FINAL REPORT
LAB. JOB NO. LJ 10309-50/KA-035
CONTROLLED AIR INCINERATOR UPGRADE, TA-50

Presented to

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EXECUTIVE SUMMARY

In 1976, Los Alamos National Laboratory (LANL) constructed a controlled air incinerator (CAI) at TA-50 in Los Alamos, New Mexico. The CAI is designed to treat both transuranic wastes and mixed hazardous/radioactive wastes; therefore a RCRA permit is required for operation. As part of the permitting process, a trial burn was conducted in 1986 to determine 1) the CAI's destruction and removal efficiency for principal organic hazardous wastes and 2) the required RCRA operating conditions and limits for the CAI (1).

The results of the test burn showed the CAI to be in full compliance with the RCRA requirements and the CAI was brought from experimental mode to operational mode in anticipation of operating under the RCRA permit. Modifications, primarily related to the air pollution control system, were made to the CAI in order to bring it into full operational mode.

ICF Kaiser Engineers was contracted to provide an independent evaluation of the modified air pollution control system to determine

1) the effect of modifications on operational reliability of the air pollution control system,

2) the effect of modifications on hydrogen chloride and particulate matter removal efficiencies, and

3) the expected performance of the air pollution control system with regard to the RCRA permit limits.

ICF Kaiser Engineers has studied both the original and modified air pollution control systems and found the modified system to be much more operationally reliable, greatly improved in its ability to remove air pollutants, and easily capable of meeting the RCRA requirements, even under worst-case conditions.

1.0 Purpose of Study

The purpose of this study is to provide the Laboratory with an independent evaluation of the modifications made to the air pollution control system of the controlled air incinerator (CAI) operated by the Los Alamos National Laboratory (LANL).

Modifications were made to the quench tower, venturi scrubber, absorption column and high efficiency particulate air (HEPA) filter portions of the air pollution control system following a 1986 trial burn conducted with the CAI. These modifications were made to bring the CAI from experimental mode to operational mode.

This report summarizes the modifications made to the components listed above and provides an evaluation of the effect of these modifications on 1) the operational reliability of the system, 2) the expected performance of the system to remove hydrogen chloride and particulate matter, and 3) the enhanced ability of the modified system to comply with the parameter values proposed in the RCRA permit.

Detailed information concerning the design and operational parameters of the original CAI tested in the 1986 trial burn can be found in LANL reports (2,3).

2.0 Modified Air Pollution Control System

The design and operation of the CAI's air pollution control system were modified subsequent to the 1986 trial burn. These changes improved operational reliability and enhanced the removal efficiencies of the system. For reference, a process flow diagram of the original system is shown in Figure 1, while Figure 2 presents the modifications which were made to the system.

In both systems, hot gas would flow first through wet collection devices, then through dry collection devices before being released to the atmosphere. Primarily, modifications were made to individual units of the air pollution control system, with the overall flow process remaining unchanged. The four units which were modified are as follows: 1) the quench tower, 2) the venturi scrubber, 3) the absorption column, 4) the HEPA filter system.

The remainder of this section summarizes the modifications made to these units.

2.1 Quench Tower

Unit Description

The quench tower is the first component of the air pollution control system and is located directly downstream from the combustion chambers. The quench tower serves to pre-condition the hot exhaust gas prior to the gas entering the emission control devices.

