INDUSTRIAL APPLICATIONS OF GAS TURBINES

Fall 2010 Course

Session #7 – Emission Reduction Case Study

by

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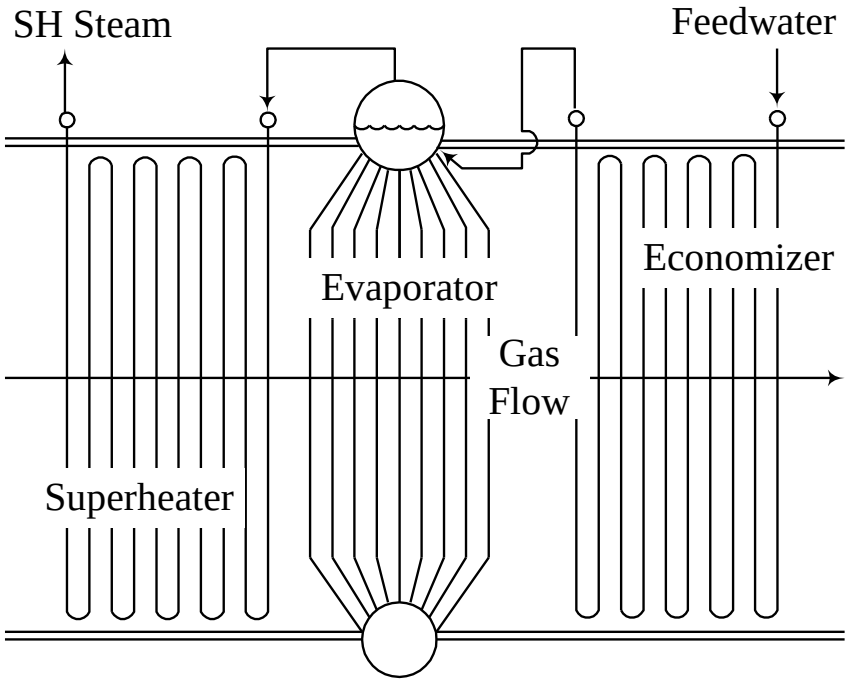
Agenda

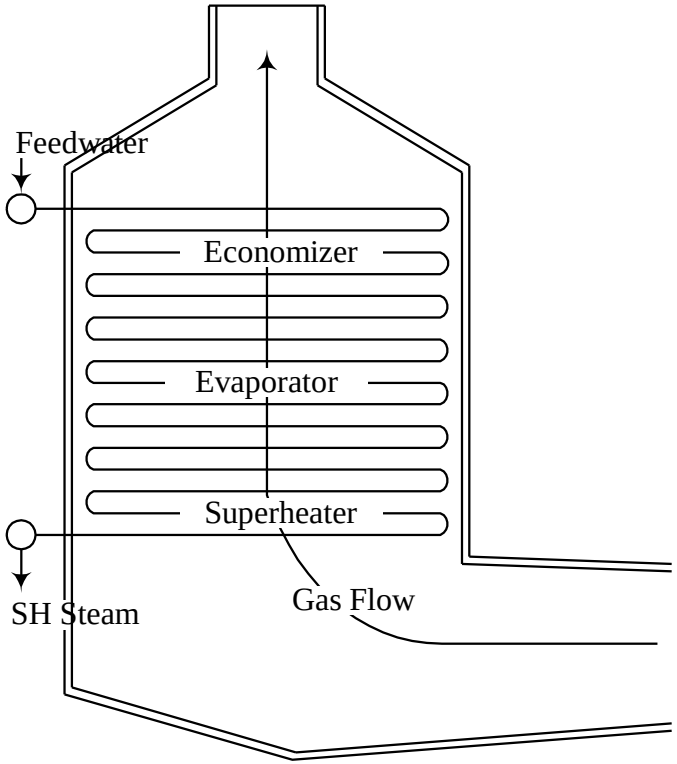
- Introduction
- Function of Catalysts
- Efficiency of the Catalyst
- Installed Configuration
- Equipment Operation
- Ammonia Slip
- Corrosion/Fouling
- Chemical Handling
- Capital Cost
- Conclusion

Introduction

- IST is a manufacturer of a type of Heat Recovery Steam Generator (HRSG) known as a Once Through Steam Generator (OTSG).



Drum Type HRSG



OTSG

Introduction

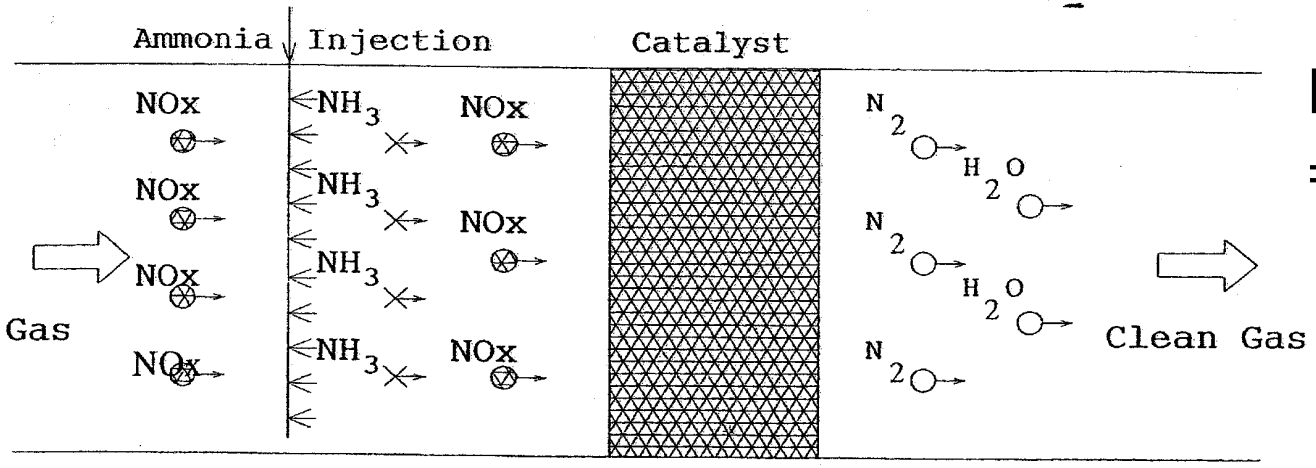
- IST is increasingly being asked to incorporate emissions control equipment due to tightening restrictions on power plant emissions

- Two main types of catalysts are used
  - Selective Catalyst Reduction (SCR) & Ammonia Injection Grid (AIG)
    - Used for reducing NOx
  - CO Catalysts

Function of Catalysts

- SCR Catalyst Function
  - Ammonia (NH_3) is injected into the gas stream upstream of the SCR catalyst. The gas stream then passes through the catalyst layer decomposing NOx (nitrous oxides, principally NO and NO_2) into harmless N_2 and H_2O.

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$$
$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$



Typical catalyst weight
LM6000 Turbine
= 63,000 lbs

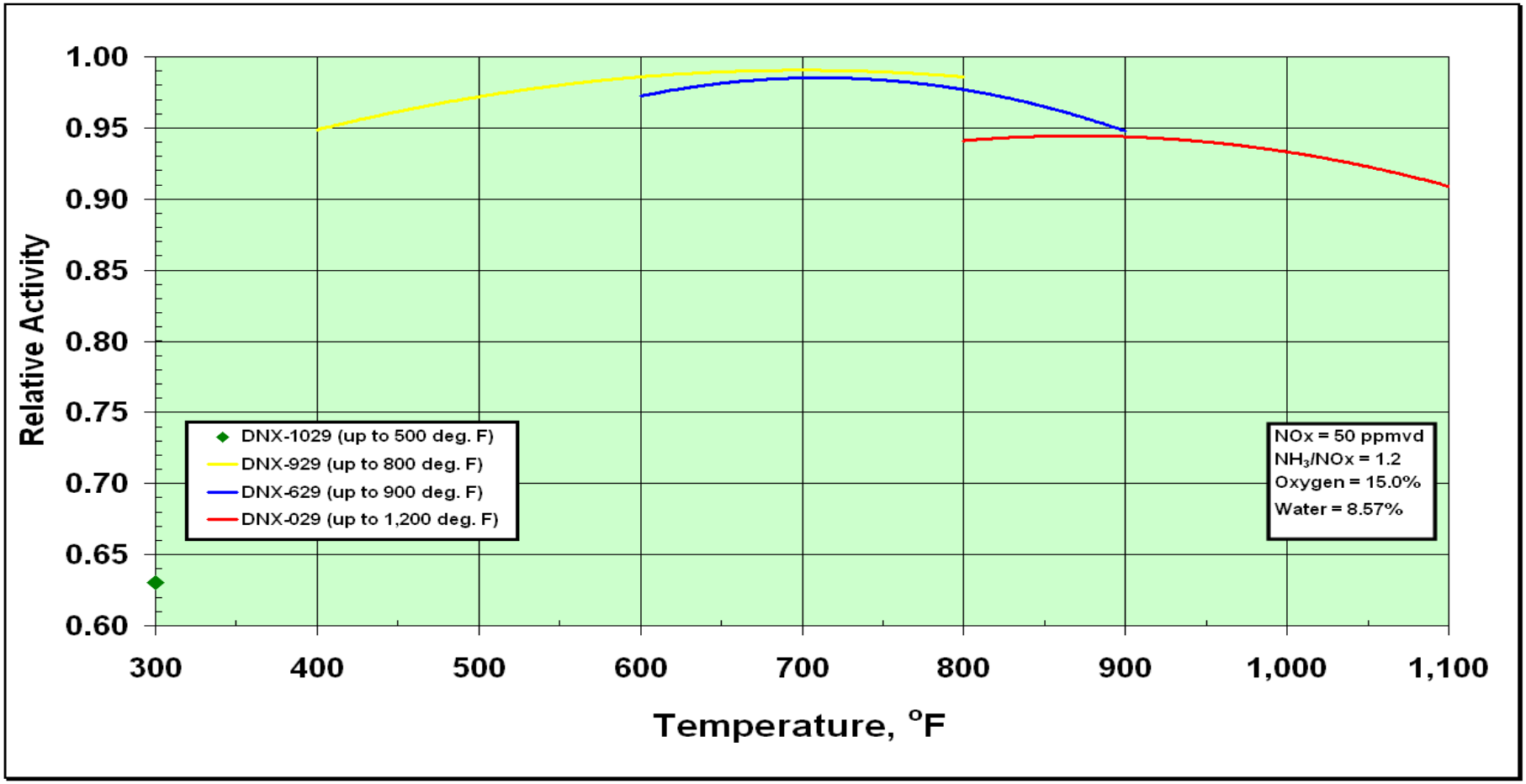
Function of Catalysts

- CO catalysts are much less involved:
  - They convert carbon monoxide to carbon dioxide
  - They can also convert SO2 to SO3 which is detrimental
    - Typical conversion rate could be from 25% to 35%

