REINHOLD ENVIRONMENTAL Ltd.

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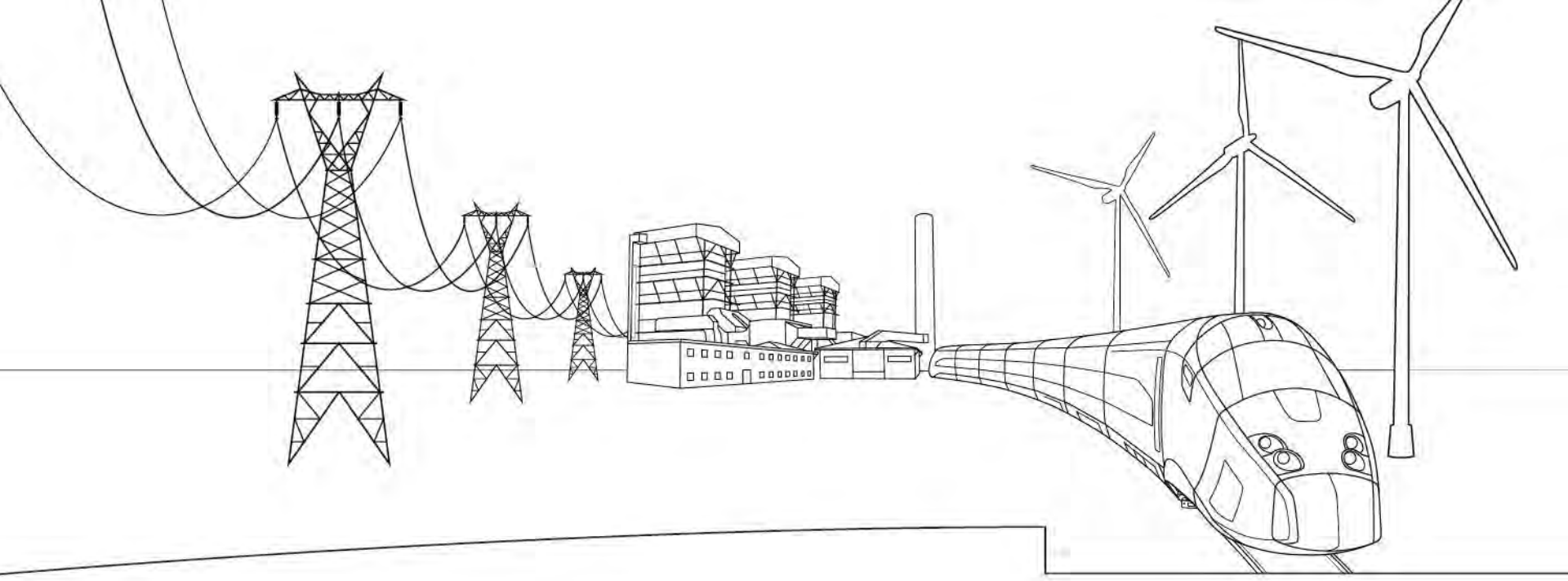

High Temperature SCR Design and Field Experience with a Coal-fired Utility Boiler

Larry Czarnecki, Torgny Ekman, Luca Spagnolo, Paulo Oliveira

Reinhold NOx Conference 2014 - Charlotte, NC

11FEB2014

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Shaping the future

- Sines Boiler Description
- NOx Emission Control Objectives
- SCR System Features
- Field NOx Emission Control Performance

Sines Power Station

- Located near Sines, Portugal. Operated by EDP, Energias de Portugal.
- Four generators with a power capacity of 4 x 314 MWe
- Conventional thermal boilers manufactured and installed by Mague (Foster Wheeler license)

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Sines Power Boilers

Sines Station Boiler Features

Boilers:	4 total
Boiler Capacity:	314 MWe, each
Boiler Fuel:	Bituminous Coal
Boiler Config:	Wall-fired, 4 x 5 burner arrangement
Boiler NOx Control:	Low NOx Burners (LNB)
	Boosted Overfire Air (BOFA)
PM Control:	Electrostatic Precipitator (ESP)
SO_2 Control:	Limestone Wet Fluegas Desulfurization (LS-WFGD)

