

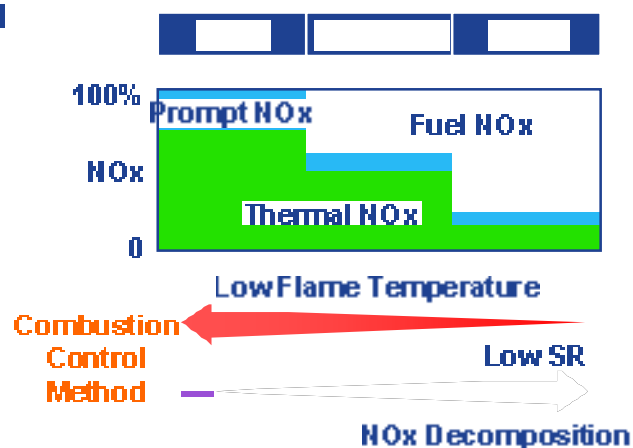
# NO<sub>x</sub> Emissions Control from Industrial Boilers, Cement Kilns and Gas Turbines

R.CHAKRAVARTI.

CHEMTROLS

## Fuel Impact on Sources of NO<sub>x</sub>

- **Thermal NO<sub>x</sub>**
  - Formed by the thermal fixation of molecular nitrogen, N<sub>2</sub>
  - Requires high temperatures (> 1,370°C)
- **Fuel NO<sub>x</sub>**
  - Oxidation of nitrogen bearing species contained in the fuel
- **Prompt NO<sub>x</sub>**
  - Reaction of nitrogen with fuel fragments



## Approaches to NOx Control

Technique	Gas	Fuel Oil	Coal
<b>Operational Modifications</b>			
Low Excess Air	X	X	X
Reduced Air Preheat	X	X	
Fuel Biasing	X		
Burners Out of Service (BOOS)	X	X	
<b>Combustion Equipment Modifications</b>			
Flue Gas Recirculation (FGR)	X	X	
Overfire Air (OFA)	X	X	X
Steam Injection	X		
Low-NOx Burners (LNB)	X	X	X
Reburning		X	X
<b>Post-Combustion Techniques</b>			
Selective Non-Catalytic Reduction (SNCR)		X	X
Selective Catalytic Reduction (SCR)	X	X	X

NOx emissions control technologies vary in performance and cost

Combustion Modification	Approximate Range of NOx Reduction	Type of NOx Reduced	Applicable Combustion Systems
Burner out of Service	40-50%	Thermal	Oil & Gas
Fuel Biasing	10-20%	Thermal	Oil & Gas
Overfire Air	15-30%	Thermal & Fuel	All
Fuel reburning	40-60%	Thermal & Fuel	Coal (cyclone)
Low excess air firing	10-20%	Thermal & Fuel	All
Flue gas recirculation	20-30%	Thermal	All
Low NOx burners	40-50%	Thermal & Fuel	All
Water / steam injection	50-70%	Thermal	Stationary engines

## Various types of NO<sub>x</sub> Control Devices

### – Burner out of service:

This technique can be used to retrofit oil or gas fired units that have multiple levels of burners. This is a staged combustion technique, where fuel flow from upper level burners is diverted to lower level burners, thus creating a fuel rich zone in the technique, where fuel flow from upper level burners is diverted zone in the area around the upper level burners. The combustion system thus consists of lower level burners that are operated fuel rich, and upper level burners that are operated on air only. This method causes less than stoichiometric air to be available for combustion in the fuel rich zone, resulting in lower peak temperatures (due to incomplete combustion of the fuel).

### – Fuel Biasing:

This is a retrofit technique which has been approved only for oil and gas fired utility boilers. Fuel biasing works on the same (staged combustion) concept as the burner out of service technique and also applies an air staging approach however, in the fuel biasing technique adjacent level of burners are operated in a fuel rich and fuel lean configuration instead of the fuel rich and air only configuration employed in the burner out of service technique.

### – Overfire air:

This is also a staged combustion technique where all burners are operated in a fuel rich mode, with additional combustion air supplied through special overfire ports (a.k.a. NO<sub>x</sub> ports) located above the primary combustion zone. The overfire air technique therefore constitutes an air staging approach.

## – Fuel Reburning

Fuel reburning is another staged combustion technique which uses a fuel staging approach versus the air staging approach seen in the previously described techniques. In the fuel reburning technique, the primary (lower) combustion zone is operated in an excess air mode, while the secondary (middle) combustion zone is operated in a fuel rich mode. Approximately 10-20% of the total fuel used for combustion is used in the secondary combustion zone. The secondary combustion zone is followed by a third (upper) combustion zone, in which only air is added to the process. The air added in the third combustion zone allows the combustion to be completed. The oxygen rich atmosphere of the primary combustion zone allows for the formation of  $\text{NO}_x$ , which is then converted into molecular nitrogen ( $\text{N}_2$ ) in the fuel rich (reducing) atmosphere present in the secondary combustion.

## – Low excess air firing:

The objective of this approach is to operate with the lowest level of excess air that is safe, efficient and practical.

