Conference Paper

The Development of Plasma Incineration Technologies for Utilization and Neutralization of Waste Hazardous Class

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Abstract

In this study, the results of studies for plasma incineration processes in technologies of waste disposal and disposal are presented. Due to the high temperatures of the plasma jet (up to 10 thousand K), the speed of the process, the small influence of atmospheric oxygen, the necessary conditions for the neutralization of almost any toxic gases arise. It is noted that the evaluation of the efficiency of toxic gases neutralization with the use of plasma torches is a multiparameter problem, since in addition to the constructive ones, the gas-dynamic and heat-power parameters should be taken into account. The gas-dynamic parameters of the air-plasma flow in the plasma torch mixing chamber for environmental technologies are determined by methods of mathematical modeling. The characteristic temperatures, velocities and heating times of the utilized gas in different areas of the mixing chamber are calculated. Different configurations of mixing chambers with varying confusability are considered. The directions of further research and development necessary to create a technology of plasma incineration with maximum efficiency of disinfection are indicated. The issues of plasma incineration introduction at certain stages of high-temperature waste disposal technologies are also considered. The main advantages of technologies based on high-temperature plasma impact on materials, as well as the main directions of their application in waste management strategies are noted.

Keywords: ecological safety, waste recycling, waste treatment, decontamination, incineration, plasma torch.

Recycling and disposal of waste is one of the priority environmental problems facing not only Russian society, but also humanity as a whole. One of the effective technological solutions that improve the ecological situation of the environment is the use of plasma torches [1] for this purpose, in which at plasma jet temperatures of several thousand degrees it is possible to process almost any waste (solid, soluble, liquid and gaseous) due to the high-energy effect of deep decomposition of substances – plasma incineration (”burning”). However, the use of plasma technologies in waste processing plants should be justified taking into account the quality criteria of the result, efficiency and safety of the process [2, 3]. Due to the significant energy costs, the introduction of plasma technologies is the most appropriate for solving local, but important tasks on sanitary-epidemiological and environmental requirements – the destruction of infected waste, cremation of animal corpses, neutralization of supertoxicants (polychlorinated dibenzodioxides, dibenzofurans, biphenyls, toxic substances, heavy metals and their compounds, etc.). At the same time, it is necessary to refer to the world practice, which has formed the opinion about the exclusivity of the use of plasma methods for the neutralization of toxic substances of hazard class I and II [4], and under certain conditions, radioactive gases.

To date, a large number of plasma torches and schemes of their application in waste disposal technologies have been developed [5] – EcoTechnologies in which waste (mainly dispersed and vapor-gas phase composition) is neutralized by direct introduction into the plasma arc (jet). The specificity of toxic materials neutralization and principles of plasma torches design for these purposes are considered by the authors earlier [3]. Taking into account these principles, a useful model of the plasma torch [6] has been developed and patented, which can be used to neutralize toxic vapor-gas flows of different composition and phase state (Fig.1). A feature of the design of this plasma torch is the presence of a nozzle that also performs the function of the mixing chamber (MC) of the main flow of plasma-forming gas (PFG) and the neutralized secondary flow. Pre-twisted by gas-vortex stabilization system, the PFG in the MC is heated by a plasma arc and interacts with the flow of a tangentially supplied toxic vapor-gas mixture. To intensify the heat exchange of the secondary flow with the arc and the plasma flow, the MC has an confusor area associated with the nozzle chamber of the plasma torch, when due to the complex trajectory of the flows performing both rotational and translational motion, the time of finding the molecules of the toxic substance in the plasma flow increases. The tubes for supplying the secondary flow can be located on the replaceable part of the plasma torch, or be taken out of its limits and located under the nozzle cut at any angle to the axis of the plasma jet.