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Sines Power Station

Sines Station Coal Supply

High Heating Value: 11,700 BTU/lb, 27200 kJ/kg

Ultimate Analysis (wt basis):

Carbon	66 %
Hydrogen	4 %
Oxygen	6.3 %
Sulfur	1.0 %
Nitrogen	1.5 %
Ash	11 %
Chlorine	0.15 %
Phosphorus	0.05 %
Arsenic	<10 ppm

Bituminous coal supply

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Sines Power Station

Sines Station Boiler Exhaust Gas @ Economizer Outlet

Design Condition:	MCR (Max. Load)	MNT (Min. Load)
Flowrate, scfm	772,050	308,820
Temperature, F	797	635
Pressure, iwg	-3.7	-2.0
O_2, vol%	4	7
Ash, gr/scf*	5.3	5.3
NOx, ppmv*	315	315
SO_2, ppmv*	925	925
SO_3, ppmv*	7	7

* Basis = dry, corrected to 6% O_2

High exhaust gas temperature is a concern

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Sines Station DeNOx Objectives

General SCR System Design Criteria

Parameter	Initial	End of Life
NOx Removal Eff., %	81.5%	76.9%
NOx Emission, ppmv*	59	73
Ammonia Slip, ppmv*	1.3	2.0
SO_2 Oxidation, %	1.0	1.1
Draft Loss, iwg	3.6	4.2
Catalyst Lifetime, hr		24,000

* Basis = dry, corrected to 6% O_2

Challenging ammonia slip and SO_2 oxidation requirements

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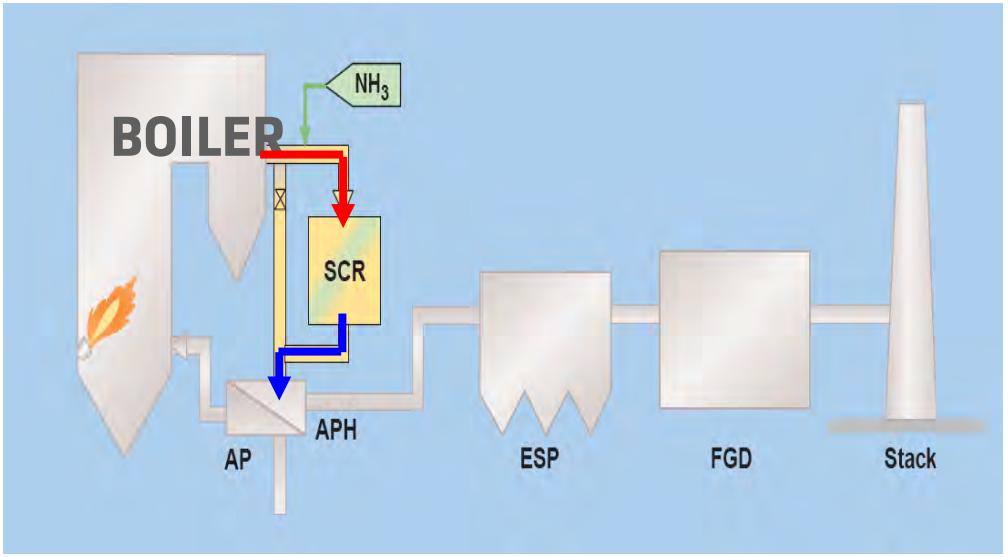
Sines Power Station – SCR System

SCR Reactor Arrangement

- Each boiler is equipped with a single, unique SCR reactor and auxiliaries system.
- SCR reactor is located between economizer outlet and Air PreHeater inlet.
- An SCR reactor bypass facilitates start-up and shut-down concerns.
- Aqueous ammonia supply is common to all four SCR systems.



