

**Recent Experience with SCR Catalyst
For
PRB Fuels, High Sulfur Fuels,
And
Low Dust Applications**

By

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ABSTRACT

Hitachi has supplied SCR catalyst for several utilities in the United States that have recently commissioned the SCRs including AES Somerset, CP&L Roxboro #4 and KCP&L Hawthorn. The Somerset and Roxboro #4 plants burn bituminous coal while Hawthorn burns sub-bituminous (Powder River Basin Coal). The Somerset SCR and Hawthorn SCR are in a high dust configuration while the Roxboro #4 SCR is installed in a low dust configuration. This paper describes the catalyst design basis, NO_x removal performance, pressure drop, ammonia slip and SO₂ to SO₃ oxidation as well as the performance of the on-line clean equipment to maintain catalyst cleanliness. Experience with both sootblowers and acoustic horns are described.

INTRODUCTION

Three diverse coal fired boilers with Hitachi plate type SCR catalyst are on line. Each represents a distinct challenge as one is a high dust configuration in a boiler firing medium to high sulfur eastern bituminous coal with sootblowers, the other in a boiler firing low sulfur Appalachian bituminous coal in a low dust configuration with cleaning from acoustic horns and the third a high dust configuration firing sub-bituminous Powder River Basin coal with a SCR that is also cleaned with acoustic horns. The designs are briefly discussed and the operation results to date, including the impact of cleaning method, are discussed.

In addition, new developments are addressed. The first is the ability of SCR catalyst to withstand the rigors of the SCR catalyst rejuvenation processes being introduced are discussed with emphasis on strength, cleaning ability, and overall life. Second, is the development of a very low SO₂ to SO₃ oxidation Hitachi catalyst. Its strengths and weaknesses are described.

Hitachi is uniquely suited to address different boiler configurations firing a wide variety of fuels. Figure 1 shows some of these including coal, petroleum products, Orimulsion gas, biological based fuels, and gases of all descriptions. These are fired in pulverized coal and cyclone boilers, both wet and dry bottom; in combustion turbines; process boilers and heaters; furnaces; coke ovens; pickling plants; municipal solid waste, and other incinerators and diesel engines. In refineries Hitachi experience includes reformers, process boilers and heaters, crude heaters plus fluidized catalytic crackers.

HIGH DUST – HIGH SULFUR

The Somerset station boiler owned by AES has been on line originally during ozone seasons but currently continuously with an operational SCR since July of 1999.

SCR DESIGN CONDITIONS

The SCR is installed in a high dust configuration, directly after the economizer on this pulverized coal

fired unit. Both an economizer and an SCR bypass are provided. The boiler fires a medium to high sulfur eastern bituminous coal in a high

arsenic impact could be somewhat high if the maximum arsenic coincides with the minimum calcium oxide level.

Size	675 MW
Fuel	Bituminous Coal
Configuration	High Dust
Operation	Continuous
Comm'l. Operation	July 1999
Gas Flow	6,500,000 lb/hr
Gas Temperature	649 °F
Inlet NOx	340 ppm
O₂	3%
H₂O	7%
SO₂	1140-3490 ppm
Dust	5 gr/dscf
Outlet NOx	34 ppm
DeNOx Eff.	90%
NH₃ Slip	3 ppm
Catalyst Vol.	897 m ³
Gas Velocity	6.0 m/s
SO₂ Oxidation	< 0.75%
Pressure Drop	2.8 "WG
Catalyst Life	24,000 hr

Table 1: Somerset SCR Design Parameters

dust configuration. The layout is shown in Figure 2 as a photograph and in Figure 3 as a schematic. Catalyst cleaning is affected by means of sootblowers. The SCR catalyst design parameters are given in Table 1.

The design fuel coal is given in Table 2 below. The average sulfur content is over 2% with the maximum being a little more than 4%. The maximum Hitachi experience is with 5% sulfur petroleum coke. In addition, the

	Units	Ave.	Max.	Min.
Heat	BTU/lb	13023	13237	12550
Moist.	%	5.87	6.18	5.53
Vol.	%	37.05	40.09	35.60
FC	%	49.49	52.03	44.79
Ash	%	7.88	9.15	6.67
S	%	2.41	4.12	1.41
C	%	71.90	74.36	68.41
H	%	4.90	5.21	4.69
N	%	1.31	1.53	1.14
O	%	6.47	7.20	5.63
Cl	%	0.12	0.14	0.07
SiO₂	%	46.44	51.30	42.81
Al₂O₃	%	22.31	26.18	19.28
Fe₂O₃	%	18.26	28.79	12.60
TiO₂	%	0.96	1.17	0.87
P₂O₅	%	0.28	0.44	0.04
CaO	%	4.20	5.92	2.61
MgO	%	0.84	0.98	0.67
Na₂O	%	0.53	0.70	0.42
K₂O	%	1.37	1.49	1.20
SO₃	%	4.96	7.18	3.05
As	PPM	4.44	6.73	2.77
Ba	PPM	5.93	10.95	0.20
Mn	PPM	15.59	21.05	10.92

Table 2: Somerset Coal Analysis

OPERATION

The SCR has been on line since July 1999. To date it has performed better than expected meeting the DeNOx efficiency, slip and SO₂ oxidation rate while having a MCR catalyst pressure drop of 1.4 in. W.G. The SCR cleanliness has been better than expected. The steam sootblower operating frequency has been reduced to once

per week. The catalyst has remained very clean as shown in Figures 4 and 5; with no dust buildup or erosion being observed and with the only ash buildup being found on horizontal surfaces within the reactor but not on in the catalyst. Throughout operation the pressure drop across the catalyst has remained constant: further evidence of a clean catalyst bundle.