## – Flue gas recirculation:

This technique for reducing  $\text{NO}_x$  generation is accomplished by taking typically 10-30% of the flue (exhaust) gas, mixing it with incoming combustion air and injecting the mixture directly into the combustion chamber. The recirculated flue gas acts as an inert thermal diluent (i.e. it dilutes the oxygen content of the combustion air) and provides for better mixing of combustion air and fuel (via increased turbulence), allowing for lower flame temperatures. Both of these results contribute to decreased generation of thermal  $\text{NO}_x$ .

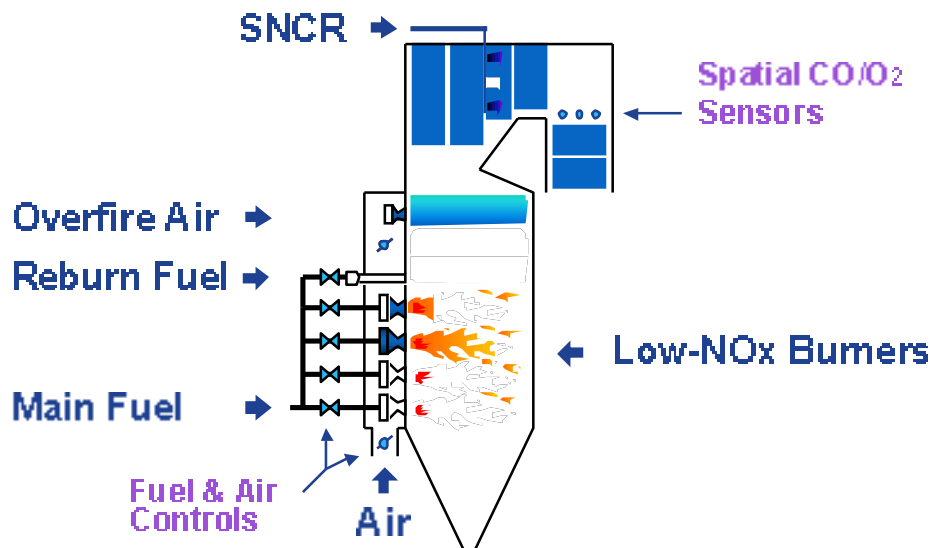
– **Low NO<sub>x</sub> Burners:**

Low NO<sub>x</sub> burners have been developed which can be used to retrofit almost any type of combustion process. Low NO<sub>x</sub> burners use modified air and fuel entry to slow the mixing rate, reduce the oxygen available for NO<sub>x</sub> formation in critical NO<sub>x</sub> formation zones, and / or reduce the amount of fuel burned at peak flame temperatures. Low NO<sub>x</sub> burners operate at much lower oxygen levels than conventional burners, and therefore generate less fuel and thermal NO<sub>x</sub>.

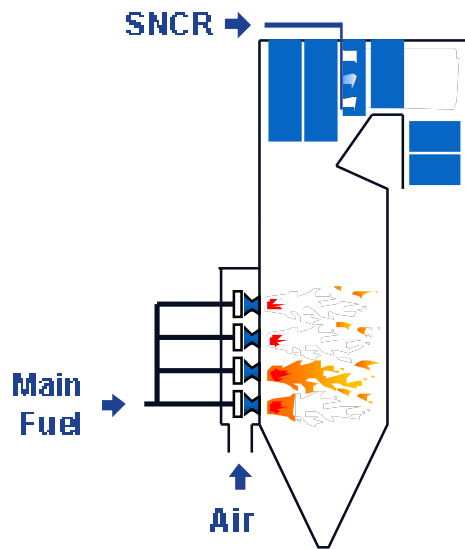
– **Water / steam injection:**

This technique is commonly used to reduce NO<sub>x</sub> generation in gas turbines. The injection of steam or water reduces the peak flame temperature of the combustion process, thus reducing the creation of thermal NO<sub>x</sub>. This technique requires that water/steam be treated to prevent corrosion, and may result in increased generation of carbon monoxide and / or hydrocarbons at low load conditions. The addition of water also slightly increases fuel consumption, because additional energy is consumed by the system for converting the water into water vapor (steam).

**Technology layering reduces NO<sub>x</sub> emissions to low levels**

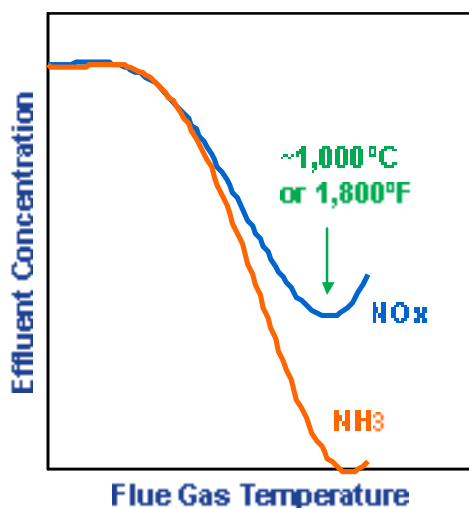


## Selective non-catalytic reduction consists of nitrogen agent injection



- Technology involves the injection of a nitrogen agent (ammonia, urea, etc.) into the post-combustion flue gases.
- At the proper temperature, the **SNCR reagent** selectively reduces NO to molecular nitrogen.

