The study of low temperature plasma of pulse discharge in relation to air cleaning units.

A Ponizovskiy\textsuperscript{1}, S Gosteev\textsuperscript{2} and O Kuzhel\textsuperscript{3}

\textsuperscript{1} Deputy chief engineer, FMKB "Horizon" CS "SPC Gas Turbine" Salute" Moscow RF
\textsuperscript{2} Head of Department, FMKB "Horizon" CS "SPC Gas Turbine" Salute" Moscow RF
\textsuperscript{3} Director, FMKB "Horizon" CS "SPC Gas Turbine" Salute" Moscow RF

E-mail: horizontL56@rambler.ru

Abstract. In paper it studied parameters of low-temperature plasma (LTP) used in systems for cleaning waste gas. LTP created by positive nanosecond corona discharges, generated by high voltage pulses with a rise time of 50 ns, duration up to 400 ns, an amplitude up to 90 kV and pulses repetition 50-1000 Hz. in coaxial electrode system with gap space 3-10 cm through which moving air with linear velocity \( v = 0.01 \) to 10 m/s.

1. Introduction
Currently being introduced systems for cleaning emissions of harmful gaseous impurities and odors based on the technology of low-temperature non equilibrium plasma (LTP) generated by nanosecond streamer discharge [1,2]. LTP characterized by significant densities and energies of electrons capable of creating in the discharge gap high concentrations of active intermediate particles (atomic oxygen, ions and radicals), which initiate radiation-chemical reactions with harmful molecules and transform them into ecologically harmless gases or aerosols. The basis of LTP treatment systems are high-frequency pulse generators and reactor chamber (RC) with wire or multi-point (MP) corona discharge electrodes, in which the plasma-chemical reactions take place. Due to high volume density charges occurring while generating pulsed corona produces charged finely dispersed aerosols, vapors and solid particles as present in the gases, and produced as a result of conversion. The removal of charged particle from air is carried out in the pause between pulses due to the drift of molecules and particles to the grounded electrode under high DC voltage. The flushing of deposit aerosols from the wall of RC carries out by circulating water. The effectiveness of such systems depends on the ability of the introduction of energy into the flow of gas, so that is of particular relevance to the study of streamers multipoint electrode system, in moving air and high pulse repetition rate. Therefore, unlike many studies streamers carried out in stationary air at a single pulse, we studied the streamer in the frequency mode in the air with ozone, nitrogen oxides and other contaminated admixtures. The results obtained allowed to optimize the design of running a series of plasma treatment installations of the "Corona M", made by FMKB "Horizon", intended for cleaning air of gaseous environmentally harmful ways and fine impurities.
2. Experimental Procedures

The pulses are generated by device collected by the scheme Fitch (PGF) with an odd number of steps (Figure 1) [2]. PGF consist of high-voltage charger (HV charge), a three stage of capacitors \(C_{st}\), two charging inductors \(L_{d}\), switch (thyratron), transformers TR1 and TR2 and block ignition (\(C, R_1, R_2\)). The capacity charge to voltage \(U_A\) from HV charger.

Main advantage PGF is that, in the first place, the capacitors are connected directly to the load, generated pulse with an amplitude equal to, \(U_{pl} \approx 3 \times U_A\) by main one switch, secondly, in the pause between pulses the load have constant potential of \(U_A\). As a result, the unit operates as a converter of impurities and as a standard electrostatic precipitator.

![Figure 1. Schematic diagram of the experimental and industrial LTP gas cleaning unit.](image1)

![Figure 2. Schematic diagram of the probe measurements of parameters of the streamer.](image2)

\(U_{pl}\) was measured with a capacitive divider\((C_{HV}, C_{LV})\), the full discharge current \((I_{sum})\) was measured with shunt. Concentrations of gaseous impurities, oxygen and ozone gas were measured by analyzers with various types with photo ionization, photometric and electrochemical sensors. LTP was generated in the reaction chamber (RC) with the coaxial electrode system - grounded pipe and central MP or wire electrode. Diameter\((D)\) of RC ranged from 10 to 273 cm, length\((L)\) from 0.3 m to 4 m, electrode spacing \((d)\) \(d=3\text{ to }10\text{ cm}\). Experiments were conducted at air flow rate \(0.01\text{ to }10\text{ m/s}\).