Evaluation of the efficiency for neutralization of toxic gases in the plasma torch is a multi-parametric task, because in addition to constructive, consider the gas-dynamic and heat-and-power technology parameters. Taking into account the above, the task was set by methods of mathematical modeling in the FlowWorks application of the SolidWorks software to determine the gas dynamic parameters of flows in the MC with different design execution of the heating and cooling zone of the utilized gas. The calculations were carried out for the purpose of subsequent evaluation of thermokinetic processes

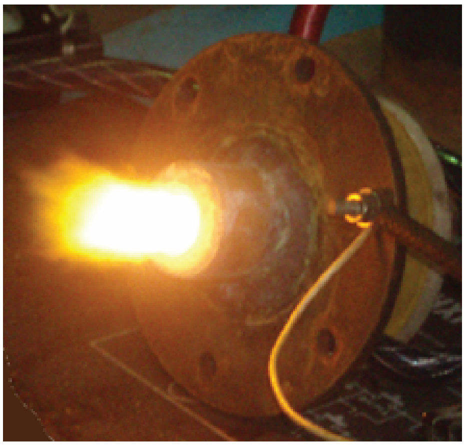

Figure 1: The plasma torch for the disposal of hazardous waste

of toxic waste disposal contained in the secondary gas flow, as well as to develop recommendations for improving the design of the plasma torch and the technological scheme of neutralization. The calculated model of the plasma torch is shown in Figure 2. The calculations were carried out for the air-plasma medium at the mass flow rate of PFG 0,011 kg/s and the diameter of the inlet in MC 4 mm typical for the effective gas-vortex stabilization of the arc plasma torch. The secondary flow of the utilized gas was fed by 2 axisymmetrically located tubes at an angle of 60°, providing the input of the utilized gas tangentially into the plasma jet, with a mass flow rate of 0.005 kg/s for each tube. The calculation of temperatures in the MC was carried out along several straight trajectories (lines) of different distances from the camera axis (Fig.3) at a typical air-plasma arc (jet) length of 90 mm and a temperature of 7000 K. Geometry of the MC: the length of at least 150 mm, the opening angle of the initial part – 20°, opening the rest of the length for confusor MC – 5°.

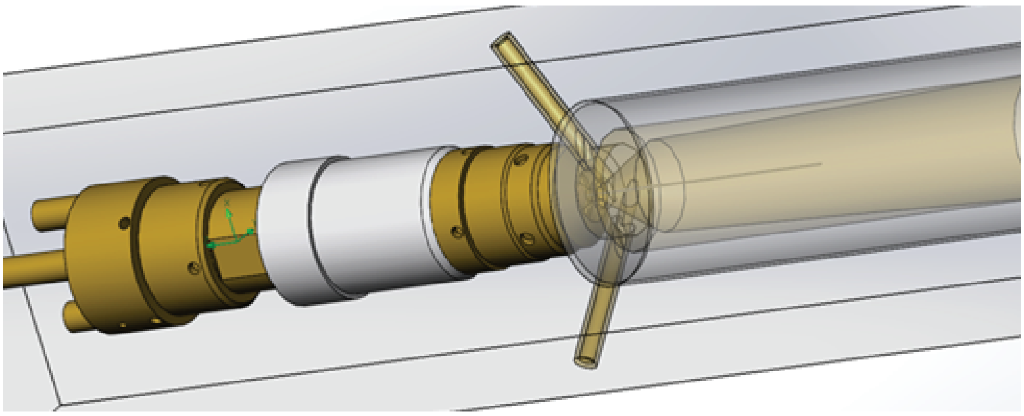

Figure 2: A computational model of the plasma torch for environmental technology

Calculations of gas flow velocities in two types of mixing chambers – cylindrical (Fig. 4) and confusor are made along the trajectories in the direction of the Y axis (Fig.3).

