Coking.com® CatCracking.com®

FCCU NO_x Reduction - SCR Retrofit

October 2011
Düsseldorf Germany

Daniel Barnett
Vice President of Engineering
KTI Corporation
001 281.249.3546
dbarnett@kticorp.com

Technip

KTI ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

FCCU Introduction

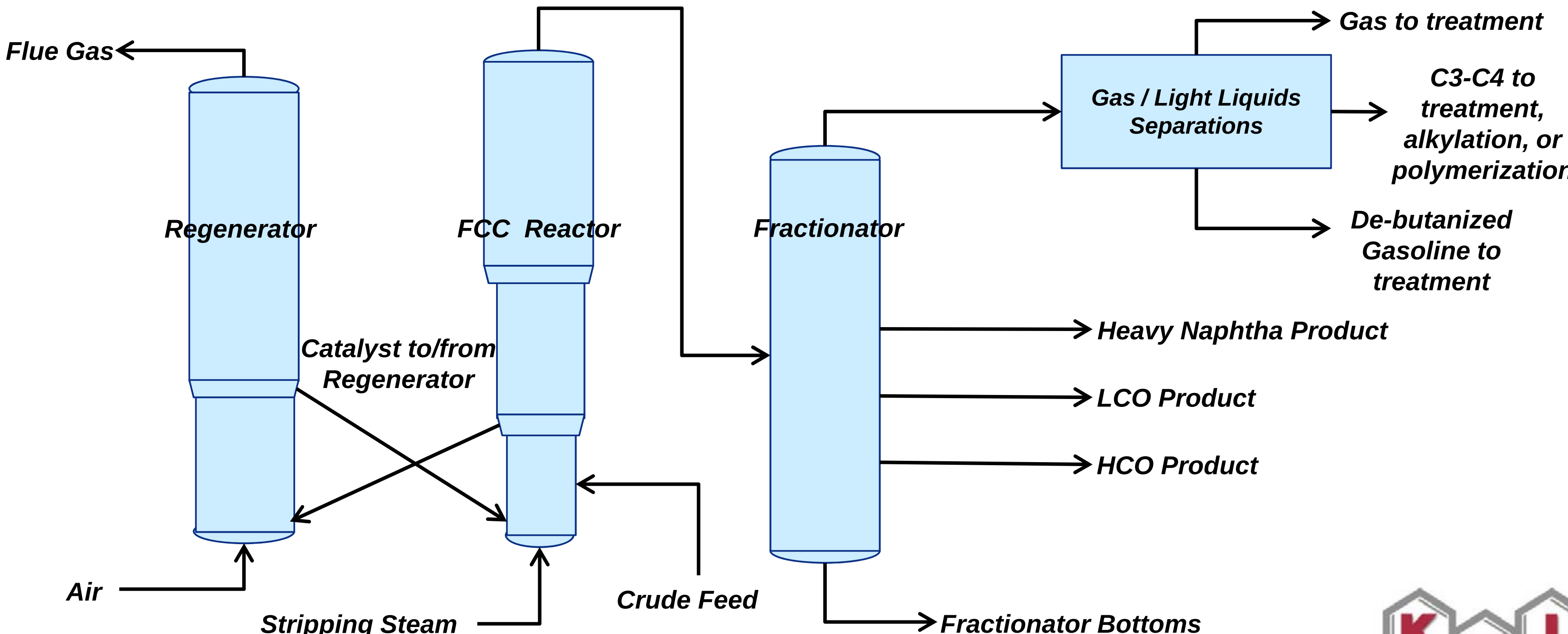
- The Fluidized Catalytic Cracking Unit is the economic heart of modern refinery operations
- Reliable and optimal performance from the FCCU is key to the viability and competitiveness of refinery operations and the downstream units served by those refineries

Selective Catalytic Reduction units designed for treatment of FCCU flue gas must not have a detrimental impact on the reliability or performance of the FCCU

FCCU NO_x Reduction – SCR Retrofit

FCCU Introduction

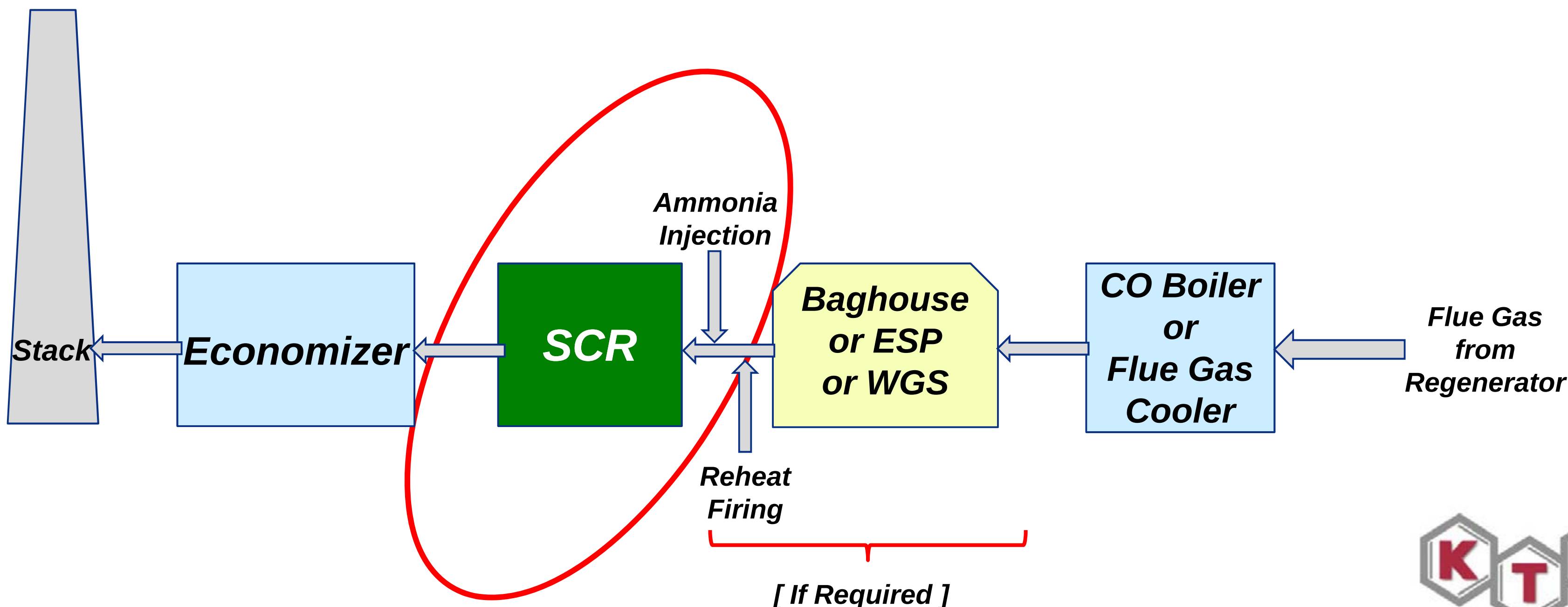
- The Fluidized Catalytic Cracking Unit is the economic heart of refinery operations



FCCU NO_x Reduction – SCR Retrofit

FCCU Introduction

- The flue gas train must be designed to support FCCU operations with a compatible level of reliability



Technip

KTI ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

SCR Introduction

- SCR uses ammonia (NH_3) as a reducing agent to react with NO_x
- Basic Reactions, Ammonia based

$$\mathbf{4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O}$$

$$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O$$

$$\mathbf{2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O}$$

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$$

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

- ~90% of NO_x is NO - First reaction accounts for most of the conversion

Technip

ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

SCR Introduction

- **Basically three types of catalysts available:**
  - Platinum based
  - Vanadium-Titania based, and
  - Zeolite catalyst

- **Vanadium-Titania based catalyst more common, available forms**
  - Pelletized (extruded ceramic substrate)
  - Monolithic (honeycomb extruded ceramic substrate)
  - Plate catalyst (stainless steel)
  - Corrugated (composite plate type structure)

