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LESSONS LEARNED FROM START-UP TESTING OF A MIXED WASTE INCINERATOR

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ABSTRACT

Start-up testing of a new mixed waste incinerator, the Consolidated Incineration Facility (CIF), has been completed at the Department of Energy's Savannah River Site (SRS). The incinerator is equipped with an air pollution control system (APCS) that includes a wet quench and scrubber followed by dry air filtration using high efficiency particulate air (HEPA) filters. The system was designed with optimum materials to maximize reliability, runtime, and ease of maintenance. Changes to the CIF operation and materials have been made to maximize system performance and minimize corrosion. This paper presents a brief overview of the incinerator design philosophy, pilot-scale testing results, and some of the lessons learned during the start-up testing of the CIF.

INTRODUCTION

The CIF is a mixed waste incinerator that is Resource Conservation and Recovery Act (RCRA) permitted to burn hazardous, low-level radioactive, and mixed waste. The CIF is designed to burn low-level waste to reduce the volume for minimizing disposal costs and to burn hazardous and mixed wastes to provide for the destruction of organic contaminants to meet regulatory requirements. The CIF will burn wastes that contain Cl, S, Pb, P, F, and Na which produce corrosive gases such as HCl, SO_2, and HF, etc. The acid gases that are generated during combustion will then be cooled in the CIF air pollution control system (APCS) and neutralized with NaOH forming predominantly chloride salt by-products. As a result, the CIF was designed with materials of construction that could withstand the highly corrosive environment.

Waste simulants with hazardous contaminants and chlorides were used in CIF start-up testing and pre-trial burn runs. Problems with corrosion surfaced in the CIF during this test phase. Corrosion in the CIF was facilitated by the high saturation temperature maintained throughout the APCS at 191°F (88°C). Even though the APCS is equipped with a reheat section to maintain the temperature sufficiently above the saturation temperature, downstream condensation occurred that facilitated corrosion.

DESIGN

The CIF utilizes a fuel-fired rotary kiln incinerator followed by a wet APCS. The APCS consists of a wet spray quench, a steam-jet scrubber, a cyclone separator and mist eliminator for liquid-gas separation, and a reheater prior to the downstream dry high efficiency particulate air (HEPA) filters. The CIF flowsheet is shown in Figure 1.

The spray quench is used to saturate and cool the flue gas stream. Next, a scrubber is used for initial particle capture and acid gas removal. Initial particle removal is required to take out the bulk of the particulate matter so that downstream devices are not fouled, poisoned, or overburdened with particulate matter. Entrained water droplets are then removed by the cyclone separator and mist eliminator. The flue gas is then heated to a temperature above the dewpoint and passed through HEPA filters which are able to capture very fine particles.