The catalyst is performing better than expected. The activity is higher than originally planned. This has been established by testing sample catalyst coupons at regular intervals. The results of these activity tests are given in Figure 6 along with the initial catalyst activity design curve for comparison. It has been known that the sample coupons are subject to inlet turbulent flow that causes their test results to be conservative, showing higher deterioration than the average of the SCR bed catalyst. To better understand the actual bed conditions, two (2) catalyst plate elements were removed from the bed and tested along their length. The average of these tests results is also shown in Figure 6.

LOW DUST - LOW SULFUR

The Roxboro 4 unit owned by Carolina Power and Light has been on line during ozone seasons with an operational SCR since July of 2001. It consists of two (2) boilers feeding one turbine/generator.

SCR DESIGN CONDITION

The SCR is installed in a low dust configuration, directly after the hot

electrostatic precipitator on each of these pulverized coal fired boilers. They fire low sulfur southern Appalachian bituminous coal.

The east side of the east boiler is shown in Figure 7. The flue gas exits the hot electrostatic precipitator flowing north to the rear of the boiler. The ammonia injection grid is seen in the picture. From there it turns upward and then to the west where it enters the reactor, flowing downward through the catalyst. A schematic of the reactor is shown in Figure 8. The SCR catalyst design parameters are given in Table 3.

Size	735/2 MW
Fuel	Bituminous Coal
Configuration	Low Dust
Operation	Ozone Season
Comm'l. Operation	July 2001
Gas Flow	1,725,300 SCFM
Gas Temperature	735 °F
Inlet NOx	278 ppm
O₂	3¼%
H₂O	6½%
SO₂	1140-3490 ppm
Dust	100 mg/Nm ³
Outlet NOx	58.5 ppm
DeNOx Eff.	79%
NH₃ Slip	2 ppm
Catalyst Vol.	314 m ³
Gas Velocity	6.0 m/s
SO₂ Oxidation	< 1.0%
Pressure Drop	1.3 "WG
Catalyst Life	24,000 hr

Table 3: Roxboro 4 SCR Design Parameters

The design fuel coal is given in Table 4. The sulfur content is 1.5 % or less. In addition, the maximum arsenic level is high compared to the minimum calcium oxide level. The catalyst design had to account for the potential arsenic deactivation of the catalyst over its life.

	Units	Max.	Min.
Heat	BTU/lb	13500	10500
Moist.	%	11.0	3.0
Vol.	%	39	28
FC	%	55	45
Ash	%	17	5
S	%	1.5	0.4
C	%	80	60
H	%	6	4
N	%	1.7	1.0
O	%	8	2
Cl	%	0.1	0.01
SiO ₂	%	70	10
Al ₂ O ₃	%	38	8
Fe ₂ O ₃	%	25	2
TiO ₂	%	3.5	0.4
P ₂ O ₅	%	0.6	0.1
CaO	%	10	0.5
MgO	%	8	0.3
Na ₂ O	%	4.0	0.1
K ₂ O	%	3.0	0.1
SO ₃	%	10	0.1
As	PPM	12	0
Ba	PPM	3	0
Mn	PPM	78	0

Table 4: Roxboro 4 Coal Analysis

Acoustic horns are used for catalyst cleaning. Actually, it is Hitachi's experience that low dust catalyst is more difficult to clean than that from high dust. Although the volumetric flow rate is lower the particulate is much smaller. This increases the pluggage potential of the catalyst pores masking the catalyst reaction

sites. The acoustic horn arrangement is shown in Figure 9.

OPERATION

To date no plugging has been experienced as evidenced in Figure 10 showing the actual catalyst inlet. Preliminary SO₂ oxidation testing indicates that the 1% limit has easily been achieved as the average for both SCR reactors is 0.73%. For the new catalyst the ammonia slip values measured were well below the requirements.

SUB-BITUMINOUS COAL (PRB)

The Hawthorn 5 unit owned by Kansas City Power & Light has been on line in continuous operation with an operational SCR since May of 2001.

SCR DESIGN CONDITION

The SCR is installed in a high dust configuration, directly after the economizer of this pulverized coal fired boiler. It fires low sulfur sub-bituminous Powder River Basin coal.

A schematic of the reactor is shown in Figure 11. It also has an economizer and an SCR bypass. The SCR catalyst design parameters are given in Table 5.

Size	500 MW
Fuel	Sub-Bit. (PRB)
Configuration	High Dust
Operation	Continuous
Comm'l. Operation	May 2001
Gas Flow	5,595,000 SCFM
Gas Temperature	695 °F

Inlet NOx	135 ppm
O₂	3½ %
H₂O	13.6 %
SO₂	420 ppm
Dust	32,710 mg/Nm ³
Outlet NOx	59.2 ppm
DeNOx Eff.	55.6 %
NH₃ Slip	2 ppm
Catalyst Vol.	477 m ³
Gas Velocity	5.7 m/s
SO₂ Oxidation	< 0.75%
Pressure Drop	2.0 "WG
Catalyst Life	24,000 hr

Table 5: Hawthorn 5 SCR Design Parameters

The design fuel coal is given in Table 6. The sulfur content is very low. In addition, there is no significant arsenic. The calcium oxide level is extremely high and the concern is catalyst porosity masking by the CaO that shortly becomes CaSO₄. The catalyst design had to account for the potential CaSO₄ masking of the reaction sites with its potential catalyst deactivation over the catalyst life.

