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LOW-DUST SCR SYSTEM EXPERIENCE FOR COAL FIRED BOILERS

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Abstract

Hitachi has more experience on coal-fired low-dust Selective Catalytic Reduction systems than any other catalyst supplier. Carolina Power & Light's Roxboro Unit 4, located in Roxboro, North Carolina, is the first domestic low-dust SCR system. This article presents the major points for a low-dust system design in comparison to high-dust systems. The Roxboro Unit 4 operating conditions, design philosophy and operating results are presented and experience from other plants is also included.

Introduction

Carolina Power and Light Company (CP&L), a wholly owned subsidiary of Progress Energy, Inc., has retrofitted its Roxboro Electric Generating Plant, Unit 4 with a low-dust configuration selective catalytic reduction (SCR) system. This 700 MWe unit has split steam generators, 4A and 4B, and operates from 18% to 100% load. Foster Wheeler was awarded the Unit 4 SCR system contract as the first of a SCR alliance agreement with CP&L. The catalyst and the flow model tests were subcontracted to Hitachi America, Inc./Babcock Hitachi K.K. (Hitachi) because of its extensive experience with the low-dust coal fired configurations.

Low-dust Design Impacts

The low-dust SCR system is characterized by an upstream hot electrostatic precipitator that removes substantial ash from the flue gas prior to its entrance into the SCR as shown in Figure 1. This significantly lowers the ash flow to the SCR. The ash however, that escapes from the precipitators is finer than the ash in general, as shown in Table 1. Although less likely to cause erosion, it does have a higher plugging potential as finer ash has been found to have a higher tendency to agglomerate. At rates approaching 100mg/Nm3, rapid plugging is possible so plate-type catalyst is used to minimize the plugging potential.

The differences in ash characteristics for the low and high-dust SCR configurations require some differences in the overall SCR system design. A higher plugging potential in a low-dust system requires a higher flue gas velocity through the catalyst to sweep its surfaces (see Table 2). The lower erosion potential allows use of unhardened catalyst; catalyst hardening is used to resist the high erosion potential normally found in high-dust systems. Hardening catalyst is good for erosion prevention, but lowers the catalyst's unit activity. Thus, for the same NOx reduction duty, more volume is required for hardened catalyst.

Because of the higher pluggage potential in low-dust designs, catalyst cleaning devices must be used. However for the lower plugging potential high-dust designs in Japan, in some instances, cleaning devices might not be considered necessary and left out of the initial supply. Often future provisions are included in the SCR system design should cleaning become necessary.

As the ammonia is injected downstream of the ESP in the low-dust configuration, there is no concern about ammonia in the ash impacting its sale. The ash plugging potential carries over to the air preheater, and in conjunction with ammonium bisulfate formation can cause more frequent washing. These differences are summarized in Table 2.

Roxboro Unit 4 Design Conditions

Roxboro Unit 4 is composed of Two (2) Riley Stoker drum type, dry bottom, pulverized coal fired steam generators designated 4A and 4B. They were originally placed in service in 1980 and operate base-loaded year round. Currently, the plan is to operate the SCR system only during the ozone season (May through September). Initial operation of the SCR began in July of 2001 and has operated through each ozone season since. The SCR is installed in a low-dust configuration, directly after the hot electrostatic precipitator on each of the two pulverized coal fired boilers. A summary of the Roxboro Unit 4 design conditions is given in Table 3. Roxboro 4 fires low sulfur southern Appalachian bituminous coal as shown 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.

Each steam generator is designed to develop 2,584,500 lb/hr continuously at 2,610 psig and 1,005 ^{o}F at the superheater outlet with both steam generators operating simultaneously; the corresponding reheat outlet at 1,005 ^{o}F and approximately 480 psig. Units 4A and 4B each have Buell electrostatic precipitators directly downstream of the boiler economizer exit that were designed to remove over 99% of the ash. One (1) Alstom/ABB/CE Air “Preheater Company Ljungstom® model number 23-VI-81-1/2 followed each ESP. Space for the SCR units was only available behind the boilers downstream of the precipitators and upstream of the air preheater, making the SCR system design a low-dust configuration.

