Development of technology of plasma processing of technogenic wastes (brief review)

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Abstract. The problem of man-made waste processing remains one of the most urgent in the world, since none of the known technologies for processing and destruction of waste fully meets the requirements of consumers. One of the safest technologies for processing and destruction of man-made waste is considered to be the use of low-temperature arc plasma. However, until now there is no widespread industrial application of plasma processing of industrial wastes. The main scientific and technical problem arising at practical implementation of plasma gasification of organic raw materials is high specific energy consumption. According to open information sources, an analysis was conducted and it was determined confirmed, that the development of technology for plasma processing of organic waste proceeds along the path of reducing specific energy consumption and heat loss, increasing the service life of electrodes and caloric content of the resulting synthesis gas.

1. Introduction
The problem of waste processing is one of the most urgent. The world amount of waste per capita increases by 4-6% annually, that is, 3 times faster than the population of the world grows [1]. Today, the most common technology to solve the problems of industrial waste recycling is combustion at a temperature from 800 to 850 K with generation of electricity and heat [2]. The main drawback of waste incineration is low environmental performance, as well as a narrow circle of incinerated waste. The issues of trapping and deactivating such harmful substances as benzopyrene, dioxin, furans and other carcinogens arise at incineration.

2. Analysis
According to the opinion of numerous experts and specialists, now one of the safest technologies for processing and destruction of man-made waste is considered to be the use of low-temperature arc plasma. The results of investigation of the plasma-thermal processing of various industrial wastes, carried out in Russia, France, Canada, USA, Japan, and Korea, testify to the high efficiency of high-temperature (plasma) technologies for solving the environmental-economic problem of organic waste recycling.

The key difference of plasma technology from firing waste processing is the high level of temperatures in the gasifier (1300–1500°C), which provides almost complete conversion of carbon contained in waste into CO and neutralizes any hazardous substances. The caloric content of the produced synthesis gas can be up to 30–35% of the calorific value of natural gas. This makes it possible to use it to operate gas turbines at electric energy generation.

The diagram on dynamics of patenting in the world, presented in Fig. 1, indicates the growth of applied research in the field of plasma processing of technogeneous waste.
Figure 1. Dynamics of patenting in the field of waste plasma recycling.

Plasma technology of waste gasification allows obtaining high-calorific synthesis gas (a mixture of CO + H2 of up to 90% vol.) with a calorific value of 8-10 MJ/m3. Its use as a fuel in power boilers or gas turbine installations (GTI) allows production of electric energy and heat. High temperatures in the reaction zone of an electric furnace (1200-1600ºС) block formation of carcinogenic substances (dioxin, furans) and provide production of liquid slag with inert properties followed by subsequent granulation (vitrification).

The leader in plasma recycling research is China, which has gotten ahead in the past decade and has overtaken the United States and Russia, which have been dealing with this topic for more than forty years.

However, until now there is no widespread industrial application of plasma processing of industrial wastes.

The main scientific and technical problem arising at practical implementation of plasma gasification of organic raw materials is high specific energy consumption.

The development of technology for plasma processing of technogeneous waste follows the path of reducing specific energy consumption and heat loss, as well as increasing the service life of arc plasma generators [3-6].

At that, in the last decade, the developments have been aimed at creating an integrated waste-free technology, including such steps as

- sorting waste, including the use of robotic manipulators, to obtain plastic, glass, metal;
- grinding and heating waste;
- production of electricity, thermal energy, liquid fuels from synthesis gas.

The only company with basic commercial plants is Westinghouse Plasma Corp. (United States) [7]. Currently, the technology of Westinghouse Plasma Corporation is used at 5 commercial facilities that process household waste, toxic waste and sewage sludge.

The technology of plasma gasification of Westinghouse Plasma Corporation includes preparation and supply of waste to the plasma reactor, gasification, purification of synthesis gas and flue gases, ash smelting, conversion of produced synthesis gas into various products, including electricity (through gas turbines and piston engines, and fuel cells in the future); thermal energy and steam; liquid fuels, including ethanol, jet fuel, diesel and naphtha, methanol, and propanol.

The products of several other companies are known from the open sources:

- Europlasma Group (France), which supplies plasma installations with a capacity from 5 to 70 tons per day to the EU and Southeast Asian countries;
- Tetronics Ltd (UK), which develops electric arc direct current (DC) generators for a wide
range of applications, including, for example, SMW recovery and hazardous waste recycling;

- Prometron Technics Corporation (Japan), which previously collaborated with Russian and Belarusian organizations to develop a plasma shaft furnace for medical waste processing. Now this company is working steadily in the market of the production of plasma equipment in cooperation with US and Canadian companies.

One of the ways to reduce the specific energy consumption in the technology of solid waste processing, actively developing now, is preparation (sorting, grinding, heating) of waste before gasification.

Tomra Systems ASA (Norway) is a world leader in production of sensor sorting systems, including those for the industry of waste recycling and management. More than 4,400 systems have been installed in 40 countries around the world. Sorting systems based on the use of sensors extract pure fractions, providing a significantly higher yield and added value relative to the incoming material than the traditional methods such as separation in a dense medium or manual sorting [8]. The high-tech sensors detect the objects on a conveyor belt, information is processed by such parameters as material, shape, size, color, defects and location of objects on the conveyor belt, and precise sorting is performed using the compressed air jets or mechanical manipulators. Tomra currently offers four main product lines: Autosort (SMW sorting), Finder (separating metals from wire and cable waste), Combisense (“fine” sorting of electronic waste and waste from car recycling), and X-Tract (separating metals from fine mixtures, slag, etc.).

