and pressure on the ionizer current voltage characteristics.

Attention is given to the temporal evolution of corona discharge current at negative and positive polarity of applied voltage, as well as to the influence of CVCs hysteresis phenomenon on corona discharge parameters.

II. DESIGN OF IONIZER

The test facility includes a high pressure tube casing with volume of 14.000 cm³ with corresponding gas input and output. The casing is grounded. Being prepared for the tests at gas high pressure, the casing lateral wall is thick, as well as the upper and bottom plates, manufactured from the stainless steel. The test facility includes a set of periphery equipment, which allows the control of gas pressure and temperature inside the casing, the temperature of casing wall, bottom and upper plates and the temperature of grounded electrode, as well as the corona discharge voltage and current.

The ionizer is installed axially inside the casing. The electrode system consists on a tube grounded electrode (see Fig. 1) with a height of 10 cm. The volume of ionizer is 226 cm³. The star-form HV corona discharge electrodes are installed inside the grounded tube, being fixed on a HV rod. The electrode gap between the corona discharge electrodes and the grounded one is ~15 mm. The HV rod penetrates through

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Corresponding author: Andrei Bologa
e-mail address: andrei.bologa@kit.edu

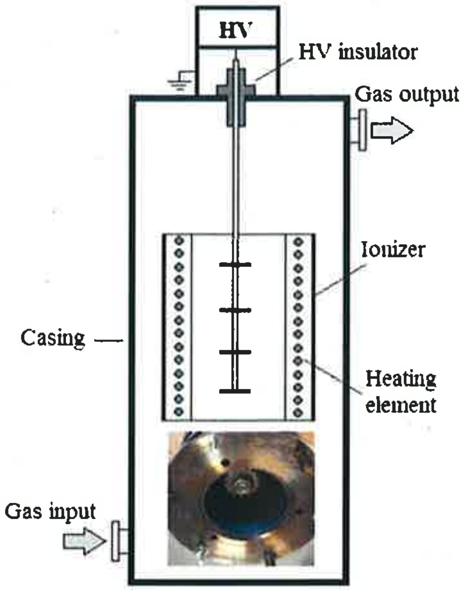

Fig. 1. Schematic view of the casing with corona discharge ionizer

the HV insulator, installed on the casing upper plate. The HV rod is connected with the output of a HV power supply unit. Two of DC power supply units (U_{max}=20 kV and I_{max}=10 mA; U_{max}=30 kV and I_{max}=5 mA) are used in the tests for the generation of corona discharge.

III. TESTS WITH CO_2:He GAS MIXTURE

The measurements of corona discharge CVCs are carried out in the CO_2:He gas mixture (69,7 Vol.% : 30,3 Vol.%) at room temperature conditions. The gas pressure inside the casing varies between 1,3-4,2 bar.

In every test, first the direct CVC, and then the indirect CVC is measured. The direct CVCs for variable gas pressure are presented in the Fig. 2. At gas pressure p=4,2 bar, the maximum corona current I_{max}=1,8 mA is measured at U_{max}=30kV, without any spark over discharges.

With decrease of gas pressure, at U=const, first the corona current increases (at p=3,3 bar). The corona current of $I \geq 2{,}0$ mA is measured for gas pressure p=2,6-3,5 bar. Then, the maximum corona current shows to be decreasing function with decrease of gas pressure.

With decrease of the gas pressure, the corona discharge onset voltage, as well the spark over voltage decreases.

