REINHOLD ENVIRONMENTAL Ltd.

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The Thrills & Chills of SCR Field Testing

A SCR Catalyst Supplier's Perspective

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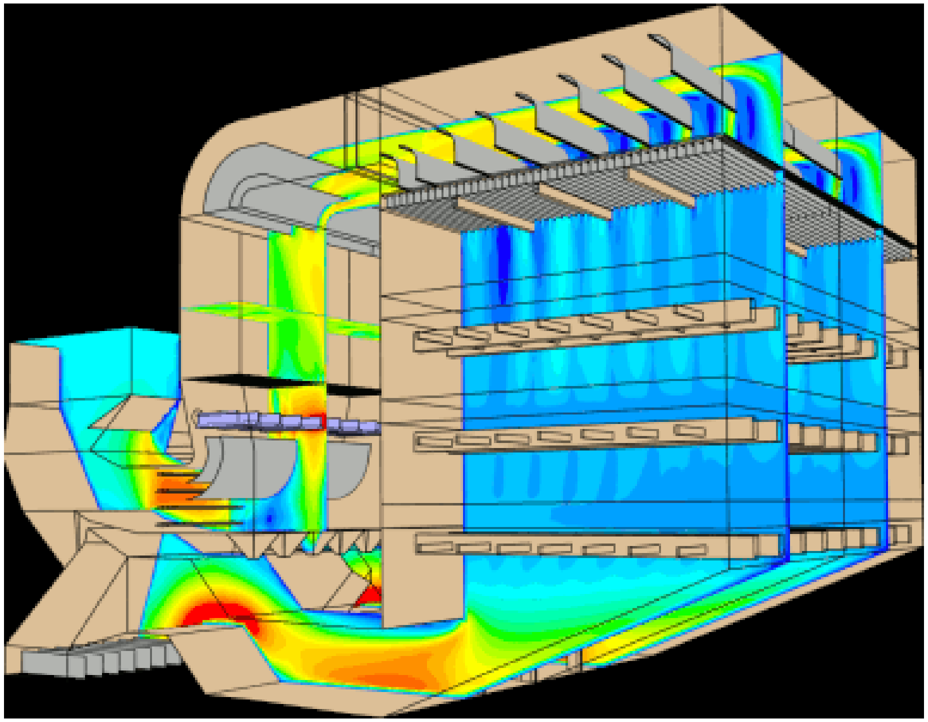
Introduction and Objectives

- Explanation of SCR system guarantees
- Overview of how field testing is performed
- Role of catalyst correction curves in field testing results
- Example case study of field testing
- Possible field testing lessons



Source: Airflow Sciences

Performance Guarantees

- Selective Catalytic Reduction systems come with initial guarantees from the system suppliers/engineering firms
  - NOx reduction percentage through guarantee period (16k, 24k or 32k hours)
  - Ammonia slip at SCR outlet through guarantee period
  - SO_2 oxidation percentage
  - Pressure Drop through the entire system
    - Catalyst pressure drop Impact
    - Mixing Grid, Ductwork, Structural Support pressure drop impact
  - NH_3/NOx Ratio
  - Velocity Distribution
  - Temperature Distribution
- These SCR Performance Guarantees can be verified by field testing

Performance Guarantees (cont)

- After initial loading, catalyst reloads can be tested for performance guarantee compliance two ways
  - Field testing
  - Laboratory testing
- After initial catalyst load, catalyst reload field testing guarantees may be provided directly by catalyst supplier
  - NOx reduction percentage through guarantee period (16k, 24k or 32k hours)
  - Ammonia slip at SCR outlet through guarantee period
  - SO2 oxidation percentage
  - Pressure drop through catalyst, only

Laboratory Testing

- Available sample sizes
  - Full Bench
    - 150 mm by 150 mm by Full element Length
  - Semi Bench
    - 65 mm by 65 mm by 500 mm
  - Micro Scale
    - 25 mm by 25 mm by 200-400 mm
- All sample sizes can perform SO_2 to SO_3 conversion and NOx activity testing
- Full bench is sometimes specified for verification of guarantees (using VGB R302He guidelines)