	Units	Ave.	Max.	Min.
Heat	BTU/lb	8350	8100	8600
Moist.	%	30.6	29.0	32.2
Vol.	%	31.1	28.8	33.4
FC	%	32.8	30.5	35.9
Ash	%	5.5	4.6	6.4
S	%	0.33	0.23	0.43
C	%	48.0	46.3	49.6
H	%	3.4	3.1	3.7
N	%	0.7	0.6	0.8
O	%	11.5	-	-
Cl	%	0.01	0.0	0.02
SiO₂	%	33.0	27.9	38.1
Al₂O₃	%	15.5	13.2	17.8
Fe₂O₃	%	6.0	3.6	8.4

TiO₂	%	1.3	0.8	1.8
P₂O₅	%	1.7	1.0	2.4
CaO	%	22.5	17.6	27.4
MgO	%	4.0	1.7	6.3
Na₂O	%	1.4	0.4	2.4
K₂O	%	0.3	0.0	0.6
SO₃	%	13.0	10.1	25.9
As	PPM	-	-	-
Ba	PPM	-	-	-
Mn	PPM	-	-	-

Table 6: Hawthorn 5 Coal Analysis

OPERATION

Hawthorn Unit 5 is a pulverized coal fired boiler with a high dust SCR. Thus we expect high dust loadings in the reactor. Four (4) acoustic horns per catalyst layer are used for cleaning, the arrangement being shown in Figure 13. Note the clean environment and the condition of the catalyst surface. No increase in pressure drop through the catalyst bundle has been observed. Tuning of the SCR was still in progress as this paper is being written. Preliminary data supports the conclusion that all the SCR catalyst performance requirements are being met.

NEW DEVELOPMENTS

Rejuvenation:

The industry is delving deeply into SCR catalyst rejuvenation as a potential operating cost saving method for catalyst replenishment. The key to catalyst longevity with these wet rejuvenation processes is the mechanical stability of the original catalyst that is to be rejuvenated. The Hitachi plate

catalyst with its stainless steel mesh core is the most mechanically stable, sturdy and rugged catalyst on the market. Its advantages are:

- It has the maximum mechanical strength of all the catalysts for handling.
- Its core strength is not weakened by moisture, as is ceramic or paper based material. Thus it lasts longer through rejuvenation processes.
- It is the least susceptible to damage during rejuvenation.
- For damaged catalyst single plate replacement is possible rather than being limited to large sections.
- Hitachi plate catalyst may be dismantled to the elemental state either locally or in its entirety to completely remove any dust or ash as illustrated in Figure 13.

SO₂ Oxidation

Hitachi offered 3 coal-fired catalysts, C1, C2, C3, for high dust loadings. These catalyst types had increasing activity with increasing SO₂ to SO₃ oxidation rates. These rates all varied in a similar fashion with temperature; the higher the temperature the higher the oxidation rate. Now Hitachi is offering a fourth catalyst type, C0, that offers very high activity with very low oxidation for relatively high temperature service. This is illustrated in Table 7.

Temp.	Relative Volume/Oxydation			
	C3	C2	C1	Co
700 F	V ₁	V ₁ + α	V ₁ + β	V ₁ + γ
	1.2 %	1.0 %	0.6 %	0.5 %
750 F	-	-	V ₂	V ₂ - δ
	-	-	1.0	0.5
780 F	-	-	V ₃	V ₃ - ε
	-	-	1.4 %	0.5 %

Where α < β < γ and δ < ε


Table 7: Low Oxidation Catalyst

This catalyst offers considerable advantages over the catalyst currently being offered. However, the activity of this new catalyst drops off rapidly at lower temperatures. Thus this catalyst may not be appropriate for boilers operated with large load swings. For base loaded units operated at or near full load this catalyst might be used to considerable advantage by minimizing the potential for ammonium bisulfate formation in down stream equipment and a blue plume at the stack.

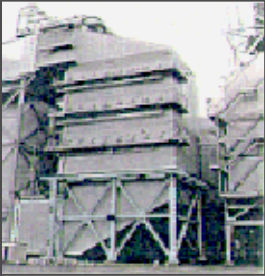
CONCLUSIONS

The versatility of the plate type catalyst is continually being demonstrated through its many diversified applications. New developments in catalyst formulations for the plate catalyst further expand its usefulness. Its rugged metallic core and elemental building block construction make it the most amenable catalyst for the wet rejuvenation processes being offered today, giving the plate catalyst the maximum overall useful life.

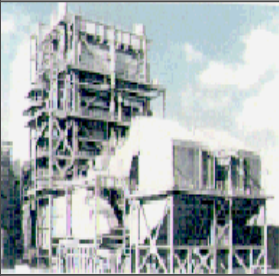
Coal
(High Dust)




Coal
(Low Dust)



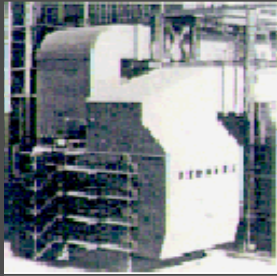
Oil, Orimulsion




Petroleum



Gas



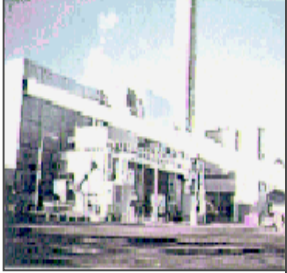
Fluidized Bed



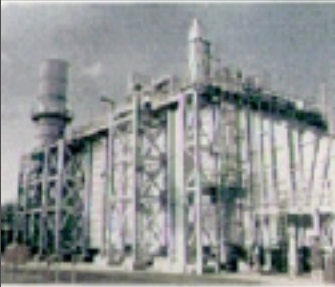
BABCOCK HITACHI SCR SYSTEM

- BOILERS
- FURNACES
- COKE OVENS
- STEEL PICKLING PLANTS
- PRODUCTION LINE
- SINTER PLANTS
- MUNICIPAL WASTE PLANTS
- INCINERATORS


