LLW PROCESSING AND OPERATIONAL EXPERIENCE USING A PLASMA ARC CENTRIFUGAL TREATMENT (PACT™) SYSTEM

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ABSTRACT

After several years of development, a commercially available high-temperature treatment system has been developed, licensed, and installed that treats heterogeneous low-level radioactive waste. High temperature plasma processing, unique torch design and operating features make it feasible to achieve a volume reduced, permanent, high integrity waste form while eliminating the personnel exposure and costs associated with conventional sorting, characterizing and handling[1].

The Plasma Arc Centrifugal Treatment system or PACT™ manufactured by Retech Systems LLC is a licensed thermal plasma system that processes and consolidates low level radioactive wastes. The first PACT™ thermal plasma system to be licensed was at ZWILAG (Zwischenlager Würenlingen AG, Switzerland) in May 2004, and the second is utilized by the Japan Atomic Power Company (JAPC) in Tsuruga, Japan, licensed in March 2005.

ZWILAG uses a drum feeder that processes the 200-liter drums from storage horizontally and pours the molten slag into molds. The drums contain organic and inorganic wastes (mixed waste). Processing the drums directly without unloading them reduces exposure to processing personnel. ZWILAG production data mid-2004 through mid-June of 2005 shows that the furnace feed included 9.4E+10 Bq of mixed waste and that 8.5E+10 Bq were stabilized in slag, with a mean activity of 2.1E+09 Bq/drum.

The operational experience demonstrated by ZWILAG and JAPC has been a testament to the success of thermal plasma and to the real benefits of using the PACT™ system.

INTRODUCTION

Located five miles South of Ukiah, California, Retech Systems LLC designs, manufactures, assembles and tests thermal processing equipments that derive their heat from plasma energy, induction (hot and cold wall), electron beam (E-beam) and resistance heating. Retech metallurgical furnaces process a variety of metals and alloys refining them into ingot and powder. Retech also manufactures furnaces containing a rotating crucible, known as the Plasma Arc Centrifugal Treatment or PACT™ system which processes hazardous and radioactive wastes that include organic, inorganic, and

[1] R.K. Womack, M.W. Shuey, "Development and Use of the Dual-Mode Plasma Torch", Proceedings of the Waste Management Conference, February 24-28, Tucson, Arizona, (2002).

mixed waste forms. The PACT™ System can process 200-liter drums containing low level radioactive wastes (LLW). The types of LLW feed in the 200-liter drums include:

- Inorganic wastes: concrete of various sizes, all types of steel products such as pipes, pumps, and I-beams.
- Mixed organic wastes: plastic, PVC, textile, rubber, solid residues
- Organic wastes: ion exchange resins, putrescent wastes, oil and solvents, debris and sludge.
- Mixed heterogeneous organic and inorganic wastes

The LLW comes from nuclear power plants, industry, research and medical applications. Typically, generated wastes are sorted and then placed into 200-liter drums and stored in a repository near the power plant, a burial site or in a national site. The PACT™ system has various drum feeding options as well as rotary feeders if it is desired to feed loose wastes such as ion exchange resins. In general, drums from a repository are brought into the plasma hall via a robotic transfer system with conveyors. The drum can enter one of two types of feeders: vertical or horizontal. The choice depends on whether the drum is to be processed standing up or on its side. The drums selected for the vertical feeder usually contain heavy wastes such as concrete and steel. Four drums are lowered into the furnace and processed vertically using a multimodal plasma torch operating in dual mode, pulling an arc over a meter in length. Drums can also be fed through a horizontal feeder where the drum is rotated and cut by a gas (LPG) torch and the contents fall into the plasma furnace. All the contents of the drum and the drum itself are processed in the primary processing chamber (PPC) centrifuge that rotates between 15 and 40 revolutions per minute (rpm). The drums processed in the horizontal feeder can be filled completely with organic wastes, or filled to varying degrees with mixed organic/inorganic waste forms and fed as a heterogeneous mixture.