- Typical catalyst weight for an LM6000 turbine OTSG
  - 12,000 lbs

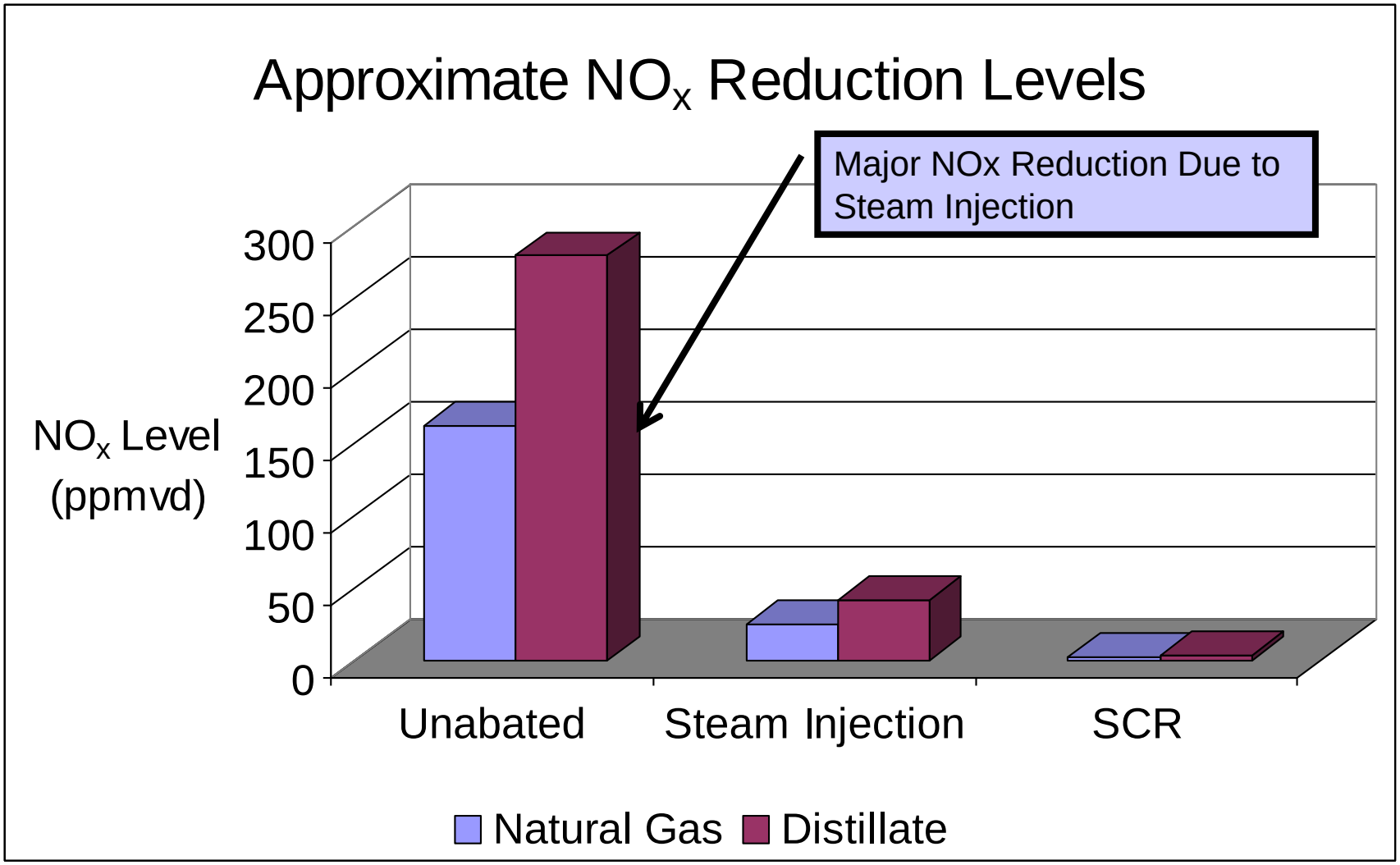
Performance of Catalysts

- SCR Catalyst Location
  - The SCR catalyst must be located in the appropriate gas temperature zone for maximum efficiency



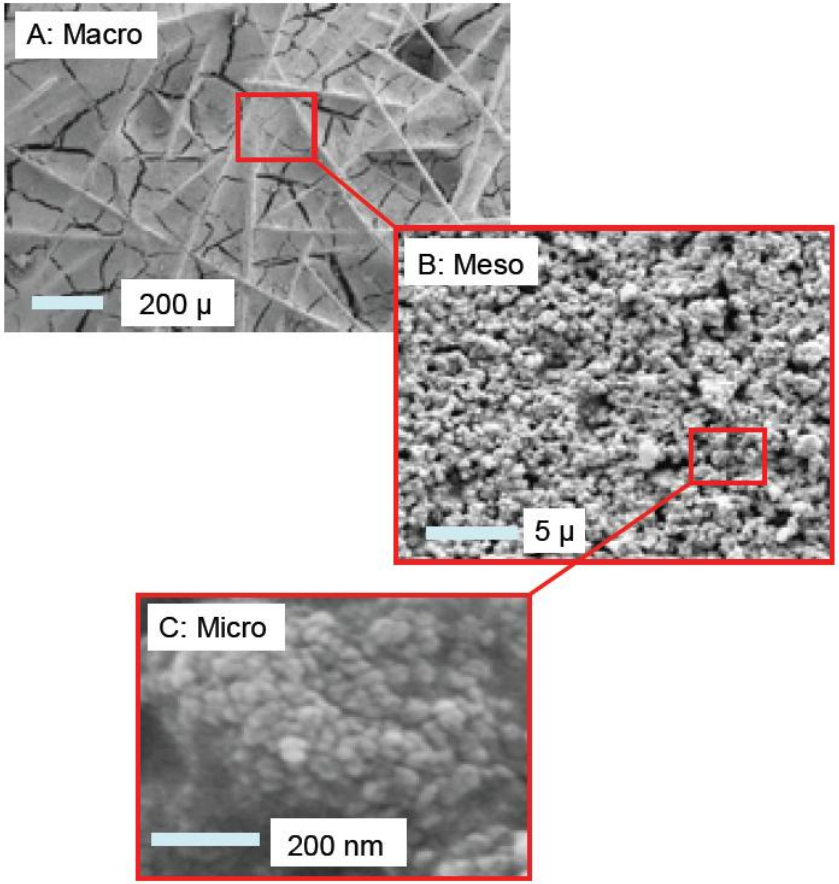
Performance of Catalysts

- Comparison of NOx Abatement Technologies



Performance of Catalysts

- What happens to catalysts that overheat?
  - The catalyst depends on its surface area in order to maintain a certain level of reactivity



