

PLAZMOVÝ REAKTOR NA SPRACOVANIE ODPADOV

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PLASMA REACTOR FOR WASTE TREATMENT

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Abstract

A millions tons of solid waste are generated annually in the world. The most common method for thermal treatment of solid waste is the incineration process, generated heat energy, drastically reducing the volume of solid waste for deposition, but producing very toxic residues - the ash and the flue dust. The plasma gasification and smelting process provides complete gasification of all organic and plastic materials to produce the hydrogen and carbon monoxide rich synthesis gas, which can be used after purification for electricity and heat generation. Any non-combustible inert materials and metals are melted and transformed into inert slag and metal alloys, which can be used for metals production or in civil engineering. On the bases of construction of 3 kVA laboratory plasma reactor and gasification tests of different type of materials the lager plasma reactors for industrial solid waste treatment was suggested and constructed. Suggested plasma reactor with hollow graphite electrode for waste treatment process without any solid or liquid waste is commercially feasible and environmentally friendly.

Key words: recovery, hydrogen, liquids, plasma, reactor, waste

Abstrakt

Na svete sa ročne produkuje milióny ton odpadov, z ktorých sa časť spaľuje, pričom sa okrem získania tepla zníži aj objem odpadu za vzniku toxického popolčeka a škvary, ktoré sa musia skládkovať na skládkach s riadeným režimom. Novým spôsobom likvidácie odpadov je ich tavenie a splynovanie v plazmovom reaktore, pri ktorom dochádza k plynofikácii všetkých organických a plastických zložiek odpadu za vzniku syntézneho plynu s vysokým obsahom vodíka a oxidu uhoľnatého, ktorý je vhodný na energetické využitie, zatiaľ čo kovové a nekovové zložky odpadu vytvoria dve tekuté fázy – kovovú zliatinu a trosku, ktoré sa dajú ďalej využiť. Na základe konštrukcie 3 kVA laboratórneho plazmového reaktora a splynovacích testov rôznych druhov odpadov boli na likvidáciu rôznych druhov odpadov pre priemyselné využitie navrhnuté a skonštruované väčšie plazmové reaktory. Navrhnutý plazmový reaktor s dutou grafitovou elektródou pre spracovanie odpadov predstavuje technológiu, pri ktorej sa využijú nielen všetky zložky odpadu, ale sa využije aj jeho energetický potenciál bez zaťaženia životného prostredia plynými emisiami alebo tuhými odpadmi.

Kľúčové slová: výťažnosť, vodík, tavenina, plazma, reaktor, odpady

1. Introduction

The human society generate annually huge amount of solid waste, which contains different type of materials such as paper, plastics, metals, glass, organic fraction etc.

The most common method for thermal treatment of solid waste is incineration [1,2,3]. The incineration process, utilised the heat energy, drastically reducing the volume of solid waste for deposition, but the ashes and flue dusts are very toxic residues, with high contents of heavy metals, dioxins and furans, which can pollute soil, ground and underground water [4,5,6]. To avoid these problems a numerous metallurgical processes have been investigated for the waste treatment. Plasma technology, commonly used in metallurgy, it seems to represent an interesting way [7,8,9]. The plasma gasification and smelting process, presented in this paper, is one-possibility way for energy recovery and complex treatment of solid waste from a viewpoint of environmental protection and recycling of resources. By plasma gasification and smelting process, presented in Fig. 1 [10,11], the solid waste with different components can be processing:

- Organic and plastic materials (textile, wood, plastics, etc.)
- Non-combustible inert materials (glass, ceramics, etc.)
- Non-volatile metals (Fe, Cu, Al, etc.)
- Volatile metals (Hg, Cd, Zn, Pb, etc.)