Two PACT™ systems are currently licensed to process LLW. The first to receive such a license was ZWILAG (Zwischenlager Würenlingen AG) in Switzerland. The second system to be licensed was the PACT™ unit processing LLW for the Japan Atomic Power Company (JAPC) located in Tsuruga, Japan. Each furnace system is known as a PACT™-8 signifying the diameter of the centrifuge (8-feet). ZWILAG utilizes one horizontal feeder and JAPC uses horizontal, vertical, and rotary feed systems. Operational experience for ZWILAG will be covered in greater detail after examining PACT™ system principles. JAPC process information will be presented at a conference in Japan in 2006 by JAPC therefore the focus of this paper regarding processing LLW will be on the ZWILAG system.

PACT™ SYSTEM PRINCIPLES OF OPERATION

In a PACT™ system, the arc between the rear electrode of the torch (anode) and the molten slag cathode generates heat in the plasma gas which dissociates and partially ionizes the gas. Much of the energy in the gas and almost all of the cathode fall energy of the arc is delivered into the molten slag. Non-volatile components of the feed stock melt

into the slag. The rotating crucible (centrifuge) moves the molten slag and untreated waste material beneath the torch at 15 to 40 revolutions per minute (Fig. 1.).
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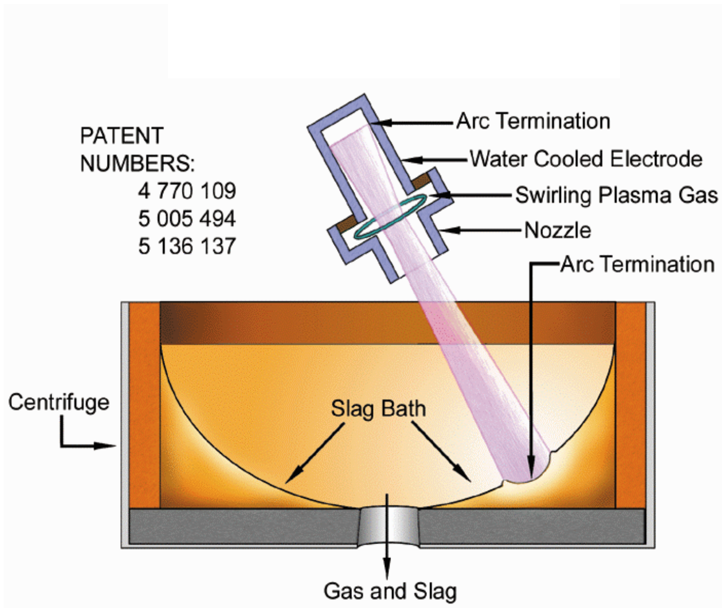

Fig. 1. PACT ™ System Single Mode Schematic

Centrifugal force keeps the molten slag and feed material clear of the central pour nozzle during processing. The centrifuge is housed within a PPC that is regulated at a negative pressure of 25 to 50 mbar to prevent release of contaminants to outside the furnace.

As the torch continuously heats the rotating slag, waste is fed in from above, dropping onto the molten slag surface. Fig. 2 illustrates the PPC centrifugal principle, feeding and transferred arc profile showing the slag/arc interface. The entire melting process is illuminated by the arc light and visible to the operator through view system cameras.

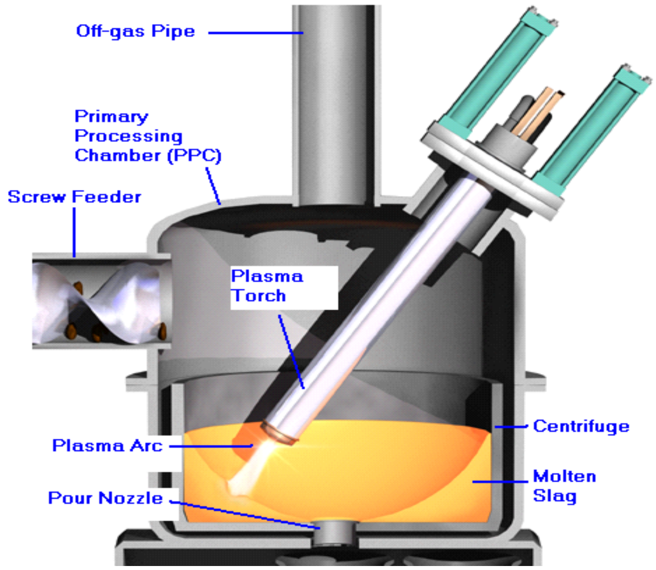

Fig. 2. PACT™ PPC centrifuge showing plasma interface with molten slag [2]

Pouring is achieved by slowing the centrifuge. Slag moves toward the center and pours through the throat into a mold.