Bio Fuel



Combined Cycle
Gas Turbine

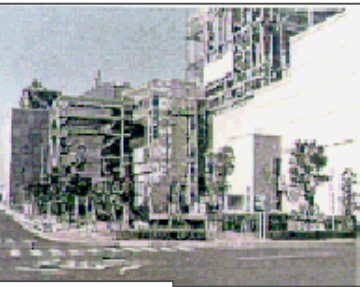


Combined Cycle
Gas Turbine



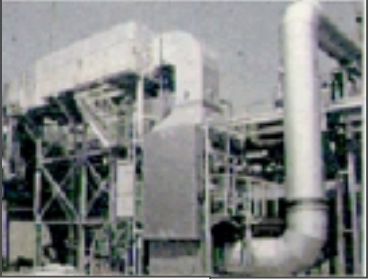
LNG

Re-powering
Gas Turbine &



LNG

Diesel Engine



Heavy Oil

Figure 1: SCR Applications and Experience



Figure 2: AES Somerset – 675 MW SCR

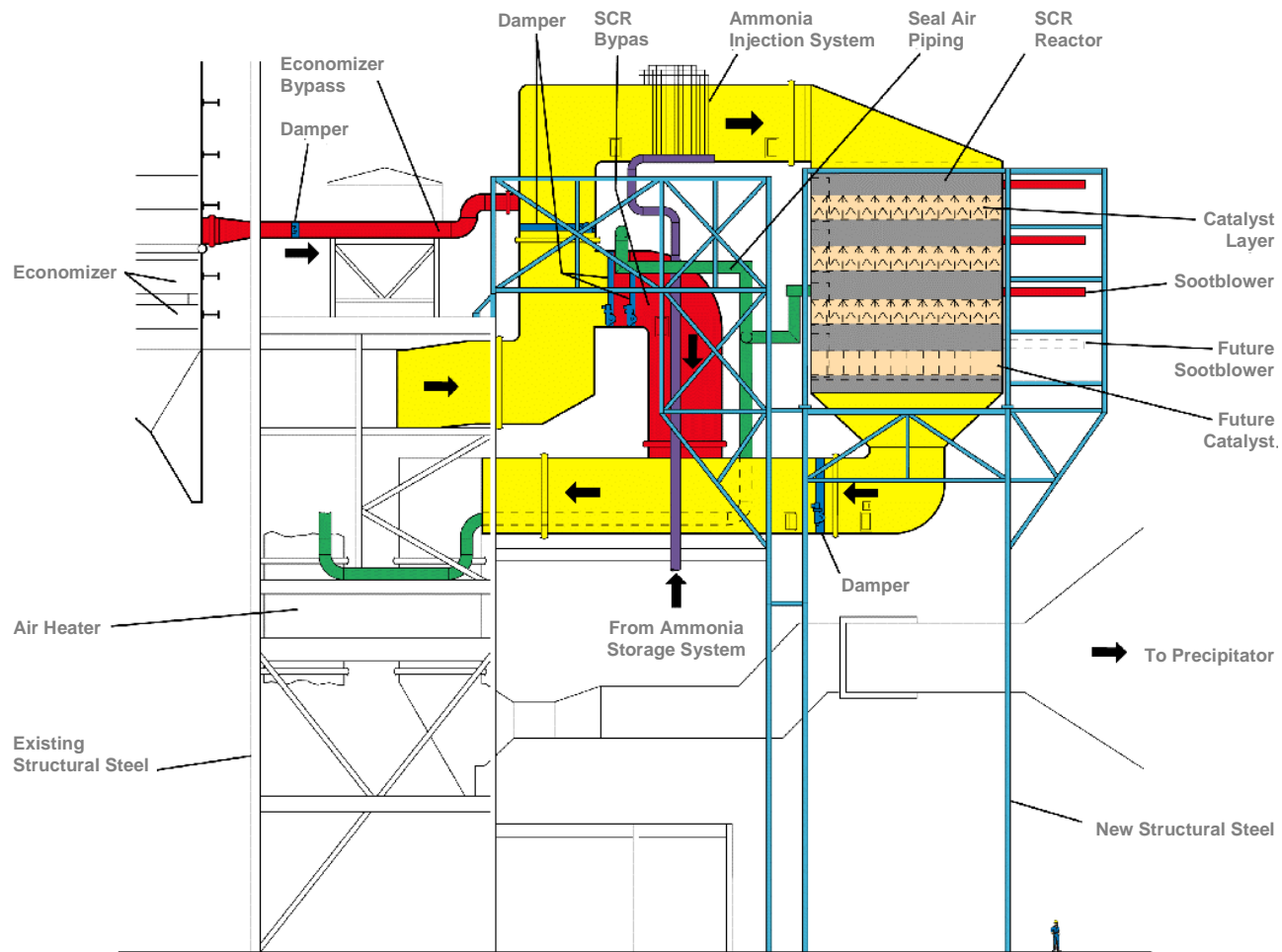


Figure 3: AES Somerset - 675 MW SCR System

