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Plasma chemical purification of flue gases using pulsed electron beams

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Abstract. The article presents the study of the pulsed electron beam propagation in oxygen and nitrogen. The researches were performed using the TEA-500 pulsed electron accelerator and drift tube. Parameters of the TEA-500 pulsed electron accelerator are as follows: the electron energy (varies) is 200-450 keV, the beam current is 10 kA, the half-amplitude current pulse duration is 60 ns, the pulse repetition rate is up to 10 Hz (in the pulse burst). The accelerator is equipped with the necessary means of diagnostics of the beam parameters: particle energy, current and current density, the total energy transferred by the beam. The drift tube includes a chamber consisting of two sections of reverse current shunts located along the entire length of the drift tube. The following precursors used N_2 and O_2. The specified types of gases were chosen as they are among the main components of the flue gases, whose treatment has been widely reported recently.

1. Introduction

Especially acute problem of ecology is pollution of atmospheric air. The enterprises of ferrous and non-ferrous metallurgy, chemistry and petrochemistry, construction industry, energy, and fuel industry particularly affect the air pollution. Thermal power plants (TPP) pollute atmospheric air by oxides of hydrocarbon, nitrogen, sulfur.

Scattering in the atmosphere and undergoing physical and chemical transformations, gaseous emissions are carried by air masses over long distances and increase the technogenetic load to the environment. Therefore, reducing the toxicity of the flue gases of thermal power plants is an actual problem. Currently, there are a significant number of methods (sorption, catalytic, carbamide, ammonium magnesite, etc.) and technologies (technologies for the separation of sulfur dioxide from waste gases, the Shelp method, Ebara technologies), which make it possible to purify the flue gases of thermal power plants from harmful constituents [1-6]. The effectiveness of these measures is quite high, but a significant disadvantage is the high cost of equipment and operation, as well as the complexity of technological processes. In addition, all equipment is designed for high performance. It should be remembered that small and medium energy enterprises significantly deteriorate the ecological situation, which in turn requires the use of compact and inexpensive technological solutions for gas cleaning [6–8]. The technology of the Ebara corporation, based on the process of plasma-chemical conversion of flue gases with ammonia, has proved to be successful enough [9-12]. In the process of a plasma-chemical reaction initiated by a continuous electron beam, solid compounds are formed which are removed by electrostatic filtration. The disadvantage of the method is the use of

linear continuous accelerators with a high cost, dimensions and costs are related to ensuring the protection of personnel from ionizing radiation.

An alternative to the above-described process for low-power enterprises may be the organization of plasma-chemical binding of harmful components of flue gases with the initiation of the process by a pulsed electron beam [13-14]. In this method, the flue gas in a mixture with ammonia and water vapor passes through a plasma-chemical reactor, then a pulsed electron beam is injected into it. The energy of the electrons is transferred to the components of the gas mixture. In the interaction with the gaseous medium, some beam electrons generate secondary electrons, which contribute to the overall energy transfer, thus plasma is formed. As a result, of the interaction of electrons and matter, various ions, radicals and other active particles are formed: N2+, N+, O2+, O+, H2O+, OH+, H+, CO2+, CO+, N2+, O2+, N, O, H, OH, and CO. In the case of a high concentration of water vapor oxidizing radicals •OH, HO2• are formed. These types of radicals take part in various chemical reactions, including complexation reactions of polluting chemicals with the formation of complex compounds that have a crystalline structure under normal conditions, so that they can be filtered out.

The complexity of physical models is determined by the nonlinear nature of the processes of energy absorption by the transferred beams, the formation of charged and excited particles, chemical reactions in the interaction zone, secondary radiation, and a number of other phenomena accompanying the interaction of pulsed electron beams with matter in the gas phase [15, 16]. In addition, the identification of regularities in the process of propagation of pulsed electron beams, the calculated ratios of the specific absorbed energy in gas compositions is important, since the productivity of plasma chemical technologies is determined by the magnitude of the pressure in the reactor and its volume.

2. Experimental setup

The experimental stand and the idea of setting up experiments are described in detail in papers [15-17]. As previously mentioned, the TEA-500 accelerator (figure 1) and a drift tube (figure 2) were used in studies of the process of propagation of pulsed electron beams in flue gases.

Figure 1. The TEA-500 pulsed electron accelerator.

Oxygen or nitrogen of different pressures (50 Torr, 300 Torr, 760 Torr) introduced into the drift tube, then a pulsed electron beam injected. With the help of reverse current shunts, the reverse current and the current of the electron beam reaching the end flange of the drift tube determined.

