Incinerator for thermal cleaning of ash and slag waste

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Abstract. The research of remelting ash of incineration waste was described. The chemical composition of ash and slag waste in the process of thermal neutralization of municipal solid waste was revealed. To determine the chemical and phase composition of the ash at a temperature of 1700K, thermodynamic calculations were performed. Based on the calculation results, experimental studies of remelting ash and slag waste from an incinerator were conducted. It was experimentally confirmed that the melt of fly ash cooled in water takes the form of an inert vitrified slag.

1. Introduction
The definition of “municipal waste” should be attributed primarily to non-industrial waste. However, the dividing line between the definitions of household and industrial waste is rather arbitrary: for example, municipal solid waste (MSW) and some industrial waste contain up to 80% of hydrocarbon raw materials. Part of household waste falls into industrial waste, and industrial products are often present in household waste. Therefore, municipal waste is a mixed waste since its composition can vary widely.

The thermal neutralization of municipal solid waste (MSW) is the most effective way to solve the problem of cleaning cities from household waste. Despite its shortcomings, the real status of the problem is such that it needs to be solved. At that, waste incineration plants (WIP) allow this to be done quite quickly. Here, the main problems concern the need to treat highly toxic waste gases and the processing of ash and slag waste.

Ash and slag waste after incineration is usually toxic and has a hazard class III. Let us distinguish between fly and hearth ash. Fly ash is carried away from the exhaust gas chamber and is retained by bag filters. It contains a high content of volatile and heavy metals and dioxins absorbed on its particles. In the hearth ash, which is discharged from the grate of the furnace, heavy metals are also present, but less than in the volatile. They also exist in slags but are present in a slightly soluble form (oxides and silicates).

Gasification of carbon-containing waste is a complex physicochemical process with a large number of effects, whose complete scientific explanation is far from completion.

The composition of carbonaceous wastes can vary over a wide range, which requires a flexible and versatile technology. The main technical problems that are holding back the widespread use of plasma technologies to process technogenic wastes have not yet been solved. This concerns the low life of the plasma torches and the high energy consumption for their pyrolysis. A separate question concerns primarily the environmental and safety technology, purification, and neutralization of harmful emissions. The need for the disposal of ash and slag waste (ASW) from WIPs is associated with the fact that these wastes contain highly toxic heavy elements and hazardous chemical compounds in a
concentrated state. Ash and slag waste is generated not only from the inorganic components of the processed solid municipal waste (MSW) but also from the burning of the organic components. The underburning consists mainly of carbon and the associated high molecular weight dangerous carcinogenic chemical compounds, such as dioxins (C12H4Cl4O2); furans (C4H4O); benzopyrenes – groups of organic substances consisting of three or more benzene rings that can accumulate in plants and living organisms. Ash and slag wastes are also formed during MSW gasification. This waste contains both inorganic components and underburning. Therefore, the methods of neutralizing ash and slag waste from WIPs are also applicable in the processing of ash and slag waste from waste processing plants.

2. Mathematical model of heat and mass exchange

Various methods of heating ash and slag waste in a combined plant (for example, a gasification chamber and an ash melting chamber are part of the same plant) affect both the gasification and combustion process, as well as the ash neutralization process.

In [1], the results are presented for the thermal neutralization of wood sawdust using a jet plasmatron in the melting chamber into which the inorganic components entered and were not burned after gasification of a portion of the wood sawdust from the gasification chamber. In the jet plasmatron, plasma was used as the plasma-forming gas in the amount necessary for gasification of carbon according to the equation: 2C + O2 = 2CO. On the gas analyzer readings given in [1], in the time intervals when the plasma acted only on the ash and gas treatment, and there was no sawdust in the gasification chamber, the composition of the produced gas was recorded: CO2 = 15%; CO = 5%; H2 = 1.5%; CH4 = 0.7%; O2 = 0.3%; N2 = 77.5%. During the joint operation of the gasification chamber and the melting chamber, the gas composition was recorded: CO = 25.5%; CH4 = 20.2%; H2 = 12.8%; CO2 = 10.6%; N2 = 30.9%. Air with a flow rate of 5 g/s was used as a plasma-forming gas for a gasifier capacity of 20 kg/h for sawdust, while the power of the plasma torch was 50 kW. Heating the ash with plasma-forming air leads to carbon burnout from the ash composition and an increase in the CO2 content in the synthesis gas.

