DEVELOPMENT AND USE OF THE DUAL-MODE PLASMA TORCH

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ABSTRACT

After several years of development, a commercially available high-temperature treatment system has been developed 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.

Plasma technology can also be used to treat previous conditioned waste packages that no longer meet the current acceptance criteria for final disposal. Plasma treatment can result, in many cases, in a substantial volume reduction, which lowers the final disposal costs.

This paper covers the recently patented dual mode plasma torch design(1), the lessons learned that fostered its development and the advantages it brings to radioactive waste processing. This paper also provides current full scale Plasma Arc Centrifugal Treatment (PACT) project status and how the dual mode torch is being used in the PACT system.

INTRODUCTION

The PACT system was conceived after a test in 1985 where a titanium melting system, of Retech manufacture, successfully used an argon plasma torch to melt 11.5 kg of surrogate radioactive waste fed in gallon cans (2). The waste was primarily made of disposable rubber gloves, cloth, glass, metal, plastic, and cesium acetate. A volume reduction of 20:1 and weight reduction of 1.8 pointed in the direction of making further tests with oxidant addition. Tests in 1987 and 1988, with a rotary hearth and diatomic plasma gas, showed that combustion could be controlled and slag that was very leach resistant could be generated. The rotary concept was patented in 1988(3). By 1991, a PACT-6 pilot system had been tested under the EPA Superfund SITE program (4) and the first upscaled system was operating at Muttenz, Switzerland.

Since 1991 five additional full-sized PACT-8 systems have been built for customers in Japan, Germany, Switzerland and the U.S. As the design matured with each application, the need for lowering maintenance and increasing performance focused on the plasma torch. Subsequent research and development culminated in 2000 with the first fully automatic dual mode torch delivery.

PACT SYSTEM PRINCIPLES OF OPERATION

In a PACT system, the plasma torch transfers electrical energy from the anode, or rear electrode, into molten slag, which is the cathode. Slag is the molten inorganic constituent of the waste material. The rotating crucible (centrifuge) moves the molten slag and waste material beneath the torch at 15 to 40 times per minute. Centrifugal force keeps the molten slag and feed material clear of the central pour hole during processing. The centrifuge is housed within a Primary Processing Chamber (PPC) that is regulated at -25 to -50 mbar to guard against release of contaminants outside the furnace.

As the torch continuously heats the rotating slag, waste is fed in from above, dropping onto the molten slag surface. Fig. 1 illustrates the Plasma Arc Centrifugal principle. The entire melting process is illuminated by the arc light and visible to the operator through view system cameras.

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

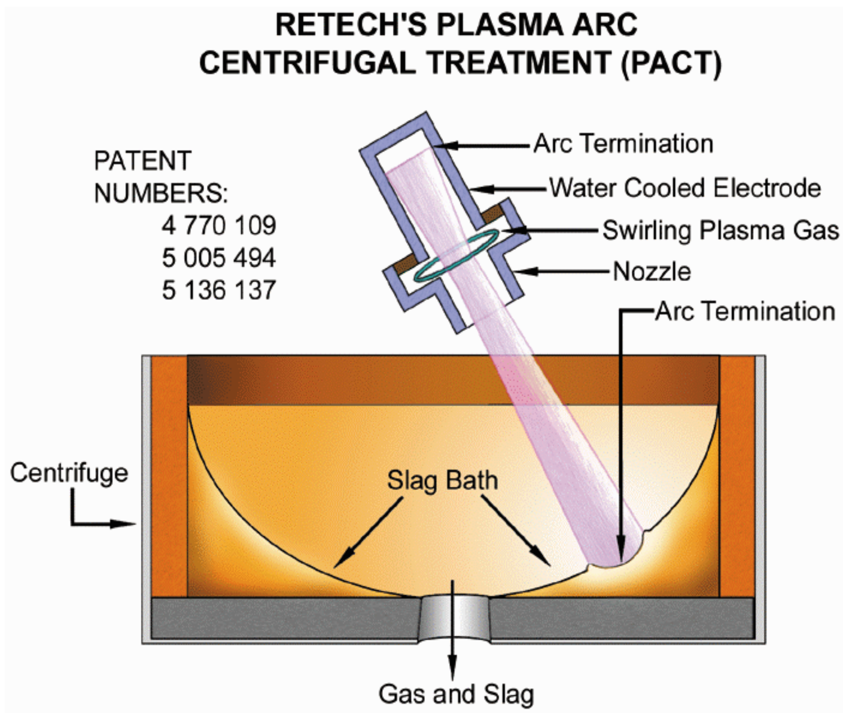

Fig. 1. Plasma Arc Centrifugal Single Mode Schematic.