The mold is located directly below the throat in a sealed slag collection chamber. Molds vary in size from 130 to 600 liters, depending on customer waste acceptance criteria. A 200-liter mold typically fills in less than a minute.

Swirl Flow Plasma Torch

Swirl flow plasma torches are so named from the tangential introduction of plasma gas into the torch[2]. Historically there have been two primary types of torches: transferred and non-transferred. Both types use current controlled DC power supplies. The two types are shown in Fig. 3.

[2]R. C. Eschenbach, et al., "Characteristics of High-Voltage Vortex Stabilized Arc Heaters," IEEE Transactions on Nuclear Science 11: pp. 41-48 (1964).

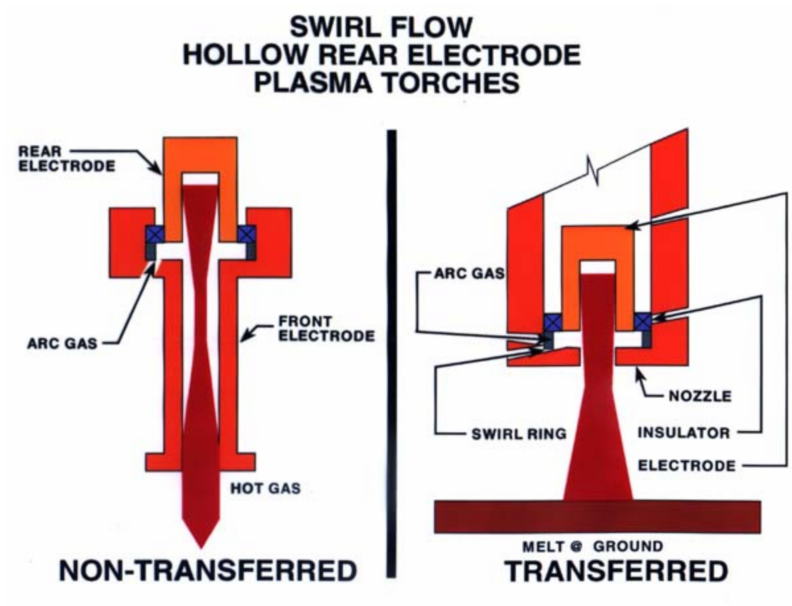

Fig. 3. Conventional Swirl Flow Plasma Torches

The traditional non-transferred arc torch has both DC electrodes within its body and a visibly longer nozzle for arc transfer. This design is a very effective method of imparting high temperatures into gases, such as for wind tunnels, but has lower efficiencies for direct melting of solid materials [3].

The transferred arc torch uses the work piece as the second electrode. Melting reactive metals, such as titanium, results in good efficiency since the work piece and crucibles are conductive regardless of temperature.

Since slag and refractory generally are not conductive at room temperature, the transferred arc torch effectively melts only *after* the centrifuge slag and refractory are hot enough to conduct electricity. This can be accomplished by a burner system during the PPC heat-up cycle or by operating the plasma torch in non-transferred mode. If a burner system is used to raise the PPC temperature to a sufficient temperature, the torch can then be started in transferred mode. There are complications when starting the torch in this manner in that the operator must lower the torch with little visual information about the torch position. The operator must rely on torch position instruments and/or a known torch start position.

From its inception, the PACT™ system has used a transferred arc torch for melting solid materials. The main reasons for the development of the multimodal torch were to have a more repeatable and effective way to start the torch, and to have a single heat source that would control the temperature in the PPC (simplifying the system).

Multimodal Plasma Torch

The Retech multimodal plasma torch can operate in non-transferred mode, transferred mode or both arc modes (dual mode). The non-transferred mode can be used to heat-up the furnace and be switched automatically to the transferred mode for processing. The most effective processing mode is having both arcs present (dual mode operation). The torch is started in non-transferred mode and the transferred arc comes on automatically. The transferred arc current is modulated to heat-up the PPC and for processing.

