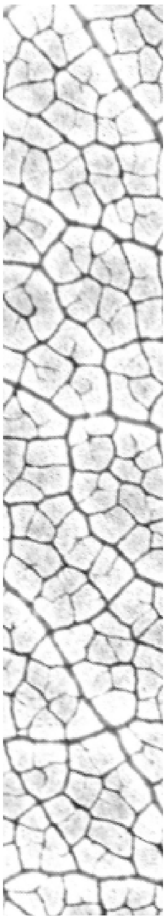

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Study of plasma incineration processes in ecological waste recycling technologies

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Abstract

The processes of high temperature material heating for plasma recycling are investigated. The gas-dynamic parameters of the air-plasma flow in the plasma torch mixing chamber for ecology 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 determined. The directions of further research and development necessary to create a technology of plasma recycling with maximum efficiency are outlined. The issues of plasma recycling introduction at certain stages of high-temperature technologies are also considered.

Keywords: plasmatron, design, efficiency, environmental safety, recycling

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INTRODUCTION

Recycling and disposal of waste is one of the priority environmental problems facing not only Russian society, but also humanity as a whole (Riaby et al. 2016). One of the effective technological solutions that improve the environmental situation is the use of plasma torches (Cherednichenko et al. 2011) 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") (Fridman and Kennedy 2016). However, the use of plasma technologies in waste processing plants should be justified taking into account the criteria of quality of the result, efficiency and safety of the process (Anakhov and Pyckin 2012, Anakhov et al. 2014). 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 (Fridman 2008), and under certain conditions, radioactive gases.

TECHNIQUE OF RESEARCHES

To date, a large number of plasma torches and schemes of their application in waste disposal technologies have been developed (Anakhov 2018, Xiuquan et al. 2015) – 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 (Anakhov et al. 2014, Pyckin and Anakhov 2013) Taking into account these principles, a useful model of the plasmatron (Pyckin et al. 2007) 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 this plasma torch design is the presence of a nozzle that also performs the function of the mixing chamber (MC) – the plasma-forming gas (PFG) flow and the neutralized secondary flow. Pre-twisted with the help of a gas-vortex stabilization system, the PFG in the MC is heated by 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 a confusor area associated with the nozzle chamber of plasmatron, when due to the complex trajectory of the flows

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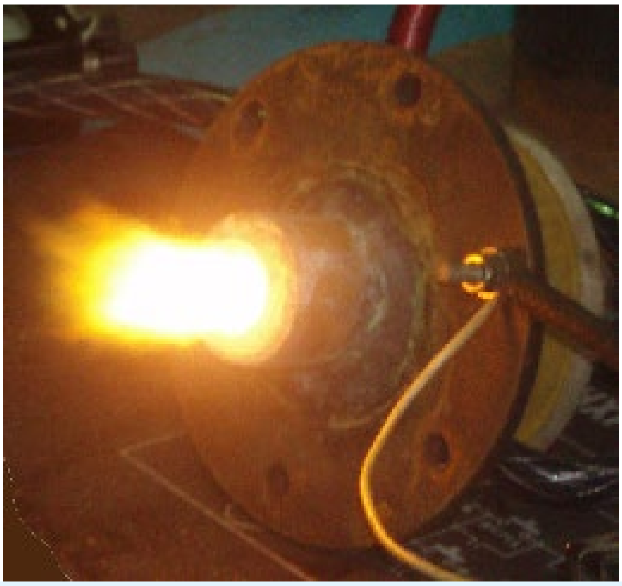

Fig. 1. The plasma torch for the material recycling

performing both rotational and translational motion, the time of finding the molecules of the toxic substance in the plasma flow increases. The nozzles 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 of the toxic gases neutralization with the use of the such type 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 purpose of subsequent evaluation of thermo-kinetic processes of neutralization of toxic waste 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 **Fig. 2**. The calculations were carried out for the air-plasma with the characteristic for effective gas-vortex stabilization of the arc plasma torch mass flow rate of the main flow of PFG 0,011 kg/s and the diameter of the inlet in MC 4 mm. The secondary flow of the utilized gas was supplied by 2 axisymmetrically arranged nozzles at an angle of 60^0, 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. The 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°.