Conventional high dust SCR design with bypass

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Sines Power Station – SCR System

SCR System Features

Reactor

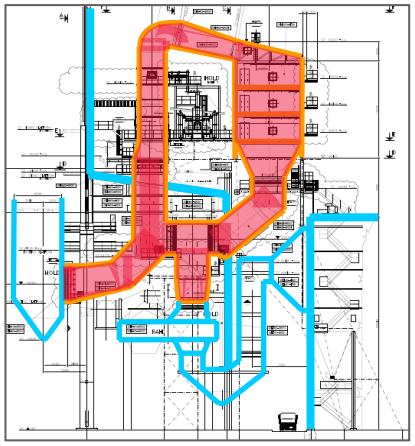
- Vertical, Down Flow arrangement
- 1 reactor/boiler. 26 ft x 92 ft area
- 2 + 1 spare catalyst layers
- Sonic horn cleaners

Catalyst

- V/W/Ti oxide composition
- Honeycomb configuration

Ammonia Supply

- 24 wt% aqueous ammonia
- Steam heated vaporizers
- Heated dilution air + mixers
- Custom designed injection grid



Red – New SCR System
Blue – Existing Boiler Facility

Conventional high dust SCR design with bypass

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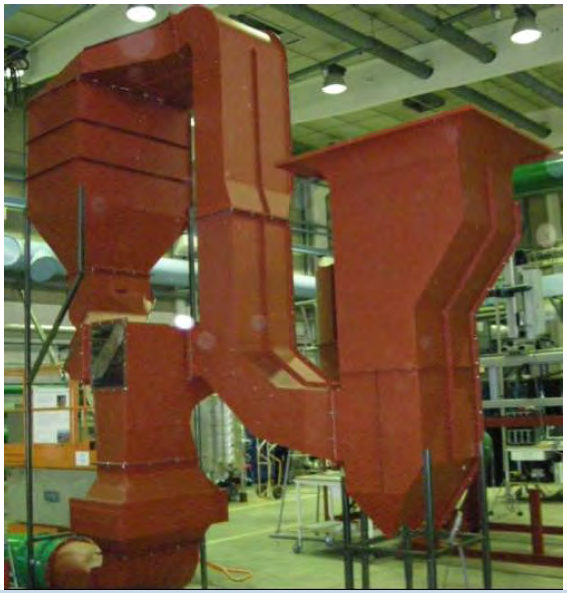
Sines Station SCR System Design

SCR System Flow Modelling

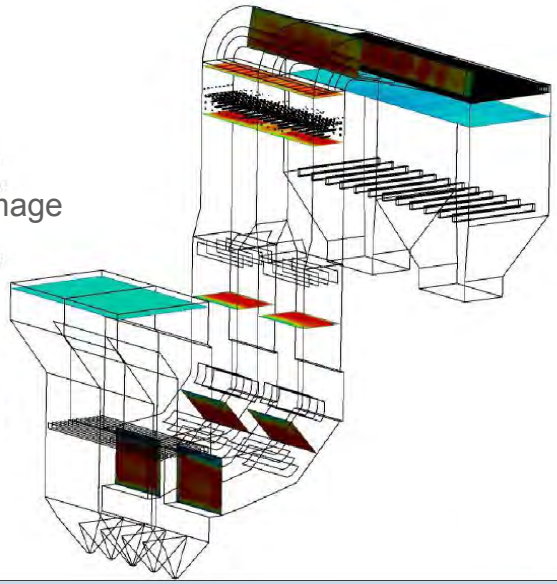
Physical and CFD models were used to address:

- Flue Gas Velocity Distributions: Ducts and Vanes
- Ammonia Distributions: Injection Grid and Mixers
- Ash Deposition: Operation Load Range



Physical Flow Model

CFD Model Image



Rigorous modelling refines and validates SCR system component designs

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Sines Station – SCR Design

High Temperature SCR System Issues

- SO_2 oxidation is a key catalyst design factor when >750 F

$$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4 \text{ (Sulfuric acid)}$$

$$SO_3 + NH_3 + H_2O \rightarrow NH_4HSO_4 \text{ (ABS)}$$

- Minimal experience with high temperature SCR systems.
- High levels of SO_3 can have detrimental effects:
  - Corrosion and fouling of exhaust gas equipment
  - Efficiency losses in Air Preheater
  - Increased opacity and SO_3 emissions

Control of SO_3 formation is paramount

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Sines Station – SCR Design

SO_3 emission concerns

- Acid corrosion in cold-end, cold-location locations
  - Below sulfuric acid dew point; 200 F - 300 F.
  - Carbon steel surfaces at risk.