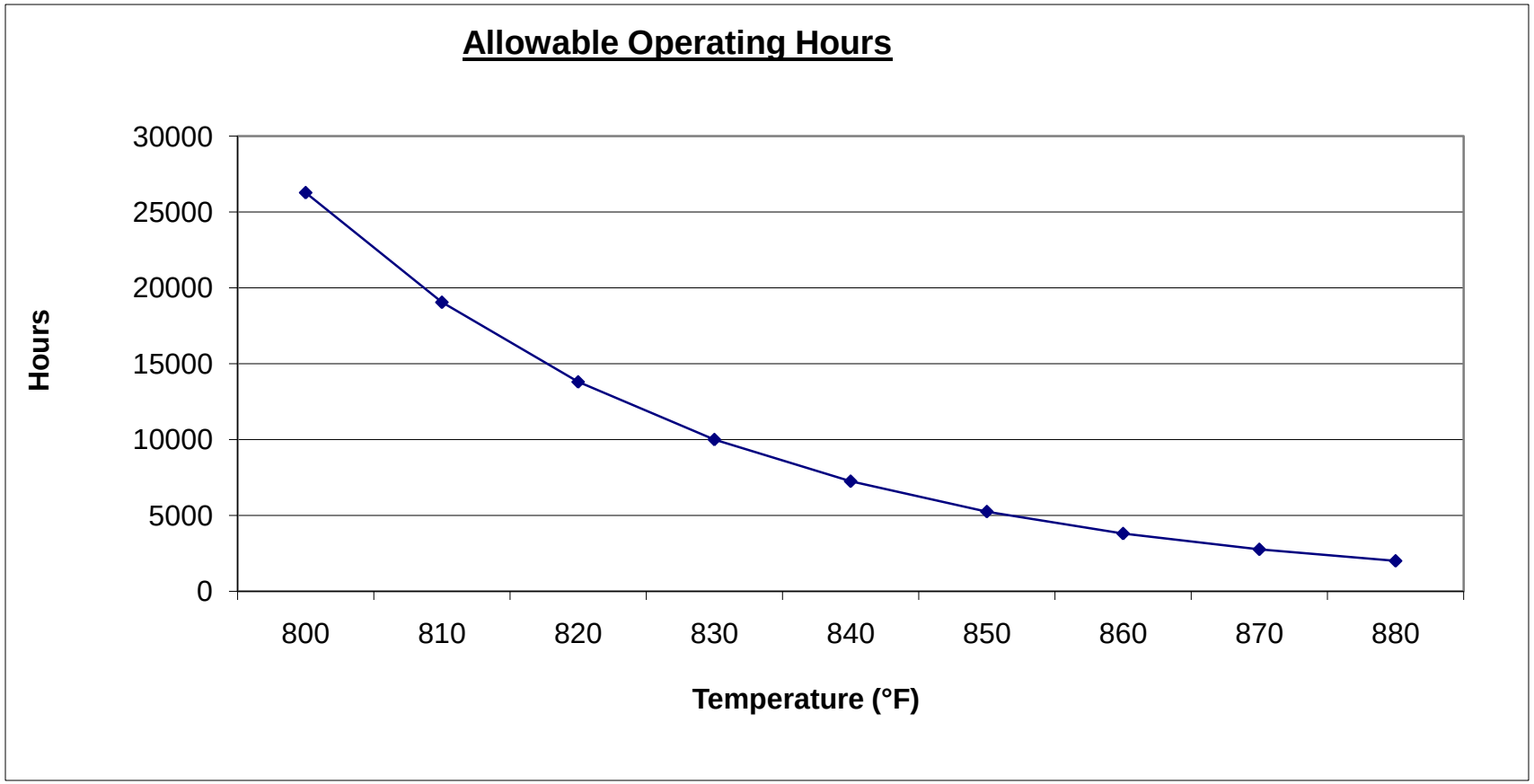
http://www.topsoe.com

The catalyst is manufactured in such a way that the surface area is maximized.

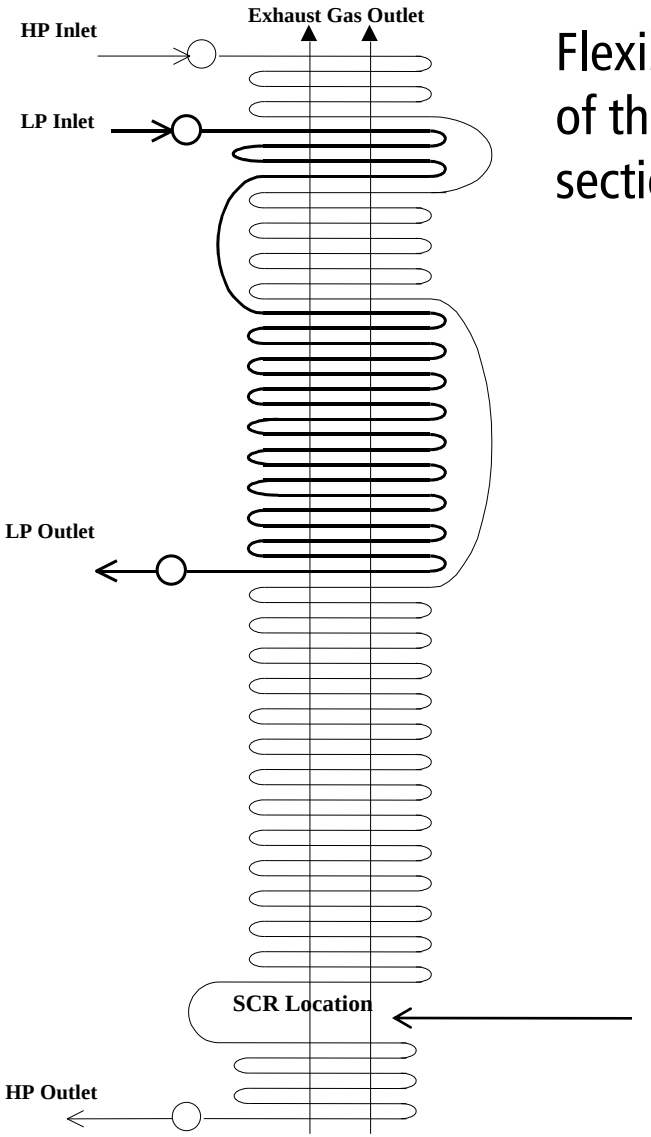
Beyond a certain temperature, these pores begin to sinter together, decreasing reactivity.

Performance of Catalysts

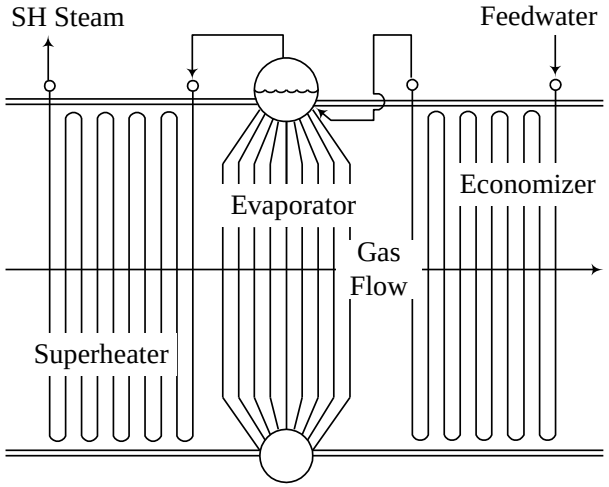
- What happens to catalysts that overheat?
  - Manufacturers will limit the duration of temperature excursions that can occur without voiding the guarantee



Installed Configuration



Flexibility of the OTSG allows for optimum placement of the SCR in either the evaporator or superheater section

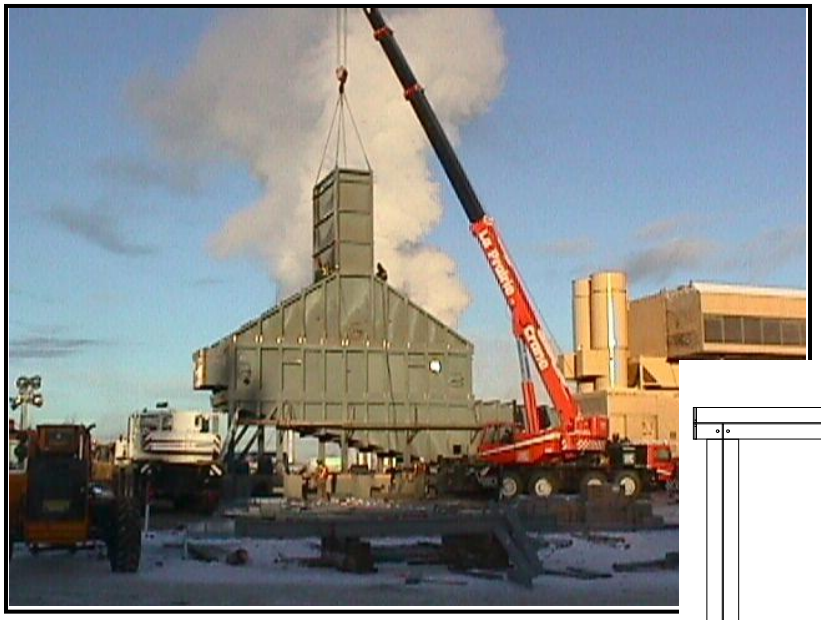


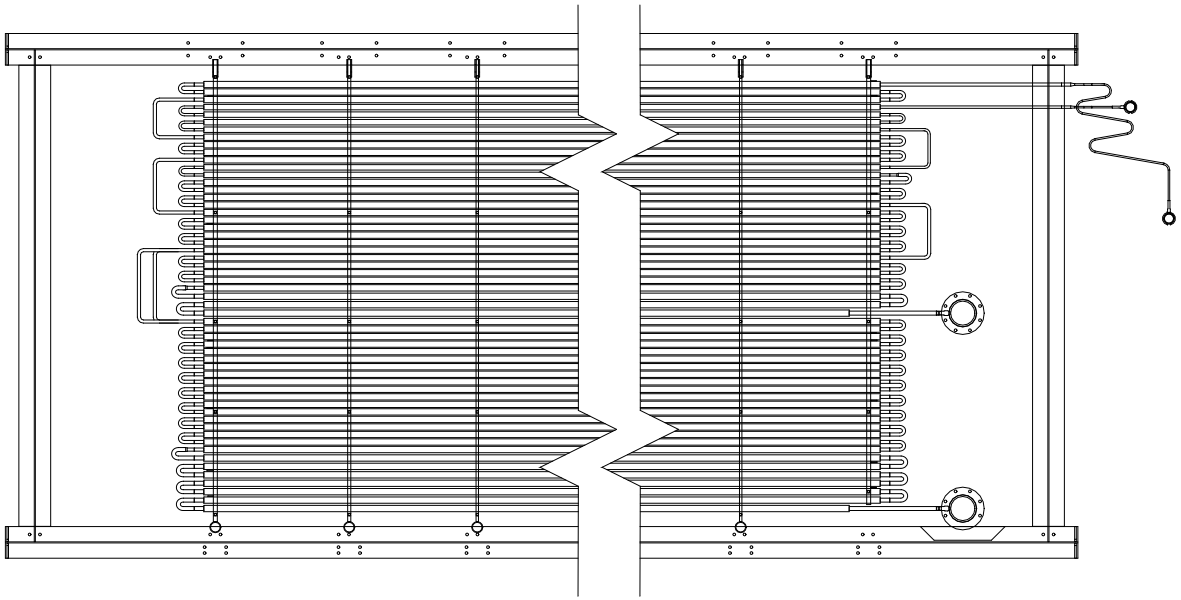
The drum connections limit the sites for where an SCR can be located within a drum type HRSG

