Analysis of the Selected Types of Waste Treatment by Plasma Technology: Part I

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Abstract— *The series of articles (Analysis of the selected types of waste treatment by plasma technology. Part I., Part II.) discusses the processing of selected three types of waste using plasma technology. In this first part, the technology of plasma gasification and melting, is presented, as well as the processed types of waste. It involves the disposal of solid waste such as ash from municipal waste, silicone rubber and asbestos-cement material.*

Keywords— Thermal Treatment of Waste, Ash from Municipal Waste, Silicone Rubber and Asbestos-Cement Material, Plasma Technology.

I. INTRODUCTION

An undesirable consequence of human activity is the ever-increasing generation of waste. It is waste generated during the extraction of raw materials, then through the processing of primary raw materials, through treatment to the final product of human activity, which becomes waste after the end of its life cycle. At the beginning, it is necessary to point out once again that the raw material becomes waste, or another thing in the process of production and processing of emerging new products, a thing that has ended its life cycle but also a thing that is still functional, but its owner wants to get rid of it.

The production of the amount of waste depends on the economic activity of the state, as well as on the increase in the demands and activities of people. The oldest methods of waste disposal are thermal waste disposal processes after landfilling.

II. THERMAL PROCESSES OF WASTE TREATMENT

To use thermal disposal methods or waste processing were initially mainly driven by hygienic reasons, later there were also reasons for reducing the volume and weight of waste and thus saving the volume of landfills. Thermal methods are an integral part of the policy of a sustainable and integrated waste management system. [1]

Thermal waste disposal processes are characterized by high temperature and a greater rate of waste transformation compared to other biochemical and physio-chemical waste treatment processes. [2]

The following methods are distinguished:

2.1 Incineration:

Incineration is the most widespread method of disposal of municipal waste in the western countries of the EU. Incinerators are used for waste disposal with air access at operating temperatures of 850-1200 °C. They bring savings in the field of classic energy sources such as coal, natural gas and oil. Outputs from the combustion process are presented in Table 1. [2]

TABLE 1
OUTPUTS FROM THE COMBUSTION PROCESS

Produced gases	Polluting substances	Solid products
CO_2, water vapor	SO_2, NO_X, HCl, dioxins and furans (PCDD, PCDF), solid components in the form of chimney waste	Ash containing e.g. also ferrous and non-ferrous residues

2.2 Pyrolysis:

Pyrolysis is the heat treatment of waste materials in a pyrolysis furnace (at a temperature of 250 to 1650 ºC) without air access, or with limited air access and at reduced atmospheric pressure. The result of pyrolysis decomposition is liquid substances (pyrolysis oil) and gaseous substances (pyrolysis gas). These substances can be used as secondary raw materials (to produce benzene, toluene, etc.), or they are burned very efficiently (without significant production of emissions) in boilers to produce heat. [1]

Most heavy metals pass into solid pyrolysis residues and are not contained in emissions. Pyrolysis is a promising technology, especially for disposal of hazardous waste. So far, very few pyrolysis processes have been implemented for municipal waste compared to the number of implementations of waste incinerators. [1]

2.3 Gasification and Melting of Waste:

Unlike pyrolysis, an oxidizing agent is used in the gasification process of decomposition of the feed material.

In waste management, gasification and melting of waste using low-temperature plasma is mainly used. The basis of this technology is the creation of a plasma arc discharge from a stream of inert gas (Ar, N_2, etc.) or from gas enriched with oxygen. The plasma-forming gas is transformed into a plasma state with the help of a high-intensity electric field. High temperatures at the edges of the plasma arc discharge (1 200 – 1 800 °C) ensure a stable heat flow necessary for the thermal decomposition of waste.