The west side of the west boiler is shown in Figure 2. The flue gas exits the hot electrostatic precipitator flowing north to the stack. The ammonia injection grid (AIG) is seen in the picture. From the AIG the flue gas turns upward and then to the east where it enters the SCR west reactor. The west reactor is shown in Figure 3. In this picture the gas flows from the right and then downward through the catalyst. From there the gas flows toward the boiler, turning up to the existing flue and then to the air preheater. The initial catalyst charge in each reactor is two layers deep, with one empty catalyst layer provided to support the catalyst management program. Acoustic horns are used for catalyst cleaning. It is Hitachi's experience that catalyst in a low-dust application is more difficult to clean than high-dust applications. Although the particulate volumetric flow rate is less than that of the high-dust configuration, 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 4.

Flow Model Test Results

The testing included both a cold flow model test based upon similitude and actual field tests to confirm the results.

The cold flow model test was performed on a 1/20 scale model to establish the necessary flow devices to achieve the required distributions throughout the model and minimize both pressure drop and dust layout. The model was used to optimize gas flow distributions at the AIG and catalyst inlets, as well as the ammonia distribution at the catalyst inlet. The cold flow tests were conducted at two (2) loads; approximately 100% and 40% load by equating the flow momentum.

The Plexiglas model is shown in Figure 5. The flow model was built to include the hot ESP outlet with the entire SCR and SCR bypass to the air preheater inlet. No economizer bypass was required.

The system requirements and test results are summarized in Table 5. The velocity distributions were all within the catalyst's original design range. The ammonia distributions were obtained by injecting CO tracer gas through the model's AIG. A uniform AIG CO flow was used, although the full-scale AIG has balancing capability. The model results indicated that the entire system pressure drop would be approximately 3 inches W.G. at full

Even though the SCR is located downstream of the ESP in a low-dust configuration, dust layout testing was performed in the model to identify areas of potential ash buildup in the ducts. At higher loads, above 75%, the flue gas swept the inlet and outlet flues reasonably clean and were generally self cleaning above 50% load. The SCR reactor floor was approximately 30% covered with dust up to 75% load and then lessened with higher load. In SCR bypass mode the dust dropped into the openings on the floor of the bypass duct at the intersection of the SCR reactor outlet duct.

Field Flow Distribution Test

Velocity measurements were made in the reactor with a hot-wire anemometer especially designed for hot gas applications. Results indicated that the flow distribution at the top (first) catalyst level were very uniform. The velocity measurements had an RMS deviation of 14.5% and 14.6% for reactors 4A and 4B, respectively, achieving the catalyst design criteria. Temperature distributions were measured at the catalyst inlet and were also very uniform. At the AIG inlet, an S-type pitot tube was used to measure velocity and results showed a velocity distribution of 17.1% RMS. Although the RMS distribution was slightly higher than the model results, the field distribution profile closely matched that obtained in the model.

NH_3/NOx distribution measurements were also inferred in the reactor from the inlet and outlet NOx measurements. Results indicated that distributions were well within the design criteria.

Thus both the field measurements and the cold flow model demonstrated that the criteria to obtain uniform flow for ammonia injection and catalyst efficiency were met.

Operation

Figure 6 shows the DeNOx efficiency throughout the first ozone season, indicating that the required NOx reduction of 79% was achieved. As would be expected, the ammonia slip for the new catalyst was well below its design limit. It was found to be about 0.4 ppm at full load and 0.1 ppm at minimum load.

Preliminary SO_2 oxidation testing found that the rates were 0.62% in reactor 4A and 0.84% in reactor 4B. This indicates that the 1% limit has readily been achieved.

The pressure drop through the SCR catalyst in the first ozone season is shown in Figure 7. It is evident that the required pressure drop through the catalyst is easily met.

To date no plugging has been experienced as evidenced in Figure 8 that shows the actual Catalyst. Figure 9 shows that at the end of the first ozone season the reactor had accumulated a light dusting.

