Modeling ohmic heating in the drying zone of the plasma shaft electric furnace, when recycling the technogenic waste

A I Aliferov\(^2\), A S Anshakov\(^1,2\), V A Sinitsyn\(^1,2\), P V Domarov\(^1,2\), A A Danilenko\(^2\)

\(^1\) Kutateladze Institute of Thermophysics SB RAS, Novosibirsk, Russia
\(^2\) Novosibirsk State Technical University, Novosibirsk, Russia

E-mail: Domaroff@yandex.ru, anshakov@itp.nsc.ru

Abstract. Efficient use of ohmic heating in the drying zone of the plasma shaft furnace for gasification of organic and technogenic wastes is studied. It is shown that by using ohmic heating in the drying zone, energy release takes place in the filling along the entire zone.

1. Introduction

Now the problem of disposal and neutralization of annually increasing technogenic wastes, including the organic ones, is urgent all over the world. One of the effective ways to solve this problem is waste gasification in the plasma shaft furnaces. However, they have significant disadvantages: high energy consumption (up to 1 MW·h per 1 ton of waste), and short service life of plasmatron electrodes [1]. Therefore, the development of new approaches to the creation of electrotechnological plasma installations with improved power parameters for the problems of technogenic waste (TW) processing is very popular nowadays. These energy-efficient installations are the electric furnaces with combined plasma-ohmic heating, used for TW processing.

During the processing, the waste are wet (in real conditions, their humidity is up to 60%) in the zone of their supply only within the drying zone. Waste should be fed dehydrated and dried to the pyrolysis zone. Therefore, ohmic heating by the current of commercial frequency will be implemented only in the drying zone. The shape of the drying zone cross-section is selected to be square, to ensure uniform power distribution \(q_{Vep}(x)\) over the waste charge cross-section.

2. Electromagnetic processes in the drying zone of electric furnace

According to analysis of publications, in summer the wet solid domestic waste show such a property as specific electric resistance, whose value is \(\rho_{el}=3\div5\ \text{Ohm} \cdot \text{m}\). Moreover, depending on humidity and morphological composition, this value can differ significantly from the value presented above. Therefore, in model calculations it was assumed that \(\rho_{el}=1\div10\ \text{Ohm} \cdot \text{m}\).

While modeling, it was taken into account that wastes contain moisture only in the loading and drying zones until it evaporates due to the temperature. Thus, ohmic heating by the current of commercial frequency can be implemented only in the drying zone. Wastes are fed to the pyrolysis...
zone in the dehydrated and dry form with the specific electric resistance, which is ten times higher than in the beginning of the drying zone.

![Diagram of plasma-ohmic furnace](image.jpg)

The shape of the drying zone cross-section was chosen square, to ensure uniform distribution of power $q_{Vep}(x)$ over the waste charge cross-section.

2.1 Mathematical model

When organizing a continuous process are formed the established dynamic and thermal regimes in the furnace chamber. Therefore, heat and mass transfer processes in these conditions, the countercurrent solid and gaseous phases can be considered stationary.

While developing the model of electromagnetic processes, some assumptions were made: 1. We neglect the displacement currents. 2. The electromagnetic field is alternating, changing sinusoidal in time. 3. There are no free discharges in the computational domain. 4. The process of mass transfer in the elementary layer of the charge believe quasi-stationary.

The differential equation of are the mathematical description of the processes of electromagnetic field, continuous in space and time, in the drying zone of the furnace.

When forming the electrical circuit “electrode - charge – electrode”, the value of current introduced into the system on the face surface of electrodes has been set (calculation was carried out at the stabilized alternating current of the commercial frequency).

The drying zone is produced in different sections of the removal of water vapor into the lower zone of the combustion furnace.

The assigned task is solved using the software complex ANSYS by the method of finite elements.

3. Results of mathematical modeling

The output of integral power in a charge with passing electric current was calculated by the software complex ANSYS. The range of voltage applied to the electrodes was $U=50\div250\text{V}$ and current $I=100\text{A}$. In the filling, specific electric resistance technogenic waste was set as humidity linear function $\rho_{el}=f(W)$, in the range of electrical resistivity $\rho_{el} = 1 \div 10 \text{ Om} \cdot \text{m}$ and waste humidity $60 \div 15\%$.

Dependence of integral power, allocated to the elementary volume release along the height of drying zone at ohmic heating on voltage applied to the electrodes is shown in Figure 2.
Figure 2. Power output along the drying zone: 1 – $U=50\text{V}$; 2 – $U=100\text{V}$; 3 – $U=150\text{V}$.

It can be seen that when increasing the specific electric resistance of waste, the power output in the filling decreases along the height. This is due to liquid evaporation from technogenic wastes, while they move down the shaft. As it can be seen from the diagram, at the level of 0.5 m from the edge of the loading window, the released power does not change, and this suggests the possibility of reducing the geometric dimensions of electrodes (decreasing their length) from 1m to 0.5m.

As it was shown in [2, 3], specific power inputs for technogenic waste processing depend significantly on their humidity. The calculation-experimental dependence determining a link between the costs required for technogenic waste processing and their humidity is shown in Figure 3.

During the drying process under the action of ohmic heating, moisture evaporates from wastes, decreasing from $(60 \div 50)\%$ to 20%. Wastes with minimum humidity of 20% contain all chemical elements required for their complete gasification. As it can be seen in Figure 3, while reducing waste humidity from 50 to 30%, the specific power inputs for gasification reduce considerably (almost twice - from 0.75 to 0.4 kW•h/kg). Thus, at combined plasma-resistive heating of technogenic waste charge, we achieve a significant reduction in specific power inputs using heat supply only from the plasmatron for processing 1kg of technogenic waste: less than 0.4 kW • h/kg (see Figure 3.).
An example of the ohmic heating effect on decreasing the plasmatron loading is as follows. For plasma furnace productivity $G_m=100 \, \text{kg/h}$, the required plasmatron power is $140 \, \text{kW}$. Reducing waste humidity to 29% leads to a decrease in plasmatron power to 50 kW. Therefore, additional power input through resistive heating $P = 140 - 50 = 90 \, \text{kW}$ in the drying zone allows reduction in plasmatron power by 58% for the given furnace efficiency.

4. Conclusions
Distribution of produced power along the height was calculated taking into account the dependence of resistance on humidity. They showed a significant change in the characteristic, and this should obligatory affect heat transfer inside the shaft.

While analyzing the results and summing them up, it should be noted that ohmic heating of wet wastes in the upper part of the shaft electric furnaces is an analogue of preliminary technological process of waste drying before loading them into the furnace, aimed at reduction of specific power inputs for gasification of organic component of the mixed wastes. This also reduces the plasmatron loading, increasing the service life of plasmatron electrodes.

References
[1] Cherednichenko V S, Anshakov A S, Kuzmin M G Plasma electrotechnological devices / - Novosibirsk: NSTU, 2011.- 602p.

[2] Kuzmin M, Cherednichenko V, Anshakov A, Aliferov A, Domarov P, Radko S, Urbakh E and Faleev V 2012 Plasma electric furnace for processing/utilization of carbon-bearing anthropogenic wastes (Proceedings of the XVII Congress ) pp 127-131.

[3] Aliferov A I, Anshakov A S and Sinitsyn V A 2009 Numerical modeling of heat transfer in plasma shaft electric furnace at utilization of anthropogenic waste Thermophysics and Aeromachanics Vol. 16 No. 1 pp 155-161