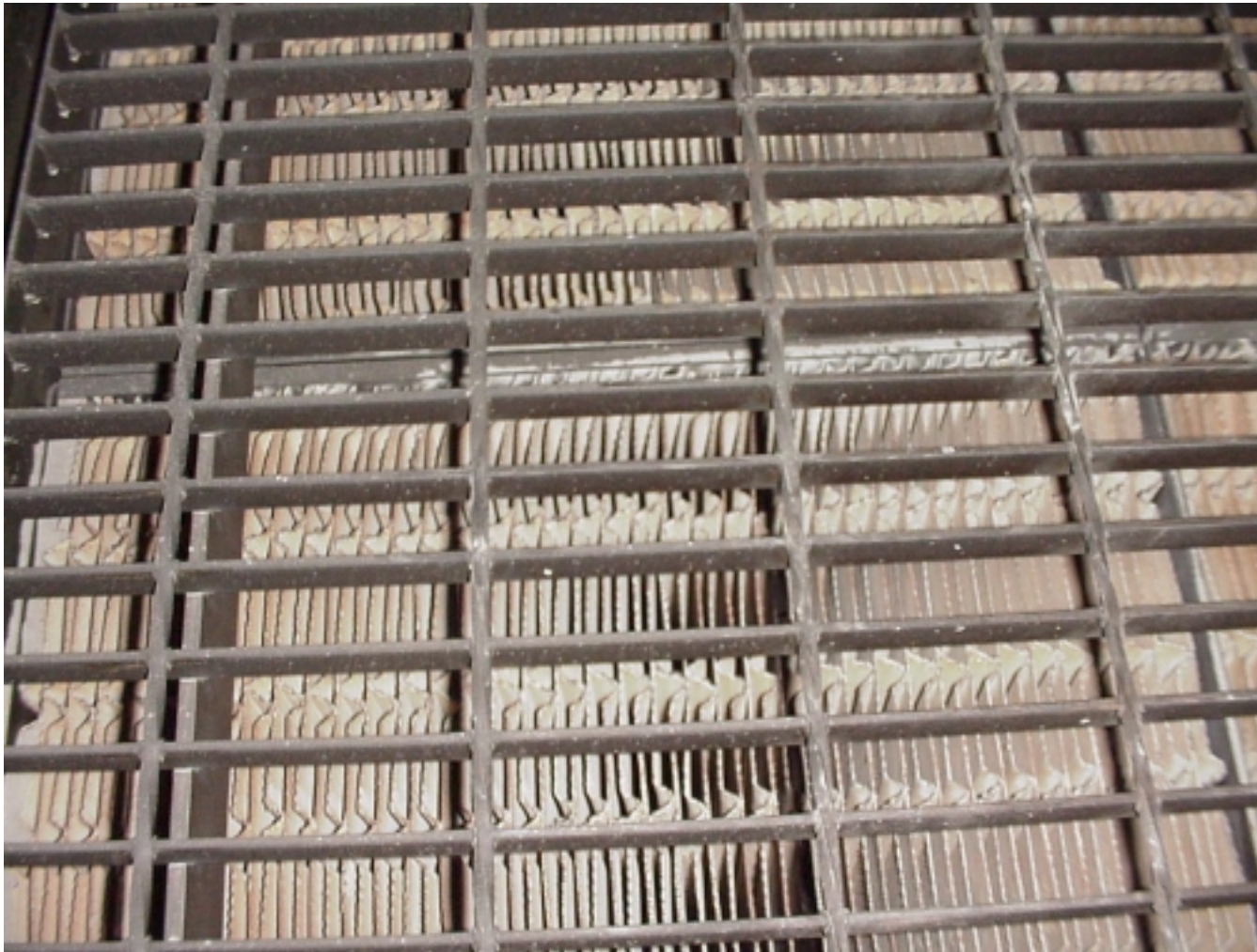


Figure 4: AES Somerset Catalyst After Two Ozone Seasons

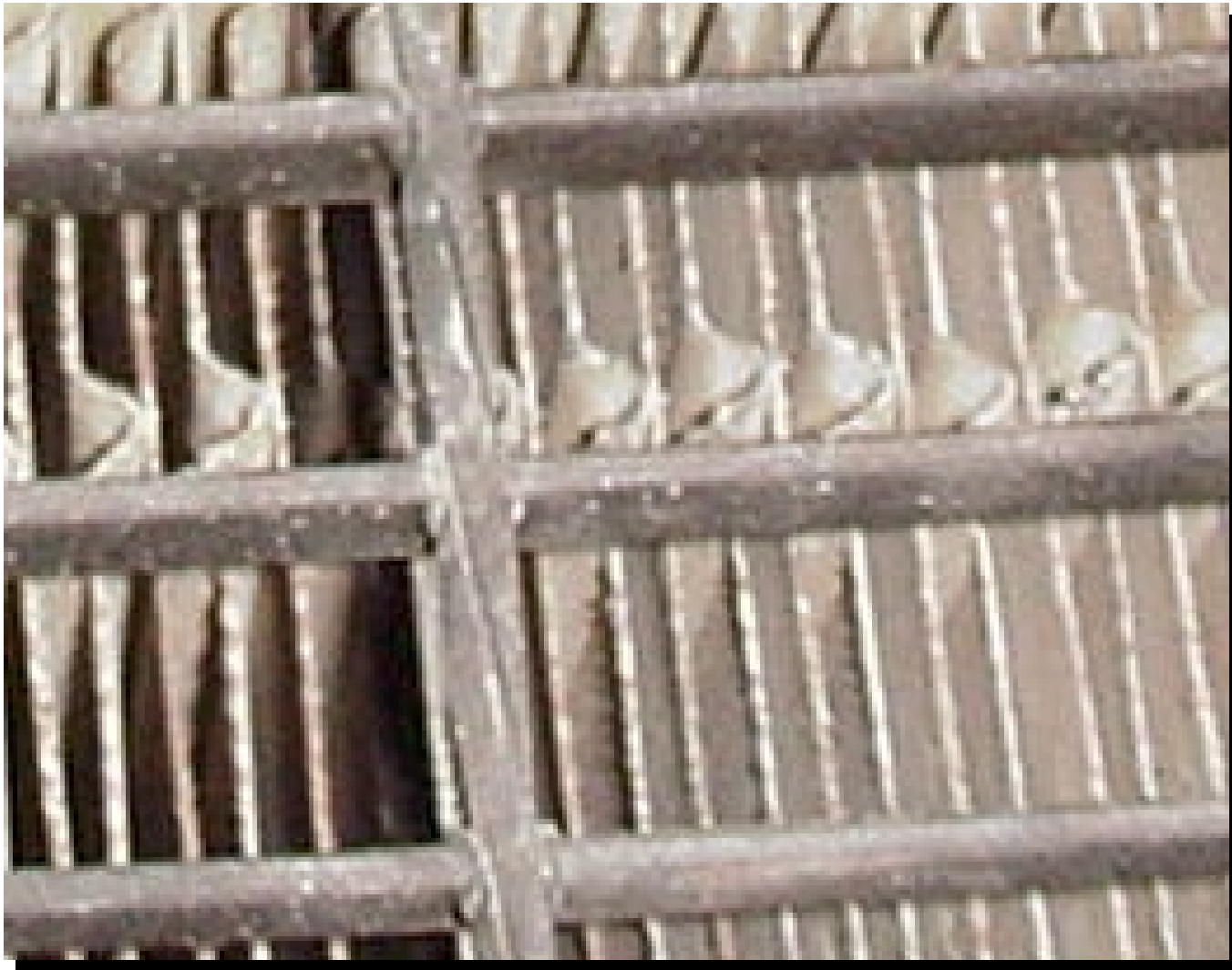


Figure 5: AES Somerset Catalyst After Two Ozone Seasons