Acknowledgements

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Tables

	Low-dust System	High-dust System	Units
Ash concentration	0.05 - 0.1	10 - 20	g/m3N
Ash size	5 – 7	15 - 25	µm

Table 1 Typical Ash characteristics

SCR Configuration	Low-dust System	High-dust System
Catalyst plugging by ash	Higher Potential due to fineness of the ash	Lower Potential
Catalyst erosion with ash	Lower Potential	Higher Potential due to quantity of ash and larger particles
Gas velocity through the catalyst	5-7m/sec: Sweep Surfaces and Avoid Pluggage	4-6m/s: Slower to Avoid Erosion
Catalyst Type	Normal Type (Hardness equivalent to the Oil firing Type)	Erosion Resistance Type (Hardened surfaces)
Sootblower/Sonic Horn	Definitely Required	Not Always Required
ESP Ash	No NH3	Some NH3
Air Heater Plugging	Higher Potential	Lower Potential

Table 2: System Comparison

Size, MW	700/2
Fuel	Bit. Coal
SCR Configuration	Low-dust
SCR Operation	Ozone Season
SCR Com'l. Date	July, 2001
Gas Flow, lb/hr	1,725,300
Gas Temp., ^{0}F	735
Inlet NOx, ppm	278
O_2, %	3¼
H_2O, %	6½
SO_2, ppm	1,140-3,490
Dust, mg/Nm^3	100
Outlet NOx, ppm	58.5
DeNOx Eff., %	79
NH_3 Slip, ppm	2
Cat. Volume, m^3	314
Gas Vel., m/s	6.0
SO_2 Oxidation,%	< 1.0%
Cat. Life, hrs.	24,000
∆P, "WG	1.3

Table 3: SCR Design Conditions:

	Units	Max.	Min.
HHV	BTU/lb	13,500	10,500
Moisture	%	11.0	3.0
Volatiles	%	39	28
Fixed C	%	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_2O_3	%	38	8
Fe_2O_3	%	25	2
TiO_2	%	3.5	0.4
P_2O_5	%	0.6	0.1
CaO	%	10	0.5
MgO	%	8.0	0.3
Na_2O	%	4.0	0.1
K_2O	%	3.0	0.1
SO_3	%	10	[illegible]
As	ppm	12	0
Ba	ppm	3	0
Mn	ppm	78	0

Table 4: Design Coal A

Table 4: Design Coal Analysis

Item	Boiler Load	Location	Requirement/Target (If Desired)	Model Results
Velocity Distribution	100%	AIG Inlet	20%/15% RMS	13.4% RMS
Velocity Distribution	40%	AIG Inlet	20%/15% RMS	13.9% RMS
Velocity Distribution	100%	Catalyst Face	15%/10% RMS	13.4% RMS
Velocity Distribution	40%	Catalyst Face	15%/10% RMS	13.6% RMS
NH_3 Distribution	100%	Catalyst Face	10% RMS	8.4% RMS
NH_3 Distribution	40%	Catalyst Face	10% RMS	7.9% RMS
ΔP	100%	System	Minimal	3+ “WG
ΔP	40%	System	Minimal	< 1 “WG
Dust Layout	100%	System	Minimal	Swept
Dust Layout	40%	System	Minimal	Some Layout