Source: Steag

Organization of SCR Performance Test

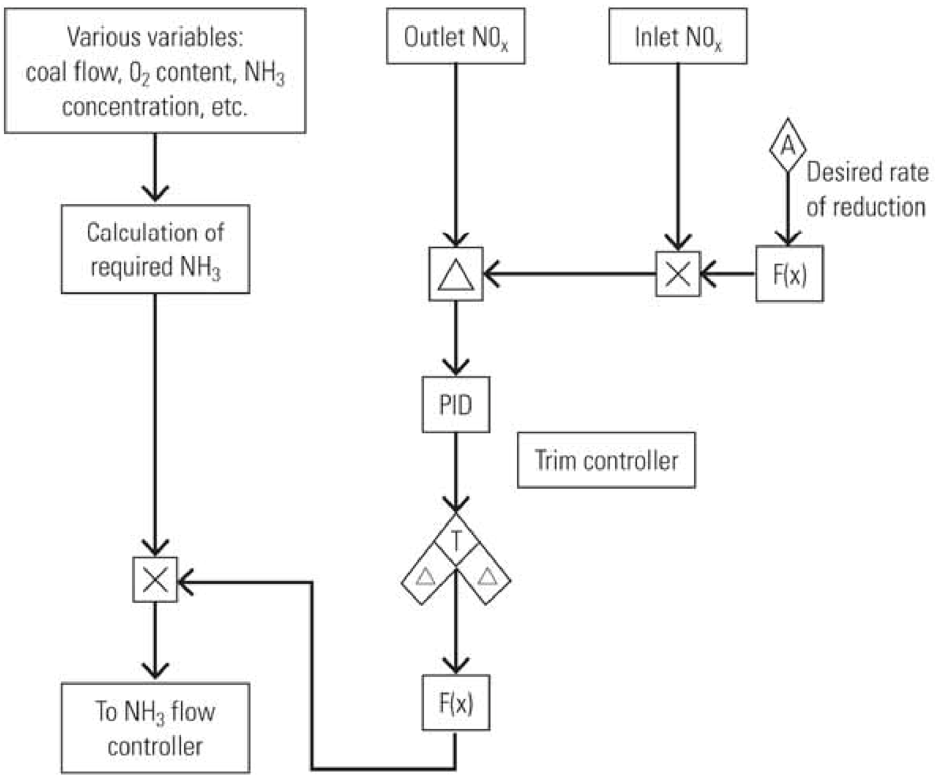
- SCR system customer must arrange for the following for the performance test dates (often 1-4 days in duration):
  - Testing company
  - Engineering Firm support
  - System Supplier support
  - Catalyst supplier support
  - SCR constructor support (if required)
  - Utility Project Management and support
- Often times, there are commercial stipulations that require testing to be performed only during certain periods
  - Initial catalyst testing must be performed within x hours of SCR startup
  - End of life catalyst testing must be performed before end of guarantee period

Organization of SCR Performance Test

- Testing group works cooperatively to perform and monitor the field test
  - Testing company
    - Calibrate Equipment, conduct testing, prepare results and report
  - Engineering Firm
    - Provide testing specification, oversee performance test
  - Plant Operator
    - Manage unit conditions
  - Constructor, SCR system supplier, catalyst supplier
    - Advisory role
- Testing group must come to mutual agreement for test abnormalities
- Results are extremely important for all stakeholders