## SNCR reaction occurs in narrow temperature window



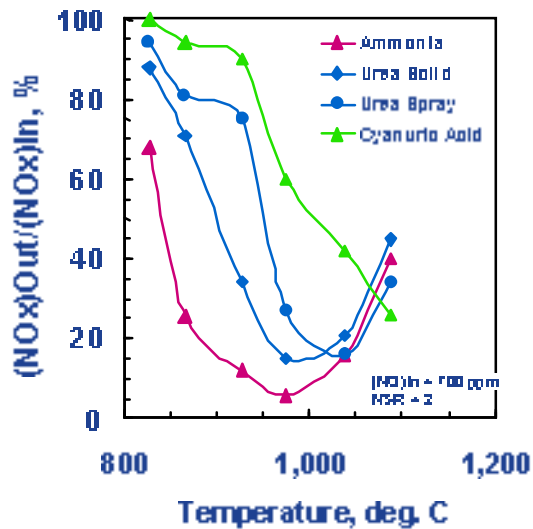
Reaction chemistry involves reagent activation and reaction with NO:



At high temperatures, reagent is oxidized to NO<sub>x</sub>.

At low temperatures, reagent does not react, leading to ammonia slip.

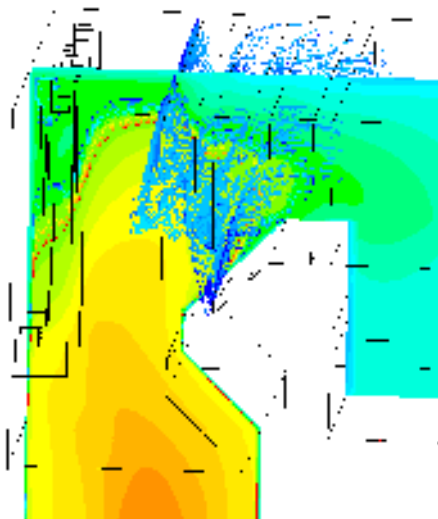
## Impact of gas temperature and reagent on SNCR performance



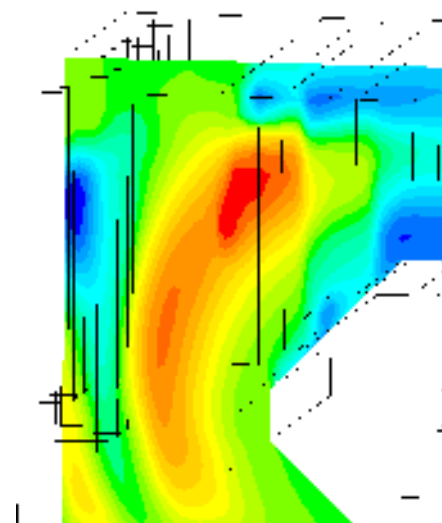
- Several reagents are available for SNCR applications.
- At ideal conditions, SNCR can yield high levels of NO<sub>x</sub> reduction.
- Reagent performance depends on mode of injection and application specific conditions.

## Use of CFD for SNCR system design for Boilers

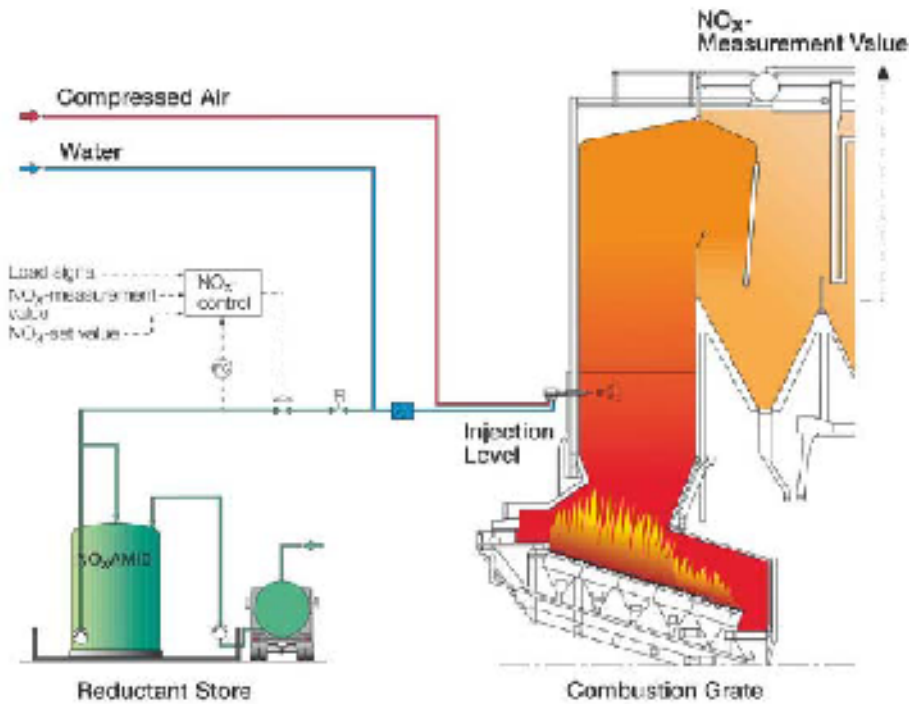
**Droplet Trajectories & Temperature Contours**