Table 5: Cold Flow Model Results

Figures

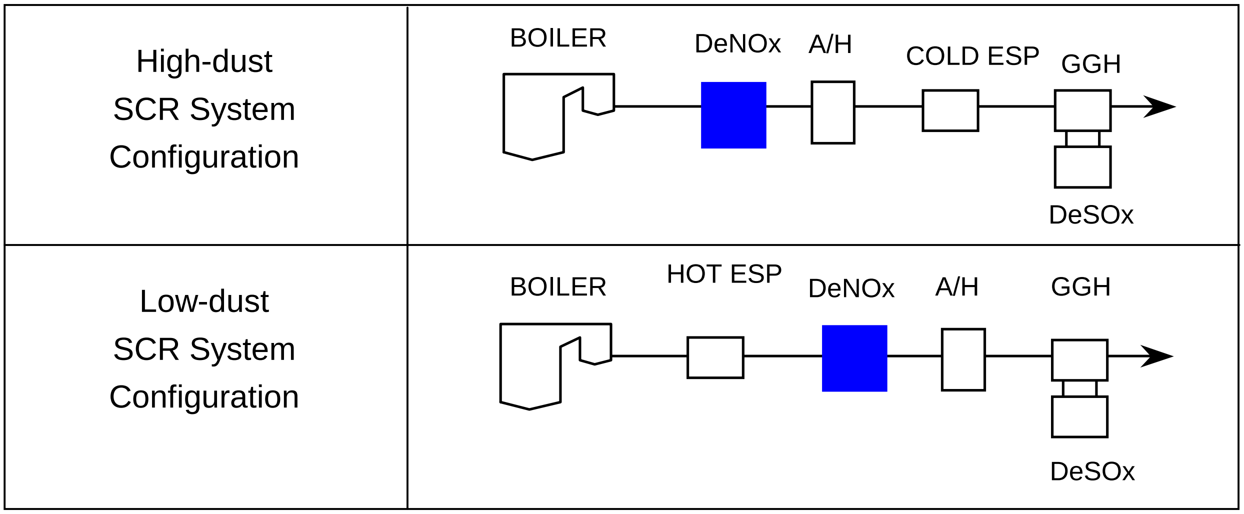

Figure 1: SCR System Flow Diagram for Coal Fired Boiler

Figure 2: Flue at West Precipitator Exit – Note AIG