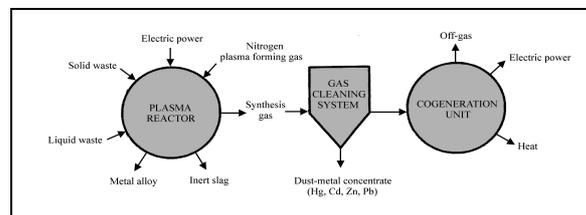


Fig. 1. Flow sheet for processing of solid waste by plasma gasification and smelting process

In plasma reactor the organic and plastic components from solid waste, is transformed in high energetic synthesis gas by thermal decomposition of the macromolecules in a simple molecules by following common equation [12]:



The volume of synthesis gas that is produce by thermal decomposition of organic and plastic materials is very small, so the high efficiency gas cleaning system can be used for effective removal of volatile metals and acid gas components. Due to the high temperature and the low oxygen potential in the plasma reactor and rapid cooling of synthesis gas in the gas cleaning system the formation of dioxin and furans will be negligible [4,5]. The volatile metals evaporated into the synthesis gas such as mercury, cadmium, zinc and lead can be separated as metal concentrate dust and the acidic gas components such as sulphur dioxide and hydrochloride acid can be washed out and precipitated as a different type of salts in the high efficiency gas cleaning system. Cleaned high energetic synthesis gas, similar to reformed natural gas, may be used in very low pollution cogeneration system for electric and heat energy generation [13]. Any non-combustible inert materials and non-volatile metals from municipal solid waste are melted and transformed into inert slag and metal alloys [14,15]. The metal concentrate dust and metal alloys are suitable for metals production and inert slag can be used in civil engineering.

2. Thermal plasma

Plasma is considered to be the fourth state of matter, consisting of a mixture of electrons, ions and neutral particles, although overall it is neutral. The degree of ionization of plasma is proportional to the number of atoms that have lost their electrons and, in the case of thermal plasmas, is controlled mostly by temperature. Plasma technology involves the creation of a sustained electrical arc by the passage of electric current through which the plasma-forming gas (argon, nitrogen, and air) is flowing. The high-intensity plasma arc has a temperature of about 8000 K [16,17]. Thermal plasmas are produced by plasma torches, which can be divided into two main groups: the nontransferred arc and the transferred arc. The nontransferred arc type torch, illustrated in Fig. 2a, contains both electrodes, so the arc actually burns within the torch and it is only by using a high gas flow that a flame of partially ionized gas leaves the torch nozzle. The transferred arc type torch, illustrated in Fig. 2b and 2c, contains only one electrode, with the counter electrode being the material to be heated. The electrode for the transferred arc type torch could be a cold (Fig. 2b) or hot (Fig. 2c). As a hot electrode is usually used, a hollow graphite electrode which can work with higher current intensity as a cold electrode. The main driving force for the plasma flame for the transferred arc type torch is the electric field between the electrodes. That means that the heat transfer and heat efficiency for transferred arc type torches is higher than for non-transferred arc systems.

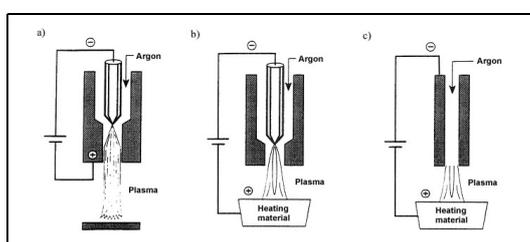


Fig.2. Schematic of plasma arc systems

- a) non-transferred arc system
- b) transferred arc system with cold electrode
- c) transferred arc system with hot hollow graphite electrode

After these conclusions the simplest plasma heating system suitable for high-power reactor operating under neutral or reducing atmosphere has been proposed. It is DC transferred plasma arc reactor with single hollow graphite electrode which can be used for processing of municipal solid waste, which 3D-CAD model is presented in Fig. 3



Fig. 3. 3D-CAD modeling of the laboratory scale DC transferred plasma arc reactor

- 1- graphite hollow electrode – cathode
- 2- refractory lined cylindrical shell
- 3- graphite crucible – anode

3. 3kVA laboratorný plazmový reaktor

The laboratory scale 3 kVA DC transferred plasma arc reactor with single hollow graphite electrode for processing of municipal solid waste by the plasma gasification and smelting process is shown in Figure 3 has been developed and fabricated in Department of Power Engineering [11,18]. The reactor comprised the refractory lined cylindrical shell, the graphite crucible, serves as the reactor hearth and the anode, and the central graphite hollow electrode arranged in a vertical configuration forms the cathode. The cylindrical steel shell lined with alumina refractory material with internal diameter 80 mm is a body of plasma reactor. The top of the shell is equipped with the water-cooled feed system and the off-gas port. The bottom anode is fixed so the plasma arc stabilisation is done through the adjustment of the top hollow graphite electrode by mechanical system, which provides up and down movement of the electrode during the operation of plasma reactor. The end of the cathode is equipped by water-cooled cathode clamp with plasma-forming gas feeding system. The alumina bushes with graphite sleeve in the axial hole in the water-cooled lid of the plasma reactor secure the free travel of the graphite hollow electrode without electrically shorting the body. The laboratory plasma reactor is supplied with a 3.5 kVA transformer and AC-DC thyristor controlled rectifier. The diagram of the laboratory scale DC transferred plasma arc reactor and 3D-CAD model are presented in Fig. 4 and the photograph of the laboratory plasma reactor is shown in Figure 5.

