Testing and Starting up of the Plasma Melting Facility for Industrial Treatment of Radioactive Waste–17362

Jan Deckers
Belgo Process, Dessel, Belgium
Eduardo Andres
Iberdrols Ingeniería y Construcción, Madrid, Spain

ABSTRACT

The operation and maintenance of nuclear power plants, the nuclear fuel cycle in general, research laboratories and pharmaceutical, medical and industrial facilities generate low-level radioactive waste which, along with the historical radioactive waste from past nuclear activities, needs to be treated and stored, awaiting final disposal. Plasma technology offers a very effective way of treating this waste with a high volume reduction factor (VRF), free from organics, liquids and moisture, and meets without a doubt the acceptance criteria for safe storage and disposal. By means of a plasma beam of approximately 5000°C, the inorganic materials are melted into a glassy slag, containing most of the radioactive isotopes while the organic material is gasified and afterwards oxidized in an afterburner and purified in an off-gas cleaning system.

This paper describes the principles of plasma, the different waste feed systems, off-gas treatment and operational experience and future plasma plants. More specifically, it presents the new full-scale plasma facility for the treatment of radioactive waste at **the Kozloduy Nuclear Power Plant in Bulgaria** for which construction and assembly was finalized end of August 2016. It also describes in more detail the Site Acceptance Tests (SAT) of this facility.

This facility is designed and built as an EPC contract by the Joint Venture Iberdrola Ingeniería y Construcción (Spain) and Belgoprocess (Belgium).

INTRODUCTION: PLASMA PROCESS

Plasma is considered by many to be the fourth state of matter, following the more familiar states of solid, liquid and gas. Plasma consists of a collection of free moving electrons and ions and energy is needed to strip electrons from atoms to make plasma. With insufficient sustaining power, plasma recombines into neutral gas. Heat energy, where added to liquid, converts the liquid into gas. The addition of heat energy to a gas converts the gas into plasma.

Lightning is an example of the plasma state of matter. Lightning is not a flame; it is rather a very high temperature beam of energy.

The plasma knowledge was not exploited until the period at NASA's space program during the sixties.

Considerable development in plasma technology was achieved in an effort to produce an intense heat source for carrying out reliability tests on re-entry heat shields of space crafts and missiles. After more than five decades, plasma technology is being utilized worldwide in many industrial processes, e.g. metal cutting, metallurgical application, vitrification of fly ash from municipal incinerators, treatment of problematic chemical wastes, etc.

Also a full scale industrial plant for treatment of low level radioactive waste started up in the beginning of 2004 and other radwaste plasma units are under construction.

This unique fourth state of matter, plasma is a highly desirable heat source for treatment of radioactive waste. Its high temperature up to 10.000 °C can treat the radioactive waste as is.

The inorganic materials are melted into a glassy slag, containing the radioactive isotopes while the organic material are vaporised into a syngas and afterwards oxidized in an afterburner.

PLASMA TORCHES

The plasma torch is a design comprising several concentrically-arranged tubes that are water cooled. The outermost tube can be cladded with refractory material to enable the burner to withstand the high temperatures within the processing-chamber.

Plasma torches contain the following main components:

- Torch with the electrodes
- Power supply unit
- Control and instrumentation system
- Cooling water circuits
- Process gas supply (e.g. N_2, air or O_2)

Most common are the non-transferred torches containing two metallic tubular electrodes (upstream and downstream with respect to the plasma flow direction) separated by a gas injection chamber. An electrical arc flows between the negative and positive electrodes and therefore the gas flow injected into the chamber is ionized. The result is a high temperature gas flow coming from the downstream electrode in a plasma jet.

Power ratings typically range from 100 kW to several MW.

Process conditions can be varied from inert (e.g. Ar or N_2) to oxidizing status (e.g. air or pure O_2) through the selection of the plasma gas.

Sensitive components on plasma torches are the electrodes. The first electrodes had lifetimes of only several hours. Nowadays electrodes lifetimes, depending on the power, vary from hundreds to several thousands of hours.

FEEDING SYSTEMS

The choice of feed systems has a direct effect on processing parameters. One distinguishes two main feed systems:

- Batch feed system
- Continuous feed system

In a batch feed system the whole 200 l-drum containing the radioactive waste such as the metals, concrete debris and organic material are fed via a drum feeder into the primary chamber.

In case the waste contains a lot of organic material the off gas system should be sized for the large instantaneous flue gas flow caused by the vaporisation of the organic material.

Metering with a shredder gives a more continuous feed and smoothes and reduces peak off gas flow rates, releasing restrictions on the size of the primary chamber that is otherwise too small to accept a whole drum.