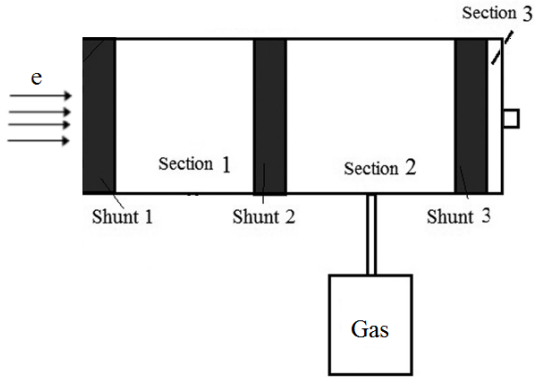

Figure 2. The schematic depiction of the drift tube.

3. Results and discussion

Oscillograms of characteristic currents (the electron current closing on the walls of the first section of drift tube (1), the electron current closed on the walls of the second section of drift tube (2), the electron current reaching the back flange of drift tube (section 3) (3), and the total reverse current closed on the walls of drift tube (4)) of oxygen at different pressures are shown in figure 3.

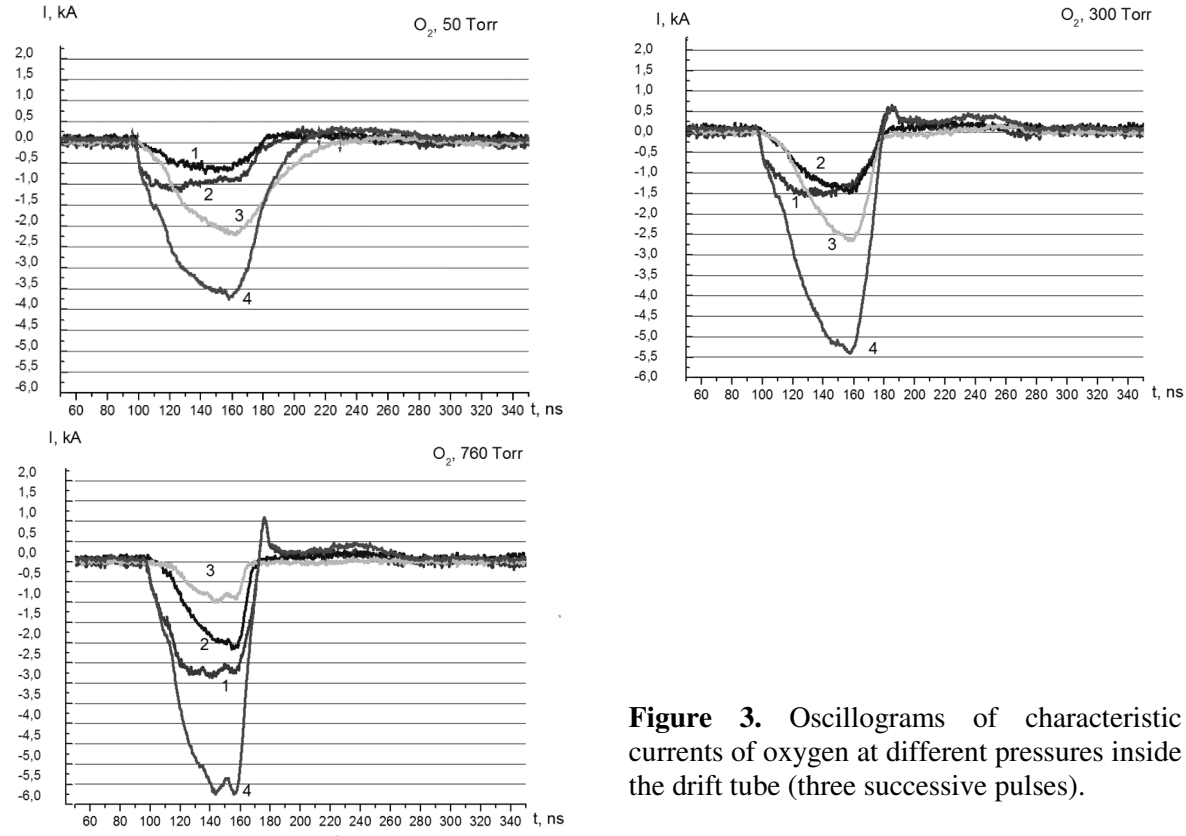

Figure 3. Oscillograms of characteristic currents of oxygen at different pressures inside the drift tube (three successive pulses).

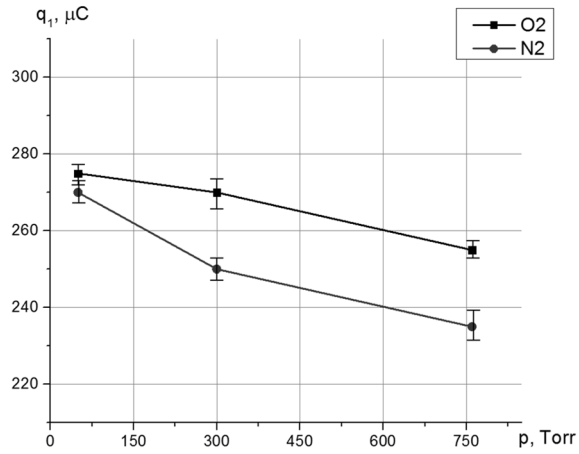

Figure 4. The value of the electron beam charge closing on the walls of drift tube (q1) for nitrogen and oxygen for 50, 300, and 760 Torr pressures in the drift tube.