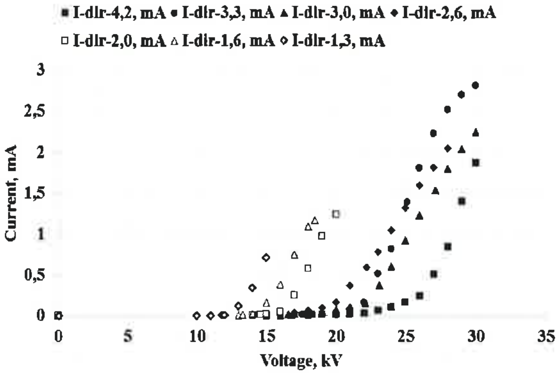

Fig. 2. Direct CVCs of negative corona discharge, variable gas pressure

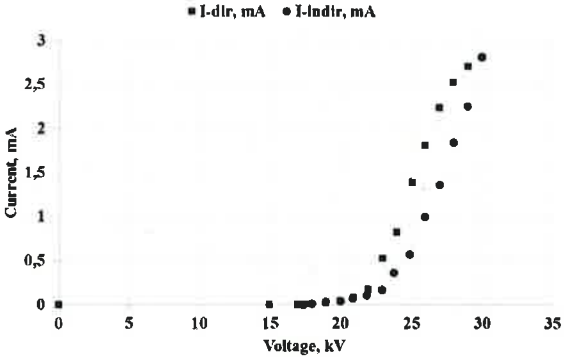

Fig. 3. Direct and indirect CVCs of corona discharge, p=3,2 bar, hysteresis phenomenon

The review of the CVCs at p=3,2 bar shows the presence of the CVC hysteresis phenomenon (see Fig. 3). For the same value of applied voltage, the direct CVCs is positioned above the indirect curve, corresponding to higher corona currents at U=const. For gas pressure p>4,2 bar and p<2,0 bar, there is no difference between the direct and indirect CVCs, hence, no any hysteresis phenomenon.

The power consumption of corona discharge is calculated as $P=U \cdot I$, where U is corona voltage and I is corona current. The corona discharge power consumption (see Fig. 4) decreases at the beginning of the operation.

For the gas pressure of p=4,2 bar, the curve P=f(t) is a decreasing function during the first 30 min of operation. After 60 min of ionizer operation, the power consumption of corona discharge decreases in 4 times in comparison with the beginning phase of the test.

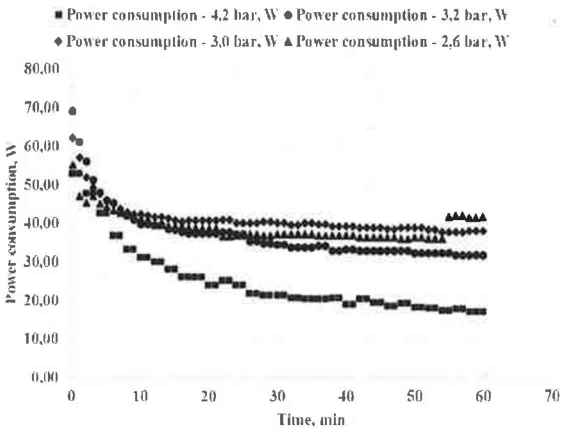

Fig. 4. Corona discharge power consumption

The behavior of the experimental curves permits to assume that corona discharge inside the ionizer changes gas composition, what influences on corona discharge characteristics. This process takes place mainly at the beginning of the operation. After ~15-20 min, the gas mixture comes to a somewhat "new status quo", namely "new gas composition", which is characterized with stable values of corona discharge power consumption.

IV. TESTS WITH CO_2:He:N_2 GAS MIXTURE

The experimental study is carried out with gas mixture CO_2:He:N_2 (68,7 Vol.% : 16,42 Vol.% : 14,88 Vol.%), at room temperature conditions and variable pressure of 1,0-4,5 bar.

The experimental direct CVCs of the corona discharge are presented in the Fig. 5. The maximum corona discharge currents are measured at gas pressure of p=2,0 bar and p=3,0 bar, what corresponds to the CVCs hysteresis phenomenon (see Fig. 6 and Fig. 7). In comparison with the gas mixture CO_2:He, where the hysteresis phenomenon is observed at p~3,0 bar, the hysteresis phenomenon in the gas mixture CO_2:He:N_2 is observed at p=3,0 bar, as well as at p=2,0 bar.