SLAG PRODUCTION

The waste containing e.g. metals, concrete debris, different types of inorganic granulates and organic materials is fed to the primary camber containing the plasma torch. Due to the intense heat of the “plasma flame” the metals are melted and partially or fully oxidized. Concrete debris, sand, inorganic granulates, insulation material such as mineral rock wool and even asbestos are melted. Their crystalline structure is destroyed and transformed into a chemical inert and amorphous glassy slag. The liquids and organic materials into the waste are vaporized so an organic-free residue is obtained.

Similar to conventional radioactive waste incinerators, the non-volatile isotopes such as Co, U, Pu isotopes stay into the slag residues while a part of the typical semi-volatile isotope Cs-137 transfers to the off-gas system. Based on experimental measurements of plasma test facilities the non volatile isotopes such as Co-60 are trapped for about 90% or more into the slag while semi-volatile isotopes such as Cs-137 are trapped for about 70%. The rest of these isotopes are carried over to the off-gas system and will be found in the collected fly ash. At the end of the cycle, the collected fly ash can be sent back to the plasma furnace.

THERMAL OXIDATION AND OFF GAS TREATMENT

Similar to conventional radioactive waste incinerators, the flue gasses, leaving the primary treatment chamber, are passed through a secondary (thermal oxidiser) chamber followed by an appropriate off-gas treatment.

In the secondary chamber the gasses containing hydrocarbons, whether or not linked with Sulphur, halogens, CO, or H_2, are oxidised to primary components such as CO_2, H_2O, HCl and SO_2.

Off-gas treatment systems for radwaste have proved their high cleaning performance safety and reliability with low production of secondary waste.

The off-gas cleaning is a multi-step procedure to eliminate chemical compounds such as fly ash, HCl, SO_2, and radioactivity. The released off-gas reaches levels which safely comply with both applicable conventional and radiological regulations. Due to the high temperature of the plasma torch, more NOx is produced, which also has to be eliminated by DENOX systems, depending on the release criteria.

The entire system is maintained under pressure by redundant extraction fans.

END WASTE FORM AND QUALITY CONTROL

With thermal treatment processes a high VRF is obtained. But this is not the only advantage in comparison with non-thermal waste treatment processes. The long-term storage and disposal facilities require that any package complies with the defined waste acceptance criteria. For example, the final waste packages cannot contain, or include only small amounts of organic solid residues, and no sludge or moisture. Applying a plasma treatment process gives indeed a final product which is a stable product free from organics and liquids and meets without doubt with the acceptance criteria for long-term storage or final disposal.

Due to the high volume reduction factor, ranging between 6 and 80, the remaining slag contains the concentrated radioactivity. One should take into account that the slag should stay in the category of low level waste, so operation limits regarding radioactivity content for the incoming waste should be set up. Higher radioactivity content can lead to medium active waste, which would need additional precautions and have more expensive storage costs.

PLASMA FACILITIES

ZWILAG Facility

A first full scale plasma system, the ZWILAG facility in Switzerland, was taken into nuclear operation beginning in 2004. Two campaigns per year of about 10 weeks are organised to treat the stored waste. Per campaign, about 500 drums or 100 tons of waste will be processed. The two campaigns are not due to technological restrictions but are for logistical and organizational purposes.

From the horizontal drum feeder the waste falls on the molten slag. Inorganic material is melted and becomes slag. Organic material is vaporized and the incomplete burned flue gas is sent to the secondary chamber. The rotating crucible (centrifuge) in the primary processing chamber moves the molten slag. Centrifugal forces keep the slag from the pour hole during processing. Pouring is achieved by opening the closing system of the throat and slowing down the centrifuge. The slag moves towards the centre and pours through the throat into a mold. The mold is located directly below the throat in the slag collection chamber.

After complete oxidation in a secondary chamber, the flue gases emitted from the centrifuge chamber are routed to an off gas treatment system, which can be divided into a wet physical and a wet chemical process.

Nitrogen oxides in the flue gas are reduced in the de nitrification system (DENOX) through selective catalytic reduction.

Plasma facility for Kozloduy Nuclear Power Plant

Functional Description

Another full scale plasma facility is ordered for the Kozloduy Nuclear Power Plant site for the Joint Venture Iberdrola Ingeniería y Construcción - Belgoprocess as an engineering, procurement and construction (EPC) contract. The contract is funded 70% by the European Bank for Reconstruction and Development (EBRD) and 30% by the Bulgarian government.

The facility consists of a tilting plasma furnace equipped with a non-transferable torch of 500 kW as heat source and will treat 250 tons per year, spread over 40 operational weeks.

The tilting furnace developed by the JV has been designed to pour the slag in a controlled way into a slag mould. This concept of the furnace with the fixed waste feeder, the off-gas equipment and the closed confinements around the slag pouring, prevents the escape of radioactive or hazardous gasses and particles into the work area and into the atmosphere, thereby improving the safety features of the plasma facility. For intellectual property protection the system is patent pending.