Due to the high dissociation energy, the organic component of the waste is broken down into simple gas molecules. Inorganic waste components (in the form of liquid slag and metals) are periodically discharged through tap holes. The gas emerging from the plasma process can be used for energy purposes, depending on the presence of combustible components. Which partly eliminates the high energy demand of the technology. [3]

III. PLASMA AND WASTE MANAGEMENT

The technology of plasma gasification and melting is mainly used in metallurgical processes and in the synthesis of materials. In the developed countries of the world, it is also extended to the disposal of hazardous waste. Plasma treatment of waste takes place at temperatures above 1000 °C. It is a complex process that involves numerous physical and chemical interactions.

For the field of waste processing, it is necessary to highlight the advantages of this waste disposal technology [4]:

- High temperature of the plasma arc discharge, i.e. the possibility of thermal treatment of waste at a temperature of several °C,
- High rate of particle heating in connection with the heat exchange between the particle and the plasma,
- The high rate of heating is therefore also associated with the rapid decomposition of part of the waste of organic origin with the explosive release of volatile substances,
- UV radiation, which is emitted from a weakly ionized plasma, ensures the decomposition of halogenated hydrocarbons,
- Plasma technology products are predictable and environmentally acceptable if technological procedures are followed,
- Wide spectrum use.

Laboratory equipment for plasma gasification and melting is used at Faculty of Mechanical Engineering, Technical University of Košice, Department of Energy Engineering, where experiments were carried out with various types of waste commodities. A 10 kVA reactor generates a plasma arc discharge between:

1) Cathode – a hollow graphite electrode through which the plasma-forming gas (N_2) is supplied and
2) Anode – a graphite crucible that is placed at the bottom of the plasma reactor.

The plasma reactor also contains a reservoir and a screw-dosing device for the charged commodity, as well as a cyclone separator and a device for cleaning the generated synthesis gas.

The plasma reactor contains a heat-resistant alumina lining, an electrode sliding mechanism, a graphite crucible and accessories providing power supply.

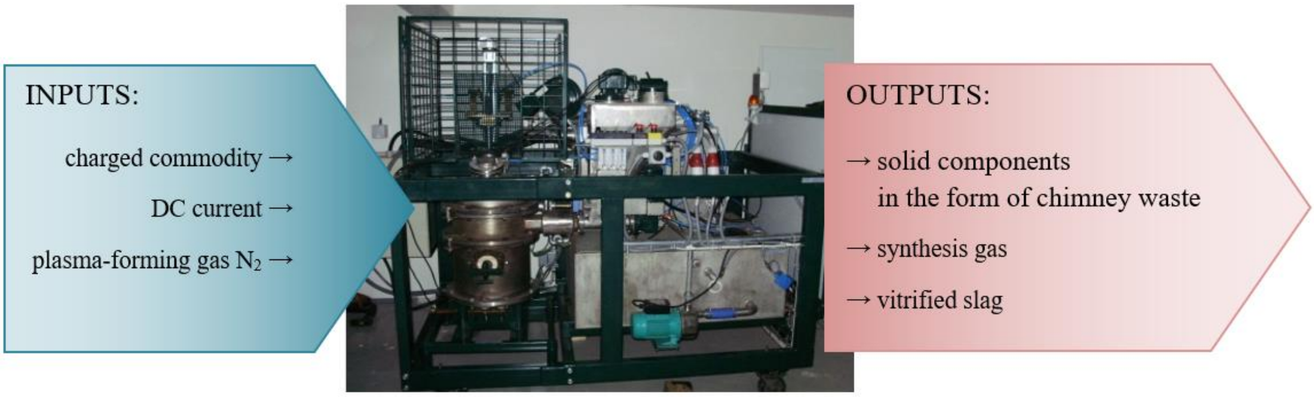

FIGURE 1: Laboratory plasma reactor with its inputs and outputs

There are technological openings on the reactor lid and shell, which are used for:

- Service purposes,
- Input of hollow graphite electrode,
- Input of waste commodity,
- Extraction of synthesis gas,
- Removal (tapping) of slag and alloy.

The generated plasma arc discharge heats and melts the charged commodity in a dependent connection. The melt is concentrated at the bottom of the reactor in two separate phases, slag and metal alloy, which are subsequently tapped from the reactor through tapping holes.