- Fouling of HEX, APH surfaces
  - SO3 promotes formation of ammonium bisulfate.
  - Binds with flyash to form deposists.
  - Occurs < 500 F

SO_3 emissions can affect equipment performance and maintenance

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Sines Station – SCR Design

SO_3 emission concerns

- Excessive stack SO_3 emissions
- SO_3 emitted as sulfuric acid.
  - Cool stack temperature, high moisture content
- Visible plume emissions
- Health and environmental affects

Restrict formation and potential emission of SO_3

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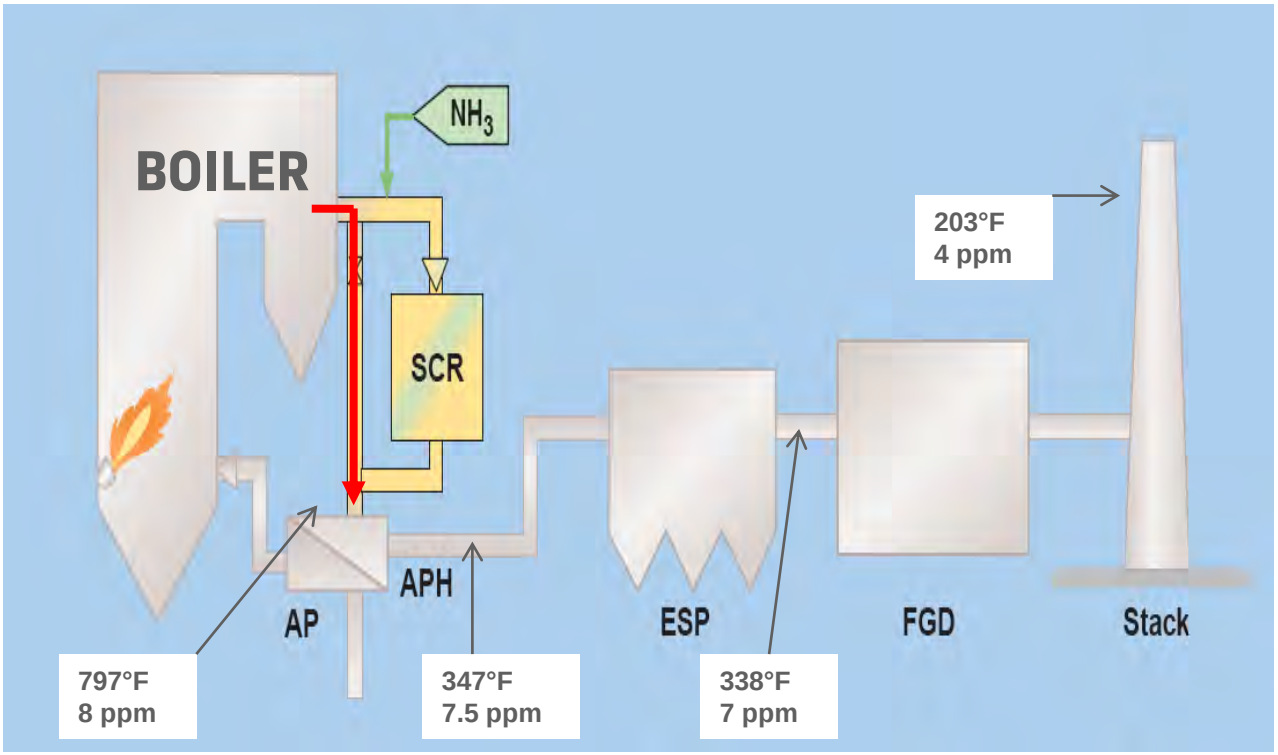
Sines Power Station – SCR System