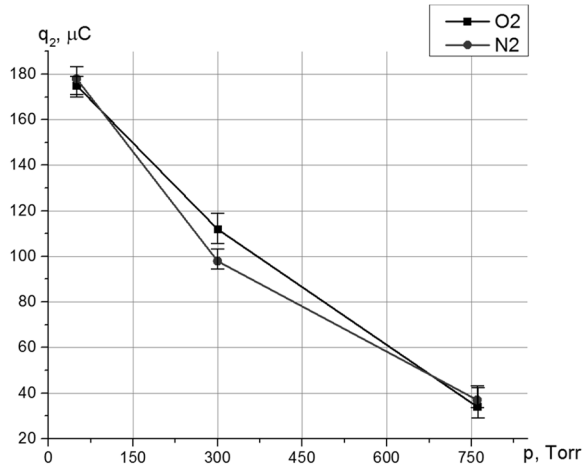

Figure 5. The value of the electron charge reaching the back flange of drift (q2) for nitrogen and oxygen for 50, 300, and 760 Torr pressures in the drift tube.

The value of the total reverse current closing on the drift tube walls was the 5.5-5.8 kA for 300 and 760 Torr pressures within the error limits. For 50 Torr this value was 3.8 kA. The electron current reaching the back flange of drift tube was 2.2-2.5 kA for 50 and 300 Torr, 1 kA for 760 Torr. In nitrogen the electron current reaching the back flange of drift tube are the same as in oxygen within the error limits. And, about 4.2 kA was the value of the total reverse current amplitude closing on the drift tube walls for 50, 300, and 760 Torr pressures [15].

Figures 4-5 present the values of the electron beam charge closing on the walls of drift tube (q1) and the electron charge reaching the back flange of drift tube (q2) for nitrogen and oxygen for 50, 300, and 760 Torr pressures in the drift tube. The electron charge reaching the back flange of the drift tube for 50, 300, and 760 Torr pressures was 175, 112, and 34 μC in oxygen and 178, 97, and 37 μC in nitrogen, respectively. For 50 and 300 Torr pressures in the drift tube, for oxygen and nitrogen the value of the electron beam charge closing on the walls of drift tube was 275 and 255 μC, 270 and 250 μC, respectively. For 760 Torr pressure in the drift tube, the values of the electron beam charge closing on the walls of drift tube and the electron charge reaching the back flange of drift tube are equivalent both for oxygen and for nitrogen within the error limits.

Assumed that the beam current is not closed on the plasma that is typical both for oxygen and for nitrogen in the region of the pressures under study we can calculate the number of electrons falling on the walls of drift tube by the following method: to subtract q2 charge from q1 charge and then to divide the obtained value by the electron charge. Thus, for example, for oxygen for 50, 300, and 760 Torr pressures these values are equal to $3.7 \cdot 10^{14}$, $9.9 \cdot 10^{14}$, and $14.8 \cdot 10^{14}$, respectively. For nitrogen, these values are equal to $6 \cdot 10^{14}$, $9.5 \cdot 10^{14}$, and $12.4 \cdot 10^{14}$ for 50, 300, and 760 Torr pressures, respectively. Besides, despite the different electronegativity of the component under study it is not reasonable to use the drift tube with the length of over 40 cm for a pulsed electron beam with 400 keV electron energy and 6 kA current.

4. Conclusion

The work has presented the research results on the pulsed electron beam propagating in oxygen and nitrogen under 50, 300, and 760 Torr pressures in the drift tube. Taking into account that the value of the charge of electrons ejected behind the anode foil is 310 μC, a pulsed electron beam in oxygen and nitrogen is transported effectively under a pressure in the drift tube of 50 Torr. However, the process of cleaning the flue gas under reduced pressure is ineffective. Under normal pressure, for the used

energy characteristics of a pulsed electron beam, a plasma-chemical reaction in a volume of not more than 7 liters can be initiated per pulse. The obtained results are of an important applied nature, since they allow us to predict the performance of flue gas cleaning technology using modern pulsed electron accelerators. Thus, the most high-frequency accelerator Astra-M, the energy characteristics of which are sufficient for carrying out plasma-chemical cleaning of flue gases, developed at the Tomsk Polytechnic University, will provide the process productivity up to 1000 m^3/h [18].

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