As shown in Fig. 4, the transferred arc is enveloped within the non-transferred arc ionized gas. Essentially, the non-transferred arc stabilizes the transferred arc to maximize throughput and to maintain long arcs without inadvertent current interrupts. This becomes important when processing heterogeneous feeds.

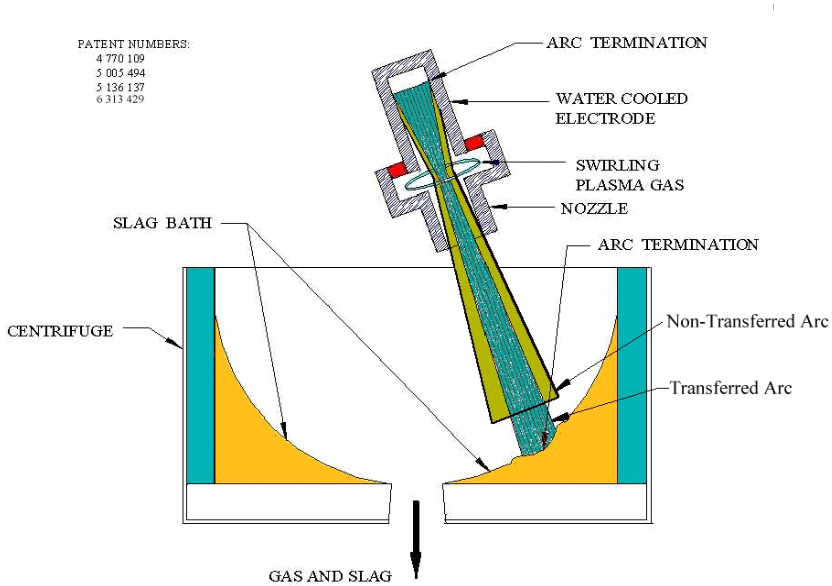

Fig. 4. Dual mode plasma torch operation

Multimodal Torch Advantages to Waste Processing

- In several 650 kg feeding tests, feed times were decreased by 70%, from 200 minutes to 60 minutes[3].

[3]Ref. 1, Page 7.

- The multimodal torch design has fewer parts and cooling circuits. This reduces the rear electrode changing time, saving approximately 3 to 4 hours per electrode change.

- The multimodal torch has a refractory covering that reduces power lost to the torch cooling water circuits by 20% to 30%.
- Improvements in the PPC refractory allow the multimodal torch to replace a 5 MBTU primary burner. During heat-up of the PACT™ system at Retech using dual mode torch operation only, the off gas volume was reduced by up to 2500 Nm^3/hr.
- The torch can now "pull" a one meter arc length, making it possible to batch melt multiple 200-liter drums weighing ≥650 kg in the centrifuge. Before dual mode torch development, a stable arc of this length was not practical.

At ZWILAG they use a transferred torch in combination with a propane burner. JAPC uses a multimodal torch and an LPG burner. During part of the heat-up and for drum processing, JAPC uses dual mode arc operation.

PACT™ BENEFITS[4]

Benefits of using the PACT™ system are that:

- It can treat mixtures of organic and inorganic wastes. Although many waste producers have implemented procedures for segregation as well as waste reduction, daily practice demonstrates that waste streams contain both organic and inorganic materials of different chemical and physical nature. Most often waste is packed in metal drums. The PACT™ system allows the thermal destruction of these wastes without any pretreatment or even opening of the drums. This leads to simpler operating procedures, safety and low dose impact to the workers, and low risk for contamination of the environment.
- It operates at very high temperatures resulting in the formation of molten metals and other inorganic products, incorporating most of the radionuclides and solid residues of organic waste thermal destruction. Also secondary wastes streams and dust from the off gas cleaning system finally are fed into the molten glass products. A plasma system therefore leads to a single solid product, incorporating almost all the radioactivity of the waste treated. The physical-chemical nature of this glass product is such that all requirements are fulfilled for direct final disposal. No further conditioning is necessary.
- The solid residues have a greatly reduced final volume. The Volume Reduction Factor (VRF) of a PACT™ system is high, leading to minimal final conditioned waste to be disposed of. Disposal costs are greatly reduced.