Tubes are "jumpered" around the SCR surface

Installed Configuration

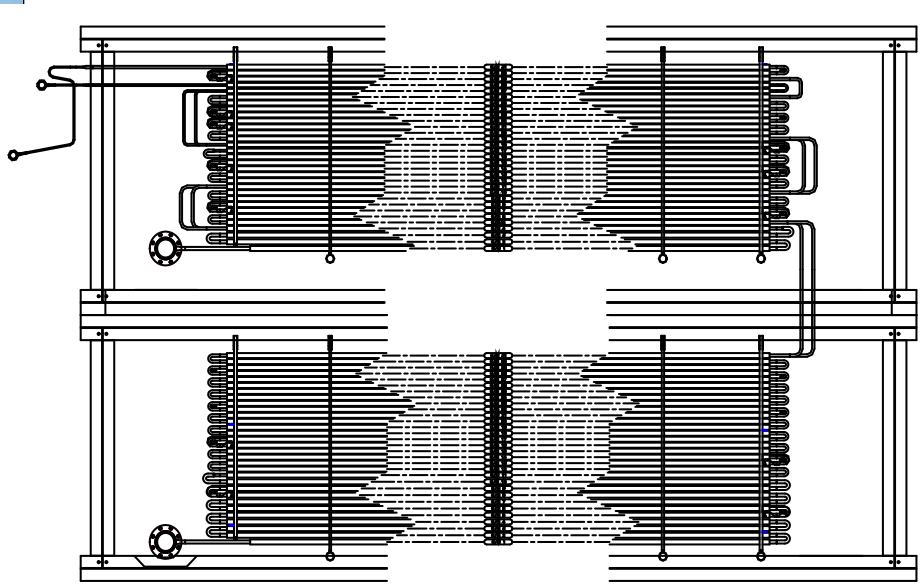
- Typical single module OTSG





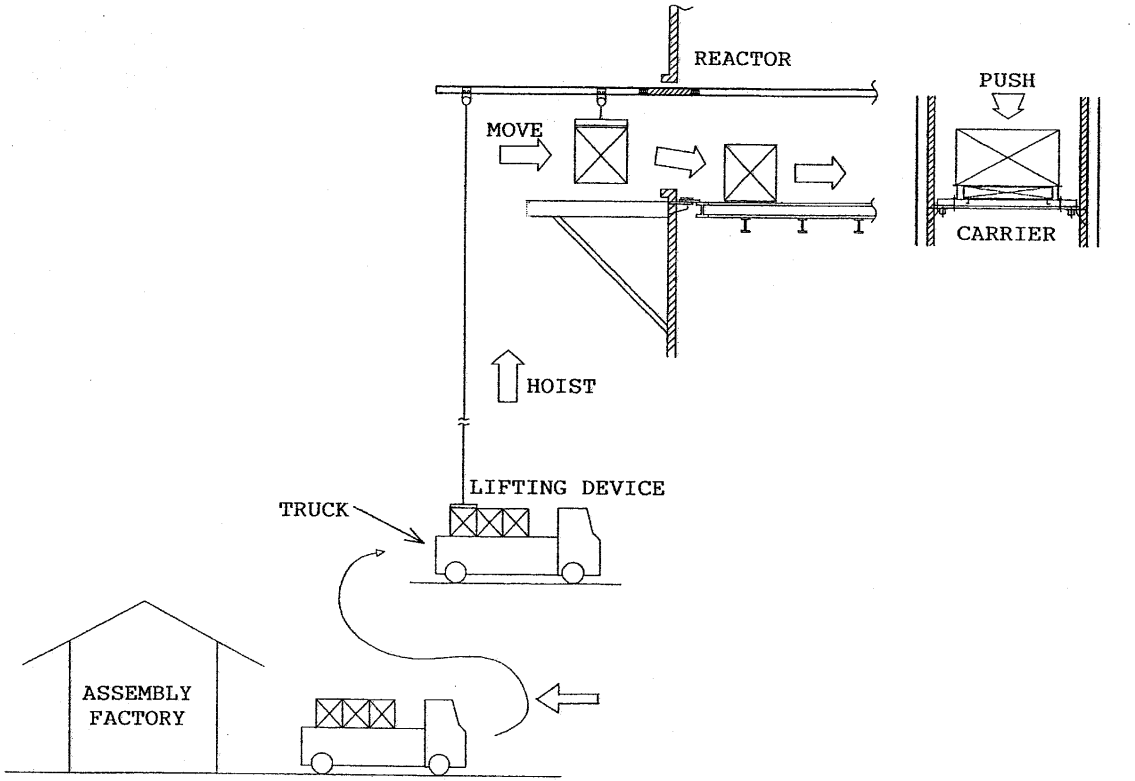
Installed Configuration

- The SCR is housed in a space between the heat recovery tubes



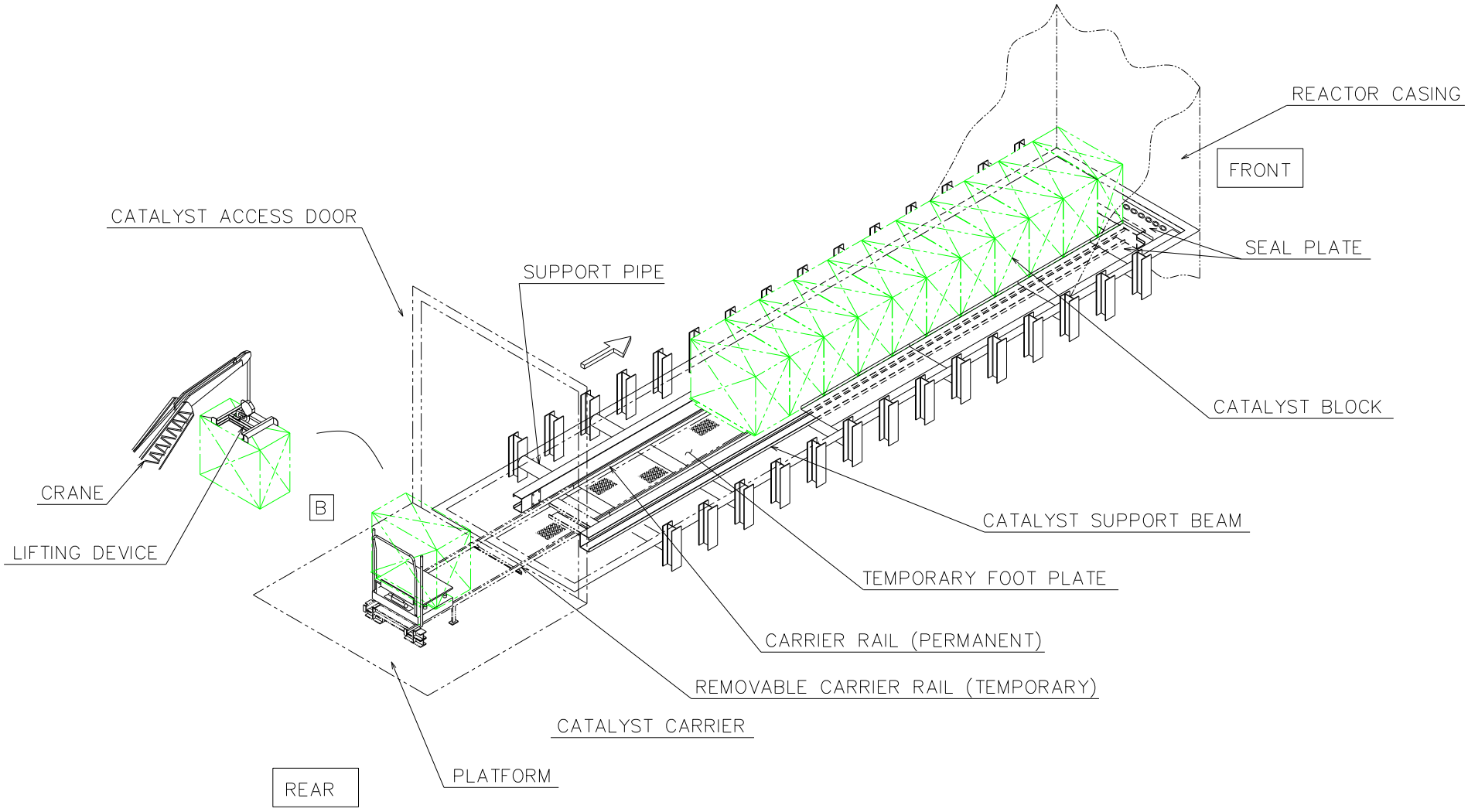
Installed Configuration

- Catalyst units are loaded through an access door located in the casing
- After lifting the catalyst units with a crane, the units are placed onto a hydraulic carrier
- The hydraulic carrier locates the blocks into the reactor casing



