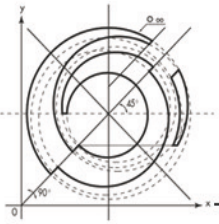
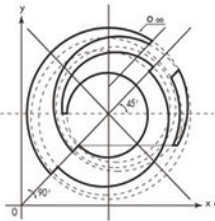


DeNOx Experience





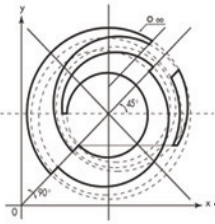
SCR System Design Approach



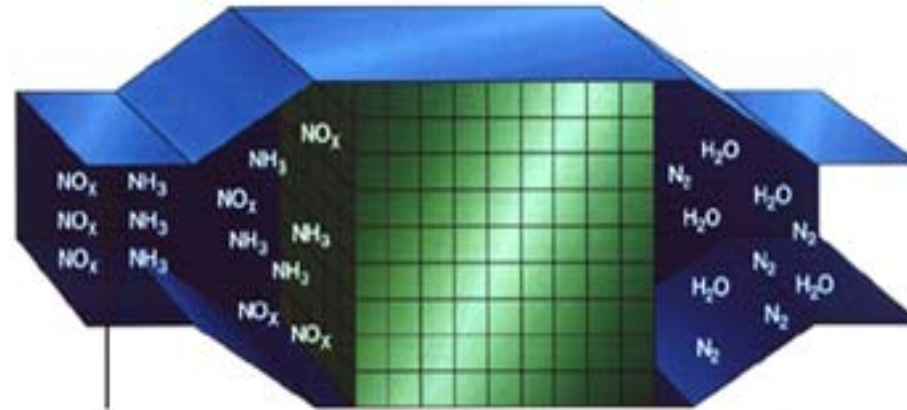
LOW NO_x CHOICES



- Firing System Tuning and/or Basic Modifications
- Fuel Switching
- Firing System/Boiler Modification - Possibly Including SOFA Systems, Pulverizer, Pressure Parts, Control System Modifications and/or Neural Networks
- SCR (or SNCR) Addition
- FGR
- Combination of Any of the Above



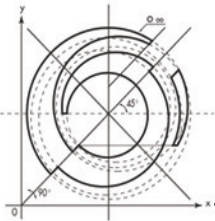
NOx Reduction Process



– Selective Catalytic Reduction (SCR) of NO and NO₂



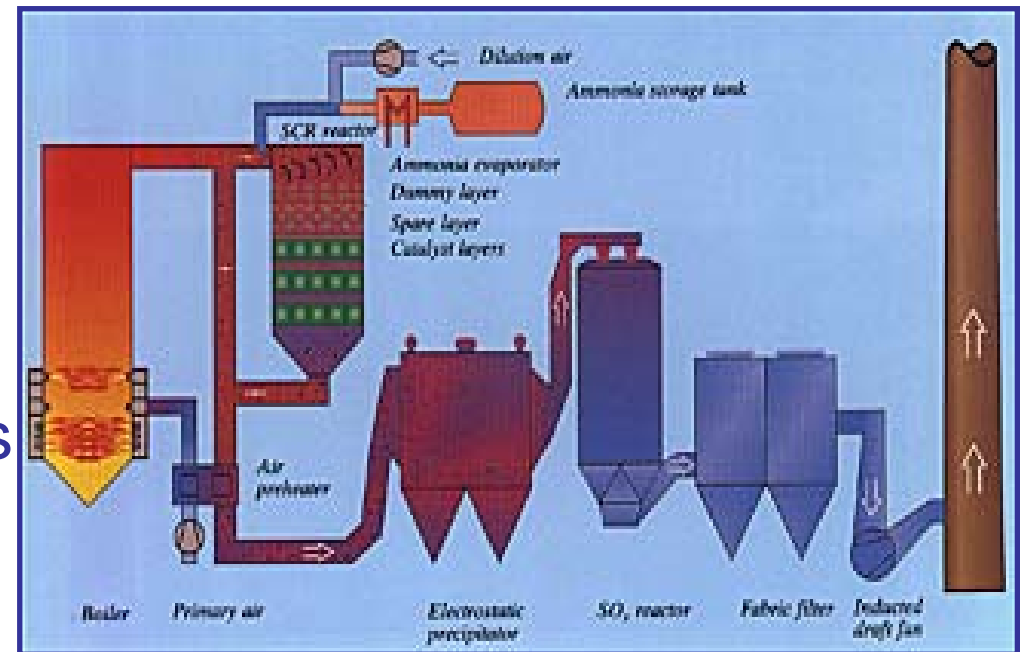
– Vanadium and Tungsten as Active Catalyst

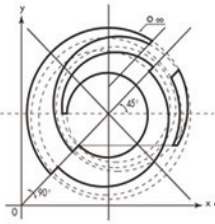


SCR Configuration

High-Dust SCR

- Reactor Upstream of APH
- Full Dust Load from Boiler Passes through the SCR Reactor
- Larger Catalyst Channels (Pitch) Required to Prevent Plugging
- Shorter Catalyst Life
- Cost Effective Solution

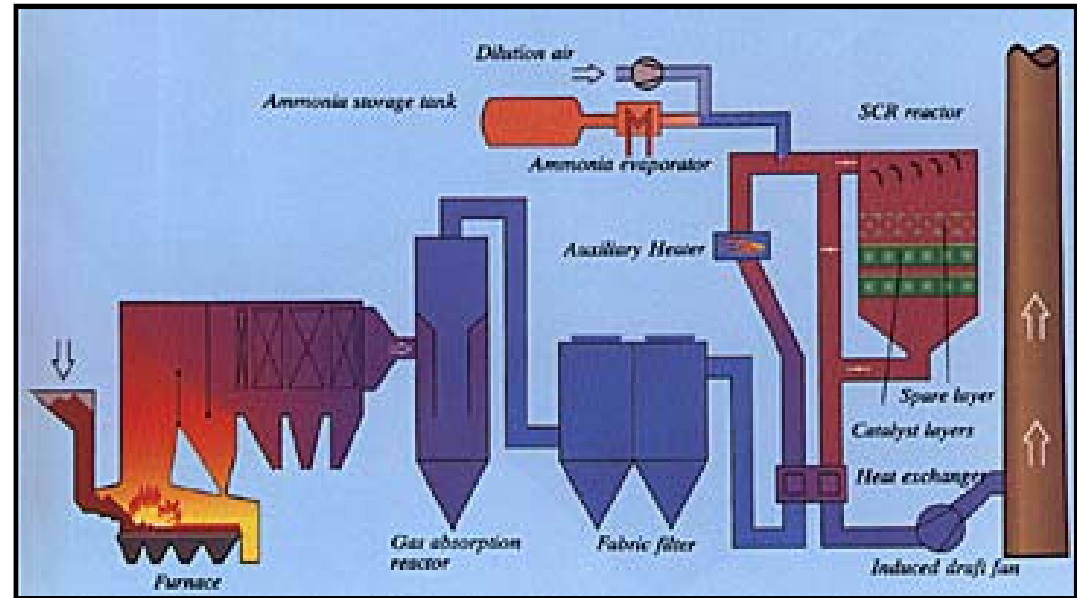


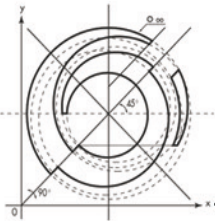


TYPES OF SCR

Tail End System:

- Very Low Dust Load in the Reactor
- Long Catalyst Life
- Heat Exchanger/ Supplemental Heater Required after ESP or FF to Increase Temperature to About 575°F
- Much Smaller Catalyst Channels (Pitch) Increase Packing Density





