TECHNOLOGY OF PLASMA TREATING RADIOACTIVE WASTE: THE STEP FORWARD IN COMPARISON WITH INCINERATION – 10166

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ABSTRACT

The shaft technology of plasma treatment of radioactive waste including both combustible and unburnable materials is developed and realized in the full-scale plant "Pluton" in the SIA "Radon" at the industrial site near Moscow. The plant "Pluton" by capacity up to 250 kg solid radioactive waste per hour has been commissioned in 2007, June. The slag compound obtained possesses high chemical durability and is directed further for long-term storage to the site of conditioned radioactive waste without additional treating. The slag matrix provides reliable inclusion both radioactive isotopes and heavy metals. The technology of plasma treatment of the radioactive waste, based upon the plant "Pluton" design, is now implemented at the radiochemical enterprise and nuclear power plants of Russia and Bulgaria.

INTRODUCTION

SIA "Radon" has developed the plasma-pyrolytic technology for thermal treatment of radioactive waste (RAW) in the shaft furnace with use of plasma heat sources. Contrary to waste incineration methods resulting in ashes as a final product, plasma methods for direct radioactive waste treatment result in a melted slag product of high chemical durability to aggressive environmental impact. Also, advantages of this method are the higher waste volume reduction factors and decreasing volume of generated secondary waste compared to traditional incineration methods.

THE MAIN CHARACTERISTICS OF THE SIA "RADON" PLASMA PLANTS

For development of the shaft furnace technology for high-temperature radioactive waste treatment with use of plasma heat sources the SIA "Radon" has constructed and tested pilot and full-scale plants having solid radioactive waste (SRW) throughput up to 50 kg/hour and 250 kg/hour, correspondingly.

Preliminary works on the choice of materials and design of high-temperature units and devices for RAW plasma treatment and optimum technological modes, treatment of simulated and real RAW were carried out on the "Pyrolysis" pilot plant [1] (see Fig. 1).

At the stages of investigating and developing plasma technologies of treating radioactive waste the problems of providing the necessary temperature conditions in the melter of the shaft furnace, allowed to refuse from fluxes to decrease temperature of slag melting, creating an oxidizing atmosphere for obtaining and a pouring slag melt.

Ways of waste feeding into the shaft furnace have been experimentally tested: in splintered kind, in paper bags, in metal barrels after preliminary compacting. Feeding the radioactive waste packed into craft-bags is recognized the optimum manner. At the same time, the opportunity of effective treating compacted waste in metal barrels has been demonstrated.

As a result of researches carried out at the SIA "Radon" the opportunity of effective thermal treatment of the mixed radioactive waste in the plasma shaft furnace with obtaining of slag waste product of high stability has been confirmed, and full-scale plant named "Pluton" by throughput ranged from 200 to 250 kg/h has been constructed (see Fig. 2, Table 1).
The hart of the plant is a shaft type furnace consisted of shaft and melter , waste feeding unit and a slag melt pouring unit. Two plasma torches installed at the top part of the melter provide heating and melting slag. Pouring device installed at the face part of the melter consists of a horizontally mounted drain unit and a stopper locking a drain channel in the process of initial heating of the melter and after completion of slag melt pouring.

