INFLUENCE OF O₂ CONTENT IN FLUE GAS AND STREAMER INTERACTION IN STREAMER CORONA ON ACTIVE PARTICLE FORMATION

Andrey A. Beloglovsky, Marina V. Sokolova, Alexander G. Temnikov, Serguey V. Zhukov
Moscow Power Engineering Institute (TU), Krasnokazarmennaya 14, Moscow, 111250, Russia
E-mail: sokolova@fee.mpei.ac.ru

Abstract

Model of kinetic plasma-chemical processes going on during a single streamer formation and propagation, developed previously, is used now to analyse a more general case of streamer propagation in a streamer corona in different gases containing oxygen, such as flue gases, air and pure oxygen. Calculations based on a model of the streamer zone described as a system of streamers propagating in parallel from a sphere electrode, are done for a simple case of pure oxygen. These calculations show that the resulting field at the head of each streamer in the streamer zone decreases and streamers appear with a time delay in comparison with a single streamer. The result of the influence of the streamer zone as a whole on plasma chemical processes in an individual streamer consists of a decrease of intensity of chemically active particle formation in the streamer channel. The active particles that are being formed, are the same, but their concentration in the streamer channel can be 1.5-2 orders less, than in a single streamer.

Calculation results are presented that show a decrease of active particle formation responsible for flue gas treatment with a decrease of O₂ content in the gas. The decrease of the O atoms concentration is less than the decrease of the O₂ content in the gas, this fact being the result of the production of O atoms through other reactions (with water, for instance) than those that are with the O₂ molecules.

1. Introduction

To have a possibility to analyse the processes in a streamer corona in a flue gas leading to formation of such active particles as O, OH, H, O₃, N, that are playing the most active role in flue gas treatment, a calculation model of a single streamer formation and propagation has been developed [1]. The main feature of this model lies in a possibility to analyse all stages of the streamer development - the conditions of its appearance near the high voltage electrode, conditions of its propagation and the decay of its channel after the end of the voltage impulse.

The model of a single streamer formed near a sphere electrode, includes a wide range of possible plasma-chemical reactions that are going on in the streamer head and its channel during its propagation, this processes being included into the system of continuity equations and the Poisson equation. The main details of the simulation are given in [1], and in [2] the results of the analysis of the flue gas treatment on base of the above model are presented. The

431
calculations have shown that the intensity of the formation of active spces during streamer propagation depends mostly on the applied voltage impulse amplitude and its front steepness.

For a more realistic case of streamer corona as a whole a more complicated model to analyse the gas treatment must be used. Such a model taking in view the parallel propagation of streamers that appear near a sphere electrode, has been developed and described in [3]. It permits to analyse the conditions of repeated streamer appearance near the sphere when the initial streamers have already gone a certain distance away from the electrode. The most serious result of such an analysis is the evaluation of the decrease of the electric field in the space near the electrode due to the streamer channels and heads.

These previous results were used to calculate the plasma-chemical processes in an individual streamer that is propagating inside a streamer corona as a whole.

2. Details of the calculation models

The approach to solve the problem in a whole includes two parts: the first one is to analyse the influence of many streamers, propagating in parallel, on plasma-chemical processes going on in an individual streamer that is developed inside the streamer zone. The analysis on this stage is done for a simple case of pure oxygen. The second stage is to analyse the influence of the O₂ content in the gas on the results previously obtained.

2.1. The mutual influence of parallel streamers

The calculation model to investigate the processes in the streamer zone is based on the results obtained in [3] for air. In [3] parallel propagation of several streamers that appear from an isolated sphere under an influence of high voltage impulse with a rectangular front, is analysed using a more earlier developed 1.5 dimension model of single streamer propagation. Although the solution is based on the system of continuity equations for charged particles, plasma-chemical reactions are not analysed, and only three processes are taken into account: the ionisation, the attachment of electrons to molecules of the gas and photo ionisation. It is shown in [3] that mutual influence of parallel streamers change the electric field distribution in the streamer zone in such a way that the field between the streamer channels decreases and it cumbers the appearance of new streamers from the electrode. More of it - the field at the streamer tip in the system of streamers is also decreased.

Using the above approach the appearance and propagation of an individual streamer in a system of parallel streamers in oxygen is analysed. The streamer propagation is analysed for a time interval up to 5 ns. Oxygen, being a simple gas to analyse, has an advantage as most of the plasma-chemical reactions going on in this gas during the discharge are known [4] as well as the constants of these reactions. At the same time oxygen is the component in flue gases answering for the removal of NOₓ [1].

The analysis is made for an isolated sphere with radius R=1 cm, radius of the streamer channel is taken rₜ = 0.03 cm and the distance between primary streamers is taken L₀ = 0.19 cm. It corresponds to the background concentration of negative ions at the moment of voltage application n₀ = 10³ cm⁻³.

As a result of the choice of the main spces responsible for the streamer propagation and O formation in oxygen during 5 ns, only 11 particles that appear during the discharge were left to be included into the continuity equations: O⁺, O₂⁺, O₄⁺, O₅, O₂, O₃, O(¹D), O₂(¹Σg), O₂(¹Σg'), O₃, O and 52 reactions that answer for appearance and disappearance of these particles were taken into account. As it has been shown earlier in [1], the main
chemically active particle, responsible for flue gas treatment, is O atom. So to analyse the intensity of the influence of different factors on the effectiveness of gas cleaning, it is possible to view the influence of these factors on the intensity of O formation and its concentration.