SCR DESIGN



- **CASING**

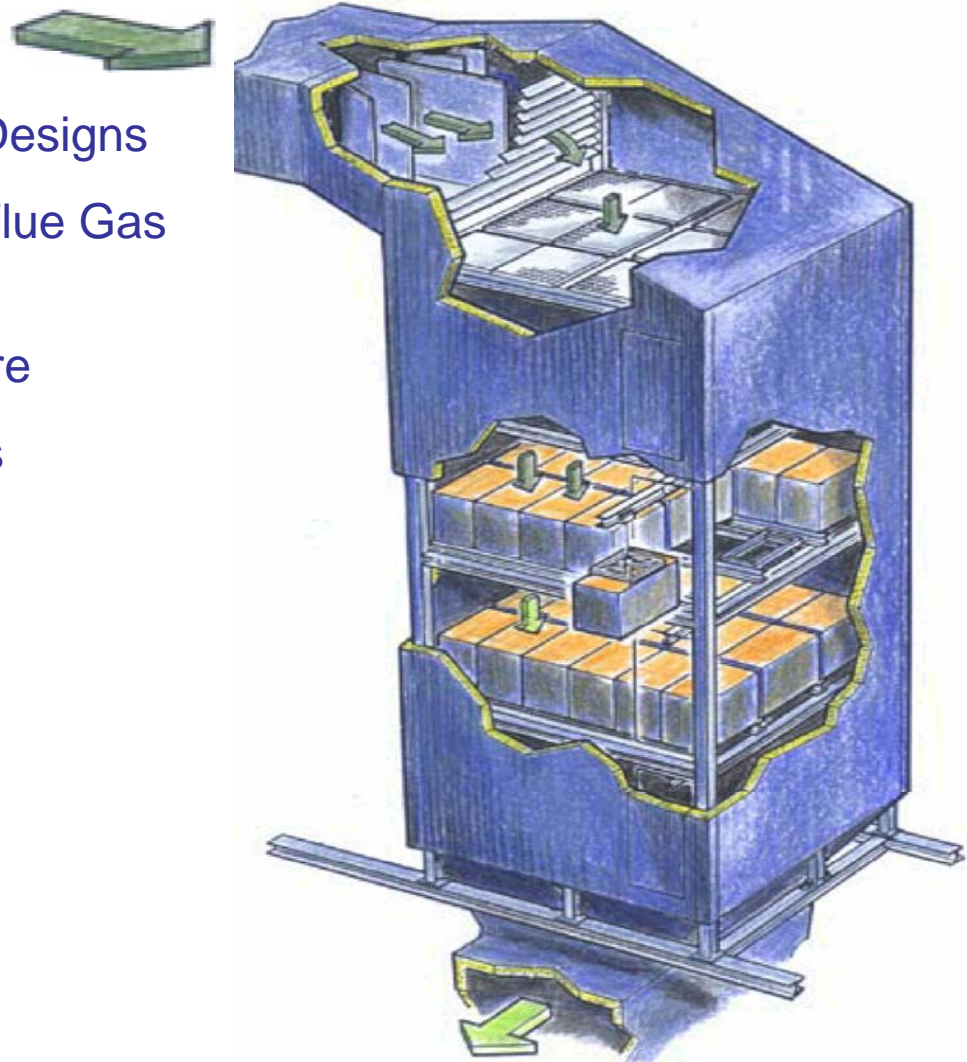
- Flexibility for Various Catalyst Designs
- Vertical Downflow - Optimized Flue Gas Distribution and Pressure Drop
- High Casing Design Temperature
- 2 to 4 layers, 1 or 2 spare layers

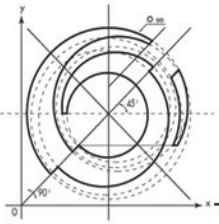
- **ACCESS**

- Leak Free Door Designs
- Maintenance Friendly Access

- **CATALYST HANDLING**

- Hoist
- Removable Monorails

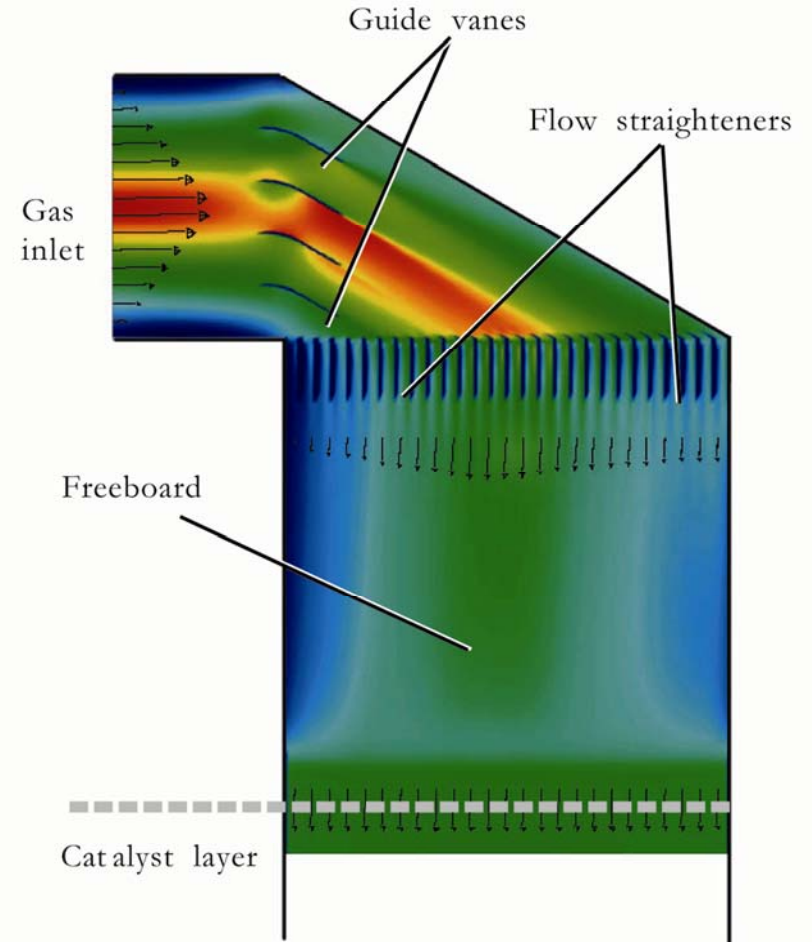


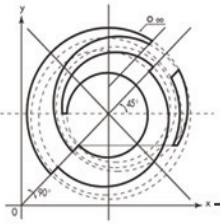


Gas Flow Model

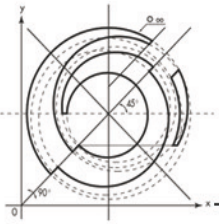
• FLUE GAS FLOW TESTING

- Physical & CFD Models
- Gas Distribution Devices
- Gas Mixer
- Turning Valves / Inlet Hood
- Straightening Vanes
- Uniform Temperature, Flow,
NO_x / NH₃ Concentration



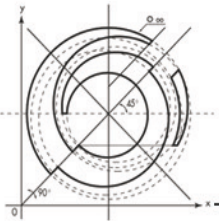


Process Issues



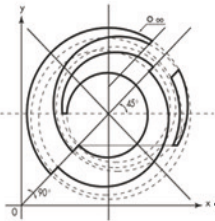
PROCESS ISSUES

- NO_x Removal Efficiency
- Ammonia
- Catalyst Life Expectancy
- SO₂ Oxidation / Ammonium Bisulfate Formation
- Seasonal Operation
- Control System
- Popcorn (LPA) Ash