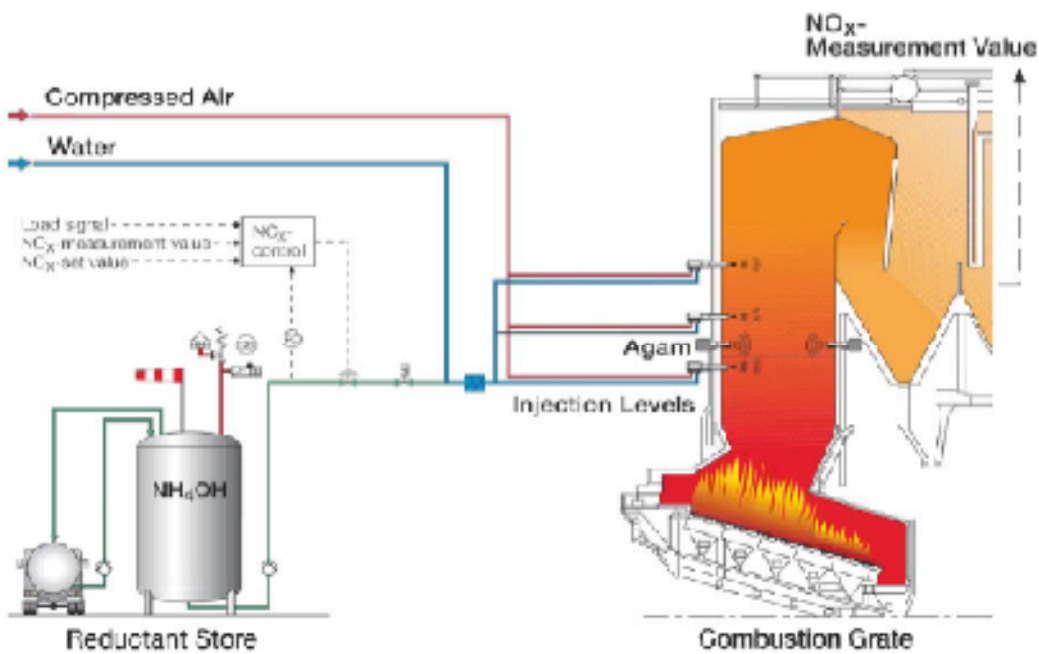
**Resulting Contours of NO<sub>x</sub> Concentration**