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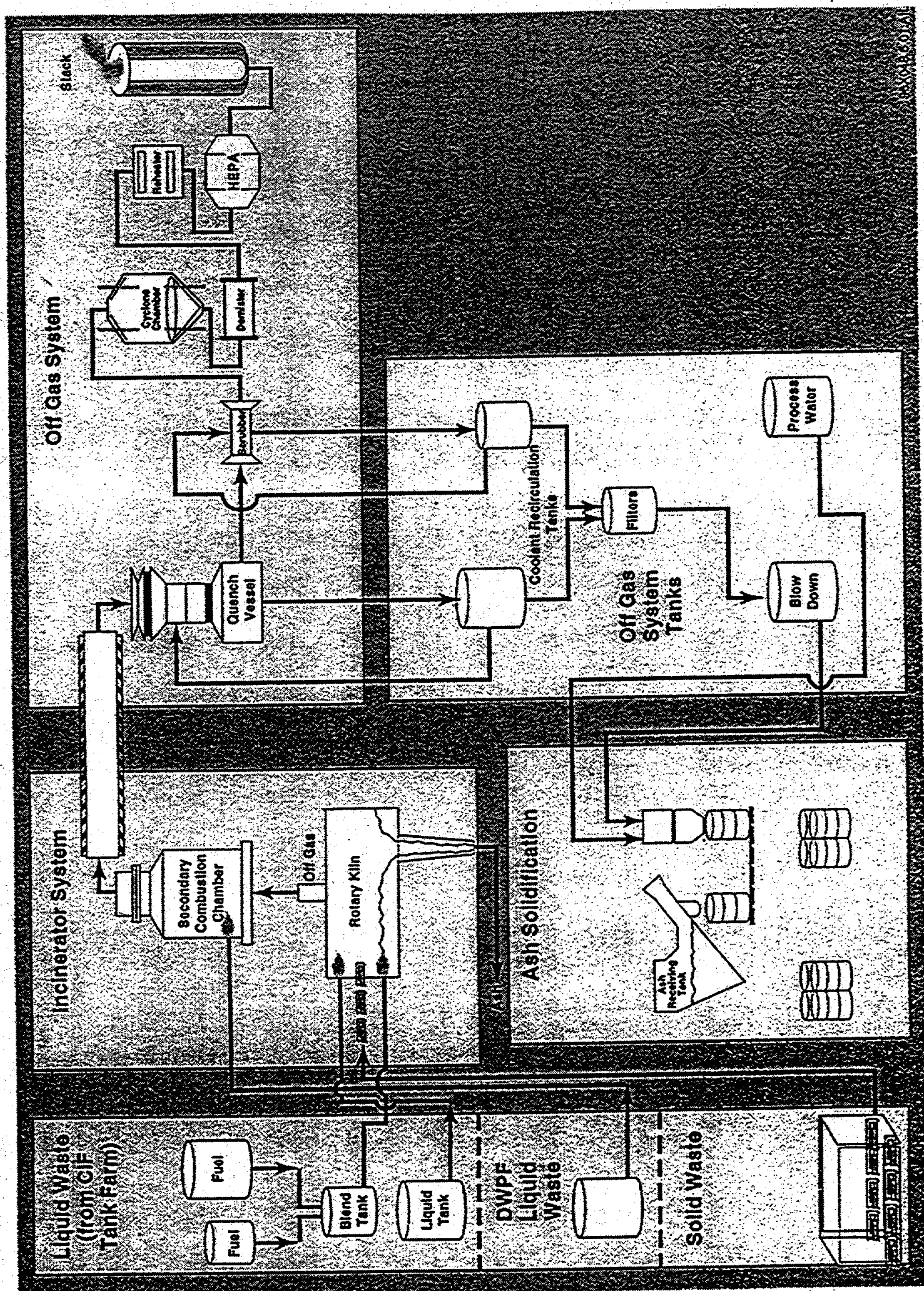

FIGURE 1. Process flow Diagram for the Consolidated Incineration Facility

It is critical that the gas temperature remain above the dewpoint and that all the water droplets completely evaporate. Otherwise, corrosion and plugging will occur in the HEPA filters and piping from condensed moisture and other gases.

PHILOSOPHY OF COMPONENT MATERIALS SELECTION

Corrosion resistance and cost were the primary criteria used in selection of the materials of construction for the CIF APCS. Fiber-reinforced plastic (FRP) was utilized where possible if the highest operating temperature anticipated in the APCS was within the recommended operating range of FRP (i.e., < 250°F (121°C)). Metal alloys or coated metals were selected for those offgas sections which were operated above the FRP design temperature.

The Spray Quench

The quench cools the flue gas exiting the secondary combustion chambers at gas exhaust temperatures above 1600°F (871°C) to the adiabatic saturation temperature of 180°F (82°C). When the flue gas stream containing SO_2, HCl, and HF is cooled, the aqueous environment can become very corrosive for stainless steels and many higher alloyed metal systems. Since the planned waste feeds contain both sulfur and chlorine, a metal that was resistant to both sulfidation and chloride attack was required for quench construction. Therefore, the quench vessel is fabricated with two materials: 1) a metal super alloy C-276 (UNS# N10276) because of its corrosion resistance quality, and 2) "polymer-coated" carbon steel to reduce the fabrication costs. The coating is a copolymer of ethylene/chlorotrifluoroethylene which is lined with carbon brick insulation for additional protection against acid attack. The steel structure is used instead of FRP to insure containment of hot gases in case of quench failure. The associated quench recirculation piping is lined with polypropylene, and the quench nozzles and flanges are also fabricated with alloy C-276.

Scrubber

The scrubber uses a high velocity steam jet to atomize the scrubbing liquor for removal of particulates. NaOH is injected into the scrubbing liquor for neutralization of acid gases. Because of the high-temperature steam jet-spray, the scrubber and associated flue gas piping was fabricated of alloy C-276. The saturation temperature of the gases exiting the scrubber are 188°F (87°C)

Liquid Gas Separators

The high velocity steam-jet scrubber facilitates significant entrainment of moisture into the flue gas. For removal of the entrained moisture, the CIF is equipped with two liquid-gas separators, a cyclone separator followed by a mist eliminator. The cyclone and mist eliminator are operated at temperatures less than 200°F (93°C), and therefore, are fabricated of FRP.

