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INVESTIGATION OF PLASMA-OHMIC ELECTRIC FURNACES FOR GASIFYING CARBONACEOUS WASTES

For the first time, the processes of reducing energy consumption of a plasma-ohmic electric furnace for the gasification of various carbon-containing wastes (municipal, biological, agricultural, and other organic wastes) were investigated. The effect of reducing the humidity, morphological composition of waste on energy consumption during plasma gasification of carbon-containing materials is shown. The possibility to exclude the process of preliminary drying from the production cycle of waste gasification has been revealed.

In the modern world, one of the global trends in technology development is the continuous increase in the efficiency and environmental friendliness of carbon-containing waste management methods. The carbon-containing industrial waste includes: municipal (municipal solid waste (MSW)), agricultural (rice husk, etc.), industrial (wood waste, coal slimes, etc.) and biological (medical, biological sludge deposits (BIO) and etc.)

Despite the different nature of this waste, they all consist of the same chemical elements: carbon, hydrogen, oxygen, nitrogen, chlorine, sulfur; ash (a complex of inorganic elements and compounds), water (moisture), but contain elements and compounds dangerous for the environment (pathogens, heavy metals, etc.). Gasification of carbon-containing wastes is a complex physico-chemical process with a large number of effects, a complete scientific explanation of which is far from completion.

Keywords: plasma electric furnace, plasma torch, organic waste, current-voltage characteristic, energy saving, ohmic heating.

Introduction

In the modern world, one of the global trends in technology development is the continuous increase in the efficiency and environmental friendliness of carbon-containing waste management methods. The carbon-containing industrial waste includes: municipal (municipal solid waste (MSW)), agricultural (rice husk, etc.), industrial (wood waste, coal slimes, etc.) and biological (medical, biological sludge deposits (BIO) and etc.)

Despite the different nature of this waste, they all consist of the same chemical elements: carbon, hydrogen, oxygen, nitrogen, chlorine, sulfur, ash (a complex of inorganic elements and compounds), water (moisture), but contain elements and compounds dangerous for the environment (pathogens, heavy metals, etc.). Gasification of carbon-containing wastes is a complex physico-chemical process with a large number of effects, a complete scientific explanation of which is far from completion.

The composition of carbon-containing waste can vary in a wide range, which requires the creation of a flexible and universal technology. The main technical problems that are holding back the widespread use of plasma technologies for the processing of technogenic wastes have not yet been solved, namely, the low life of the plasma torches and the high energy consumption for their pyrolysis.

The use of plasma technology allows: to significantly reduce the volume of gas that is subjected to treatment in sewage treatment plants (to reduce the volume of sewage treatment plants themselves); to melt and vitrify the inorganic part of the waste in the reactor itself (to obtain inert slag, which can be used in construction); eliminate the formation of oxides due to the reducing environment in the reactor; obtain commercial synthesis gas (10-13 MJ/m³) suitable for its subsequent combustion in power boilers in order to obtain thermal energy for its own needs (heating, hot water supply, etc.) thermal power 0.5–0.6 5Gcal/h

At present, waste recycling using plasma technology is one of the most secure techniques. Worldwide, there are only a few small plants testing plasma technology, the main drawback of which is a very small lifetime of the plasma torch electrodes (up to 100 hours) and have another drawback, which is manifested in high energy consumption.

Thus, the task of developing an energy-efficient and environmentally friendly plasma technology for utilization (gasification) of carbon-containing wastes, the use of waste as alternative energy sources, and environmental protection lies in the area of promising and significant research areas.

The development of technology for the processing of technogenic waste requires the creation of methods that solve the problem of increasing the energy efficiency of plasma furnaces and increasing the life of the plasma torch.

An increase in the energy efficiency of plasma furnaces is currently possible using combined plasma-ohmic heating for the gasification of carbon-containing waste.

In real conditions, the humidity of the CCW reaches 60 %. During gasification, CCW get wet into the loading zone, waste remains wet only within the drying zone. Further, as you move down the mine, getting into the pyrolysis zone of the plasma electric furnace, the waste should be dried. Therefore, it is advisable to organize additional ohmic heating in the drying zone.