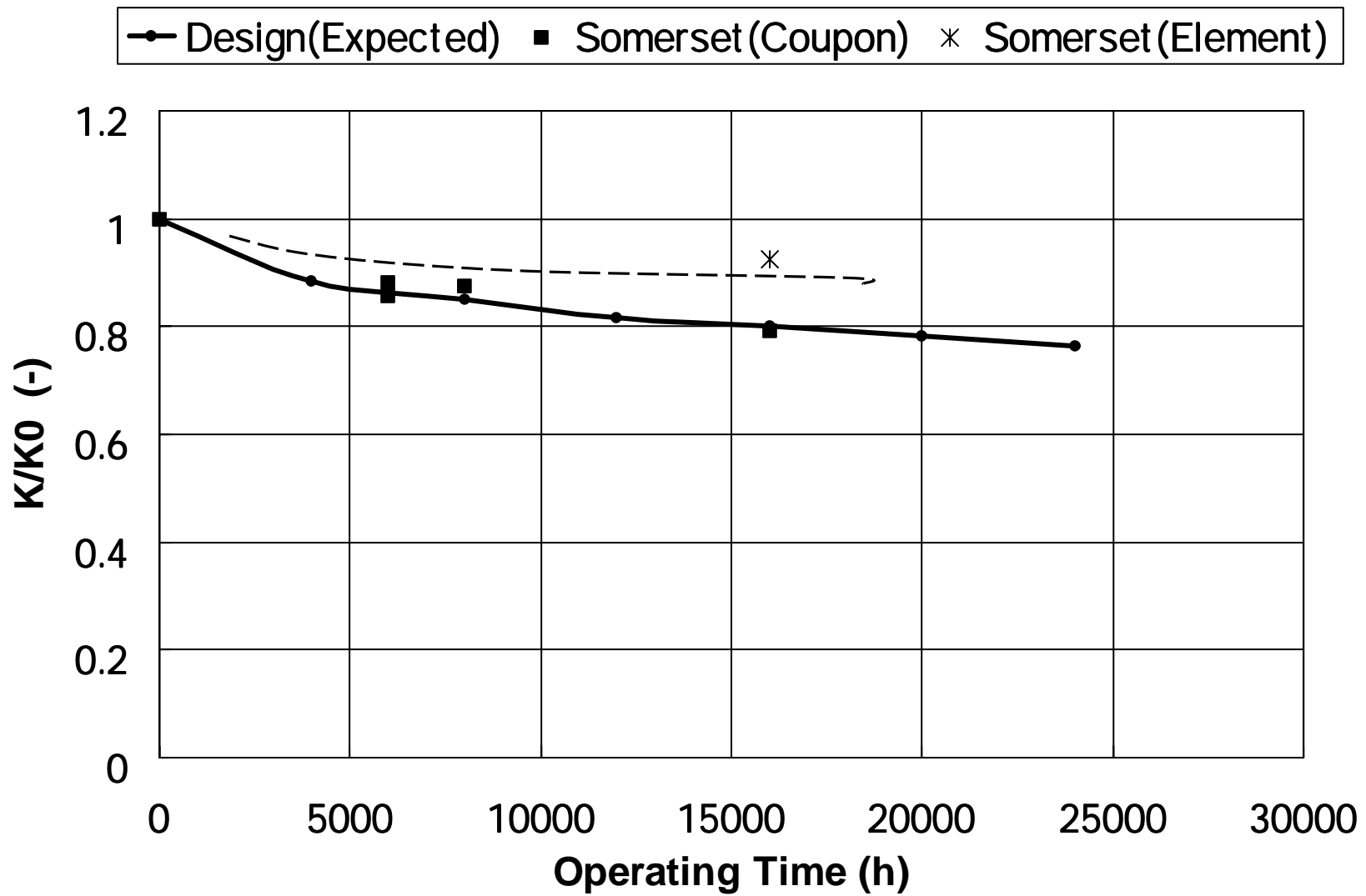


Figure 6: Somerset Catalyst Deactivation



Figure 7: Roxboro No. 4 SCR – East Side

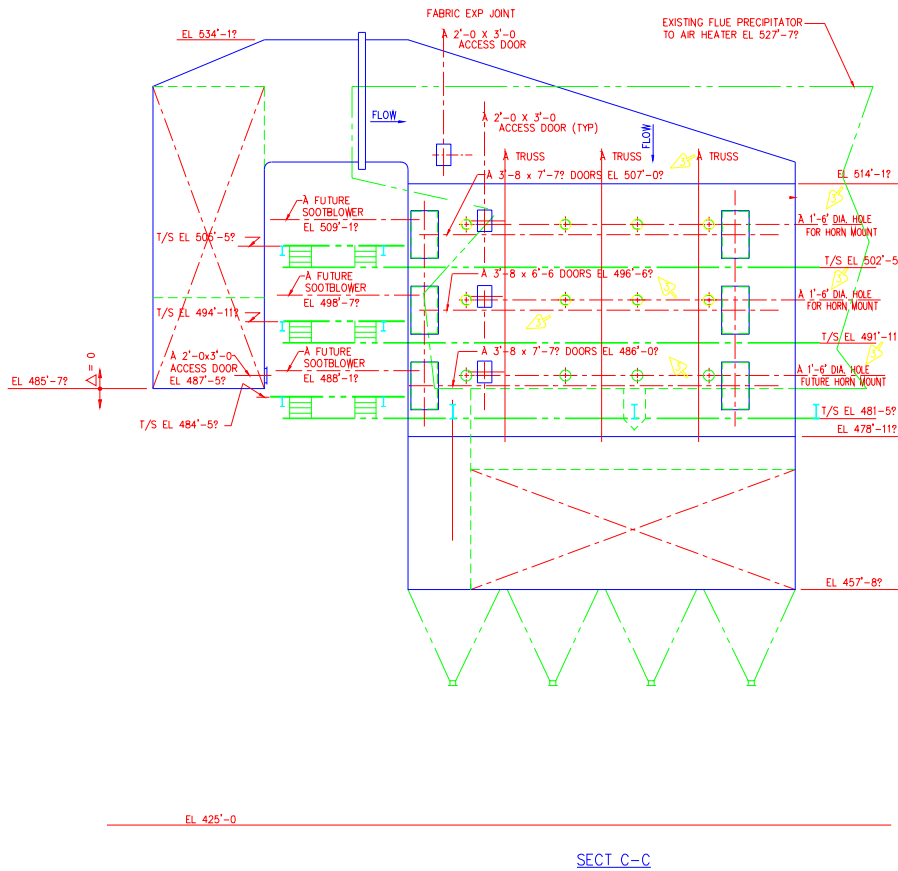
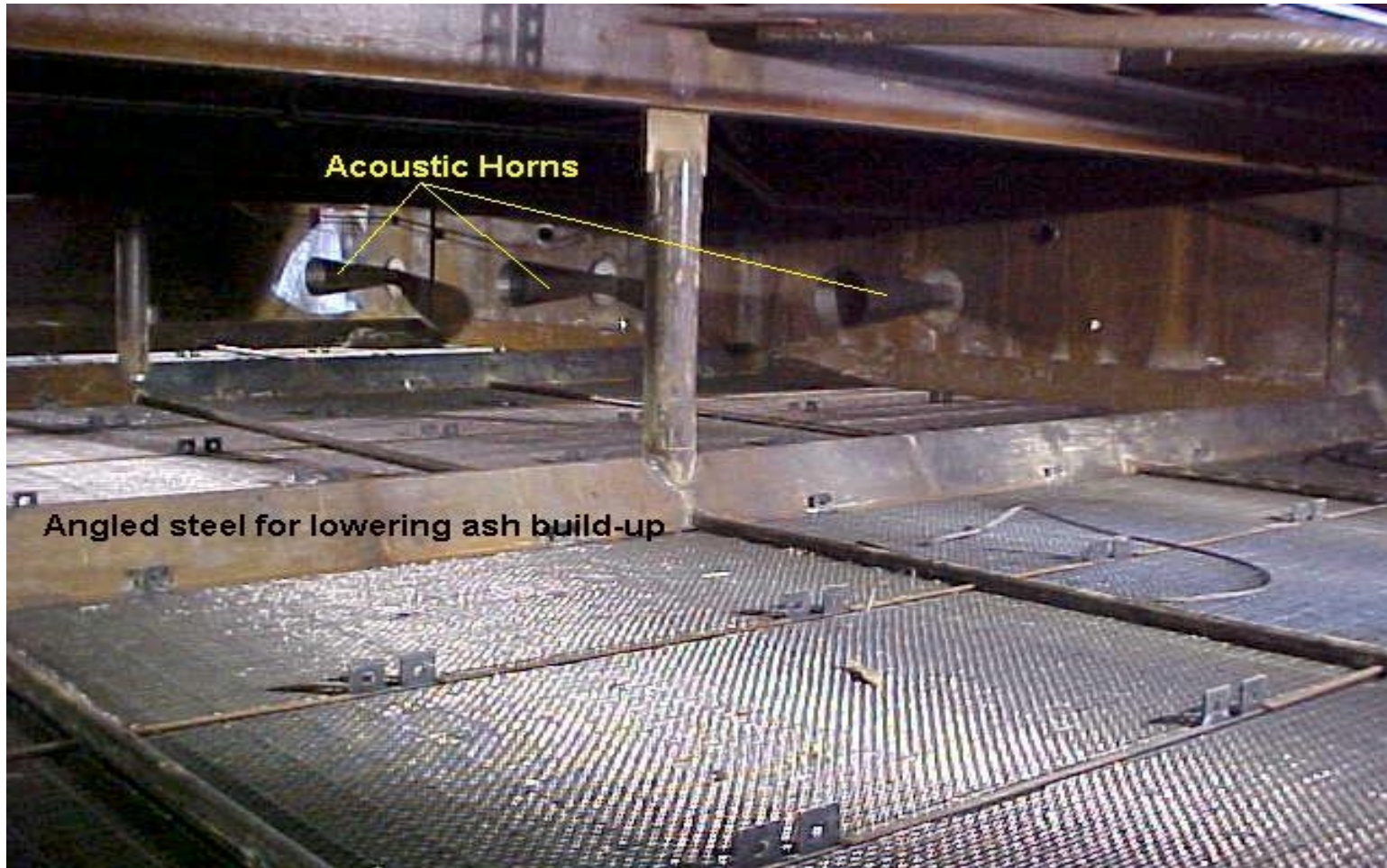