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 a matter of a few minutes.

Swirl Flow Plasma Torch

Swirl flow plasma torches are so named from the tangential introduction of plasma gas into the torch. Historically there have been two primary types of torches; a transferred arc and a non-transferred arc. Both torches use current controlled DC power supplies. Each type of torch is shown in Fig. 2.

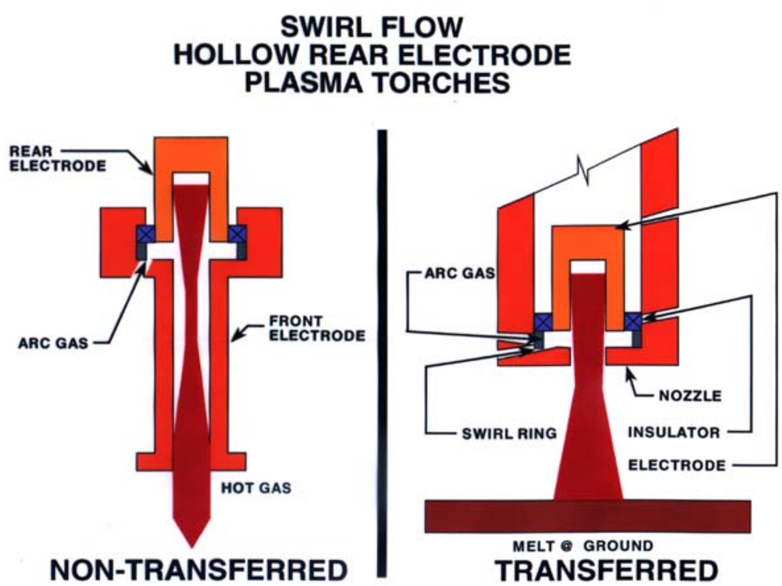

Fig. 2. Conventional Swirl Flow Plasma Torches.

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.

The transferred arc torch uses the workpiece as the second electrode. Melting reactive metals, such as titanium, demonstrates good efficiency since the workpiece 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 is usually accomplished by a burner system during the PPC heat-up cycle. After the PPC temperature is raised to a sufficient temperature, the torch is then 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 accuracy of the torch position. The operator must rely on torch position instruments and/or a known torch start position.

DUAL MODE TORCH DEVELOPMENT

From its inception, the PACT system has used a transferred arc torch for melting solid materials. The main reasons for the development of the dual mode 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). The first step was to use the non-transferred arc to heat-up a pre-charge of waste material in the PPC then transfer to the plasma arc. This allowed the transferred arc to operate at all times on waste material (slag) and not the refractory.

Several concepts were tried to help with starting the torch that led to the dual mode torch. These concepts were a water-cooled conductive throat, a conductive refractory throat, thermite, and an arc starting rod. A brief description of these including lessons learned is provided below.

Water-Cooled Conductive Throat

A conductive path through the centrifuge was originally provided by using a water-cooled copper throat. Iron or graphite rings were often used as starting material to shorten the arc time on the throat.

Lessons Learned:

- The cold area around the throat froze metal feeds, which then did not readily pour.
- The torch action wears copper, which increases the maintenance interval for the throat and rotating water seals.
- The torch suffered instability and arc outs with bulky heterogeneous and aqueous feeds.
- The graphite rings tended to float, providing a "moving target" for arc transfer.

Refractory Throat

The copper conductive throat was replaced with a conductive refractory throat that did not require water-cooling. The conductive refractory throat, coupled with a new refractory design in the centrifuge, showed some performance improvement with system operation and decreased the time spent maintaining the throat area.

Lessons Learned:

- Since the torch provides enough heat to melt refractory, maintenance on the throat continued to be more frequent than desired.
- Torch instability still occurred with bulky heterogeneous and aqueous materials with little improvement in restarting.

Thermite

Thermite powder, made of aluminum and iron oxide, was fed into the cold centrifuge. Upon torch starting, the temperature of the slag instantly rose to conductive temperatures.

Lessons Learned :

- While thermite was successful in achieving conductive temperatures, the risk associated with incorrect thermite feeding was considered too high.
- Rapid changes in centrifuge temperatures accelerated refractory wear.

- Torch instability still occurred with bulky heterogeneous and aqueous materials with little improvement in restarting.