The proposed work is the development of research in the direction of creating energy-efficient plasma electric furnaces for gasification of USO and is dedicated to the development of methods for reducing the energy consumption of plasma electric furnaces for gasification of waste.

Materials and methods

To organize the best plasma gasification process for carbon-containing wastes, it is necessary to organize an additional process for drying wastes, leading to additional energy consumption.

According to research [1], waste has a specific electrical resistance of 3 to 5 Ohm m with natural humidity. Given this feature of waste, the drying process is more expedient to carry out ohmic heating. This type of heating has an efficiency of 100 %.

The process of drying waste can be organized directly in the electric furnace itself.

In fig. 1 shows a diagram of a shaft plasma-ohmic electric furnace for the gasification of carbon-containing waste.

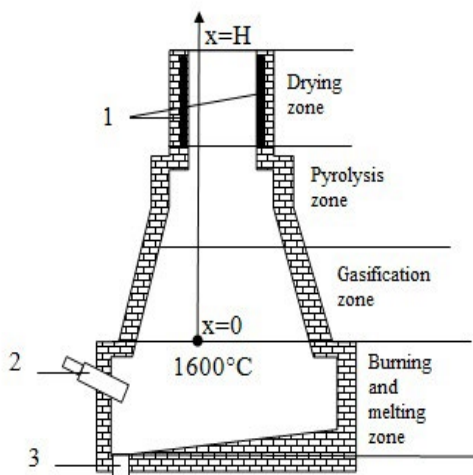


Figure 1 – Diagram of a plasma-ohmic furnace:

1 – electrodes; 2 – plasma torch; 3 – discharge of liquid slag

In the simulation, it was taken into account that the waste will contain moisture only in the loading zone and within the drying zone until all moisture evaporates

from them under the influence of temperature. Because of this, ohmic heating with an industrial frequency current can only be carried out in the drying zone. Waste enters the pyrolysis zone as dehydrated and with low moisture content.

When organizing a continuous technological process, an established gas-dynamic and thermal regimes are formed in the furnace chamber. Therefore, the processes of heat and mass transfer in such a process in the system of counter flows of the solid and gas phases can be considered stationary. And as a result of heat and mass transfer, a temperature field is formed in the charge and gas phase.

The work of automatic process control system (APCS) is based on the principle of generating the control actions on actuating mechanisms by processing the data (temperatures, current, voltage, etc.) obtained from the measuring instruments and sensors. The controller of the control system forms, according to the algorithm of technological process control, the necessary control signals for the voltage regulator ensuring regulator switching on or off, or generates a signal to the rheostat when the plasmatron power changes.

All APCS equipment is located in the control cabinet (Fig. 2). To prevent dust, splashes and other foreign objects from entering the cabinet, and prevent unauthorized access to the equipment of the cabinets, cabinet operation is allowed only with the door closed and locked securely. The door is equipped with a seal and it provides adequate protection of equipment in the cabinet from dust and humidity.



Figure 2 – Automatic control cabinet for hydraulic drive of the waste

Gaskets through which the supply and signal cables are fed into the cabinet are also sealed.

The cabinet housing is securely grounded by connecting the protective earth conductor to a special bolt located on the mounting panel of the cabinet and fixing it with a nut.

The control cabinet of hydraulic drive is equipped with a controller «OVEN», built into the general network of automatic control.

The modular programmable controller, designed for constructing the automation systems of low and medium complexity, modular design, work with natural cooling, ability to apply local and distributed I/O structures, extensive communication capabilities, many functions supported at the operating system level, ease of operation and maintenance provide the opportunity to obtain cost-effective solutions for constructing automatic control systems in various areas of industrial production. The ability to use several types of CPUs of different performance, availability of a wide range of I/O modules of discrete and analog signals, function modules and communication processors facilitate the effective use of controllers.

Results and discussion

In the process of drying, under the action of resistive heating, moisture from the waste evaporates, decreasing from (60÷50) % to 20 %. As shown in [2], waste with a minimum humidity of 20 % contains all the chemical elements necessary for their complete gasification. Resistive heating, like direct heating, in this plasma-resistive furnace is highly efficient. Its efficiency (excluding heat losses through the lining) is close to 100 %. At the same time, the heating of the drying zone by the gas stream by the indirect method from plasmatrons, whose power is transferred to plasma-forming gas with an efficiency of $\approx 80\%$, will be less effective than with resistive gas.