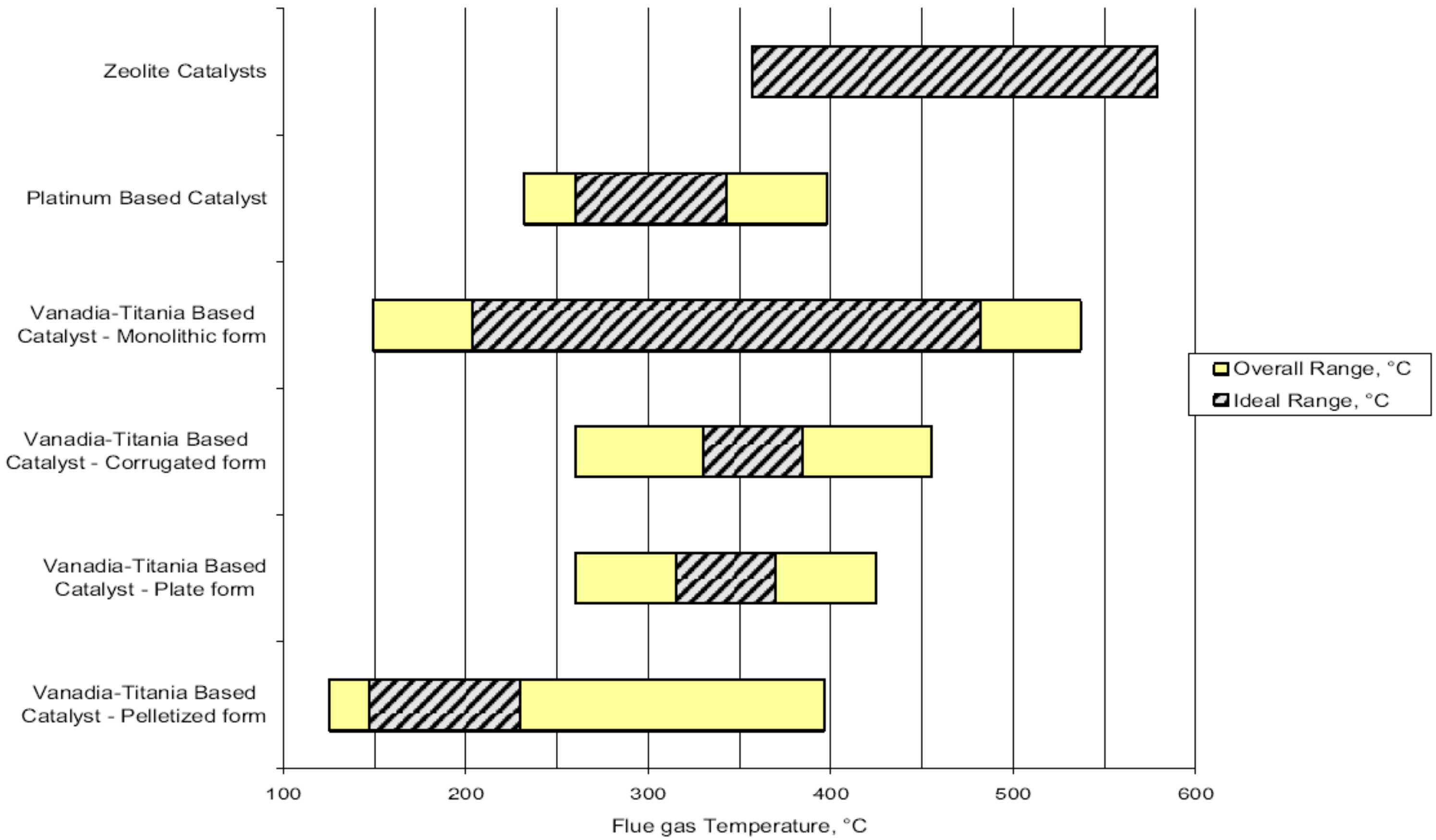
Technip

KTI ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

SCR Introduction

- **Typical temperature ranges for SCR Catalysts**



Technip

ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

SCR Introduction

- **Vanadium-titania catalyst – three temperature ranges:**
  - Low Temperature Catalyst (pelletized)
  - Medium Temperature Catalyst (monolithic, plate, corrugated)
  - High Temperature Catalyst (monolithic, plate, corrugated)

- **Medium Temperature Catalyst most appropriate for FCCU SCR application:**

Vanadium-titania based catalyst coated on extruded ceramic honeycomb or metallic substrate (WO_3 : 5-10 wt%, V_2O_5 : 0-4 wt%, TiO_2 : 80-90 wt%)

	Typical	Possible Range
Operating Temperature, °F	550 – 750	475 – 800
Pressure Drop, "WC	2 – 3	<1
NOx Conversion	90%	can be 95% +
NH_3 Slip, ppmvd	10 ppm	as low as 2 ppm

Technip

KTI ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

Design Basis of an SCR System:

- Flue gas flow rate / temperature / composition
- Inlet NO_x concentration
- Required NO_x reduction efficiency or outlet NO_x concentration
- SO_2, SO_3 levels
- Particulate loading rate / particle size distribution
- Allowable pressure drop
- Physical site constraints
- Location relative to other equipment in flue gas stream
- Poisons
- NO to NO_2 split

Design Basis must define both Normal and Upset Operating conditions of the FCCU

Technip

ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

Design Activities of SCR System:

- Process and detailed engineering
- Catalyst specification and selection
- AFCU skid specification and selection
- Isolation / Control damper specification and selection
- Sootblower / Cleaning device specification and selection
- Layout of SCR housing, support system and seal plate system
- Computational Fluid Dynamic [CFD] / Cold Flow Modeling [CFM]
- Design of AIG/manifold
- Design of ducting
    - Static Mixers / Perforated Plates / Turning Vanes / Splitters

Early engagement of suppliers with concurrent layout & CFD/CFM is Key to Success

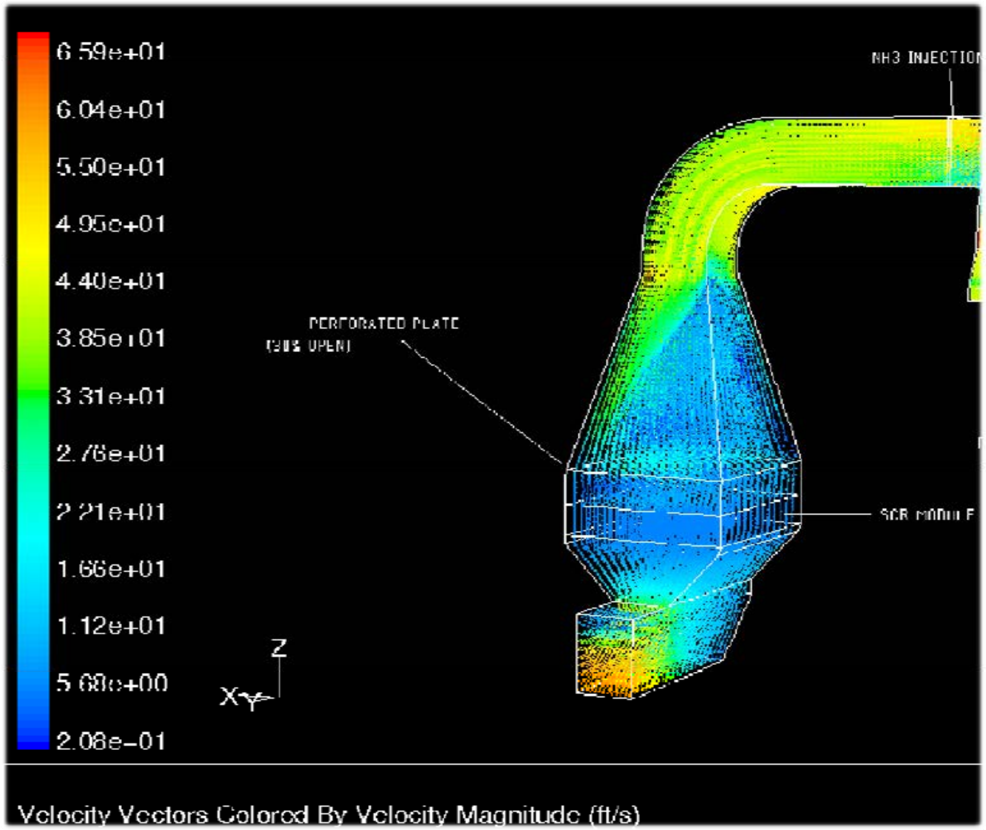
Technip

ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit
Computational Fluid Dynamic Modeling

CFD used as a tool for:

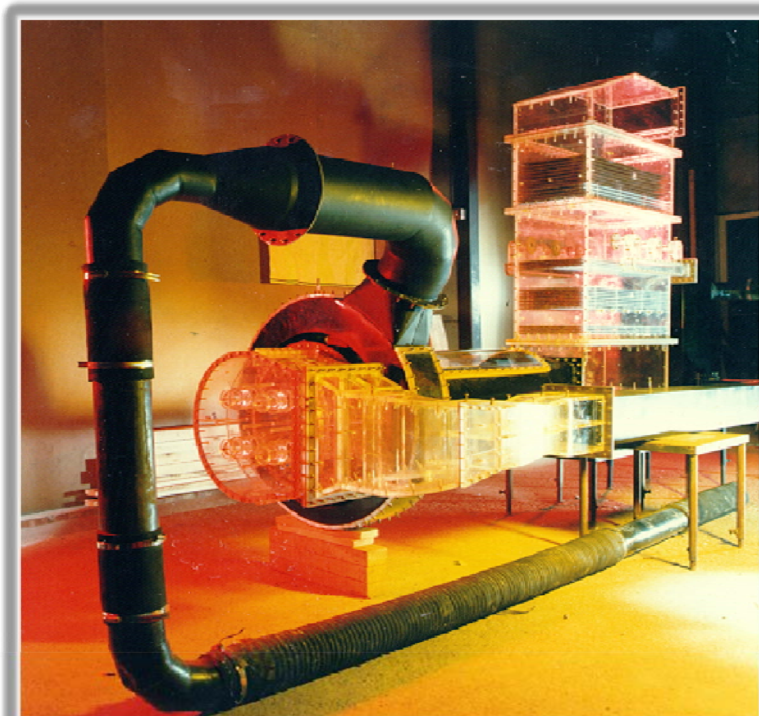
- *Design of turning vanes*
- *Design of flow splitters*
- *Design of flow distributors / perforated plates*
- *Design of AIG*
- *Design of Static Mixers*
- *Quantifying uniformity of flow and mixing*

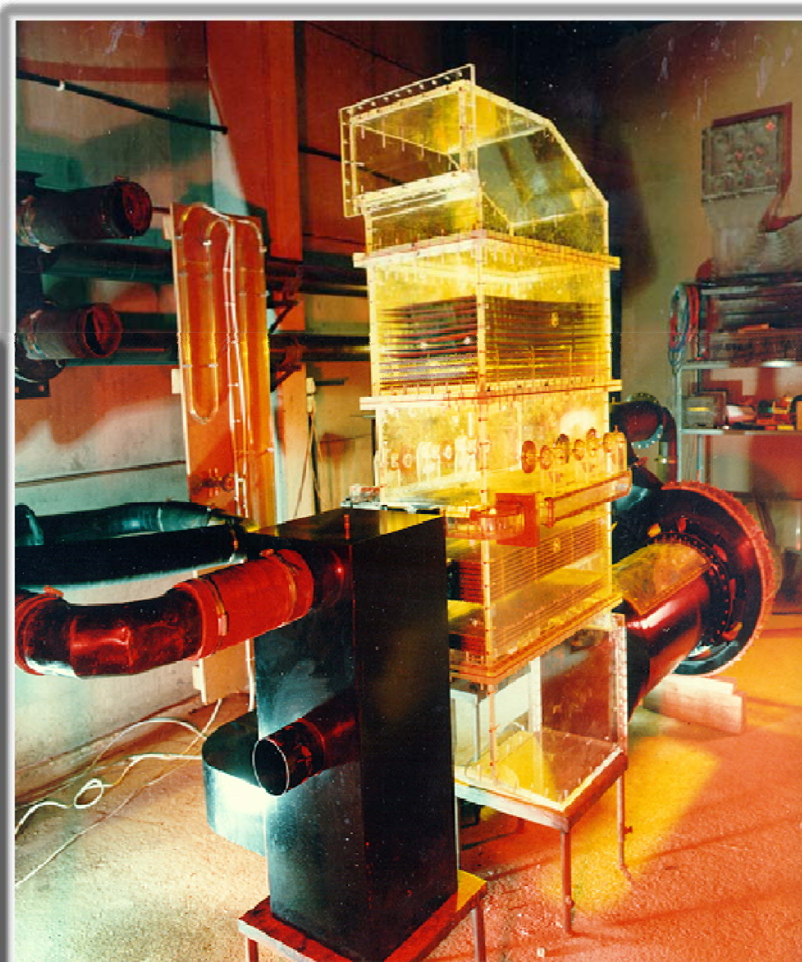


FCCU NO_x Reduction – SCR Retrofit
Cold Flow Modeling

CFM used as a tool for:

- ***Design of turning vanes***
- ***Design of flow splitters***
- ***Design of flow distributors / perforated plates***
- ***Design of Static Mixers***
- ***Quantifying uniformity of flow***





Technip

ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

- Engage Catalyst Suppliers Early
  - Define design conditions
    - Process conditions
      - Flow / temperature / pressure
      - Composition / NO_x / SO_2 / Particulate
      - Poisons
    - Guarantee parameters
      - Pressure drop limitations
      - Catalyst life requirements
      - NO_x reduction requirements
      - Ammonia slip requirements

Catalyst Volume

Flow / Temp / NO_x Distribution Tolerance

NH_3 Mixing Tolerance

  - Enables definition of access / handling requirements
    - Select catalyst type / module size / weight / # layers

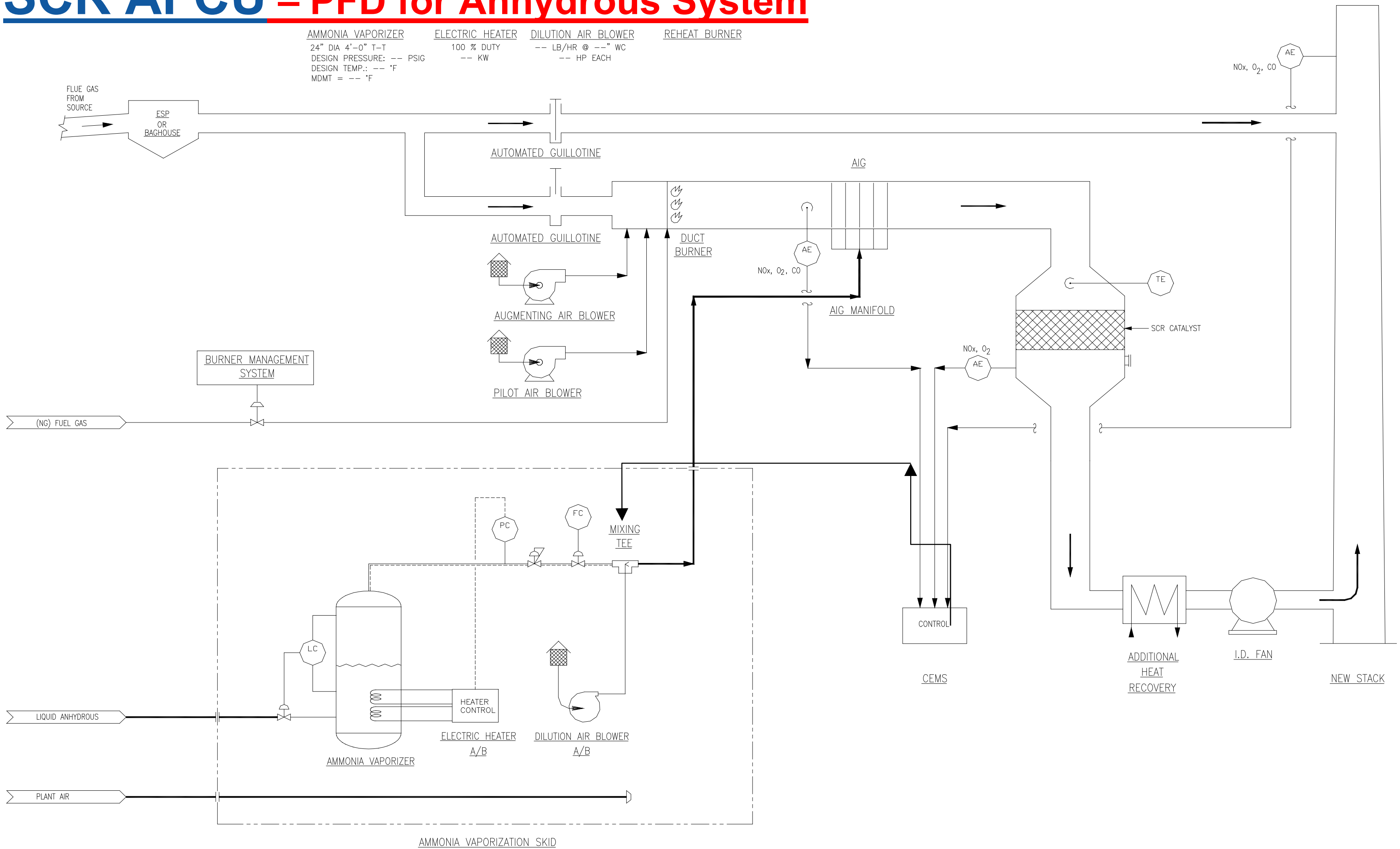
Provides definition needed for design of other critical components of the system