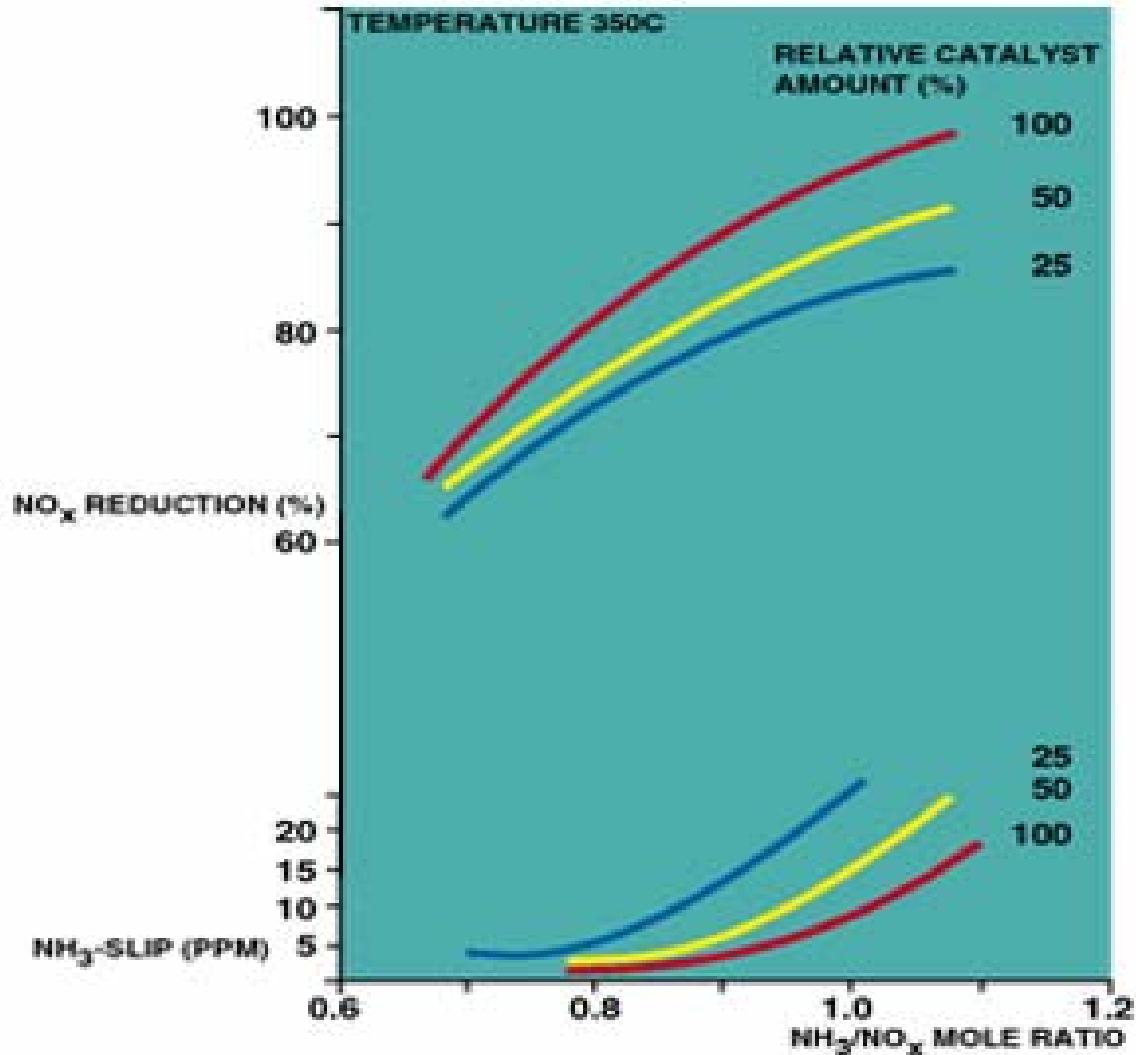


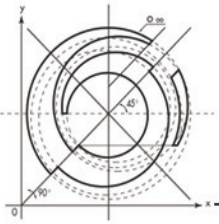
NO_x Removal

- Capable of 90 % +
 - Add ammonia for extra removal
 - Slip may become issue
- Average over time
- Measured at SCR Inlet and Outlet for Control
- CEMS in Stack for Compliance Reporting



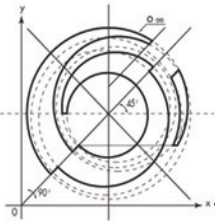
Typical NO_x Removal Efficiencies





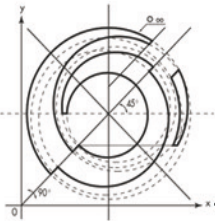
Ammonia Impact

- Ammonia from the SCR will end up in/on and will affect
 - APH surfaces
 - Fly Ash
 - Filter Bags
 - FGD Waste Water
 - FGD Gypsum
 - FGD Oxidation



Ammonia Levels in Fly Ash after SCR plants

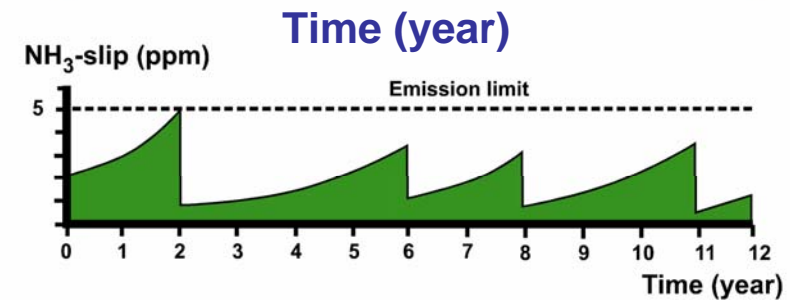
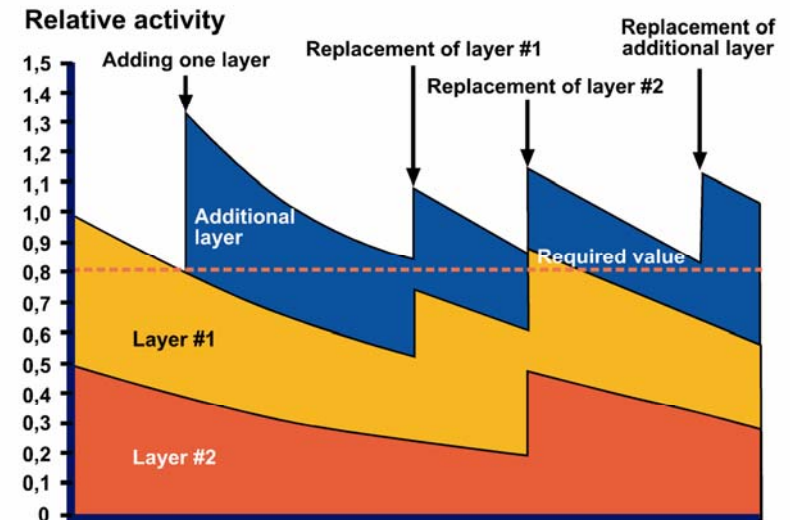
- Plant measurements reported levels of ~ 100 ppm NH_3 in fly ash at NH_3 gaseous slip levels of ~ 5 ppm
- High slip
 - Poor Measurements
 - Poor Distribution
 - Variable NO_x Distribution
 - Catalyst Deactivation

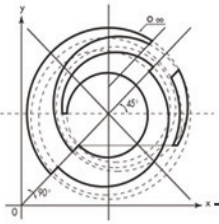


Catalyst Performance Over Time

Catalyst replacement cycles

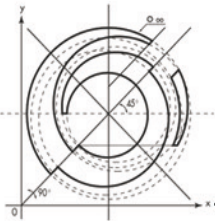
- All Catalysts Become De-activated with Time Due to:
 - Sintering: Pores are Blocked and Fused at High temperatures
 - Poisoning: Foreign Molecules Bind to the Catalyst
 - Pore Blockage: Fine Particles Become Imbedded in the Pores
- By an Active Catalyst Replacement Program, NOx Removal Efficiency and Ammonia Slip can be Maintained within Emission Limits





SO₂ Oxidation

- Catalyst Oxidizes SO₂ to SO₃
- Similar to Catalytic Converter on Cars
- The formulation affects oxidation
- Low Oxidation Rates Achievable at Higher Catalyst Cost



Bisulfate Formation

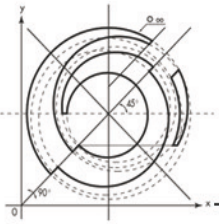


Causes:

1. High concentrations of SO_3 and unreacted ammonia in the flue gas
2. Low operating flue gas temperature

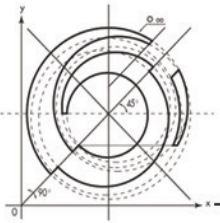
Countermeasures:

1. Design for low ammonia slip
2. Design catalyst for low SO_2 to SO_3 oxidation rate
3. Install economizer bypass system
4. Install ABS Tolerant air heater baskets
5. Reversible with high operating temperature

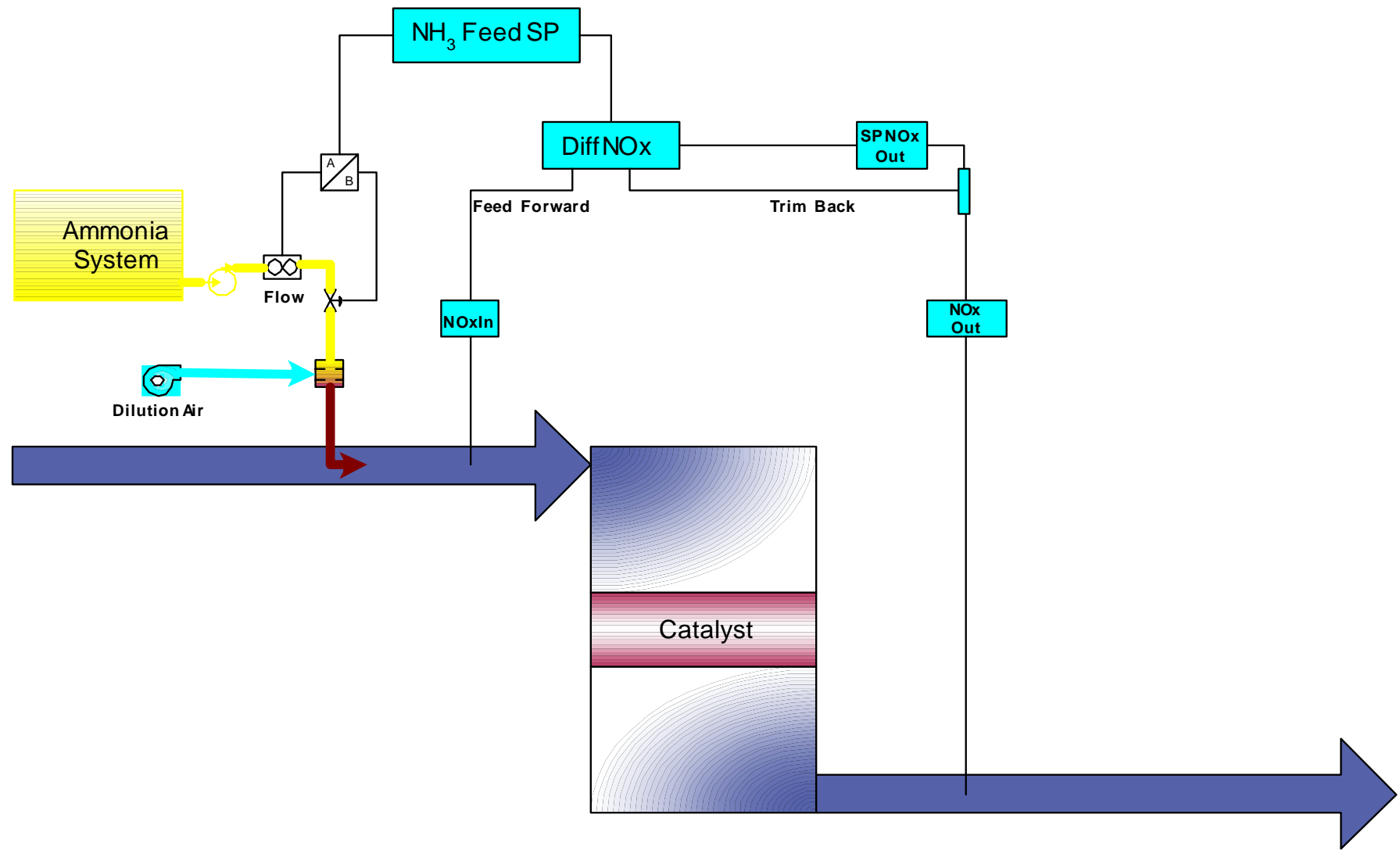


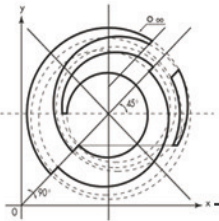
Seasonal Operation

- Isolate Catalyst from Gas Path at end of Ozone season
- Purge Flue Gas from SCR reactor
- Use Sonic Horns or Soot blowers to clear ash deposits
- Maintain Catalyst above dew point during storage
- Near Zero aging when stored properly
- Damper Seal Air Pressurization of Reactor



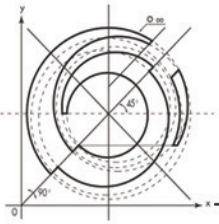
Control System





Control Issues

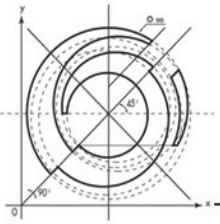
- Unreliable NOx analyzers
- Time delay of samples
- Overfeed of ammonia during step changes to process (loss of pulverizer)
- Underfeed during ramp up
- Sample / Hold during monitor calibration
- Ammonia slip monitors



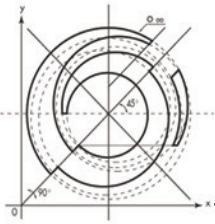
Large Particle Ash (LPA)



- “Popcorn” from Combustion
- Slag from Boiler Tubes
- Agglomerated Ash Particles
- Over 2 to 3 mm
- Plug Air Heaters
- Plug Screens Over Catalyst or Catalyst
- Poor NO_x Performance, Erosion from High Velocity