Probe technique for measuring the parameters of the streamer [3] is to measure the current \((I_{st})\) through wire probe diameter of 0.5 mm the set flush with the RC wall(Figure 2) loading on resistor \(R_{load}\). This allowed measurement of single streamer current after reaching the probe head streamer.

3. Results

3.1 Investigation of the parameters of streamers probe method.

Using frequency PGF and multichannel oscilloscopes provided evidence of the development of the tape after it crossed the inter-electrode space. Figure 3 shows waveforms of a single streamer current \((I_{st})\), \(I_{sum}\), \(U_{pl}\) and a signal from the photo electron amplifier(PEM) in RC with \(D=6\text{ cm}, L=30\text{ cm}\) and wire electrode.

We believe that the start of streamers \((t_{in})\) corresponds fracture on the waveform PEM signal. In time streamers is touching the probe and is beginning register of \(I_{st}\). Waveform of \(I_{st}\) has a characteristic peak the duration of the \(t_0\) to \(t_m\) and then decline with some smooth portion stabilization.
Such character of the current appears to be associated with the neutralization of the head of the streamer (peak) and the deionization of plasma streamer channel (part of the current recession). The time from $t_{in}$ to $t_0$ is approximately 30 ns that means the velocity of the streamer $\sim 10^8$ cm/s.

Figure 3. Three scenarios of nanosecond streamer discharges (a) no breakdown; (b) (c) – breakdown.

The development of the streamer after the touch probe has several scenarios. The first one (Figure 3a), associated with the collapse of the plasma channel streamer during the procedure leading to 0.5 $\mu$s. Experiments have shown in the intervals d=3-10 cm such a scenario takes place at the middle pulse field strength ($E_{pl}$=$U_{pl}$ / d) $E_{pl} <7$ kV/cm.

With increasing $E_{pl} >7$ kV/cm there are two other scenarios. In the first case, immediately after touching the streamer probe does not decrease, but increases rapidly, leading to a breakdown in the gap $E_{pl} =8$ kV/cm (fig.3b). In the second case (fig 3c), $I_a$ after touching the probe is maintained stable for hundreds of nanoseconds at 30-50 mA and then increases rapidly. The streamer breakdown occur in the fall of the pulse at $E_{pl} =5$ kV/cm. Theoretically streamer breakdown was predicted in [4], but this work suggests that this effect may occur when $E \approx 20$ kV/cm. We have shown that the streamer breakdown can occur at three times lower values of $E$.

3.2 The main factors affecting the efficiency of waste treatment plants

The integral electrical parameters of nanosecond corona and single streamers measurements allowed to explain the dependence of the efficiency of energy transfer into gas from $E_{pl}$ which directly determines the efficiency of cleaning. Fig. 4 shows the frequency of occurrence of streamers on the probe (N), Q, $I_{sum}$ and efficiency of energy transfer from a PGF into gas ($\eta$) as a function of $E$ in RC with D=23.7 cm, d=10 cm, l=2 m. The graph shows that the efficiency means of $\eta$ occurs in the range of 5 < $E$ <6.5 kV/cm, i.e. when streamers are all inter-electrode distance (frequency of their appearances on the probe increases by an order of magnitude) and charge their heads increases significantly.

The upper limit values of $E_{pl}$ is the field strength at which the streamer breakdown take place. Figure 5 shows $W_{in}$ and $I_{sum}$, the concentration of ozone kO$_3$, hour of ozone production (hO$_3$) and specific energy consumption for ozone production (W/hO$_3$) from the air flow rate ($\theta$). The graph shows that the maximum efficiency of ozone production take place the transition of flow from laminar to turbulent. The above results showed that the highest efficiency of the plant is provided with the values of the order of $E$ 6.5 kV/cm and duration of pulse $\sim 0.5$ $\mu$s. In this case on the one hand streamers cover the all inter electrode gap and thereby maximize the conversion zone but the other hand do not allow the streamer breakdown occur, whereby instead impurities conversion of nitrogen oxides is generated. Another factor that significantly affects the conversion efficiency is the design of the RC.
Our experiments showed [5] that the energy efficiency of introduction of W increases with increasing distance between HV and ground electrodes. So increasing the diameter of the RC from 30 to 260 mm increases the current from 30 to 200 A at the same pulse voltage gradient $E=6.5$ kV / cm. This is due not only to an increase in the discharge point that the wire is not more than 200 l/m, and. But D of our RC be limited to 260 mm due to the complexity of designing high-frequency generators for voltage more than 100 kV.