# UREA BASED SNCR FOR BOILER

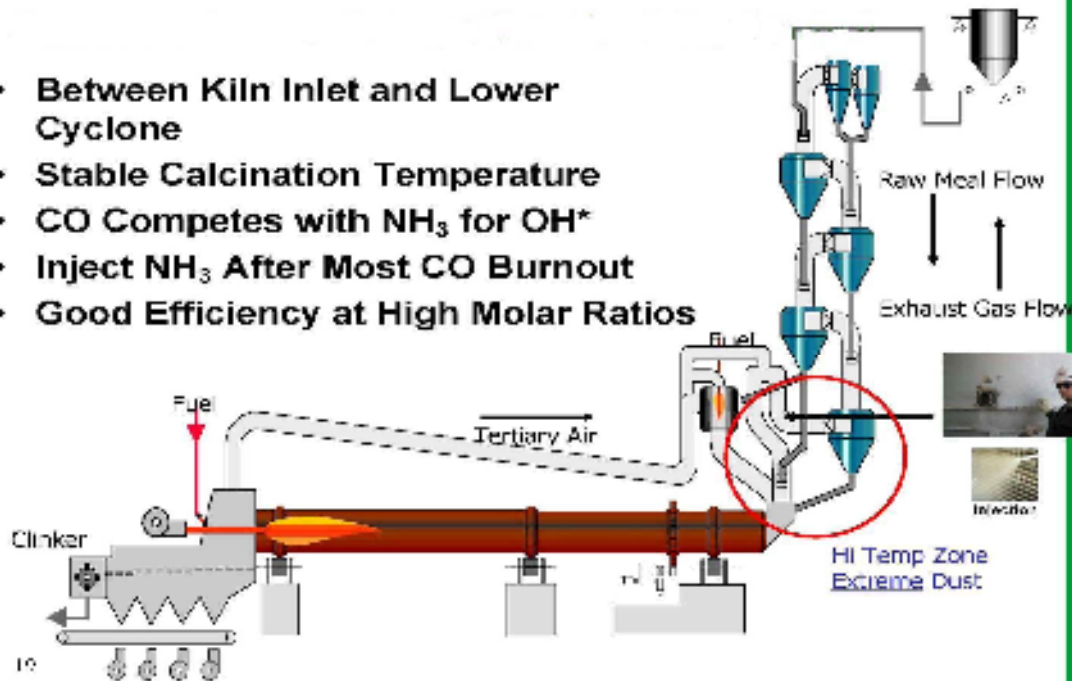


# SNCR FOR BOILER WITH MULTI LEVEL INJECTION

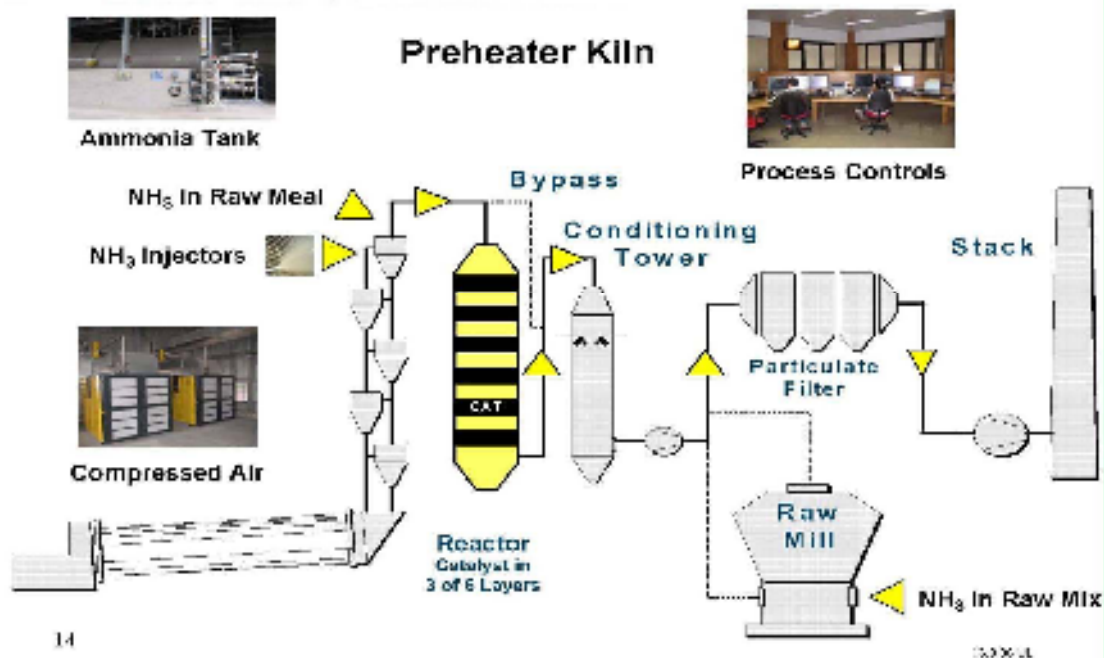


# SNCR FOR CEMENT KILN (Aqueous Ammonia Injection)

- Between Kiln Inlet and Lower Cyclone
- Stable Calcination Temperature
- CO Competes with  $\text{NH}_3$  for  $\text{OH}^*$
- Inject  $\text{NH}_3$  After Most CO Burnout
- Good Efficiency at High Molar Ratios



# SCR FOR CEMENT KILN



# Regulations for NO<sub>x</sub> Removal in Gas Turbines

## Model Rule for Additional Nitrogen Oxides (NO<sub>x</sub>) Control Measures

For a simple cycle combustion turbine:

- a. For a **gas-fired** turbine without oil back-up, 1.0 Kg of NO<sub>x</sub> per MWh (**55 ppmvd**, corrected to 15% O<sub>2</sub>)
- b. For an **oil-fired** turbine, 1.36 Kg of NO<sub>x</sub> per MWh (**75 ppmvd**, corrected to 15% O<sub>2</sub>)

## NO<sub>x</sub> Reduction Strategies for Gas Turbines

- Remove NO<sub>x</sub> from exhaust after production
- Reduce NO<sub>x</sub> production
- Combination of Removal & Reduction

## NOx Reduction in Gas Turbines

### High Pressure Water Injection (HPWI)

#### PROS

- PROVEN technology
- Simple Installation / packaged system
- Small installation footprint
- Low capital cost
- Low Operation & Maintenance Costs
  - Only consumable is DI water and filters
- Power increase (~7%) due to increased mass flow
- Reduces Opacity

## NOx Reduction in Gas Turbines

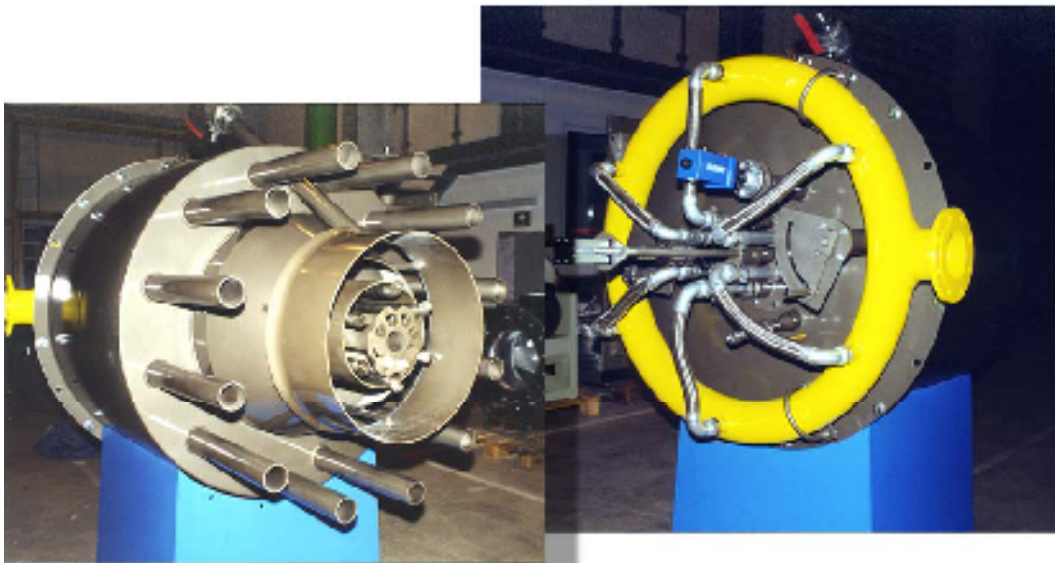
### •High Pressure Water Injection

#### •CONS

- Increases CO
  - NOTE: CO for Liquid fuel w/ HPWI is < CO for Gas w/ No HPWI
- Need reliable source for DI water
  - Large Tank, or
  - Smaller tank and on-site DI Water Processing System
  - Requires about 76 LPM per engine
- If you have a Gas only FT4, requires dual fuel manifolds
- Water flow limited by fuel system nozzle capacity

