REINHOLD ENVIRONMENTAL Ltd.

2015 NOx-Combustion Round Table & Expo Presentations

February 23 & 24, 2015, in Richmond, VA / Hosted by Dominion

Low Load Operation
A Study of Catalyst MOT and MIT

2015 NOx-Combustion Round Table

February 24th, 2015

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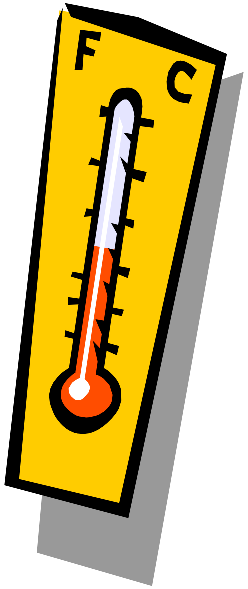
Outline

- – Why are MOT and MIT Important
- – What are the Drivers for Reduced MOT and MIT
- – MHPS R&D Efforts
- – MHPS Approach to Low Temp SCR Operation
- – MOT and MIT Bench Test Study
- – MHPS Procedures for Low Temp SCR Operation
- – Further Operating Temperature Reductions
- – Catalyst Recovery



Minimum Continuous Operating Temperature (MOT):

- Temperature at which the SCR can be operated in which no ABS will accumulate on the catalyst.
- Continuous operation of the SCR must be above MOT.

Minimum Ammonia Injection Temperature (MIT):

- Temperature in which ammonia can begin to be injected into the SCR. Some activity deterioration may occur due to the formation of Ammonium Bisulfate (ABS), but this can be reversed by operation at or above the MOT.
- Operation below MIT may result in permanent catalyst deactivation.

What Are the Advantages of Being Able to Operate SCR at Lower Loads?

More Flexibility for Generation Dispatching

Provides Cost Savings on Fuel

- Lower loads = less “un-wanted” generation

Allows Unit to Operate without the Need for Economizer Bypass

- No loss of boiler efficiency

Reasons For Low Load Operation Concerns

Environmental Regulations

- More Stringent Emissions Levels Leading to Continued SCR Operation at Lower Loads
- Year Round Operation of SCR’s Required

Load Cycling and Load Demand

- Decreased Load Demand due to Lower Gas Prices and Renewables
- Weekend and Overnight Operation

Operating Conditions

- More SO_3 and/or NH_3 results in higher minimum Operating Temperatures

Impacts of Low Load Operation

Concerns

- Ammonia Salt Formations

Reactions

- Ammonium Sulfate (Particulate)

$$SO_3 + 2NH_3 + H_2O \rightarrow (NH_4)2SO_4$$

- Ammonium Bisulfate (ABS) (“Sticky”)

$$SO_3 + NH_3 + H_2O \rightarrow NH_4HSO_4$$

Potential Impacts

- Reduced Catalyst Activity Area Due to Salt Pluggage
- Pluggage of Downstream Equipment (i.e. Air Heater)

MHPS R&D Efforts on MOT and MIT

History of Development For MHPS SCR Catalyst

2010

Slower Deactivating Catalyst

High Hg oxidation(TRAC®)