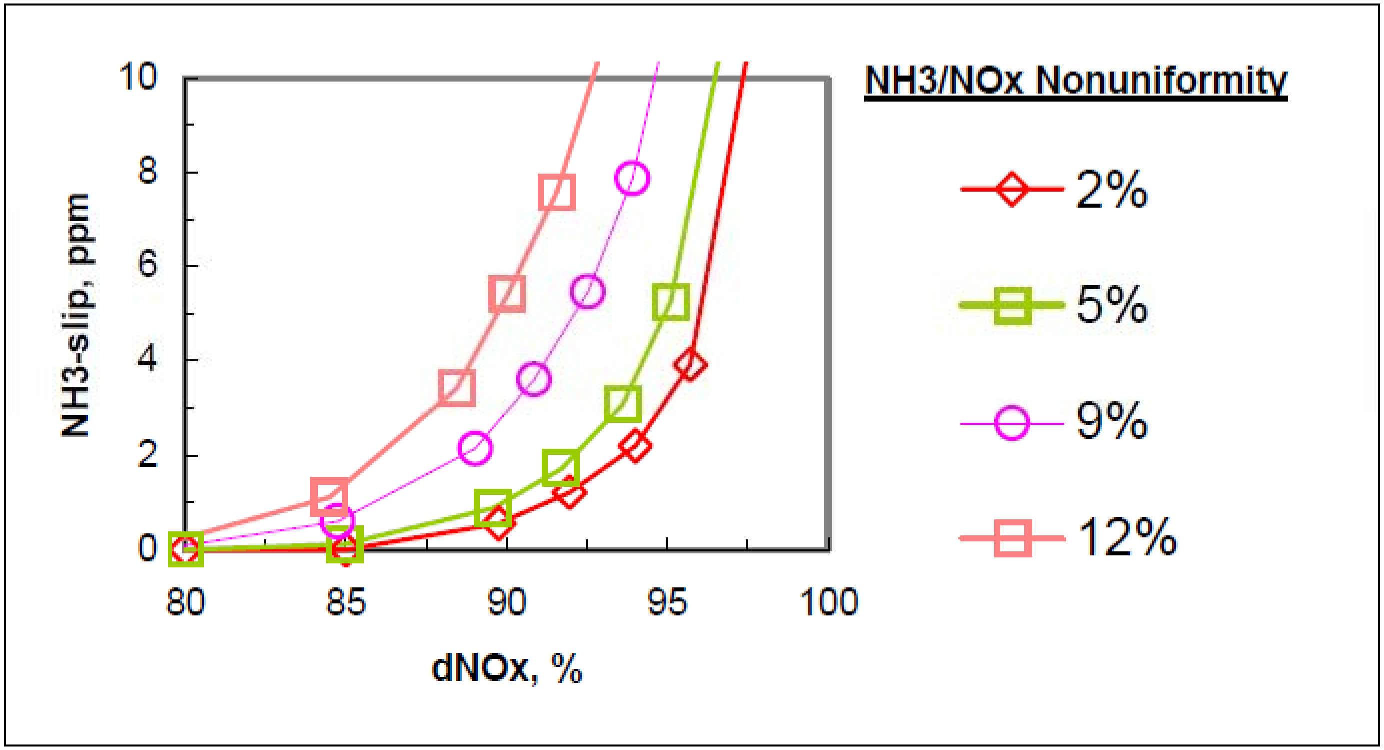
Field Testing Pre-requistes

- Before entire testing team arrives, SCR tuning must be ensured or performed
  - Testing requires correct mixing, temperature, and velocity distribution
- Ammonia Flow Control Scheme must be in optimal working order
- Required Inlet SCR conditions must be feasible
- Steady state operation is required



Source: Power Engineering, January 2010

Effect of Ammonia to NOx Ratio



Source: Fossil Energy Research Corp.

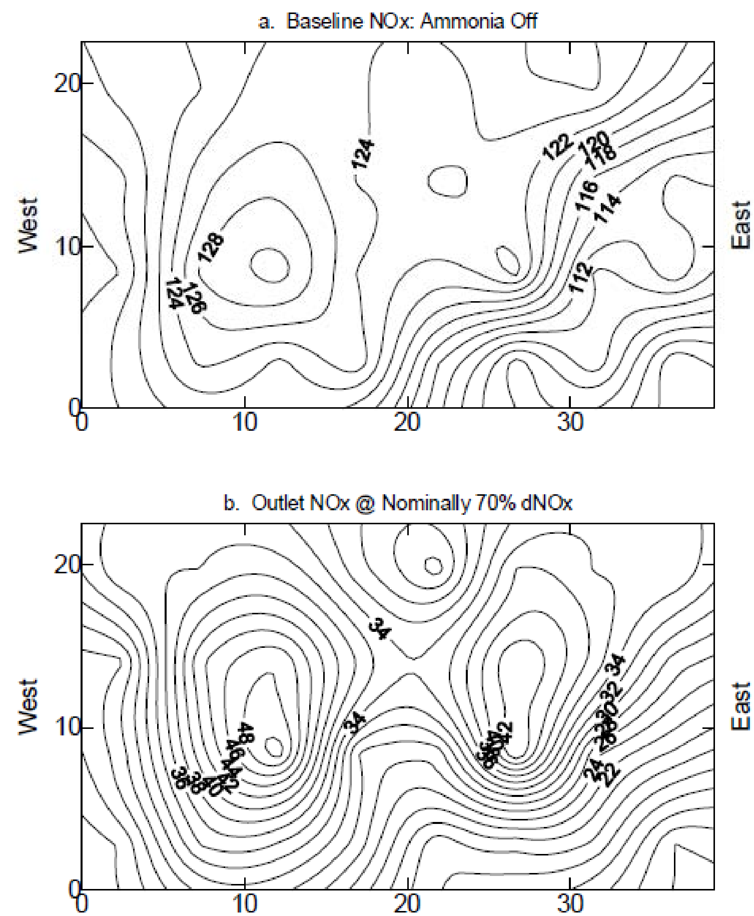
Field Testing Variables

- Inlet NOx
- Outlet NOx
- Volumetric Flow Rate
    - Temperature, Pressure, Density
- Ammonia slip
- SO_2 and SO_3
- Gas composition at SCR inlet and outlet
    - CO_2, O_2, Moisture
- Coal Analysis to guarantee fuel fired is aligned with design

Measuring NOx

NOx measurements are performed at the inlet and outlet of the SCR

- EPA Method 7E
  - Heated probe withdraws flue gas
  - Sample conditioner removes moisture from gas stream
  - Gas stream then is transported to a NOx Analyzer
- This analysis is done on-site, in real time
- NOx measurement is made at multiple points throughout the ductwork to create a NOx profile



Source: FERCo

Measuring Gas Composition

- Volumetric Flow Rate
  - Uses EPA Methods 1-4
- Gas Composition
  - Uses EPA Method 3A
- The analysis is done on-site, in real time
- Gas composition sampling is performed at multiple points over the duct and profile plots can be determined, if needed