Figure 1

PERFORMANCE-TESTED AIR POLLUTION CONTROL SYSTEM LAYOUT FOR THE CONTROLLED AIR INCINERATOR

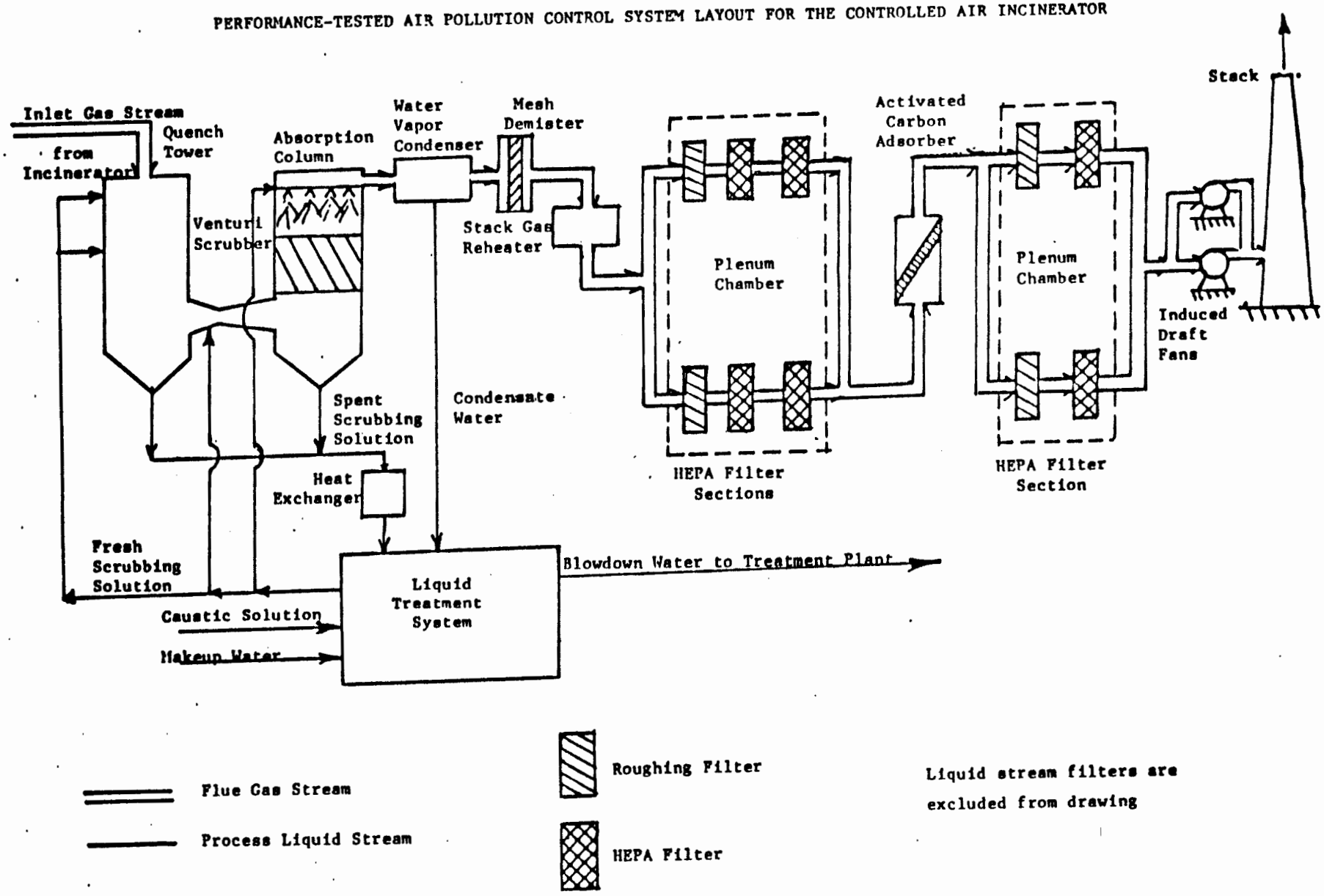
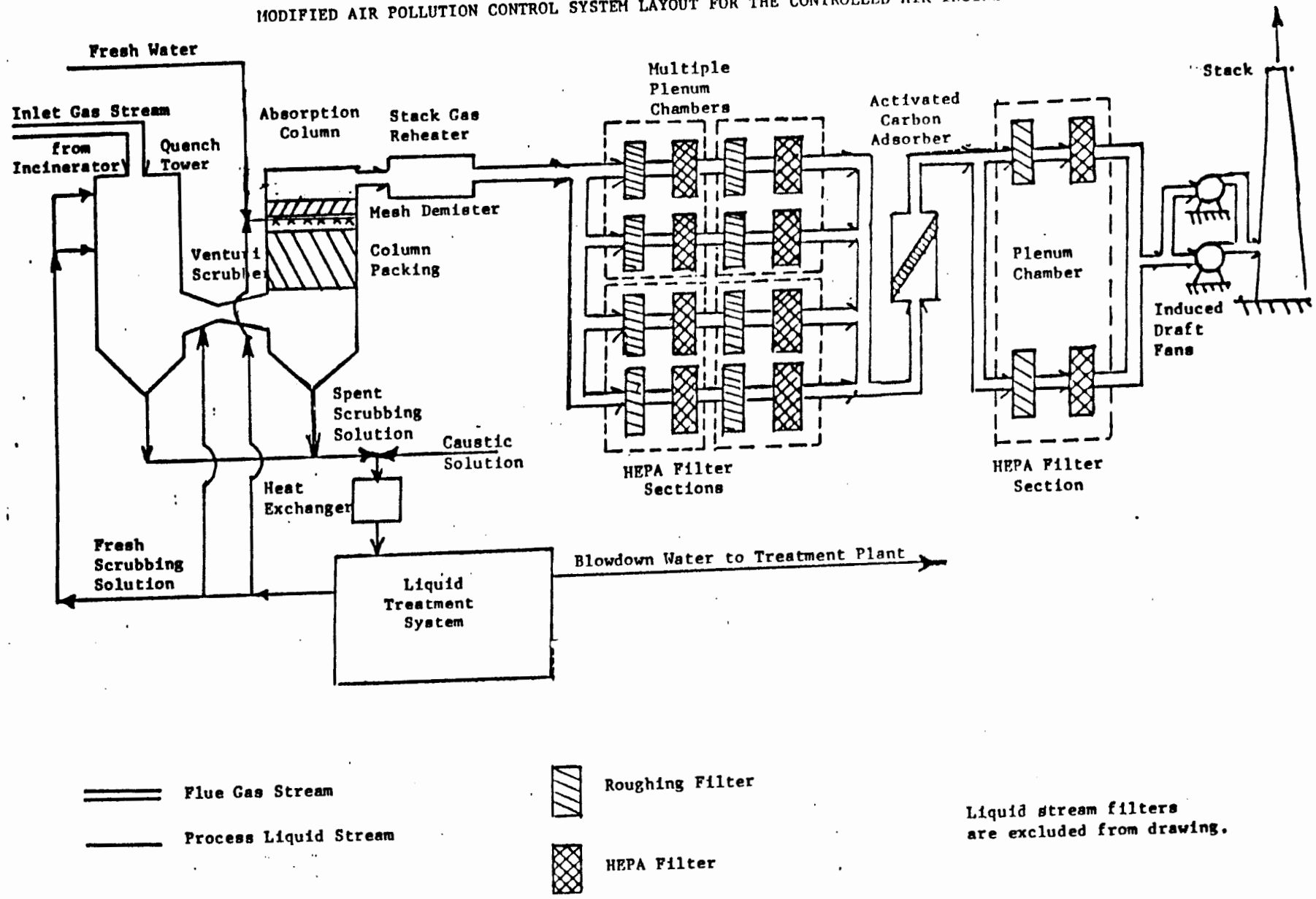


Figure 2

MODIFIED AIR POLLUTION CONTROL SYSTEM LAYOUT FOR THE CONTROLLED AIR INCINERATOR



Water evaporation within the quench tower cools the hot gas from 2,000° F to 180° F and raises the moisture content of the gas from approximately 6 percent to 18 percent (by volume). The cooled, neutralized scrub solution used in the quench tower is added by a combination of wetted wall and spray droplet mechanisms. Used scrub solution is drained from the bottom of the quench tower for subsequent neutralization, purification, and recycling.

Unit Modifications

Five modifications were made to the quench tower in order to improve its operational reliability, reduce maintenance requirements, and improve its ability to cool and humidify the gas stream. Four of these modifications dealt with physical changes to the unit, while the fifth was an operational change. These modifications are as follows:

1. Modification: Replacement of the original FRP fiberglass unit with a similar unit made of Hastelloy C-22 alloy.

   Purpose: Improve resistance to 1) corrosion caused by chloride ions under acidic conditions and 2) thermal stress damage caused by sudden increases in gas temperature during process upsets.

2. Modification: Replace the original liquid overflow weir assembly with a welded annular multiple-spray injection system constructed from Hastelloy C-22. The system consists of 12 upward-directed, curved-cylindrical nozzles, 30° on center, which injects the scrub solution against a splash plate.