[4]J-P Wenger, R. Ineichen, R. Vanbrabrant, J. Deckers, J. Crouch, M. Shuey, "Radwaste Treatment System Using Thermal Plasma", Proceedings of the 8th Conference on Radioactive Waste Management ICEM'01, Belgium, Page 1 .

- It operates using air and oxygen for the complete oxidation of organic components in the waste. Due to the specific operating conditions in the primary and secondary combustion chamber minimal volumes of off-gases are produced with lower levels of dust. Treated by an efficient off-gas cleaning system, clean gases are produced obeying stringent clean air regulation limits.
- Due to its specific working conditions, it can treat industrial hazardous wastes, radioactive wastes, and mixed hazardous-radioactive wastes. Many times radioactive wastes also contain hazardous constituents: asbestos, oil, complex chemical liquids from research or medical applications, soils contaminated with heavy metals or chemically toxic components. One process can treat this wide variety of waste streams.

LLW PROCESSING AND OPERATIONAL EXPERIENCE AT ZWILAG

ZWILAG received its license to process LLW radioactive (rad) waste in 2000 and surrogate testing took place through 2002. After 2002, the equipment was modified for rad shielding, and a series of tests were performed for the Swiss Nuclear Regulatory Agency. Having completed testing for the regulators, ZWILAG was granted permission to process LLW rad waste from their national repository in Würenlingen in 2004. As of February 2005, ZWILAG has had several successful campaigns processing rad waste.

Fig. 5 shows a top view of the Plasma Hall showing the PACT™-8 PPC, Secondary Combustion Chamber (SCC), plasma torch assembly and horizontal drum feeding system.

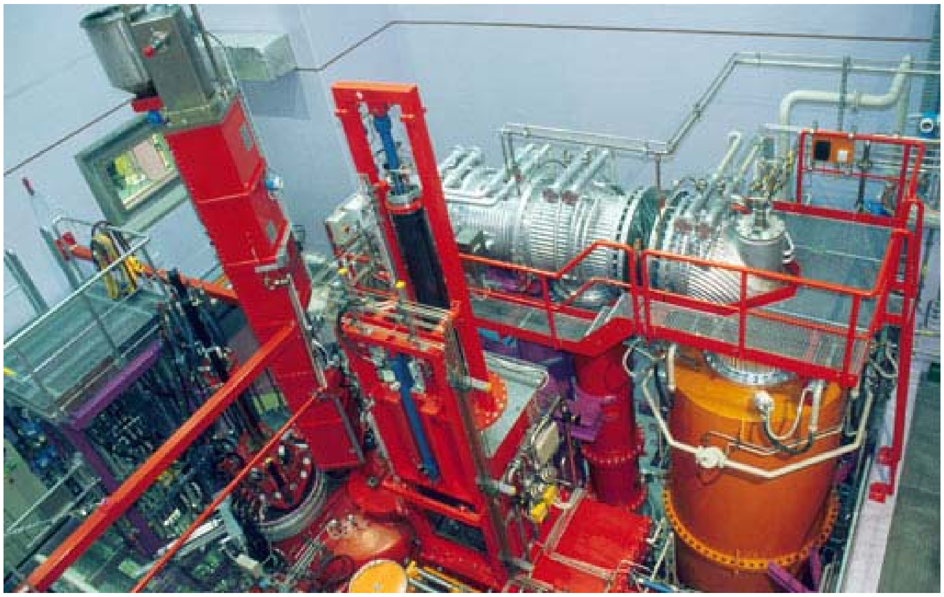

Fig. 5. ZWILAG Plasma Hall[5]

[5]ZWILAG World Wide Web site, www.zwilag.ch, specifically, www.zwilag.ch/project/zwilagfacility.asp, verbrennungsanlage, 2005.

The SCC is in the right of the photo shown in Figure 5 and colored orange. Gas ducting is above the SCC (silver) centered on a maintenance deck. To the left of the SCC and in the middle-front of the photo is the horizontal drum feeder. A drum (yellow top) is seen just before entering the isolation valve of the isolation chamber above the actual feeder. To the left of the drum is the PPC and in the middle of the PPC is the plasma torch assembly.

ZWILAG General Process

Fig. 6 shows the ZWILAG plasma system flow chart.