2.2. Active particle formation in gases of different O$_2$ content

To analyse the influence of the O$_2$ quantity in the gas on the effectiveness of active particle formation four gases were analysed. They include pure oxygen, air with 20% of O$_2$ and two types of flue gas: FG1 - with 6% and FG2 - with 1% of oxygen. The flue gas FG1 which corresponds to burning of coal, consists of 72% N$_2$, 6% O$_2$, 10% H$_2$O, 12% CO$_2$, 40 ppm CO, 700 ppm SO$_2$ and 600 ppm NO. FG2 consists of 72% N$_2$, 1% O$_2$, 12% H$_2$O, 15% CO$_2$, 40 ppm CO, 700 ppm SO$_2$ and 600 ppm NO.

The calculations have been made using a 1.5 dimension model of a single streamer, the same as is used in the calculations for a system of streamers propagating in parallel. The continuity equations include all spices that can appear during the streamer development and all reactions that can lead to appearance and disappearance of active particles [2]. To make a comparison only the O atoms production is taken into account.

The current of a propagating streamer has been calculated as a conduction current in an element of the streamer channel that is at a point x on the streamer channel axis. The volume of such an element is $V = \pi r_s^2 dx$, where $r_s$ and dx are the streamer radius and the step of the calculation mesh in the direction of the streamer axis. In this case the current through the streamer channel

$$I_i(t) = v_e n_o(t) K[E_i(t)] E_t(t),$$

where $v_e$ is the charge of electron, $n_o(t)$ - the electron concentration in the i element, $K[E(t)]$ - the electron mobility as a function of local field $E_i(t)$.

3. Calculated results and their analysis

The results of calculations using the above approach are shown in fig.1 and 2. Figure 1 demonstrates an increase with time of the O atom concentration in the streamer channel at the cross-section of the channel that lies 2.5 mm away from the electrode, for two cases - a single streamer and one in the system of streamers. The results are for two values of the applied voltage: 25 and 30 kV with a rectangular front. In fig.2 the calculated current curves are presented for the same cases as above.

It is clearly seen that the decrease of the field due to mutual influence of parallel streamers leads to a significant decrease of the active spices concentration this being the result of a decrease of the ionising processes in the streamer channel. The last is seen from the current curves. The appearance of O atoms in the streamer channel that is propagating in the streamer zone occurs later and practically coincides with the appearance of O atoms in a single streamer for a lower value of the applied voltage. This fact additionally proves that mutual influence of parallel streamers in streamer zone leads practically wholly to a decrease of the local field.
Fig. 1. The variation with time of O atom concentration in a section of a streamer channel in O\textsubscript{2} at a distance 2.5 mm from anode.

The influence of the O\textsubscript{2} content on the intensity of O production is clearly seen from fig.3 where the concentration of O atoms in the streamer channel as a function of time is given for the section of the channel that lies at a distance 2.5 mm from the electrode surface. There are two features in fig.3 that must be pointed out. The decrease of the O concentration is less than the decrease of the O\textsubscript{2} content in the gas, this fact being the result of the production of O atoms through other reactions (with water for instance) than those that are with the O\textsubscript{2} molecules.

The same cause leads to a more early appearance and increase in time of the O atom concentration in flue gases where there are from 10 to 12\% of water. On other side a profusion of O\textsubscript{2} molecules in pure oxygen leads to a delay of the moment of O atoms appearance in the streamer channel as it is seen in fig.3, this last feature being the result of high attachment rate of oxygen molecules that leads to a scarcity of electrons in the streamer channel and to a slowing down of the reactions of O\textsubscript{2} dissociation.

In a whole there is seen a significant decrease of active particle formation responsible for flue gas treatment with a decrease of O\textsubscript{2} content in the gas. For 20\% of O\textsubscript{2} in the gas the amount of O (one of the main active particles) becomes only 38\% of the value reached in pure oxygen, and it falls to 14\% with 6\% of O\textsubscript{2} and to 2.8\% with 1\% of O\textsubscript{2} in the initial flue gas.
Fig. 2. Current curves for two cases as in fig. 1.

Fig. 3. The variation with time of O atom concentration in a section of a single streamer channel at a distance 2.5 mm from anode.
To make a comparison of the intensity of the flue gas treatment in gases, containing different amount of oxygen, calculations of the intensity of NO removal have been made on base of the model described in [2]. Number of NO molecules, removed in streamer channel elements along its axis by reactions with electrons and such spices as atoms of O and N, radicals HO₂, OH and O₃ molecules - were calculated for two flue gases with different O₂ content. On an average the decrease of the amount of oxygen molecules in the flue gas from 6% to 1% makes the intensity of NO removal by O atoms 4 times less, by OH - 3 times less, by HO₂ - even 3 orders less. Although the amount of water molecules in the analysed flue gases is nearly the same (10% and 12%) such decrease of the NO removal by OH spices (three times) can be explained by a decrease of the intensity of OH formation in reactions with O(¹D) spices, the amount of which decreases with the decrease of the O₂ content.

4. Conclusions

1. The development and propagation of a streamer inside a streamer zone (that is in a system of many streamers, propagating in parallel), leads to a decrease of the electric field in the streamer channel and in front of its head. As a result of the influence of this decrease of the field on the intensity of active particle formation in the streamer channel their concentration can be 1.5-2 orders less than in a single streamer that develops alone.

2. The decrease of the O₂ content in the gas leads to a decrease of active particle formation and diminishes the intensity of NO removal in flue gases. The kinetic of the active particle formation in flue gas does not change, but the quantity of active particles become less up to 3 - 4 times (O or OH) and even 3 orders HO₂.

References


Acknowledgement
The work has been supported by the Russian Foundation of Basic Research (Grant 99-02-17604).