The temporal evolution of corona discharge power consumption P is investigated for variable pressure of the gas mixture. For this purpose, the corona voltage U and current I values are measured every minute, being further used for the calculation of P.

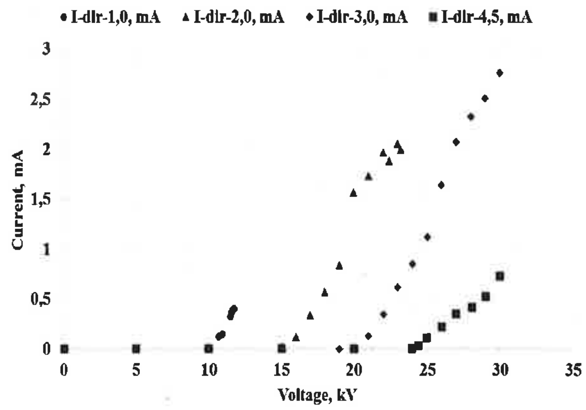

Fig. 5. Experimental CVCs in the gas mixture CO_2:He:N_2, variable gas pressure

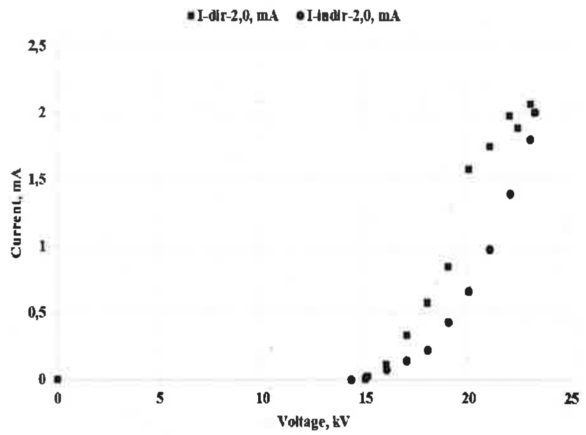

Fig. 6. Direct and indirect CVCs of corona discharge at p=2,0 bar in CO_2:He:N_2 gas mixture, hysteresis phenomenon

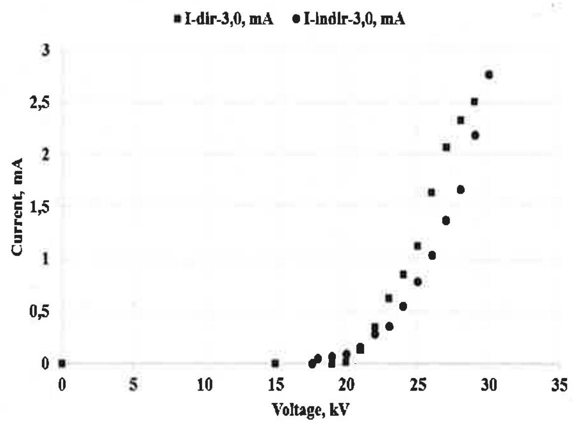

Fig. 7. Direct and indirect CVCs of corona discharge at p=3,0 bar in CO_2:He:N_2 gas mixture, hysteresis phenomenon

During the 1st test, corona discharge is generated in original gas mixture at p=4,5 bar for 60 min. Then, corona discharge is switched off and the gas probes are taken from the casing (reduction of gas pressure in the casing from 4,5 bar to 4,1 bar). Further, corona discharge is switched on and the 2nd test is carried out for 60 min. After this, the next gas probes are taken from the casing, what results in decrease of gas pressure from 4,1 bar to 3,9 bar. During the 3rd test, which lasts 60 min, corona discharge is further generated at applied voltage U=30 kV.

The results of the test are presented in the Fig. 8, which shows, that at U=const, the decrease of gas pressure results in increase of corona power consumption due to increase of corona current. For all of the tests, at the beginning, the power consumption of the corona discharge decreases, and then it stabilizes at defined value.

