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Problem of Utilization of Solid Production and Consumption Wastes. Plasma Treatment of Solid Wastes

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Abstract—Plasma technology allows organizing a highly effective and pollution-free waste conversion and offers significant advantages over traditional technologies when waste is either incinerated or disposed in a landfill.

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Quality of the environment will become in the nearest years one of the key factors of competitiveness of the country and each Russian region .... Serious measures to waste liquidation should be taken.

President of the Russian Federation D.A. Medvedev.
Statement at the meeting of the Security Council on ensuring the environmental safety of Russia, Moscow, January 21, 2008

Formation and accumulation of production and consumption wastes creates a serious ecological and economic problem in the sphere of municipal services and secondary waste utilization. Expanding production scale and emergence of new diverse consumption products are accompanied by qualitative changes and increasing quantity of wastes, which puts in the forefront the problem of waste conversion into technically valuable products by environmentally friendly technologies.

There are three principal ways of waste utilization: dumping, incineration, and sorting and use as a secondary raw material.

Underground and water waste dumping is the most unfavorable way. In this case, waste cannot be used as a secondary raw material resource, the degradation products of the organic part of wastes generate methane and toxic substances which are inevitably released into the environment and further to food chains of natural ecosystems.

In Russia about 4 bln ton of solid wastes are formed annually. Of them, about 3 bln tons are dumped in temporary landfills. By the present time, more than 85 bln ton of solid wastes have been accumulated at landfills. The area of closed (full) landfills is about 50 thsd ha, and operating landfills occupy a territory of 40 thsd ha. Annually, 1−3 thsd ha of useful lands are expropriated for dumping solid wastes. Moreover, waste landfills pose a serious threat to the environment (the vapors and gases released by landfills contain substances hazardous for human health).

Incineration of solid wastes, too, is associated with certain environmental threats (emissions of stack gases, fly ash, and extremely toxic compounds, such as polychlorinated dioxins and others, as well as slug formation).

An alternative to the incineration technology is plasma waste treatment which has started to be actively introduced in many countries (Russia, Japan, England, Canada, USA, etc.) [1–11].

At present no less than 6 installations realizing different technologies of plasma treatment of solid wastes are operated:

– Yoshii, Utashinai (Hitachi Metals & Westinghouse Plasma), Japan, daily performance 166 ton of waste;

– Mihama-Mikata (Hitachi Metals Ltd. & Westinghouse Plasma), Japan, daily performance 28 ton of waste;

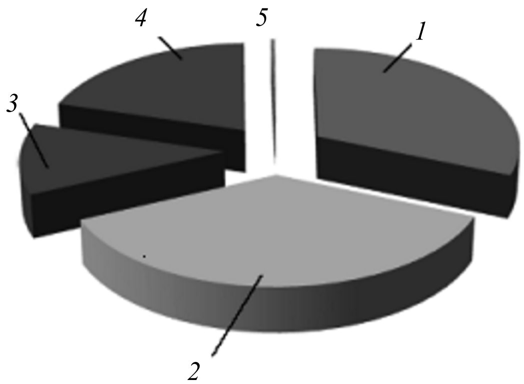

Fig. 1. Structure of industrial and household wastes: (*1*) dry solid wastes; (*2*) food wastes; (*3*) heavy oil residues, (*4*) wastewaters, and (*5*) wastewater sludges.

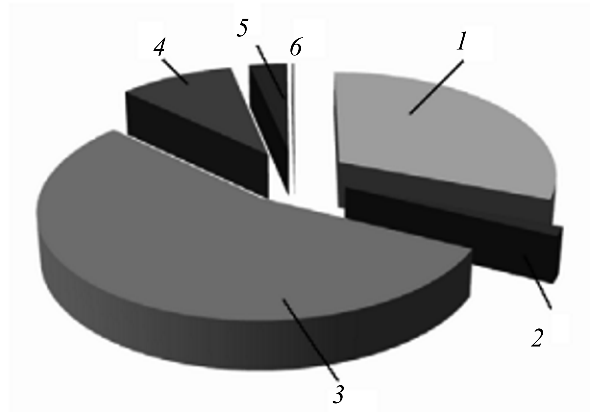

Fig. 2. Quantitative composition of solid wastes: (*1*) organic substances; (*2*) metals; (*3*) water, (*4*) glass, (*5*) inert ash, and (*6*) chlorine- and fluorine-containing materials.