In Russia and CIS countries, only single pilot plants are known [9].

A plasma shaft furnace of periodic action for processing biomedical waste directly in medical institutions has been developed in Belarus at the Luikov Institute of Heat and Mass Transfer (IHMT, Minsk).

A prototype of mobile plasma unit for disposal of toxic chemical wastes of various origin, including polymer toxic waste in liquid and dispersed form, has been developed by “Tekhekoplazma” LLC, Moscow.

A pilot plasma-chemical installation for processing mixed waste, including medical ones, has been created at the Institute of Electrophysics and Electric Power Engineering of the Russian Academy of Sciences (IEE RAS), St. Petersburg. This technology is based on two-zone high-temperature waste processing with subsequent multi-stage detoxification of flue gases.

The main areas of applied research concerning arc plasma application for waste processing are associated with a decrease in specific energy consumption and heat loss, an increase in the lifetime of electrodes, and improvement of the caloric content of produced synthesis gas.

The development of technology is on the way of:

- reduction of heat losses by waste heating with generated synthesis gas, for example, the technology of Westinghouse Plasma Corp., USA [7];
- reduction of energy consumption by using electricity generated from synthesis gas to power the plasma generators, for example, the technology of GEVADA LLC, USA [12];
- increasing the service life of plasma generators by developing plasma generators capable of long-term operation without replacing electrodes, for example, the technologies of IT SB RAS [9] and IEE RAS [6];
- reduction of energy consumption by pre-treatment of waste (sorting, grinding, heating), for example, sorting and grinding by the technologies of Westinghouse Plasma Corp., USA [7]), and GEN ELECTRIC, USA [10]; heating waste by the technology of IT SB RAS [11].

The technology for processing organic waste using arc plasmatrons with a long service life of electrodes (1000 hours) when heating any gaseous media to a temperature of 3000 ÷ 5000 K has been developed at the Kutateladze Institute of Thermophysics SB RAS. At that, the resulting synthesis gas differs by high caloric content, 8–10 MJ/m³. The flow chart of the plasma process for SMW utilization using the developed technology is shown in Figure 2.
**Figure 2.** Plasma-thermal system of SDW processing.

1 – waste; 2 – feed line; 3 – loading mechanism; 4 – hopper; 5 – piston; 6 – valve; 8 – flame; 9 – gas to storage; 10 and 15 – sampling points; 11 – fan; 12 – caustic soda; 13 – furnace for pyrolysis; 14 – gas; 16 – gas annealing; 17 – gas cleaning; 18 – heat exchanger; 19 – sludge; 20 – sending to heap; 21 – slag drainage; 22 – water bath; 23 – conveyer; 24 – slag; 25 – plasmatron; 26 – sealant; 27 – scrubber; 28 – bin for slag; 29 – service systems of electrical, gas and water supply of plasmatron.

The technological scheme includes a shaft electric furnace, waste loading system, service systems for ensuring the efficiency of electric arc plasmatron, system for cleaning waste gases in a scrubber, and systems for slags and sludge collecting.

The characteristics of the known electroplasma technologies are compared in Table 1.

**Table 1.** Comparison of characteristics of electric-plasma technologies.

| Technical and economic parameters of the product | Plasma setup of IT SB RAS | Westinghouse (USA) | Plasma furnace of Luikov Heat and Mass Transfer Institute of NAS of Belarus | Plasma setup of IEE RAS |
|-------------------------------------------------|--------------------------|--------------------|------------------------------------------------------------------------|------------------------|
| Type of waste Productivity                      | All                      | All                | All                                                                     | All                    |
| Plasmatron power, kW                            | 50                       | up to 3600         | 150                                                                     | 50                     |
| Specific power inputs, kW, h/kg                 | 1.0                      | n/a                | 1,5-2,5                                                                | 1.0                    |
| Operation life of plasmatron                    | 1000                     | 1000               | 100                                                                    | 1000                   |
3. Conclusions
Thus, the analysis confirmed that the development of technology for plasma processing of organic waste proceeds along the path of reducing specific energy consumption and heat loss, increasing the service life of electrodes and caloric content of the resulting synthesis gas.

References
[1] Sapozhnikova G P 2004 The end of the “junk civilization”: solutions to the problem of waste (Pushchino)
[2] Justification of the choice of the optimal method for disposal of solid household waste in the cities of Russia Site of the Federal Service for Supervision of Natural Resources (website: http://rpn.gov.ru/node/686)
[3] Alekseenko S V, Perepechko L N., Tugov A N 2013 Utilization of solid household waste in the Novosibirsk region: scientific and technical developments and current state Bulletin of the NSU 13 16
[4] Tugov A N, Moskvichev V F 2014 On the feasibility of using plasma technologies for thermal utilization of SMW Solid household waste 9 44
[5] Cherednichenko V S, Anshakov A S, Kuzmin M G 2008 Plasma electrotechnical installations(Novosibirsk) p 602
[6] Rutberg F G 2006 Encyclopedia of low-temperature plasma (Moscow: Janus-K) p 7
[7] Technology of Westinghouse Plasma Corp 2014 Review of qualification requirements.
[8] Tomra Systems ASA (website: https://www.tomra.com/ru-RU)
[9] Sharina I A, Perepechko L N, Anshakov A S Prospects of the use of plasma technology for the processing/deruction of technogeneous waste 2016 Eco 12
[10] USA Patent US2009064581 2009 US Patent Office (website: http://uspto.gov)
[11] USA Patent No. 2616079 2015 US Patent Office (website. http://uspto.gov)
[12] USA Patent US2011067376 2011 US Patent Office (website. http://uspto.gov)