WATERWALL CORROSION PREVENTION EXPERIENCE AT THE COMMERCE REFUSE TO ENERGY FACILITY

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INTRODUCTION

The Commerce Refuse to Energy Facility started up in December 1986 and is a 380 ton per day mass fired solid waste incinerator with a waterwall furnace. The plant produces 11.5 MW from burning mostly commercial/industrial refuse. Overall, waterwall failures have been the largest cause of unscheduled downtime at the plant. This paper will describe the experience with various protection methods used and the results to date. Methods tried are: studs with silicon carbide refractory; 625 alloy weld overlay; and precast refractory tiles. Although the testing is not complete, a pattern has emerged which appears to show the most cost effective method for various elevations of the furnace.

Parallel operational efforts to reduce corrosion include the following:

(*1*) oxygen (excess air) control.

(*2*) modeling of the over fire air port sizes, angle, and flow distribution to reduce the flame height and keep the flame in the center of the furnace.

(*3*) limestone injection in the furnace for acid gas removal before corrosion can begin.

(*4*) refuse source studies to find refuse which can cause high acid gases when burned.

Although these operational controls have been effective and will continue to be investigated, they will not be discussed in this paper.

INITIAL DESIGN

The cross section of the furnace is shown in Figure 1. The waterwalls are 3 inch diameter × 0.203 inch wall ASTM A178 grade C tubes with $1'' \times \frac{1}{4}''$ membranes. The original waterwall protection was phosphate bonded 80% silicon carbide refractory over $\frac{3}{8}'' \times \frac{3}{4}''$ stainless steel (SS) studs on 44 studs/SF density. This material has installed to just above the upper overfire air (OFA) nozzles on all four walls.

FAILURE HISTORY

Through 1993, there have been 33 forced outages due to waterwall tube failures with a total downtime of 1365 hours. The failures are a result of chloride and sulfide corrosion. The following shows the number and hours of down time from these forced outages:

Year	# of Outages	Hours Lost
1987	1	274
1988	0	0
1989	2	182
1990	5	184
1991	10	290
1992	6	205
1993	9	230

This paper defines different zones on the waterwalls which appear to have the same corrosion characteristics. These include: the arch of the front wall; the lower 10 feet of the side walls; from 10 feet to 35 feet above the grates on all four walls; and the walls above 35 feet.

Studs and silicon carbide (SiC) refractory with both low and high stud densities had limited success on the crown

