WASTE MINIMIZATION WITH PLASMA PROCESSING

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ABSTRACT

Three ways in which plasma processing can be used to minimize waste are reported. All use a transferred arc to a bath within a hermetically sealed furnace.

In the first, waste forms with some solid products are fed through an air-locked feed-chamber onto a centrifuge with an axial, bottom port. Organics are quickly vaporized and burn in the headspace of the primary chamber, then combustion is completed in a secondary combustion chamber. An off-gas cleanup system ensures compliance with regulatory standards. The condensed phase accumulates as a glassy slag in the primary chamber, from which it is cast at intervals into a mold. The cooled product is very leach-resistant.

The second concept recycles the furnace off-gas through the torch to make a very large reduction in effluent gas compared to other processes.

The third way to use plasma for minimizing waste involves remelting metallic scrap in a sealed inert gas environment to eliminate vaporizable contaminants and convert the scrap into a form suitable for forging or manufacture of components.

BACKGROUND

Minimizing the amount of hazardous waste in the treatment process is obviously a very desirable goal. This paper describes three ways in which plasma processing can be applied toward this goal.

A plasma arc generates heat by carrying an electric current in a gas. By using electric energy, independent control of temperature and atmosphere can be achieved. Swirl flow hollow electrode arc torches have a long history, dating back to nitrogen fixation of air by Birkeland and Eyde in 1903. Such swirl flow torches have been operated in a wide range of gases, including air, oxygen, nitrogen, carbon monoxide, carbon dioxide, argon, helium, methane and hydrogen. The amount of energy added can be varied by adjusting the arc current. Energy input is limited by electrode erosion at high currents and by arc stability at low currents.

An arc has two terminations - where the current carriers (ions and electrons) enter and leave the condensed phase, which has higher conductivity than does the gas phase. Plasma torches are usually classified as either non-transferred or transferred devices. In the non-transferred torch, both electrodes are within the torch, and the electric energy is delivered as sensible heat in the hot gas leaving the torch. In the transferred torch only one arc termination is inside the torch, and the other termination is on a condensed phase, usually a liquid, and usually consisting of the material to be heated by the arc process.

Non-transferred swirl flow torches (1) are quite efficient ways to heat gases to temperatures of 2000°C and higher. Usually 70 to 90% of the electric energy will be in the gas emerging from the torch. However, when the energy must be delivered to a liquid or solid bath of material, transfer of energy from the hot gas to the bath is not efficient unless the geometry is akin to that of a shaft furnace, so that the gas can leave at a low temperature. In many melting situations, a shaft geometry can not be used, and a transferred arc is then more efficient. The three applications of plasma in this report all involve transferred, swirl flow torches (2).

When hazardous materials are treated, the integrity of the separation between inside and outside the treatment vessel (furnace) becomes vitally important. The integrity of high temperature rotating seals is notoriously fragile (e.g. "puffs" from rotary kilns). The furnace enclosures described below all involve double-walled, water-cooled construction, with all sealing materials near room temperature, frequently using O-rings.

THE PLASMA CENTRIFUGAL FURNACE

The first application involves heating hazardous materials in a controlled atmosphere, usually oxidizing, to separate the feedstock into a gas phase and a slag. In this plasma furnace concept, waste material is fed into a sealed centrifuge where it is heated by a transferred-arc plasma torch (Fig. 1). Organic material is evaporated and reacts almost immediately upon entering the primary chamber. Off-gas travels through a gas/slag separation chamber, then on to a secondary combustion chamber where the temperature is maintained at greater than 1100°C for more than two seconds. The gas then flows through an air pollution control system. The slag is cast into molds for permanent storage or disposal.

The process is most useful when there is a significant solid residue after treatment. Because the residue is melted and homogenized in processing, the process costs are justified when the melting and homogenization is beneficial, such as when the residue is radioactive or contains heavy metals.

Tests with the PCF concept started with a centrifuge with an I.D. of 0.45 meter (3, 4). The early work showed that the PCF could accept a wide range of waste forms and that the glassy slag resulting from plasma treatment was very leach-resistant.

The encouraging results from the lab-size unit (designated PCF-1.5) led to acceptance of Retech's process into the United States EPA's second Superfund Innovative Technology Evaluation (SITE) solicitation. In order to meet the requirements for a demonstration project, Retech designed and built a larger unit with a 1.8 m (6 foot) diameter centrifuge (PCF-6). As in all the PCF's, the centrifuge is located inside a double-walled, water-cooled shell which can withstand substantial positive or negative pressures without leakage.