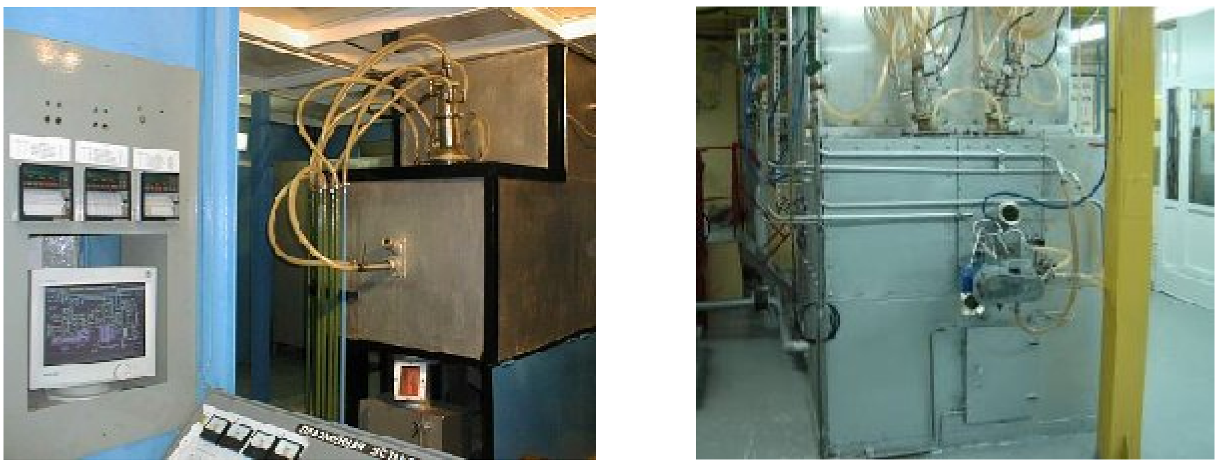

Fig. 1. View to the shaft furnace of the pilot plant "Pyrolysis" (left) and plant "Pluton" (right)

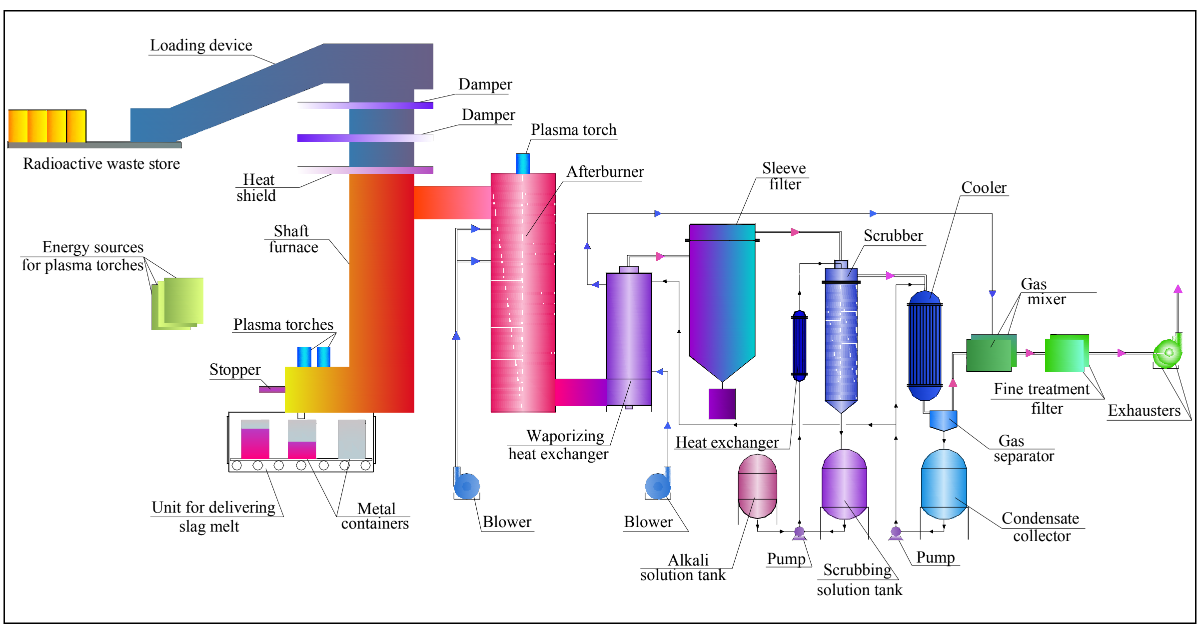

Fig. 2. Process flow sheet of the "Pluton" plant.

Table 1. Comparative technical data of plasma plants for RAW treatment.

Technical data	"Pyrolysis"	"Pluton"
Furnace throughput on SRW, kg / h	40-50	200-250
Dimensions of plant, m	8*8*10	12*18*12
Quantity of the plasma torches at the shaft furnace	1	2
Power capacity of plasma torches, kW	70-120	85-150
Preheating period (before feeding), hours	8-12	16-24
Specific energy consumption, кW*h/kg	2-4	1-3
Shaft furnace:		
- inner shaft dimensions, m	0.4 × 0.4	0.8 × 0.8
- outer shaft dimensions, m	1.6 × 1.6	2.0 × 2.0
- height, m	6.5	7.2

The shaft furnace is constructed of refractory and thermoinsulating materials inside a steel case. In the melting chamber vault there are two plasma torches by capacity of 100 - 150 kW that provide melting temperature of 1500-1800 ^oC.