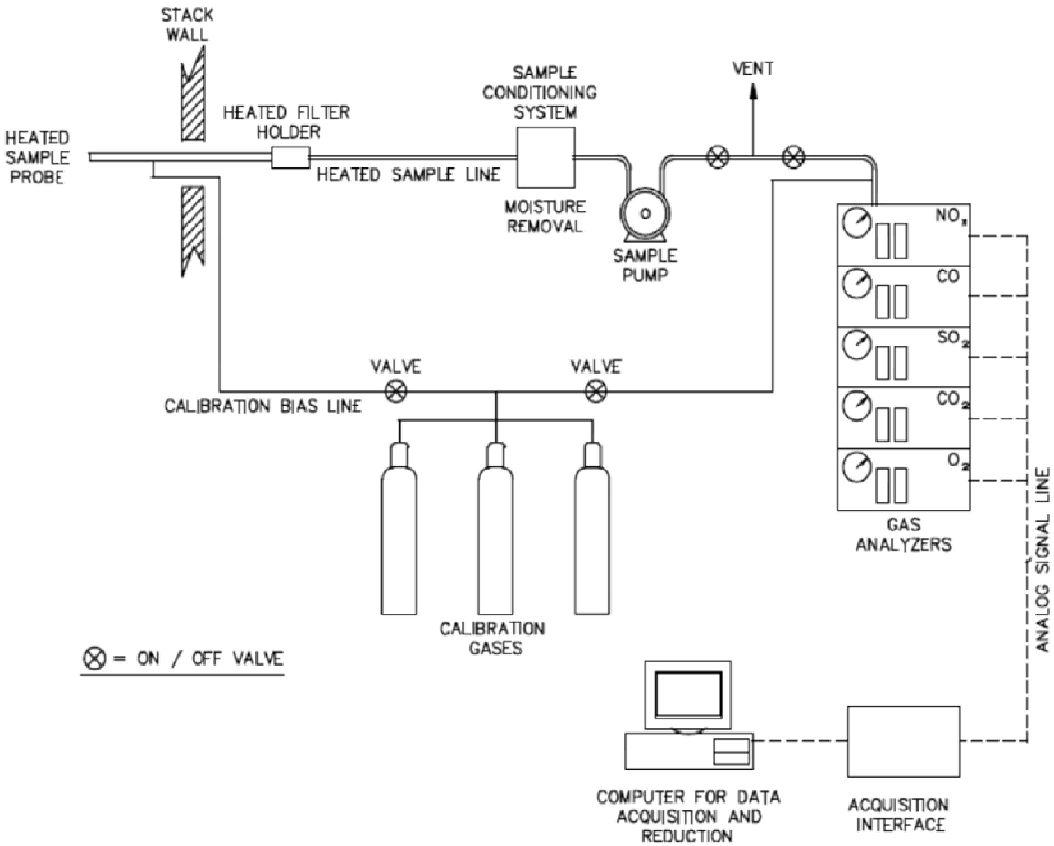
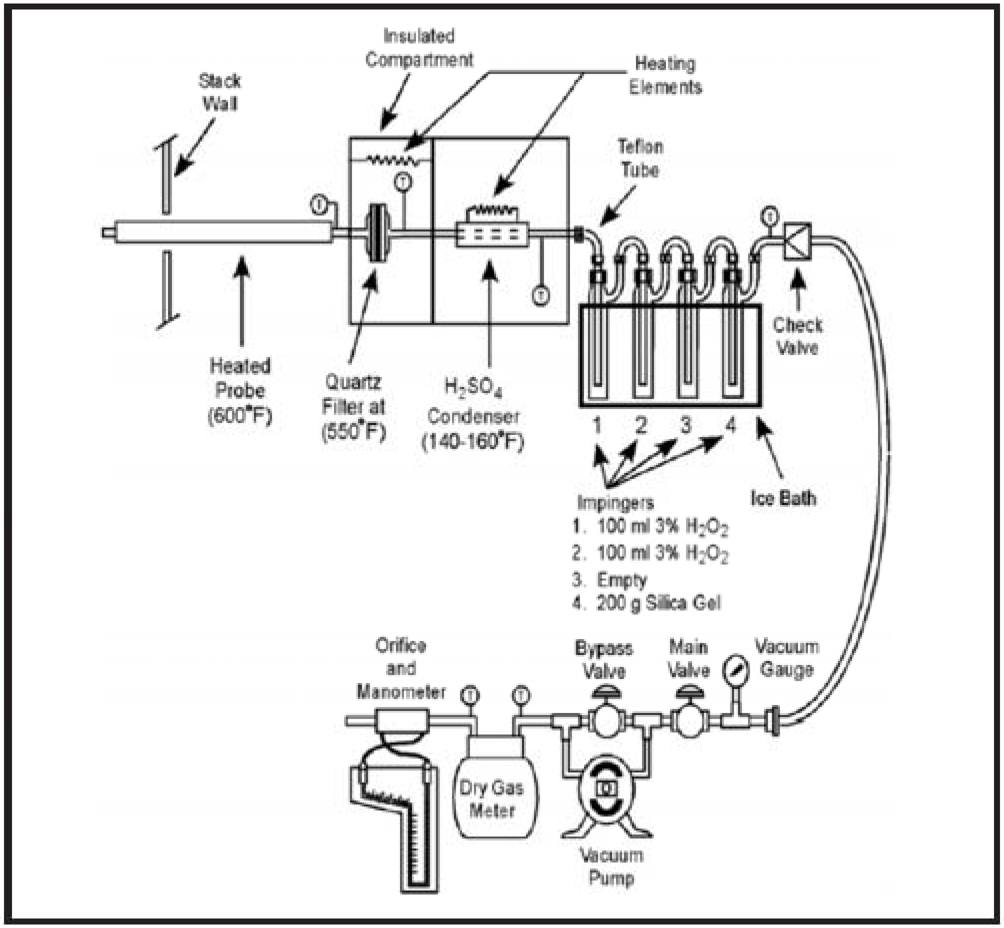