Anticipated Temperature and SO_3 Levels without SCR



AQCS train should lower SO_3 emissions

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Sines Station – SCR Design

SO_3 Emission Strategy

- Some SO_2 oxidation to SO_3 will occur in both the boiler and the SCR system.
  - Boiler: Fuel sulfur and firing conditions.
  - SCR: Catalyst design and operating temperature.
- Post-SCR AQCS systems can contribute to lower SO_3 emissions.
  - APH: Acid and ABS condensation.
  - ESP: Condensation on fly ash.
  - WFGD: Droplet scrubbing and mist elimination.

SCR design must consider SO_3 formation

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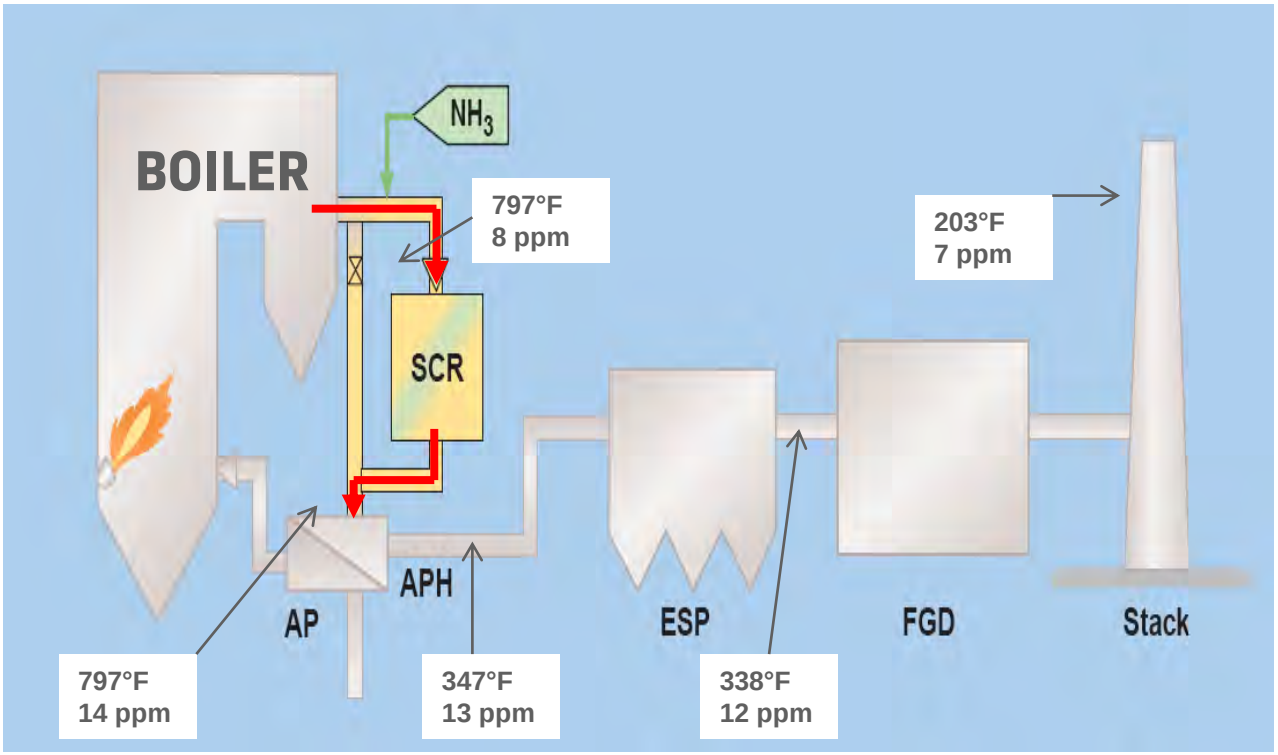
Sines Power Station – SCR System

