الوضع الراهن للتطور في مجال تغويز البلازما ومعالجة النفايات

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الخلاصة :

إن الغرض والغاية لهذا البحث هو التأكيد على أهمية استخدام تقنيات البلازما لمعالجة النفايات وتغويز المواد الخام في الظروف الحديثة والحاجة إلى تحسين طرق تصميم مولدات البلازما بطريقة القوس الكهربائي ولاسيما المدمجة في وحدات تغويز المواد الخام. إن التأثير الإيجابي لإدخال تقنيات تغويز النفايات الصلبة هو إحصائيات سوق النفايات ولا سيما مثل إدارة الطاقة الناجحة في عدد من البلدان الأوربية .

تضمن البحث مقارنة استخدام تغويز الفحم بالطرق التقليدية مع طريقة تغويز الفحم بالبلازما حيث تتمتع تقنية البلازما بإنتاجية عالية ولا يوجد استهلاك للوقود الصلب والسائل والغازي بالإضافة إلى إمكانية التسخين السريع لجزيئات الفحم الخشنة إلى درجات حرارة عالية في منطقة التغويز بسبب حرارة الاحتراق الجزئي الصغير بالإضافة إلى إمكانية ضبط المعلومات التكنولوجية في نطاق واسع واكتناز المعدات ونفقات الطاقة والمعادن الصغيرة المحددة .

العامل الرئيسي الذي يؤخر الأدخال الواسع لتقنيات البلازما في مختلف الصناعات هو عدم كفاية مستوى الموثوقية والعمر الافتراضي لمولدات البلازما مع توفير التشغيل المستدام لجميع انواع المعدات وللتغلب على هذه المشكلة اقترح الباحثون عددا من الحلول التقنية لزيادة كفاءة وحدات تغويز المواد الخام مع مولدات بلازما القوس الكهربائي المتكاملة .

CURRENT STATE OF DEVELOPMENT IN THE FIELD OF PLASMA GASIFICATION AND WASTE PROCESSING

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Abstract: The purpose and purpose of this research is to emphasize the importance of using plasma technologies for waste treatment and gasification of raw materials in modern conditions and the need to improve methods of designing plasma generators by the electric arc method, especially integrated in the gasification units of raw materials. The positive impact of the introduction of solid waste gasification techniques is the waste market statistics, especially the example of successful energy management in a number of European countries.

The research included a comparison of the use of coal gasification by conventional methods with the method of gasification of coal by plasma, as the plasma technology has high productivity and no consumption of solid, liquid and gaseous fuels in addition to the possibility of rapid heating of coarse coal particles to high temperatures in the gasification area due to the small partial combustion temperature in addition to the possibility of setting parameters. Technological in large-scale equipment hoarding, energy expenditure and specific small minerals

The main factor delaying the widespread introduction of plasma technologies in various industries is the insufficient level of reliability and life span of plasma generators while providing sustainable operation of all types of equipment. To overcome this problem, researchers have proposed a number of technical solutions to increase the efficiency of raw material gasification units with integrated electric arc plasma generators.

Keywords: electric arc plasma generator, processing of municipal solid waste, plasma gasification, synthesis gas.

Introduction. Due to the growing shortage of fuel and energy resources, in particular coal of the anthracite group, there is a need to increase efficiency of this type of fuel and reduce emissions into the environment [1]. The set of measures to increase profitability of energy sectors, as well as to reduce load on the ecosystem, may include the following measures:

1 Modernization of technological processes of coal combustion. Coal combustion technologies that have existed for many decades do not meet modern requirements, as they exceed the permissible level of air pollution by solid carbon particles and nitrogen oxides. Moreover, due to incomplete combustion of coal parts, there is a risk of the soil contamination from emissions of ash and slag [1].

2 Processing of ash and slag residue at thermal power plants. About 70% of all electricity in Ukraine is generated by the thermal power plants. At present, the whole set of waste from thermal power plants is stored without further processing, although the practice of the developed Western countries shows the prospects and economic efficiency of the introduction of slag processing technologies.

3 Gasification of municipal solid waste (MSW) and biomass. At present, the issue of solid waste recycling in Ukraine is the most acute, because waste is stored mostly, not recycled. According to the statistics, more than 5% of the territory of Ukraine is

occupied by landfills, the total amount of accumulated garbage is 32.4 billion tons. Today, there are only 4 waste processing plants in the country, of which only one is 100% loaded[1].