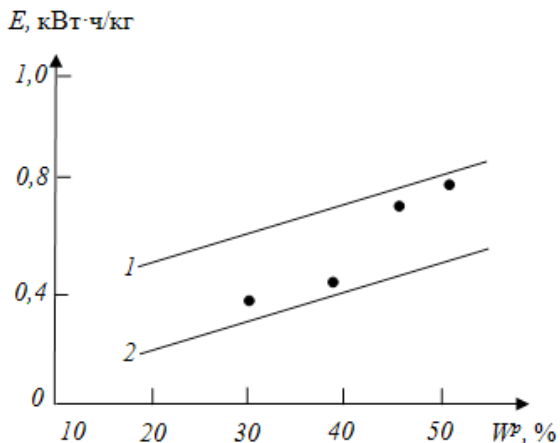


Figure 3 – The dependence of the specific energy consumption pyrolysis of 1 kg of waste from their moisture
 1 – there is no plasma-forming air flow, 2 – air flow rate of 0.15 g/s per 1 kg of waste per hour, experiment symbols

In fig. 3 that when the moisture content of the waste decreases from 50 to 30 %, the specific energy consumption for their gasification decreases significantly (almost twofold, from 0.75 to 0.4 kWh/kg). When combined plasma-resistive heating of carbon-containing wastes is implemented, a significant reduction in specific energy consumption is achieved using heat supply only from the plasma torch to the processing of 1 kg of man-made waste — less than 0.4 kWh/kg (see Fig. 3).

Let us consider a specific example of the influence of ohmic heating of the CCW on the energy of a plasma-ohmic electric furnace.

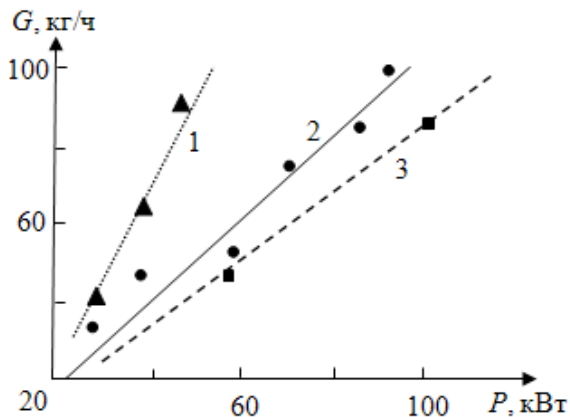


Figure 4 – Effect of plasma torch power for gasifier capacity.
Solid waste moisture: 29 (1), 45 (2), 50 (3) %

As can be seen from the calculated and experimental data, Fig. 4 [3], the gasification of organic waste with a humidity of 50 % with a furnace capacity of $GM = 100 \text{ kg/h}$ requires a plasma torch capacity of about 120 kW. Reducing waste moisture to 29 % reduces the power of the plasma torch to 50 kW. Therefore, the introduction of additional power through resistive heating $P = 120 - 50 = 70 \text{ kW}$ in the drying zone allows to reduce the power of the plasma torch by 58 % for a given performance of the electric furnace.

In the process of numerical and experimental studies, the morphological composition influences the energy consumption of waste gasification. The inorganic part of the composition of MSW in the process of gasification of waste takes about 0.09 kW of energy per 1 kg for heating and remelting. With the exclusion of the inorganic part of the waste, energy consumption is reduced by 9 kW at an electric furnace capacity of 100 kg/h.

With a long-term (in time) technological process of TCR gasification, there is a significant energy saving.

Reducing the required power of the plasma torch allows you to significantly increase the resource characteristics of the plasma unit of the installation, switching to plasma torches with lower operating currents while increasing the service life of the electrodes.

Operational parameters of the electric furnace are determined by the stable operation of its constituent elements. One of the main, of course, is the plasma torch. Below are the results of its experimental characteristics.

