FCCU NO\textsubscript{x} Reduction - SCR Retrofit

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FCCU NO\textsubscript{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
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FCCU Introduction

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

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

- SCR uses ammonia (NH\textsubscript{3}) as a reducing agent to react with NO\textsubscript{x}
- Basic Reactions, Ammonia based

\[
\begin{align*}
4\text{NO} + 4\text{NH}_3 + \text{O}_2 &\rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \\
6\text{NO} + 4\text{NH}_3 &\rightarrow 5\text{N}_2 + 6\text{H}_2\text{O} \\
2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 &\rightarrow 3\text{N}_2 + 6\text{H}_2\text{O} \\
6\text{NO}_2 + 8\text{NH}_3 &\rightarrow 7\text{N}_2 + 12\text{H}_2\text{O} \\
\text{NO} + \text{NO}_2 + 2\text{NH}_3 &\rightarrow 2\text{N}_2 + 3\text{H}_2\text{O}
\end{align*}
\]

- ~90% of NO\textsubscript{x} is NO - First reaction accounts for most of the conversion
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**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)
SCR Introduction

- Typical temperature ranges for SCR Catalysts
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**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 \((\text{WO}_3 : 5\text{-}10 \text{ wt\%}, \; \text{V}_2\text{O}_5 : 0\text{-}4 \text{ wt\%}, \; \text{TiO}_2 : 80\text{-}90 \text{ wt\%})\)

<table>
<thead>
<tr>
<th></th>
<th>Typical</th>
<th>Possible Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature, °F</td>
<td>550 – 750</td>
<td>475 – 800</td>
</tr>
<tr>
<td>Pressure Drop, “WC”</td>
<td>2 – 3</td>
<td>&lt;1</td>
</tr>
<tr>
<td>NO\textsubscript{x} Conversion</td>
<td>90%</td>
<td>can be 95% +</td>
</tr>
<tr>
<td>NH\textsubscript{3} Slip, ppmvd</td>
<td>10 ppm</td>
<td>as low as 2 ppm</td>
</tr>
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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*
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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
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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
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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
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- Engage Catalyst Suppliers Early
- Define design conditions
  - Process conditions
    - Flow / temperature / pressure
    - Composition / NO\textsubscript{x} / SO\textsubscript{2} / Particulate
    - Poisons
  - Guarantee parameters
    - Pressure drop limitations
    - Catalyst life requirements
    - NO\textsubscript{x} reduction requirements
    - Ammonia slip requirements
- 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
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SCR AFCU – PFD for Anhydrous System
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SCR AFCU – PFD for Aqueous System

Technip

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**SCR AFCU**
SCR Operating Parameters

Acceptable operating temperature window can be defined

- Inlet NOx = 40 ppmvdc @ 3% O2
- NH3 Slip = 5 ppmvdc @ 3% O2
- Flue Gas Flow Rate = 1,100,000 lbs./hour
- NH3:NOx Maldistribution = ± 5% RMS
- Flue Gas Maldistribution = ± 15% RMS
- Temperature Maldistribution = ± 20 Deg F

- 93.75% @ 600 Deg F
- 93.48% @ 750 Deg F
- 71.58% @ 450 Deg F
High reduction efficiency requires high degree of flow and mixing uniformity

Inlet NOx = 40 ppmvdc @ 3% O2
NH3 Slip = 5 ppmvdc @ 3% O2
Flue Gas Flow Rate = 1,100,000 lbs./hour
SCR Operating Temperature = 600 Deg F
Flue Gas Maldistribution = ± 15% RMS
Temperature Maldistribution = ± 20 Deg F

NH3:NOx Maldistribution

93.75% Target
92.75% Max @ 10% RMS
93.75% Max @ 5% RMS
89.35% Max @ 15% RMS
SCR Operating Parameters

Flow and mixing uniformity can be relaxed with higher ammonia slip

- 94.83% Max @ 5% RMS
- 94.61% Max @ 10% RMS
- 93.75% Max @ 15% RMS

93.75% Target

Inlet NOx = 40 ppmvdc @ 3% O2
NH3 Slip = 10 ppmvdc @ 3% O2
Flue Gas Flow Rate = 1,100,000 lbs./hour
SCR Operating Temperature = 600 Deg F
Flue Gas Maldistribution = ± 15% RMS
Temperature Maldistribution = ± 20 Deg F
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
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SCR Design Parameters SO\textsubscript{2} to SO\textsubscript{3} Conversion

![Graph showing SO\textsubscript{3} Concentration vs. NH\textsubscript{3} Concentration for different temperatures (200°C to 250°C)]
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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
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
Elements are packed and sealed into standard or tailor made steel modules.
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Corrugated Catalyst Characteristics
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Catalyst Loading

Safe Access / Facilitated Maintenance / Turnaround Methods Established
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
Degree of Pre-Fabrication
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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
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- Design for improved reliability by incorporating space for added SCR catalyst
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- Design for high reliability by incorporating standby SCR capacity

![Diagram of FCCU NO$_x$ Reduction - SCR Retrofit](image-url)
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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
Two Reference FCCU – SCR Retrofits

Citgo Lemont

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