Purpose: Provide a more uniform liquid distribution to the quench tower. The concentric barrier promotes gas separation and the formation of a wetted layer along the sides of the quench tower. The Hastelloy C-22 provides improved corrosion and thermal resistance.

3. Modification: The three concentric spray nozzles located in the lower portion of the quench tower and originally constructed with Hastelloy C-276, have been replaced with nozzles made of C-22 alloy. The new nozzles are now located 120° horizontally on center, pointed at 30° below the horizontal.

   Purpose: The Hastelloy C-22 provides greater thermal and heat resistance than the original material. The new alignment promotes effective cooling/humidification through increased gas-liquid contact.

4. Modification: All original gaskets have been replaced with Viton plastic gaskets. All plug valve linings in the new unit are constructed of teflon.

   Purpose: The new gaskets have improved sealing properties as well as improved thermal and corrosion resistance. The new plug valve linings have improved thermal and corrosion resistance.

5. Modification: A booster pump has been added to the scrub solution supply line. This pump increases the pressure at the three lower spray nozzles from 80 psi to 110 psi.

   Purpose: The increased pressure provides finer atomization of the scrub solution and more rapid cooling of the offgas.

6. Modification (operational): The liquid flow rate in the quench tower has been increased from 24 to 28 gallons per minute (gpm) by the addition of 4 gpm to the liquid flow rate in the upper part of the quench tower.

   Purpose: The increased flow rate increases the liquid shower rate, provides an additional 10° F cooling of the exit gas stream and increases the moisture content of the gas stream by 2 percent to 3 percent (by volume). These improvements in turn enhance the performance of the downstream venturi scrubber.

2.2 Venturi Scrubber

Unit Description

The venturi scrubber, located between the quench tower and the packed absorption column, is the CAI's primary device for particulate removal. The venturi scrubber's purpose is to sufficiently reduce the particulate loading of the gas stream in order to increase HEPA filter life by preventing blinding and plugging of the filters. The venturi scrubber also acts to remove a portion of the soluble gaseous constituents.

Unit Modifications

Several modifications have been made to the venturi scrubber to improve its operational reliability and removal efficiency. These modifications consist of three physical and two operational changes to the unit. These changes are as follows:

1. Modification: Replace original diffuser sections made of FRP fiberglass with identical sections constructed from Hastelloy C-22.

   Purpose: Improved thermal and corrosion resistance.

2. Modification: Alignment of the venturi diffuser duct relative to the packed absorption column has been changed. Originally, the duct aligned axially with the center of the cylindrical, separation unit of the packed absorption column. The modified exhaust duct is aligned tangentially, forcing the gas stream to enter the cylindrical separation unit at its outer periphery.

   Purpose: The modified system causes a cyclonic flow pattern to be established which improves removal of entrained droplets and prevents them from becoming re-entrained.

3. Modification: Modifications were made to the nozzle restriction section of the venturi scrubber. The original flow restriction orifice, which was lined with Hypalon plastic, has been replaced by a new control pinch valve lined with Viton plastic; and the inlet liquid spray elbow nozzle - originally a 1/4 inch orifice diameter - has been replaced with a 3/8 inch orifice diameter nozzle.

   Purpose: The new materials utilized are more durable and corrosion/erosion resistant then the original materials. The new elbow nozzle is 1) less subject to plugging and abrasion and 2) allows a higher liquid flow rate with no net increase in liquid-phase pressure drop.

4. Modification (operational): The liquid flow rate to the venturi scrubber has been increased from 5 to 10 gpm.

   Purpose: Improve particulate removal efficiency of the system. Increasing the liquid flow raises the liquid to gas ratio, which raises the number of liquid droplets in the gas stream. This in turn increases the potential for liquid droplets to collide with particulate matter and thereby remove the particulates from the gas stream.

5. Modification (operational): The variable area orifice opening of the venturi scrubber is restricted to a greater extent in order to increase the gas phase pressure drop across the unit from 40 inches of water to 60 inches of water.

   Purpose: Improve particulate removal efficiency of the system. The additional energy provided by increasing the gas phase pressure drop and velocity breaks the liquid stream into a greater number of small size droplets, thereby improving the mixing of the gas stream with the liquid droplets. This in turn increases the potential for liquid droplets to collide with particulate matter and remove them from the gas stream.

2.3 Absorption Column

Unit Description

The packed absorption column was installed for the primary purpose of removing hydrogen chloride and other soluble gases from the exhaust gas stream. The absorption column is designed to remove hydrogen chloride from the gas phase into the liquid phase by countercurrent contact with a sodium hydroxide solution in a packed column.

Unit Modifications

Several modifications have been made to the packed absorption column since the RCRA trial burn to improve its performance and reliability. These modifications include three physical changes, one operational change, and three process design changes.

The physical changes are as follows:

1. Modification: Replace FRP fiberglass as the material of construction with Hastelloy C-22 alloy.

   Purpose: Increased durability and corrosion resistance.

2. Modification: Increase the column diameter from 24 inches to 30 inches.

   Purpose: Improve removal efficiency by reducing the gas velocity and increasing gas phase retention time.

3. Modification: Replacement of the structured polypropylene packing with a structured-type Hastelloy C-276 packing.

   Purpose: Increase surface contact area, increase thermal resistance, and lower the unit linear pressure drop from over 3.0 inches of water to under 1.0 inch of water.

The operational change is as follows:

4. Modification: Increase the liquid shower rate from 7 gpm to 20-25 gpm.

   Purpose: Increase removal efficiency of the absorption column by increasing the liquid capacity.

The three design process changes are as follows:

5. Modification: Replace the indirect contact gas phase condenser with a liquid phase heat exchanger.

   Purpose: Improve moisture removal in the absorption unit by providing additional cooling of the water entering the absorption unit and allowing the unit to act as a direct contact condenser.

6. Modification: Replace the external polypropylene demister with an internally located, intermittently showered Hastelloy C-22 demister; located immediately below the packing in the absorption unit.

   Purpose: Reduce corrosion, thermal stress and filter blinding by reducing salt mist carryover into the HEPA filter system.

7. Modification: Relocate the stack gas super heater from immediately upstream of the HEPA filters to immediately downstream of the absorption column.

   Purpose: Reduce potential for blinding of the HEPA filters due to water droplet carryover. The new location provides for a longer hot gas retention time which in turn allows for increased water evaporation.