DI water: Distilled or Deionised water used in Gas turbine inlet fogging system

## ERC Low NO<sub>x</sub> Burners



## Construction features of the burners, ERC

- Performance level 8 - 90 MW
- Duo - Block design
- axial swirl regulator
- adjustable gas lances during the maintenance
- triple air graduation
- internal flue gas recirculation

## Nox-Reduction state of the art technologies

- selective non-catalytic reduction (SNCR, 950 °C)
- selective catalytic reduction (SCR, 400 °C)

### REACTION AGENTS:

- ammonia (-water)
- urea, dotated (carbamin S)

The choice of the technology and the reduction agent has a considerable influence on the capital and operating costs.

## Concepts for the reducing of nitrogen in flue gases

### SNCR Process

Selective, non-catalytic Nox-reduction at high flue-gas temperatures.

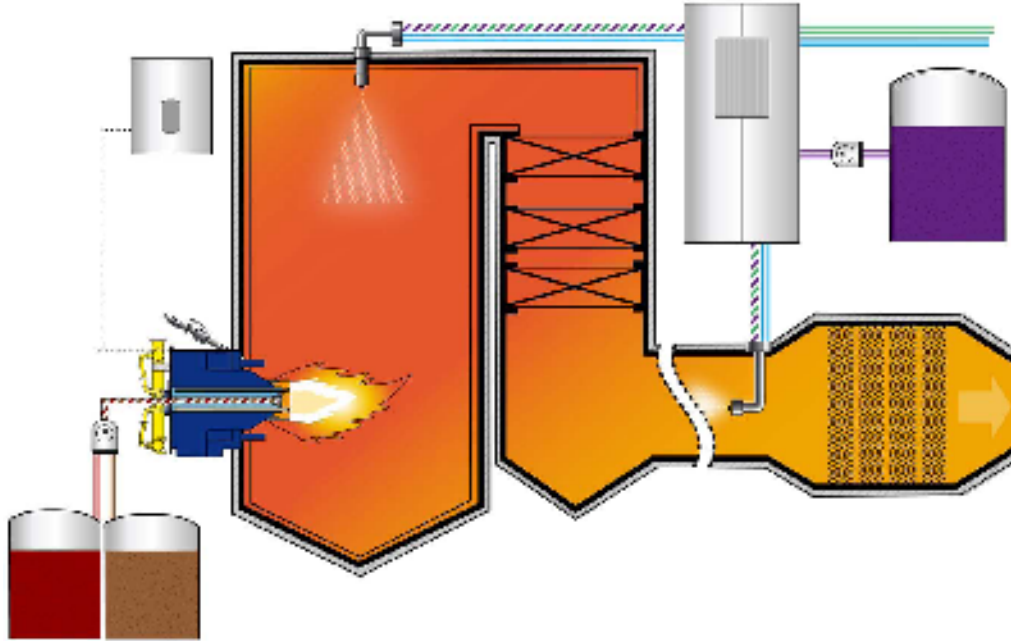
### SCR Process

Selective, catalytic Nox-reduction at low flue-gas temperatures.

### Combination Process

The cost-effective combination of SNCR and SCR processes.