Radioactive waste packages are fed to the top layers of the shaft furnace filled with treated material by a conveyor through the gate devices of the loading unit. Moving down due to gravity, the treated materials are heated up by rising gaseous stream moving through the waste column in the furnace shaft. At the upper layers of the shaft waste packages are warmed and dried by heat of off-gases, at the middle layers waste is subjected to pyrolysis at the lack of free oxygen, accompanying with intensive gas evolving. Heavy organic components, cake and inorganic residues of waste arrive to the bottom layers of shaft (a zone of coke residue burning and slag melting).

Slag melt is collected in a melting bath where it is homogenized and overheated with plasma air jets and then goes through the pouring channel to a melt receiving container. The slag is poured either in a continuous or periodic mode into metal containers installed in the pouring box. The temperature of the slag melt in the furnace bath reaches 1600 - 1800 ^oC, thus the temperature of off-gases at the shaft furnace outlet does not exceed 250 - 300 ^oC. After cooling the slag melt in the receiving containers, the solidified slag melt product is loaded to the shielding container and then directed to the long-term storage facilities for conditioned radioactive waste forms.

The shaft furnace is equipped with air supply to regulate furnace throughput and pyrogas composition. Pyrolytic gases leaving the furnace shaft, having rather high calorific value (from 4.5 to 9 MJ/kg depending on waste morphology), are directed to an afterburner where combustible gaseous and aerosol components are burned down at the temperatures exceeding 1100 ^oC. Then off-gases are cooled in the quencher to temperature 300 ^oC, cleaned of aerosols in a sleeve filter, cooled in a heat exchanger and harmful gas components (HCl, NO_2, SO_2) are neutralized in an absorber sprinkled by a circulating alkaline water solution. Before exhausting to the atmosphere off-gases are subjected to additional purifying in HEPA filters.

The arc plasma torches of direct current (non-transferred type) with power capacity from 85 to 150 kW, used for heating the furnace and afterburner, are developed at the SIA "Radon" especially for the shaft plasma-pyrolytic process. Compressed air is used as plasma forming gas. The thyristor and condenser sources of direct current are used for plasma torches power supply.

The plasma-pyrolytic shaft technology developed at the SIA "Radon" has the following features distinguished it from conventional methods of waste incineration and other thermal technologies:

- One-step deep thermal conversion of waste providing obtaining product of high quality;
- Producing pyrolytic gas with high calorific value;
- Safety temperature level of pyrolytic gas at the shaft furnace outlet;
- Decreased factor of volatile radionuclides and heavy metals escape from slag product due to their condensation and adsorption in the middle and upper parts of the shaft.

PRACTICAL RESULTS OF THE "PLUTON" PLANT OPERATION

In 2007 Rostechnadzor of Russia has issued to SIA “Radon” the License for plasma treatment of low and intermediate radioactive solid waste at the “Pluton” plant, the planned treatment of SRW is carried out since January, 2008.

Mixed radioactive wastes including both combustible materials and noncombustible components by share up to 40-50 % (average composition of waste is given in Table 2) were treated. Specific activity of the waste to be treated is limited by $3,7*10^6$ Bq/kg for β,γ - emitting radionuclides and $2,2*10^5$ Bq/kg for α- emitting isotopes.

Table 2. Composition of radioactive waste treated.

Components	Content , wt. %.
Paper	10 - 90
Wood (fire wood)	2 - 50
Textiles (rags)	2 - 25
Plastic (polythene, PET etc.)	2 - 25
Glass (household and laboratory)	2 - 25
Rubber (hoses, tyres etc.)	2 - 5
Chlorinated polymers	2 - 5
Electric board, radio components	2 - 15
Debris	4 - 25
Heat insulating materials	5 - 25
Metal scrap	1 - 10
Ion exchange resins	0.3 - 5
Silts and soils	2 - 25
Vegetative materials with soil	2 - 20
Total ash value of waste	10 - 50
Total moisture of waste	5 - 40

Using compressed air as working gas of plasma torches provides and most complete oxidation of all components of slag and obtaining more homogeneous product at the hearth part of the furnace. Slag compound obtained included the wide range of β-emitting radionuclides (Cs-137, Cs-134, Sr-90, Y-90, Co-60 etc.) and α-emitting isotopes (Ra-226, uranium isotopes and trans-uranium elements).

The density of slag was ranged from 2.4 to 2.9 g/cm^3. In contrast to borosilicate glasses, slag melt can have the raised content of alumina herewith low contents of silica and alkali metals oxides (see Fig. 3). The slag softening temperature varies from 1200 up to 1500 ^oC (see Fig. 4). Specially carried out experiments have shown an opportunity of reliable immobilization of heavy metals such as lead, chromium, copper, nickel, zinc and many others in a slag matrix.