Installed Configuration

- Catalyst installation schematic

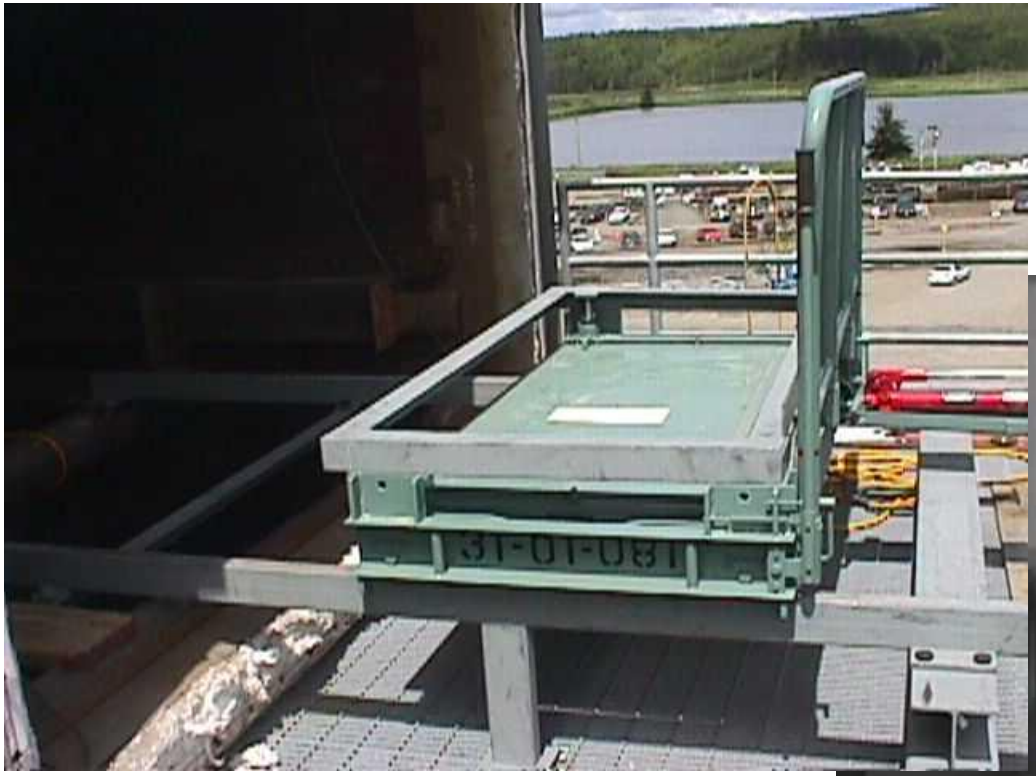


Installed Configuration

- Catalyst installation at Las Vegas Cogen

Installed Configuration

- Hydraulic catalyst block carrier



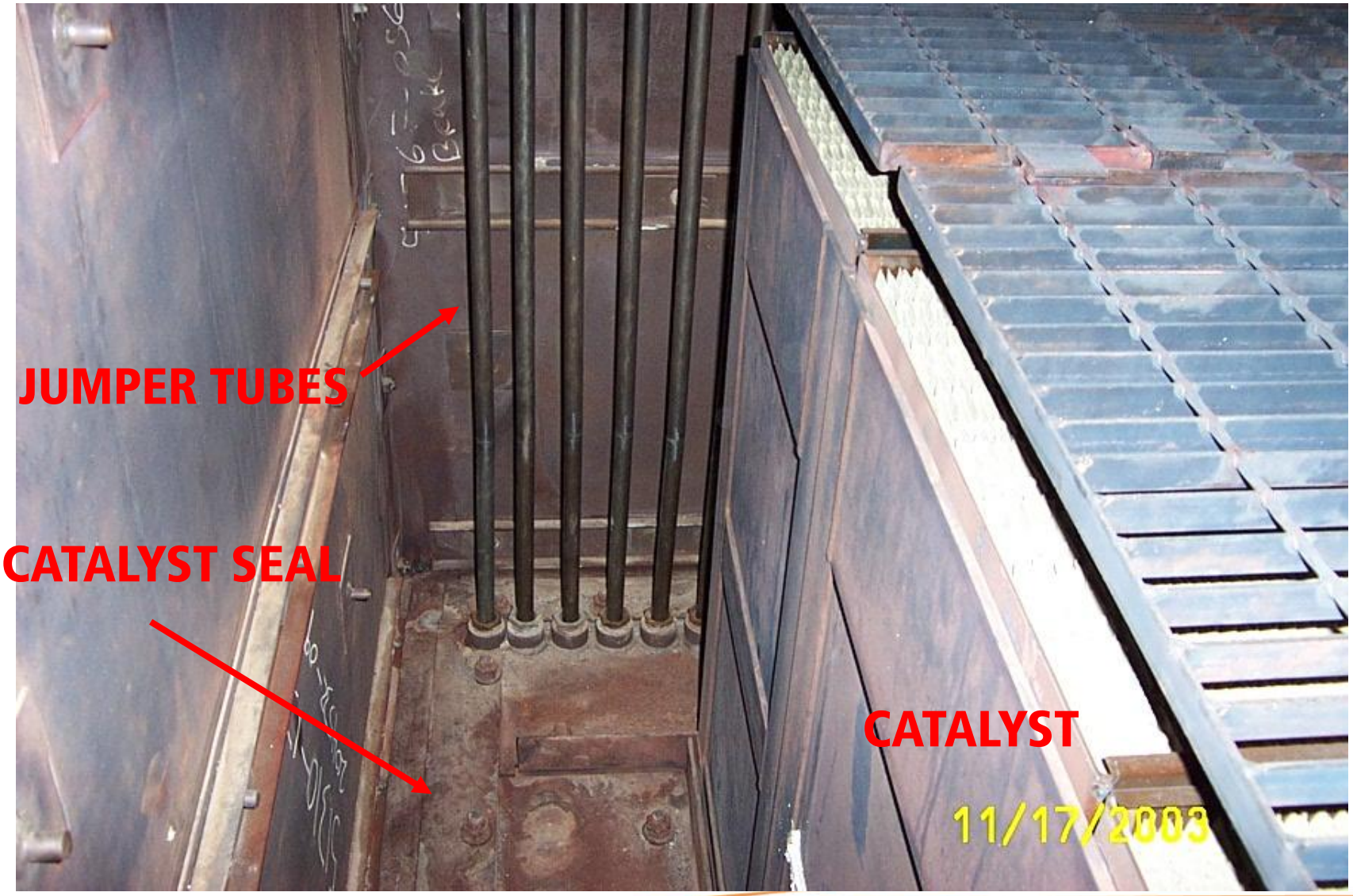
Installed Configuration

The SCR is housed in a space between the heat recovery tubes.