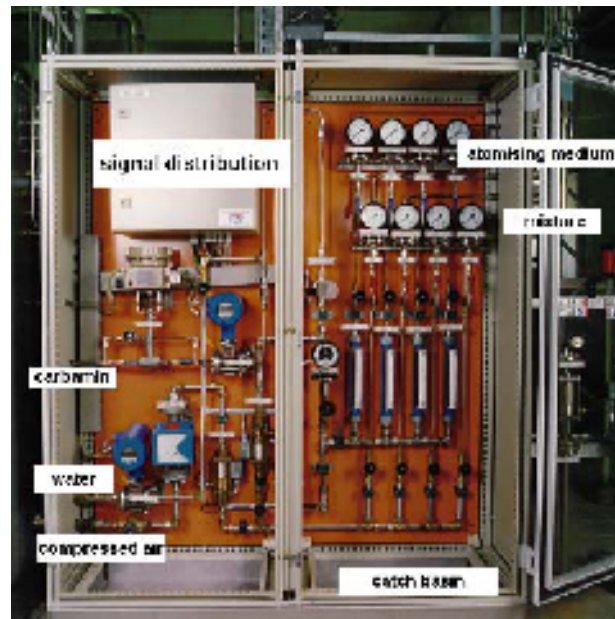
## SNCR/SCR, ERC



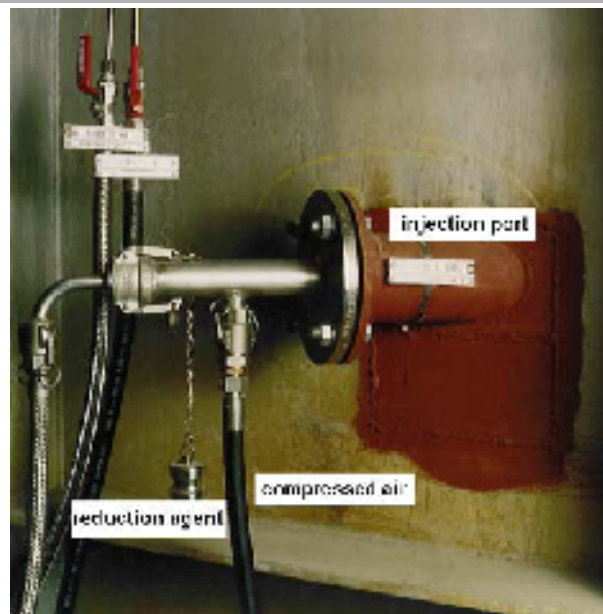
## Storage system for D'NOX additives with unloading area, ERC