Figure 3:
West Reactor

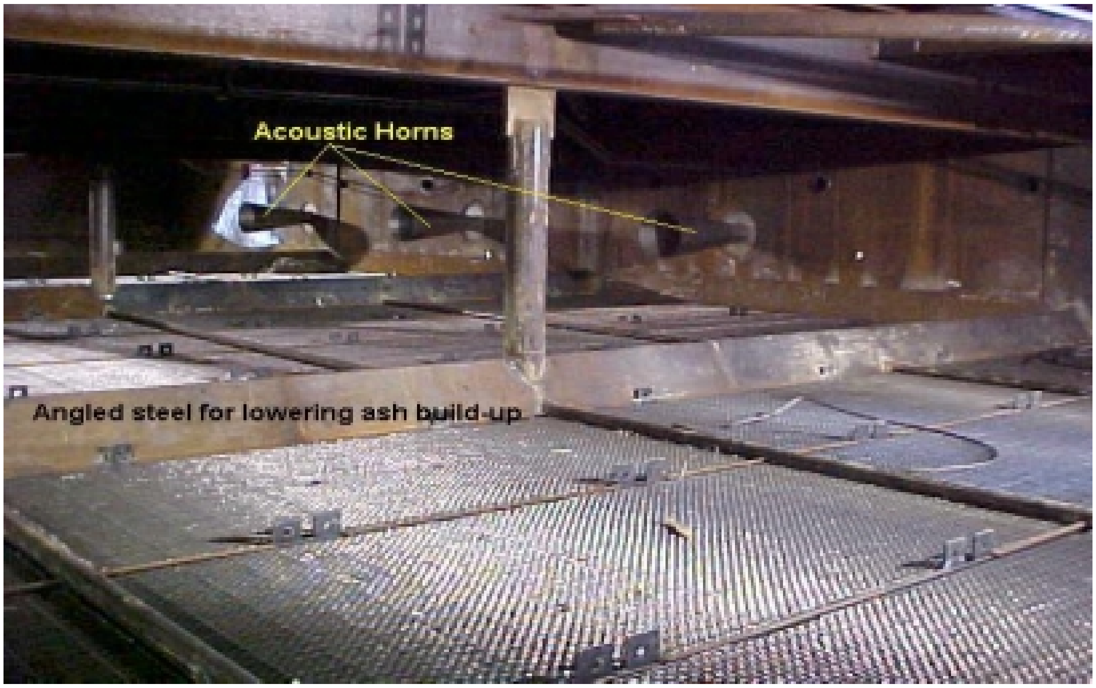

Figure 4: The Acoustic Horn Arrangement

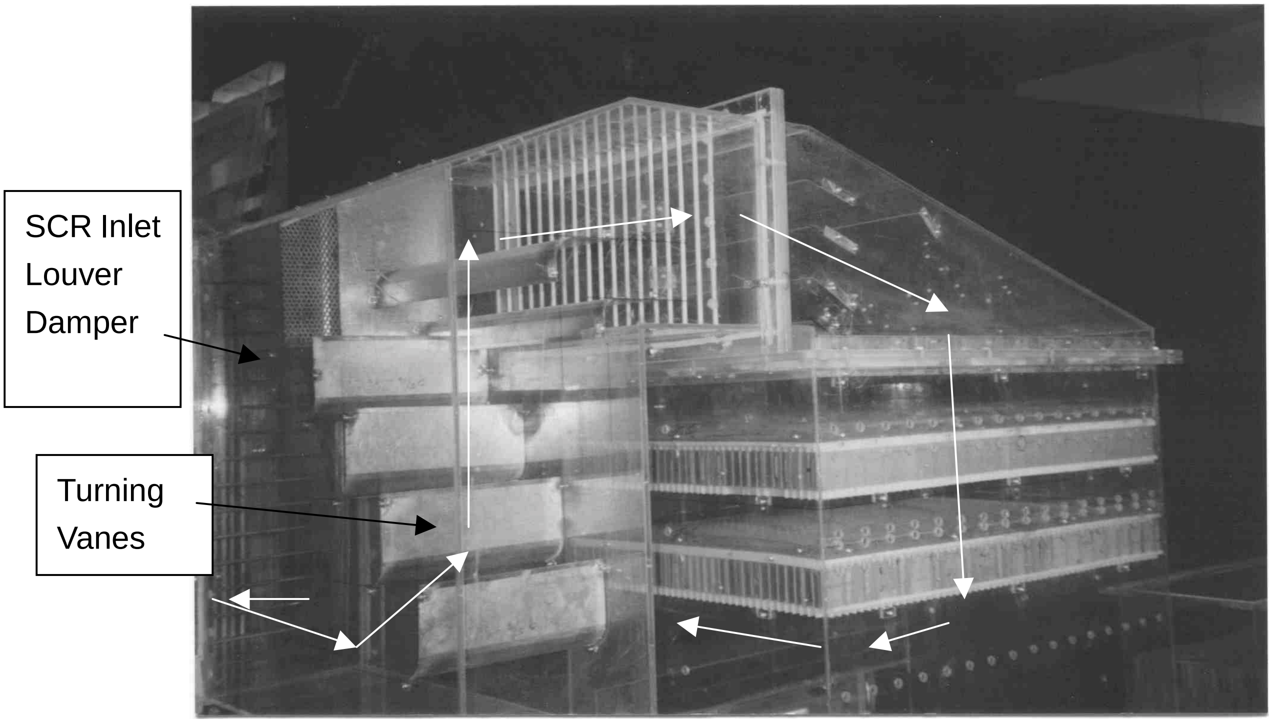