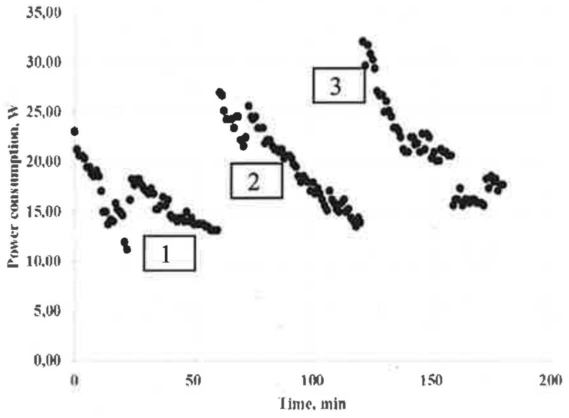

Fig. 8. Temporal evolution of corona discharge power consumption in CO_2:He:N_2 gas mixture, 1 – p=4,5 bar, 2 – p=4,1 bar, 3 – p=3,9 bar

V. HEAT TRANSFER IN THE IONIZER

At room temperature conditions, without external heating of grounded electrode, the generation of corona discharge results in increase of the temperature of the grounded electrode, as well as in increase of the temperature of gas and casing itself.

Due to electric wind and thermodynamic phenomena, gas circulates inside the casing. The measurements show, that the temperature of casing lateral wall above the ionizer and upper plate is higher than the temperature of the casing lateral wall below the ionizer and bottom plate. The heat losses from the casing to the environment take place via conductive, convective and radiation mechanisms.

An example of the temporal evolution of the grounded electrode temperature in the CO_2:He gas mixture is presented in Fig. 9. These data correlate well with the results for temporal evolution of corona discharge power consumption, presented in the Fig. 4. The stabilization of power consumption after ca. 15 min results in corresponding stabilization of the temperature of the grounded electrode (Fig. 9).

The results of the measurement of the grounded electrode temperature by the corona discharge in the gas mixture CO_2:He:N_2 are presented in the Fig.10.

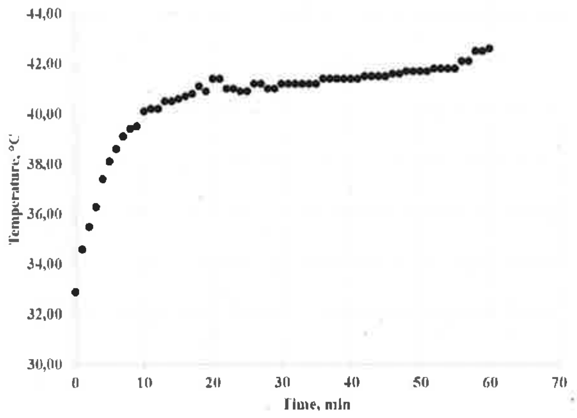

Fig. 9. Temporal evolution of the temperature of the ionizer grounded electrode, CO_2:He gas mixture, p=2,6 bar

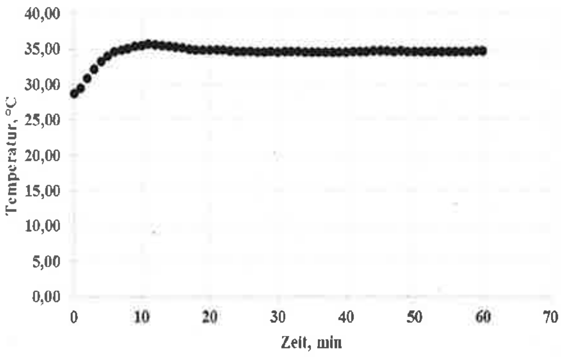

Fig. 10. Temporal evolution of the temperature of the ionizer grounded electrode, CO_2:He:N_2 gas mixture, p=3,0 bar

The data well correlate with the results for the gas mixture CO_2:He (see Fig. 9), showing the increase of grounded electrode temperature during the first 15 min of operation, which is characterized by increased power consumption. Futher, the temperature of grounded electrode stabilizes at defined constant value.