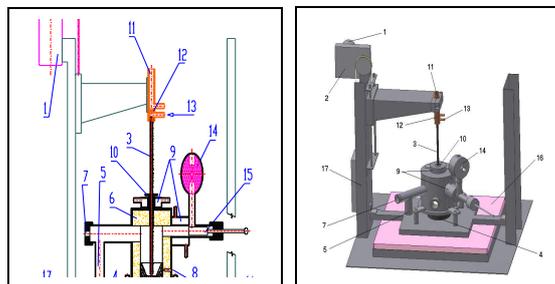


Fig. 4. The diagram of the laboratory scale DC transferred plasma arc reactor and 3D-CAD model 1-electromotor, 2-cathode motion mechanism, 3-hollow graphite electrode –cathode, 4- graphite crucible-anode 5- off-gas port, 6- alumina lining, 7- gas sampling hole, 8-thermocouples, 9-water-coolers, 10-cathode sealing, 11- water- cooler of cathode clamp, 12- cathode clamp, 13-plasma forming gas, 14- batch feeding system, 15- feeding system, 16-isolation plate, 17-rack



Fig. 5. The 3 kW laboratory scale DC transferred plasma arc reactor

Plasma is generated between a hollow graphite electrode - cathode and a graphite crucible - anode. The plasma power is controlled via its electric current and voltage. The length of the plasma arc is proportional to the current, which is controlled by adjusting the distance between anode and cathode. The electrical computerized control and mechanical movement systems have been developed for controlling and adjusting the cathode's vertical position in the plasma reactor.

During operation the nitrogen gas flow through the hollow graphite electrode with flow rate 5.5 l.min^{-1} is used as plasma forming gas. The optimum operation conditions for the stable plasma arc are 120 A current and 25 V voltages. This means that the electrical control system is operating in the electrical current intervals from 115 A to 125 A as is documented in Figure 6.

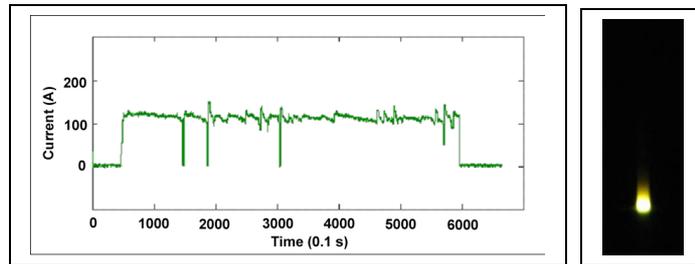


Fig. 6. The time fluctuation of electric current in plasma reactor and plasma arc

4. Plasma reactors with higher power

On the bases of experimental data obtained from construction of laboratory 3 kVA DC transferred plasma arc reactor and the preliminary tests with plasma gasification of different type of plastic materials [13] in this reactor, the DC transfer plasma arc reactors with higher power has been suggested and constructed for continuous study of plasma gasification and smelting process. The example of the 80 kVA DC transferred plasma arc reactor with hollow graphite electrode is shown in Fig. 7.

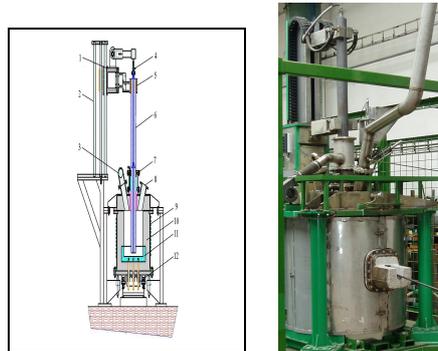


Fig. 7. The diagram and view of the 80 kVA DC transferred plasma arc reactor
 1-cathode motion mechanism, 2-rack, 3-off-gas port, 4-plasma forming gas-nitrogen, 5-cathode clamp, 6-hollow graphite electrode-cathode, 7- water- cooled cathode sealing, 8- materials feeding port, 9-steel shell, 10- alumina lining, 11-graphite crucible-anode, 12-anode connection.