Together with slag and metal alloy (if the input commodity also contains metal parts), gaseous products are also produced - a mixture of gaseous components containing solid pollutants, which are removed in a cyclone separator.

Cooling of the electrode is provided by water-cooling as well as by the supply of the plasma-forming gas itself, i.e. of nitrogen, which also prevents syngas leakage at the point of entry of the electrode into the reaction chamber of the reactor. The introduction of nitrogen also prevents oxidation of the graphite electrode.

Monitoring of several basic parameters is important for the proper course of the waste treatment process by plasma gasification and melting:

- Operating temperature,
- Current and voltage parameters,
- Total power input of the technological line,
- Cooling medium flow,
- Mode and rate of dosing of the commodity being charged.

IV. WASTE PROCESSED BY PLASMA TECHNOLOGY

Three waste commodities were subjected to plasma gasification and melting at our workplace:

1. Fly ash from solid municipal waste,
2. Waste containing asbestos,
3. Silicone rubber.

4.1 Fly ash from solid municipal waste:

During the incineration of municipal waste, solid and gaseous products are formed:

- Gaseous emissions,

- Ash (cinder)
- and Fly ash.

Electrostatic or mechanical separators within the flue gas cleaning system capture fly ash, as a by-product of heating and energy production. The mineralogical, granulometric and chemical composition of the ash depends on the type of incinerated batch, the type of focus or the technical method of solving the incineration process. Its use as a secondary raw material is therefore subject to certain requirements arising from the standards.

FIGURE 2: Fly ash from municipal solid waste

Cinder and fly ash from municipal waste make up 25 to 30 % of the weight, but only 10 to 15 % of the original waste volume. Toxic substances are concentrated in fly ash and cinder, so although the area required for their storage is significantly reduced, such waste must be stored in controlled landfills, it is necessary to ensure their stabilization. For example, it involves its fixation with cement, extraction with acids or stabilization with chemical additives. Ultimately, the goal of the stabilization processes is to solidify this fine dust fraction of waste.

In the most widespread method of ash solidification, i.e. fixation of fly ash in a silicate matrix using the cementation method reduces the leaching of toxic fly ash substances but does not solve the problem of placing fly ash in a landfill.

On the contrary, a more suitable technology for disposing of fly ash is its melting in a thermal-chemical process, the so-called vitrification. The resulting product is an extremely stable glass matrix.

4.2 Waste containing asbestos:

Asbestos is the technical name of a group of minerals that can be divided into flexible and brittle fibers. It is a fibrous silicate that occurs in several forms (Figure 3).

FIGURE 3: Forms of asbestos [5]

In the last century, due to its properties, asbestos was used in many branches of industry. Asbestos stands out for the following properties:

- Excellent resistance to temperatures and chemicals,
- High tensile strength,
- Flexibility,
- High stability under normal conditions.

However, its high danger lies in the release of fibres of microscopic dimensions into the air during the natural weathering of building materials, as well as during unprofessional handling or processing (cutting, abrasion or vibration).

The harmful effects of asbestos fibres on the human body have been proven. Due to their hardness, microscopic asbestos fibres with dimensions of approximately 5 micrometres and a thickness of 3 micrometres easily penetrate the lungs when inhaled. Long-term exposure to asbestos fibres on the body can cause diseases such as asbestosis or lung cancer.

However, there are several studies dealing with asbestos inerting technologies, e.g.:

- High temperature processing (firing, melting, vitrification) [6, 7],
- Microwave heating [8 – 10],
- Hydrothermal transformation [11, 12],
- Non-thermal technologies [13, 14].

4.3 Silicone rubber:

Rubber is a material of natural or synthetic origin that belongs to the category of polymer materials. It is a material with a high degree of elasticity. It is the basic building block for rubber production.

FIGURE 4: Products of silicone rubber [15]

The rubber production process takes place using various technologies for processing rubber compounds, which are divided into [16]:

- Preparatory (mixing and kneading),
- Basic (extrusion and rolling),
- Associated (pressing, extrusion and injection moulding),
- Supplementary (joining and surface treatments).