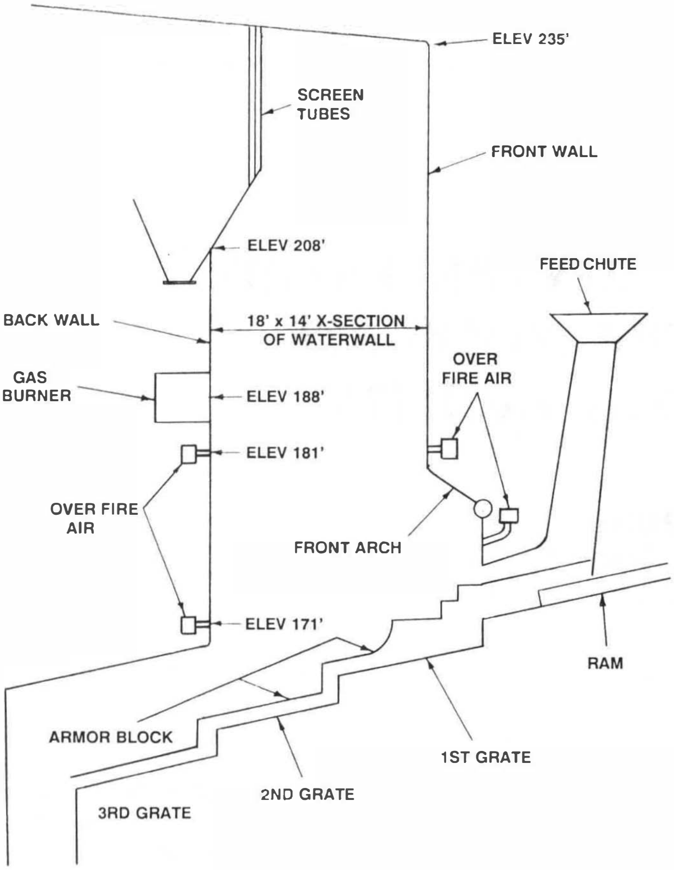

FIG. 1 COMMERCE REFUSE TO ENERGY FACILITY

of the tube but good success on the membranes. The early waterwall tube failures occurred at the refractory interface due to eddy currents.

As parts of the walls thinned, weld overlay using alloy 625 weld wire was installed above the refractory and later replaced part of the refractory. During several major outages, overlay was added to replace degraded refractory since it had the added benefit of reducing the temperature of the flue gas going into the superheater which was also having corrosion problems. So much refractory was replaced, however, that it began to cool the flame and made it harder to burn out the refuse. Although not successful in some zones due to high temperature corrosion, the majority of the overlay is still in place after five years with several remaining years of life.

In the last several years, precast SiC refractory tiles became available and were installed in the lower furnace with limited success and later in the upper furnace with better success. The following is a detailed history of the failures and the changes.

HISTORY OF PLANT CHANGES

1987

MAY 1987. The first failure of the waterwall occurred five months after startup of the front wall just above the refractory. Because the plant was still under warranty, the manufacturer decided to replace a 4′ wide × 15′ high panel section. Ultrasonic thickness (UT) readings were taken on the front and side walls which showed corrosion rates of 10 to 240 mils per year with slower rates at the higher elevations and closer to the back wall.

In addition to the waterwall corrosion, several evaporator tubes failed which are located before the superheater in flue gas at 1450 F to 1600 F.

AUGUST 1987. UT readings were taken on the back wall which showed corrosion rates of 10 to 30 mils per year except in one corner at the burner elevation, where the rate was over 60 mils per year.

Much of the original refractory had fallen off the crown of the tubes and an extensive repatch job was completed using the same refractory.

NOVEMBER 1987. The phosphate method silicon carbide refractory was raised 10 feet above the original refractory on the front and tapered on the side walls from 2 feet near the back wall to 10 feet near the front wall. This had a mixed blessing of covering the thin waterwalls but it also raised the flue gas temperature into the evaporator tubes. To minimize the temperature rise, the thin back wall tubes were overlayed with carbon steel.

In addition, the manufacturer added a 70 mil test overlay patch on the side wall using alloy 625 weld wire. This is a high nickel/chrome alloy to resist corrosion but had limited test use at other refuse facilities.

Again, many sections of the refractory were cracking with pieces missing on the crown of the tube which exposed the tube. The exposed studs were beginning to corrode at the tip but not at the base which formed a cone shape. The loose refractory was removed and new refractory installed.

1988

MAY 1988. UT readings on the side walls just above the new refractory showed accelerated corrosion in the 150 mils/yr range. These tubes had showed little corrosion until the refractory was raised. It was concluded that the transition from refractory to bare tubes caused eddy currents just above the refractory. This, in turn, caused hotter metal temperatures due to the more turbulent flow of flue gas. An interim fix was to raise the refractory another 2 feet on the front half of the side walls.

The original refractory continued to crack and fall off and the studs continued to become cone shaped. We added some studs and replaced missing refractory.

Three refractory test sections using an air set calcium bonded 90% silicon carbide were installed. The three sections had studs placed as follows: 120 $\frac{1}{2}''$ carbon steel (CS) studs/SF, 80 $\frac{1}{2}''$ CS studs/SF, and 70 $\frac{3}{8}''$ CS studs/SF. The purpose of the test was to find a method to keep the refractory on the wall and to improve heat transfer to lower the evaporator inlet temperature.