Anticipated Temperature and SO_3 Levels with SCR



AQCS train should lower SCR SO_3 emissions

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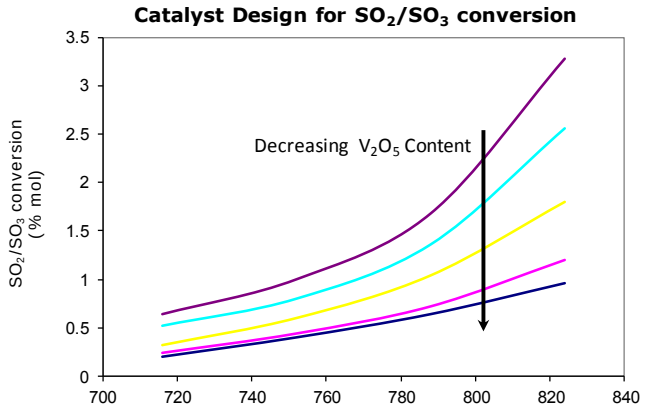
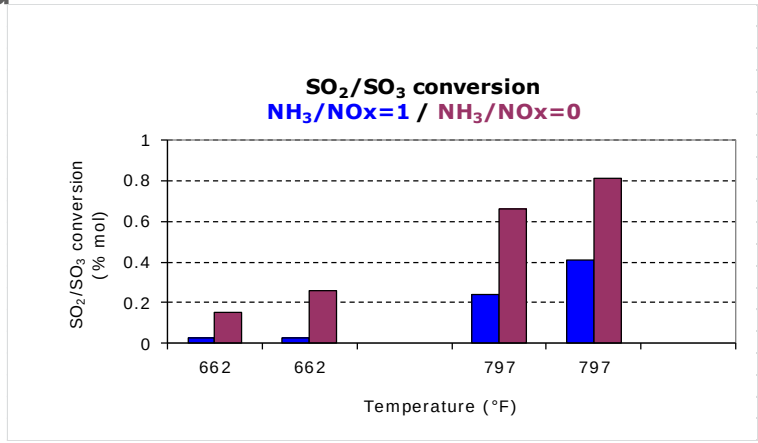
Sines Station - SCR Design

SCR Catalyst Design for SO_3 Formation

- Catalyst Formulation impacts SO_2 Oxidation rates.
- Assess catalyst production samples under simulated design conditions, including gas temperature
- Supplier and 3rd party testing by method VGB R302He
  (Measure SO_2 oxidation with and without NH_3)
- Estimate SO_2 oxidation based on lab results.
  - 1st layer (SR = 0.82); 0.34% conversion
  - 2nd layer (SR = 0.40); 0.54% conversion
  - Total catalyst bed; 0.88% conversion





Catalyst selection and design are important

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Sines Station DeNOx Performance

Boiler Unit #1 SCR Performance

Parameter	Target	MCR	MNT
Gas Temperature, F		780	657
NOx Removal Eff., %	81.5	81	83
NOx Emission, ppmv*	59	59	57
Ammonia Slip, ppmv*	1.3	<0.1	<0.1
SO_2 Oxidation, %	1.0	0.44	0.03
Draft Loss, iwg	3.6	3.3	1.4

* Basis = dry, corrected to 6% O_2

All system DeNOx requirements satisfied

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Sines Station DeNOx Performance

Boiler Unit #4 SCR Performance

Parameter	Target	MCR	MNT
Gas Temperature, F		792	657
NOx Removal Eff., %	81.5	85	84
NOx Emission, ppmv*	59	47	49
Ammonia Slip, ppmv*	1.3	0.3	0.3
SO_2 Oxidation, %	1.0	0.35	
Draft Loss, iwg	3.6	3.1	1.7