Figure 4. The dependence of the frequency of occurrence of streamers on the probe $N(1)$, efficiency of energy transfer from a PGF into gas $(\eta)(2)$, $Q(3)$, $I_{\text{sum}}(4)$ as a function of $E_{\text{pl}}$ (RC - D=25.7 cm, d=9 cm, l=2 m.),

Because of the short duration of the pulse, the value introduced into the discharge gap volume energy less than 20 J / m$^3$. Given that the conversion to a concentration of impurities of 100 ppm requires the energy density of at least $10^4$ J / m$^3$, it is obvious that the pulse repetition frequency (f), industrial installations should be much higher than 100 Hz.

4. Installations for waste gas by means of LTP
All of the above have been taken into account in the establishment in FMKB "Horizon" series of installations for cleaning waste gas of contaminants via LTP. Under the scheme of Figure 1 developed and commercially available modular treatment plants ranging from 1 to 8 kW performance $(0.3-15)\cdot10^3$ m$^3$/h., Whose photos are shown in figure 6-9. Main specification of units are presented in table 1; results of cleaning efficiency – in table 2.

| Name of the parameter | Value/characteristic |
|-----------------------|----------------------|
| SPC Gas Turbine “Salute” Moscow | 5000 | 200 | 5000 | 15000 |
| Project “Mars 500” Moscow | 6 | 2 | 4 | 6 |
| Pump station Moscow | 115 | 90 | 90 | 90 |
Pulse duration ns 450 120 250 250
Pulse frequency max Hz 100-400 100-1000 1000 1000
Reactor chamber 4-tube wet-type 1 tube 4-tube 4-6 tube
Denison m 1x2.5x5 0.6x1.5x2 1 x 2 x 4 2x1.5x6
Weight ton 1.5 0.2 .8 1.2
№ of figure 7 9 8

| Type of pollution | Concentration mg/m³ | Gas flow rate, m³/h | Purification degree, % | Specific power, W-h/m³ mg | Installation site |
|-------------------|----------------------|---------------------|------------------------|---------------------------|-------------------|
| SO₂               | 5000                 | 800                 | 70                     | 0.002                     | Non-Ferrous Metals Plant |
| NOₓ               | 3000                 | 36                  | 95                     | 0.006                     | MSE Corp., USA * with addition of ammonia |
| Toluene + Benzene | 300                  | 50                  | 90                     | 0.13                      | “FSUE SIC” Salut |
| Aerosol CrO₃      | 10                   | 200                 | 99                     | 0.2                       | KIA “Sportage”136kW |
| NOₓ, soot         | 350, 15000           | 50                  | 90                     | 0.016, 10                 | “FSUE SIC” Salut |
| HF, aerosol       | 30                   | 5000                | 95                     | 0.06                      | “FSUE SIC” Salut |
| H₂S               | 150                  | 1000                | 0.2                    | 0.02                      | Sewage treatment tank |
| The smell of sewage | 5000             | 5000               | No smell               | 0.2, **)                  | **Specific power W-h/m³ |
| H₂S               | 16.2                 | 5000                | 80.4                   | 0.2, **)                  | **Specific power W-h/m³ |
| Ammonia           | 0.55                 | 5000                | 89.8                   | 0.2, **)                  | **Specific power W-h/m³ |

5. Conclusions
1. The results of experimental studies of plasma parameters generated by nanosecond corona discharge applied to plants for plasma cleaning emissions.
2. For the first time experimentally shown that it is possible streamer breakdown of air gaps of a few centimeters.
3. The factors affecting the efficiency of the treatment plants were determined.
4. The descriptions photos and specification pilot and industrial plants.
5. Presented main results of cleaning emissions from industrial and communal enterprises, diesels engine.

References
[1] Masuda S. and Nakao H. IEEE-IAS Annual Conference. 1986 Denver. pp.1173-1182
[2] Ponizovskii A.Z. Ecological Systems and Devices 2007 №11., S.9-14.9 (In Russian)
[3] Mel'nikov V., Ponizovsky A., Gosteev S., et al Proceedings of the 19th International Symposium on Plasma Chemistry ISPC19 - 2009, Bochum, Germany 26-31 July 2009 P1.5.04
[4] Larsson A J 1998 Phys. D: Appl. Phys. 31 1100–1108
[5] Ponizovskiy A. Gosteev S., et al. Russian Electrical Engineering, vol.64, No3, 1993, pp.77-83