2.4 HEPA Filtration

Unit Description

The HEPA filter system is utilized to provide a very high degree of particulate removal from the exhaust gas stream and provide protection against the release of radionuclides. The HEPA filtration system is a second stage treatment and acts as a final polishing of the gas stream by removing the very fine particles which remain following cleaning by the quench tower, venturi scrubber and absorption column.

The HEPA filter system consists of two sections which are separated by an activated carbon adsorber.

Unit Modifications

The section of HEPA filters upstream of the activated carbon adsorber has been duplicated. The duplicate bank of filters provides for continued operation during filter replacement. Because only one bank is on-line at a time, the removal efficiencies of the system are not affected by this modification.

3.0 RCRA Requirements

The RCRA trial burn (1) of the CAI was conducted in September of 1986. Permit conditions for operation of the CAI are based on the experimental operational conditions utilized during the successful trial burn. These draft permit conditions are listed in Table 1 for both solid fuels and liquid fuels (4).

3.1 Trial Burn Performance Data

A RCRA trial burn was conducted on September 4-7, 1986 on the controlled air incinerator (CAI). The purpose of this trial burn was to determine incinerator performance and the destruction and removal efficiencies (DRE) for the principal organic hazardous contaminants (POHCs) to be processed in the CAI. The trial burn was conducted by burning a mixture of 30-40 percent by weight carbon tetrachloride and 15-20 percent by weight trichloroethylene to simulate a high chlorine content waste feed.

The feed material was burned at a rate of 166-203 pounds per hour (solid feed) and 147-173 pounds per hour (liquid feed). The liquid fuel test runs were made with feed material containing varying amounts of aluminum stearate, which was added to simulate ash and particulate producing feed.

A summary of the results of the RCRA trial burn is presented in Table 2. The parameters investigated during the trial burn were 1) oxygen and carbon monoxide content of the off gas, 2) DREs for carbon tetrachloride and trichloroethylene, 3) hydrogen chloride

Table 1

RCRA OPERATING REQUIREMENTS FOR THE CONTROLLED AIR INCINERATOR

Operating Parameter	Units Employed	Solid Feed	Liquid Feed	Specific Comments
Emission Standards				
POHC DRE[1]	%	99.99	99.99	Most compounds
HCl Emissions or Removal Efficiency	lb/hour	4.0	4.0	Less restrictive shall apply
	%	99.0	99.0	
Particulate Concentration	gr/dscf	0.08	0.08	60°F, 14.7 psia 7.0% O_2, dry
Combustion Imputs				
Max. Heat Rate	MM Btu/hr	1.5	1.5	
Max. Waste Feed	lb/hour	125.0	Not a permit condition	
Max. Organic Chlorine	lb/hour	99.4	99.4	Total
Operating Temp.				
Primary Chamber	°F	>1,400	>1,400	Feed cutoff
Secondary Chamber	°F	>2,000	>2,000	Feed cutoff
Exhaust Gas				
Max. Flow Rate	lb/hour	3,654	3,933	Feed cutoff
CO Concentration	ppm (vol)	100/500	100/500	Timed immediate feed cutoff
Minimum O_2, wet Sec. Comb. Chamber	% (vol)	7.5	6.0	Feed cutoff
Scrubbing Water				
Minimum Flow Rate	gal/min	10.0	10.0	
Minimum Exit pH	-	1.0	1.0	Feed cutoff
Pressure Drop				
Venturi Scrubber	inch H_2O	40.0	40.0	
HEPA Filter	inch H_2O	0.1	0.1	

Note: 1. Destruction and removal efficiency of the primary organic hazardous constituents.

Table 2

SUMMARY OF THE RCRA TRIAL BURN EMISSION LEVELS

Parameter Measured	Units Employed	Average Value	Observed Range
Carbon Tetra-chloride Destruction	% of input	99.99924	99.99898 - 99.99999
Trichloroethylene Destruction	% of input	99.99987	99.99933 - 99.99999
Liquid Feed Rate	lb/hour	169.2	147 - 173
Solid Feed Rate	lb/hour	186.2	166 - 203
Oxygen Content(wet)	% by vol	-	6.0 - 11.0
Carbon Monoxide	ppm by vol	5.5	3.0 - 14.0
Particle Exit Concentration[1]	gr/sdcf	0.0135	0.0001-0.0244
Particle Emission Rate	lb/hour	0.0550	0.0010-0.1132
Chlorine Feed Rate[2]	lb/hour	87.25	67.01-102.14
Chlorine Emission Rate[2]	lb/hour	0.1425	0.0015-.4220
Chlorine Exit Concentration[2]	ppm by vol	40.287	0.447-82.000
Chlorine Removal Efficiency	% of input	99.825	99.585-99.998
Exit Liquid pH	-	-	1.0 - 10.3

Notes: 1. Corrected to 7.0 percent oxygen by volume.

2. Reported as hydrogen chloride vapor.

emission rates, 4) the pH of the exit liquid, 5) the particulate matter concentrations in the off gas, and 6) the incinerator temperature (2,000°-2200°F).

The oxygen content of the gas stream was continually above 6.0 percent by volume (wet) during the trial burn. The average carbon monoxide concentration was always below 14 parts per million (ppm) by volume in the incinerator exhaust gas.

Stack tests were made to determine the level of carbon tetrachloride and trichloroethylene in the exhaust gas. These exit concentrations were compared to inlet feed rates to the incinerator to determine the DRE's for these two constituents. Test results showed that the DRE for carbon tetrachloride, in all cases, exceeded the minimum requirement of 99.99 percent of the input. Under the successful, Day 4 operating conditions, the DRE for trichloroethylene was greater than the minimum allowable DRE of 99.9999 percent. These operating conditions are the basis for the CAI's RCRA permit.

The hydrogen chloride emission rates were all well within regulatory requirements. The maximum hydrogen chloride emission noted during the test burn was 0.422 lbs/hr which is one-tenth of the allowable RCRA limit. The hydrogen chloride removal efficiency ranged from 99.585 percent to 99.998 percent and was at all times greater than the minimum allowable removal efficiency of 99.0 percent.

The pH of the exit liquid ranged from 1.0 to 10.3 during the trial burns. All pH values reported were at or above 1.0, which is the suggested minimum value for the permit limitation.