Drum Transport

The process starts by an operator selecting a drum from the repository. The drum is collected by a robotic retrieving mechanism and lowered onto a conveyor system. This conveyor system, which includes several isolation valves, manages and moves the drum to the plasma hall. Once the drum is close to the drum feeder, an isolation valve opens at the top of the feeder and receives the drum. The hydraulic vertical drum gripping mechanism clamps onto the top of the drum and lifts the drum vertically. The conveyor moves out of the isolation chamber and the isolation valve closes. Once the isolation valve is closed and the isolation chamber is purged, the drum is lowered into the drum tilting mechanism, where the vertical drum gripper releases, and the drum is made horizontal. Lastly a horizontal hydraulic gripper clamps onto the drum and moves it forward into a refractory lined drum feeder.

Drum Feeding and Processing

As the drum advances through the feeder housing, oxygen lances for the PPC and Secondary Combustion Chamber (SCC) are turned on and the flow is verified. The PPC and SCC pressure during operations ranges from -20 mbar to -30 mbar. Simultaneously with horizontal gripping, a propane-oxygen cutting torch ignites. The drum advances and stops, projecting slightly into the PPC. The PPC is a double walled, water-cooled chamber that is refractory lined and contains the centrifuge and a transferred type, nitrogen gas plasma torch.

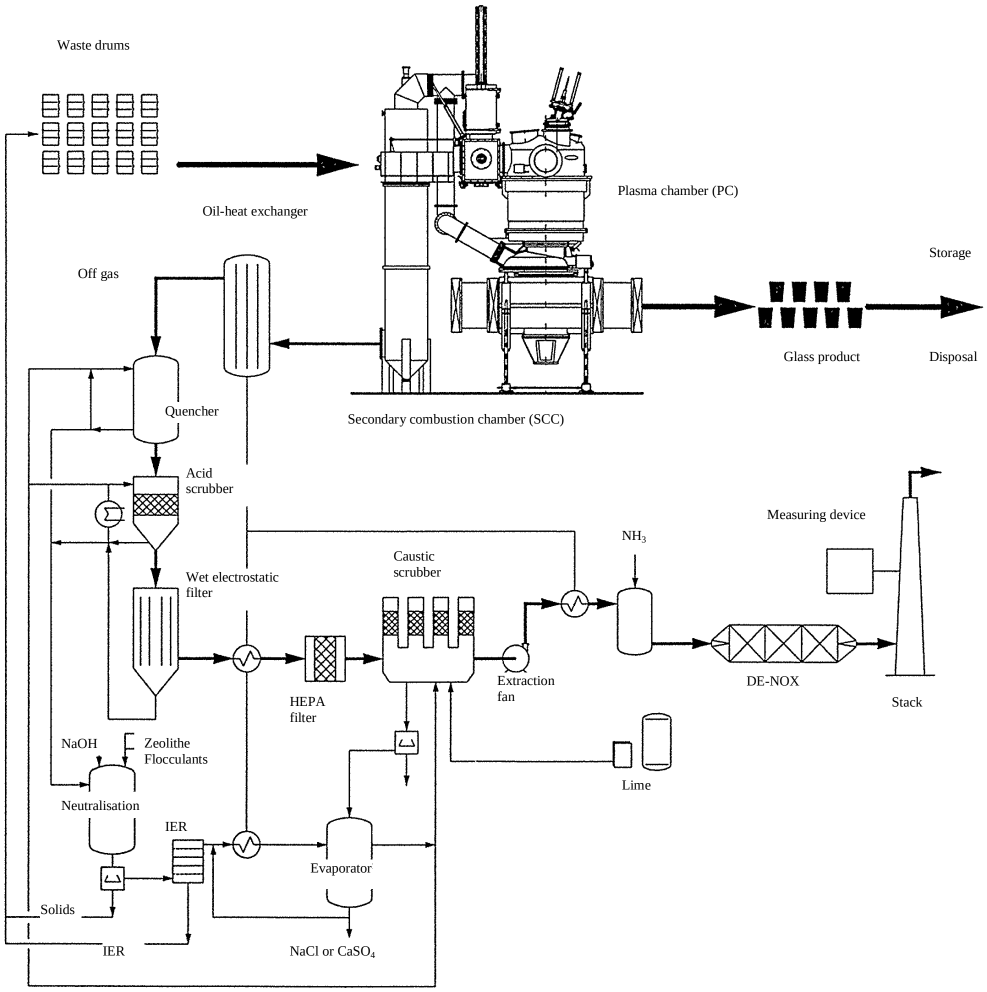

Fig. 6. ZWILAG PACT™ System Flow Sheet[6]