VI. CORONA DISCHARGE POLARITY

Experimental study is carried out for negative and positive polarity of applied voltage. The direct and indirect CVCs are measured for variable gas pressure. The comparative data for the temporal evolution of corona discharge power consumption, measured for negative and positive polarity of applied voltage in CO_2:He:N_2 and CO_2:He gas mixtures, p=2,0 bar and constant applied voltage U=30 kV, are presented in the Fig. 11 and Fig. 12, correspondingly.

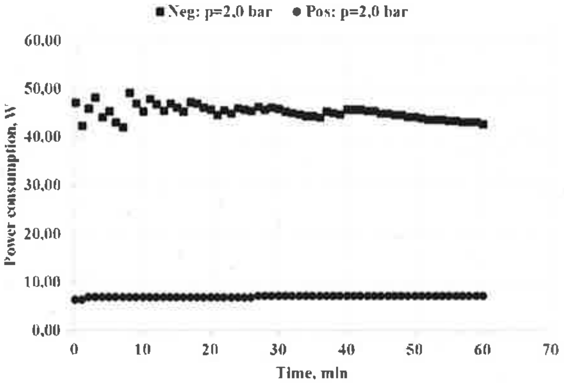

Fig. 11.Temporal evolution of corona discharge power consumption, CO_2:He:N_2 gas mixture

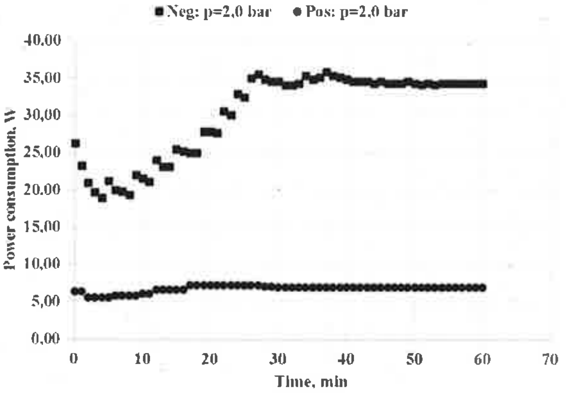

Fig. 12.Temporal evolution of corona discharge power consumption, CO_2:He gas mixture

The results show that at U=const, negative corona discharge allows the generation of higher values of corona discharge current, than the positive corona. Hence, for negative corona is characterized with higher corona discharge power consumption. In comparison with positive corona, the negative one could be generated also at higher gas pressure. The power consumption of negative corona discharge varies with change of gas composition. However, the positive corona discharge is characterized with rather same values of corona discharge power consumption.

VII. LONG-TERM OPERATION STABILITY

The comparative data for temporal evolution of corona discharge power consumption in CO_2:He and CO_2:He:N_2 gas mixtures at pressure of p=3,0 bar and p=2,0 bar (when the hysteresis phenomenon is observed) are presented in the Fig. 13.

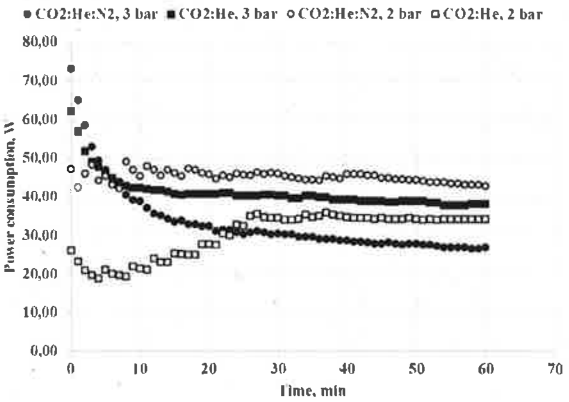

Fig. 13.Temporal evolution of corona discharge power consumption in the gas mixtures, hysteresis phenomenon