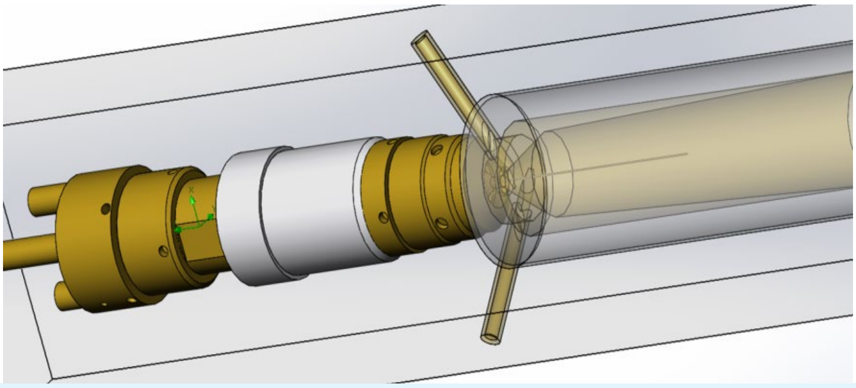

Fig. 2. A computational model of the plasma torch for EcoTechnology

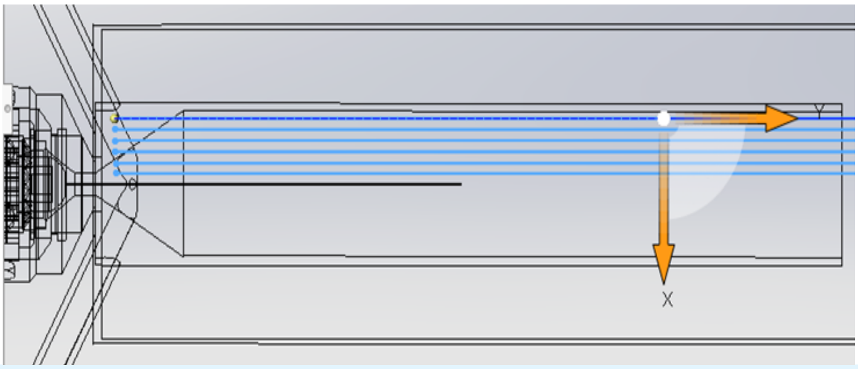

Fig. 3. Trajectory calculation of speed and temperature in the mixing chamber of the plasma torch

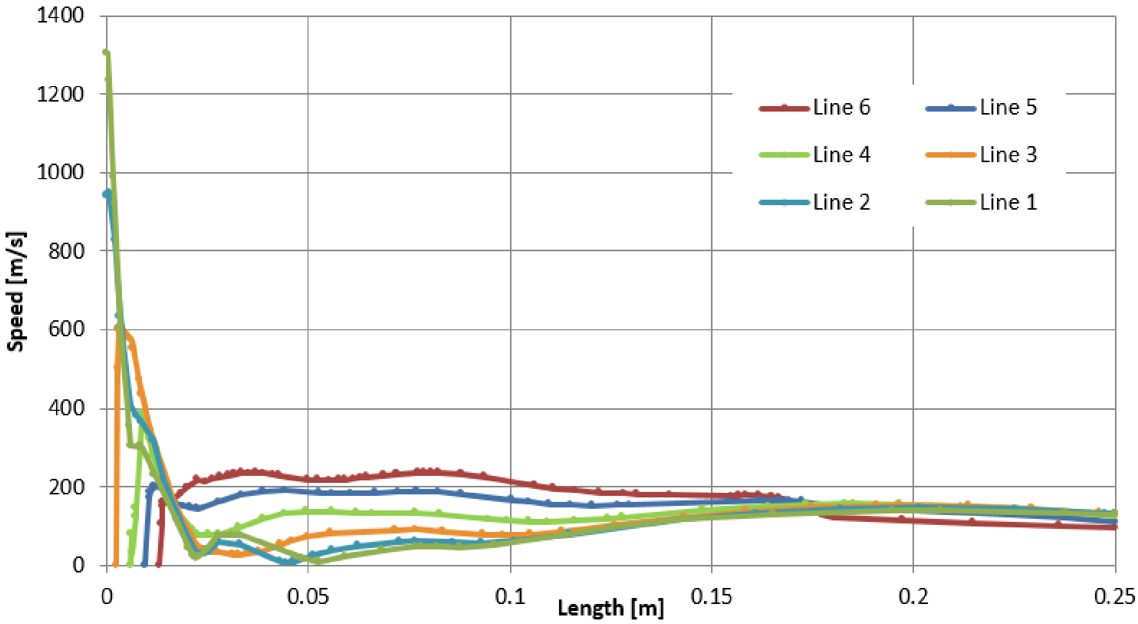

Fig. 4. The calculation of the speed in the mixing chamber of the cylindrical type torch