The particulate matter concentrations during the trial burn ranged from a minimum of 0.0001 gr/dscf to a maximum of 0.0244 gr/dscf. The average particulate concentration in the exhaust gas was 0.0135 gr/dscf, which was well below the maximum allowable level of 0.08 gr/dscf.

It should be noted that these low particulate emissions were achieved despite the fact that when these tests were made, a corroded mild carbon steel, induced draft fan was contributing rust particles to the particulate load. This fan had been severely corroded during years of previous service, and its use during the trial burn resulted in the abrasion of iron oxide and iron chloride particles, thus adding to the particulate matter collected during sampling. Particulate matter concentrations measured during the trial burn would have been measurably lower if the fan were in proper condition.

3.2 RCRA Draft Permit Limitations

The September 1986 trial burn of the CAI provided the data for establishing the specific permit conditions that, in addition to standard RCRA requirements, will apply to the modified incinerator. The list of draft permit conditions is given in Table 1 and apply to the incineration of solid and liquid wastes.

4.0 System Performance Assessment

An evaluation of the performance capabilities of the CAI air pollution control system was made to determine the effects of modifications made since the RCRA trial burn. Three performance measures were considered in making this evaluation as follows:

1) estimation of the potential effects of the modifications on operational reliability of the air pollution control system,

2) estimation of the potential effects on the removal efficiencies for hydrogen chloride and particulate matter, and

3) an analysis of the expected compliance of the modified system with the proposed RCRA permit limits for hydrogen chloride and particulate matter.

The calculation of removal efficiencies is discussed in subsection 4.1. The remainder of section 4.0 presents the findings of the system performance assessment.

4.1 Calculation of Removal Efficiencies

The system performance assessment was based on worst case conditions in terms of chlorine and particulate matter concentrations in solid and liquid feed. To assess the hydrogen chloride and particulate matter removal characteristics of the CAI, a total feed rate of 175 lbs/hr was used to represent an intermediate condition which simulates both solid and liquid feed. The chlorine content of the fuel was assumed to be 57 percent by weight which is equivalent to burning the maximum allowable chlorine-containing mixture of carbon tetrachloride and trichlorethylene (4). The fuel fly ash content used for the

particulate matter performance assessment was 5 percent by weight, with 6 percent of this ash content assumed to be retained in the combustion chambers. This fly ash content is equivalent to burning the worst case Navy flare materials (5).

The individual removal efficiencies for hydrogen chloride and particulate matter have been estimated for each component of the air pollution control system.

The determination of the collection efficiency factor of each emission control device for removal of each air pollutant allows an overall removal efficiency factor to be calculated as demonstrated in the literature (6,7,8,9,10,11,12).

The calculation of air pollutant removal efficiencies was based on the fuel mixture characteristics discussed above, and the contact times/mass transfer characteristics of the respective gas-liquid contact devices.

4.2 Operational Reliability

The purpose of the modifications made to the air pollution control system was to improve operational reliability of the CAI in converting it from the research and development mode to the operational mode. These modifications have been described in Section 2.0. The remainder of this section evaluates the effects of modification on the operational reliability of the quench tower, the venturi scrubber, the absorption column and the HEPA filters.

4.2.1 Quench Tower

Modifications to the quench tower should either increase operational reliability by reducing maintenance needs, or improve the efficiency of the unit.

Utilizing Hastelloy C-22 material to construct the quench unit itself, the spray nozzles, gaskets and seals, greatly reduces the maintenance needs by increasing corrosion resistance and cooling efficiency of the system. The quench tower is subject to both high temperatures and corrosive conditions. The parts constructed with the new material will prove much more operationally reliable.

Replacing the weir in the upper part of the quench system with a spray system ensures a more uniform water flow distribution to the quench tower.

Achieving additional cooling and humidification of the gas stream through increased liquid flow rate serves to enhance the operation of the venturi scrubber. Venturi spray droplets which previously were expended in cooling the offgas are made available for particulate capture.

4.2.2 Venturi Scrubber

The design and operational changes to the venturi scrubber should improve operational reliability, and lower maintenance requirements.

The most important changes for improving operational reliability are changing the materials of construction from fiberglass to Hastelloy C-22, modifying the wet surfaces of the

control pinch valve to Viton rather than Hypalon, and changing the sizing of the gas-liquid contact system components. These modifications 1) improve resistance to thermal and corrosion degradation and 2) improve the particulate removal efficiency of the venturi scrubber, thus reducing the chance of blinding HEPA filters located downstream from the venturi scrubber. Blinding of filters reduces filter life, causing increased maintenance and operational costs.

4.2.3 Absorption Column

The design and operating modifications to the absorption column and demister have several beneficial effects. The replacement of the old fiberglass absorption unit with a new Hastelloy C-22 unit, and the old polypropylene packing with Hastelloy C-276 packing, will make the system less subject to damage from sudden temperature increases.

The potential for filter blinding of the downstream HEPA filters due to water droplet/salt mist carryover has been greatly reduced by 1) the relocation of the demister, 2) use of fresh water intermittently in the demister shower and 3) the relocation of the stack gas super heater.

4.2.4 HEPA Filter System

Operational reliability of the HEPA filtration has been greatly increased by the addition of the parallel bank of filter units within the upstream section of HEPA filters. Continued

operation of the filter system during filter replacement is now possible with this modified configuration.

4.3 Hydrogen Chloride/Particulate Matter Removal

Various modifications were made to the original air pollution control system for the purpose of enhancing the removal of either hydrogen chloride or particulate matter from the gas stream. These modifications have been described in Section 2.0. The remainder of this section evaluates the effects of modification on the removal efficiencies of the quench tower, the venturi scrubber, the absorption column and the HEPA filters.

4.3.1 Quench Tower

The quench tower should achieve a limited amount of removal of hydrogen chloride and other soluble gases and/or particulate matter. It can act as a wetted-wall, concurrent-flow absorption column in the upper portion and as a crossflow spray chamber in the lower part of the column. Considering solubility, liquid flow and gas retention time, the quench tower could achieve 28 percent hydrogen chloride removal before system modification, and an estimated 36 percent removal after system modification.