The necessary operations for processing rubber compounds into the final product are:

1) Mixing rubber compounds:

Rubber products are composed of several components that must be mixed homogeneously. Fillers, antidegradants, plasticizers, and vulcanizing agents are practically always used in the formulation of rubber compounds. Depending on the type of specific product, pigments, blowing agents, adhesion agents, peptizing agents, or reinforcing materials can also be part of rubber systems. In addition to plasticizers, which are not defined as solvents, no organic solvents are used in this stage of the preparation of rubber compounds.

2) Processing of rubber compounds:

Rolling (calendering) and extrusion technologies are mainly used to shape rubber compounds. The rolling technology is used to produce the rubber bands themselves, which are used in the assembly of finished products (e.g. tire casings, conveyor belts), for impregnation and rubberization of textiles, friction application and others. Extrusion technology is used for the preparation of semi-finished products of more complex products (e.g. tire production), or to produce final products (e.g. hoses, gaskets, various profiles), if the extruded profile is simultaneously pulled through the zone where it is vulcanized (continuous vulcanization). No organic solvents are used in this stage of preparation of rubber compounds.

3) Vulcanization:

Vulcanization is the process of transforming a plastic rubber mixture into a highly elastic final product - vulcanizate, or what is commonly referred to as rubber. It acquires highly elastic properties as a result of the creation of physical and especially chemical cross-links between segments of rubber chains, during reactions of functional groups of rubbers with functional groups of vulcanizing agents (Figure 5).

This creates a spatial three-dimensional network of the rubber matrix, in which the other components of the rubber mixtures are dispersed, dissolved, physically, or chemically bound to rubber chains. The vulcanization process usually takes place at elevated temperature (150-200 °C) and pressure. Pressing, extrusion and injection technologies are used for the vulcanization of rubber compounds. No organic solvents are used in this stage of preparation of rubber compounds.

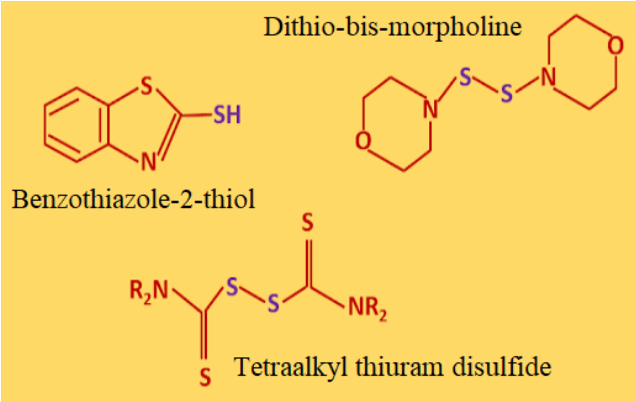

FIGURE 5: Vulcanization initiators [17]

Silicone rubber recycling is quite complicated, unlike plastic, paper or glass recycling which is straightforward. When silicone rubber is recycled, it is possible to reduce the amount of this waste and thereby reduce primary production costs. There are two main ways to recycle silicone rubber: moulding and extrusion.

During pressing, the silicone rubber is melted and formed into a new shape. This method is often used to recycle waste from production or to recycle used products.

In extrusion, the silicone rubber is melted and pushed through a die to form new pellets or "noodles". These pellets can be used to make new products or sold as is.

When silicone rubber is reprocessed, its properties are gradually degraded.

V. CONCLUSION

It is very important to focus more strongly on appropriate methods of waste processing, as its generation has a constantly growing trend. Thermal methods of waste disposal represent reliable and effective methods of disposing of various forms of waste. After classic waste incineration, plasma gasification and waste melting devices are used. Several studies have already been carried out to assess the suitability and effectiveness of using the plasma thermal process. To verify the suitability of plasma waste processing technology, 3 different types of waste were selected – fly ash from municipal solid waste, waste containing asbestos and silicone rubber.

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