OCTOBER 1988. This was a major outage. The lower refractory was replaced with $120\frac{1}{2}''$ CS studs/SF with calcium bonded 90% silicon carbide refractory up to elevation 182 feet (just above the upper OFA nozzles). Also, 1116 SF of 70 mil minimum 625 overlay was added above the refractory to the following heights:

Back wall	16′	elev 198′
Front wall	20′	elev 202′
Side walls (front half)	18′	elev 200′
Side walls (back half)	16′	elev 198′

The original stainless steel studs could be removed by tapping them with a hammer, however, the cavity left by the SS stud was hard to sandblast and to weld without creating inclusions. The lower front arch area had to have CS weld overlay before the studs could be installed. Due to thinning of the side walls near the front wall, both had 5′ wide ×10′ high panel sections replaced in the area to be overlayed.

During the outage when the overlay work was getting behind schedule, the decision was made to overlay the tube only and not the 1 inch membrane. As a result, about one third of the lower overlay section did not have the membrane overlayed. The decision was based on the observation that the crown of the tube had the most wastage and that the membrane was away from the flue gas and more protected.

1989

OCTOBER 1989. The second and third waterwall leaks occurred in October. These were located on the front wall at the top of the refractory where a small portion of the refractory has fallen off. Again, the eddy currents at the refractory interface may have accelerated the thinning.

1990

JANUARY 1990. The fourth waterwall leak occurred on the south wall 5 feet from the back wall at the OFA port elevation. Again the refractory had fallen off; however, for the first time, the leak was on the side of the tube at the 1:30 position facing the front. This leak was suspected to be caused by the turbulence of the back OFA nozzle closest to the side wall.

MARCH 1990. 210 SF of 625 overlay was added in two patches on both side walls. The overlay was only installed on 120 degrees of the crown of the tubes. The overlay was located on 8′ × 10′ patches on the side walls near the back wall from elevation 174′ to 182′. These patches included the area of the January leak and thus several tubes required CS weld buildup on the sides of the tubes before the 625 could be added.

The other patches on the side walls were 5′×5′ immediately above the Number 1 grate. These patches were an experiment to determine if the overlay could survive the heat and abrasion of the refuse at the grates. When the studs and refractory were removed for the small patches, the tubes were still the original thickness even though much of the refractory had fallen off the crown of the tube. Again, only 120 degrees of the crown was overlayed.

JULY THROUGH OCTOBER 1990. The fifth through the eighth waterwall leaks occurred in the front arch area. Three were at the bend before the tubes become vertical. The arch area had been the hardest area to keep refractory in place. Each outage the wall was restudded as needed and hand packed with different types of refractory, however, it would not stay longer than six months.

NOVEMBER 1990. The membranes of the lower 10 feet of the front wall was overlayed due to thinning.

1991

JANUARY THROUGH SEPTEMBER 1991. One leak occurred in each of the following months: January, February, March, July, and August (leaks 9 through 13). These were all leaks in the front arch or just above the arch in the refractory area. Leaks 14 through 16 occurred in September on the side walls in the refractory area at the overlay interface.

MAY 1991. The remaining portion of the tubes and membranes in the area overlayed in March 1990 was overlayed. Some of the sides of the tubes were as thin as 0.09 inch. If the membrane had burned out, new bar stock was tacked in over the remaining membrane and then overlayed.

OCTOBER 1991. 140 SF of overlay on the front arch and front wall were overlayed up to the overlay at elevation 182′. This was the area with 11 of the first 16 leaks. This overlay work was very difficult not only because the tubes were thin but also because they had to overlay on the underside of a 30 degree sloped tube.

As a test, twelve each of two different types of 8″ × 8″ precast refractory tiles were added. One had a thru-bolt attachment and the other had a hidden clip.

NOVEMBER AND DECEMBER 1991. Leaks 17 and 18 occurred in November and December on the front and side walls respectively just above the overlay at elevation 204′ (35 feet above the grates). Spot UT readings ranged from 0.120 inch to 0.150 inch at elevation 205′.

1992

JANUARY AND FEBRUARY 1992. Leaks 19 through 21 occurred again on the front and side walls above the overlay at elevations 203′ to 205′.