2000

Low SO_2 Conversion

High activity

1990

CU plate

Ceramic plate

Anti-Arsenic

Study on ABS Deposition

1980

Plate type for coal fired gas

Plate type

1970

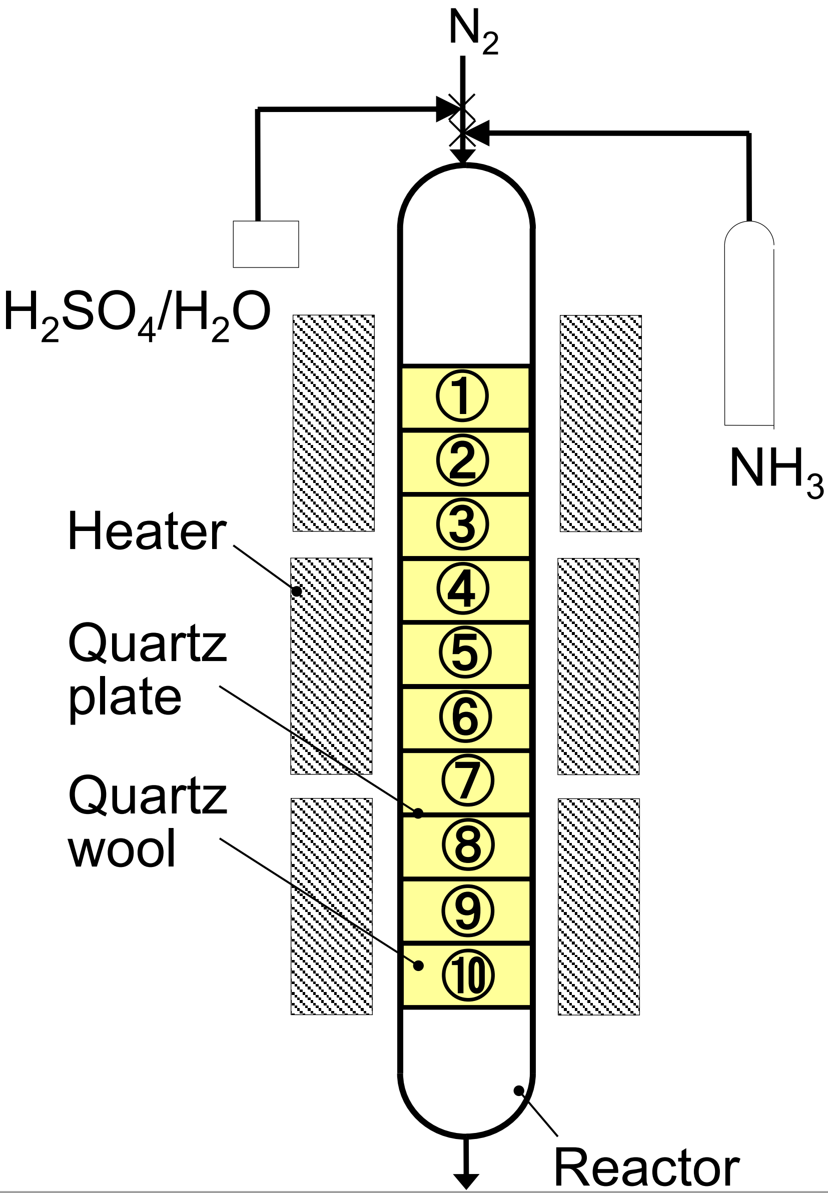
Pellet or Ring

Patented TiO_2 Base catalyst to avoid SOx poisoning

Started development in 1960's

1960

Experimental Method – ABS Deposition Temperature (in 1983)