– Ottawa, Ontario (Plasco Energy Group), Canada, daily performance 200 ton of waste;

– Faringdon, Oxfordshire (Advanced Plasma Power), England, pilot plant;

– Swindon, Wiltshire (Advanced Plasma Power), England, annual performance 100 thsd ton of waste. The installation supplies electricity to 10 000 houses and heat to 700 houses. It accepts 99% of wastes from nearby enterprises. The installation is operated under a slightly reduced pressure (which excludes release of odors to the atmosphere).

– Pilot plant of the "Kurchatov Institute" Russian Research Center in Israel (Haifa), annual performance 3.5 thsd ton of waste.

At least 6 installations realizing plasma technologies are planned for launching:

– St. Lucie County, Florida (GeoPlasma), USA, daily performance 3000 ton of waste with production of 550 ton of fused gravel;

– Vancouver, British Columbia (Plasco Energy Group), Canada;

– Port Hope, Ontario (Sunbay Energy Corporation), Canada.

– Tallahassee, Florida (Green Power Systems), USA, daily capacity 1000 ton of waste.

– Hirwaun, Wales (EnviroParks), Great Britain, annual capacity 250 000 thsd ton of waste;

– Jackson, Georgia (PR Power Company), USA, treatment of waste car tyres.

Plasma technologies allow treatment of household and industrial wastes, as well as low- and medium-radioactivity and medical wastes. Figure 1 shows a diagram illustrating the structure of wastes. In terms of treatment, of interest is the composition of solid wastes (Fig. 2). The quantitative composition of industrial wastes is presented in Table 1.

The plasma technology makes it possible to process the organic fraction of wastes, including heavy oil residues and petrochemical wastes to obtain a flammable pyrolysis gas (pyrogas) which can be used as a source of energy, heat, various hydrocarbons, and pure hydrogen. The inorganic waste fraction is transformed into a glassy basaltiform slug, a water-insoluble and chemically inert material; this prevents release of toxic inorganic components into ecosystems.

In terms of the environmental safety, the requirements to the plasma treatment technology are determined by the nature (quantitative composition) of wastes. The general approach to treatment of industrial and household wastes, even though they have different compositions, is the same, without special limitations. As to medical and low- and medium-radioactivity wastes, their treatment technology should meet special safety requirements. These wastes are not used for pyrogas production. Moreover, in the case of radioactive wastes, special safety requirements are posed on the glassy slag: radioactive components of wastes should be chemically firmly fixed in the slag. Such binding is provided by the matrixing technology developed by the Radon Moscow Scientific and Production Association. The slag formed during treatment of radioactive wastes is not used and subject to disposal.

Table 1. Quantitative composition of industrial wastes (by waste types in Moscow)

Waste type	Waste volume, ton/year	Waste type	Waste volume, ton/year
Medical wastes (including pharmaceutical industry wastes)	240000	Waste oils (including food oils)	10200
Biological wastes	200000	Organic halogen-free wastes	2268
Contaminated grounds	12600000	Organic halogen-containing wastes	102
Roofing material wastes (bitumen-containing)	20000	Waste tyres	47000
Oil sludges	13748	Waste large-sized household and industrial technics	700000
Greasy wood wastes (including ties)	2756	Waste freon-containing equipment	25000
Greasy waste cloth, hemp, etc.	702	Electronic and electrotechnical scrap	145000
Air filter loading	2488	Film and photo production wastes	3500
Filtering oil elements	164	Glass and glassware	210000
Waste lubricating and cooling fluids	6369	Waste polymer materials	210000
Sludges containing solvents, lacquer-and-paint materials, glues, mastics, resins, etc.	751	Hazard class 1−3 wastes	240000
TOTAL			14680048

Table 2 lists the composition of the low- and medium-radioactivity wastes from the Novovoronezh Nuclear Power Plant [12].

The plasmachemical transformation of the waste substance occurs under the action of plasma-forming gases obtained in a plasmatron. The working gas outgoing from the plasmatron channel has a fairly high temperature (5000–8000°C) and can process any wastes, including refinery materials.

One of the problems of plasma treatment of unsorted wastes arises from their widely varied composition. Solid wastes can contain chemically active compounds (in particular, chlorinated ones) which react to form highly toxic compounds, such as polychlorinated dibenzodioxins (PCDD) and dibenzofurans (PCDF), and others. A right choice of treatment parameters, primarily temperature, can minimize formation of toxic compounds. Controlled plasmochemical reaction allows maintaining required treatment parameters in a real time.