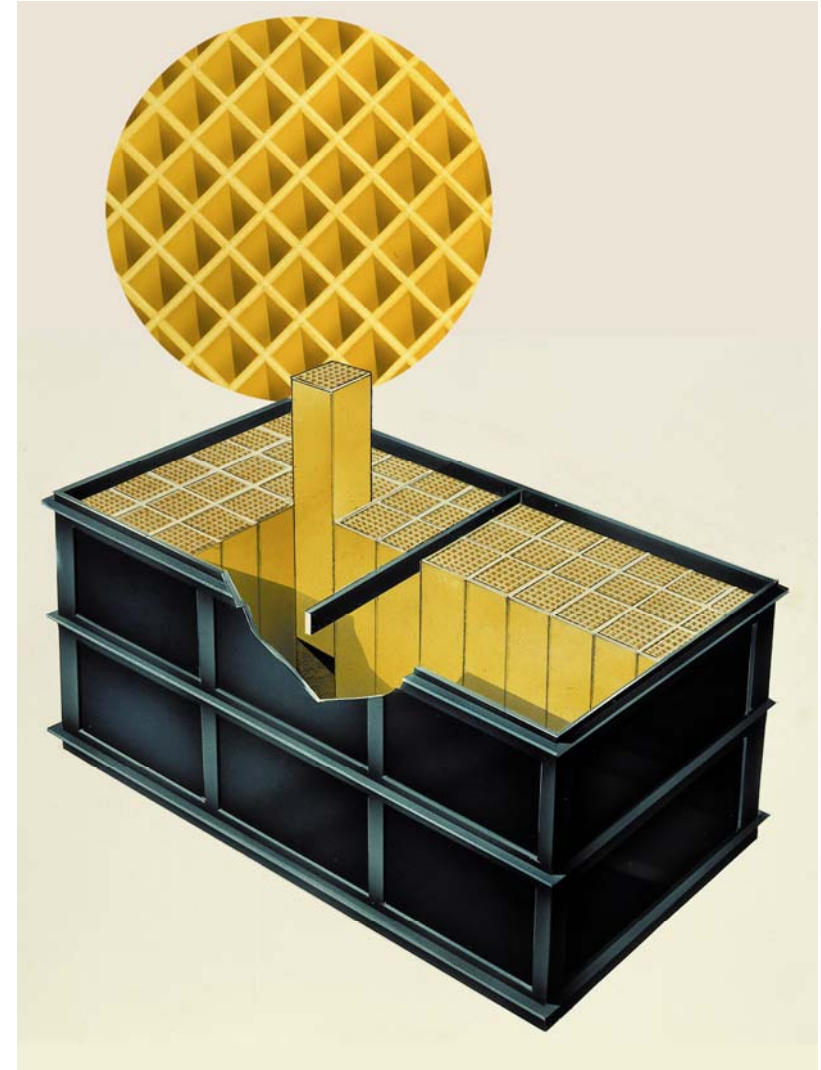
Catalyst Design

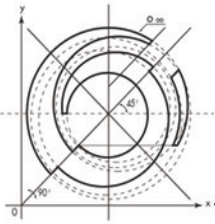


Types of Catalyst Construction



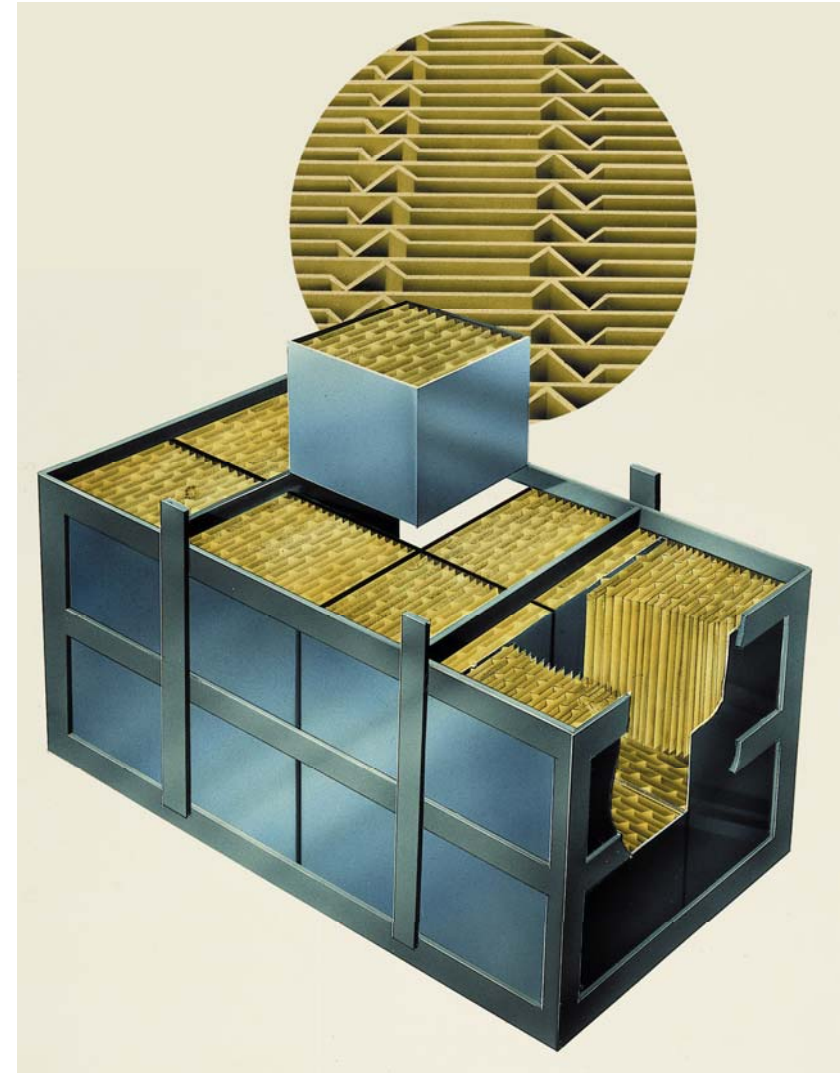
- Honeycomb Type:
 - Extruded Ceramics with Titanium Oxide Carrier and Catalyst Surface
 - Square Cross Section with Pitch to Suit Application
 - Typical Element:
 - 150 x 150 mm Cross Section
 - 350 to 1200 mm Long
 - 4 to 16 mm Pitch

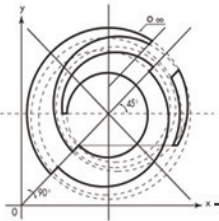




Types of Catalyst Construction **ALSTOM**

- Plate Type:
 - Catalyst Surface on a Metal/Fiber Substrate
 - Rectangular Cross Section with Reinforcement Bends
- Typical Element:
 - 500 x 500 mm Cross-Section
 - 500 mm Long
 - 4 to 16 mm Plate Spacing





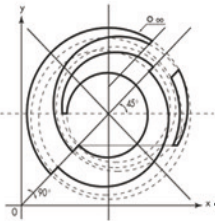
Catalyst Type - Pros & Cons **ALSTOM**

- Honeycomb

- High specific area - low volume
- Mechanically strong – low erosion susceptibility
- Higher pressure drop
- Sensitive to high fly ash loadings
- Need Screens for Personnel Walking

- Plate

- Lower specific area - Higher volume
- Fiber lower mechanical strength, more susceptible to erosion
- Lower pressure loss
- Lower sensitivity to fly ash loadings
- Can handle large particle sizes
- Need Screens of Personnel Walking



Catalyst Suppliers

ALSTOM

Many Manufacturers Worldwide

Cormetech

Haldor Topsoe

Argillon (Siemens)

Ceram (BASF)

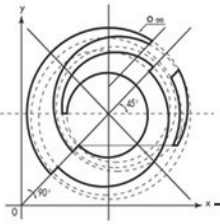
KWH

Hitz (Hitachi Zosen)

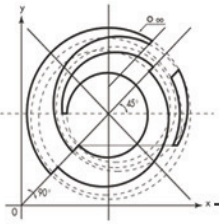
Hitachi

MHI

Nippon Shokubai

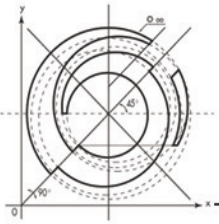


Ammonia Systems



General

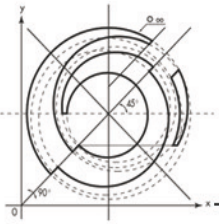
- Three Sources of Ammonia can be used
 - Anhydrous
 - Aqueous
 - Urea
- Local Rules, Permit Issue
- An Analysis of Risks and Consequences for each Plant



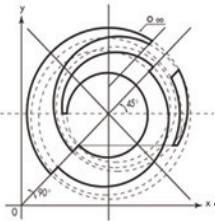
Anhydrous Ammonia

ALSTOM

- Commercial Quality > 99%
- Vapor Pressure 115 psig (8 bar) (room temp.)
- Pressure Vessel
- Non-corrosive - Mild Steel
- NH_3 - Relative low Cost
- Classified as a Poison
- Some Heating Probably Required for Winter Operation



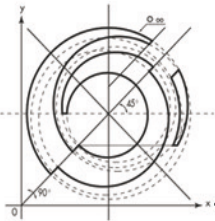
- ANSI K61.1 -1999
 - American National Standard Safety Requirements for the Storage and Handling of Anhydrous Ammonia
- OSHA 1910.111
 - Storage and handling of anhydrous ammonia