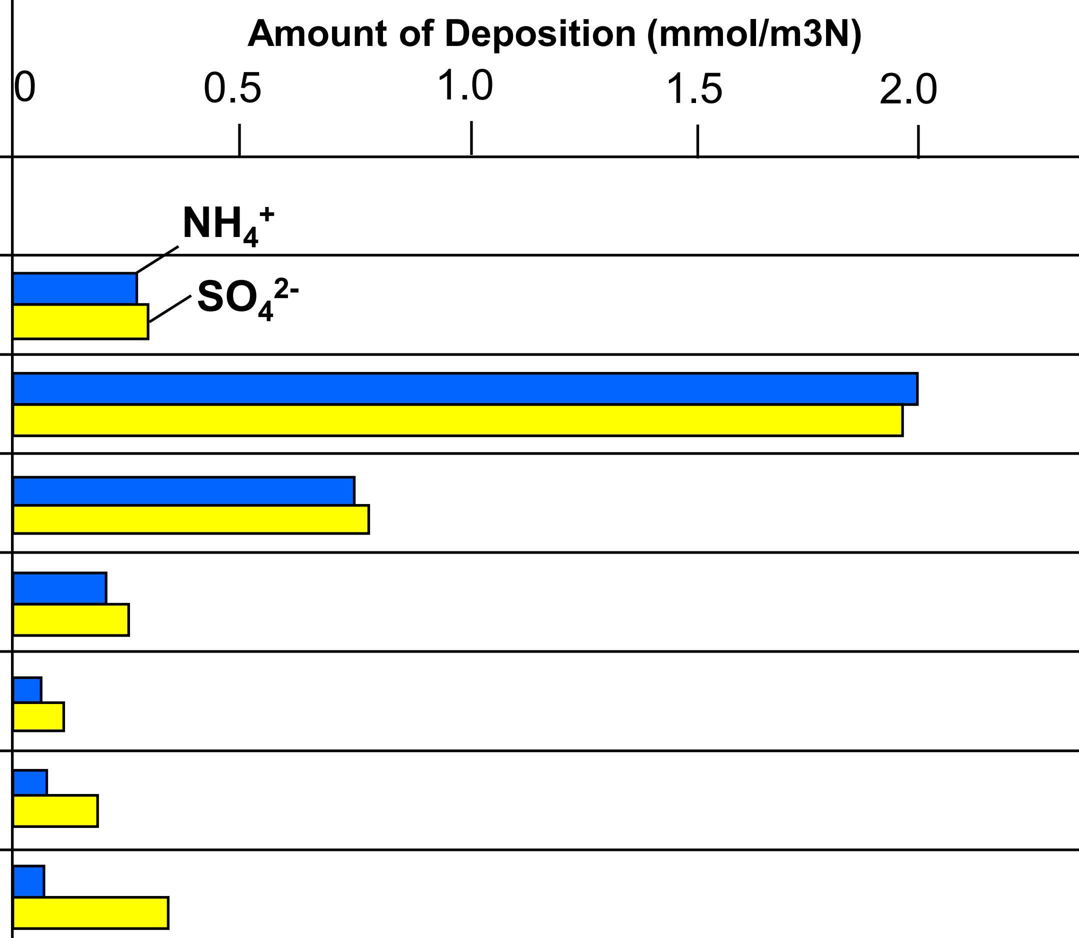
Measurement Condition

Item	Condition
Temperature Setting	Reactor Inlet: 1022F Inlet ①: 680F Outlet ⑩: 212F
Duration Hours (h)	20
Inlet Gas Condition	Several sets of NH_3/H_2SO_4 Concentration