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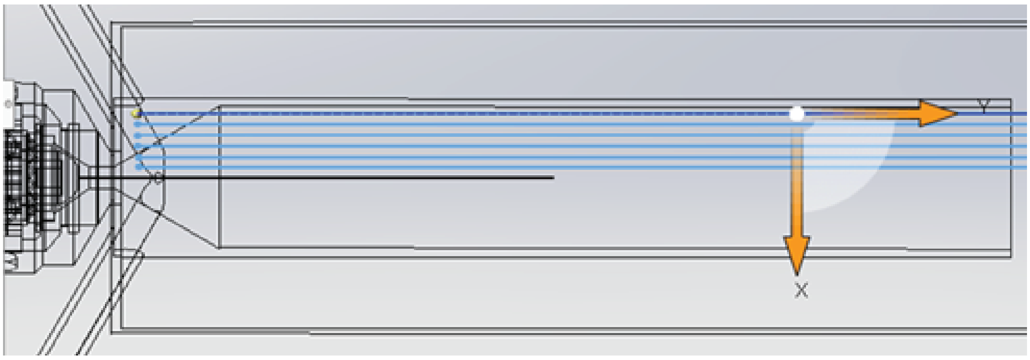

Figure 3: Trajectory calculation of velocity and temperature in the mixing chamber of the plasma torch

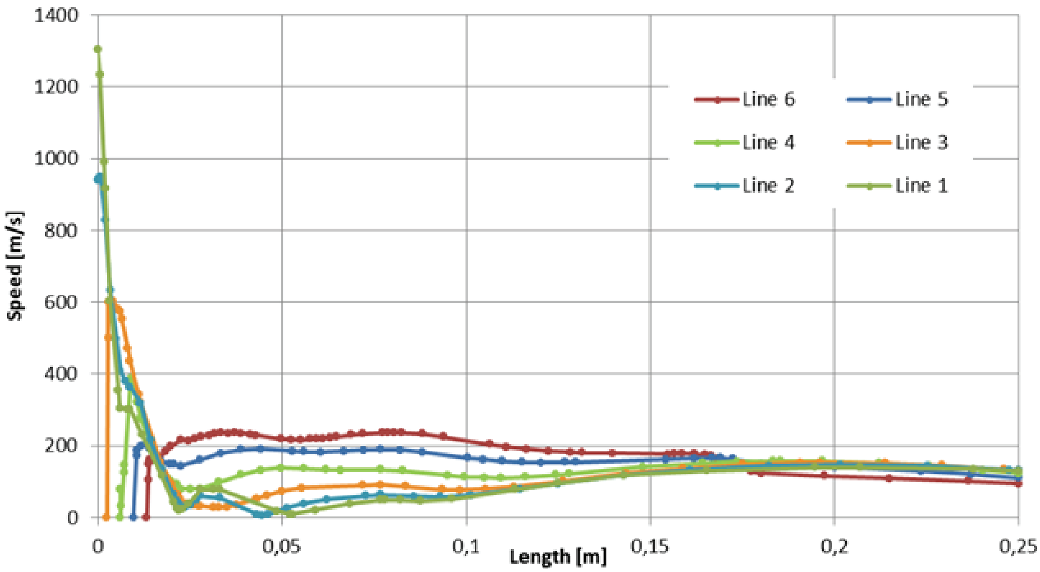

Figure 4: The calculation of the velocities in the mixing chamber of the torch cylindrical type

The numbering of lines from the axis of the MC. It is seen that in areas of flow mixture velocity are of the order of 150-200 m/s in cylindrical and 75-150 m/s in the confusor MC. The estimation of average flow velocities along the design lines shows that in the cylindrical MC there is no significant change in velocities as the distance from the MC axis, and in the presence of confusor, the average velocities as the distance from the axis decreases 2-3 times, which is obviously due to both the change in the trajectories of the flows and the decrease in the flow temperature at a distance from the axis in the cone-type MC.

Estimates of the characteristic residence time of the utilized gas in the mixing chamber give values less than 0.01 s along the selected linear and spiral trajectories. It should also be noted that the increase in heating time in areas with a slightly lower temperature (near the walls of the MC) contributes to the efficiency of neutralization. The same conclusion can be made when comparing the effect of two types of MC on the heating time. In the case of a confusor type, the heating time increases by 1.5-3 times depending on the trajectory, with the greatest increase occurring near the walls of the MC.