[6] J-P Wenger, R. Ineichen, R. Vanbrabrant, J. Deckers, J. Crouch, M. Shuey, "Radwaste Treatment System Using Thermal Plasma", Proceedings of the 8th Conference on Radioactive Waste Management ICEM'01, Belgium, Page 3 .

The centrifuge contains a molten slag bath and rotates at about 30 rpm to 40 rpm. The plasma torch can be running, or extinguished to control energy input during drum feeding. The cutting torch cuts the drum, and the contents as well as pieces of the drum fall gradually onto the surface of the slag layer. Any organic material falling onto the slag is quickly heated and evaporated into the headspace. The headspace has enough oxygen available to prevent soot formation. The gasses and steam pass from the PPC to the SCC. The SCC is a double walled, water-cooled chamber that is refractory lined and essentially completes combustion of pyrolysis gasses so that the effluent stream emanating from the SCC is generally composed of CO_2, O_2, NOx, steam, and other compounds containing sulfur and chlorine depending on the waste composition.

Off-gas Cleaning

The effluent stream passes from the SCC to a heat exchanger where oil is heated and used to re-heat the gasses prior to entry into the de-NOx unit. After the gasses pass through the heat exchanger, they enter the quench tower. The gas temperature at the inlet to the quench tower is about 350°C to 380°C, and the exit gas temperature is less than 80°C. The quenched gasses pass to the scrubber unit where the acids are neutralized. From the scrubber the gasses pass through an electrostatic precipitator and HEPA filter bank to capture particulates, and then to a de-NOx unit that uses ammonia to convert the remaining NOx to N_2 and water. After the gasses pass through the de-NOx unit they go to the stack and are released.

Pouring Cycle

The centrifuge becomes full when it contains about 1 m^3 of slag. Treatment of the material from the last drum fed is completed, then a pour is initiated by slowing down the centrifuge. The slag is collected in a storage mold that rests in a steel cooling mold. Several pours may be done in order to evacuate most of the molten slag from the centrifuge.

After cooling, the slag product in the storage mold is sent to the interim storage area where it is placed in an over-pack drum and sealed. This sealed drum is returned to the repository. Fig. 7 shows a final storage mold and over pack drum.

In general, twenty drums containing organic wastes produce one storage mold, ten to fifteen mixed organic and inorganic wastes drums produce one storage mold, and four inorganic waste drums produce one storage mold.

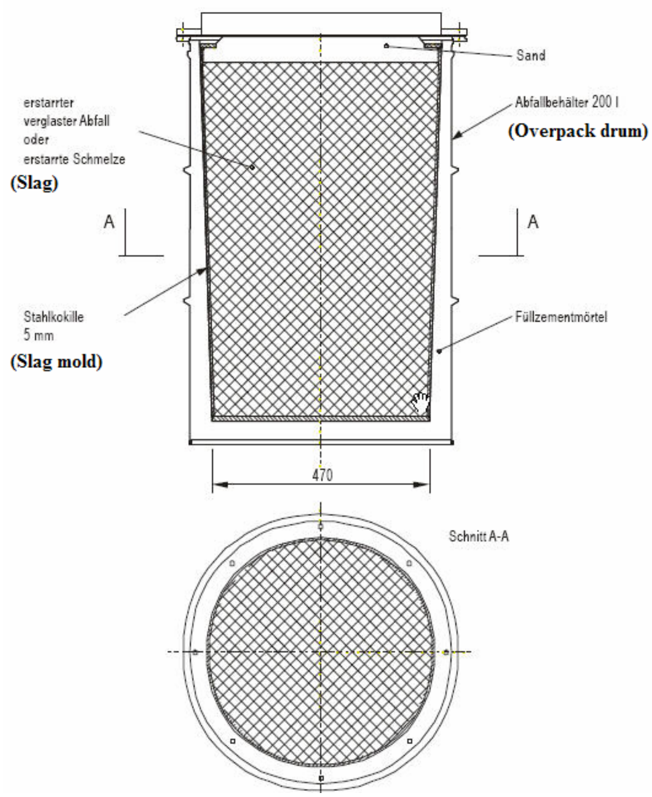

Figure 7. Final storage mold and over pack drum

ZWILAG LLW Rad Waste Processing Results

Table 1 shows data from the commissioning phase of the ZWILAG facility.