The expected degree of particulate matter removal in the quench tower is also enhanced, but to a lesser degree, as the quench tower primarily affects only the larger particles present in the gas stream. Removal of particulate matter is estimated to

improve from 15.5 percent prior to modification to 20.5 percent after modification.

4.3.2 Venturi Scrubber

Hydrogen Chloride Removal

The venturi scrubber has only a limited gas phase retention time so there can be only a modest increase in the hydrogen chloride removal efficiency, due primarily to the increase in liquid flow rate. The hydrogen chloride removal efficiency across the venturi scrubber would be expected to increase from 15 percent to 33 percent due to the changes made.

Particulate Matter Removal

The major portion of particulate matter present in the gas stream is removed in this unit of the air pollution control system due to the high energy input to the venturi scrubber. The estimated particulate matter removal efficiency is 96.8 percent with 40 inches of water pressure drop for the performance-tested system as compared to 97.5 percent removal efficiency with 60 inches of water pressure drop, after making modification. These estimates of removal efficiency are based on theoretical calculations and not on actual material balances or measurements.

The most important changes for improving particulate matter removal efficiency are as follows:

1) altering the venturi diffuser duct alignment from axial to tangential to improve liquid droplet separation;

2) increasing the gas phase pressure drop across the system to increase collection efficiency, and

3) increasing the liquid flow rate to the venturi scrubber to augment the liquid-to-gas flow ratio.

4.3.3 Absorption Column

Hydrogen Chloride Removal

The design and operating modifications to the absorption column and demister have several beneficial effects relating to the removal of hydrogen chloride from the gas stream.

The increase in the column diameter acts to reduce the superficial gas velocity in the column. The decrease in gas velocity in turn promotes a longer contact time with the liquid and provides greater potential for absorption of hydrogen chloride and other soluble gases.

The replacement of the polypropylene packing with Hastelloy C-276 packing allows for a greater interfacial contact area with an increased potential for removal of the acidic gases into the alkaline aqueous phase.

The increase in the liquid flow rate with no corresponding increase in the gas flow rate results in an increase in the liquid-to-gas flow ratio with a reduction in acid gas concentration in the absorption column effluent liquid stream, and a lowered pressure drop across the absorption column. Thus, a higher gas-to-liquid phase concentration driving force is maintained, with a resultant increase in gas phase removal efficiency of hydrogen chloride.

For the absorption tower alone, the increased gas phase retention time, increased liquid flow rate, and reduced gas stream velocity is expected to increase the removal efficiency for hydrogen chloride and other soluble gases. The average hydrogen chloride removal efficiency is expected to increase from 99.5 percent before modification to 99.95 percent after modification. This increase in removal efficiency will result in a substantial reduction in hydrogen chloride emission levels for the modified CAI.

Particulate Matter Removal

The effect of the modifications to the absorption column on particulate matter removal efficiency is considerably less than for hydrogen chloride removal efficiency because particulate matter removal is more dependent on energy input than retention time. However, the particulate removal efficiency would be expected to increase from 25.3 percent prior to modification to 28.8 percent after modification.

4.3.4 HEPA Filter System

The HEPA filtration system does not significantly contribute to the removal of hydrogen chloride from the gas stream.

The modifications to the HEPA filtration system do not increase the particulate removal efficiency. The duplicate bank of filters is utilized only as an alternate to the original bank of filters.

4.4 Comparison to RCRA Requirements

There are a number of RCRA permit requirements which must be fulfilled by the air pollution control system. All of these requirements relate either to hydrogen chloride control or particulate matter control. The modified air pollution control system has been analyzed to determine the expected compliance of the system with the applicable RCRA requirements. The findings of this analysis are given in the remainder of Section 4.

4.4.1 Hydrogen Chloride Control

Information reported by Bonner (8) indicates that hydrogen chloride removal is particularly dependent on gas-liquid contact time. The absorption of hydrogen chloride is primarily dependent on the contact time, provided that there is sufficient contact area available and sufficient neutralization capacity in the liquid phase, such as provided by addition of sodium hydroxide to the scrub solution. The required contact time to achieve 99.0 percent hydrogen chloride removal from the gas phase into the liquid phase is reported to be approximately 0.50 seconds. The estimated hydrogen chloride removal efficiencies of the air pollution system before and after modification are presented in Table 3.

For the performance-tested system, a gas phase retention time of 0.95 seconds was calculated for the wet contact devices,

Table 3

HYDROGEN CHLORIDE REMOVAL EFFICIENCIES (ESTIMATED)

System Component	Removal Efficiency (%) Original System	Modified System
Incineration System	0.0	0.0
Quench Tower	28.0	36.0
Venturi Scrubber	15.0	33.0
Absorption Column	99.50	99.95
Condenser	3.0	-
Mesh demister	-	12.0
First HEPA Filter	0.0	0.0
Second HEPA Filter	0.0	0.0
Activated Carbon Adsorber	0.0	0.0
Third HEPA Filter	0.0	0.0
Total System	99.70	99.980

based on equipment sizes and gas flow rates. The estimated operating conditions for the gaseous emission controls before system modification were 1) an overall liquid to gas flow ratio of 23.3 gal/1000 cf, and 2) an overall gas phase pressure drop of 45 inches of water across all of the contact units.

RCRA Requirement, Hydrogen Chloride Removal Efficiency

The estimated hydrogen chloride removal efficiency of the air pollution control system before modifications were made was 99.70 percent. In comparison, the actual average hydrogen chloride removal efficiency measured during the RCRA trial burn was 99.825 percent, with measured values ranging from 99.585 to 99.998 percent. These removal efficiencies were in compliance with the RCRA requirement of 99.0 percent minimum removal efficiency.

The modifications to the air pollution control system increase the design hydrogen chloride removal efficiency. This increase is primarily due to two modifications. First, the overall gas phase retention time is increased from 0.95 to 1.38 seconds, primarily through an increase in the absorption column contact time from 0.69 seconds to 1.10 seconds. Second, for the air pollution control system as a whole, the liquid-to-gas flow ratio is increased from 23.3 to 39.8 gal/1,000 cf as the liquid addition rate is increased from 36 to 60 gal/min.

The modified system design hydrogen chloride removal efficiency is consequently increased from 99.70 percent to 99.98 percent. This increase in removal efficiency increases the margin

by which the CAI meets its RCRA requirement for minimum allowable hydrogen chloride removal.