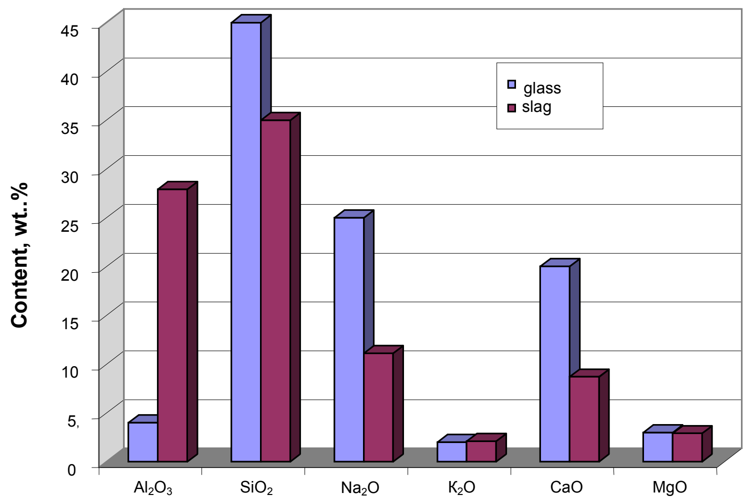

Fig. 3. Averaged contain of the main chemical components in borosilicate glass and slag samples.

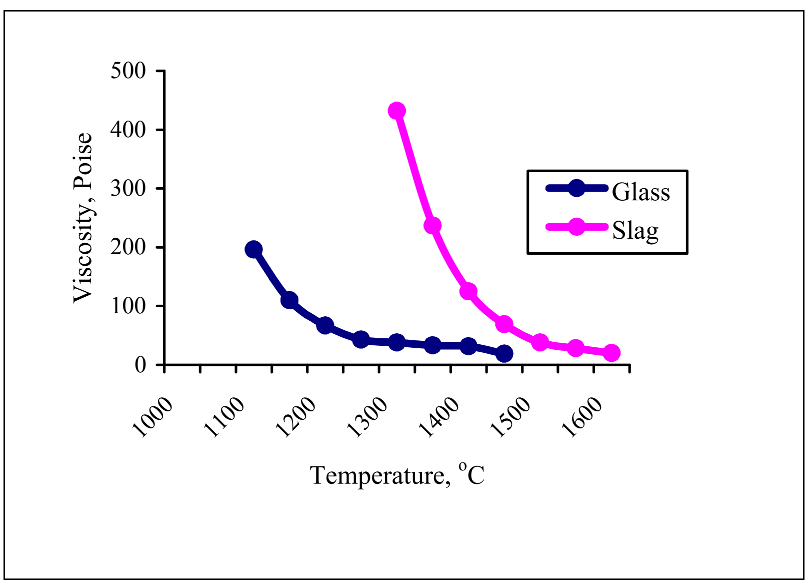

Fig. 4. Comparison of borosilicate glass and slag melt viscosities.

The slag obtained in result of plasma process is extremely chemically durable product; leaching rate of sodium, one of the most "mobile" elements, by results of water immersion leaching tests, is within the limits of $(2÷3)*10^{-6}$ g/(cm^2*day), that, on average, by the order is below similar parameter for borosilicate glass and by 2 - 3 orders is lower, than cement matrixes (see Table 3). Leach rate of the majority of other elements, including heavy metals, by 2 - 3 order is even lower, therefore the slag waste product is considered to be one of the most perfect forms for immobilization of radioactive elements and inorganic toxicants.

Table 3. Chemical durability of slag product

Component	Na^+	Cs-137	Pu-239
Leach rate, g/cм^2*day	(2-3) *10^{-6}	(0,3-5)*10^{-6}	(0,8-2)*10^{-7}
Leached share (100 days), %	1,1	0,61	0,008

The slag structure is close to volcanic glass. Carried out petrographic and x-ray structure analysis of the obtained product have found in an amorphous slag structure the content of crystal phases up to 10-15 %, main of which are alkaline aluminum silicates [2].

Chemical durability of the slag product is considerably higher than chemical durability of many mineral structures, for example, a road broken stone, therefore the developed plasma technology can be very perspective for treatment of other, non radioactive, kinds of waste with use of the obtained product as a road building material.