In [2], the results of the thermal neutralization of wood sawdust using the direct effect of an arc discharge on the ash discharge coming from the surface of a heat-gasifier without supplying plasma-forming air are presented. In this case, the current channel of the electric discharge passed directly through the ASW either in the form of an arc discharge burning in ASW vapors and the produced gas or the conducting medium of molten slag (ohmic heating). The power of this discharge was 8 kW. The results of a chemical analysis of the obtained gas samples during the joint operation of the arc discharge and the heater revealed its composition: CO2 = 6.84%; CO = 26.34%; H2 = 60.7%; CH4 = 0.32%; N2 = 5.8%. In this case, the ash was affected by the temperature from the electric discharge, but there was no plasma-forming air and the carbon oxidation partially proceeded according to the equation C + H2O = CO + H2. Therefore, in the composition of the synthesis gas, the increased hydrogen content and the total fuel content were respectively low in CO2 and nitrogen. This increased the calorific value of the synthesis gas.

The experimental results of the plasma remelting of ash and slag mixtures obtained from the WIP are given in [3]. Studies were conducted with different ratios of hearth ash and fly ash obtained from the bag and electric filters. Due to the small particle size (from 0.5 to 0.01 mm), fly ash had a significant specific surface, so dioxins and other biologically hazardous organic compounds accumulated on its surface. To conduct experiments, the authors of [3] created a special installation for ash melting, and the ash was supplied from an operating WIP. As a source of thermal energy, the authors used a jet plasma torch with a power of 70 kW operating on nitrogen. The authors of [3] note the release of gaseous products (SiO, CO, CO2, K, Cl, Na, Zn, Cu, Cd, Pb, etc.) during the plasma remelting of ZWO (?) and the absence of dioxins in the remelting products – vitrified slag.

Since fly ash of WIP is a carrier of several biohazardous organic compounds and has specific features (for example, fluidity, caking, hygroscopicity, etc.), the study of remelted product composition and properties is of interest in their disposal. To determine the chemical and phase composition of the ash at
a temperature of 1700 K, we performed thermodynamic calculations according to the procedure described in [4] for the condition of the thermodynamic equilibrium of the system.

For calculations, we used the composition of fly ash from a real WIP obtained from bag filters and electrostatic precipitators. The composition under consideration was as follows: CaCO$_3$ – 50 kg; CaO – 66.08 kg; MgO – 6.88 kg; SiO$_2$ – 122.88 kg; Al$_2$O$_3$ – 34.56 kg; Fe$_2$O$_3$ – 16.48 kg; Na$_2$O – 14.24 kg; K$_2$O – 12.32 kg; P$_2$O$_5$ – 22.08 kg; SO$_3$ – 16.16 kg; TiO$_2$ – 2.4 kg; Cl – 5.92 kg. Total mass is 370 kg.

Thermodynamic calculations carried out using the ASTRA-4 program gave the following composition of products for heating fly ash assuming the thermodynamic equilibrium of the system at 1700 K: CO – 0.583 kg; CO$_2$ – 20.965 kg; NaCl – 0.743 kg; Ca$_3$Ti$_2$O$_7$ – 4.957 kg; Na$_2$SO$_4$ – 12.557 kg; Na$_2$CO$_3$ – 14.047 kg; CaO – 17.756 kg; Na – 0.150 kg; KCl – 2.153 kg; Ca$_3$P$_2$O$_8$ – 48.708 kg; K$_2$SO$_4$ – 19.757 kg; SO$_2$ – 0.089 kg; Al$_2$O$_3$ – 34.572 kg; MgSiO$_3$ – 17.084 kg; SiO$_2$ – 59.932 kg; Fe$_3$O$_4$ – 13.043 kg; FeCl$_2$ – 5.231 kg; CaSiO$_3$ – 96.782 kg; other (with a concentration of less than 0.01 mol / kg, for example: FeCl$_3$; FeCl; AlCl$_3$; Cl$_2$; ClO; O$_2$; MgCl$_2$; MgCl; ClO; Fe$_2$Cl$_4$; NaKCl$_2$; KS; Na$_2$Cl$_2$; SO; K$_2$SO$_4$; K$_2$CO$_3$; SO$_2$; CaCl$_2$; MgCl$; Fe; Cl et al.) – 0.817 kg. Total 370 kg.