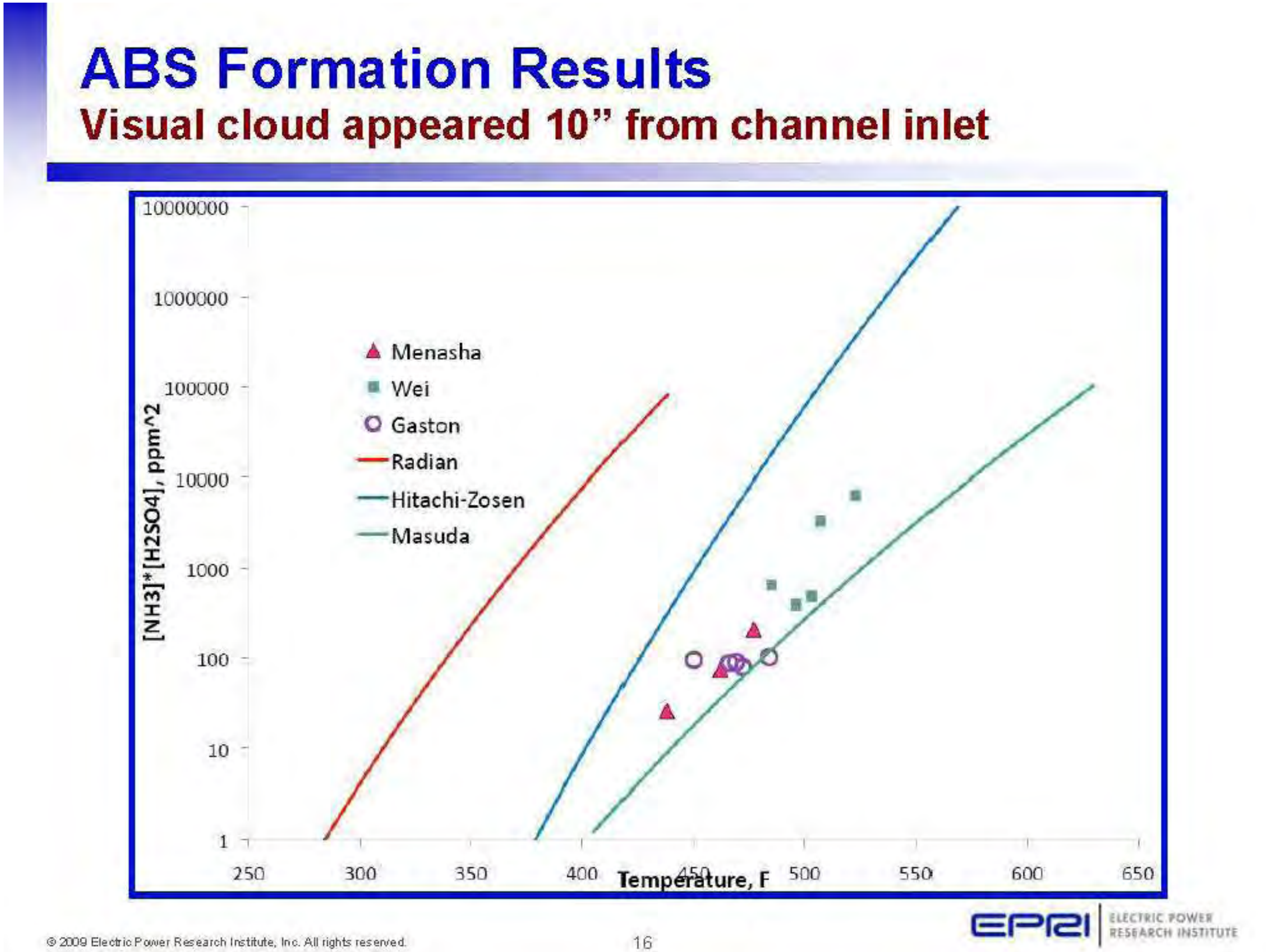
After 20 hours duration, each part of glass wool and plate wall was removed and analyzed for NH_4^+ and SO_4^{2-} to determine the temperature of ABS deposition

Example of Measurement Result (at specific SO_3, NH_3, and H_2O levels)