MAY 1992. 150 SF of 625 overlay was added above the 1988 overlay in the area of the last 5 leaks. This included 5 feet across the front wall, 5 feet on the front half of the north wall, 3 feet on the back half of the north wall, and 2 feet on the front 5 feet of the south wall. Extensive UTs were done up to 10 feet above this new overlay on all four walls. Also, membrances were overlayed which had previously not been overlayed.

Although the test precast tiles had only been in for seven months, it was decided to install 150 of the thru bolt precast 8″ × 8″ refractory tiles on the north and south walls from elevation 170′ to 182′. The decision between thru bolt and hidden clip was basically economic since both of the experimental blocks were still in place. These were installed as an interim solution until the wall could be overlayed. The studs were removed close to the tube in preparation for eventual overlay.

JUNE 1992. Leak 22 occurred on the south wall at the refractory/overlay interface.

SEPTEMBER THROUGH OCTOBER 1992. Leaks 23 and 24 occurred on the front wall just above the arch. These were the first leaks that occurred within a wall that was overlayed. The leaks occurred on tubes in which the overlay contractor had missed a single weld bead for one foot in length.

NOVEMBER 1992. 100 SF of 625 overlay was added above the 1988 overlay on the south wall. This was added as a result of the UTs taken in May 1992. The front wall lower header was overlayed since refractory would not stay. The back wall lower bends were also overlayed due to thinning. Membrances were also overlayed as time permitted.

In examining the 24 original test precast refractory tiles after one year, the thru bolt tiles were all missing and the hidden clip tiles were cracked but still in place. Four of the 150 thru bolt tiles installed in May were also missing and replaced.

1993

JANUARY THROUGH FEBRUARY 1993. Leaks 25 through 28 occurred on the north wall at the refractory line or in the overlay of the front arch. The front arch leaks occurred in a section of the tube which appeared to have missing overlay. Stud sized spots began to appear on the front arch overlay that were missing but were not missing when it was first overlayed. One conclusion was that when the studs were removed and sandblasted, that the stud island could not be completely cleaned to bare metal. Therefore, when the overlay was added, inclusions were trapped under the overlay. The inclusions, in turn, caused poor heat transfer and the overlay burned off quickly over these stud islands.

Other possible causes were separation of the weld bead when welding on the underside of the tube or that the direct flame impingement during operation causes local boiling inside the tube, mineral deposits result, and the deposits insulate the metal and allow the metal to overheat. It may be a combination of all three.

A few more precast tiles fell off.

MARCH 1993. 490 SF of 625 overlay was added on the lower side walls down to the second grate. Except for a 40 SF patch near the feed chute, this job eliminated all stud/refractory and precast refractory tiles on the side walls for the first and second grates. Also the back wall was overlayed from the lower bends up to elevation 171′ and from elevation 177′ to 181′.

Since the front arch was losing the overlay at the stud islands, the islands were ground down, welded CS buildup, and overlayed with 625.

163 hidden clip refractory tiles were added on the back wall from elevation 171′ to 177′ using two different materials. Based on our experience with the original tiles, these tiles are projected to last 18 months.

The membranes which were added over the old membrane and overlayed in the past were already beginning to burn out within a year. It was concluded that this occurred because the new membrane is closer to the flue gas and thus is not cooled as well.

More importantly, however, was that much of the original overlayed membrane was also burning out after 4.5 years especially in the 10′ to 20′ elevation off the grates. The overlayed tubes in these same areas did not show any noticeable thinning. It was obvious that the hottest part of the membrane, half way between the tubes, burned out first.

APRIL 1993. Leak 29 occurred on the front arch at the bend and the south wall at an overlay weld bead which was never completed.

MAY 1993. Again the front arch was losing overlay at the stud islands so they were ground down, welded with CS buildup, and overlayed with 625. The worst half of the missing overlay was completed.

JULY 1993. Leak 30 occurred on the north wall at elevation 178.5′. This was in the same spot as two previous leaks and a repair during the hydrostatic test when it was overlayed in March. Problems with this tube may have been avoided if it had been overlayed before it had gotten so thin.