Reheat Section

Any droplets that are entrained from the liquid-gas separators will be evaporated by the CIF reheater. The reheater is equipped with three finned steam coils fabricated of alloy AL6XN (UNS #N08367). The coils are designed with a double-fold number of fins per inch to maximize the heat transfer.

Offgas Duct

The offgas duct downstream of the reheater was fabricated of metal since the reheater exhaust temperature was at the high operating limit of FRP (i.e., < 250°F (121°C)). The duct was originally fabricated of carbon steel since condensation was not expected since the flue gas was heated to a temperature sufficiently above saturation.

Particulate (HEPA) Filtration

The final stage of the CIF APCS consists of fiberglass HEPA filters that are equipped with "cleanable" metal pre-filters to reduce the loading on the HEPA filters. The CIF is equipped with three banks of filters of which two are required for operation and one is on standby. The design of the HEPA enclosures consists of a welded assembly of 316 stainless steel boxes, which is fully seal welded with 304 SS, except for gasketed inlet and outlet ports and filter access doors. The enclosure is insulated on the exterior and covered with a welded sheet metal skin, which provides some measure of secondary containment.

LESSONS LEARNED BASED ON PILOT-SCALE TESTING

The Savannah River Site (SRS) supported an extensive technical support program designed to obtain APCS performance data to support CIF start-up and operation. Key components of this technical support program included test runs at EPA's Incineration Research Facility and Energy, Environmental Research Corporation's Solid Waste Incineration Test Facility, and a 1/10 scale CIF offgas pilot plant at the SRS. The CIF technical support program has resolved several technical issues concerning facility design, operation, and process optimization and has provided information to ensure a successful trial burn. The issues and evaluations include salt carryover, metal volatilization, destruction removal efficiency, and vacuum control.

Salt Carryover

Previous incinerator operating experience on wet offgas systems with downstream HEPA filters indicated that HEPA life was significantly shortened due to excessive salt emissions generated during acid gas neutralization. Pilot-scale test studies were conducted to characterize salt generation in wet offgas systems and to evaluate the removal efficiency of upstream air pollution control equipment. It was believed that the salt would become air-born during the evaporative stage of the quench. However, the test results indicated that air-born salt resulted from scrubber carry-over and not the evaporative quench operation. HEPA filter life was not impacted when the salt concentration in the quench liquid was high as long as it was maintained at low concentrations in the scrubber.

Metal's Volatilization

Tests burns using surrogate CIF wastes spiked with hazardous metals and organics were conducted to measure heavy metals partitioning between kiln bottom ash, scrubber blowdown solution, and incinerator stack gas. The tests were designed to investigate the effect of several parameters on metal partitioning including kiln temperature, waste chloride concentration, waste form (i.e., solid or liquid), and salt concentration in the scrubbing liquid. Testing results indicated that mercury was the most volatile metal tested with none remaining in the kiln bottom ash. Lead, cadmium, thallium, and silver exhibited semi-volatile behavior partitioning between kiln ash, blowdown, and stack gas. Chromium, nickel, barium, antimony, and arsenic exhibited non-volatile behavior at incineration temperature with greater than 90 wt% remaining in the kiln bottom ash. Incineration temperature had a significant effect on volatile and semi-volatile metals partitioning and no effect on nonvolatile metals partitioning. As incineration temperature were increased, the fraction of volatile and semi-volatile metals leaving the kiln increased. Increasing waste chloride concentration resulted in a larger metal fraction of lead, cadmium, and mercury partitioning to the stack offgas. Metal contaminants in liquid feeds partitioned more readily to the blowdown and stack gas than those in solid feeds.

Destruction Removal Efficiency

Test burns processing liquid waste containing benzene and chlorobenzene as the principal organic hazardous constituents (POHCs) indicated that the destruction removal efficiency (DRE) was greater than 99.99998, independent of the waste type or incineration temperature. The liquid waste (95% benzene) was burned without detectable benzene levels in the incinerator offgas. The high chloride solid waste produced the largest concentrations and number of both VOCs and SVOCs. Detected VOCs included chloromethane, chloroform, carbon tetrachloride, benzene, toluene, and xylene. Detected SVOCs included benzyl alcohol and polyaromatic hydrocarbons (PAHs) such as naphthalene, fluorene, and pyrene.