Installed Configuration

- Locating the catalyst block within the OTSG cavity

Installed Configuration

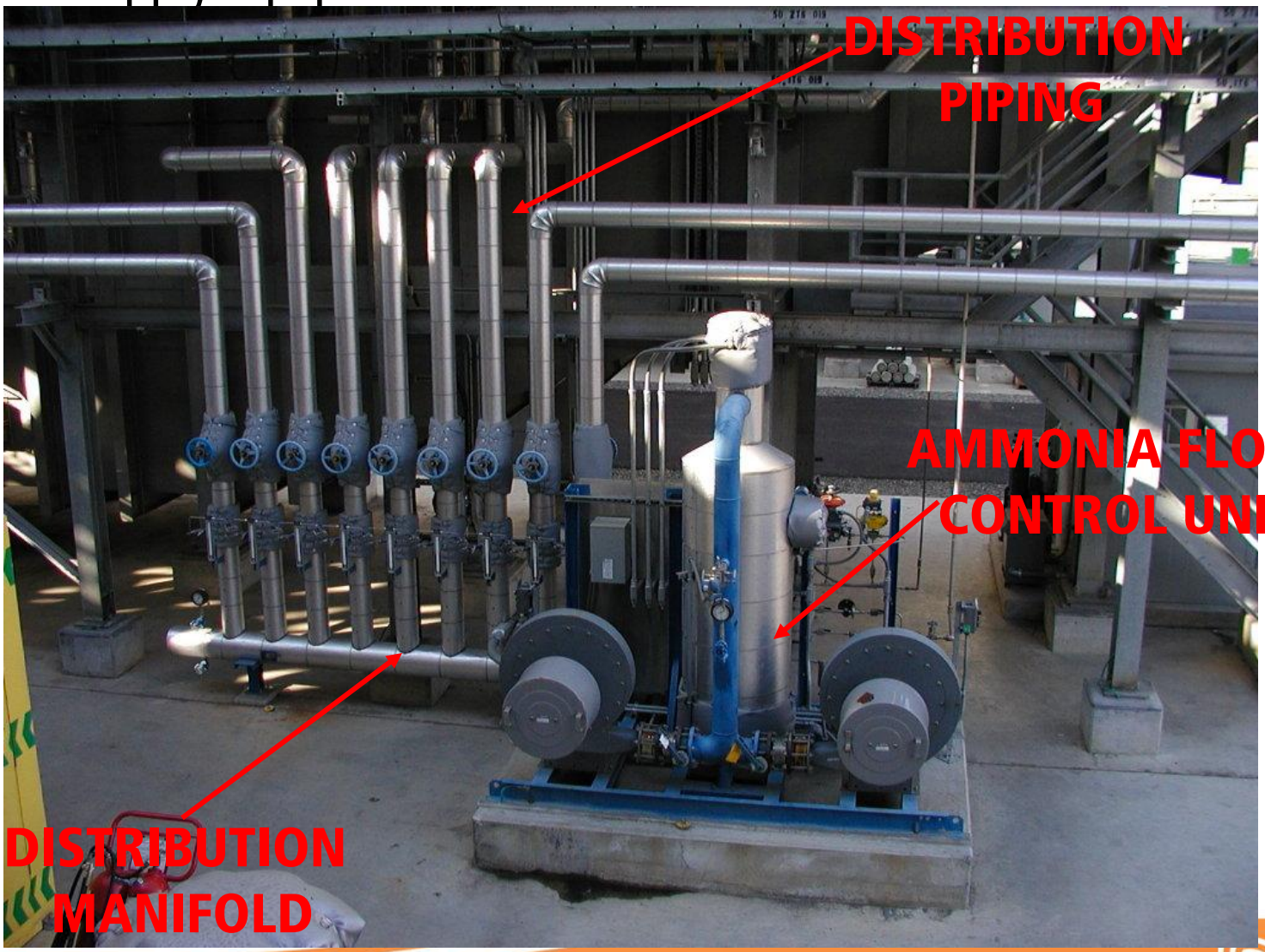


Installed Configuration

- Ammonia Injection Grid (AIG) configuration

Installed Configuration

- Ammonia supply equipment



Installed Configuration

- Ammonia supply equipment

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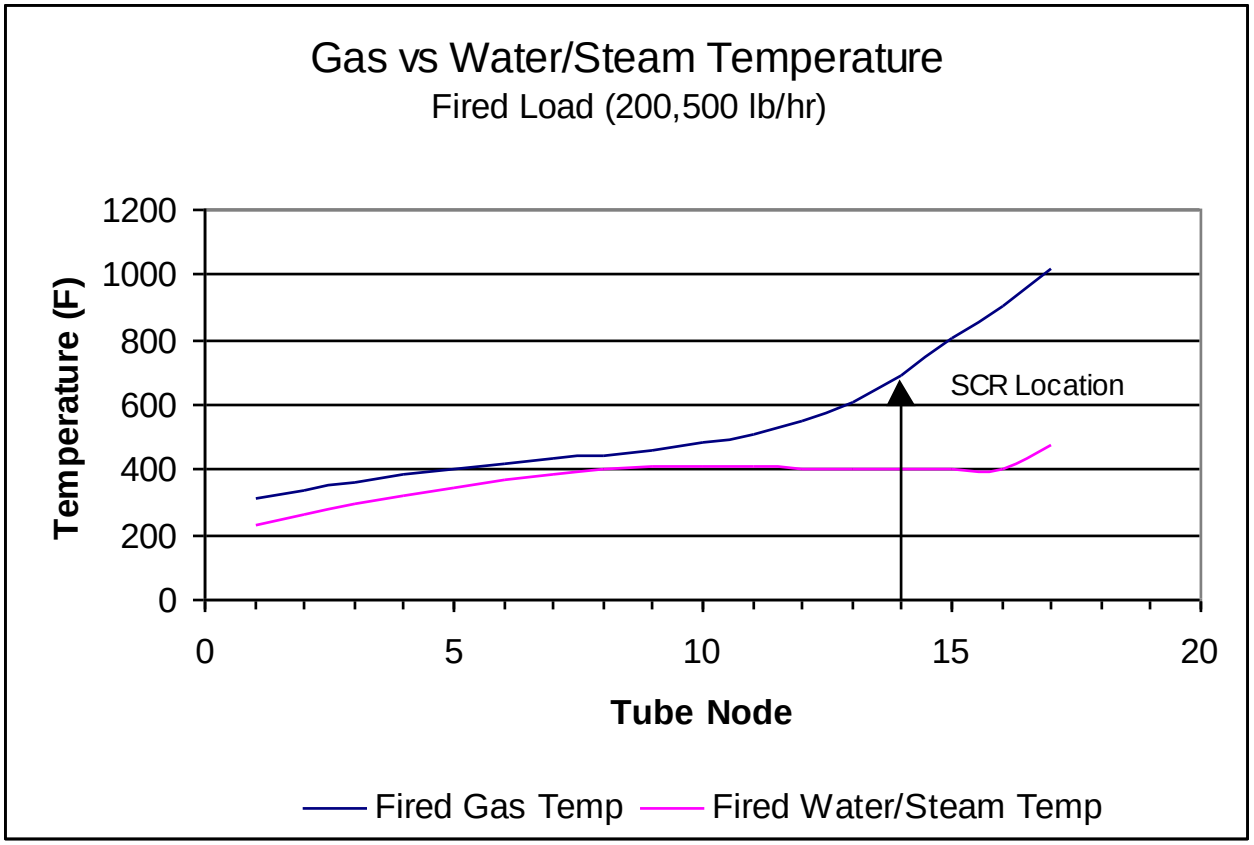
Installed Configuration

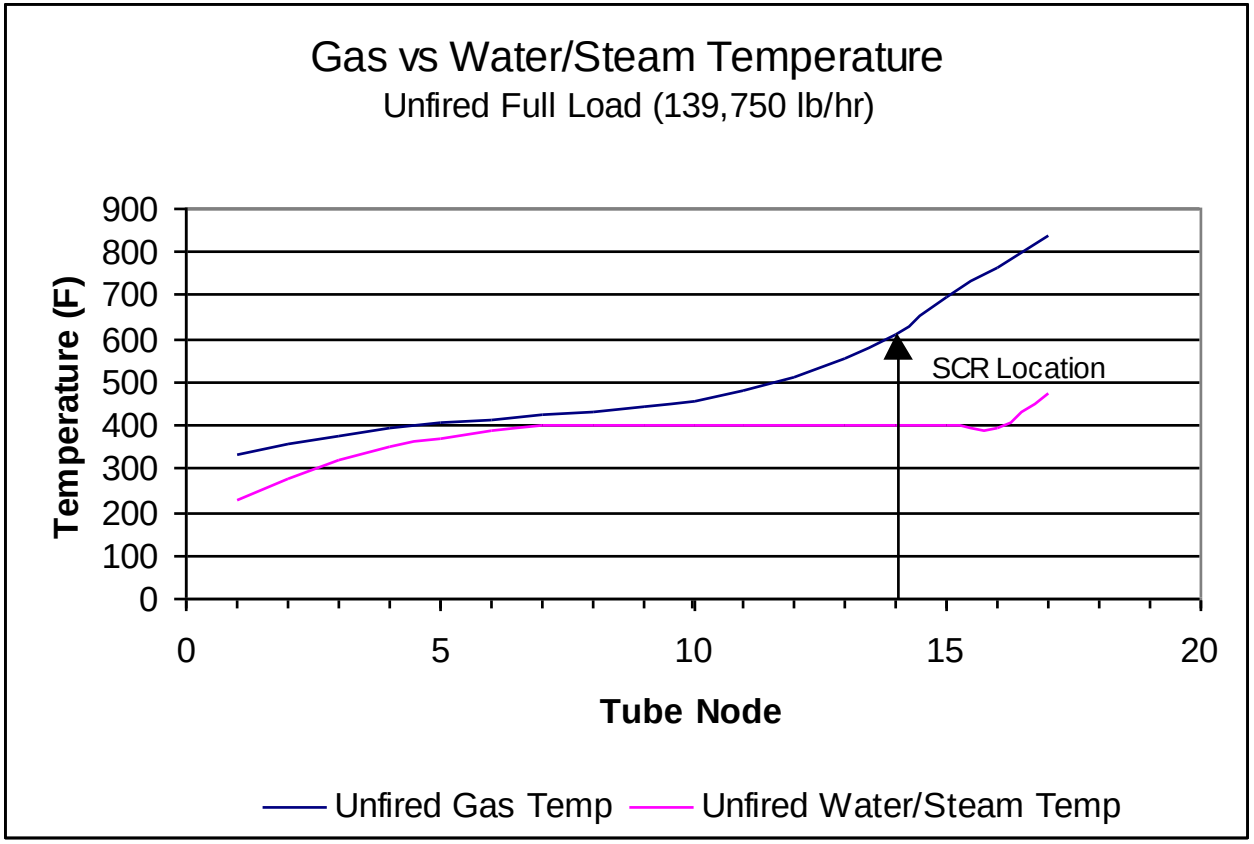
- Ammonia supply equipment

SCR Operation



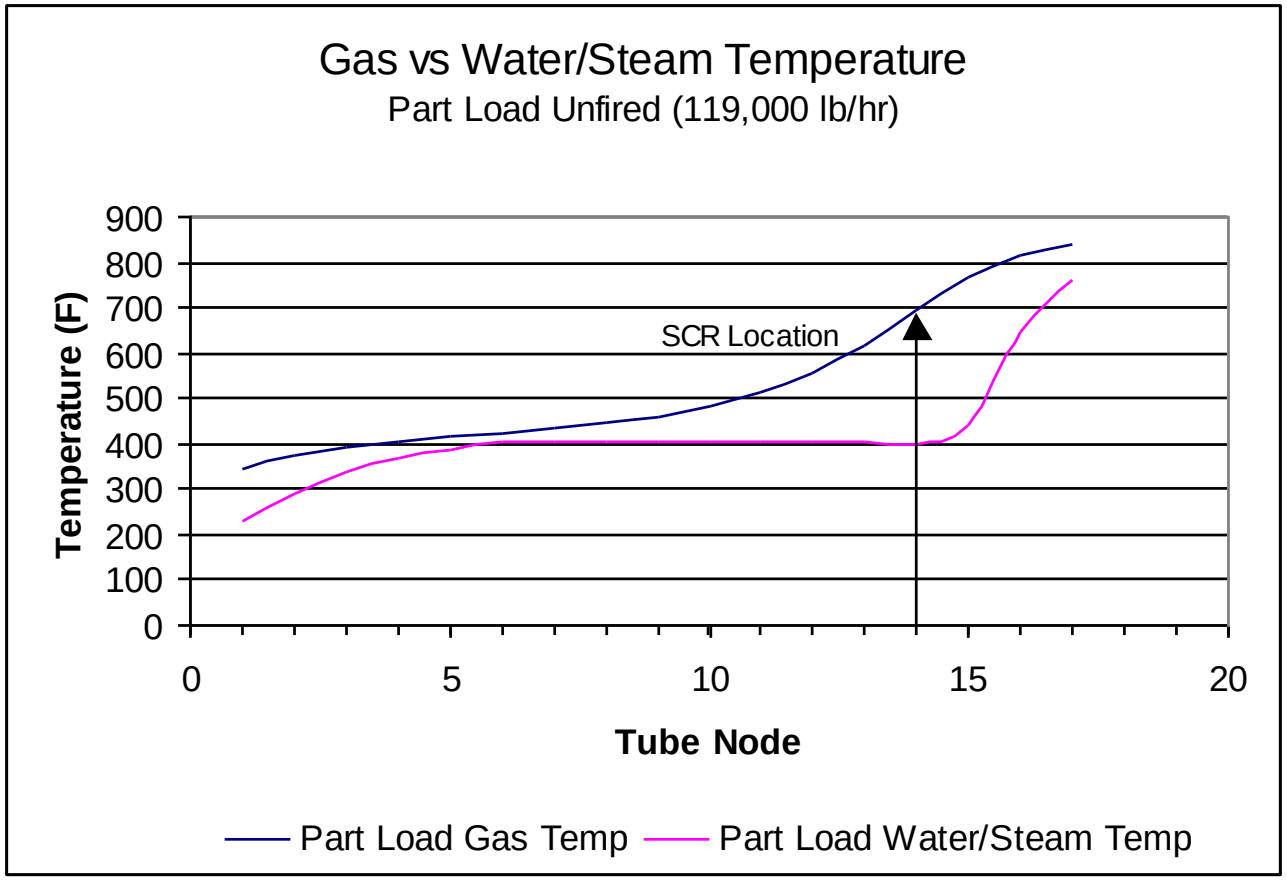
- Design point for SCR location
- Gas temp at SCR catalyst is 690 Degrees F
- SCR operating at maximum efficiency