Anhydrous Ammonia Liquid / Vapor

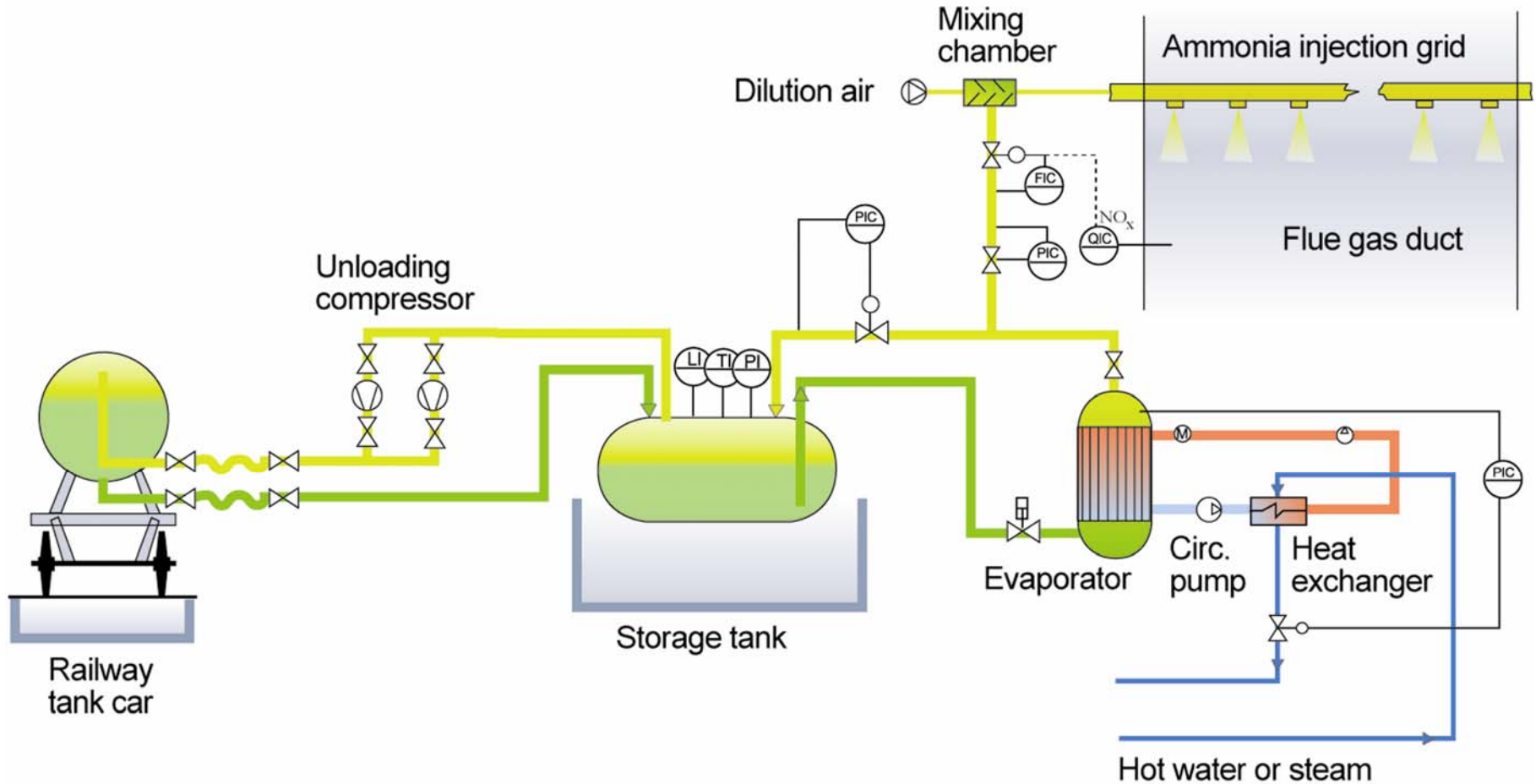
ALSTOM

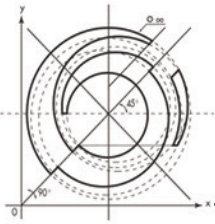
- 1 gallon of Liquid NH₃ = 800 cubic feet of gas
- 1000 ft of 1" pipe produces a cloud of 35,704 cubic feet = 33'x33'x33'
- 1000 ft of 2" pipe produces a cloud of 139,152 cubic feet = 52'x52'x52'
- 1000 ft of 3" pipe produces a cloud of 206,563 cubic feet = 67'x67'x67'



Anhydrous Ammonia Flow Diagram

ALSTOM

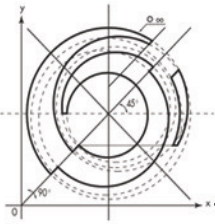




AMMONIA EVAPORATION SYSTEM

ALSTOM

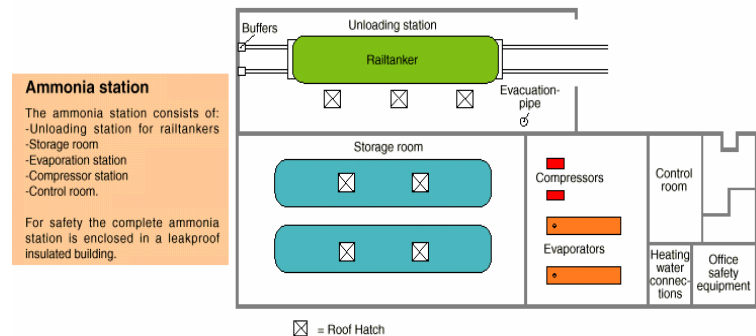
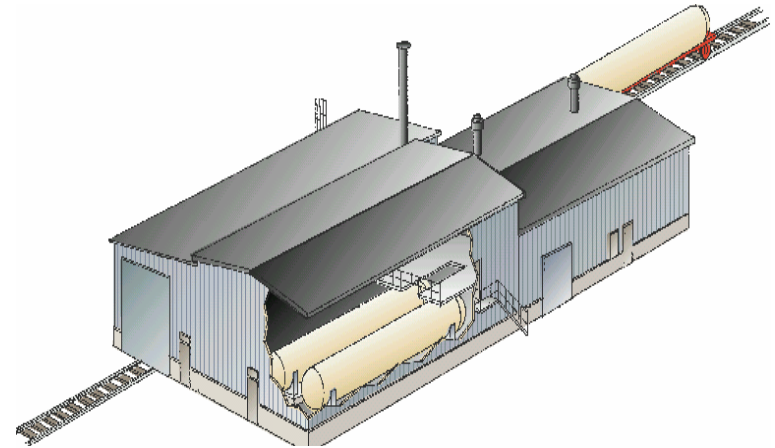


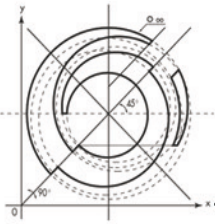


Ammonia Storage & Feed



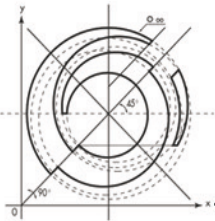
- **Ammonia Storage & Feed**
 - Anhydrous or aqueous ammonia
 - Storage tanks
 - Vaporization trains
 - Compressor station
 - Control room
 - Safety systems
 - leak proof insulated building