Starting Rod
A graphite starting rod was added as a arc start ground path. It extended a few inches above the centrifuge as the arc was struck so the hot plasma gas would flow against the centrifuge bottom. Since the centrifuge was in motion, the refractory heated evenly as during normal processing. The starting rod was typically graphite and was withdrawn as much as possible from the chamber during system operation.

Lessons Learned
- Provides additional system costs and complexity with little improvement in performance.
- The starting rod rapidly oxidized, requiring frequent replacement.
- The starting rod required the torch to work close to the centrifuge surface causing refractory erosion.
- Torch instability still occurred with bulky heterogeneous and aqueous materials with little improvement in restarting.

Manual Switching
Experiments with the model RP 250-T torch at 200 kW proved that a simplified swirl flow transferred arc torch could heat up the PPC while operating in a non-transferred mode. With no appreciable wear on the characteristically short nozzle, the experiment was repeated with the model RP-600T at 1200 kW in a PACT-8 (8 foot inside diameter centrifuge) with similar results.

A dual mode torch (with manual mode switching controls) was implemented on the PACT-8 system for the Norfolk Navy Base. Simultaneous proprietary improvements in the centrifuge refractory kept the non-transferred arc run time to a fraction of the total system warm-up time. The torch (750 kW) performed as expected, heating the centrifuge and PPC until the operator manually switched the torch to transfer mode. Having manually switching modes did not affect performance.

Lessons Learned
- Arc-outs from instability were still possible, but brief, with aqueous or bulky heterogeneous feeds. Rapid restarting in non-transfer mode meant that feed time lost to visibility and instability were minimal.

Refractory designs continue to be studied, changing the throat material to a non-conductive chemistry. Other refractory design work is in progress to further improve thermal conservation and promote rear electrode life.

The development events listed above spanned the delivery of 12 systems over as many years.

Dual Mode Principles
The Retech dual mode plasma torch can operate in non-transferred, transferred modes or both modes (true dual mode). The non-transferred mode can be used to heat-up the furnace and switched, by operator action or automatically, to the transferred mode for processing. The most

effective processing mode is having both arcs present or dual mode operation. The torch is started in non-transferred mode and the transferred arc comes on automatically. Then the non-transferred arc current is lowered to about 300-500 Amperes. The transferred arc current is modulated to heat-up the PPC and for processing.

As shown in Fig. 3, 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.

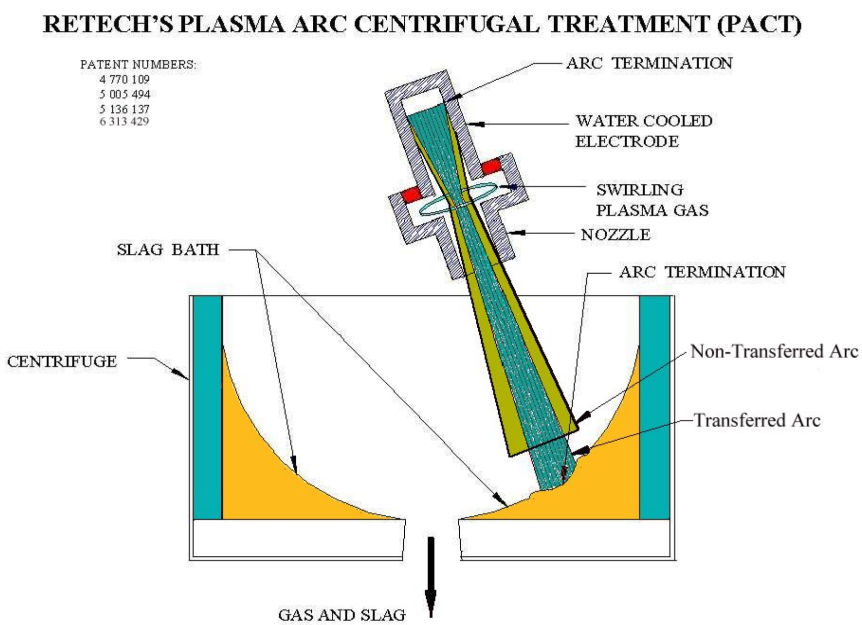

Fig. 3. Plasma Arc Centrifugal Dual Mode Schematic.

Dual Mode Torch Advantages to Waste Processing

- With the prior single mode torch designs, cold heterogeneous feed material would cause a high voltage spike with visible instability as the arc sought a better ground path. Repeated instability, such as with a large amount of bulky feed material, would cause arc-outs and lost visibility inside the PPC. To correct instability and maintain torch operation, the operator would temporarily reduce current, reducing the melt rate. With the dual mode torch, the non-transfer gas envelope stabilizes transferred arc voltage so that arc-outs and arc instability are eliminated. In several 650 kg feeding tests, feed times were decreased by over 200%, from 200 to 60 minutes.