A summary of the performance characteristics of the performance-tested and modified air pollution control systems for hydrogen chloride removal is presented in Table 4.

RCRA Requirement, Hydrogen Chloride Emissions

The effects of system modification were evaluated with respect to the estimated hydrogen chloride emission rates. A worst case condition was assumed based on a hydrogen chloride emission rate of 102.15 lbs/hour from the incinerator, with a secondary chamber exhaust hydrogen chloride gas concentration, before pollution control, of 22,500 ppm by volume, and no net retention in the combustion chambers. This hydrogen chloride emission rate is also the inlet loading used to evaluate the performance-tested pollution control system, in order that the emission rates and emission concentrations for the two systems could be compared on a uniform basis.

For the original system, the expected hydrogen chloride emission rate corresponding to the maximum chloride feed rate is 0.303 lbs/hour and the expected exit gas concentration is 66.74 ppm by volume.

The modifications to the air pollution control system provide for an overall removal efficiency of 99.98 percent of the hydrogen chloride equivalent present in waste feed. The hydrogen chloride emission rate from the incinerator exhaust stack following the

Table 4

PERFORMANCE CHARACTERISTICS RELATED TO HYDROGEN CHLORIDE REMOVAL (ESTIMATED)

Performance Factor	Units Employed	Original System	Modified System	RCRA Limit
Input Feed Rate	lbs/hour	102.15	102.15	NA
Outlet Concentration	ppm by vol	66.74	4.56	880[1]
Outlet Emission Rate	lbs/hour	0.303	0.021	4.00
Removal Efficiency	% of input	99.70	99.980	99.0
Penetration Level[2]	-	3.0×10^{-3}	2.05×10^{-4}	NA
Decontamination[3] Factor	-	337	4880	NA

Notes:
1. Calculated value based on flow conditions at a 99.0 percent removal efficiency.
2. Ratio of the outlet concentration to the inlet concentration.
3. Inverse of the penetration level.

system modifications thus would be reduced to 0.021 lbs/hour with an exit gas concentration of 4.56 ppm by volume.

Both the original and modified systems are well under the maximum allowable levels for outlet emission rates and outlet concentrations. Again, the modifications to the air pollution control system provide an additional margin of safety in meeting the RCRA requirements.

Hydrogen Chloride Decontamination Factors

The additional hydrogen chloride removal achieved by system modifications represents a net reduction of 93.1 percent as compared to the performance-tested system. The calculated decontamination factor for hydrogen chloride removal prior to making the system modifications was 337 as compared to a decontamination factory of 4,880 after system modifications, a factor of nearly 15. The decontamination factor is not controlled by a RCRA permit limit.

RCRA Requirement, Exit Stream pH

The RCRA permit requires the exit stream pH be no lower than 1.0. This condition was met during the trial burn as the final pH of the exit liquid stream from the wet contact air pollution control system ranged from 1.0 to 10.3 even in the most extreme cases. Therefore, operating conditions were primarily acidic but were never so acidic as to inhibit hydrogen chloride mass transfer into the aqueous phase to any appreciable extent.

The modifications made to the air pollution control system are not anticipated to affect the pH of the exit stream. An analysis of the proposed liquid pH permit condition indicates that a minimum scrub solution pH of 1.0 is reasonable in order to provide a margin of safety against increased emissions during periods of process upset.

Hydrogen chloride vapor pressure data indicates that a liquid pH below 0.5 in combination with hydrogen chloride concentrations above 1.0-2.0 percent by weight is necessary to inhibit mass transfer into the liquid phase sufficiently to lower removal efficiencies below the required 99 percent (13). These findings are in agreement with a recent laboratory study by the U.S. Environmental Protection Agency which shows that hydrogen chloride removal efficiencies can generally be maintained even under conditions of low absorbing liquid pH (14).

4.4.2 Particulate Matter Control

An analysis was made of the effects of system modifications on particulate matter removal efficiency. This analysis indicates that important factors affecting particulate matter removal include 1) the type and sequence of the emission control devices employed, 2) the liquid-to-gas contact ratio for the wet collection devices, and 3) the gas phase pressure drop across the individual collection devices, both wet and dry.

A summary of the estimated particulate matter removal efficiencies for the components of the air pollution control system is presented in Table 5.

The overall performance characteristics of the particulate air pollution control system compared to the RCRA requirements are presented in Table 6.

Particulate Matter Removal Efficiency

The RCRA permit does not specifically state a minimum particulate removal efficiency to be met by the CAI, rather a maximum emission limit of 0.08 gr/dscf is cited.

The particulate matter emission control system for the CAI can be divided into a wet collection section and a dry collection section.

The major wet particulate emission control device upstream of the HEPA filters is the venturi scrubber. The estimated particulate removal efficiency of the venturi scrubber before making system modifications was 96.8 percent, based on a gas phase pressure drop of 40.0 inches of water with a gas-liquid contact ratio of 3.1 gal/1,000 cf. The calculated particulate removal efficiency of the venturi scrubber after system modification is 97.5 percent, based on a gas phase pressure drop of 60.0 inches of water with a gas-liquid contact ratio of 6.2 gal/1,000 cf.

Table 5

PARTICULATE MATTER REMOVAL EFFICIENCIES (ESTIMATED)

System Component	Removal Efficiency (%) Original System	Removal Efficiency (%) Modified System
Incineration System	3.0	3.0
Quench Tower	15.5	20.5
Venturi Scrubber	96.8	97.5
Absorption Column	25.3	28.8
Mesh Demister plus condenser	6.2	9.5
First HEPA Filter	99.99[1]	99.99[1]
Second HEPA Filter	99.99[1]	99.99[1]
Activated Carbon Adsorber	0.00	0.00
Third HEPA Filter	99.97[2]	99.97[2]
Total System	99.99999999999[3]	99.999999999993[3]

Notes: 1. HEPA filter removal efficiency for a particle size distribution including particles greater than 0.3 microns.