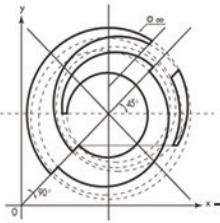
TVA Paradise NH3 Installation



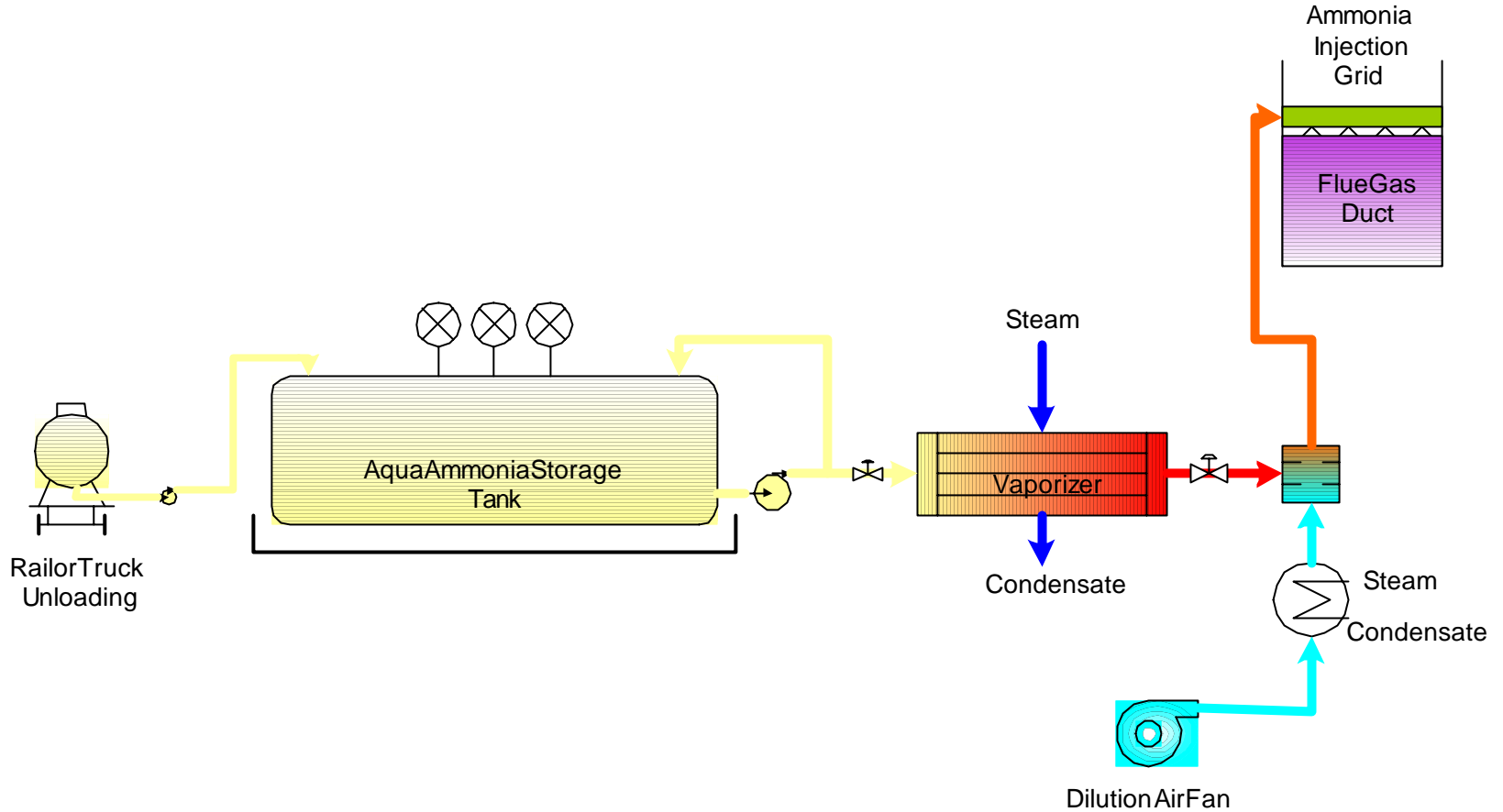


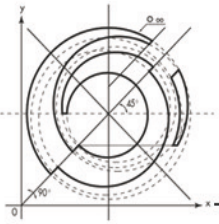
Aqueous Ammonia

- Usually 19 to 29% NH_3 (by weight)
- Vapor Pressure < 14 psig (1 bar) (Open Tank possible)
- Corrosive - Plastic or Stainless Steel
- 71 to 81% Water - to transport, store, handle, and evaporate (Water carrier needs to be vaporized and accounted for in process)
- Classified as a Hazardous Chemical
- Possible to directly inject with a dual fluid nozzle
- Heating Required for Winter Operation



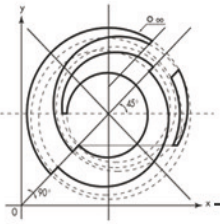
Aqueous Ammonia System ALSTOM



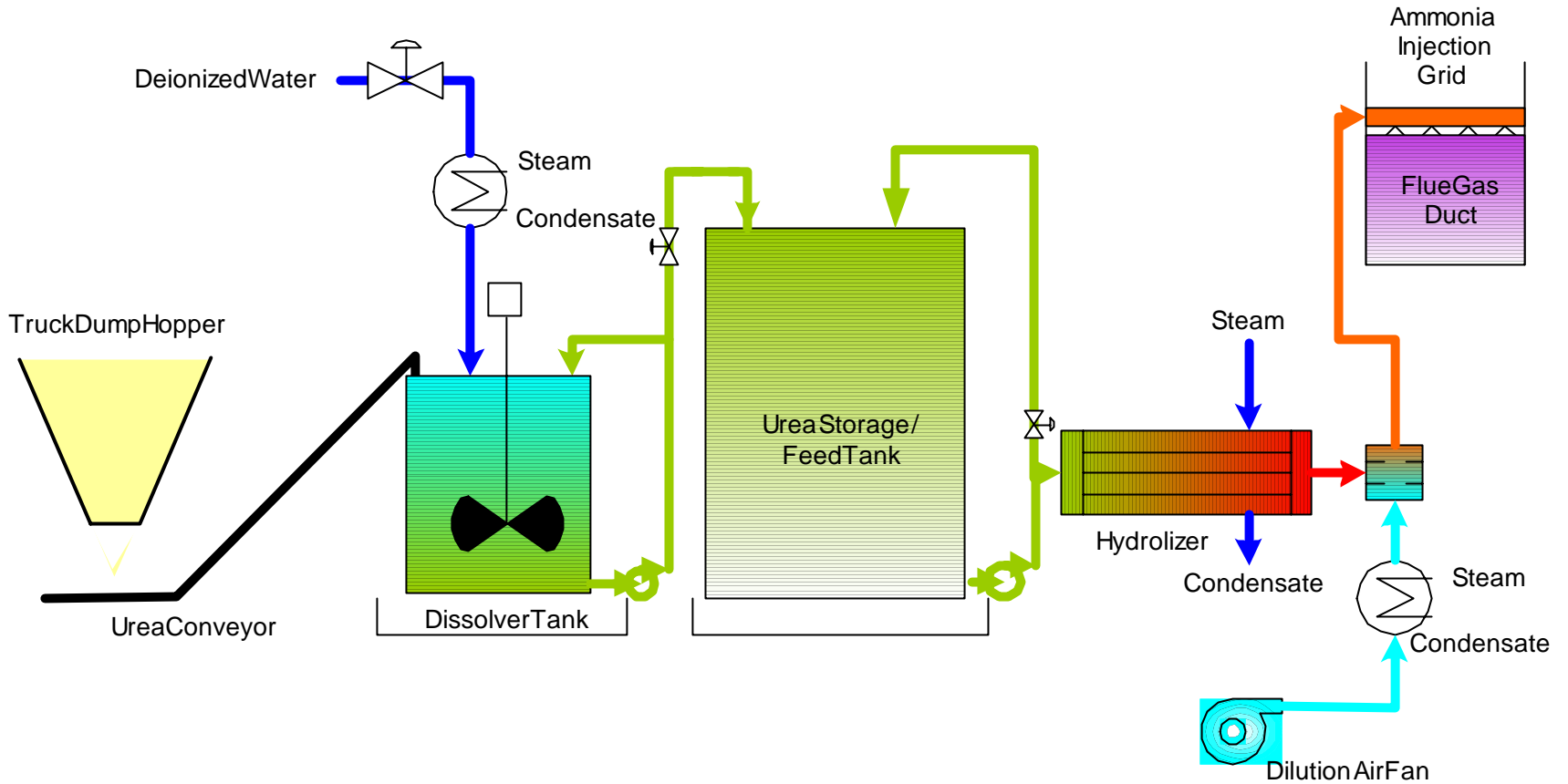


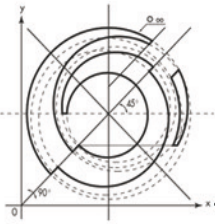
Urea - $(\text{NH}_2)_2\text{CO}$

- As a solid or a solution (up to 40%)
- Low vapor Pressure
- Open Tanks
- Material - Plastic or Stainless Steel
- Non-Hazardous Chemical (harmless)
- Relatively high Freezing Point (10°F 35%)
- Dissolving needs Heat (105 - 125 °F)
- Heating Required for Winter Operation