There are a number of plasma treatment technologies [13–19], and they offer quite broad possibilities. No detailed sorting of wastes before their loading into a plasma installation is required. Wastes with a moisture content of up to 45–50%, including agricultural wastes, can be processed. Maintaining a high temperature (up to 1800°C) inside the plasma reactor and preventing access of air results in destruction of waste components, and the deficit of oxygen excludes combustion. The average daily concentration of PCDD and PCDF in gaseous emissions is no more than 0.1 ng m^{-3}, which is much lower than European standards.

Pyrogas, a valuable energy feedstock (hydrocarbon-enriched) which can be used to produce power, pure hydrogen, and other products is formed at the exit from the plasma gasification zone.

The fly ash collected at gas filters should not be disposed, and it is recycled with wastes.

The basaltiform slag is an ecologically pure material which can be used in various industries.

The produced heat carriers (hot water) can be used for technical and social needs. Steam is used for power

Table 2. Composition of solid radioactive wastes treated at the Novovoronezh NPP

Component	Content, wt %
Paper, cloth, wood	55–65
Building wastes	15–35
Heat-insulation materials (glass and mineral wool)	10–20
Ferrous and nonferrous metal scrap	1–3
Ion-exchange resins	3–5
Plasticized materials, rubbers, and polymers	2–3

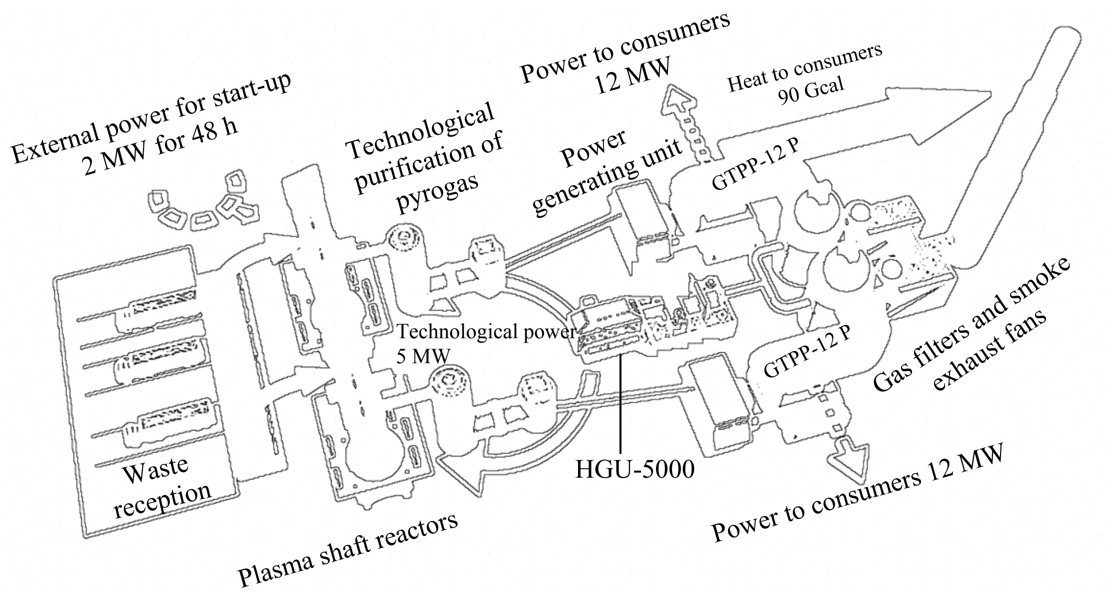

Fig. 3. Scheme of the technological process at a plasma waste treatment and power generation complex (50000 ton/year)

production (installed power capacity up to 10 MW) in a closed production cycle of the plant.

Plasma technology allows treatment of dry sludges from wastewater treatment facilities (sapropels), heavy oil refinery sludges, other oil production wastes, nonflammable rice hulls, and various types of cakes. Therewith, their gradual addition to the inhomogeneous waste bulk helps to improve the composition of the latter and the quality of pyrogas, thus increasing performance of the power-generating complex.

The existing plasma waste treatment installations include all necessary technological components for treatment of solid wastes, as well as heat, power, and glassy basaltiform slag production. This implies a possibility to construct fairly big installations (solid waste treatment plants) which would not only ensure complete (wasteless) treatment of solid wastes, but also produce power and heat (from cooling of apparatuses and equipment), as well as a secondary raw material as a basaltiform slag (potential building material), and, probably, synthetic motor fuels and/or hydrogen from pyrogas.

Several versions of engineering solutions of a power-generating complex have been developed, depending on a specific production objective.

(1) Treatment of diverse wastes in a quantity of 3500 to 250000 ton/year (from 400 to 3000 kg h^{-1}) with the realization of a full power supply cycle due to own heat and power resources. Network connection is used exclusively to start up the complex. The final product is basaltiform slag. Pyrogas is burned, and ash is subjected to repeated plasma treatment.