Figure 5: Gas Flow Model: Inlet and 4A (East) Reactor

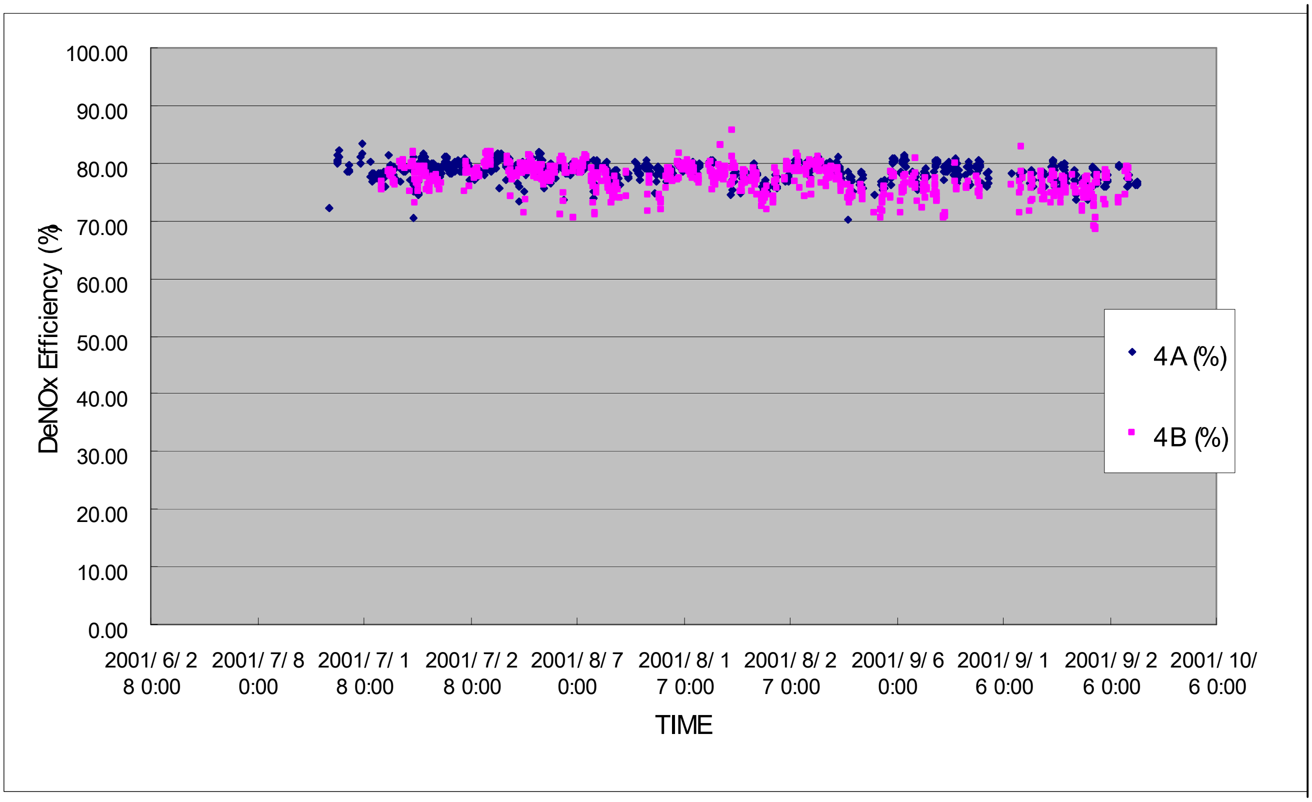

Figure 6: DeNOx Efficiency

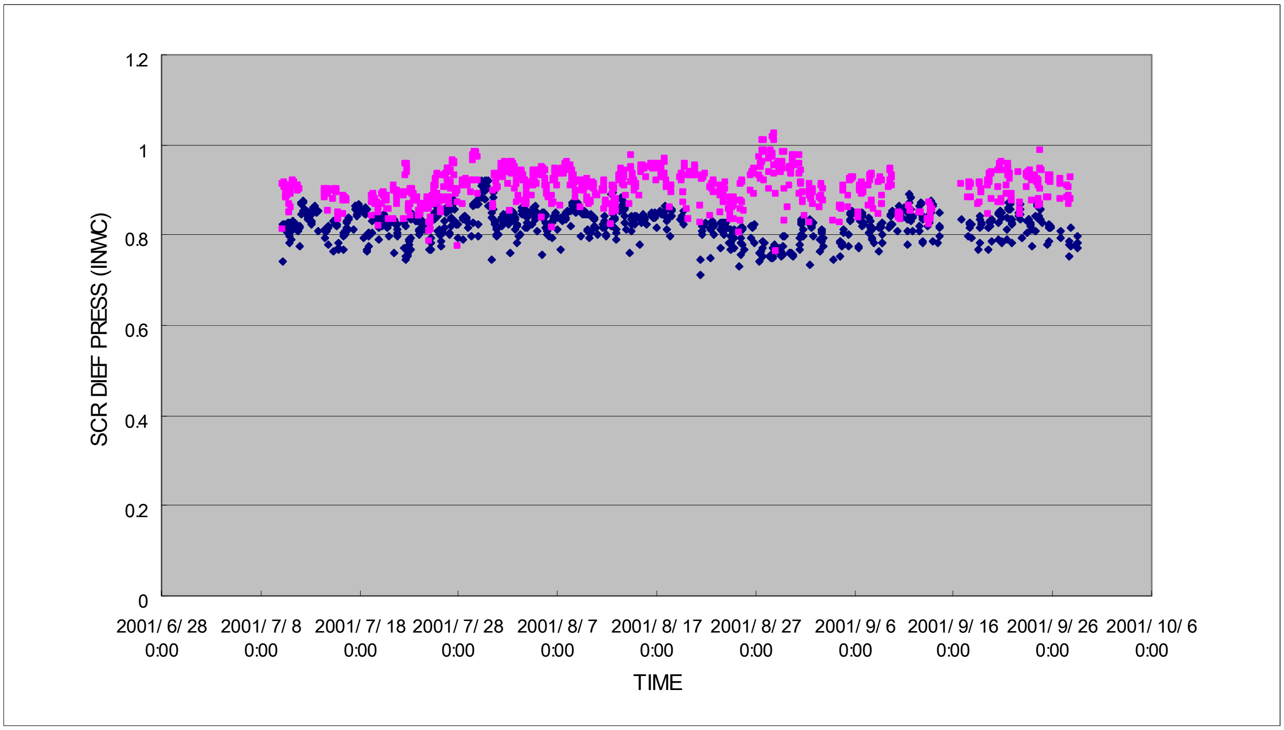

Figure 7: Catalyst Pressure Loss - First Ozone Season.