Figure B-1 Continuous Emission Monitoring System

Source: Weston

Measuring SO3

- Field testing of SO2 to SO3 is done using EPA Method 8A or CTM-013
- Full traverse of duct is performed using EPA Method 1 criteria
- Concentration of SO3 is determined using the barium-thorin titration method at both the SCR inlet and outlet
- Must ensure sufficient flue gas flows through the system in order to be within detection range



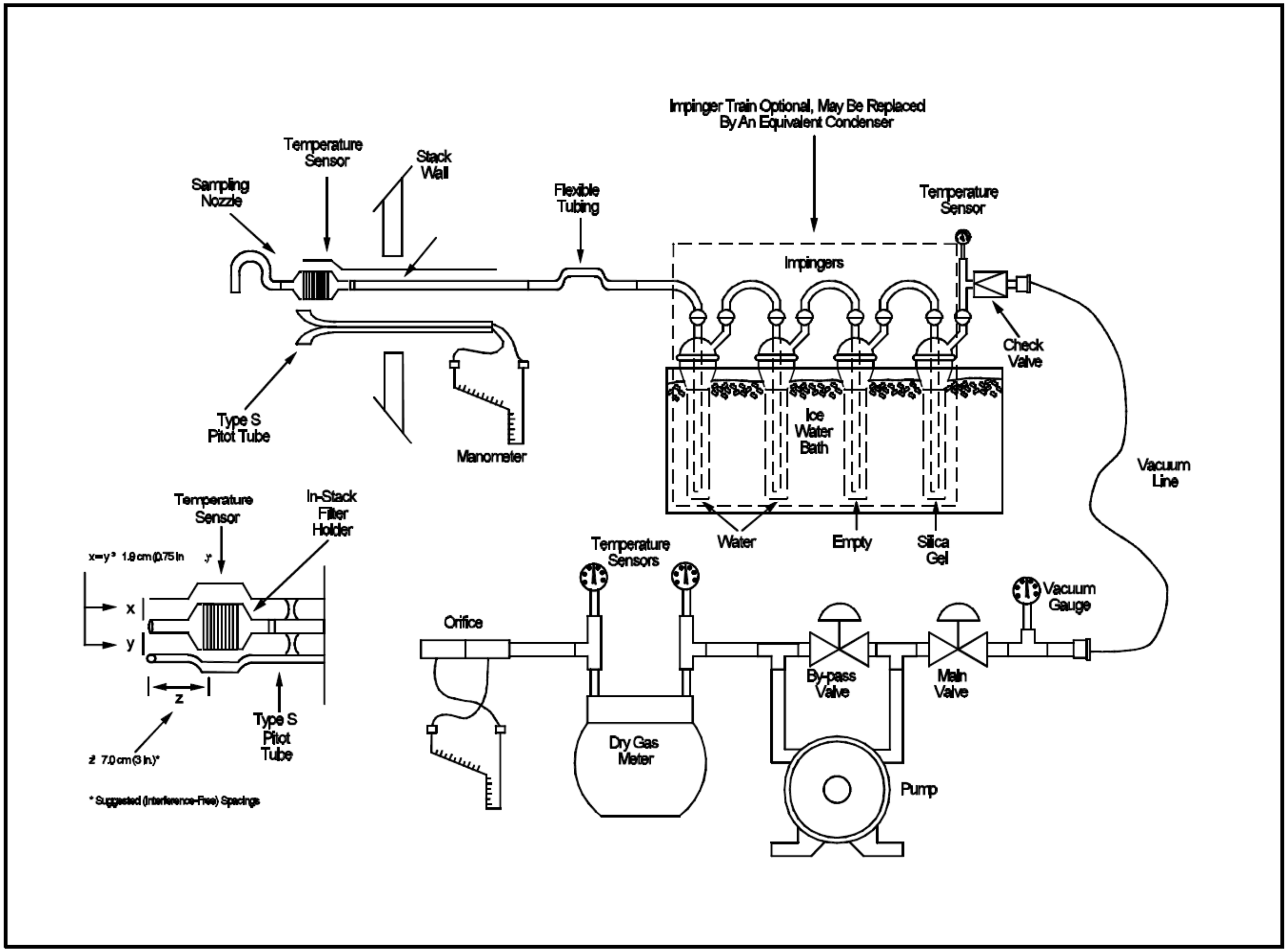
Source: Clean Air Engineering

Field Testing NH3

- Condensate testing method, CTM-027
  - EPA method 17 sample train, with H_2SO_4 in the impingers in lieu of water
  - Heated, glass line probe is utilized to avoid the catalyzed reaction of NH_3 and NO
- NH_3 slip varies within the outlet duct