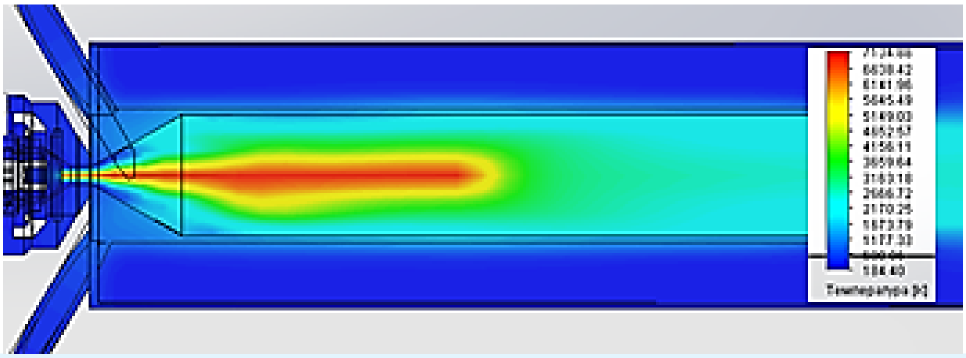

Fig. 5. Temperature distribution in a plasma torch with cylindrical MC

RESULTS AND DISCUSSION

Calculations of gas flow speeds in two types of mixing chambers – cylindrical (**Fig. 4**) and with confusor are made along the trajectories in the direction of the y axis (**Fig. 3**). The numbering of lines from the axis of the MC. It is seen that in areas of flow mixture speeds are about of 150-200 m/s in cylindrical and 75-150 m/s in the confused MC. Assessment of average flow speed along the calculated lines shows that in a cylindrical MC of a significant change in speed as the distance from the axis of the MC is not observed, and in the presence of confusingly average speed as the distance from the axis reduced in 2-3 times, which obviously is related to a change of the trajectories of the flow, or decrease flow temperature at a distance from the axis of the MC cone type.

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 of heating time in the 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 confusor type of MC, the heating time increases by 1.5-3 times depending on the trajectory, with the greatest increase occurring near the walls of the MC.

To assess the effectiveness of thermo-kinetic processes in addition to the speeds and the time of heating was determined the temperature of gas flows in the MC (**Fig. 5**). The results of the temperature calculations are shown in **Fig. 6** (for a plasma torch with a confusor MC) and **Fig. 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, more efficient heating is observed in the plasma jet region (from 2500 to 6500 K) with minimization of the radial