OCTOBER 1993. Once again repairs continued on the front arch missing overlay at the stud islands. It appeared to have many more missing overlay patches than in May. Only 20% of the missing overlay was completed.

To help protect the membranes from 10 feet to 16 feet above the grates, studs were added on the sides of the overlayed tubes and refractory installed over the membrane but leaving the crown of the overlayed tube exposed.

SUMMARY OF PROTECTION LIFE AND COST

The protection life depends on the location in the furnace. This paper defines various zones on the waterwalls in order to decide the least cost protection method. The size and location of the zones are very general and other furnace designs may find different results.

Table I shows the life and cost to date of the various protection options used by CREA in each zone. Note that overlay is normally bid on an extended square footage area to account for the curvature of the tube. For easy comparison, all the costs have been calculated on a straight square footage basis (one straight SF = 1.43 extended SF for 3 inch tubes on 4 inch centers).

The months of life listed in Table I are sometimes based on experience and sometimes are estimates. Even with experience, it is difficult to define when the life is over. For example, is the life over for a stud and refractory or refractory block wall when the first section of tube is exposed or when some percentage of the tubes are exposed.

The repair costs are also difficult to define. Some of the overlayed walls have been in for five years and have not needed repairs. For the repair cost, will the wall be completely re-overlayed or will bare spots appear and only the spots need overlayed. For comparison in Table I, all the repair costs are assumed to be the same as the initial costs.

The cost/SF in the table are time and materials only. The amount of down time varies with each option, however, it is difficult to calculate a cost/SF since most of the wall protection work is done during scheduled outages.

FINAL CONSIDERATIONS FOR EACH ZONE AT CREA

Besides the cost to install, many other considerations must be evaluated in choosing a waterwall protection system. Some of these considerations include: heat transfer and temperature limitations, time between normal outages, time available and access during outages, availability of contractors, lead time before the outage, boiler code inspector requirements, condition and thickness of the tubes and membranes when making the decision, bends and/or warpage of the tubes, cash flow limitations, etc.

The following will discuss a brief history of each zone along with future changes and the reasons for these changes.

TABLE I WATERWALL PROTECTION LIFE AND COST

LOCATION	LIFE (MO.)	COST/SF (1993 $)	COST/SF/YEAR
FRONT ARCH WITHIN 15' OF GRATE:			
1) TYPE 1 STUD & REFR. (Note 1)	6	120	240
2) TYPE 2 STUD & REFR. (Note 2)	9	150	200
3) 625 OVERLAY OVER PREVIOUS STUDS	12	250	250
4) 625 OVERLAY OVER BARE TUBE	36+	200	67
SIDE WALLS - LOWER 10' (ORIGINAL STUDDED TUBES):			
1) TYPE 1 STUD & REFR.	6	120	240
2) TYPE 2 STUD & REFR.	9	150	200
3) REFR BLOCK W/ STUD & NUT	8	80	120
4) REFR BLOCK W/ HIDDEN CLIP	13	80	74
5) 625 OVERLAY INCL. MEMBRANE	48 MEMB.	80	
	120 TUBE	205	41
6) 625 OVERLAY INCL. MEMBRANE	24 REFR	20	
PLUS REFR ON MEMBRANE	120 TUBE	250	35
WALLS FROM 10' TO 35' ABOVE GRATES (ORIGINAL STUDDED TUBES):			
1) TYPE 1 STUD & REFR.	8	120	180
2) TYPE 2 STUD & REFR.	10	150	180
3) REFR BLOCK W/ STUD & NUT	12	80	80
4) REFR BLOCK W/ HIDDEN CLIP	18	80	53
5) 625 OVERLAY INCL. MEMBRANE	18 MEMB.	80	
	96 TUBE	205	79
6) 625 OVERLAY INCL. MEMBRANE	24 REFR.	20	
PLUS REFR ON MEMBRANE	96 TUBE	250	41
WALLS FROM 35' ABOVE GRATES AND UP (ORIGINAL BARE TUBES):			
1) BARE TUBES (REPLACE PANELS)	72	250	42
2) REFR BLOCK W/ STUD & NUT	24	40	20
3) REFR BLOCK W/ HIDDEN CLIP	48	40	10
4) 625 OVERLAY INCL. MEMBRANE	60 MEMB.	80	
	144 TUBE	205	33
5) 625 OVERLAY INCL. MEMBRANE	36 REFR.	20	
PLUS REFR ON MEMBRANE	144 TUBE	250	28