(2) Treatment of diverse wastes in a quantity of 3500 to 250000 ton/year (from 400 to 3000 kg h^{-1}) with the organization of an own power supply system. Network connection is used exclusively to start up the complex.

Final products: basaltiform slag, power for network customers with the installed power capacity varying from 12 to 100 MW, depending on the performance of the complex, hot water and steam as heat carriers for industrial and social needs. Ash is subjected to repeated plasma treatment.

(3) Treatment of diverse wastes in a quantity of 3500 to 250000 ton/year (from 400 to 3000 kg h^{-1}) with the organization of an own power supply system. Network connection is used exclusively to start up the complex.

The plasma installations are equipped with DC arc plasmatrons with heat capacities of 180 kW to 1 MW. They provide automated temperature control inside the plasma chamber, depending on the composition and calorific power of treated wastes. Therewith, the higher the capacity of plasmatrons, the longer their service life (it is only cathode and anode that should be replaced after 300 and 1000 h of continuous operation,

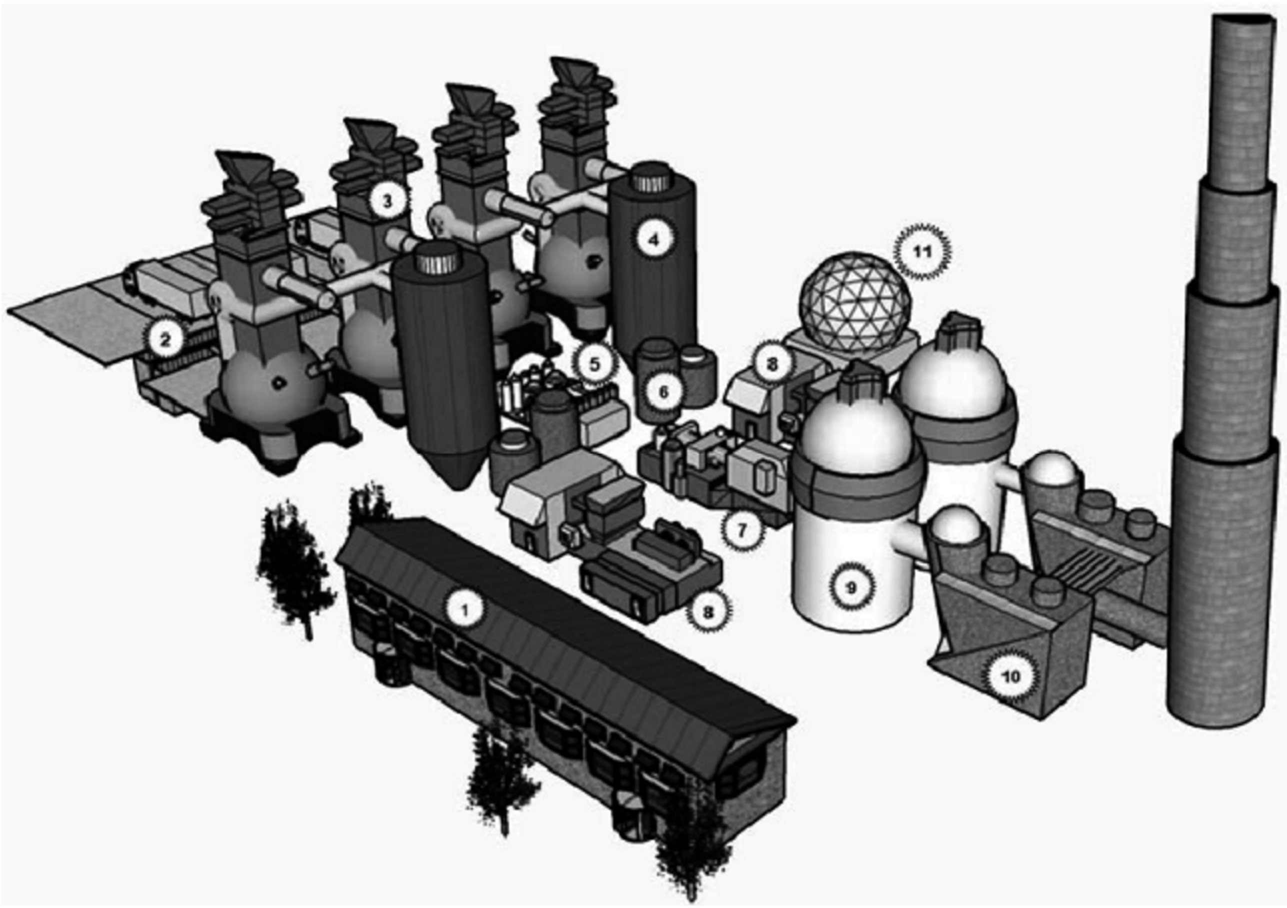

Fig. 4. Variant of a plasma waste treatment and power generating complex (100000 ton/year): (1) monitor and control unit; (2) waste reception unit; (3) plasma shaft reactors with waste loading system; (4) gas purification columns; (5) water treatment system; (6) water heaters; (7) steam turbine and generator; (8) gas turbine power plant; (9) waste-heat boiler with exhaust gas neutralizer; (10) smoke exhaust fan; and (11) pyrogas collector.

respectively; replacement takes 15–20 min and is performed on-the-run).

Power production complexes on the basis of controlled plasmochemical waste treatment can form one of the elements of modern alternative power engineering.

Figure 3 shows a block scheme of the technological process on a plasma-based waste treatment and power production complex (50000 ton/year). The complex is constructed by a modular principle and includes two plasmochemical reactors (shaft furnaces). The capacity of each reactor is 25000 ton/year (in wastes).

The plasma waste treatment and power production complex comprising technology modules each with the capacity of 25000 ton/year (Fig. 4) features flexible operation, long service life, and modular capacity build-up.

At present we can speak about a 100% readiness to design and construction of plasma waste treatment and power-generating complexes. It should therewith borne in mind that every time decisions concerning the high-tech equipment to be used should rely upon the nature of raw material (wastes), operational conditions, and the external infrastructure in a concrete dislocation place, which will require verifications, tests, and research works in the framework of terms and costs fitting the principal parameters of the plan of implementation of the design and construction of the power-generating complex.

The plan of implementation of the design and construction of a power-generating complex includes four stages.