Comparison of technical and economic parameters of plants for dangerous and radioactive waste incineration and its plasma treatment in the shaft furnace also gives evidence for the benefit of the last. For example, premises for the equipment of incinerating facility by capacity 50÷60 kg/h and shaft furnace for plasma-pyrolitic treating waste (200÷250 kg/h) are comparable in their sizes at a difference in throughputs of the plants in 3-4 times. At the same time specific emissions of fume gases into an atmosphere produced in result of plasma treating waste are lower in 1.5-2 times, than after incineration (Fig. 5), and slag compound is suitable for long-term storage without additional operations, in contrast to incineration ash.

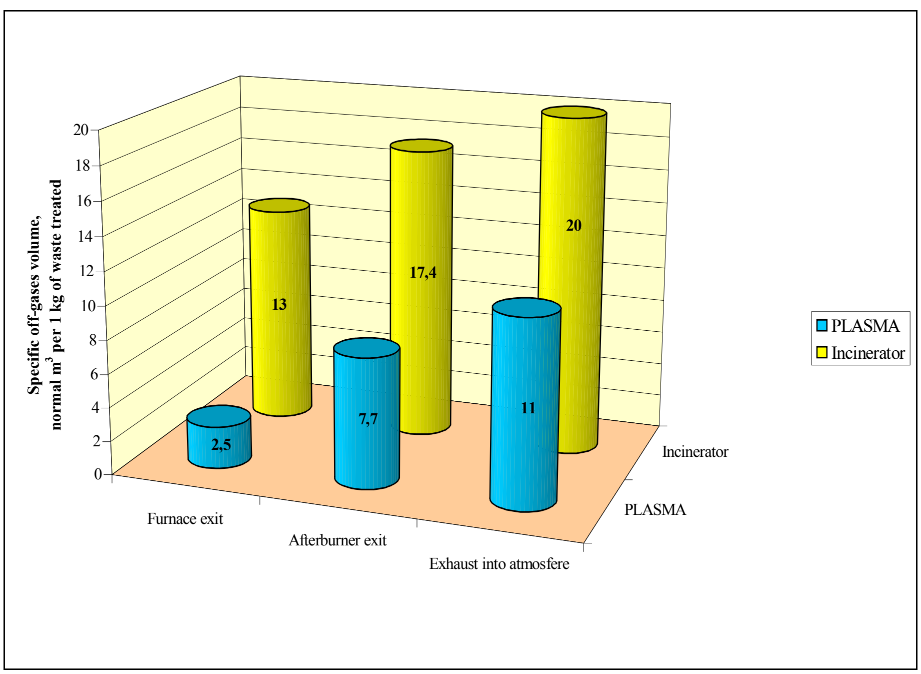

Fig. 5. Comparison of specific values of the technological gases exhausts into an atmosphere resulted from the processes of radwaste plasma treatment and conventional incineration.

PROSPECTS OF THE PLASMA SHAFT PROCESS

At the present time SIA “Radon” in association with several Russian scientific and designing centers takes part in project activity on developing of plants for plasma treatment of radioactive, municipal and industrial kinds of waste both in Russia and abroad.

Particularly the designing and implementation works are carried out to develop the plant for plasma treatment of low and intermediate active RAW providing waste throughput up to 250 kg/h for the Novovoronezh NPP and the Joint-stock Company “Siberian chemical complex” near Tomsk.

SIA "Radon" has been invited to participate in designing and creation of the plasma treatment plant for the newly developing Bulgarian NPP "Belene".

Also SIA "Radon" has participated in development and putting into operation of the demonstration complex of municipal waste plasma treatment with capacity 500 kg/h for EER company in Israel; the complex has successfully passed the tests and commissioned in 2007.

CONCLUSION

As a result of researches carried out at the Moscow SIA "Radon" the opportunity of effective treatment of the mixed type radioactive waste (up to 50 wt. % incombustible materials) in the plasma shaft furnace with obtaining slag product of high quality has been confirmed, and full-scale plant by productivity up to 250 kg / h has been designed, constructed and commissioned.

The slag melt forms obtained in result of plasma process are extremely chemically durable products. The Toxicity Characteristic Leaching Procedure (TCLP) has confirmed significant advantages of melted slag product over mineral materials.

Contrary to conventional incineration processes plasma technology for mixed forms of solid radioactive waste, developed and realized in SIA "Radon", Russia ("Pluton" plant), provides obtaining conditioned product in one stage suitable for long-term storage with minimum hazard for the environment.

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