NOTES:
1) 50 3/8" studs/SF and 80% SiC refractory
2) 100 1/2" studs/SF and 80% SiC refractory
3) All costs are for time & mat'l only, not lost downtime income.

Front Arch

The original design was 4.5 inches of alumina refractory held by V anchors. This was changed to stud and SiC refractory in the first year and then changed to overlay in October 1991. Because the stud island causes faster burn out of the overlay, many repairs to this overlay have occurred (see January 1993 discussion above).

In February 1994, the front arch will have several inches of SiC castable refractory installed with SS V anchors welded to the tubes. Although a cast refractory was used before and did not last very long, the increase in loss of the overlay has forced a method to protect the tubes.

Another reason to add the refractory is that CO emissions have gone up slightly due to overlay on the front arch and lower side walls. The better heat transfer with overlay compared to refractory cools the flame and causes higher CO and less burn out of the refuse. The refractory will increase the temperature of the flame and thus reduce CO.

In the future, several tubes on the front arch may be replaced using 625 alloy tubes. The tubes which are removed, can be checked for internal deposits to see if boiling has occurred and cross sections checked to help determine the cause of the accelerated wastage.

Lower 10 Feet of Waterwalls Above Grates

The original design was 44 SS studs/SF with 80% SiC refractory. This was changed to 120 CS studs/SF with 80% SiC refractory in October 1988 and to overlay in March 1990 and March 1993. The membrane has started to burn out in the overlay section which is 3.5 years old. As stated above, CO emissions rose slightly due to the better heat transfer cooling the flames.

The holes in the membrane also result in air leakage since the furnace is kept at a negative pressure. This leakage can cause CO emissions to increase.

In February 1994, refractory will be added to the membrane only and held with one row of studs along the inside edge of the tubes or with V anchors. This refractory will accomplish three things: 1) it will protect the membrane from burning out; 2) it will reduce heat transfer which will increase flame temperature thus reducing CO; and 3) it will plug any holes in the membrane which will reduce leakage thus reducing CO.

10 Feet to 35 Feet Above Grates

The original design was 44 SS studs/SF and 80% SiC refractory in the lower 10 feet of this zone and bare tubes above the refractory. In November 1987, the refractory was raised 10 feet. In October 1988, the lower 10 feet of this zone was replaced with 120 CS stud/SF and 80% SiC refractory and the remainder of the zone was overlayed. In March 1990, 160 SF of studs and refractory was removed on the side walls and overlayed. In October 1992, the studs and refractory on the side walls were removed and refractory blocks added. In March 1993, the remainder of the studs and refractory and the side wall refractory blocks were removed and the side walls overlayed and refractory blocks added to the back wall. In October 1993, the lower 6 feet had refractory added to the membrane only and held with one row of studs along the inside edge of the tubes.

In May 1994, the membranes will be re-overlayed as needed and UT readings taken to determine remaining life of the overlay on the tubes.

35 Feet and Above

The original design was bare tubes. In May 1992, the front and north walls were overlayed in the lower five feet. In October 1992, the south walls was overlayed in the lower four feet. UT readings above the overlay show a corrosion rate of 5 to 20 mils per year. UT readings will continue to be taken each year to determine when and where the wall needs overlay.

CONCLUSIONS

The Commerce Refuse to Energy Facility has utilized V anchors and refractory, studs and refractory, refractory blocks, and 625 alloy overlay for waterwall protection. Each has been found to be useful in different sections of the furnace.