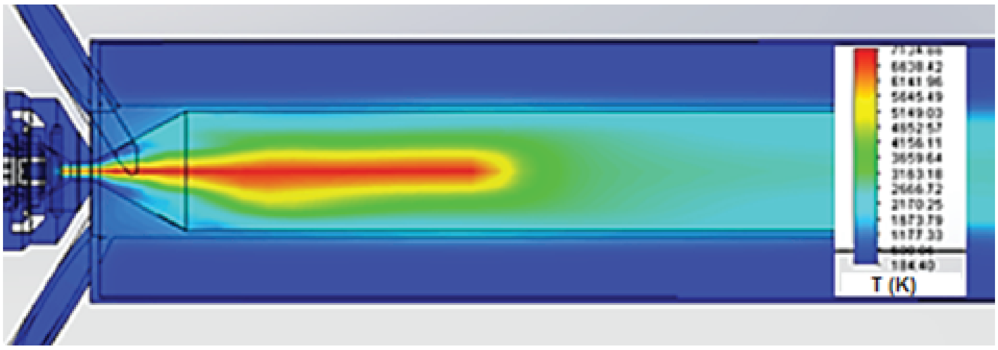

Figure 5: Temperature distribution in a plasma torch with cylindrical MC

To evaluate the efficiency of thermokinetic processes in addition to the rates and duration of heating, the temperatures of gas flows in the MC were determined (Fig.5). The results of the temperature calculations are presented in Figure 6 (for the plasma torch with a confusor MC) and Figure 7 (average temperatures). The analysis of these results shows the appearance of a significant temperature difference (from 2000 to 6000 K) in the radial direction from the MC axis with a significant decrease (from 1500 to 2500 K) in the region of the cylindrical mixing chamber remaining outside the plasma jet. For a plasma torch with a confusor MC, there is a more efficient heating in the plasma jet (from 2500 to 6500 K) with minimization of the radial temperature gradient in the MC outside the plasma jet. At the same time, in a plasma torch with a cylindrical MC, there is actually no axial temperature gradient outside the plasma jet, unlike a plasma torch with an confusor MC, in which the temperature decreases by about 1000 K to the outlet from the MC.

The obtained results (Fig.6 and Fig.7) make it possible to make the necessary for thermokinetic calculations estimate the average heating temperature during the stay of the secondary gas flow in the mixing chamber. These temperatures range from 3500 to 4500K in the areas close to the axis of the MC and about 2,500 K for the fields remote from the axis. For an approximate assessment of the plasma incineration efficiency, it is possible to take the average heating temperature in the plasma torch MC for EcoTechnologies about 3000 K, at which the characteristic time of neutralization for one of the most dangerous supertoxicants – dioxin – can be approximated according to available information [7] by a value of 2-5 ms (less than the above value about 0.01 s). This result shows significant advantages of the plasma method in comparison with the known technologies of pyrolysis or grate combustion of waste, at which the maximum temperatures, as a rule, are less than 1000 K and do not provide effective destruction of the above-mentioned supertoxicants.