Figure 8: Roxboro No. 4 Reactor Schematic



Acoustic Horns

Angled steel for lowering ash build-up

Figure 9: Roxboro No. 4 Acoustic Horns



Figure 10: Roxboro No. 4 Hitachi Catalyst

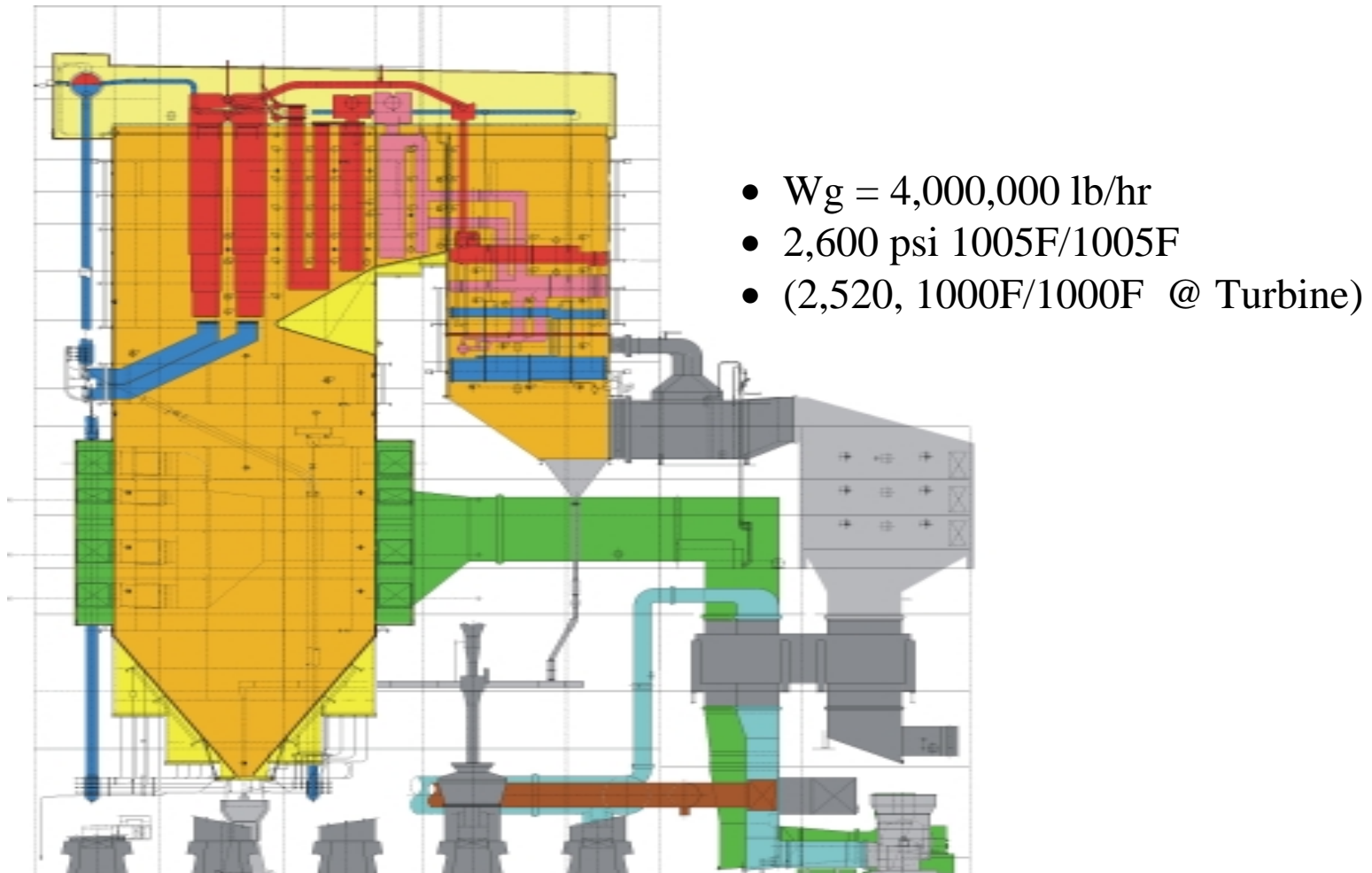
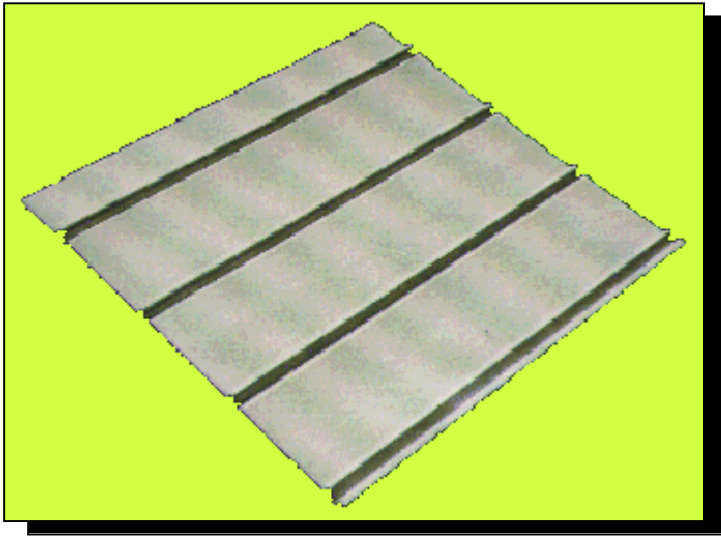


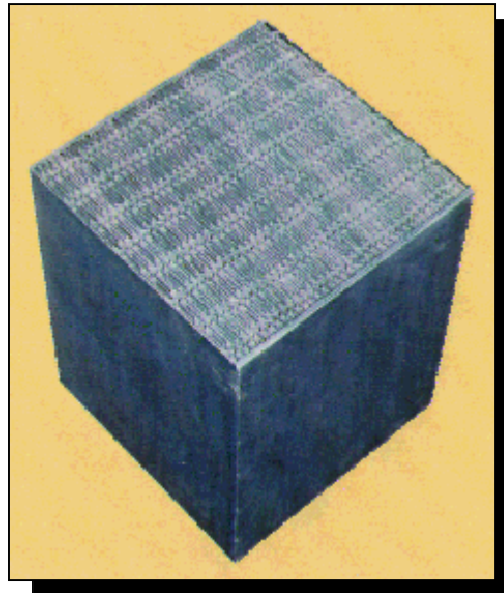
Figure 11: Hawthorn Unit 5 Side Elevation



Figure 12: Hawthorn Unit 5 Acoustic Horns



CATALYST ELEMENT
[Thickness: Approx. 0.9mm]



CATALYST UNIT
[Size: Approx. 450 x 450 x 350-800 (mm)]



CATALYST
BLOCK/MODULE

Figure 13: Hitachi Catalyst Building Blocks