Construction of the PCF-6 was completed in March of 1989, and a preliminary test, supported by the EPA, was conducted in Ukiah, April 25, 1989. The test disclosed problems with the feeder and SCC temperature. Modifications were made, and ten additional shakedown runs were made in

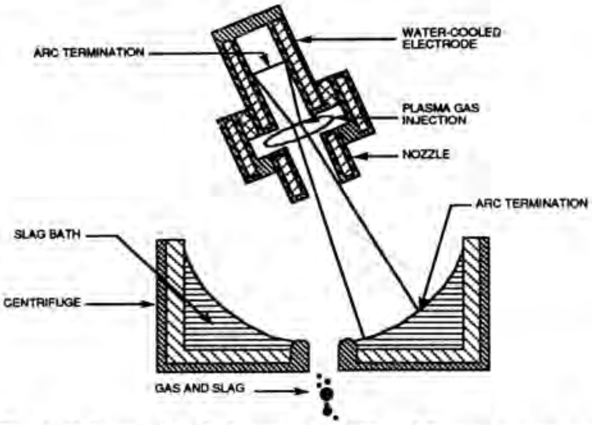

Fig. 1. Schematic of plasma centrifugal furnace concept.

Ukiah in May before the furnace was disassembled and shipped to Butte.

The Component Development and Integration Facility (CDIF) of the U.S. Department of Energy, in Butte, MT was picked as a test site for three main reasons: 1) Butte had a Superfund location with pentachlorophenol contaminated soil having a high content of heavy metals - this combination is readily treated with the PCF, 2) there was vacant lab space at the CDIF with good support facilities, and 3) at that time the CDIF was under the administrative supervision of the Idaho National Engineering Lab (INEL) and INEL was interested in evaluating the utility of the PCF for treating several types of problem wastes at INEL.

About thirty shakedown tests were performed by MSE personnel between October 1989 and June 1991 (MSE, Inc. is the contractor for DOE at the CDIF). Results of some of the shakedown tests have been reported (3).

During these shakedown tests, modifications were made to the original system design (Fig. 2). These modifications included the installation of an air-gas burner to the secondary combustion chamber and the addition of a afterburner in the secondary combustion chamber and the installation of a chiller on the gas treatment system to compensate for the additional heat input.

The waste selected for treatment consisted of heavy metal-bearing soil from the Silver Bow Creek Superfund site mixed with 10% by weight No. 2 diesel fuel. The mixture was spiked to provide 28,000 ppm of zinc oxide and 1,000 ppm of hexachlorobenzene. Zinc was added as a tracer to determine the leachability of the slag and the hexachlorobenzene was the Principal Organic Hazardous Constituent (POHC) used to determine organic Destruction and Removal Efficiency (DRE).

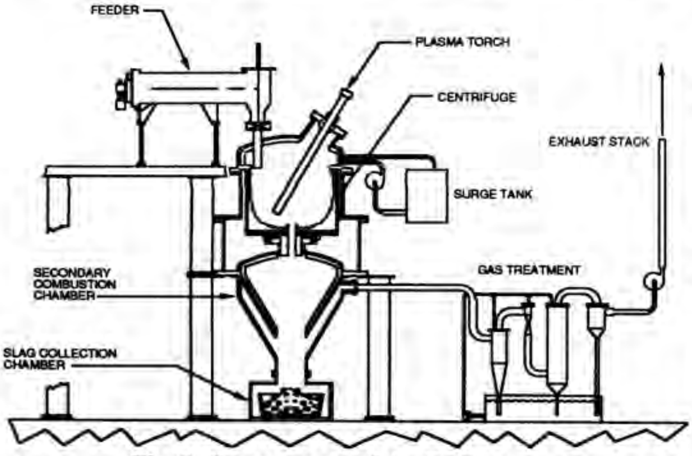

Fig. 2. Components of the PCF system.

Three replicate test runs were made July 22, 24 and 26, 1991. A summary of the test procedure and results was given at the 1992 Incineration Conference (5). The detailed final report appeared in two volumes (6,7). An Applications Analysis Report has also been issued by the EPA (8).

After the three SITE tests were completed, the PCF-6 at Butte was used to treat surrogates of wastes now at INEL. These tests have been summarized by MSE (9).