Technip

ENGINEERED TO PERFORM™

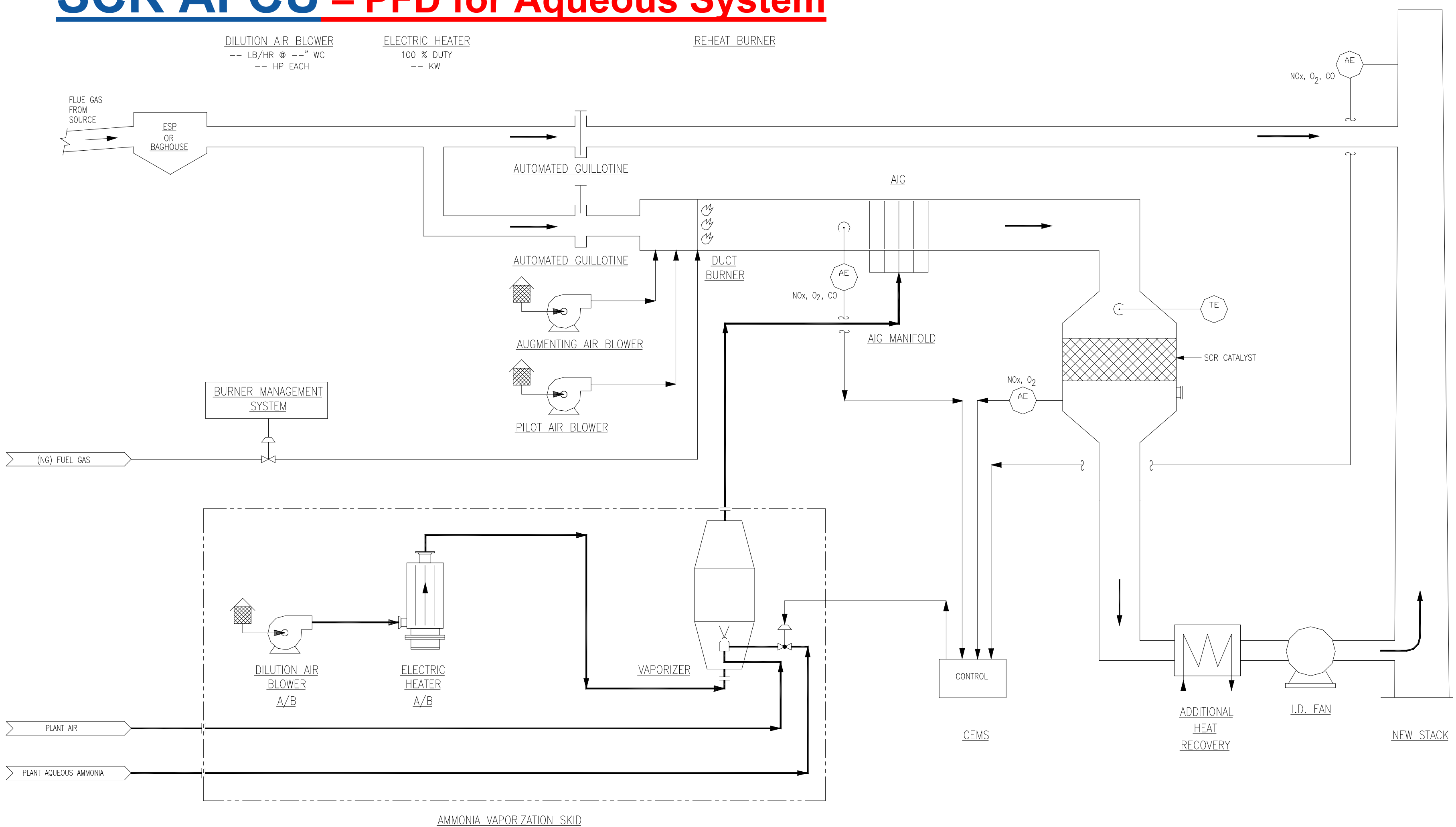
FCCU NO_x Reduction – SCR Retrofit

SCR AFCU – PFD for Anhydrous System



FCCU NO_x Reduction – SCR Retrofit

SCR AFCU – PFD for Aqueous System



Technip

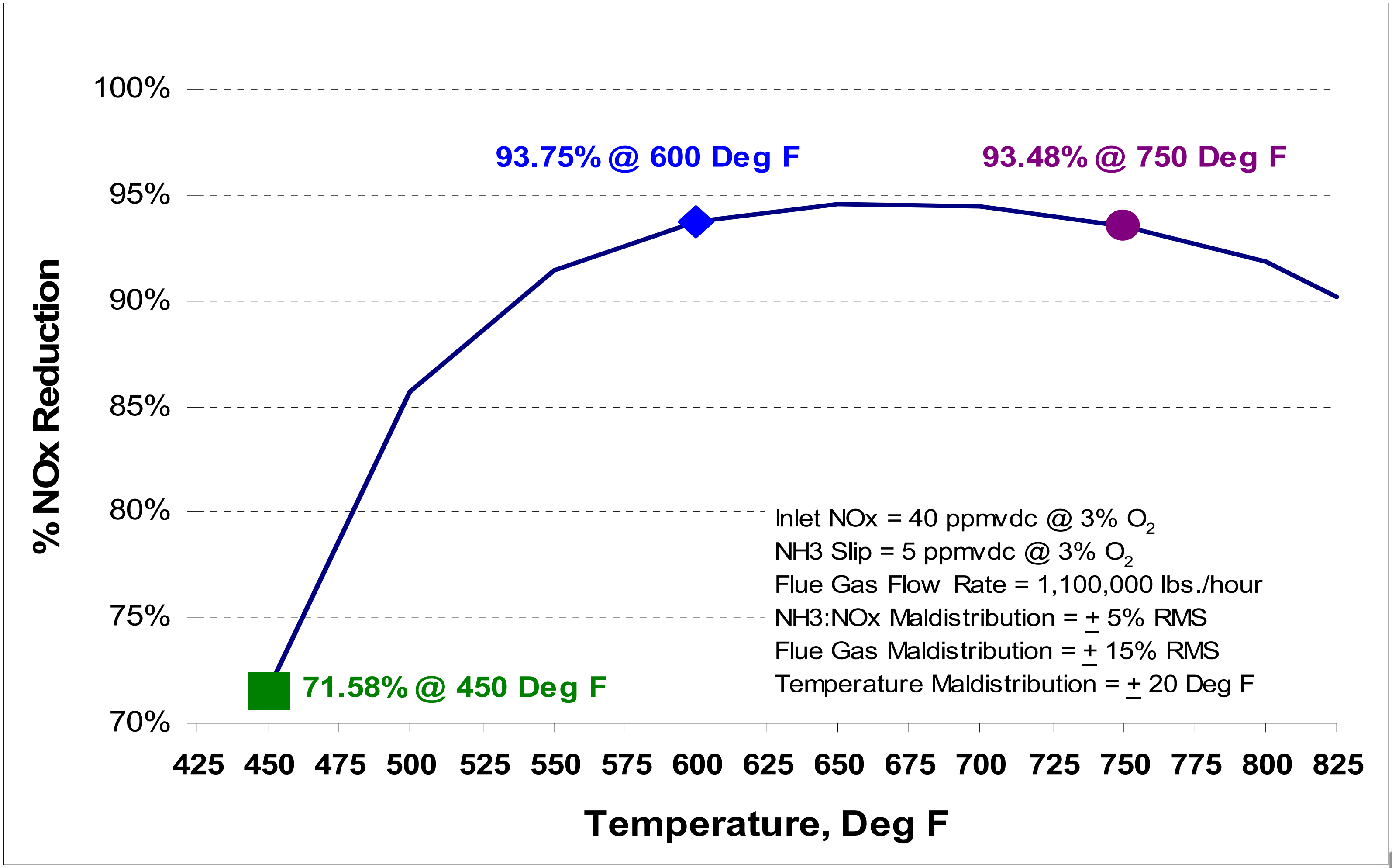
KTI ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit

SCR AFCU

SCR Operating Parameters

Acceptable operating temperature window can be defined

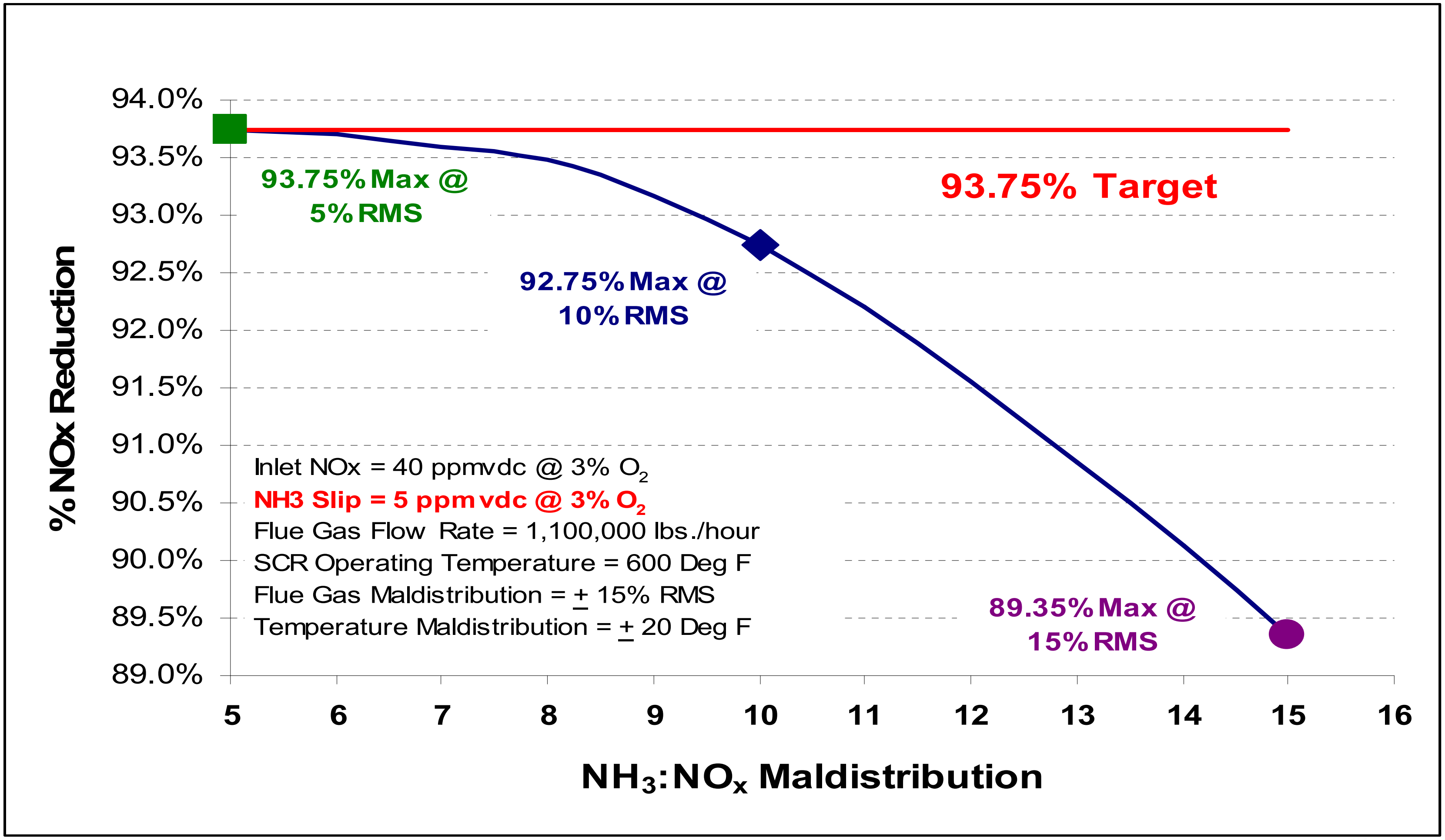


Technip

KTI ENGINEERED TO PERFORM™

SCR Operating Parameters

High reduction efficiency requires high degree of flow and mixing uniformity

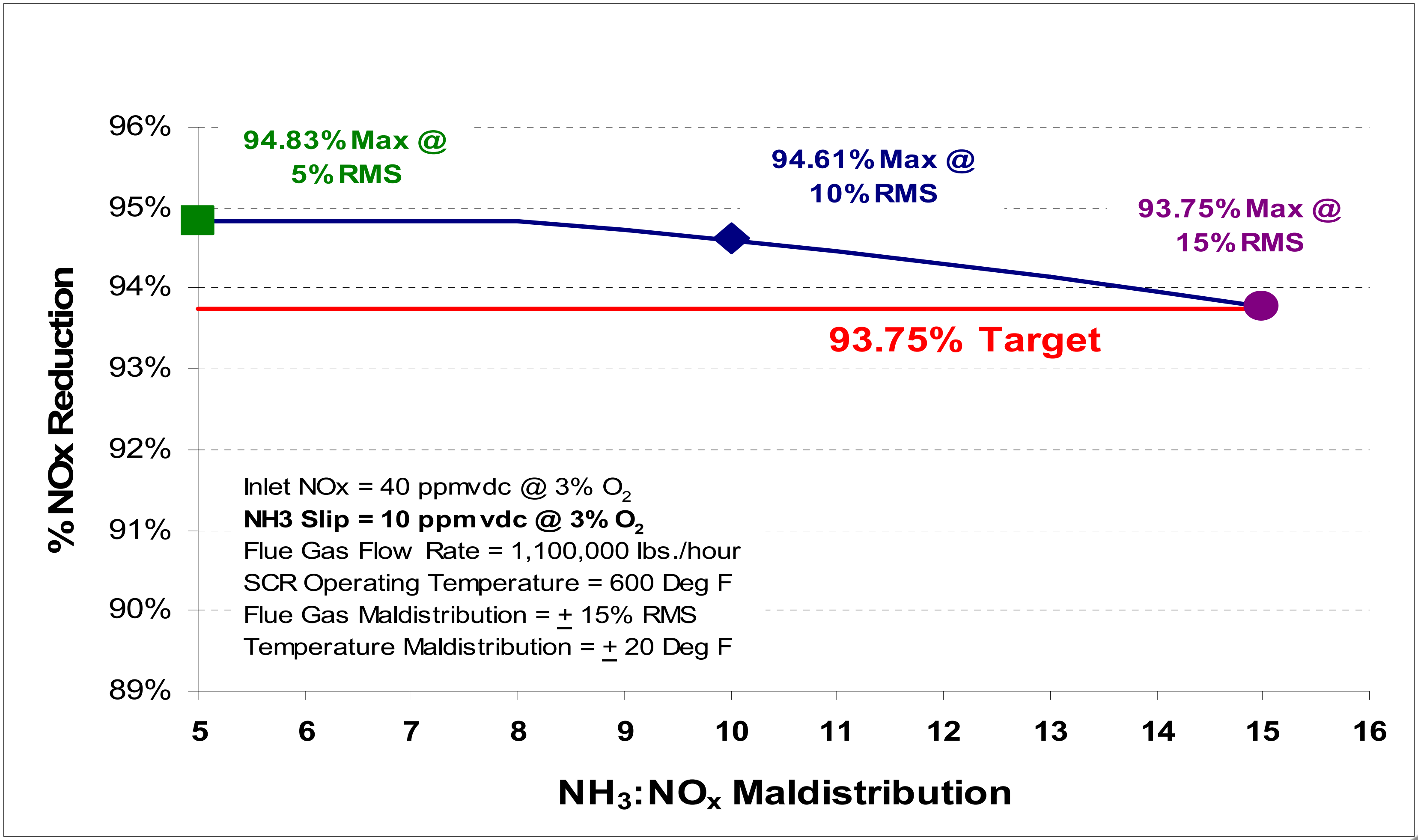


Technip

KTI ENGINEERED TO PERFORM™

SCR Operating Parameters

Flow and mixing uniformity can be relaxed with higher ammonia slip



Technip

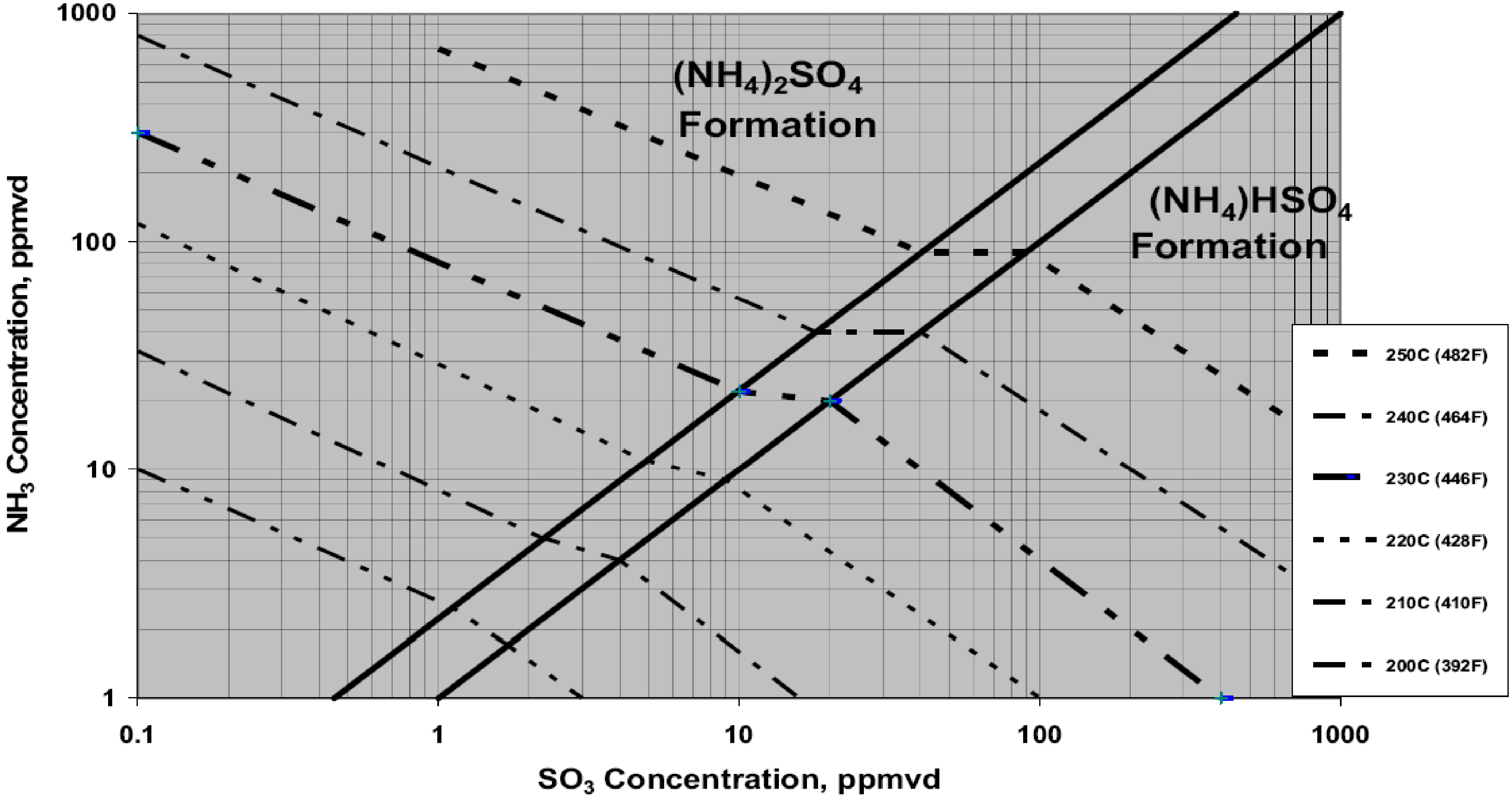
ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit
SCR Design Parameters SO_2 to SO_3 Conversion

- **SCR design must consider conversion of SO_2 to SO_3 [generally <0.1%]**
  - A small portion of SO_2 present in the FCCU flue gas is converted to SO_3 when passing through the SCR catalyst. The SO_3 then reacts with remaining excess NH_3 to form Ammonium Sulfate [$(NH_4)_2 SO_4$] / Bisulfate [$(NH_4)HSO_4$] which can then deposit on downstream equipment.
  - Ammonium Sulfate is a dry powdery material [adds to flue gas particulate]
  - Ammonium BiSulfate [ABS] is a sticky, viscous material that is corrosive when exposed to atmospheric moisture upon shutdown
    - ✓ Deposition & accumulation of Ammonium Sulfate / BiSulfate
    - ✓ Ammonium BiSulfate will accumulate on relatively cold surfaces
    - ✓ Periodic soot blowing
    - ✓ Periodic heating to vaporize ABS

FCCU NO_x Reduction – SCR Retrofit

SCR Design Parameters SO_2 to SO_3 Conversion



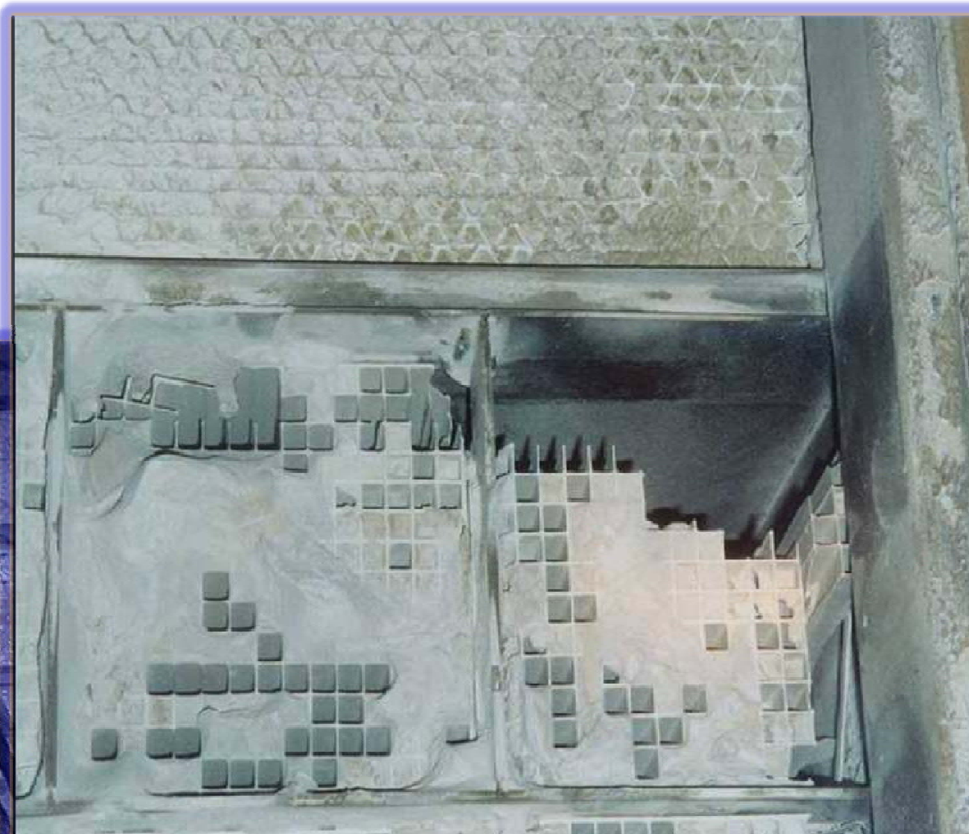
Technip

KTI ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit
SCR Design Parameters Particulate Loading