At a temperature of 1700 K, the gaseous components of the heating products leave the furnace volume, reducing the total ash mass. The gaseous components in the composition of the molten fly ash have a total weight of about 34 kg. From the calculation results, it can be seen that among the heating products, molecules appeared with atoms of 2x and 3x different chemical elements and with a large molecular weight in the condensed phase: Ca$_3$Ti$_2$O$_7$; Na$_2$SO$_4$; Na$_2$CO$_3$; Ca$_3$P$_2$O$_8$; K$_2$SO$_4$; MgSiO$_3$; CaSiO$_3$; Fe$_3$O$_4$; Al$_2$O$_3$; SiO$_2$, which are prerequisites for the formation of mineral deposits.

Chlorine entering the melting chamber reacts with sodium, potassium, iron, forming compounds: NaCl; KCl; FeCl$_2$. In [5] the authors experimentally obtained a safe complex inorganic compound containing chlorine. Chlorine was used from the dioxins contained in fly ash.

To conduct an experiment on the melting of fly ash from WIP bag filters, a heating scheme was selected using a graphite electrode and a graphite hearth. Figure 1 shows the schematic diagram of the cinder melting electrical installation. The installation consists of an electric furnace, electrode holder with an electrode, power supply, ash loading unit, and slag discharge unit. The furnace is a metal water-cooled casing, lined with a high-temperature brick inside.
The furnace was loaded with a single supply of material into the furnace volume. The arc was ignited by the contact between the graphitized electrode and the molten bath. The melt temperature was measured with an optical pyrometer. Smoke fumes were vented through the filters into a chimney exhaust. Previously, the electric furnace was heated for 20 minutes on carbon. During the warm-up period, the applied voltage was 60V and the current was 4kA. Initially, 95kg of ash and slag wastes were loaded into the melting chamber of the electric furnace. A decrease in current did not occur because the main process took place on carbon. After 27 minutes during the remelting process, the current remained unchanged. Ashes not yet remelted were located on the walls of the electric furnace. The total load weight was 320 kg. During loading, the current decreased to I = 3.5kA. After loading the entire ash mass, the current decreased to I = 2.5kA, the voltage remained at the same level U = 60V. As the melt appeared, the current gradually increased. By the time the ash was completely melted, the current increased to I = 4.5kA, the voltage remained at the upper level U = 60V. The discharge was carried out into a container with water having a temperature of 20°C (Fig. 2). The temperature of the ash melt at the discharge was 1350 °C.
For the entire melting cycle of ash and slag waste in the production of vitrified slag, 402 kWh of electricity was consumed. According to published data, the specific energy consumption for ash melting ranged from 800 to 1000 kWh per ton. As a result of the experiment, the specific energy consumption amounted to 1.08 kWh per kilogram of ash. After draining the slag from the melt into a container of water, vitrified slag was obtained in the form of coarse sand (Fig.3). In terms of specific energy consumption, this technology corresponds to analogs in [3].
Conclusion
During the thermal neutralization of the ash and wastewater treatment from the WIP, according to the results of the calculations, the total weight of the slag waste decreases due to evaporation of the gas phase of the products and portion of the melt vapor. At that, complex compounds having a large molar mass, such as NaKCl2; Na2CO3; Na2SO4; Ca3Ti2O7; Ca3P2O8, etc., as well as safe compounds containing chlorine, such as NaCl; KCl, and others, were formed during the MSW incineration. Moreover, at this temperature, chlorine-containing dioxins should completely decompose. The experimentally obtained melt of fly ash, cooled in water, does not differ in appearance from similar ones obtained by thermal methods of processing ash and slag materials.

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References
[1] Alekseenko S V, Anshakov A S, Domarov P V, Faleev VA 2019 T&A (6) 991–5
[2] Pinaev A V, Faleev V A, Urbakh A E 2011 Combustion, Explosion and Shock Waves 47(2) 59–65
[3] Hyun-Seo Park 2011 T&A 18(2) 313–21
[4] Trusov B G 1991 Modeling of chemical and phase equilibria at high temperatures «ASTRA-4» (M.: Publishing House of MSTU) 39
[5] Gonopolsky A M, Kosykh V A 2011 Chemical and Oil and Gas Engineering 7 40–3