Chemical analysis of the ash residue of dumps of Ukrainian TPPs(Thermal Power Plants) shows a high percentage of unburned coal – 20%, as well as ferrosilicate 40%. The ash dumps of most of the thermal power plants are 90% full, when only 5% of ash is sold annually, while the total amount of coal waste is estimated at millions of tons per year at the average cost of ash UAH(Ukrainian Hryvnia) 70.0 per ton. Taking into account the number of TPPs, the processing of their waste can have a significant economic effect[1].

Purpose of the paper: To emphasize the relevance and prospects for the use of plasma technologies for waste processing and gasification of raw materials in the modern conditions the need to improve the design methods of electric arc plasma generators, in particular integrated into the raw materials gasification units.

Main part. One evidence of the positive effect of the introduction of MSW gasification technologies can be the statistics of the waste market, in particular the example of successful energy management in Sweden, where the processing of garbage provides 20% of its energy balance. In order to do this, the country imports 800 thousand tons of garbage annually, turning it into a valuable resource for the society.

A separate problem is the destruction of hazardous waste, including chemical fertilizers and pesticides with expired shelf life, chemical production waste, medical waste and other types of waste with special conditions of storage or processing [1-3]. The modern world experience shows that all these problems can be solved on the basis of plasma technology. The undeniable advantages of such technologies are:

- Possibility to manage the composition of processed products except the formation of hazardous substances;
- High speed of chemical reactions and increased processing depth of raw material due to high temperatures in plasma reactors;
- Compactness of plasma equipment and auxiliary gas cleaning systems.

MSW plasma gasification technologies have been on the market for a relatively long time. Experience of operation of experimental and then industrial units of plasma gasification allowed establishing the following key advantages of these technologies:

- Ability to process a wider range of waste than most other technologies;
- Possibility of cost-effective use with less amount of processing than for competitive approaches;
- Formation of vitreous solid residues in contrast to the ash in thermal processes, which simplifies their reuse or disposal;
- More complete processing of waste with less risk to human health and better environmental efficiency;
- Possibility to obtain synthesis gas of high-purity, which simplifies its use in energy units (gas engines, turbines, fuel cells) or production of chemicals and fuels.

The plasma gasification is carried out in conditions of oxygen deficiency which leads to the production of synthesis gas, vitrified slag and molten metal, proportions and composition of which depend on composition of input waste [4, 5].

The main factor in the development of this process type is the ability to recover gases rich in chemical energy, which can be used in high-efficiency energy recovery systems or used as chemical raw materials.

An example of such a process is the technology of MSW plasma gasification – the Recovered Energy System by Recovered Energy, Inc. (USA). In this process, one ton of solid waste produces more than 1 MWh of electricity.

In addition to electricity, during the processing metal received , vitrified slag, hydrochloric acid and other products. After processing, no emissions and waste is generated subject to storage

One of the leaders in the field of plasma gasification is the Canadian company Alter NRG, which promotes its own plasma gasification technology (obtained through the acquisition of Westinghouse Plasma Corporation). The basis of the Alter NRG/WPC process is a reactor with passive-type plasmatrons, which is a standard vertical shaft furnace by design commonly used in foundry production. It is lined with a suitable refractory material to withstand high internal temperatures and aggressive environment in the reactor.

In this process, the waste does not pass through the plasma torch. Instead, plasma torches are used to provide the high temperatures required for the stable operation of the reactor. In the Alter NRG/WPC design, the plasma temperature will be between 5,000 and 7,000 °C, and the temperature in the melting zone (lower part of the reactor) will be approximately 2,000 °C – much lower than 20,000 °C of APP(application) process. The actual operating temperature is sufficient to control gasification reactions and to decompose resins and compounds of the higher molecular weight into CO and H_2.[6,7]

Synthesis gas from the AlterNRG/WPC reactor is obtained at a temperature of 890 C to 1100 °C at atmospheric pressure. Then the gas is purified in a multi-stage process, the amount of which depends on how much pure gas is required for a particular process of use and conversion specified in each specific project.

In Japan, three waste management plants have been built using WPC technology. The plants at Yoshii, Utashinai and Mihama-Mikata were built by Hitachi Metals under WPC license for MSW processing. AlterNRG announced plans to build a gasification plant in the North East of England using the AlterNRG/WPC plasma reactor.

The leading European manufacturer of equipment for waste plasma gasification is Europlasma (France). It manufactures and sells self-developed passive arc plasmatrons and plasma waste processing systems, including hazardous ones, under a license from Aerospatiale (now EADS – the European Aeronautic Defence and Space Company).