High Particulate Loading

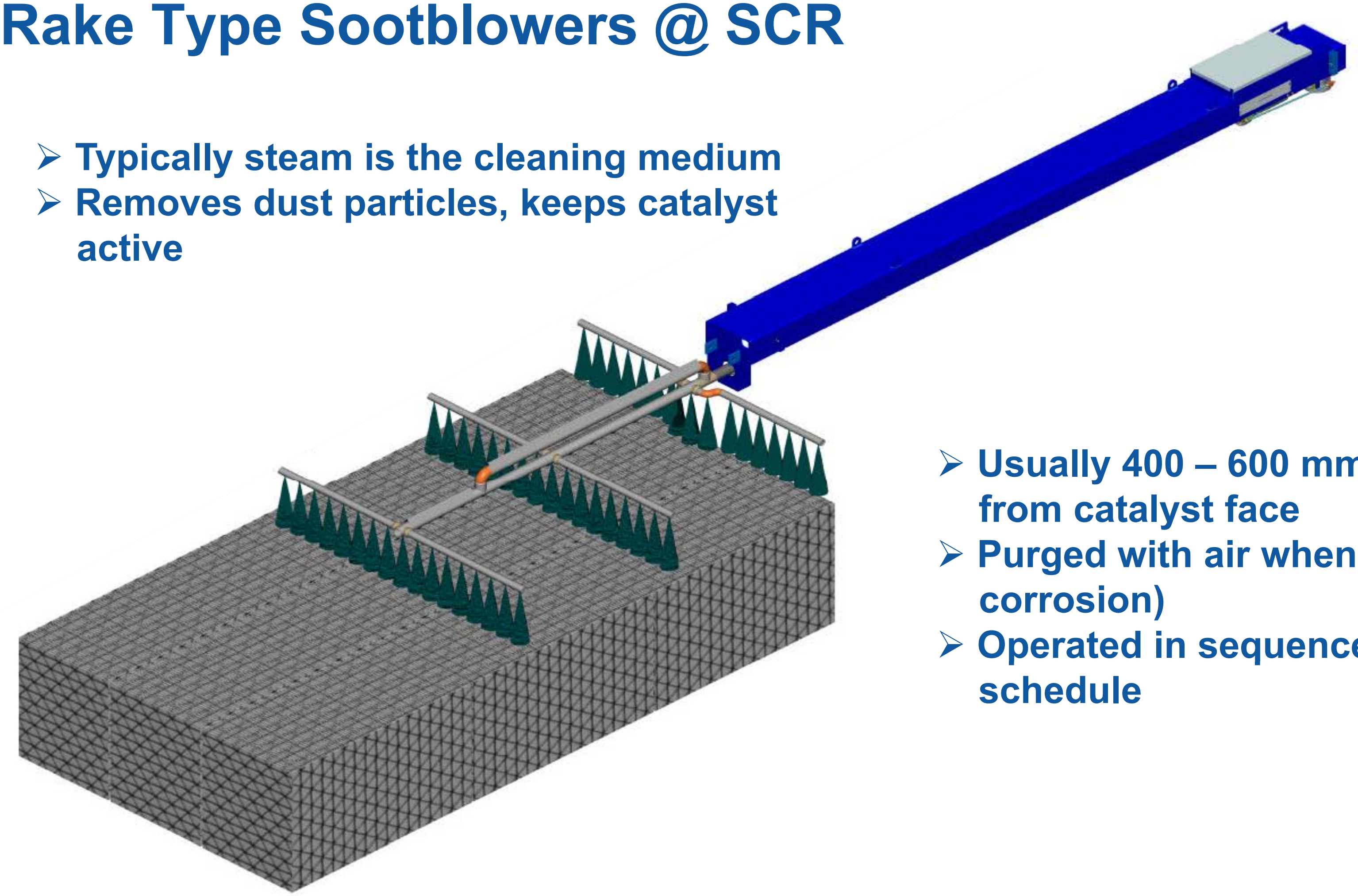
- *Can result in accumulation and plugging*
- *Can produce catalyst erosion in severe cases*
- *May justify including sootblowers in the design*



FCCU NO_x Reduction – SCR Retrofit
SCR Design Parameters Particulate Loading

Rake Type Sootblowers @ SCR

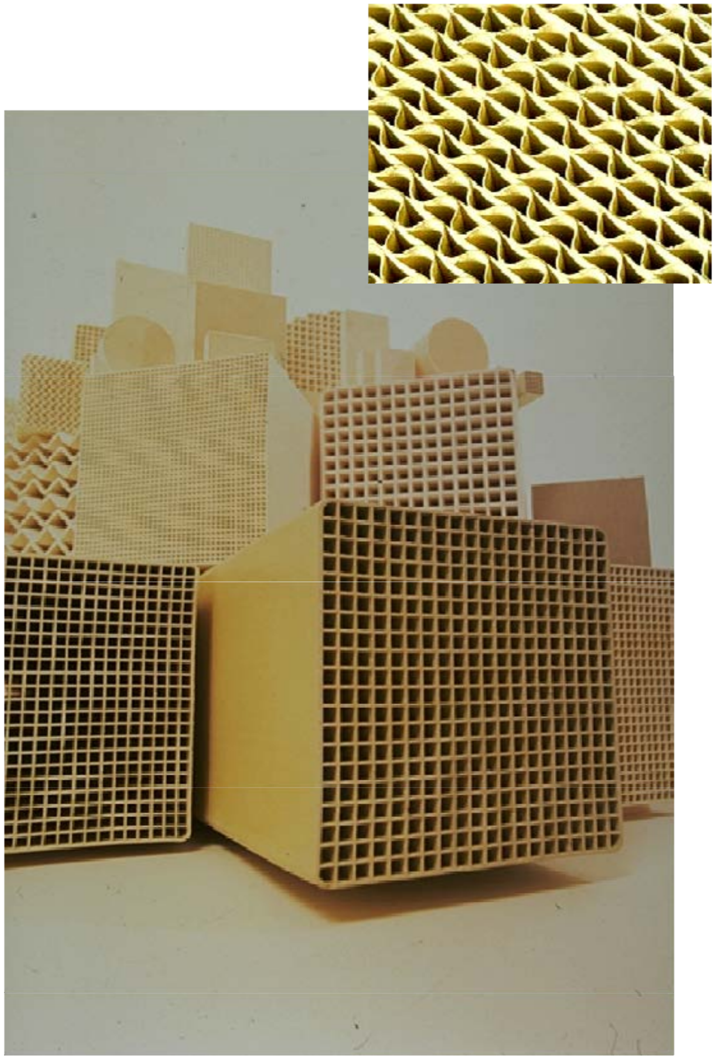
- Typically steam is the cleaning medium
- Removes dust particles, keeps catalyst active



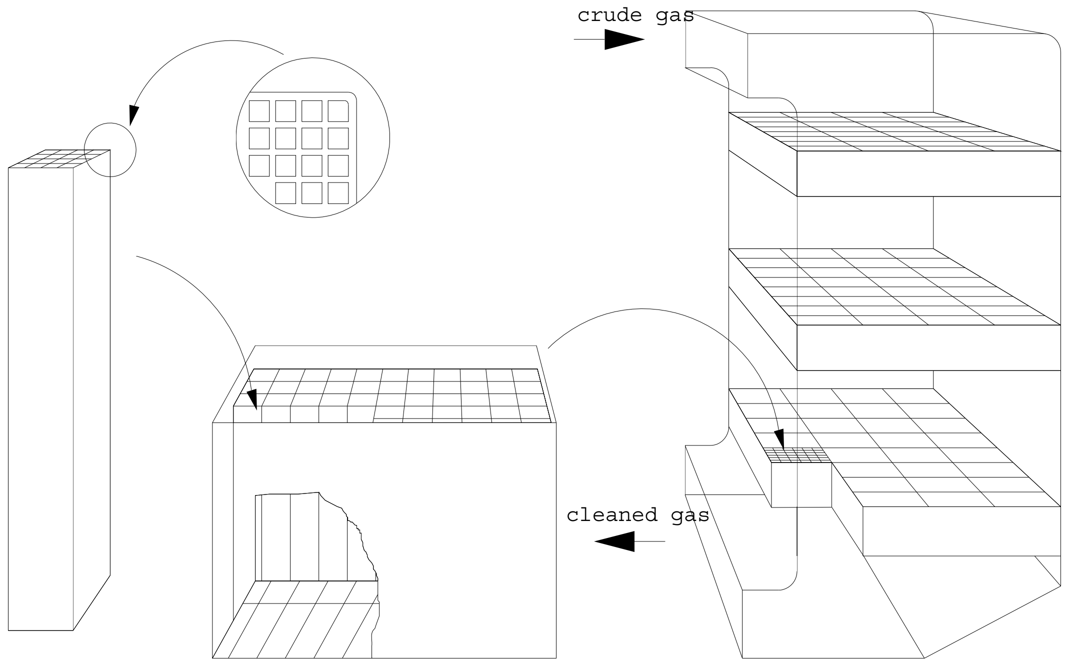
- Usually 400 – 600 mm distance from catalyst face
- Purged with air when idle (avoid corrosion)
- Operated in sequenced schedule

FCCU NO_x Reduction – SCR Retrofit

HoneyComb Catalyst Characteristics



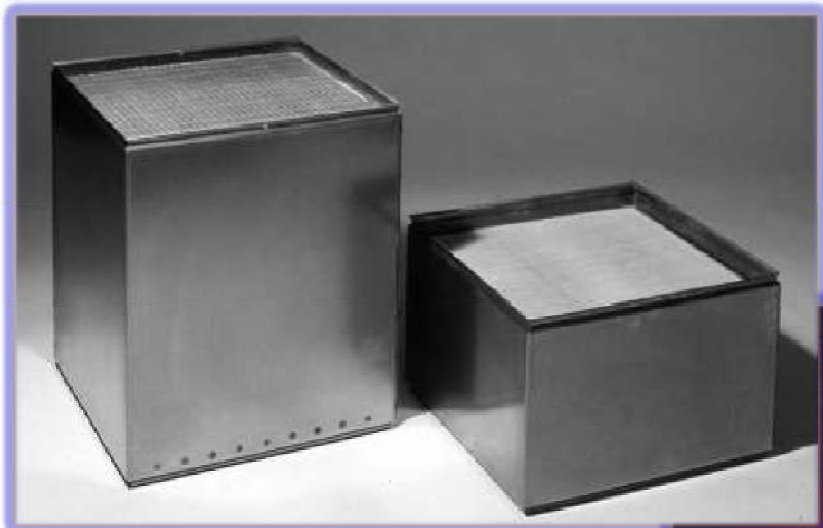
Elements are packed and sealed into standard or tailor made steel modules