For gas pressure p=3,0 bar, the data for the CO_2:He:N_2 and CO_2:He gas mixtures for the first 10 min of operation are rather same, showing the quick decrease of power P with time. Further, both of the curves are stabilized at the rather constant value, which is higher for the CO_2:He, than for the CO_2:He:N_2. For gas pressure p=2,0 bar, the situation is vise verse, and after the stabilization, the current for CO_2:He:N_2 gas mixture is higher, than for the CO_2:He. Hence, it is possible to suppose, that with decrease of gas pressure, the nitrogen starts to influence intensively on the corona discharge characteristics. The difference between the gas mixture curves at p=2,0 bar and stable operation is less pronounced, than for gas pressure of p=3,0 bar.

For the experimental study of the long-term operation stability of the corona discharge ionizer, the gas mixture, which allows to generate the highest corona current, is selected, namely CO_2:He gas mixture at p=3,0 bar.

The study involves four tests, which are carried out during 4 days, including the time intervals, when the corona discharge is switched off, and the casing with the ionizer is cooled to the room temperature conditions. The tests are carried out with the same gas mixture, e.g. the gas is not changed from the test to test.

The results of the study are presented in the Fig. 14. The tests are carried out at room temperature conditions and constant applied voltage U=30 kV, for negative polarity DC corona discharge. The data show, that at the beginning of the 1st test, the corona discharge power consumption quickly decreases in a rather short time interval and stabilizes itself after ~180 min of operation. The next coming tests show same values of the corona current practically from the beginning of the corona discharge generation.

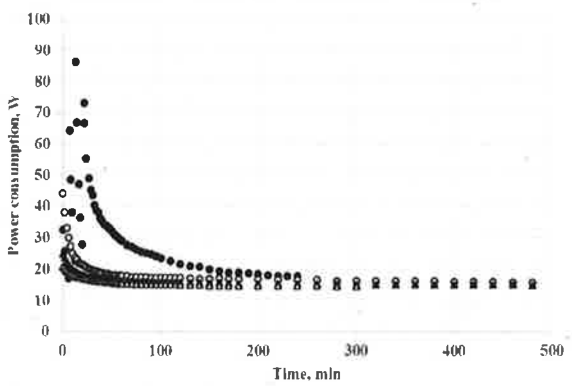

Fig. 14. Temporal evolusion of corona discharge power consumpotion during long-term tests

VIII. CONCLUSIONS

The study of the corona discharge characteristics in the gas mixtures, namely CO_2:He and CO_2:He:N_2, shows the presence of CVCs hysteresis phenomenon, which extends the variability of corona discharge current and power consumption at constant applied voltage.

The tests show, that the "direct" CVC are above than the "indirect" ones.

Gas pressure influences on corona discharge characteristics. With increase of gas pressure, corona discharge onset voltage and spark-over voltage increase. At constant applied voltage, the increase of gas pressure results in decrease of corona current.

At room temperature conditions, corona discharge changes the temperature of grounded electrode and the temperature of gas inside the casing. These changes are more pronounced for negative corona discharge, which power consumption is higher, than for the positive corona discharge.

At room temperature conditions and gas pressure p=2,0 bar, the change of gas composition influences on CVCs characteristics of negative polarity corona discharge, however, for the positive corona discharge, the power consumption remains rather stable for both gas mixtures.

The ionizing process is responsible for the change of gas composition inside the ionizer. During long-term tests, at the beginning, the change of gas composition can provoke the decrease of corona power consumption. After a defined period of time, a "new gas composition status quo" is reached and the corona power consumption stabilizes at constant value.

It is possible to assume, that for effective CO_2 conversion, the ionizer should be operated at the reduced power consumption, what means the reduction of the heating of the grounded electrode, the gas and the casing.

As prolongation of the study, the next step of the work should be focused on the study of the influence of gas composition and corona discharge characteristics on the efficiency of CO_2 conversion in the compact corona ionizer.