The 80kVA DC transfer plasma arc reactor consists from cylindrical steel shell, 920 mm in diameter, lined with a castable alumina ended with the graphite crucible, serves as the reactor hearth and the anode (Fig.7). Three stainless steel-graphite rods are used for connection of graphite crucible anode to air-cooled copper clamps. The taphole is located in the graphite crucible near the hearth. The cathode is the central graphite hollow electrode, with 100 mm diameter, arranged in a vertical configuration with sufficient mechanical movement, which provides up and down movement of the electrode during the operation of plasma reactor. During operation the nitrogen gas flow through the hollow graphite electrode is used as plasma forming gas. The roof of reactor is the steel shell lined with a castable alumina. Three ports are located in the roof (Fig.7); one centrally located port is for the water-cooled cathode seal, which secure not only synthesis gas

leaking out from plasma reactor but provided also a electrical isolation of the cathode from the remainder of reactor which is earthed for safety reason, and two peripherally located ports are for materials feeding and for off gas exhausting. A sophisticated water-cooled feed system has been developed by which the feed materials in the size range from 0.1 to 5.0 mm is continuously feeding directly under gravity through the feed port into the bath near plasma arc column without any air penetration into the plasma reactor. This construction of the cathode seal and feed system allow running the plasma reactor under slightly negative pressure condition.

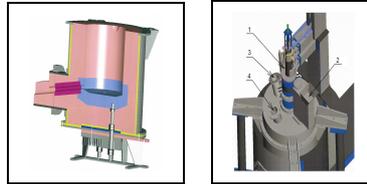


Fig.7 3D-CAD model of hearth and roof of 80 kVA plasma reactor
1- hollow graphite electrode–cathode, 2-feed port, 3-off gas,
4-sight-hole

The plasma reactors are supplied with an three-phase transformer and AC-DC thyristor controlled rectifier. Variable power intensity can be selected. The running of the plasma reactor is monitoring and control by electrical computerized control system. During operation the nitrogen gas flow through the hollow graphite electrode and the optimum operation parameters – current and voltages are automatically holding at constant levels for the stable plasma arc are running. The examples of the time fluctuation of electric current, voltage and temperature in 30 kVA plasma reactor and plasma arc in 80 kVA plasma reactor are presented in Fig. 8.

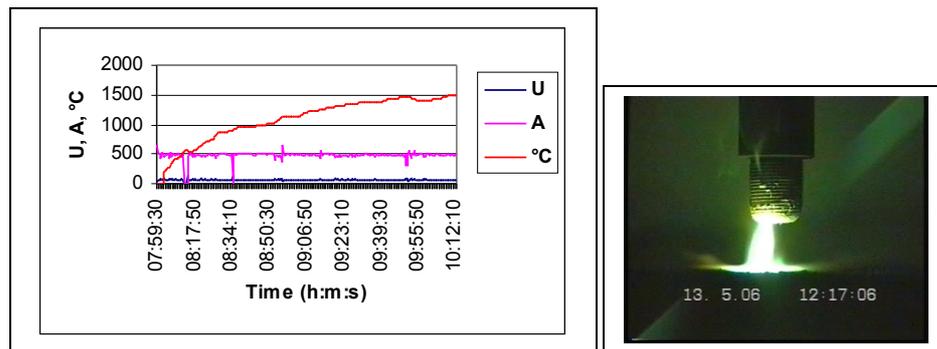


Fig. 8. The time fluctuation of electric current, voltage and temperature in 30 kVA DC plasma reactor with hollow graphite electrode and plasma arc in 80 kVA plasma reactor

5. Conclusion

The new regulations of EU require material recycling and energy recovery from solid waste so in the future wider use of plasma gasification and smelting process are expected for waste treatment because suggested process is commercially feasible and environmentally friendly with high materials and energy utilization without any solid or liquid waste.

On the bases of construction of laboratory plasma reactor and gasification tests of different type of materials in the Technical University of Košice and after the cooperation with QEL Ltd.

and GAZOTECH Ltd. Companies in Bardejov, the new DC plasma reactors with hollow graphite electrode has been suggested and constructed for industrial application.

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