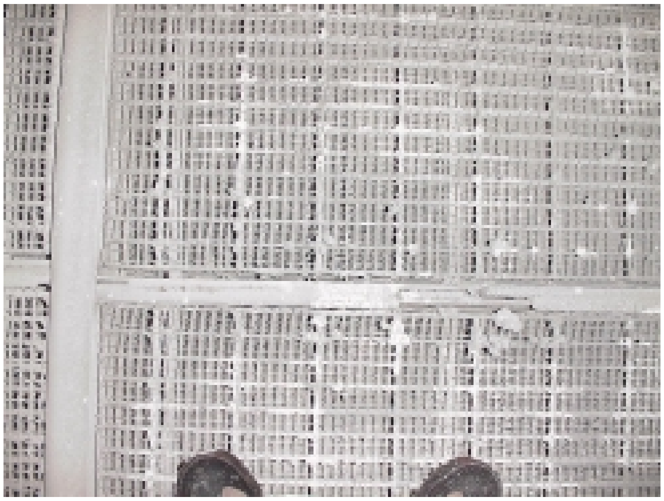

Figure 8: Catalyst After one Ozone Season

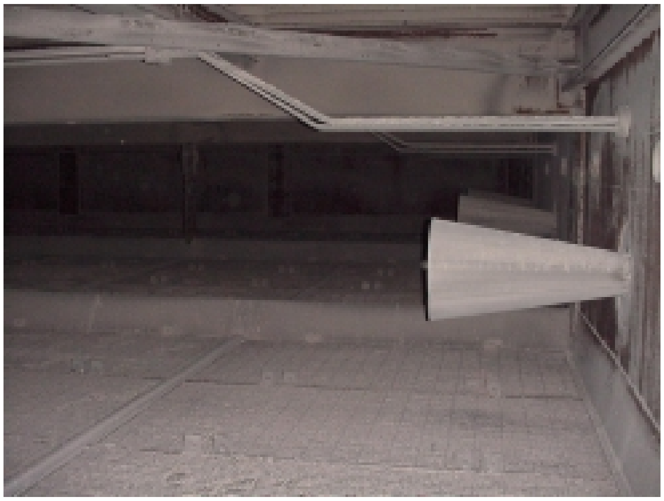

Figure 9: Reactor After one Ozone Season