2. HEPA filter removal efficiency for a particle size distribution 0.3 microns and under.

3. The total removal efficiencies are theoretical numbers and do not represent significant figures.

Table 6

PERFORMANCE CHARACTERISTICS RELATED TO PARTICULATE MATTER REMOVAL (ESTIMATED) (BASIS)

Performance Factor	Units Employed	Original System	Modified System	RCRA Allowable Level
Inlet Feed Rate[1]	lbs/hour	8.282	8.282	NA
Outlet Concentration	gr/dscf[2]	1.32×10^{-13}	8.80×10^{-14}	0.080
Outlet Emission Rate	lbs/hour	9.30×10^{-13}	6.18×10^{-13}	0.552[3]
Removal Efficiency	% of input	99.99999999999	99.999999999993	NA
Penetration Level[4]	-	1.1×10^{-13}	7.5×10^{-14}	NA
Decontamination Factor[5]	-	8.9×10^{12}	13.4×10^{12}	NA

Notes:

1. Particulate feed to the quench tower.
2. Based on standard conditions of 60.0°F, 14.7 psia and 7.0 percent oxygen by volume (dry).
3. Calculated value based on flow conditions at 99.0 percent removal efficiency.
4. Ratio of the outlet concentration to the inlet concentration.
5. Inverse of the penetration level.

The overall estimated particulate matter collection efficiency of the wet collection system is 98.11 before making modifications compared to 99.8 percent after modifications.

The particulate matter removal efficiency for the dry collection system (HEPA filters) is much higher than for the wet collection system. The estimated particulate matter removal efficiency before and after modification is 99.9999999994 percent, which is equivalent to a decontamination factor of 167 billion.

The overall particulate matter removal efficiency for the complete air pollution control system is so extremely high that the concept is meaningless. Prior to system modification, the overall particulate removal efficiency of the air pollution control system was 99.99999999999 percent, equivalent to a decontamination factory of 8.9 trillion. The calculated overall particulate matter removal efficiency after system modification has increased to 99.999999999993 percent, which is equivalent to a decontamination factor of 13.4 trillion. The improvement in system performance resulting from modification is demonstrated by an increase of 50 percent in the decontamination factor of the overall air pollution control system.

RCRA Requirement, Particulate Matter Emission Rate

The estimated particulate matter emission loading from the combustion chambers to the air pollution control system is 8.28 lbs/hour. This emission rate is the same before and after system modification.

The estimated particulate emission rate following the wet collection system is 0.155 lbs/hour before system modification. This emission rate is equivalent to an emission concentration of 0.022 gr/dscf and is based on a stack flow rate of approximately 700 dscf/min. The calculated particulate emission rate following the wet collection system after making modifications is 0.103 lbs/hour, which is equivalent to an exit particulate concentration of 0.014 gr/dscf. Both of these particulate matter concentrations are sufficiently low to meet the RCRA emission standard of 0.080 gr/dscf, even without the additional particulate removal provided by HEPA filtration.

HEPA filtration reduces the estimated particulate matter emission rate from the stack to 9.30×10^{-13} lbs/hour or 1.32×10^{-13} gr/dscf, for the unmodified system. The calculated particulate matter emission rate from the stack after system modification is 6.18×10^{-13} lbs/hour, or 8.80×10^{-14} gr/dscf. Comparison to the allowable 0.08 gr/dscf shows that both the performance-tested system and the modified system are well within the RCRA requirements.

5.0 Conclusions

The evaluation of the effects of modifications to the air pollution control system of the controlled air incinerator at TA-50 results in the following conclusions.

5.1 Hydrogen Chloride Removal

The original, performance-tested system was able to obtain a hydrogen chloride removal efficiency of 99.7 percent, which is well above the minimum standard of 99.0 percent. The off-gas treatment control system was able to reduce the hydrogen chloride emissions under the worst case chlorine inlet load to 0.303 lbs per hour, compared to an allowable maximum of 4.0 lbs/hour. The decontamination factor for the system was 337.

The modified air pollution control system is able to achieve significant reduction in hydrogen chloride emissions as compared to the performance-tested system. The removal efficiency is increased to 99.98 percent and the emission rate is reduced to 0.021 lbs/hour, at the worst case chlorine inlet loading. The decontamination factor is increased to 4,880 and the margin of safety is increased to 193.2, which is substantially higher than for the original system. Consequently, the modified system is able to meet the proposed hydrogen chloride permit limits with a considerable improvement in the margin of safety over the performance-tested system.

The modified emission control system is able to maintain a high degree of hydrogen chloride removal efficiency under

foreseeable operating conditions. The system is able to effectively remove hydrogen chloride from the gas stream under conditions of liquid pH 1.0 or greater.

5.2 Particulate Matter Removal

The evaluation of the air pollution control system for particulate matter removal indicates that the performance-tested configuration was able to meet the applicable emission standard of 0.08 gr/dscf. This standard was met even under the worst case condition where rust from the induced draft fan, resulting from hydrochloric acid corrosion and moisture damage during prior use, was entrained in the exit gas stream during the trial burn.

The modified air pollution control system is able to achieve considerably better performance than the performance-tested system. The particulate matter decontamination factor for the modified system is improved by approximately 50 percent, compared to the original system, due primarily to the increased pressure drop across the venturi scrubber. The expected exit particulate matter concentration is 12 orders of magnitude below the allowable level.

The allowable concentrations can be met even if no HEPA filters are used to treat the flue gas stream. Therefore, the HEPA filters provide a high degree of safety against exceeding emission standards during any process upsets, such as sodium chloride aerosol entrainment due to absorption column malfunction.

5.3 Destruction Removal Efficiencies

The performance-tested incineration system was able to meet the DRE requirement of 99.99 percent for carbon tetrachloride under all test conditions. The DRE for trichloroethylene was above the minimum allowable level of 99.9999 percent when the CAI was operated under the same conditions as detailed in the RCRA permit. DREs are primarily a function of the combustion chamber rather than the air pollution control system and the modifications discussed in this report are not expected to significantly affect them.

5.4 Radioactive Dose Commitment

Radioactive dose commitment calculations were made for the performance-tested air pollution control system (15). These dose commitment calculations were based on stack height of 12.2 meters (40 feet), a stack diameter of 0.91 meters (3 feet), and an exit velocity of 8.6 meters/second (28 ft/sec). The equivalent exit gas flow rate under these conditions was calculated as 5.60 cubic meters/second or 11,869 cf/min and includes the building air vent exhaust. Modifications to the air pollution control system of the CAI do not affect the above values.

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