Solid waste to be processed will be delivered in:

- Bags containing mainly organic waste
- Metallic 200 l drums containing precompacted organic waste and metal particles.
- Pucks resulting from the super compaction of metallic 200 l drums containing mixtures of concrete, wood and other organic material. Pucks have heights up to 40 cm

Typical specific radioactivity of the waste is about 5E5 Bq/kg. It is also foreseen to treat liquids and drummed spent ion exchange resins.

The incoming waste is transferred to a shredder and from there to the feeder tube. Close to the furnace, the feeder tube has a rotating connection so that the feeder tube of the shredder is fixed-mounted in relation to the tilting furnace.
On the opposite side of the furnace the contaminated hot gasses with a temperature of 1300°C are diverted to the afterburner chamber.

The system processes mixtures of organic waste such as plastic and celluloses, with inorganic waste such as concrete, mineral insulation, glass and metals. Depending on the incoming waste composition, a glassy-like slag or a metal-like slag is obtained. When about 200 litres of slag are produced, the slag is poured into the slag mould. After pouring, about 50 litres of slag remains in the furnace and it is used as a thermal flywheel for the next waste batch. The remaining slag also forms a protection for the refractory against the high temperature of the plasma flame.

The tapping of slag into the slag mould is carried out in a confinement in order to prevent spreading of contamination in the normal work area and into the environment.

The tilting furnace offers a number of innovative features for treating radioactive or hazardous waste that eliminate the drawbacks of existing systems:

- completely closed system so there is no escape of radioactive or hazardous substances,
- good control of the pouring cycle, which can be stopped at any time,
- no plug or stop in the tapping hole,
- easy accessibility of the tapping hole,
- a minimum of moving parts on the plasma furnace which become contaminated and need maintenance and a lot of precautions in order to protect maintenance personnel,
- flexible treatment of glassy-like or metal-like slag.

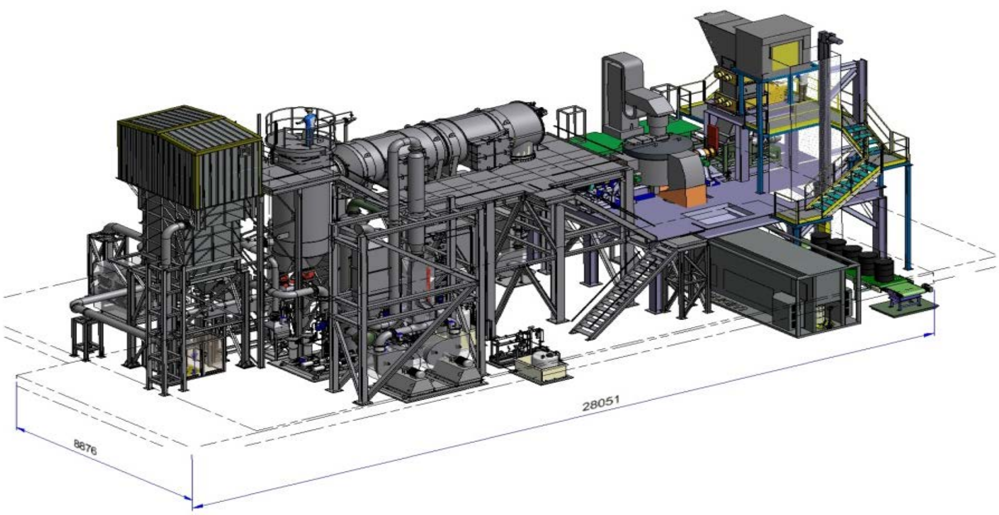

Figure 1 overview plasma facility

An overview of the plasma facility is given in Figure 1 and consists of the following main components:

- A robust dual shredder with extruder feeder with a Nitrogen blanketing system
- A primary treatment chamber equipped with a non-transferable torch and a sealed slag collection chamber
- A secondary combustion chamber in which the syngas are mixed with excess air to complete oxidation to primary combustion components;
- A boiler to cool the off-gasses;
- Off-gas filtration and radiological purification, consisting of a bag-house with bag filters and high efficiency particulate air (HEPA) redundant filters;

- A wet off-gas scrubbing system, consisting of a quench tower and a counter current scrubbing tower to remove HCl and SO_2.
- Redundant flue gas extraction fans for keeping continuous negative pressure into the entire system and evacuating the flue gasses
- A DENOX system provided with a catalyst in order to reduce the NO_x
- At the end a continuous emission monitoring (CEM) and radiomonitoring system is also foreseen

Testing Stages

To date, detail design was approved at the of beginning of 2012, components were manufactured and factory acceptance tests (FAT) have been completed in June 2013. In particular, successful FAT was carried out with simulated waste on the shredder/feeding system and the plasma furnace. Before the end of 2013 all components were send to the ware house of the Kozloduy Nuclear Power plant. In august 2015 the permission was given for starting civil works and the construction of the facility.
In September 2016 low voltage power was given to the facility. In the first stage of the Site acceptance test (SAT) input/output of the different PLC systems was carried out. Different systems means feeding system with the shredder, slag collection chamber (SCC), off gas cleaning system, plasma furnace with the torch, continuous emission and radiological monitoring and finally the general services and utilities. General services comprise the ventilation of the controlled area, cooling water circuits, fire detection and protection, fuel pipe line circuit, etc.