Technip

KTI ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit
Corrugated Catalyst Characteristics



Technip

KTI
ENGINEERED TO PERFORM™

FCCU NO_x Reduction – SCR Retrofit
Catalyst Loading

Safe Access / Facilitated Maintenance / Turnaround Methods Established





FCCU NO_x Reduction – SCR Retrofit
Layout and Constructability

SCR Design Details

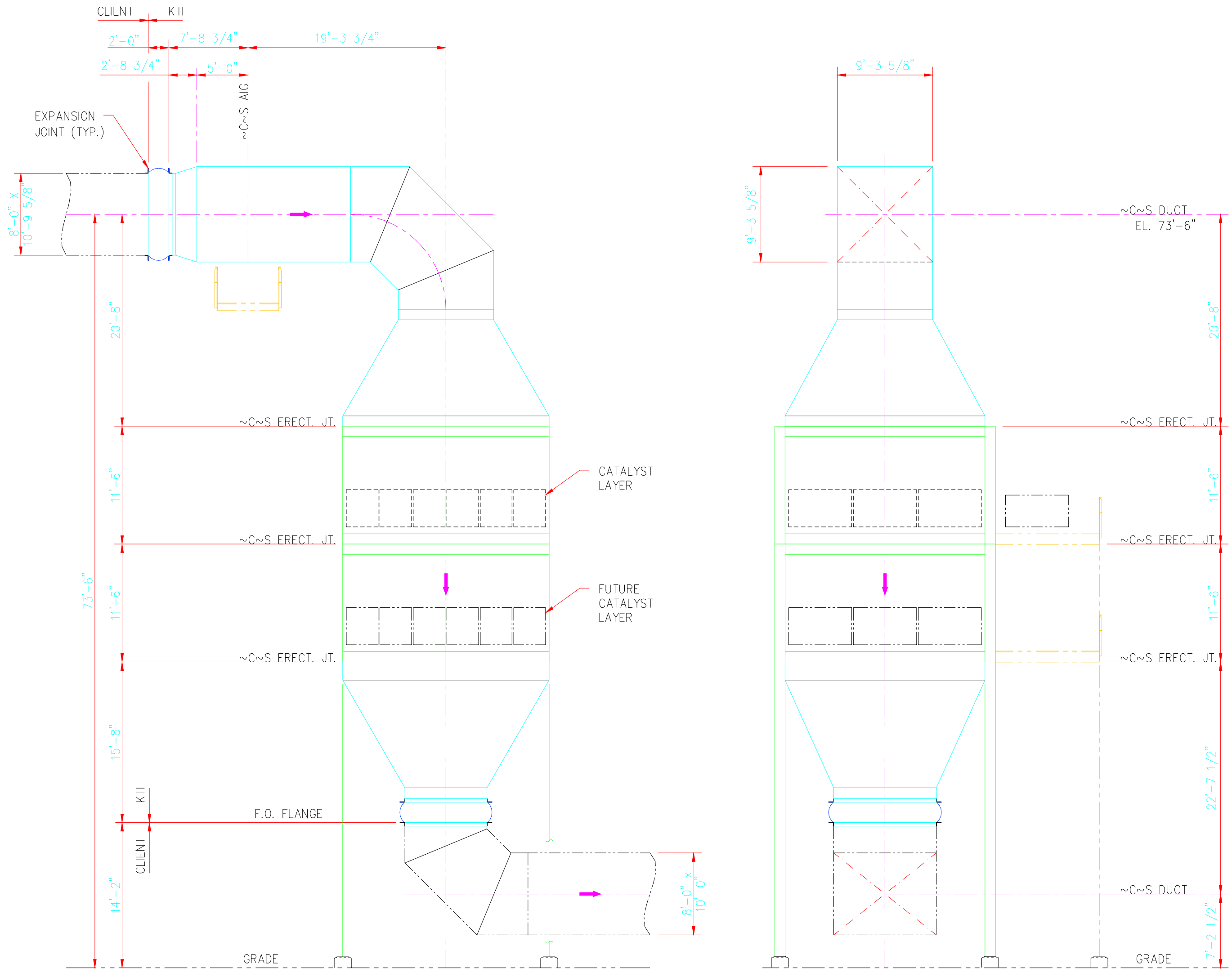
- **SCR system design coming together**
  - Site Restrictions
    - Local space constraints / restrictions
      - Placement of construction equipment / cranes
      - Future maintenance provisions
      - Adjacent equipment clearance requirements
    - Transportation / logistics issues in plant & from shops to plant
  - Shop fabrication / degree of modularization
    - Delivery sequencing for facilitated construction
  - Detailed construction planning

✓ **Avoidance of surprises in the field**

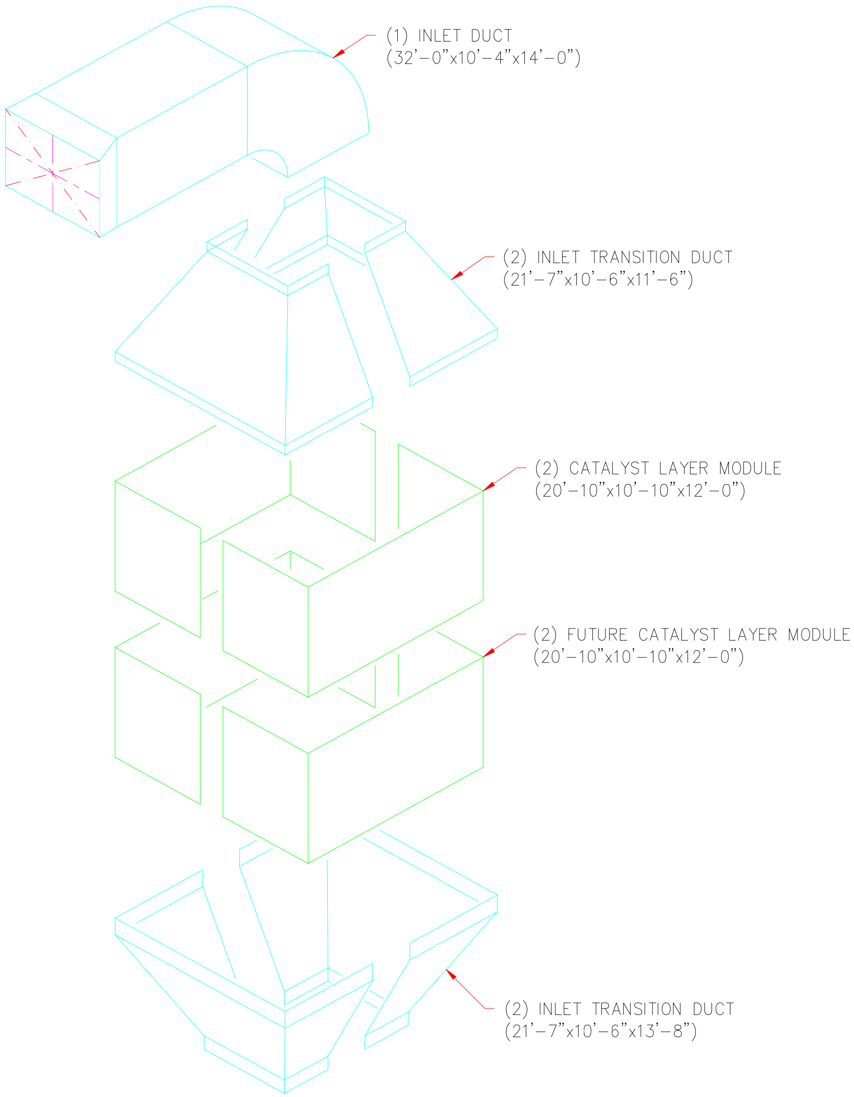
Technip

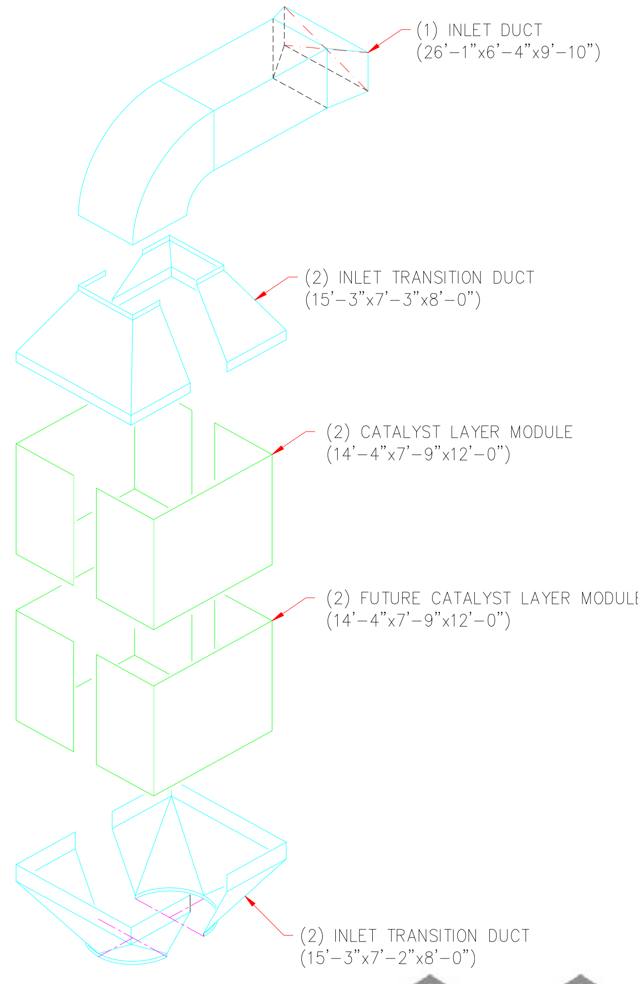
ENGINEERED TO PERFORM™

SCR Layout – Example



Degree of Pre-Fabrication





FCCU NO_x Reduction – SCR Retrofit
Operating Reliability and Maintenance

SCR Design Details

- **SCR system designed with Operation and Maintenance in mind**
  - Provisions for monitoring performance to diagnose issues
    - Additional sample connections and pressure taps at appropriate locations
  - Provisions for Maintenance with minimized disruption to Operation
    - Provision of online sootblowing equipment if justified
    - Provision of space for added catalyst
    - Provision of spare / parallel SCR reactor if justified
    - Provision of access to and handling of catalyst modules