* Basis = dry, corrected to 6% O_2

All system DeNOx requirements satisfied

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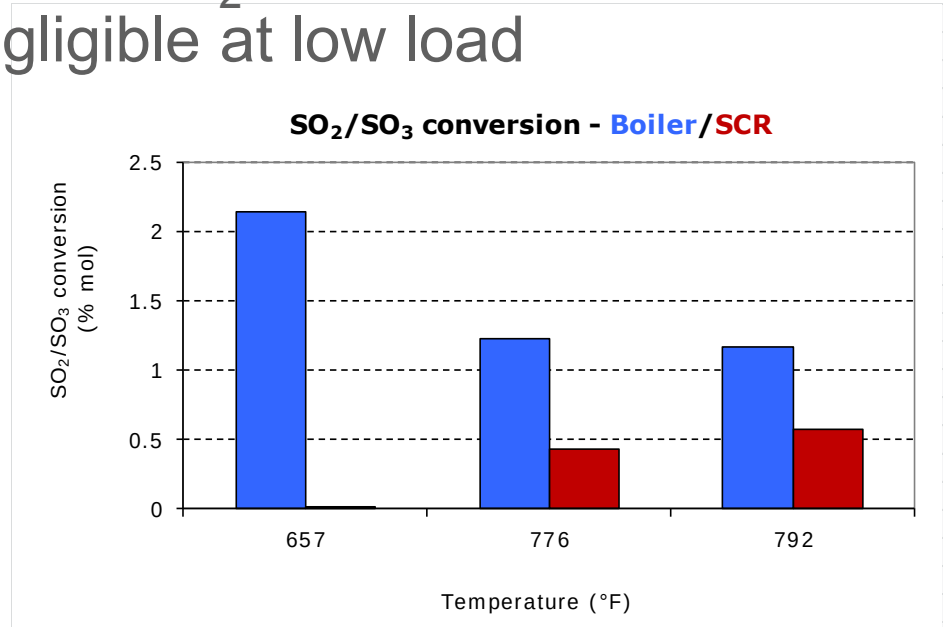
Sines Station DeNOx Performance

Unit #4 SO_2 Oxidation Performance

- Boiler SO_2 conversion is nominally 1% at full load and nominally 2% at minimum load
- SCR System SO_2 conversion is <1% at full load and is negligible at low load



SCR System does not substantially increase SO_3 emissions

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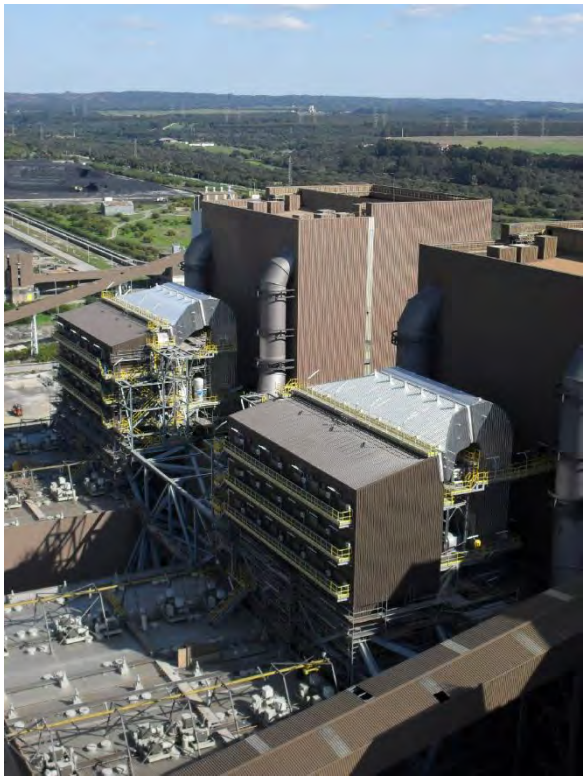
Sines Station SCR System Summary

Summary of Sines SCR Design and Performance

- Conventional SCR system design arrangement applied to existing, bituminous coal-fired boilers.
- High flue gas temperature, >750 F, was a concern for SO_3 formation and its potential effects.
- Careful catalyst selection and system modelling yielded minimal SO_3 formation while meeting NOx removal and NH_3 slip requirements.