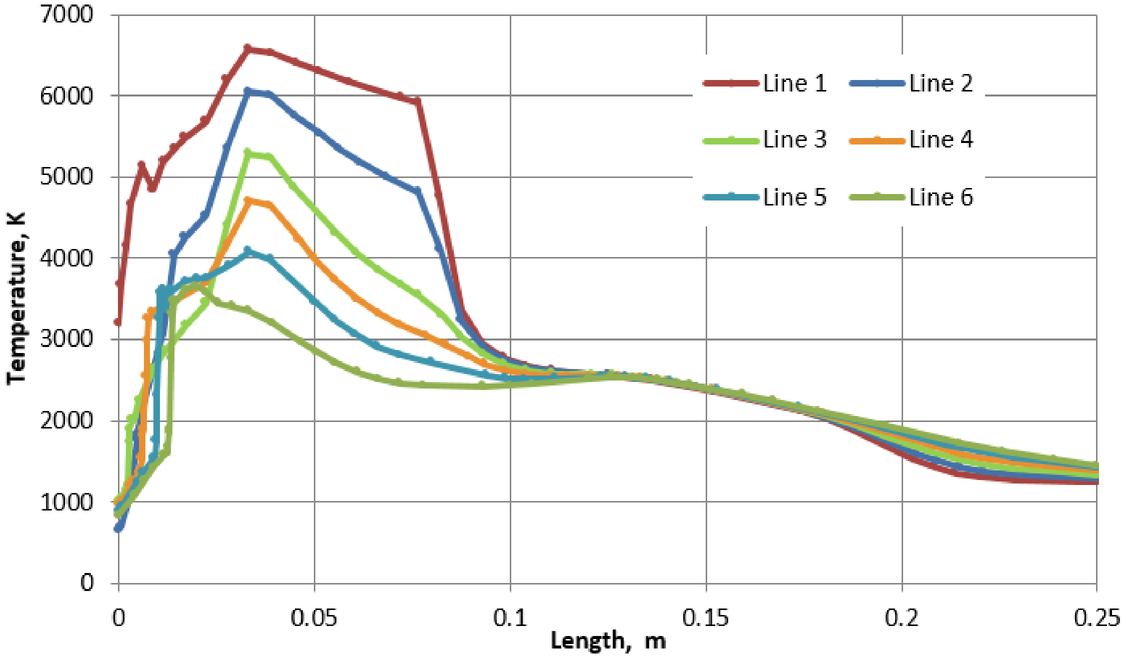

Fig. 6. Temperature distribution in a plasma torch with cylindrical MC

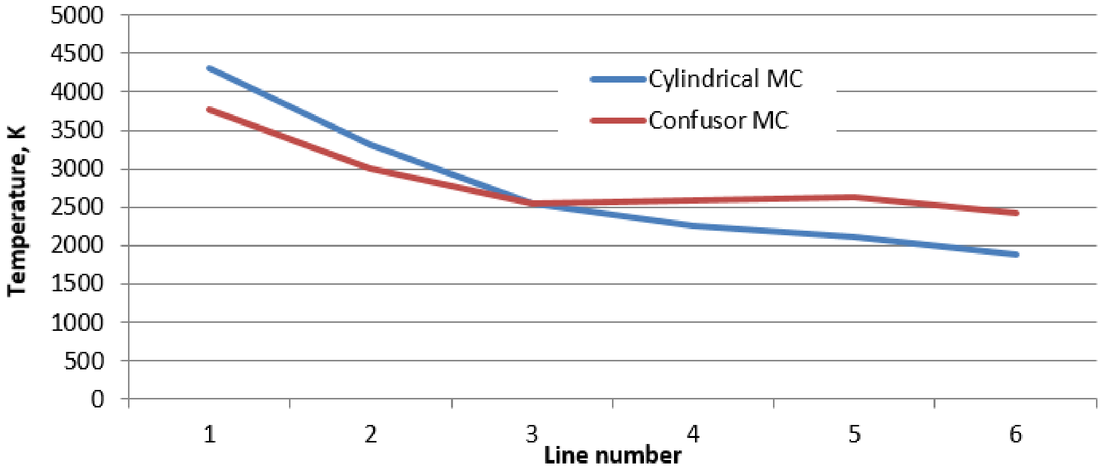

Fig. 7. Average temperatures in the plasma torches with cylindrical and confusor MC

temperature gradient in the MC region 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, in contrast to a plasma torch with a confusor MC, in which there is a decrease in temperature by about 1000 K to the output of MC. The results presented in **Fig. 6** and **Fig. 7** allow to make the necessary for thermo-kinetic calculations assessment of the average heating temperature during the passage of the secondary gas flow through the mixing chamber. These temperatures range from 3500-4500 in areas close to the axis of the MC and about 2500 K for outlying from the axis fields. For an approximate assessment of the plasma recycling efficiency, it is possible to take the average heating temperature in the plasma torch MC for EcoTechnologies about 3000 K, at which the characteristic neutralization time for one of the most dangerous supertoxicants – dioxin (Parfenuk et al. 2002) – can be approximated by a value of 2-5 ms (less than the above value of the order of 0.01 s). The last result shows significant advantages of the plasma method in comparison with the known technologies of pyrolysis or grate combustion of waste (Kasatkin 1971), at which the maximum temperatures, as a rule, are less than 1000 K and do not provide effective destruction of the above-mentioned supertoxicants.

CONCLUSIONS

The presented results of gas-dynamic parameters evaluation for plasma recycling technology allow using them to calculate the efficiency of toxic gas neutralization using the claimed design of the plasma torch. With low efficiency of neutralization, the technology can be improved both structurally (by modifying the size and geometry of the MC) and technologically (by using higher enthalpy gases or more powerful plasmatrons). Plasma decontamination can be carried 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 medium for the purpose of 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 technological schemes of application of the plasmatron for EcoTechnologies is the use in the reactor for afterburning of waste gases after thermal neutralization.

Potential consumers of plasma recycling technologies (Anakhov and Pyckin 2011) are institutions and centers for waste processing, waste sorting complexes in large cities, structural units of the Ministry of emergency situations (Ministry of emergency situations) – in places of man-made accidents, agricultural and livestock complexes – for burials of infected organic matter (Pyckin and Anakhov 2010), etc. Attention should be paid to the use of plasma technologies in solving environmental problems of forestry (Dorozhkin and Tkacheva 2008) and water management (Kulagin et al. 2008), in training future ecologists, etc.

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