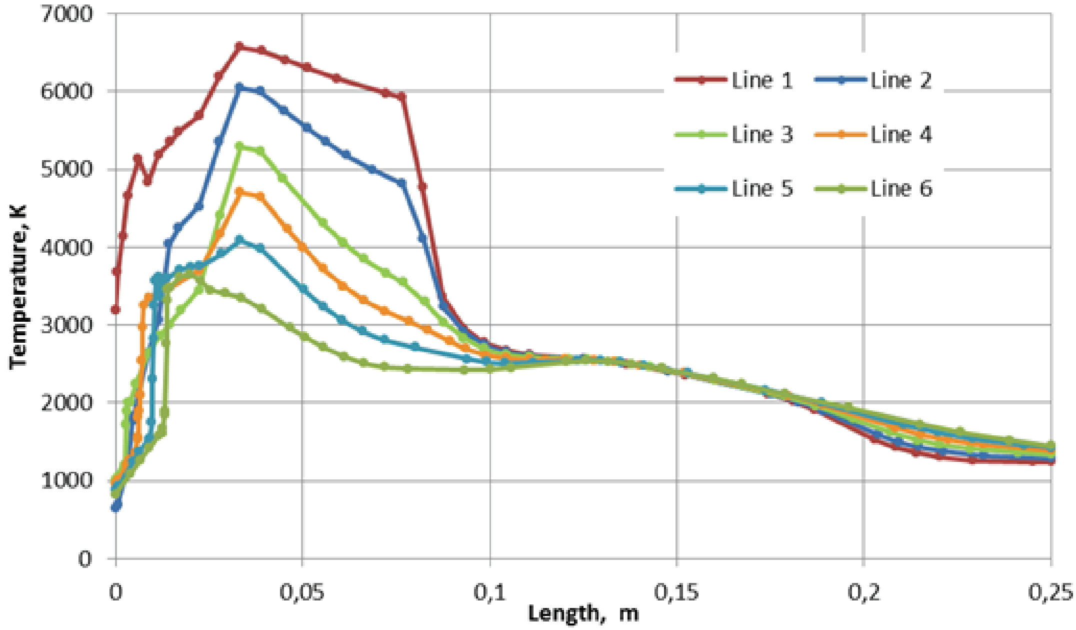

Figure 6: Temperature distribution along trajectories in a plasma torch with a confusor MC

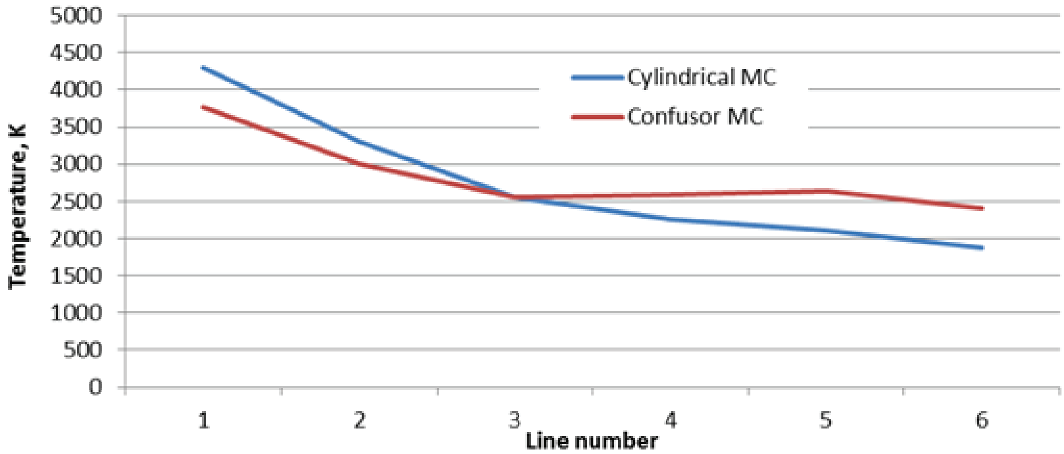

Figure 7: Average temperatures in the plasma torches with cylindrical and confusor MC

The presented results allow to use them to calculate the efficiency of toxic gas neutralization using the claimed design of the plasma torch. When the low efficiency of the decontamination technology can be improved as structurally (by modifying the size and geometry of the MC) and technologically (using more high-enthalpy gas or more powerful torches). Plasma decontamination is advisable to carry out in an oxidizing or reducing environment with the supply of air, oxygen and other gases, thereby making it possible to regulate the parameters of the environment for effective action on a particular utilized substance (dioxins, pesticides, herbicides, etc.). It is obvious that additional studies are needed to assess the effectiveness of the quenching (cooling) system formed after the plasma destruction of the decay products. One of the possible