Study of electric arc plasma torch

To maintain a high temperature in the furnace chamber, an arc plasma torch is used. For the smooth operation of the installation requires reliable long-term operation of the plasma torch. In this regard, on the basis of numerical studies, a plasma torch with a power of 50 kW (Fig. 5) was designed and manufactured and tested with supply of various plasma-forming air flow $(3 \div 6) \cdot 10^{-3}$ kg/s with a change in current from 120 A to 200 A.

The current-voltage characteristic (VAC) of the arc is the most important electrophysical and energy characteristic of an arc plasma torch. It determines the area of steady arc burning when changing the defining parameters: current strength, flow rate and type of plasma-forming gas, pressure of the medium, geometrical dimensions of the discharge chamber of the plasma torch. According to the type of current-voltage characteristics and the level of achievable values of voltage and current of the arc, the parameters of the power supply source are determined to ensure reliable operation of the plasma torch in a continuous mode.



Figure 5 – Photograph of the plasma torch in operation

Figure 6 shows the experimental current-voltage characteristics of the arc as a function of the plasma-forming gas flow.

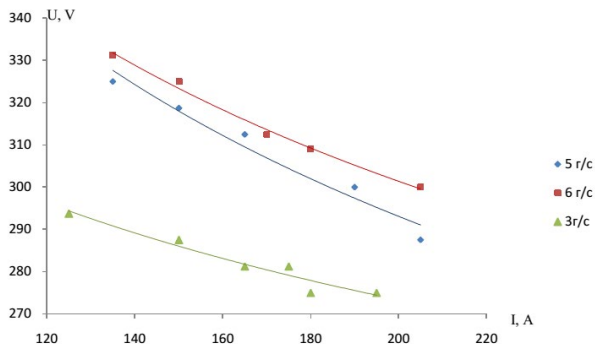


Figure 6 – Current-voltage characteristics of the plasma torch arc

One of the defining parameters that determine the efficiency of the plasma torch, is its thermal efficiency. In electric arc plasma generators, electrodes perceive heat from arc radiation, convective heat exchange between an arc discharge, plasma-forming gas and electrode walls, conductive heat exchange, and finally, from cathode and anode arc spots. Heat from the outside of the electrodes is removed by cooling water. The magnitude of the measured heat flux is determined by the efficiency of the plasma torch. In this case, the integral heat fluxes entering the electrodes and other water-cooled structural elements are determined, without dividing them into components. The method of measuring heat fluxes is standard: it is necessary to know the flow rate and temperature difference of water at the entrance to the plasma torch and at the exit from it.

The obtained experimental data are shown in Figure 7. As can be seen, the value of thermal efficiency at certain small air flow rates is about 80 %.

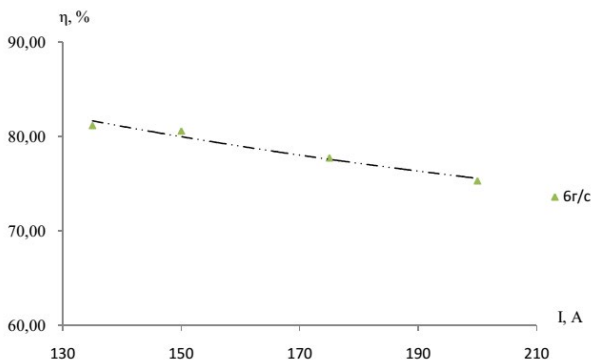


Figure 7 – Thermal efficiency of the plasma torch depending on the arc current

Conclusions

Analysis of the calculated results obtained shows that the organization of ohmic heating of wet waste in the upper part of the electric shaft furnace is analogous to the preliminary technological process of drying the waste before loading it into the furnace to reduce the specific energy consumption for gasification of the organic component of the mixed waste. As shown in [5], reducing the load on the plasma torch can significantly increase the resource characteristics of its work.

With a long-term (in time) technological process of TCR gasification, there is a significant energy saving. Also with a decrease in the power of the plasma torch there is an increase in the resource characteristics of the electrodes.

In the experiments, the specific energy consumption for the gasification of waste exceeds the calculated by 15–20 %. This is due to errors in the efficiency of the plasma torch and the installation as a whole.