- Dual mode operation allows the operator to focus more attention on system trending and other operating data.

- The dual mode 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 dual mode torch has a refractory covering that reduces power loss to the torch cooling water circuits by 20% to 30%. Further improvements to the covering materials continue to be studied.

- The dual mode torch allows the centrifuge and throat refractory design to focus primarily on heat retention resulting in a 70% decrease in power lost to centrifuge cooling circuits.

- Improvements in the PPC refractory allows the dual mode torch to replace a 5 MBTU primary burner. During heat-up of the PACT-8 system with the dual mode torch, the off gas volume is 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 >500 kg in the centrifuge. Before dual mode torch development, a stable arc of this length was not practical. Longer arc length or processing in non-transferred mode also means the system can be operated at reduced heat for processing more volatile materials such as cesium. As research progresses, process development may point toward higher retention in slag of cesium and like materials.

- If a piece of feed material happens to block the throat, the non-transfer mode is used to clear the blockage without melting the throat.

DUAL MODE TORCH AND WASTE PROCESSING

The Toyo Engineering PACT-8 system was designed to feed an inventory of waste which is stored in concrete lined 200-liter drums. These drums generally weigh more than 500 kg. There is no throughput benefit from horizontal feeding since the LPG Rosebud will not readily cut concrete and the feed port is not accessible to the plasma torch for direct drum melting. Other drums may contain single bulky objects that are not practical for dropping into the centrifuge.

Four drums are loaded, by rotating the centrifuge 90° for each load, when the PPC has reached a temperature between 700°C to 900° C. The feeder is continuously purged and can accept and load drums through 2 interlocked valves that keep the melter atmosphere from contaminating the facility.

The dual mode torch is positioned above the 4 drums and started in non-transfer mode, then the transferred arc is initiated and melting commences using dual mode operations.

The horizontal drums are projected to contain small metal parts, insulation, concrete, pipe and other inorganics. Due to the bulky nature of these materials, they benefit from the non-transfer ionized gas envelope for maintaining a stable arc.

The manually controlled dual mode torch at the Norfolk Navy Base System treats shredded feed material, most of which is oily rags, waste paint and liquids. Arc instability is not expected due to the high percentage of organic materials and shred size. During the factory acceptance test, dirt clumps caused some arc instability. Manual switching to non-transfer mode restarted the torch quickly with minimum loss in processing time(5).

CURRENT PACT STATUS

- The PACT system in Muttenz, Switzerland, mentioned previously, processed pharmaceutical sludges in 200-liter drums and recovered copper and zinc from brass dross. It also served as a demonstration unit for the Moser-Glaser Company.

- The PACT system in Munster, Germany has not yet completed qualification trials. This system will process the products from washing soils contaminated by military explosives and chemical warfare agents.

- The PACT System at ZWILAG (in Wurenlingen, Switzerland) has successfully completed its PACT pre-qualification trials. ZWILAG's intent is to treat non-radioactive materials in 2001 and process radioactive materials in 2002. The system processes 200-liter drummed wastes through a drum feeder. The drums contain low and medium level beta and gamma production wastes from Swiss nuclear power plants(6).

- The PACT system at Retech has been used for development of the dual mode torch and production scale process testing.

- The PACT system delivered to the Norfolk Naval Base will be installed after the Naval Base obtains the necessary permits and completes an environmental impact statement. Its acceptance tests were completed at Retech before shipment. This system was designed to treat waste paint, solvents, oily rags, batteries, and other non-recyclable waste.

- The PACT system, delivered based on a contract with Toyo Engineering Company, is being installed in Japan and will undergo thermal tests in 2002. It is designed to treat horizontally and vertically fed 200-liter drums containing inorganic wastes and loose organic waste from the Tsuruga nuclear power plant.

- Six smaller systems have been built; two PACT-1 units that were used for laboratory studies, three PACT-2 units and one PACT-6 that were used for pilot scale treatability studies. One of the PACT-2 units is installed at CEA, Cadarache, France where CEA plans to treat radioactive material by 2006(7).

CONCLUSIONS

The successful development of the dual mode plasma torch brings improved performance and lower maintenance to the PACT system for treating radioactive and hazardous waste. The associated changes to other parts of the system improve melting efficiency through heat retention. The recent implementation of the dual mode torch augments the PACT system with new capability to treat heavy drums of stored waste.

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