SCR Operation



- At full unfired load, the temperature entering the SCR is 613 Degrees C
- Not at maximum efficiency of SCR operation
- Can reduce water from to the OTSG to control the gas temperature upstream of the SCR

SCR Operation



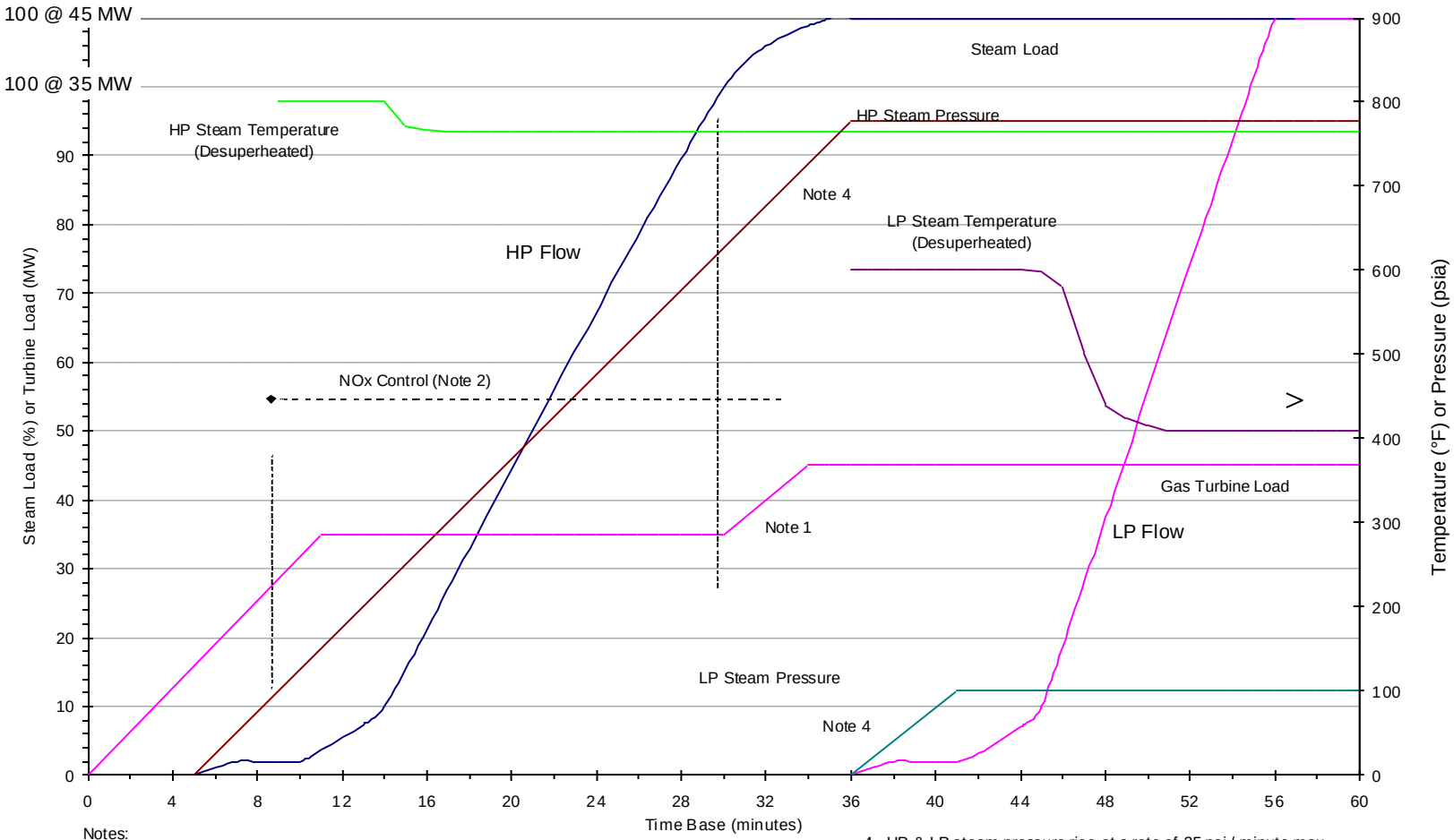
- Reducing the water flow to the OTSG changes the gas temperature upstream of the SCR catalyst to 694 Degrees F
- SCR now operating at maximum efficiency

Boiler Start Up

- Gas turbine initially ramped to a predefined load to initiate SCR operation
- Ammonia injection begins when a minimum temperature is measured at the catalyst inlet
- OTSG water ramp sequence starts once the inlet gas temperature and stack temperature are 500 F and 350 F, respectively
- HP section attains 100% steam flow in approximately 25 minutes
- Gas turbine ramped to full load, trimmed according to the gas temperature entering the catalyst
- LP section sequence initiated once the HP circuit has reached temperature control

Boiler Start Up

Typical Start Up (Hot or Cold Start)



Notes:

1. GT Ramp will be based on maintaining a pre-determined gas temperature into SCR. OTSG water flow is ramped as GT load increases (Maximum ramp rate is 6% / minute).
2. Ammonia can be injected once gas temperature entering SCR exeeds 500°F.
3. Time 0 is GT ramp start
4. HP & LP steam pressure rise at a rate of 25 psi / minute max

Ammonia Slip

- The distribution of turbine exhaust will not be uniform or constant at the SCR surface for all turbine/burner conditions
- Some tuning can be done to match turbine exhaust mass flow to corresponding ammonia mass flow
  - Part load / off design conditions may have the greatest efficiency at another tuning point
- When ammonia does not react within the catalyst and continues to follow the exhaust path, this is known as ammonia slip

Corrosion/Fouling

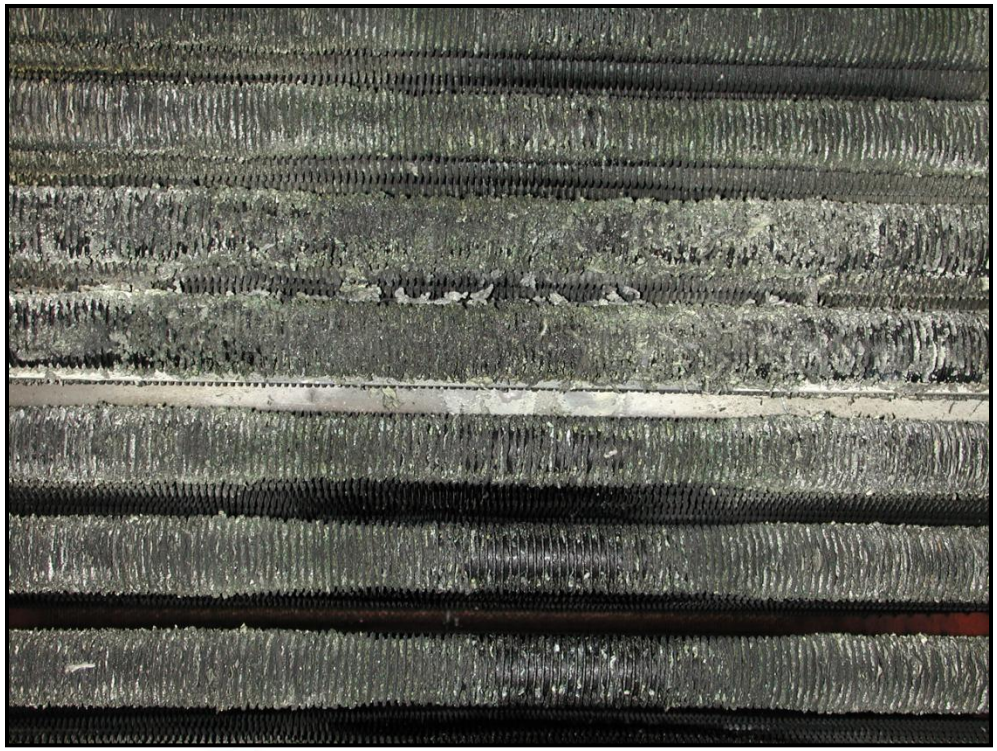
- Ammonia slip is detrimental for the following reasons:
  - The release of ammonia into the atmosphere
  - Formation of ammonium sulphate and/or ammonium bisulphate
    - The type of contaminant depends on ammonia/sulphur levels and gas temperatures
- In natural gas fired applications with low slip, ammonium sulphate formation is the most common
- Operation of pressure parts below the water dew point can lead to formation of sulphuric acid and hydrochloric acid
- Selection of pressure part material is critical