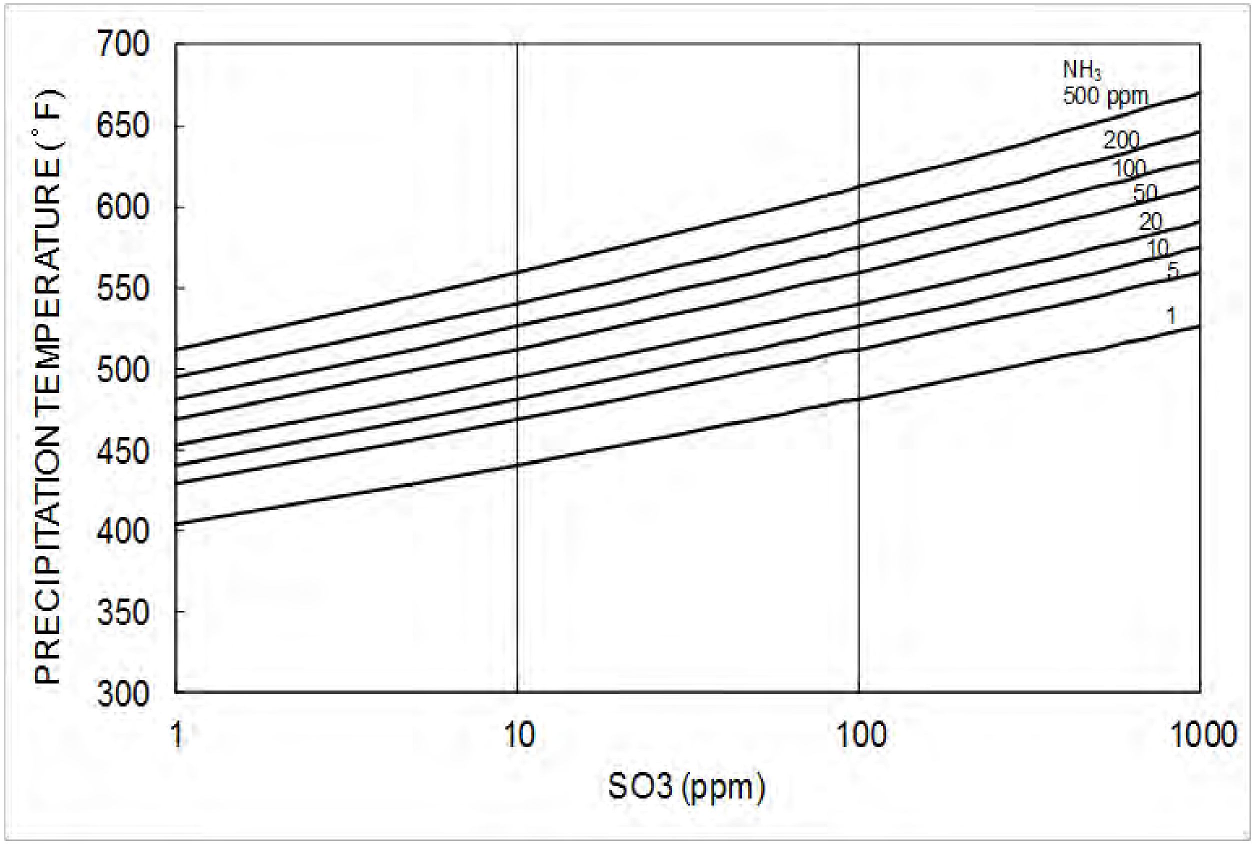
Region	Temperature (Deg F)	NH_4^+/SO_4^{2-} (Mole Ratio)
1	673-613	-
2	613-556	0.91
3	556-509	1.00
4	509-466	0.95
5	466-432	0.77
6	432-397	0.26
7	397-361	0.14
8	361-316	0.11