The destruction and removal efficiency (DRE) was calculated from analysis of hexachlorobenzene in the feed soil and detection limits in the samples of stack gas (since no C_6Cl_6 was detected in the stack gas). The values ranged from 99.9968% to 99.9999%. The level of total hydrocarbons in the exhaust was low (<4 ppm). The level of CO in the exhaust averaged 1.4 ppm.

Leaching properties of the slag produced were good, but particulate in the exhaust was above regulatory limits. The off-gas system is being modified to improve particulate removal.

In 1989 a Swiss firm, MGC Plasma ordered a PCF-8 furnace which was installed in the summer of 1990 in Muttenz, a suburb of Basel (10). A gas cleanup system built by Ceilcote was installed to permit the effluent to meet the very strict Swiss standards. The furnace has a very unique charging system. Whole drums are inserted, five at a time, into a drum-feeder chamber. A drum manipulator clamps the lid of the lead drum and holds the drum in the furnace while an auxiliary cutting device opens up the drum to dump the contents gradually into the furnace. There have been some problems with this feeder and a different feed system is under construction.

Retech is currently designing three more systems for three European customers. One is a PCF-8 for treating soil contaminated with military wastes. Most of the PCF feed in this application will arrive from a soil-washing process which will enable at least 90% of the contaminated soil to be returned as "clean" soil.

The second is a PCF-8 for treating low/intermediate level radioactive wastes. In this application, three categories of feed will be charged to the furnace - organic liquids, combustible solids and metal waste. All three categories will come to the furnace in 200 liter drums.

The third project is a smaller furnace, a PCF-2, which will be used to test first radioactive surrogates, then radioactive mixed wastes. A separate paper at this conference discusses the development of the PCF-2 (session XVI, paper 1).

GAS RECYCLE

The second aspect involves a novel approach, made possible by the twin features of the low gas flow rates associated with plasma and the hermetic sealing of the plasma centrifugal furnace.

Earlier work in melting reactive and refractory metals, with transferred plasma arcs using helium as the plasma gas, has resulted in production systems in which the plasma gas is recycled through the torch. Because helium is a rather expensive gas, reducing helium consumption by a factor of 50 through recycle made a significant improvement in the cost of melting (10).

It is advantageous when treating radioactive wastes to limit the off-gas volume as much as possible. The gas flow with arc-heated thermal treatment systems is much less than with combustion-heated systems, frequently by a factor of four or more. Since the swirl flow electrode can operate in a variety of atmospheres, merely recompressing and recirculating the effluent would reduce the flow rate by another factor of two to fifty, depending on the amount of organics fed (which burn to carbon dioxide and water when oxygen is added to the primary chamber). The small amount of effluent could be accumulated in a previously evacuated receiving tank.

One might even consider adding a carbon dioxide absorption system to eliminate completely any gas discharge. This last is thus far speculative, but plans for tests with a minimum flow system and a holding tank are well-advanced.

METAL RECOVERY

The third way to use plasma for minimizing waste involves remelting metallic scrap in a sealed inert gas environment to eliminate vaporizable contaminants and convert the scrap into a form suitable for forging or manufacture of components. This work stems from developments achieved in reprocessing aerospace alloys.

Titanium alloys have been used in aircraft engines and airframes for about thirty years. Until about ten years ago, titanium alloy turnings, generated in large quantities while making parts, were useful only as an oxygen getter in making steel. However, the advent of plasma melting for scrap recovery changed this dramatically (11).

Plasma cold hearth melting is now used for making the highest quality parts for aircraft engines from titanium alloys (12). Work has been done to extend the benefits of PCH melting to superalloys (13).

Plasma metal melting should be useful in the nuclear field both for remelting alloy turnings for reuse and for minimizing storage volume of obsolete or non-serviceable metal parts. One application might be making bar from turnings of depleted uranium to reduce scrap loss almost to zero.

Another possible use was demonstrated several years ago. The Zircaloy tubes and Inconel/stainless steel cages used to house the fuel elements in a nuclear reactor must be discarded at some point due to radiation damage effects. The residual radioactivity is high enough that the cages need a lined canister. The bulk density of the cages as manufactured is a factor of 44 lower than the bulk density of the metal in cast form. A small test program with unused ("cold") fuel cages showed that the theoretical increase in bulk density could readily be achieved by melting with plasma in an inert gas environment.

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