Corrosion/Fouling

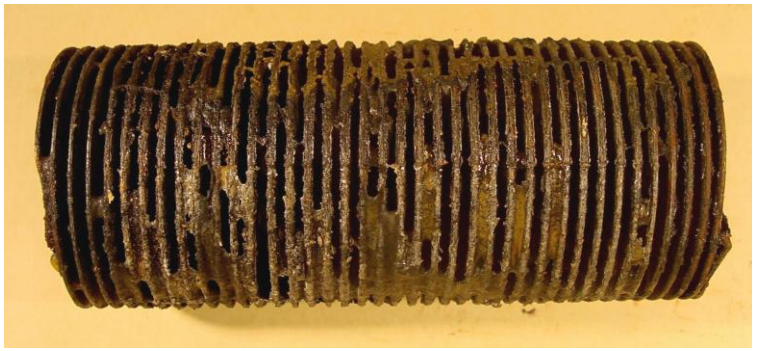
Corrosion/Fouling

View during start up.
Ammonium deposits are returning to the flue gas and resulting in an opacity event

Soot deposits on inlet tubing of liquid fired LM2500 with SCR

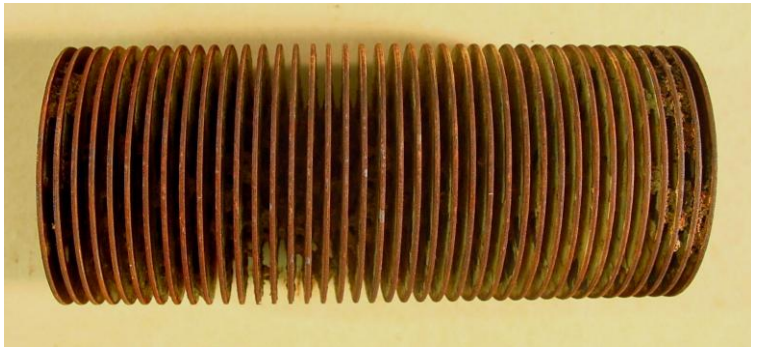


Corrosion/Fouling



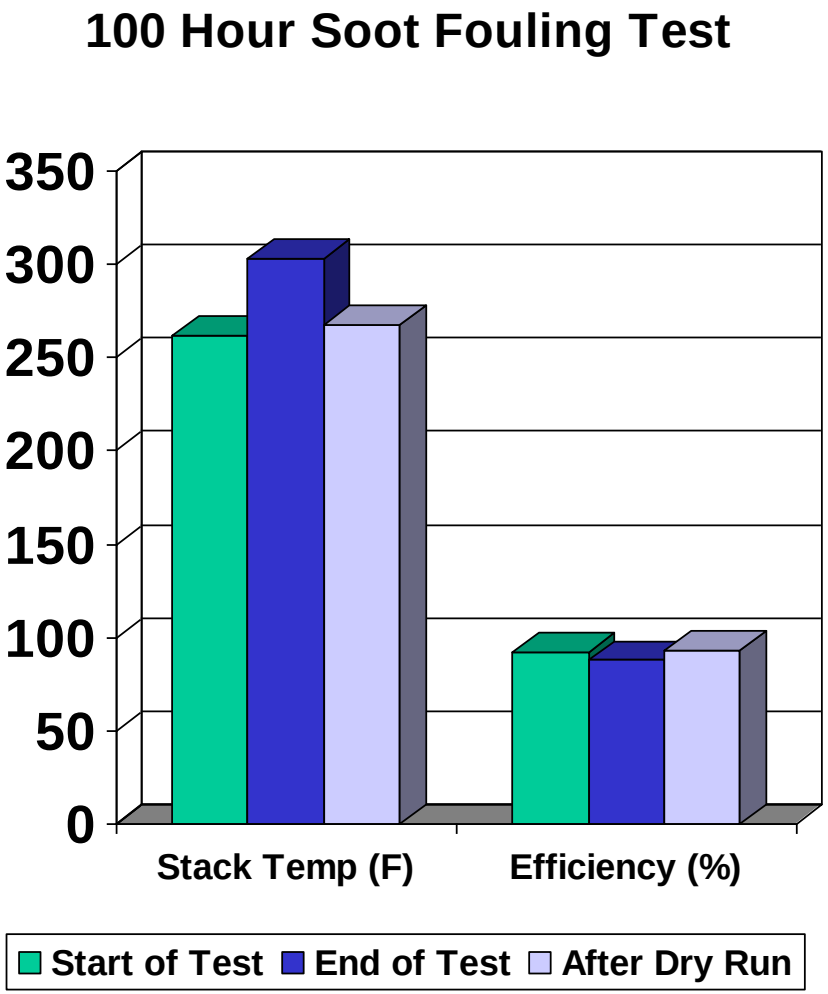
Tube coated with ammonium sulphate

After heating at 900 F for four hours



After blowing with compressed air

Corrosion/Fouling



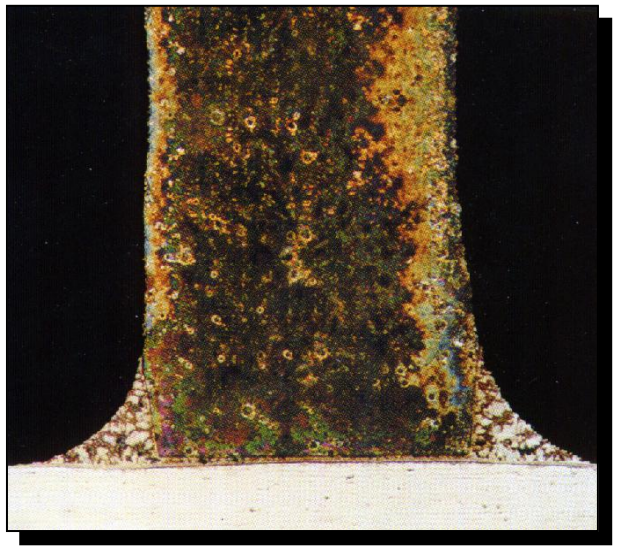
- Dry running can restore thermal performance on oil fired units
- Test completed by IST on diesel fired OTSG
- Heat transfer performance diminished by 5% in 100 hours of operation
- Recovery by performing a dry run at 900 F for 100 minutes
- However, don't overheat the catalyst!

Corrosion/Fouling

- Beyond deposits, corrosion is also an issue
- Lower stack temperatures possible by admitting cold feedwater
- Feedwater temperatures below 60 F have been accommodated through corrosion resistant materials at the cold end of the boiler below the water/sulphur dew point

	Incoloy 825 (Tube)	316 SS (Fins)
Nickel	38.0 – 46.0	11.0 –14.0
Iron	22.0 min.	Balance
Chromium	19.5 – 23.5	16.0 – 18.0
Moly	2.5 – 3.5	2.0 – 3.0
Copper	1.5 – 3.0	n/a
Titanium	0.6 – 1.2	n/a
Carbon	0.05 max.	0.08 max.
Manganese	1.0 max.	2.00 max.
Sulfur	0.03 max.	0.03 max.
Silicon	0.5 max.	0.75 max.
Aluminum	0.2 max.	n/a
Phosph	n/a	0.040 max.
Boron	n/a	n/a

Corrosion/Fouling



- Accelerated corrosion test in ASTM G28-97, Method B
- Solution (very aggressive)
  - 23% H_2SO_4, 1.2% HCl, 1%$FeCl_3$, 1% $CuCl_2$

Corrosion/Fouling

48 hour corrosion test

- Incoloy 825 / 409 SS fin
- Fin material not intact

6 week corrosion test

- Incoloy 825 / 316 SS fin
- Tube/Fin/Braze material intact

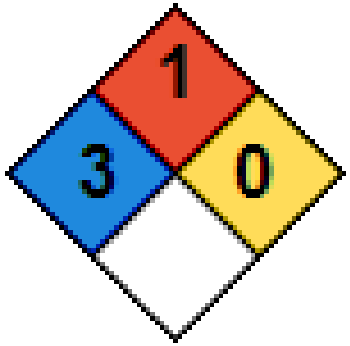
Chemical Storage/Handling

- Anhydrous ammonia is the easiest to use with an SCR
  - SCR manufacturers typically recommend reagent grade ammonia.
  - A technical grade of ammonia can be used if within the SCR manuafacturers spec
  - Do NOT use agricultural grade ammonia
    - This contains Na, K, Ca, Mg impurities which can poison a catalyst

Chemical Storage/Handling

- Anhydrous ammonia is the easiest to use with an SCR, but on site urea to ammonia systems are available

- Urea
- Dry Powder
- Can be stored in waterproof sacks
- Shipping is easy



- Anhydrous Ammonia
- Special shipping requirements
- Requires storage facilities – high pressure, low temperature

Chemical Storage/Handling

- Urea to ammonia systems are advantageous in terms of receiving, handling and storing urea vs. ammonia, but suffer from several drawbacks:
  - Corrosion of the reaction vessel and instrumentation
  - Heavy liquid accumulation
    - Partial urea decomposition products can make heavy compounds
  - Deposits in down stream piping
    - The compounds described above can be entrained in the gas phase to downstream piping, AIG and catalyst

Capital Cost Comparison

- LM6000 W/OTSG
  - Cost depends on options
- LM6000 W/OTSG & CO Catalyst
  - Base + 0.7 million
- LM6000 W/OTSG & SCR Catalyst
  - Base + 1.3 million
- LM6000 W/OTSG, CO and SCR Catalyst
  - Base + 2.0 million

Conclusions

- Simple to accommodate SCR systems into vertical gas flow OTSG's
  - Due to absence of intermediate drums, any location possible
- Pressure part material selection for expected environments
  - Standard materials of construction very resistant to corrosive attack
- Operational advantages
  - Part load optimization of SCR inlet gas temperatures
  - Quick startup of SCR system and OTSG due to dry start
  - Dry running/compressed air blasting of OTSG tubing to clean soot off tubing

Thank You for Your Attention!