Preliminary stage: development of a concept design. This stage involves selection of principal parameters of the power-generating complex and variants of principal technological regimes, and well as the site for the complex. Principal technological equipment, apparatuses, devices, and systems are selected. Specifications for detailed design with technical economic substantiation are developed, and preliminary cost estimates for the design are performed. A preliminary business plan with account for concrete operational conditions is developed. Thus, full-cycle predesign works are implemented, which takes 6–8 months.

The first stage involves concurrent development of technical and working designs and design construction documentation. Initial approval documents for constructions are developed, and contracts for delivery of standard and nonstandard equipment are concluded. Design and working engineering documentation at co-contractor enterprises is developed. The technical economic substantiation and total cost of the project are refined. The working design is corrected with data from co-contractor enterprises. Implementation term 12–16 months.

The second stage involves construction and mounting works, delivery of standard equipment, manufacturing and delivery of nonstandard equipment, mounting devices, complexes, and systems, connection to external networks and infrastructure. Implementation term 26–40 months (depends on the volume of construction and mounting work).

The third stage involves precomissioning works and training of personnel for service at the complex. Start-up and acceptance tests are performed, and all defects are eliminated. Implementation term 4–6 months.

In conclusion let us dwell on approaches to economic assessment of plasma waste treatment and power-generating complexes.

In the Russian Federation, there are no established base costs for waste treatment at waste treatment (incineration) enterprises. This especially applies to solid household wastes whose fraction in the total waste volume is more than 50%, and the total waste volume tends to increase from year to year. These facts imply that the payback period of such objects is longer than 20 years, whereas investments into their construction or purchasing are quite high (equivalent to 250 mln euro).

Foreign countries set up base prices for waste treatment (100−650 euro/ton and up to 2500 euro/ton for dangerous and especially hazardous wastes).

The uncertainty of tentative economic estimates with preliminary design and working-out (at least of the concept design) is ±30%, and the share of incidentals is 20%. Thus, the risk of incorrect tentative estimates varies rom 10 to 50%.

The tentative cost estimate includes tentative total expenses for design, construction, and equipment of the power-generating complex on the turnkey basis. Detailed assessment of economic efficiency is performed for each concrete case in accordance with chosen types of the technological equipment. This assessment is reflected in the concept design and refined in the working design.

Thus, the plasma technology makes it possible to organize a high-efficiency and environmentally friendly solid waste treatment industry. This opens up the way to commercialization of solid wastes, thereby offering undeniable advantages over the traditional incineration and dumping of untreated solid wastes.

An important direction of the realization of plasma technology is creation on its basis of power-generating complexes using wastes as a raw material to produce power and thus return it into the production and social sectors of the State's activity.

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