Summarizing the above, it should be noted that the organization of resistive heating of wet waste in the upper part of the electric shaft furnace is an analogue of the preliminary technological process of drying the waste before loading it into the furnace to reduce the specific energy consumption for gasification of the organic component of mixed waste.

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КӨМІРТЕГІ ҚАЛДЫҚТАРЫН ГАЗДАНДЫРУҒА АРНАЛҒАН ПЛАЗМАЛЫҚ-ЭЛЕКТР ПЕШТЕРІН ЗЕРТТЕУ

Алғаш рет көміртегі бар әр түрлі қалдықтарды (коммуналдық, биологиялық, ауылшаруашылық және басқа да органикалық қалдықтарды) газдандыру үшін плазмалық-омдық электр пешінің энергия шығынын азайту процестері зерттелді. Құрамында көміртегі бар материалдарды плазмалық газдандыру кезінде энергия шығынын ылғалдылықты, морфологиялық құрамын төмендетудің әсері көрсетілген. Қалдықтарды газдандырудың өндірістік циклінен алдын ала кептіру процесін алып тастау мүмкіндігі ашылды.

Қазіргі әлемде технологияларды дамытудың жаһандық үрдістерінің бірі көміртегі бар қалдықтарды басқару әдістерінің тиімділігі мен экологиялылығын үнемі арттыру болып табылады. Құрамында көміртегі бар өнеркәсіптік қалдықтар: коммуналдық (қатты тұрмыстық қалдықтар (ҚТҚ)), ауыл шаруашылығы (күріш қауызы және т.б.), өнеркәсіптік (ағаш қалдықтары, көмір иламдары және т. б.) және биологиялық (медициналық, биологиялық шөгінділер (БИО) және т. б.).

Бұл қалдықтардың әр түрлі сипатына қарамастан, олардың барлығы бірдей химиялық элементтерден тұрады: көміртегі, сутегі, оттегі, азот, хлор, күкірт, күл (Бейорганикалық элементтер мен қосылыстар кешені), су (ылғал), бірақ құрамында қоршаған ортаға қауіпті элементтер мен қосылыстар бар (қоздырғыштар, ауыр металдар және т.б.). Құрамында көміртегі бар қалдықтарды газдандыру – күрделі физика-химиялық процесс, оның толық ғылыми түсіндірмесі аяқталуға жақыны.

Кілтті сөздер: плазмалық электр пеші, плазмалық алау, органикалық қалдықтар, ток-кернеу сипаттамасы, энергия үнемдеу, омыдық қыздыру.

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ИССЛЕДОВАНИЕ ПЛАЗМЕННО-ЭЛЕКТРИЧЕСКИХ ПЕЧЕЙ ДЛЯ ГАЗИФИКАЦИИ УГЛЕРОДНЫХ ОТХОДОВ

Впервые исследованы процессы снижения энергозатрат плазмозмической электропечи для газификации различных углеродсодержащих отходов (бытовых, биологических, сельскохозяйственных и других органических отходов). Показано влияние снижения влажности, морфологического состава отходов на энергозатраты при плазменной газификации углеродсодержащих материалов. Выявлена возможность исключения процесса предварительной сушки из производственного цикла газификации отходов.

В современном мире одной из глобальных тенденций развития технологий является постоянное повышение эффективности и экологичности методов обращения с углеродсодержащими отходами. Углеродсодержащие промышленные отходы включают: коммунальные (твердые бытовые отходы (ТБО)), сельскохозяйственные (рисовая шелуха и т.д.), промышленные (древесные отходы, угольные шламы и т.д.) и биологические (медицинские, биологические осадки (БИО) и т.д.).

Несмотря на различную природу этих отходов, все они состоят из одних и тех же химических элементов: углерода, водорода, кислорода, азота, хлора, серы, золы (комплекса неорганических элементов и соединений), воды (влаги), но содержат элементы и соединения, опасные для окружающей среды (патогенные микроорганизмы, тяжелые металлы и т.д.). Газификация углеродсодержащих отходов – сложный физико-химический процесс с большим количеством эффектов, полное научное объяснение которого далеко от завершения.

Ключевые слова: плазменная электропечь, плазмотрон, органические отходы, вольт-амперная характеристика, энергосбережение, омический нагрев.

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