Distribution of energy characteristics in plasma chemical reactor for waste processing

R. Uscila, V. Valinčius, R. Kėželis, V. Grigaitienė, D. Gimžauskaitė, M. Aikas

Plasma Processing Laboratory, Lithuanian Energy Institute
Breslaujos g. 3, Kaunas, Lithuania
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Presenting author email: Rolandas.Uscila@lei.lt

One of the most important issues for preserving the surrounding environment is the disposal and recycling of domestic and industry-generated waste. The processing of waste must be treated as the most important link between the man-made techno sphere which generates the largest part of the waste, including harmful and environmental (Young, 2010). However, nowadays up to this time used waste management technologies do not satisfy modern requirements. By reinforcing environmental requirements for reducing natural pollution, it is necessary to seek new, friendly to environment, methods and technologies for the storage, recycling or recovery energy of all types of waste (industrial, household or hazardous).

The technologies currently in use are not sufficient to attain above-mentioned objectives. Especially this concerns wastes containing harmful or toxic substances which require high temperatures for recycling. The thermal decomposition techniques are mainly used for this purpose. However, the low-temperature pyrolysis method or heat treatment (incineration) for the decomposition of such waste is not suitable. At the temperatures of 700 to 900 K (pyrolysis) or up to 1300 K (burning), new toxic substances such as dioxins, furans and other hazards, that are much more harmful than the initial product, may form. In order to fully counteract the effects of harmful substances to environmental and human health, it is necessary to recycle them at significantly higher temperatures, reaching 1800 to 2000 K. At such temperatures, the molecules of the toxic compounds are broken into atoms, radicals, electrons and positive ions and with decreasing plasma temperature, simple harmless substances are formed. The thermal plasma technology is best suited for this purpose. The waste is destructed usually using arc plasma generated by plasma torch. The main advantage of a plasma waste recycling (when compared to physiochemical or biological) is its versatility allowing decomposes any kind of waste (Chang, 2001; Gomez *et al*, 2009; Young, 2010; Anshakov *et al*, 2015). Therefore, the technology of waste processing using plasma energy sources has been studied experimentally in the presented work.

All hazardous waste decomposition facilities are subject of high risk and are subject to special technical, occupational safety and environmental requirements. They can only be guaranteed by the use of the modern latest scientific and technical knowledge and precision measuring equipment. The main requirement for a waste decontamination plant is not only that the emissions of neutralizing substances after neutralization have does not exceed the permissible levels. They must not occur at all. This is possible if the conditions under which a given substance is broken down into harmless compounds for humans and the environment are known. This requires an experimental procedure to determine the required temperature, additional gas flow and its composition needed for chemical reactions (e.g. O_2, H_2, water vapor, etc.) and to analyse the exhaust gas and solids formed, and then start the industrial neutralization of the given material. A schematic presentation of the plasma chemical reactor used for the initial experiments of the waste decomposition process is given in Fig.1.

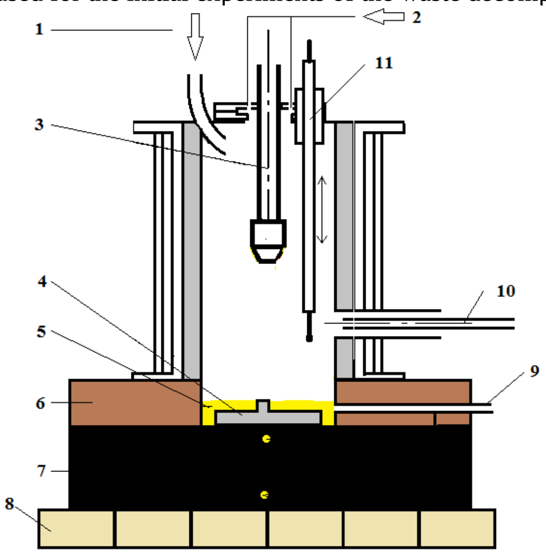

Fig. 1. The scheme of plasma chemical reactor. 1 – raw material input into the reactor, 2 – protective air supply, 3 – plasma torch, 4 – metal plate, 5 – recyclable waste layer, 6 – high temperature insulation plate, 7 – graphite anode, 8 – insulating base of porous brick, 9 – melted waste outlet, 10 – cooled probe for gas sample pickup for analysis, 11 – thermocouple

During the experiments, the plasma arc power, gas flow rate, cooling water flow rate and its temperature were measured. The amount of material recycled was also controlled and measured. The plasma arc power in the reactor was determined by measuring electric arc voltage and current. Power supply system, as well as air supply and cooling systems also the data collection and measuring systems are in details described elsewhere in previous works (Kėželis *et al*, 2004; Valinčius *et al*, 2004). During the experiments plasma chemical reactor working parameters were as follows (Table 1):

Table 1. Plasma chemical reactor working parameters

	I (A)	U (V)	P (kW)	Air inlet (g/s)	Arc length (mm)
Start	160	121	19,4	0.9+6.9	65
Operation	160	200	32	0.9+6.9	100

An experimental approach firstly is presented for the analysis of thermal characteristics of a plasma chemical reactor containing a plasma torch inside with hot cathode and a flat plate-shaped anode (Valinčius et al, 2019). The most important characteristic of the plasma source is the voltage drop on its electrodes; however, on exploiting the facility as the heat energy source the knowledge of this quantity alone is not enough. It is expedient to know both electric and thermal characteristics of the plasma ambient; therefore, heat transfer is calculated in addition to the electric-field strength (EFS) distribution in the arc chamber.

When the arc interacts with the gas flowing around it and with the wall, the nature of gas flow, EFS and heat transfer change significantly. Investigations of electric arc characteristics enable to determine the gas flow scheme when the arc is in operation. In the upper part of the chamber, the length of which is determined by the turbulization point of the arc is burning in the laminar regime, EFS is constant and comprises about $(1.0–1.5)\cdot10^3$ V/m in the case of air flow. After sufficient of plasma forming gas is injected into the reaction zone of the arc, the flow is turbulized so that the boundary layer is disrupted at the channel surface. This result increase EFS, which depends upon the diameter of the reaction chamber, flow rate, amount of gas, flow nature, the impact of the magnetic field, the injection point and intensity of additional gas flow. When the gas flow is properly injected into the chamber along the arc, the EFS is increased and energy losses due to the convection decrease.

During the tentative investigation it has been observed that arc length and stability depend upon the plasma torch construction and the processes occurring in the reaction chamber. Electric discharge, known as the arc shunting can be of both long and short gap. When the discharge occurs between the arc column and the anode the arc current has the biggest impact on heat flux intensity. However, sometimes the discharge occurs between the separate parts of the arc or between the arc column and certain parts of the reactor walls. When the shunting amplitude is high, the parameters of the arc and gas flow characteristics change with simultaneous increase in instability. Gas inflowing into the reaction chamber by radial injection together with feeding waste particles flows around the arc decreases the shunting effect and increases gas temperature.

The melted waste layer in the chamber is electrically conductive, and when it forms, the shunting processes disappear. It has been found that the current density is $10^4–10^7$ A/m^2 in the arc column, $10^8–10^{10}$ A/m^2 in the pre-cathode zone of the arc, and $10^6–10^9$ A/m^2 in the anode zone. The length of the pre-cathode zone of the atmospheric pressure plasma arc is about 10^{-6} m, i.e., is equal to several lengths of the particle free path [4,5]. This indicates that the thermal emission of electrons from the cathode is possible.

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