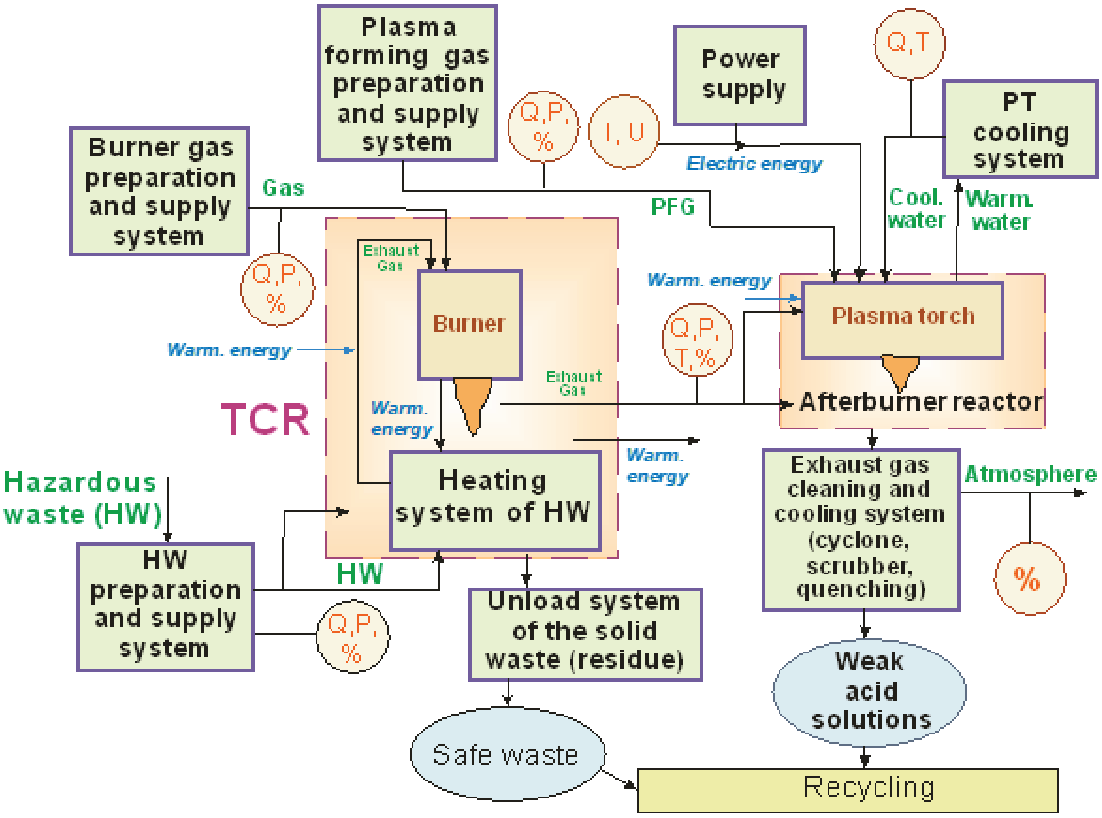

Figure 8: Material-energy scheme of hazardous waste disposal with plasma afterburning of waste gases (PT – plasmatron, TCR – thermochemical reactor; PFG – plasma forming gas; HW – hazardous waste; Control sensors: I – current, U – voltage, Q – flow rate, P – pressure, T – temperature, % - composition) [2, 3]

technological schemes of the plasma torch for EcoTechnologies application in the reactor for waste gases afterburning after thermal neutralization is shown in Figure 8.

Potential consumers of plasma incineration of waste technologies are enterprises for waste processing, waste sorting complexes in large cities, structural departments of the Ministry of emergency situations – in places of man-made accidents, agricultural and livestock complexes – for burials of infected organic matter, etc.

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