Successful high temperature SCR was achieved

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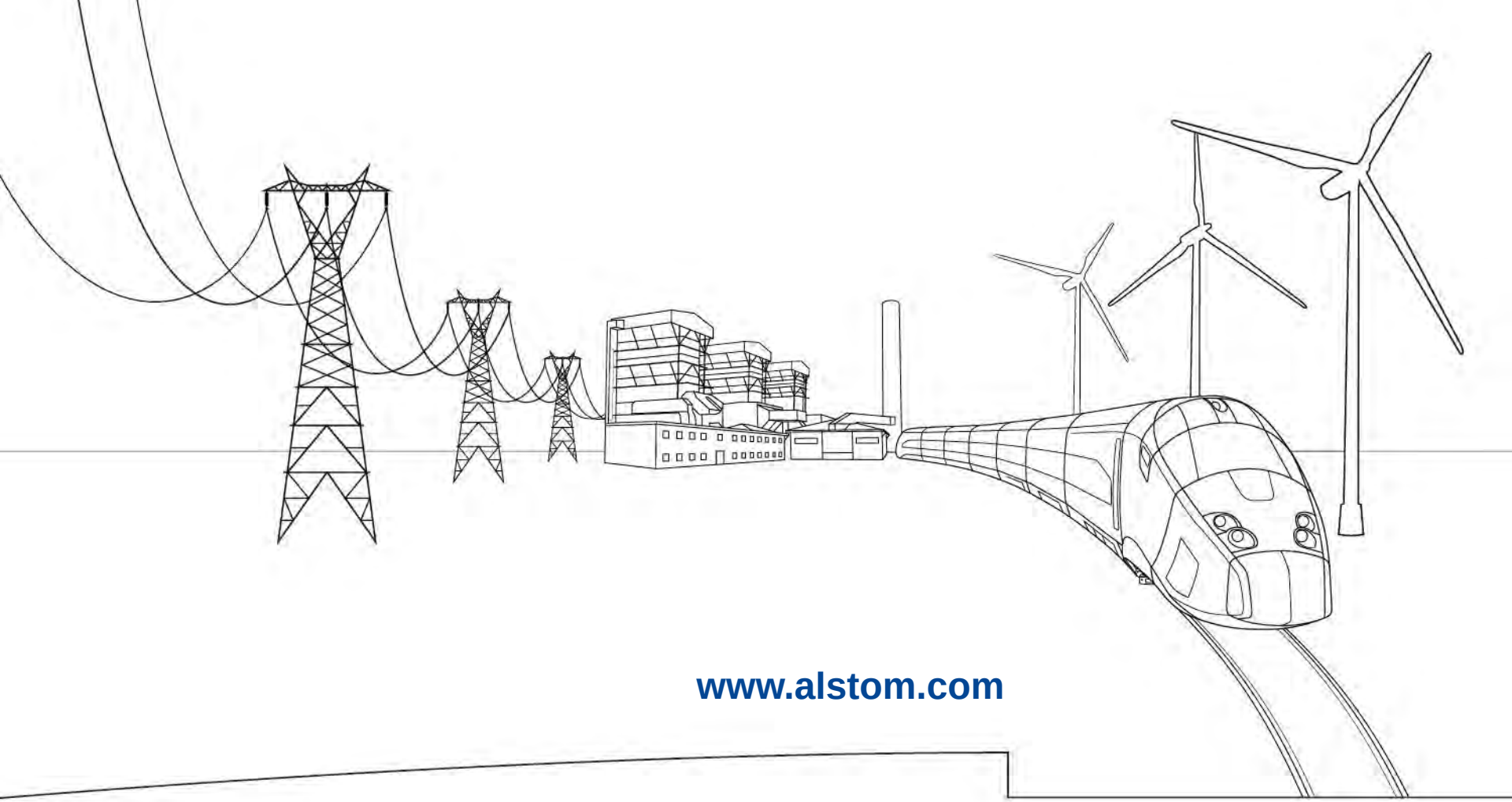

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