  - Samples of equal duration must be taken at numerous points inside the outlet duct and averaged
    - Length of sampling must be sufficient to yield detectable levels of ammonia
  - No outlet profile plot
    - A small number of large high slip values can greatly skew the results

Field Testing NH3

Source: EPA Method 17



Measuring NH3

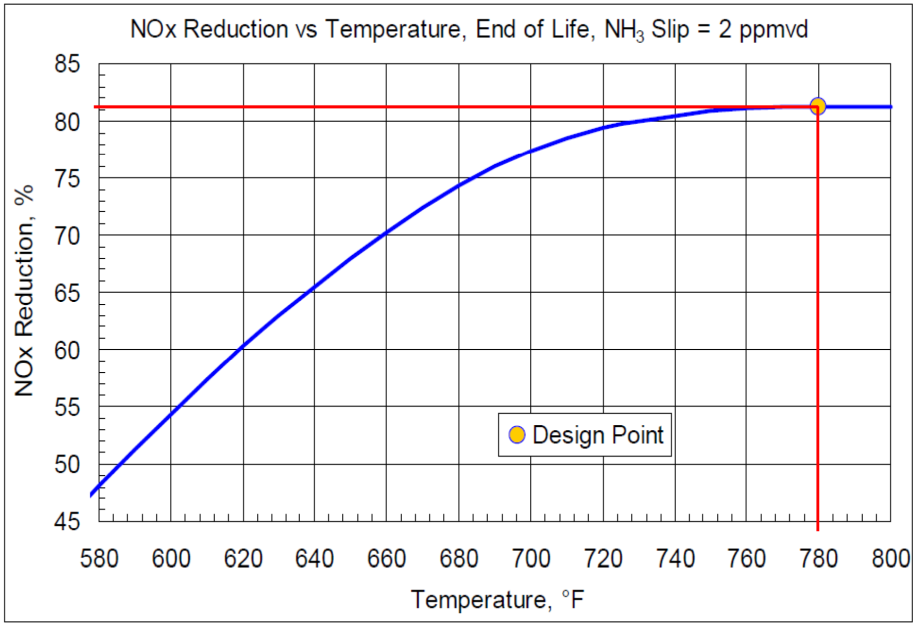
- The final impinger solutions are collected and taken to an analytical lab
  - The ammonium ion concentration is determined using one of various techniques
    - Ion chromatography
    - Specific ion electrode technique
  - After ammonium ion concentration is determined, it is converted to total volume of ammonia gas
  - Total volume of ammonia gas is divided by the total volume of gas sampled to determine the ammonia ppmvd