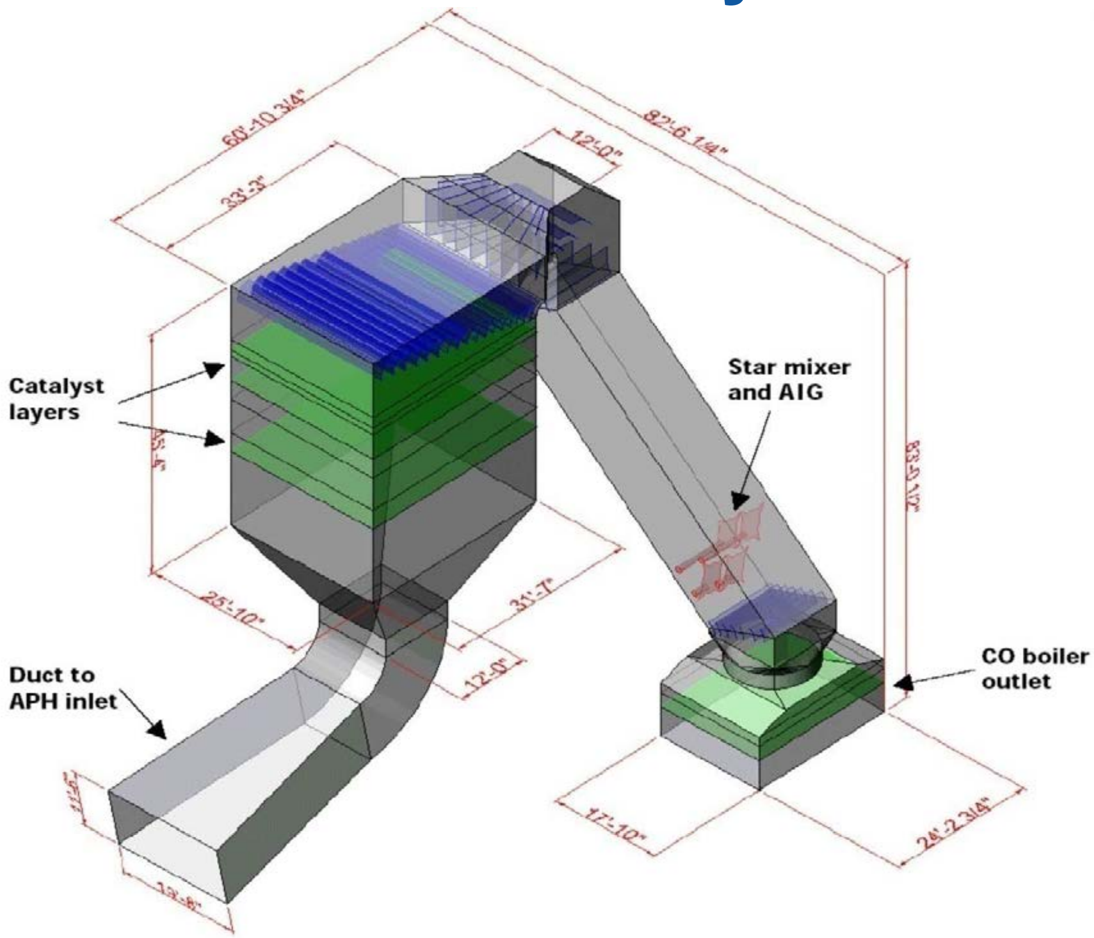
✓**Anticipation of future Operation and Maintenance issues**

Technip

ENGINEERED TO PERFORM™

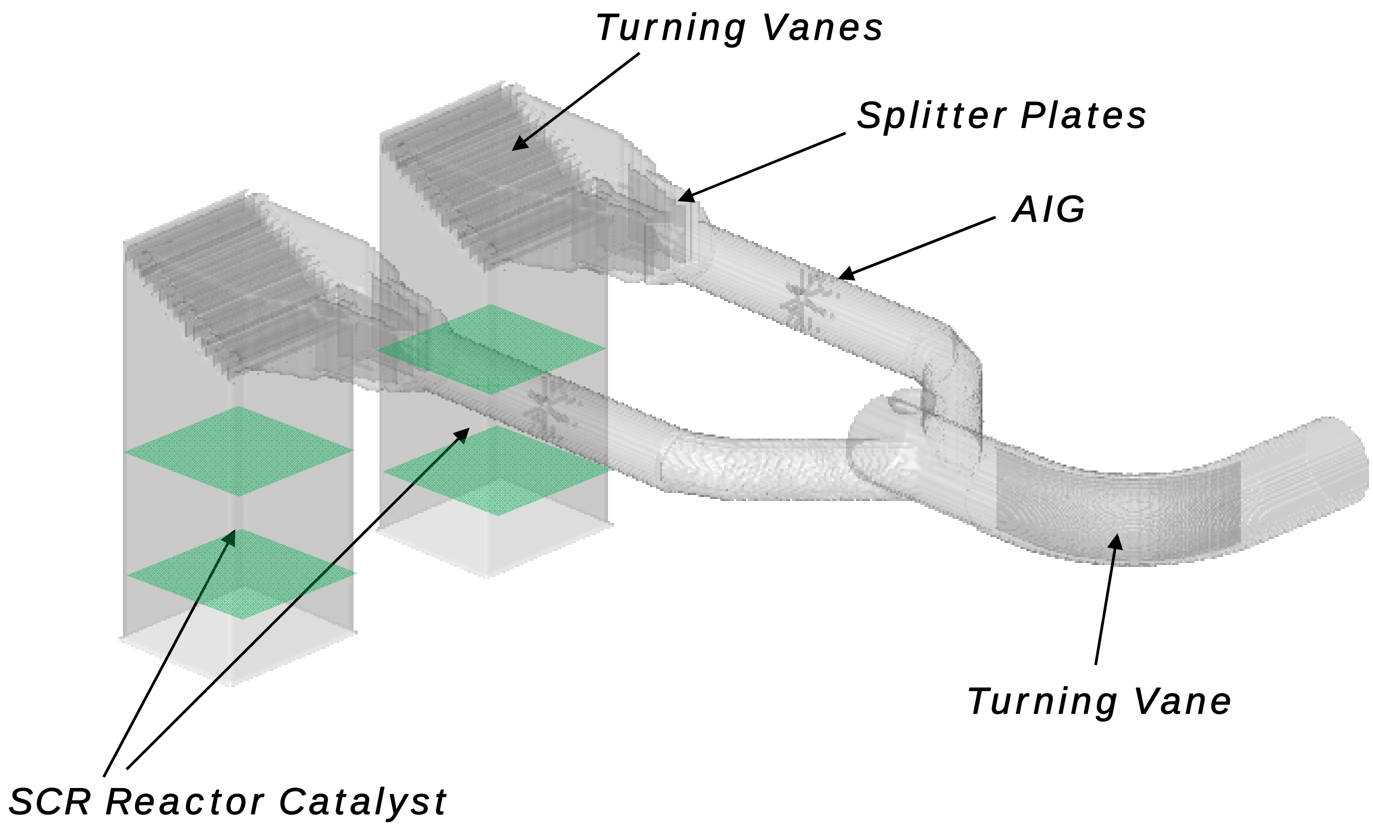
FCCU NO$_x$ Reduction – SCR Retrofit

- Design for improved reliability by incorporating space for added SCR catalyst



FCCU NO_x Reduction – SCR Retrofit

➢ **Design for high reliability by incorporating standby SCR capacity**



FCCU NO_x Reduction – SCR Retrofit

Summary – A well executed FCCU SCR Retrofit

- **Begins with Detailed Planning**
- **Qualified Expertise**
- **Avoidance of Common Execution Issues**
- **Engaging Critical Suppliers Early**
- **Application of Proven Design Methods**
- **All Efforts Directed Towards Safe & Reliable Operation**

On Schedule

On Budget

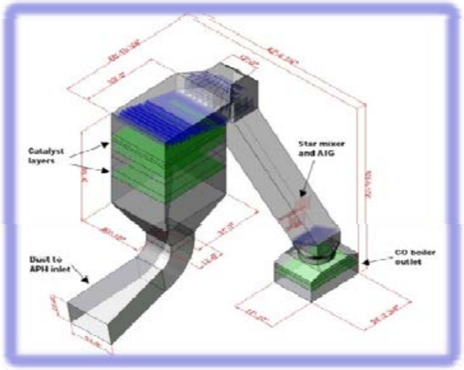
Meets Performance Objectives

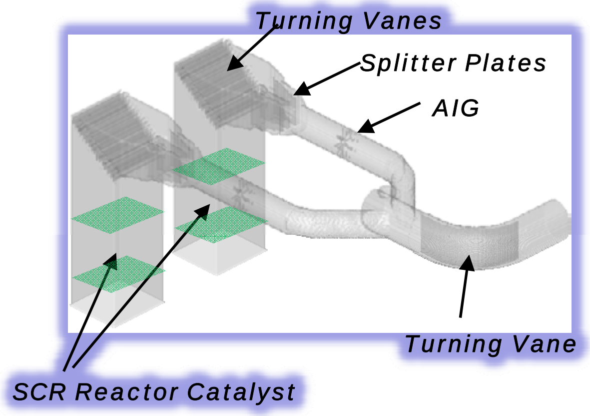
Achieves Long-Term Operability / Maintenance Goals

Technip

KTI ENGINEERED TO PERFORM™

Two Reference FCCU – SCR Retrofits





Citgo Lemont

Confidential