Next stage was the functional testing of the different systems where interlocking, safety features, level 1 and level 2 alarms, working under normal power and emergency power, UPS (uninterruptable power supply) batteries for the PLC and computer system, etc are tested.
At the beginning of 2017 integration test of all the systems will start with the heating up and feeding of the waste. In this stage the whole plasma facility will be tested in hot conditions under normal and abnormal situations such as level 1 alarms, loss of normal power and starting of emergency power by the diesel generator. During this stage different simulated waste batches of metal drums containing organic and metal debris, bags with organic waste such as plastics and celluloses, spent resins, drums containing concrete, glass, brick work and other types of inorganic granulates, supercompacted drums containing concrete and wood will be treated into the shredding system and afterwards fed to the plasma furnace where the waste is gasified and melted in order to produce a glassy like slag.
Finally there is the official 72 hours SAT test and is the last step before going over to nuclear operation. During this test capacity, VRF, safe functioning of the facility in normal and abnormal conditions and different modes and emissions will be verified. After SAT test final documentation and application for nuclear operation will be prepared. At the end there is the 100 hours test with the real radioactive waste.

ADVANTAGES

Plasma treatment of radioactive waste provides following advantages:

- One single process can treat the waste as is. There is no need of costly sorting and pre-treatment infrastructures.
- The process fulfils without doubt the ALARA principles. There is no need for pre-treatment of the waste and entire waste drums are fed unopened, virtually eliminating the amount of direct radiation exposure and contamination risks to personnel.
- A robust waste form, similar to the vitrification process, is obtained free from any organic and liquid material and suitable for long term storage and disposal.
- Important volume reduction factor. Volume reductions can range inclusive the waste containers from 6 for drums containing mostly metals to more than 80 for primarily organic waste.
- The plasma furnace can be equipped with the same type of well proven off-gas systems used in conventional radwaste incinerators.
- High throught-put process available

SELECTION OF THERMAL TREATMENT TECHNOLOGY

Table 1 shows a summary of the applicability of different currently used thermal technologies for different types of radioactive waste, solid or liquid.

Depending on the technology, the waste has to be sorted out into organic and inorganic material.

It is clear that the plasma technology can treat virtually all radioactive waste types. In particular the plasma technology is suitable for historical wastes, which are present in a lot of nuclear facilities around the world. These historical waste types can contain mixtures of inorganic, organic, liquids, sludge, etc, and can be treated with a high volume reduction factor (VRF) and with limited preparation and minimum risks for radioactive contamination.

Not only the high VRF is relevant, but also the growing requirements for improved quality and stability of the final waste form. So even historical conditioned waste in a bituminous or concrete matrix, which do not meet current acceptance criteria for conditioned waste, can be retreated in a plasma facility and obtain an acceptable conditioned product.

TABLE 1: THERMAL TECHNOLOGIES FOR COMMON WASTE TYPES

Technology	**Waste type**						
	Organic liquids	Inorganic liquids	Organic solids	Inorganic solids	Mixed organic-inorganic solids	Mixed organic-inorganic liquids	Spent resins
Incineration	A	A	A	NA *	NA *	A	A
Melting	NA	NA	NA	A	NA	NA	NA
Plasma	A	A	A	A	A	A	A
Pyrolysis	A	NA	A **	A **	A **	A	A
Vitrification	NA	A	A **	A **	A **	NA	A

Legend:

A Technology is applicable to this waste type

NA Technology is not applicable to this waste type

* Small inorganic pieces are acceptable without causing damage or plugging of the system

** Applicable only for granular or powder form of this waste type

CONCLUSIONS

Plasma technology can treat the waste "as is" with limited preparation efforts so it complies with ALARA principles and produce a final product with a high VRF that meets without doubt acceptance criteria for conditioned waste free from organics and liquids.

Off-gas systems for treating the radioactive contaminated flue gasses can be used from conventional radioactive waste incinerators which have proven their high reliability and safety standards.

Factory acceptance tests (FAT) were carried out successfully and after construction of the plasma facility functional tests were carried out and so the plant is ready for doing the final Site acceptance test (SAT) as a last step to go over to nuclear operation.

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