Today, four plants in Japan use Europlasma technologies. Moreover, a plant for the plasma processing of asbestos-containing waste has been built in Bordeaux, France. The above company became a member of the Plasco Energy Group. The company’s demonstration equipment with a capacity of 100 tons per day has been operating intermittently since the summer of 2007 in Ottawa (Canada). The company has announced plans to build a plasma gasification plant with a capacity of 150,000 tons per year in Ottawa. It has also announced three more projects in Canada, Japan and the Bahamas[6,7].

In Europe, Plasco has set up a joint venture (Hera Plasco) with the Spanish company Hera Holdings for the European market. The company operates a plasma pilot plant near Barcelona and is actively promoting plasma gasification technologies in Europe.

Thus, despite the great potential proper for the methods of waste plasma gasification, today the use of these technologies is limited by separate enterprises. The main reasons for this situation are the insufficient level of reliability and service life of plasma generators used in such installations.

Usually, their declared life is 1,000 ... 2,000 hours of continuous operation, but the actual life in the conditions proper for plasma gasification reactors may be determined not by the electrodes life, but occurrence of unwanted electrical breakdown caused by high operating current and surface dust and atmospheres.

Reducing the operating voltage for these plasmatrons solves the problem only partially, because maintaining thermal power will increase the current, which, in its turn, will decrease sharply the electrodes life.

This problem could be solved through the use of high-resource electric arc plasmatrons with thermoemission cathodes resistant to poisoning by oxygen-containing gases. However, this requires research and solutions to the problems associated with the integration of such plasmatrons in plasma gasification systems, in particular, the peculiarities of the modes of operation, supply of shielding and plasma-forming gas, with due regard to the equipment of plasma gasification systems[6,7].

One of the problems of MSW plasma gasification is the heterogeneity of initial raw materials and the uncertainty of its composition. This leads to the fact that with plasma gasification, the composition of the synthesis gas and its caloric content can change significantly during operation. In the case of power generation inclusion into industrial systems, this disadvantage can be compensated by the adaptive addition of auxiliary fuels, such as natural gas.

Plasma gasification units of raw materials homogeneous in composition – coal or biomass, have no this disadvantage. In the process of plasma gasification can be obtained gases of different compositions and heat of combustion suitable for widespread use as fuel in the industry and at home, and as chemical raw materials for various syntheses, including to obtain liquid products in Fischer-Tropsch synthesis [6, 7]. There are dozens of ways to gasify solid hydrocarbon crude. They can be systematized according to a number of criteria [6-8]:

1. According to the state of the fuel in the gas generator, there are a method of gasification in a fixed bed, gasification in a fluidized bed and gasification in a stream of pulverized fuel.
2. According to the method of heat supply to the gas generator, gasification processes are divided into autothermal and allothermal. In autothermal processes, for the course of endothermic reactions in gasifiers, it is burnt the part (35… 40%) of fuel supplied by oxygen-containing agents[9].
3. According to the direction of reaction flows, the gasification methods are divided into countercurrent and direct-flow. In countercurrent methods, coal is loaded from above, and gasifying agents are fed from below, which provides good heat transfer. In

direct-flow methods, coal is fed in the same direction as the gasifying agent.

The methods of gasification are also divided into the method of ash removal from the gas generator (solid or liquid state), process pressure (normal and elevated), composition of obtained gas (energy, process or substitute natural gas), industrialized methods of gasification of solid carbon fuel.

In autothermal continuous processes, the temperature required for the normal course of the reaction is maintained by heat release. The control of the autothermal process is closely related to the stability of the gasifier. The state of equilibrium in the autothermal process is achieved when the heat dissipated and the heat released as a result of the reaction are equal. Assuming that the reactor is well insulated, the heat will be dissipated only by the gases leaving the reactor. The main feature of the autothermal process is the occurrence of hysteresis. If at a constant feed rate of the raw material, its temperature increases, the reaction ignites at a certain feed temperature and the reactor operates at the upper stable operating point. When reducing the feed of raw material[9].

the reactor continues to operate with a high degree of conversion until attenuation occurs at the feed temperature.

