Simulation of thermal processes of shaft plasma furnace for waste gasification

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Abstract. Mathematical modeling of a part of a mine plasma electric furnace for waste gasification is presented. In model calculations, the study of the effect of additional resistive heating as an in-furnace process of drying waste was carried out. In the course of modeling, the electrical resistance of the waste at natural moisture was taken into account. A study was carried out to identify the uniform release of energy inside the waste batch in the drying zone with different connections of the electrodes and the type of current.

1. Introduction
One of the main environmental tasks of the contemporary world is waste recycling and disposal. The man-made waste consists of various types of waste, including organic waste. The amount of man-made waste is increasing annually at a catastrophic rate. There are many ways to deal with waste. However, the most effective today is the plasma gasification of organic waste in mine electric furnaces. Such plasma electric furnaces in the course of waste gasification are characterized by high energy consumption (1 kW per 1 kg of waste) [1]. This indicator is a disadvantage of such installations. In the contemporary world, the trend in the development of new technologies focuses on energy efficiency. Therefore, the development of new approaches to the implementation and development of plasma installations for gasification of organic waste with lower energy consumption is dictated by time. Such installations, capable of consuming less energy, are electric furnaces with the ability to combine heating, plasma heating, and ohmic heating.

During the development and study of combined plasma-ohmic heating, applicable to waste gasification, it was found that organic waste has electrical resistivity at natural moisture (in real conditions, moisture reaches up to 60%). The waste is loaded from top to bottom and passes the drying zone first. Therefore, ohmic heating is realized only in this zone of the electric furnace. The following areas of the furnace should be supplied dry with a minimum amount of moisture.

2. Mathematical model
The research object is a mine plasma electric furnace with electric arc plasmatrons, installed in the lower part (furnace productivity for waste, plasma torch power is arbitrary). Wet waste is loaded from top to bottom.

When studying the resistive heating of technogenic waste, it is necessary to know their thermophysical (λ, c, γ) and electrophysical (ρel) properties, as well as the methodology for
calculating thermal conductivity, specific heat capacity, and density of waste (on the example of solid domestic waste).

When developing a mathematical model, the value of the apparent effective electrical resistivity was used, measured by the radio magnetotelluric method for household waste dumps, and presented in the article [2]. The value of specific electrical resistance, determined by the authors of this article was $3-5$ Ohm$\cdot$m.

This resistance was measured in the summer at a natural moisture content of the waste. When processing municipal solid waste (MSW), it will be moist only within the drying zone. The waste enters the heating zone dehydrated and dry, with a resistivity ten times higher than that at the beginning of the drying zone. Therefore, resistive heating is implemented only in the drying zone.

When formulating a model of electromagnetic calculations, the geometric shape of the furnace chamber is important. Considering that mine high-temperature units for ore processing, MSW, and MW have a circular cross-section, a vertical working chamber of cylindrical shape was chosen when creating a model of resistive heating.

Figures 1a and 1b show single-phase and three-phase resistive heating circuits for the drying zone. When creating the model, we assume that within the drying zone, the electrical resistivity remains constant, equal to $\rho=5$ Ohm$\cdot$m.

One of the tasks that must be solved by resistive heating of the drying zone is heating the MSW charge evenly over the cross-section of the furnace working chamber. Therefore, the purpose of the performed study of electromagnetic processes during resistive heating of the drying zone is to estimate how uniformly the power of internal heat sources is distributed over the cross-section of the furnace shaft.

**Figure 1.** Layout of electrodes in an electric furnace: 1 - electrodes; 2 - MSW charge. a) single-phase electrode arrangement system; b) three-phase electrode arrangement system.
The mathematical description of continuous in space and time processes of the electromagnetic field in the drying zone of the furnace are presented by differential equations of electrodynamics in partial derivatives, written with respect to the vector magnetic and scalar electric potentials, and the equation of continuity.

The initial data for the calculation are the geometric dimensions of the "graphite electrodes - MSW charge" system and the electrophysical properties of materials in the computational domain. The current in the electrodes is set as the source of the electromagnetic field. To obtain the most correct results, the ANSYS software package was used with a uniform partition of the electrodes - MSW system loading.

3. Results of mathematical modeling

For the calculation and analysis of the processes occurring in the mine of an electrical installation, several basic and variable parameters were determined, namely, voltage, geometric shape, and a number of phases. The thermophysical properties of the charge, as well as the electrophysical (electrical) properties of the graphite electrodes and the MSW charge, were taken as the main parameters.

Based on the presented geometric and mathematical models, calculations were carried out, as well as an analysis of their results. At the stage of preliminary analysis, the output parameter was the power distribution of internal sources over the height and cross-section of the drying zone, obtained by resistive heating of the zone. With a model representation of a drying zone with a height of 1 m with the same resistivity throughout the entire volume of this zone and a height of 0.3 m of a single-phase system of electrodes, the power distribution of the internal sources, shown in Figure 2, was obtained, forming an arc with an angle of 60°. The power density graph is uneven in height with a maximum at the edges of the electrodes.

Based on the analysis of the power release graph (Figures 2 and 3), it can be concluded that up to 70% of the power, released due to resistive heating is concentrated at the ends of the electrodes, and the rest of the power is distributed in the rest of the cross-sectional space, weakening towards the central (axial) mine area.

![Figure 2. Power dissipation at U = 1000 V (three-phase version of the electrode arrangement).](image)

![Figure 3. Distribution of current density in the bulk of the solid waste, U = 1000 V.](image)

In this case, neither the connection of a three-phase voltage to three electrodes located along the perimeter of the furnace charge surface (Figure 2) nor a single-phase voltage, supplied to two symmetric electrodes (Figure 4) provide the necessary uniform power release from internal heat sources over the section of the mine.
Analysis of the results in the mathematical modeling of various geometries of the connection of electrodes and changing the voltage phase (one- or three-phase) in the cylindrical drying zone showed that the release and distribution of power inside the waste batch were uneven. At that, 70% of the released power occurs in a narrow area of the charge in the near-electrode space, weakening towards the central part of the mine.

Figure 4 shows that the distribution of the specific power in the square cross-section of the shaft is uniform. The distribution of this power over the height of the drying zone is also uniform (if the calculation is carried out for the same resistivity over the entire volume of the drying zone).

The power level introduced into the charge by means of resistive heating in the drying zone can reach 20-50% of the plasma torch power required to implement the solid waste processing technology.

4. Conclusions
Analysis of the results of calculations of the power distribution of internal heat sources in the cross-section of the furnace, obtained for round, rectangular, and square sections at constant and alternating (single-phase, three-phase) currents, showed that in the upper part of the furnace in the drying zone, the section should be square, and within the rest of the zones – it should be round conically diverging.

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References
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