Vacuum Control

A 1/10 scale CIF offgas system pilot plant was installed to demonstrate system operability and maintainability, evaluate and optimize equipment and instrument performance, and provide direct CIF start-up support. One of the most significant issues that was resolved by this test facility prior to start-up of the CIF was vacuum control. The CIF is equipped with a vacuum control damper between the quench and scrubber that maintains the specified kiln vacuum. Pilot-scale testing revealed that water droplet build-up above the vertical damper resulted in such a high pressure drop that system vacuum could not be maintained. The damper which was in a vertical convergent section of the offgas duct acted as a venturi resulting in increased air flows through the section which prevented sufficient drainage of scrubbing liquid. Mathematical modeling proved that if the droplets above (i.e., downstream) of the damper represented 20% of the void space, a pressure drop of 20 in. WC could result. Vacuum control was resolved in the CIF prior to start-up testing by replacing the damper and convergent duct with a nonconverging duct that doubled the damper ID. The larger damper minimized the air velocity and allowed adequate drainage of scrubbing liquid.

OPERATING EXPERIENCE DURING PRE-TRIAL BURN RUNS

The CIF has completed its start-up testing phase and is in the final process of obtaining its operational permit which includes successful completion of the Trial Burn. The pre-trial burn test runs have included processing of various hazardous wastes including those containing chlorides. After a year of pre-trial burn runs, several issues concerning the operation, materials of construction, and design of the facility have surfaced. The most significant technical issues were those associated with the high saturation temperature of the CIF. The high saturation temperature has been the root cause of system water accumulation, HEPA life, corrosion, and potential wicking. The summary includes how these issues were resolved to allow successful operation without lowering the saturation temperature which would result in significant facility costs.

Water Accumulation

Post-testing maintenance indicated that the CIF downstream offgas duct and HEPA housing contained large volumes of water, occasionally in excess of 200 gallons. Water accumulation was due to either droplet carryover or condensation or a combination of both. Excessive carryover could be the result of two factors: low mist eliminator removal efficiency or reheater inefficiency to vaporize the water droplets. Condensation could result from a slight drop in offgas temperature due to localized air inleakage or "deadlegs" where air becomes trapped and cooled. The offgas at a saturation temperature of 188 F contains 50 wt% water, therefore, allowing potentially significant quantities of water to condense.

CIF offgas testing using hot wire anemometers to measure both droplet size and loading revealed that offgas carryover was less than anticipated by design. In addition, the reheater was achieving temperatures 60 F above saturation (i.e., 40% relative humidity) which is sufficient to prevent condensation. Offgas modeling also indicated that residence time was sufficient to allow complete evaporation of any water droplets that entered the reheater. Investigation revealed that water accumulation was due to "localized" condensation via air cooling from four primary sources: 1) high air inleakage rates in the HEPA filter housing, 2) bringing cold HEPA filters on-line, 3) uninsulated offgas duct downstream of the reheater, and 4) allowing a HEPA filter housing to remain off-line during operation creating a "dead-leg" for trapped air to cool.

Corrosion

Corrosion of the Offgas Duct - Severe corrosion in the carbon steel ductwork was identified by physical inspections, even though ultrasonic testing did not reveal any appreciative wear of the duct based on nominal pipe thickness specifications. The corrosion resulted from exposure to the hot, wet environment aggravated by the presence of chlorides and sulfates.

The downstream offgas duct was exposed to significant quantities of water that were accumulating during isolation of a HEPA filter bank (2 out of 3 HEPA banks are required for operation). This "dead-leg" duct allowed vaporized water in the flue gas, which contained approximately 50 wt. % water at the high CIF saturation temperature, to condense. Therefore, the duct would be exposed at various times to high temperature salt water containing condensed acid gases at temperatures as high as 200°F (93°C). In addition, localized thin-film water condensation occurred along the uninsulated walls of the offgas duct downstream of the reheater.

Corrosion of the HEPA Filter Enclosure - HEPA filter enclosures were found to contain significant quantities of water. Even though the flue gas temperature was sufficiently above saturation, air in-leakage allowed localized cooling resulting in sometimes significant condensation.

Several tests and inspections revealed that numerous cracks occurred within the HEPA housing. Visual and dye penetrant examinations revealed that the nature of the cracks were both fine and large, some of which were branched and extensive. The locations of the cracks were in areas that had been immersed in the offgas condensate. Some of the cracking was attributed to chloride stress corrosion cracking. This would be expected with the wet chloride environment present in the HEPA housing, since cracking of austenitic stainless steel is well documented.

Corrosion of the Metal HEPA Pre-Filters - The integrity of the stainless steel metal pre-filters was maintained during non-hazardous testing. However, after the introduction of hazardous chlorinated wastes, the filters quickly degraded. The pre-filters were replaced with alloy C276. These filters are more expensive, but are anticipated to last more than double the life of the original metal filters.