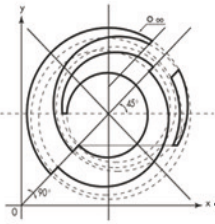
Urea / Ammonia System





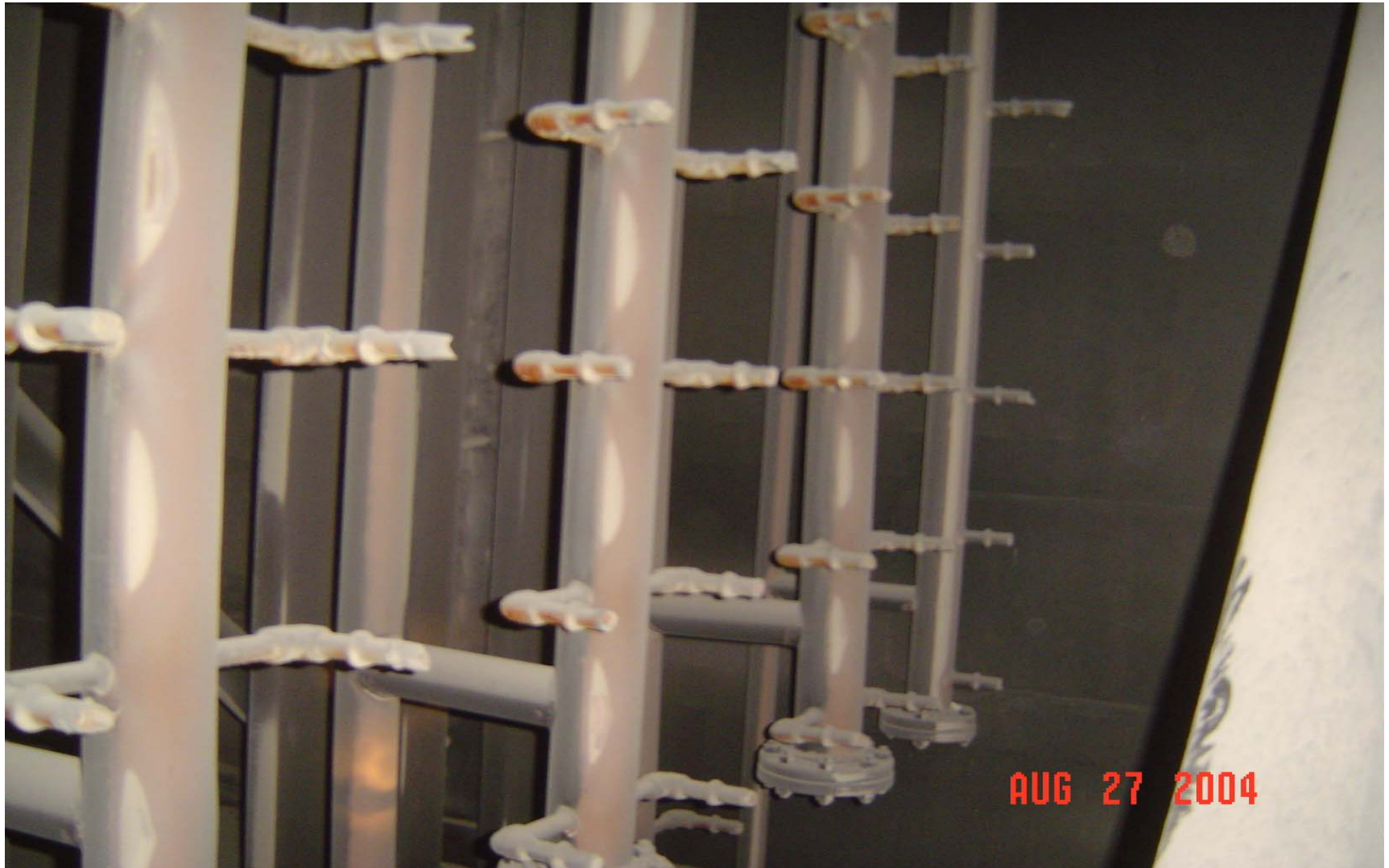
AMMONIA INJECTION HEADER

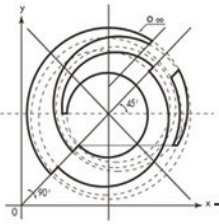




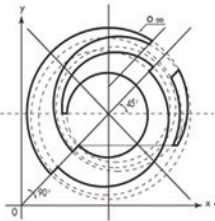
AMMONIA DISPERSION - HEADER / NOZZLE

ALSTOM





Balance Of Plant Issues



MAJOR CONCERNS FOR SCR RETROFIT APPLICATIONS



1. Space Limitation

Relocation of Fans, Air Heaters, ESP, Stack

Economizer modifications

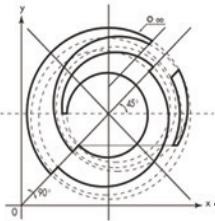
Rerouting of ductwork

Access/Laydown Areas

Ammonia Equipment Layout

2. Modification of Existing Foundations / Steel Structures

3. Relocation of Underground Facilities



MAJOR CONCERNS FOR SCR RETROFIT APPLICATIONS



4. Boiler Integrity

Higher Operating Pressure - Check Buckstay System

- Check Ductwork

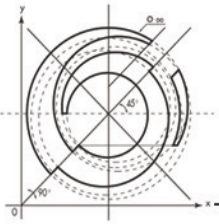
- Check Fans FD/ID

Air Heater Modifications for Ammonia Applications

Boiler Performance

5. Boiler Downtime - Construction Schedule

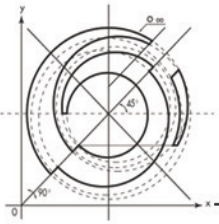
6. Dampers



Dampers

Damper Selection Criteria

- Customer Specific
- SCR Module Inlet / Outlet
 - “Man Safe”
 - No flue gas intrusion (catalyst)
- Bypass Damper – Zero / Low Leak



Louver Dampers

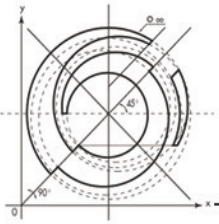


- **Parallel Blade Dampers**

- One set of blades in a single frame
- Seal is blade to blade contact
- No Seal Air
- Not “Man-safe”

- **Double Louver Damper**

- Two parallel blade louver dampers in a single frame with seal air between blade set.
- “Man-safe” with seal air

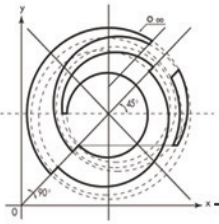


- **Guillotine Dampers or Slide Gates**

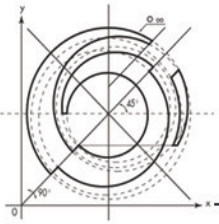
- Large area required external to duct - for blade removal
- “Man-safe” with seal air in peripheral blade seal chamber
- Not suitable for modulation

- **Flap Damper**

- Large Door like damper
- Adapted from HRSG application -size 10'-12' dia.
- Often Require Large Hydraulic drives
- Difficult to position for modulation
- “Man-safe” with seal air in peripheral seal chamber

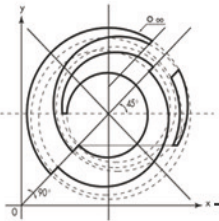


Catalyst Cleaning Considerations



SCR Ash Loads

- Fly Ash – 8,000 lb/hr to 85,000 lb/hr
- Ash Load passes through the SCR for High Dust SCR
- Most Fly Ash – micron size
- Some – $\frac{1}{4}$ to $\frac{1}{2}$ in



Soot Blowers

Venturi nozzles are more effective than drilled holes

Use only when there is flow in Reactor

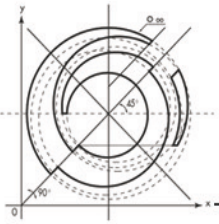
Typical conditions at the inlet flange

400 PSIG 700 F 270 F Superheat

It is important to keep the blowing media free of droplets.

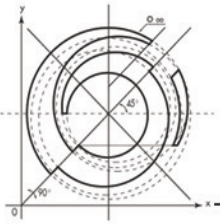
One blower at a time work the SCR Box from top to bottom.

Once per shift (8 hours) until experience is gained.



Sonic Horns

- Lower Frequency works best
- Consider attenuation by internals
- Sound often to keep ash moving
- Use when there is gas flow
- Most new installations use Sonic Horns



Questions ?