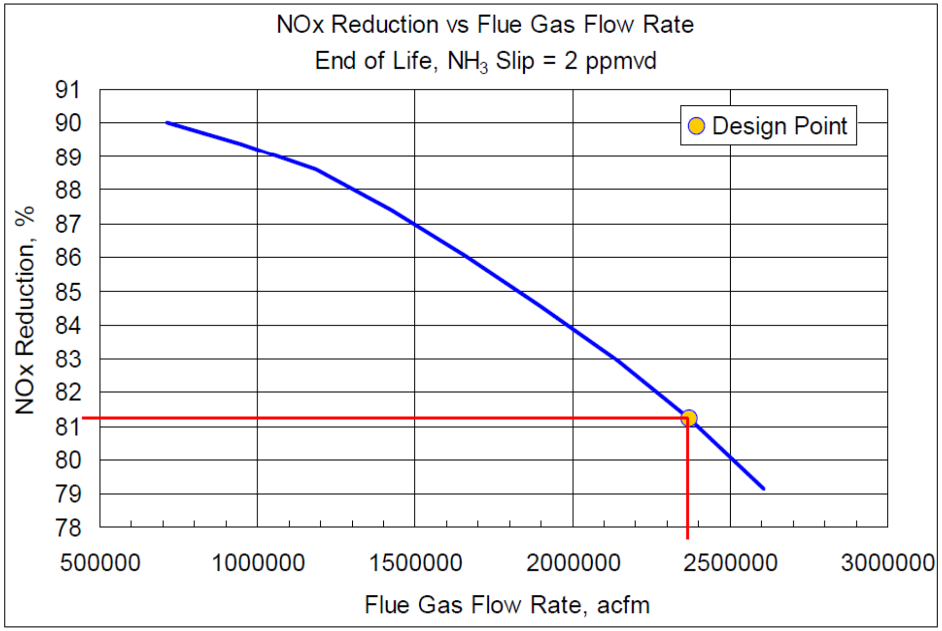
Summary of Field Testing Measurements

- Large number of testing measurement and methods must occur in order to prove SCR compliance
  - Time intensive
  - Large team
  - Some variables easy to measure, others not
    - Analyzers vs. sample trains
    - Real time results vs. delayed analysis
  - Sufficient testing equipment/spare parts required
  - Diligent work must be performed in order to minimize bias
- Multiple runs are performed and averaged to prove repeatability

Reconciling variations with correction curves

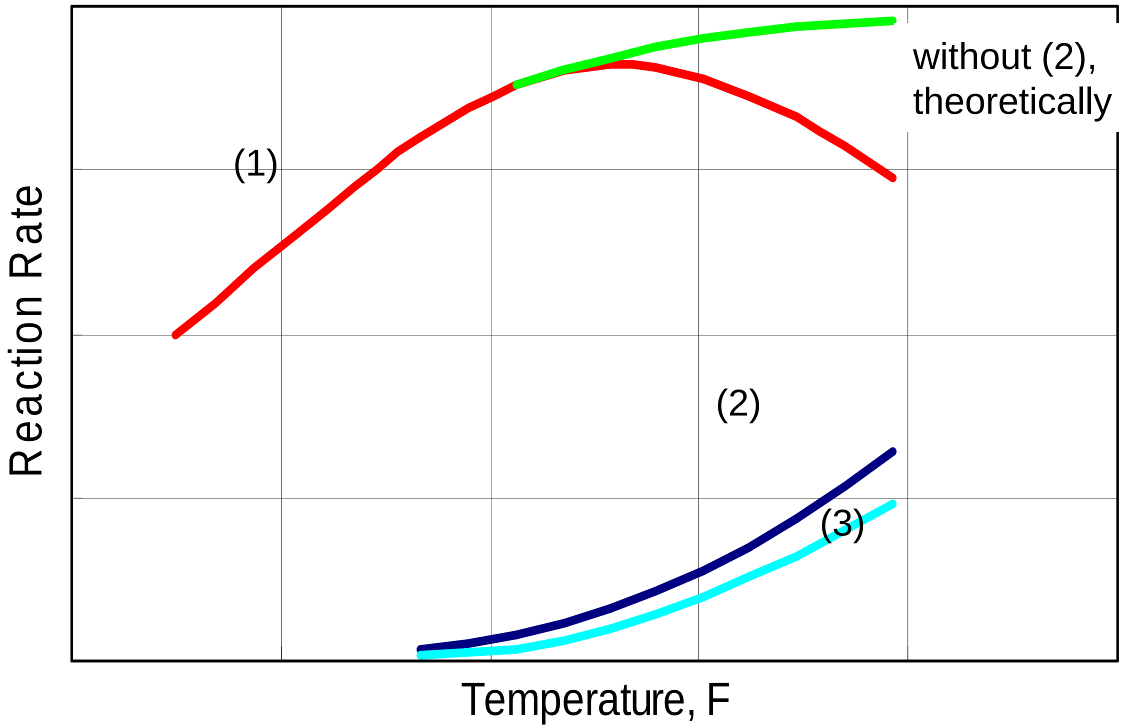
- Very difficult to meet exact design conditions during a test run
  - Reconciling variations between actual conditions and design conditions done using catalyst supplier’s correction curves
  - Largest impacts are from different flue gas flow rates and temperatures





Transient Operation

- Transient Operation of the SCR during testing is more difficult to reconcile
  - Small time periods of disproportional ammonia slip due to transient operation can have a large impact
  - Reconciling with correction curves works when SCR is operating near steady state conditions
    - Transient operation causes uncertainty



1. SCR-Reaction
   $NO_x + NH_3 = N_2 + ...$

Side Reactions:

2. NH_3 Oxidation
   $NH_3 + O_2 = NO_x + ...$

3. SO_2 Oxidation
   $SO_2 + O_2 = SO_3 + ...$

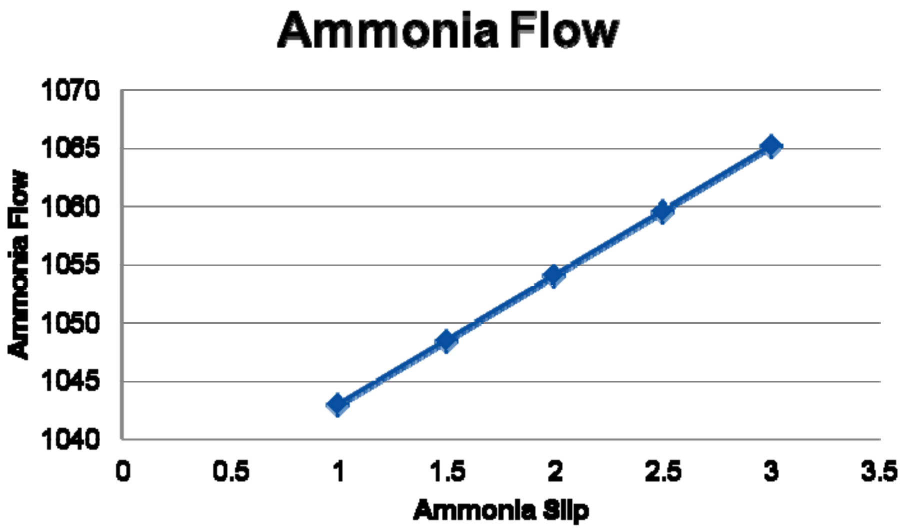
All 3 reactions catalyzed by V_2O_5

Potential causes of failure

Cause of Failure	Verification Method
Direct Catalyst Failure (deactivation)	Laboratory testing of catalyst
Catalyst Plugging or erosion	Reactor Inspection
Catalyst Fire or moisture damage	Reactor Inspection, Catalyst testing
Flow Distribution Problems	Analyzing velocity and NOx profiles
Testing Errors	Re-test
Reagent Control	Comparing results of different control schemes/manual operation

Case Study

- Testing group convened at power plant for two days of testing
  - Design NOx inlet and outlet different than normal operation
    - Started the test runs using the wrong outlet NOx setpoint
  - Difficulties controlling ammonia flow during the test, so testing group decided to control the ammonia flow valve manually
    - Vaporization system and control scheme issues



Amount of excess ammonia to create 1 additional ppm slip if reactor had reached maximum deNOx was ~12 lb/hr

Case Study (cont)

- Ammonia measurements were performed off-site
- Some ammonia slip measurements were above guarantee
  - Abnormalities in the results did not effectively point to culprit
    - Significantly different results for ammonia slip from run to run
    - Various field testing experts were contacted to determine if results were conclusive
    - Re-test was scheduled ASAP
    - On-site wet chemistry lab would have allowed for more on-site trouble shooting

Case Study (retest)

- Ammonia grid tuning performed prior to retest
- Some changes in logic control for Ammonia control valve were performed
- On-site ion chromatography equipment was arranged, as was a testing audit team
- Extra testing days and Catalyst sampling procedure developed for contingency
- Run 1 on day 1 started after pre-test meeting, testing crew calibrated equipment, and boiler had correct settings
    - Because of outlet duct configuration, a 17' long probe was used
        - Cumbersome and created problems changing sample ports
        - Particulate filter frequently plugged and needed changing
        - Halfway through Run 1 a process upset occurred, resulting in over injection of ammonia
        - Long run times put pressure on plant operators and dispatch to guarantee steady state conditions and need for produced power

Retest (cont)

- Even with the process upset and incomplete traverse, Run 1 was analyzed to determine ammonia slip while the remaining ports were sampled (called Run 2)

Day 2

- Results from Day 1 were reviewed by testing team to determine best path forward
  - Day 1 results yielded out of conformance ammonia slip
  - A decision to test one port from both sides of the reactor to try and determine local variations in ammonia slip was made by the team
    - These tests also yielded high ammonia slip
- After Day 2 results proved to have high ammonia slip, project team brainstormed ideas
  - Decided in a last ditch attempt to very carefully manually operate the ammonia flow control valve in hopes ammonia slip would decrease

Retest (cont)

- Day 3
  - First run of the day had just begun when a mill change created a large change in process conditions
  - Run restarted and results analyzed to find ammonia slip dropped to within conformance requirements
    - Two subsequent runs were performed to prove repeatability

Lessons Learned/Conclusions

- SCR field testing has many variables
  - Determining cause of failure is sometimes difficult
- On-site and timely run results allowed for troubleshooting activities to occur and optimize testing
- Have contingency plans in place to maximize time
- Project team should work together to determine best path forward

Thank You!

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