HEPA Life

CIF HEPA life was not as long as projected (i.e., > 1 month) during the pre-trial burn test runs. In addition, "breakthrough" or tearing of the filter would actually occur at 3.0 in. w.c. rather than the expected 10.0 in. WC differential pressure. Conversations with the vendor indicated that the acrylic binder on the HEPA filter surface that provides strengthening and water proofing could be evaporating at the high operating temperature of 250 F. The primary reasons for the decreased HEPA life were 1) blinding by corrosion products and 2) inadequate quench cooling.

Corrosion Product Blinding - During testing, the HEPA filters were becoming pre-maturely plugged with iron oxide particles. Analysis of contaminants from plugged filters revealed the presence of significant quantities of iron oxide. The presence of iron oxide was the first indication of corrosion of the carbon steel duct since this element was not present in the waste feed or scrubbing water in the quantities that were detected in the filters. Air-borne iron oxide particulates reduce HEPA-life and increase the frequency of pre-filter cleaning/replacement.

Inadequate Quench Cooling - Higher salt carryover was occurring in the system due to inadequate cooling of the offgas in the quench. The offgas was not being completely cooled to the saturation temperature in the quench, and therefore, the offgas would continue cooling in the scrubber which resulted in evaporation of scrubber water, and hence, loss of removal efficiency. Pilot-scale testing had previously shown that the scrubber is the most important control unit in removing salt that becomes air-born during the evaporative phase of the quench.

High temperatures in the flue gas exiting the quench initiated inspection of the alloy C-276 spray nozzles responsible for atomizing the cooling liquid. The erosive nature of the ash particulates had eroded the spray nozzles impacting the atomization, and hence, had reduced the surface area for heat transfer to occur. Testing of various metal alloys is planned to identify the nozzle material and designs that are the most durable under the conditions.

Wicking

Several efforts are underway to quantify the phenomenon of wicking in the CIF HEPA filters. This particular analysis determines the offsite dose if wicking or if HEPA "breakthrough" occurs at the CIF. It is recognized that soluble contaminants may migrate through the HEPA filter if a transport medium such as water is available. An analysis was conducted that had shown that even if wicking occurs, the CIF radioisotope source terms are low enough to not exceed the CIF NESHAPS Permit Limit for offsite dose. Also, if HEPA breakthrough occurs, the CIF permit limit will not be exceeded if actual scrubber efficiencies are considered as opposed to the lower efficiencies assigned by the regulations.

SYSTEM MODIFICATIONS

The CIF technical issues that were identified as a result of pre-trial burn testing have been resolved. The CIF will continue to operate at a high saturation temperature, but the following modification have been implemented to minimize the impact of this operation. Post-modification testing has shown that the system changes have significantly reduced system water accumulation, corrosion, HEPA blinding, and wicking.

Several changes in design and operation were required to minimize corrosion and build-up of water. The HEPA filter stainless steel enclosure was replaced with alloy C-276 which is resistant to chloride attack, but is not entirely immune. The nature of the chloride problem is such, that once corrosion has been initiated in such a complex structure as the HEPA housings, it is difficult to eliminate the chlorides and the problem since the ions can be trapped within cracks and crevices. Therefore, operations were modified to avoid an accumulation of condense in the HEPA housing and the flue gas duct during standby HEPA filter operation. A continuous drain system for the was provided for all the housings and ducts so the build-up of liquids will not occur. Elimination of the standby filter operation will be considered to eliminate the "dead-leg" that facilitates condensation. Other changes that have reduced the corrosion potential include coating the carbon steel duct with a high temperature vinyl ester resin polymer liner and replacing the 304 SS metal pre-filters with C-276 pre-filters. Modifications that reduced wicking included incorporation of HEPA pre-heaters that raise the temperature of the HEPA filters with dry heat prior to operation with saturated offgas.

CONCLUSIONS

The results of CIF pre-trial burn testing indicate that much of the design is adequate to withstand the harsh environment generated during the processing of hazardous wastes. Equipment and process sections fabricated of polymer-coated metals, fiber-reinforced plastics, and metal super alloys withstood the conditions brought on by acid gases and high temperature brine. These process sections included the quench vessel, scrubber, cyclone, mist eliminator, and reheater vessel and coils. However, post modification testing indicated that the design could be improved to make the unit more efficient and maintenance-free without significant expense to increase its life. The CIF will continue to operate with a high saturation temperature, but will no longer live with the consequences (i.e., water accumulation, corrosion, short HEPA life) because of the modifications.