Allothermic processes are the processes in which the required heat is supplied from the outside by means of a solid or gaseous heat carrier. For the production of synthesis gas used to obtain ammonia and methanol, in oxosynthesis or in Fischer-Tropsch synthesis, it is necessary to maintain accurately the ratio of $CO:H_2$ and $H_2:N_2$ in the primary gas. All these requirements determine the control of the course of reactions during gasification. This is achieved not only by selecting pressure and temperature; the

composition of the gasifying agent is crucial: it should consist mainly of oxygen and superheated water vapour; the presence of CO_2 is possible.
If the resulting gas is directed to the synthesis of ammonia, then such gas should ideally contain 75% of H_2 and 25% of N_2; it is beneficial to use oxygen-enriched air for gasification of coal. It being understood that gasification of fuel is carried out continuously.
The plasma gasification technology is already a technology for industrial use, has commercially successful installations around the world (Japan, India, England, China, USA). The design and construction works are being performed in the European Union. The use of plasma gasification is integrally linked to the Kyoto Protocol that aimed to reduce human influence on the atmosphere. The influence on nature and human being is 10… 15 times lower than the existing world norms of the corresponding maximum possible concentrations.
The plasma gasification of coal is designed to produce environmentally friendly fuel – synthesis gas free from oxides of sulfur and nitrogen and is a set of the following basic homogeneous and heterogeneous reactions:

1. $C + O_2 \rightarrow CO_2$ **3.** $C + H_2O \rightarrow CO + H_2$
2. $CO_2 + C \rightarrow 2CO$ **4.** $C + 2H_2 \rightarrow CH_4$.

Hydrogenation of carbon monoxide in Fischer-Tropsch process is a complex of composite parallel and consecutive reactions that include formation of primary adsorbed complex, growth of hydrocarbon chain and its break. The course of these reactions leads to formation of acids, esters, etc. By catalytic processing of synthesis gas on metal, oxide, zeolites, and metal complex catalysts, other important products of petrochemical synthesis (olefins, paraffins, alcohols, etc.) can be obtained [9]. The essence of the method is shown in Fig. 1.[9]

The power system 1 supplies the coal dust to the plasma reactor 3, steam from the steam generator 2 is also supplied there. Coal dust and steam enter the arc area burning between the rod electrode passing through the cover of the reactor 5 and the ring electrode. The electromagnetic coil 6 rotates the arc in the horizontal plane. Influenced by the high temperature with present oxidant, coal vapour is gasified resulting in the formation of synthesis gas consisting mainly of carbon monoxide and hydrogen. The non-combustible part of coal in the form of slag enters down into the chamber separation 4, the muffle 9 and then into the slag collector 13.

The synthesis gas obtained in the first stage is sent to the upper separation chamber 4 where, from the dust system 8 through the horizontal part 7, the coal dust is received and oxidizing agent air is supplied by the compressor 10. When mixing the aeromixture consisting of coal dust and air with synthesis gas, the latter ignites. As a result of combustion of synthesis gas in the muffle 9, the heat required for gasification of coal dust is released. The process of separation of obtained synthesis gas and slag takes place in the lower separation chamber 11 where the synthesis gas is exhausted through the horizontal part 12 by the compressor 14. The slag enters the slag collector 13.