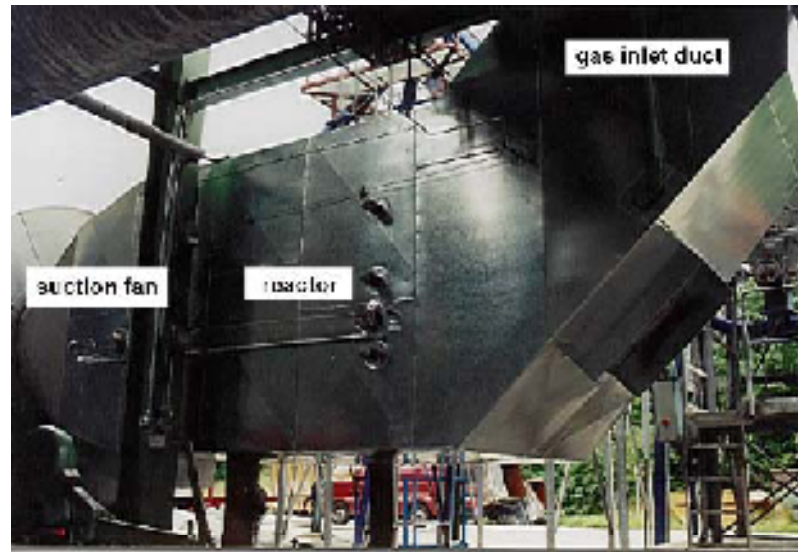
## Mixing module, ERC



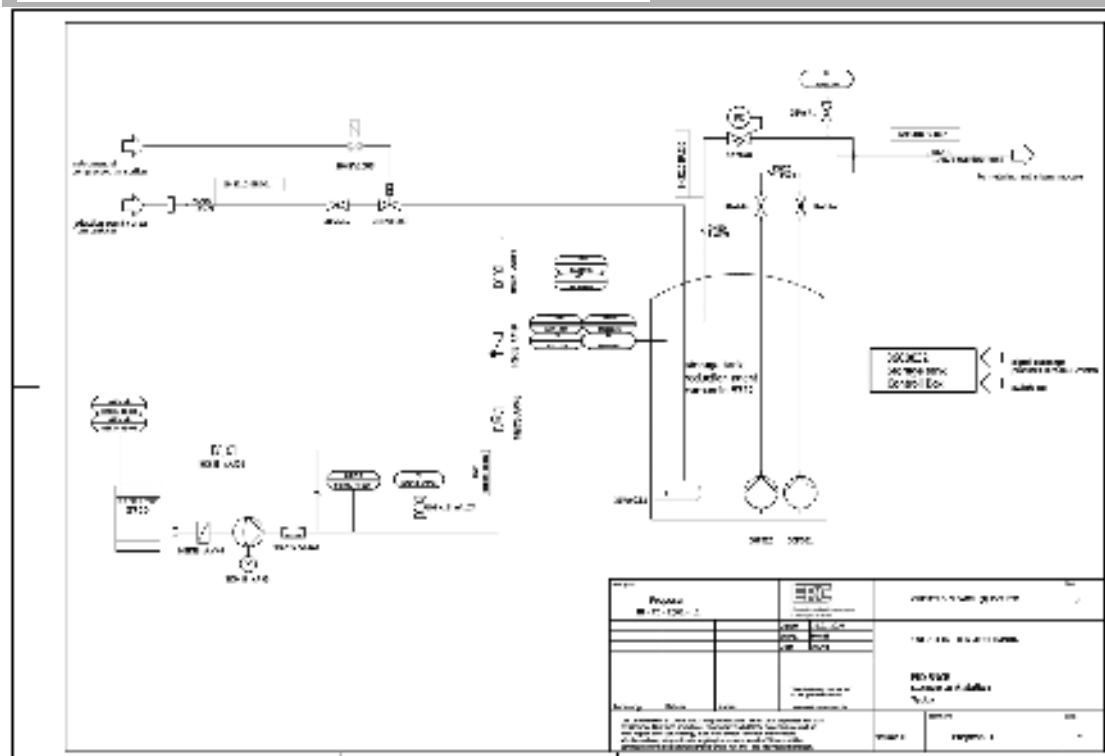
## Injection lance, ERC



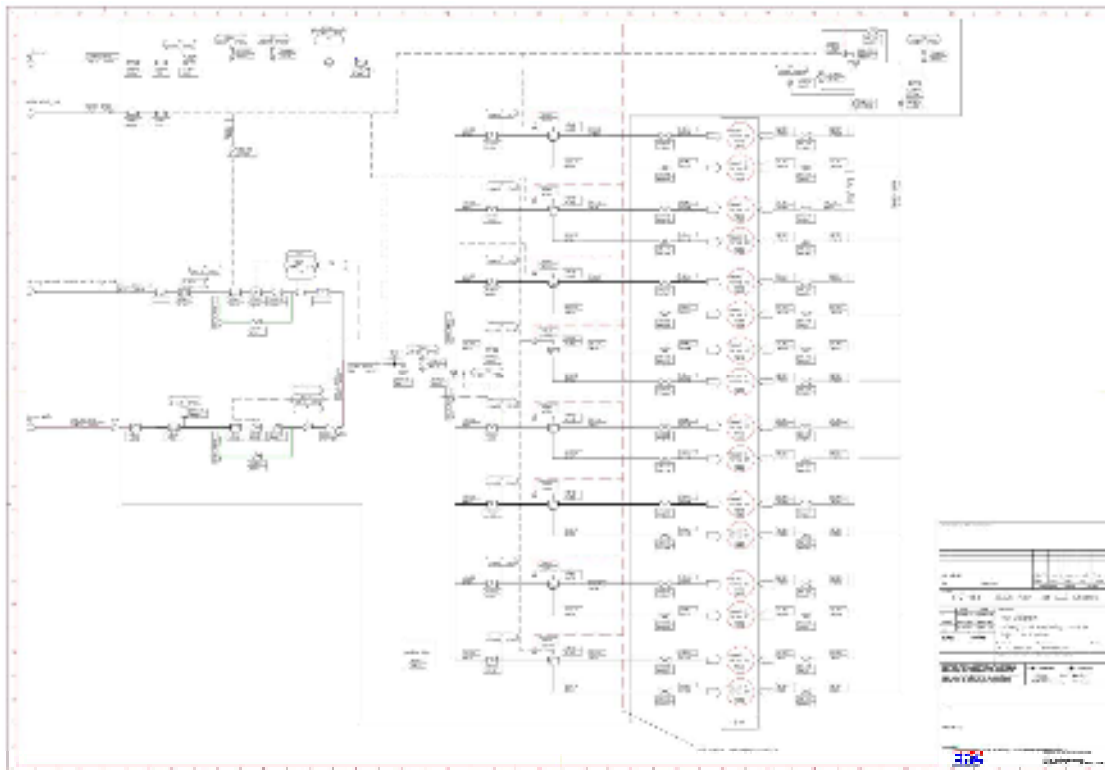
# Catalytically DENOX-Stage, ERC



# PID Storage Tank Station



## PID Diagram SNCR mixing and metering modul Model



## ERC Installation for SNCR

ERC, GmbH  
 Hiltmannstraße 12  
 42699 Solingen

NEWTON-PLatz 10, 42699 Solingen  
 Tel.: +49 (0)212 649-1100  
 Fax: +49 (0)212 649-1101



### Reference List

Die ERC GmbH hat für die ERC und die ERC-Produkte die folgenden Referenzliste zusammengestellt.

Die folgenden Referenzliste ist ein Auszug der Referenzliste.

Produktname	Produkttyp / Typ	Leistung / Durchsatz	Produktionsmenge (t/Tag)	Produktionsmenge (t/Jahr)
ERC 1000	1000 l/h	1000 l/h	1000	1000
ERC 2000	2000 l/h	2000 l/h	2000	2000
ERC 3000	3000 l/h	3000 l/h	3000	3000
ERC 4000	4000 l/h	4000 l/h	4000	4000
ERC 5000	5000 l/h	5000 l/h	5000	5000
ERC 6000	6000 l/h	6000 l/h	6000	6000
ERC 7000	7000 l/h	7000 l/h	7000	7000
ERC 8000	8000 l/h	8000 l/h	8000	8000
ERC 9000	9000 l/h	9000 l/h	9000	9000
ERC 10000	10000 l/h	10000 l/h	10000	10000
ERC 12000	12000 l/h	12000 l/h	12000	12000
ERC 15000	15000 l/h	15000 l/h	15000	15000
ERC 20000	20000 l/h	20000 l/h	20000	20000
ERC 25000	25000 l/h	25000 l/h	25000	25000
ERC 30000	30000 l/h	30000 l/h	30000	30000
ERC 40000	40000 l/h	40000 l/h	40000	40000
ERC 50000	50000 l/h	50000 l/h	50000	50000
ERC 60000	60000 l/h	60000 l/h	60000	60000
ERC 70000	70000 l/h	70000 l/h	70000	70000
ERC 80000	80000 l/h	80000 l/h	80000	80000
ERC 90000	90000 l/h	90000 l/h	90000	90000
ERC 100000	100000 l/h	100000 l/h	100000	100000







**Thank You**