Table 1. ZWILAG Commissioning Data: Date 2001 to mid-March 2004

Item	Data	Description
Total wastes processed, kg	346	Total of all feed wastes processed during commissioning
Total slag/glass poured, drums	150	Total slag/glass produced during commissioning and stored in mold + over pack
Total drums processed, #	496	Total organic/inorganic waste drums processed during commissioning
Total molds used	104	Total number of molds used during commissioning
Mean drum feed rate, kg/hr	~ 200 kg/hr	Mean drum feed rate during commissioning defined as "select drum from storage to end of drum feeding."
Radioactive tracers used (please list)	----	
VRF organic waste	6-7:1	Volume reduction factor
VRF inorganic waste	6-7:1	Volume reduction factor

Please Note: Data courtesy of ZWILAG

Table 2 shows data from processing LLW waste through June of 2005. Note the commissioning data is nearly identical to actual LLW production and is due to ZWILAG's knowledge of the actual stored waste and careful compounding of simulated wastes to match the stored waste profile.

Table 2. ZWILAG Production Data Mid-2004 through Mid-June, 2005

Item	Data	Description
Total wastes processed, kg	39'653	Total of all feed wastes processed during production
Total slag/glass poured, kg	24'851 (Drums) 17'271 (Slag)	(Drums) = weight of slag, mold, over pack deposited in storage. (Slag) = total produced.
Total drums processed, #	265	Total organic/inorganic waste drums processed during production
Total molds used, #	41	Total number of molds used during production
Mean drum feed rate, kg/hr	~ 200 kg/hr	Mean drum feed rate during production defined as "select drum from storage to end of drum feeding."
VFR organic waste	Mixed waste (organic and inorganic) 6.5:1	VRF = Volume reduction factor
VFR inorganic waste	Not treated	VRF = Volume reduction factor
Activity per drum organic waste, Bq/drum	Mean: 2.8E+08 Bq Max.: 4.6E+10 Bq	Bq = becquerel = 1 disintegration per second. 851 drums surveyed
Main Isotopes organic waste (list)	^{54}Mn, ^{60}Co, ^{65}Zn, ^{95}Zr, ^{134}Cs, ^{58}Co, ^{125}Sb, ^{137}Cs, ^{3}H, ^{14}C, Am^{241}	
Activity per drum inorganic waste, Bq/drum	Mean: 6.0E+08 Bq Max.: 1.1E+10 Bq	Bq = becquerel = one disintegration per second. 291 drums surveyed
Main Isotopes inorganic waste (list)	Not Treated and Measured	
Total activity stabilized in slag/glass, Bq/drum	9.4E+10 Bq fed 8.5E+10 Bq in slag tot. 2.1E+09 Bq/drum	Total activity stabilized in slag/glass from all drums processed
Exposure to personnel due to processing LLW drums	Total dose for processing 200 drums (2005): 1.47 man-mSv	Man-dose total
Exposure to personnel due to maintenance.	Total dose for maintenance: (4 month in 2005): 1.73 man-mSv	Man-dose total

Please Note: Data courtesy of ZWILAG

The collective doses are very low which means that the equipment is well optimized regarding radiation protection.

CONCLUSION

Retech Systems LLC manufactures the PACT^{TM} system to offer excellent process flexibility and environmental protection while reducing the volume of LLW rad waste. One of the major benefits of processing 200-liter storage drums either vertically or horizontally is the reduction of radioactive exposure to workers. From it first conception over twenty years ago, the PACT^{TM} system is ready to be the process choice in thermal plasma as indicated by being fully licensed to process rad LLW waste in two countries: Switzerland and Japan. The operational experience demonstrated by ZWILAG and JAPC has been a testament to the success of thermal plasma and their status proves the benefits of using the PACT^{TM} system.