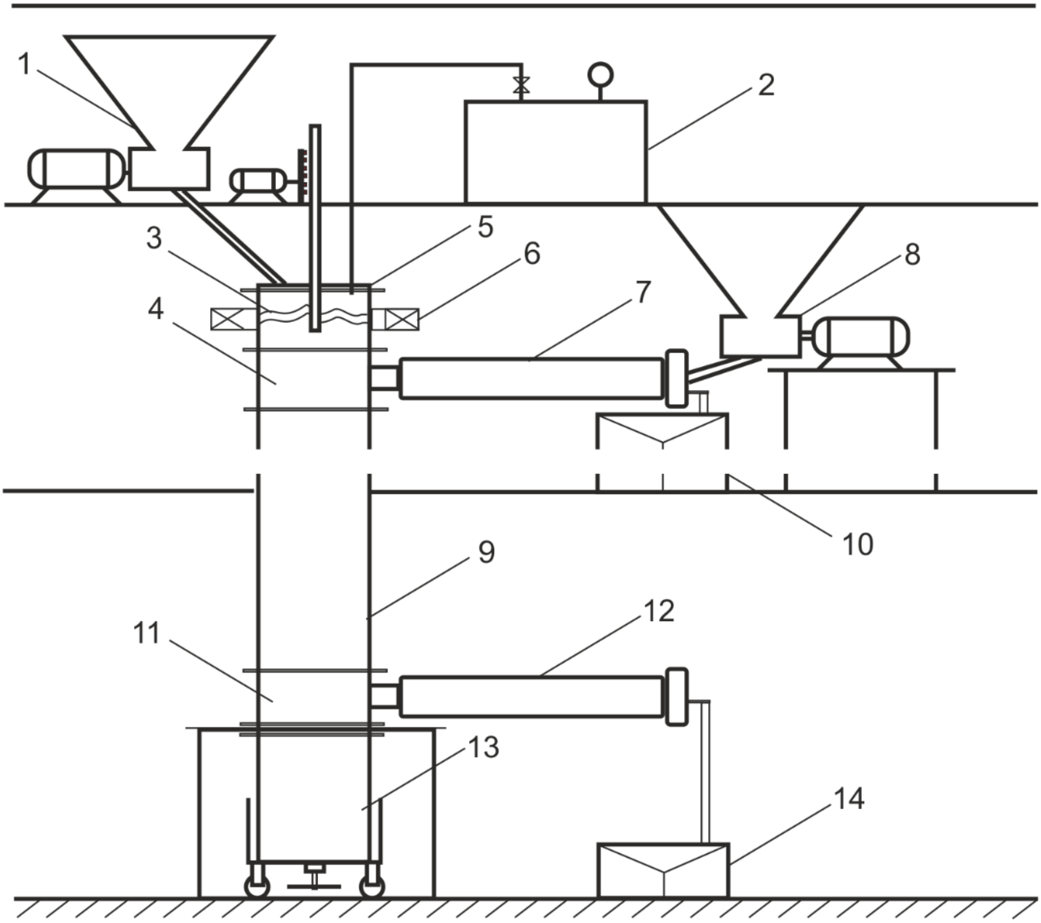

Figure 1 – Installation of allo-autothermal gasification of coal[9].

1, 8 – dust supply system; 2 – steam generator; 3 – plasma reactor; 4 – upper separation chamber; 5 – reactor lid; 6 - electromagnetic coil; 7 – horizontal part of the dust supply system; 9 - muffle; 10, 14 – compressor; 11 – lower separation chamber; 12 – gas outlet chamber; 13 – slag collector.

The composition of the synthesis gas from the plasma reactor (according to the results of the experiment with coal [6]):

CO_2 – 1.1%, O_2 – 0.8%, CO – 40.2%, H_2 – 46.7%, Σ = 88.8%, others – 11.2% - ballast (volume percent). The ratio of CO: H_2 = 40.2: 46.7 = 1:1.16. If we work not adjusting the gas composition, the resulting synthesis gas is suitable for the reaction over Fe catalyst which requires a ratio between the fractions CO: H2 = 1:1. The amount of inert impurities is 13.1% (should not exceed 10… 15%); the yield of synthesis gas from 1 ton of coal [6] and 700 kg of steam is 1.5 tons, i.e. 2300 m^3. From the total composition of obtained synthesis gas: C - 928.6 m^3 - 41.4×10^3 mole; H_2 - 1079 m^3 - 48.1×10^3 mole. The calculation of synthetic liquid fuel (SLF) follows the chemical reaction equation for Fe catalyst: $2CO + H_2 \rightarrow CH_2 + CO_2$. The yield of
hydrocarbons is: 20.7×10^3 mole or 290 kg of 1 ton of coal. The practical yield of all hydrocarbons does not exceed 90% and is 260 kg, for Fe – SLF …. 62%, i.e. 161 kg per 1 ton of coal. According to the traditional technologies, the practical yield of SLF is in the range of 120… 140 kg per 1 ton of coal.[9]

Conclusions. The high yield of SLF in the plasma method is accounted for a higher quality initial product (synthesis gas). Compared with the traditional coal gasification technologies, the plasma technology has the following advantages [6, 9]: high specific productivity of the process; no consumption of solid, liquid and gaseous fuels; possibility of rapid heating of coarse coal particles to a high temperature in the gasification area due to the heat of small fraction combustion; simplicity of technical implementation of the process; possibility to adjust technological parameters in a wide range; compactness of the equipment and small specific energy and metal expenses.

In the case of coal gasification, and in the case of biomass gasification, the requirements for gas treatment systems are significantly simplified when used in comparison with MSW processing. Nevertheless, the inclusion of such equipment in plasma gasification complexes is mandatory. In general, with increased requirements for the purity of gasification products, the cost of gas purification equipment may exceed the cost of other components. In the case of low-performance gasifiers, this may be economically inefficient. Therefore, in these cases it is possible to use the simplest means of gas treatment in the form of cyclone-type separators to remove solid particles from the synthesis gas, and during its subsequent combustion in a gas engine, the final treatment of exhaust gases can be carried out using traditional means for treatment of exhaust gases of internal combustion engines.

The main factor that delays the widespread introduction of plasma technologies in various industries is the insufficient level of reliability and life of plasma generators. A separate problem is the integration of plasma generators into technological circuits with the provision of sustainable operation of all types of equipment. To solve the above problems, the authors proposed a number of technical solutions to increase efficiency of raw materials gasification units with integrated electric arc plasma generators presented in the papers [10–13].

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