EPRI's Test Results of ABS Formation at Gas Phase



Precipitation Temperature of Ammonium Bisulfate at Gas Phase

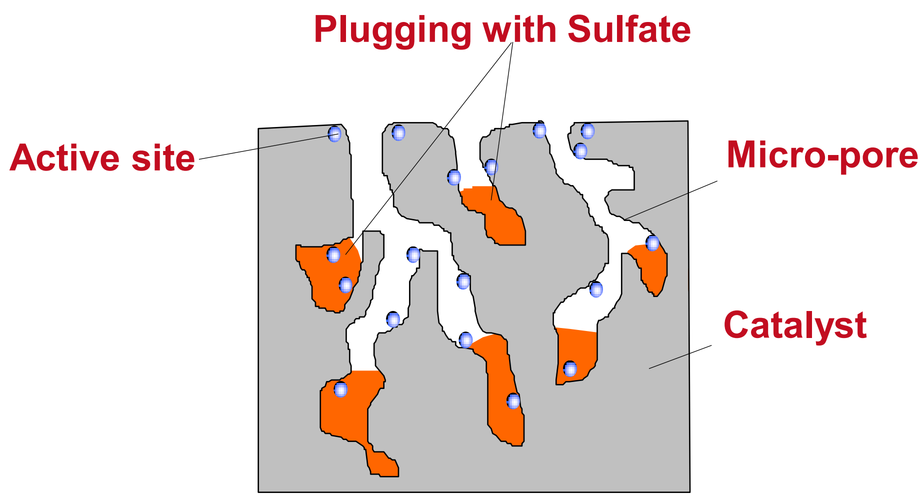


ABS Formation is Dependent on Temperature, NH3 and SO3 Concentrations

Precipitation Temperature of ABS in Catalyst

Ammonium Bisulfate Formation in Catalyst Pore

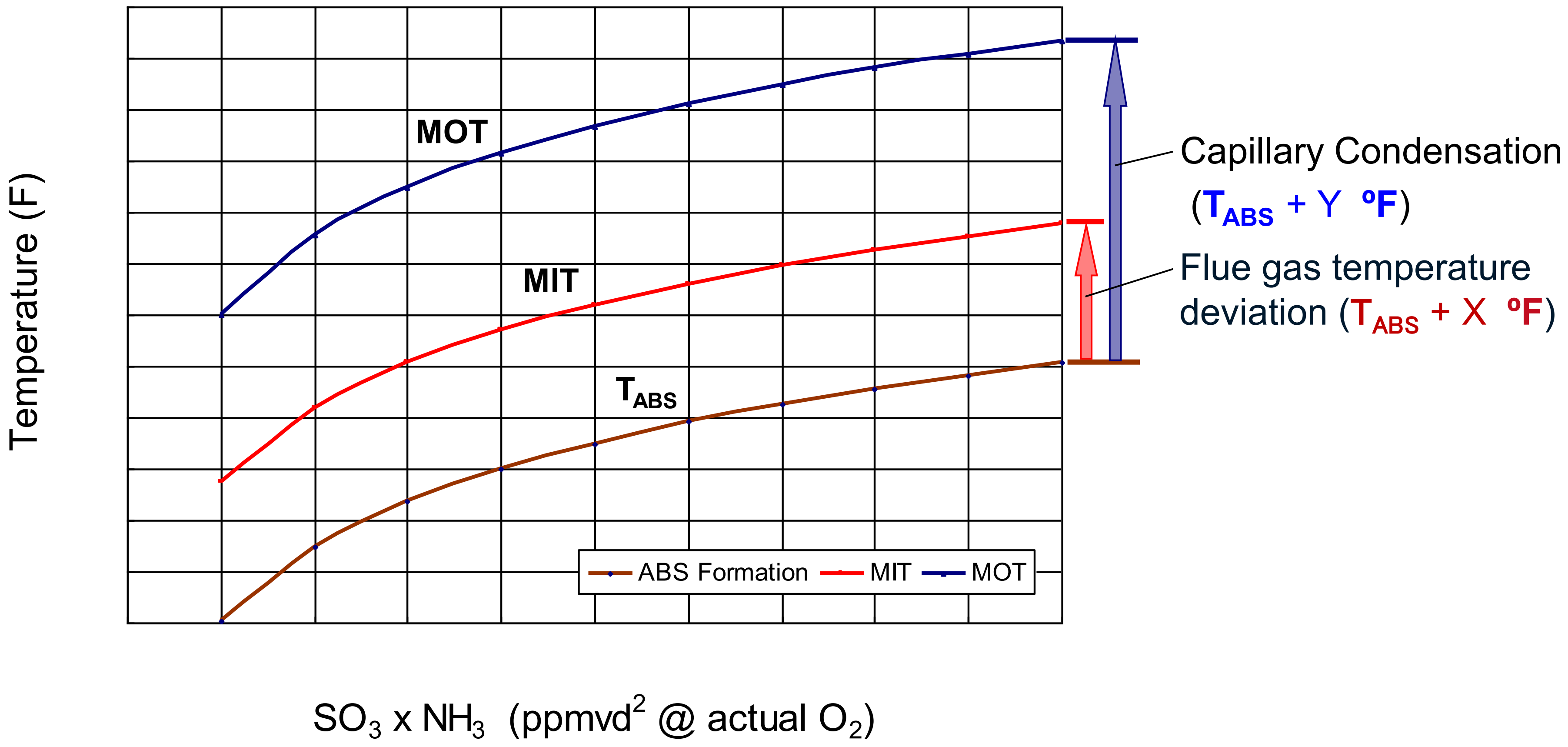
- Deposition of ABS causes plugging of the micro-pores in the catalyst through the process of Capillary Condensation and covers the catalyst surface where the active sites are located.
- This phenomenon causes decreased catalyst activity.
- ABS formation temperature in catalyst is higher than formation temperature at gas phase, and is dependent upon catalyst pore size.



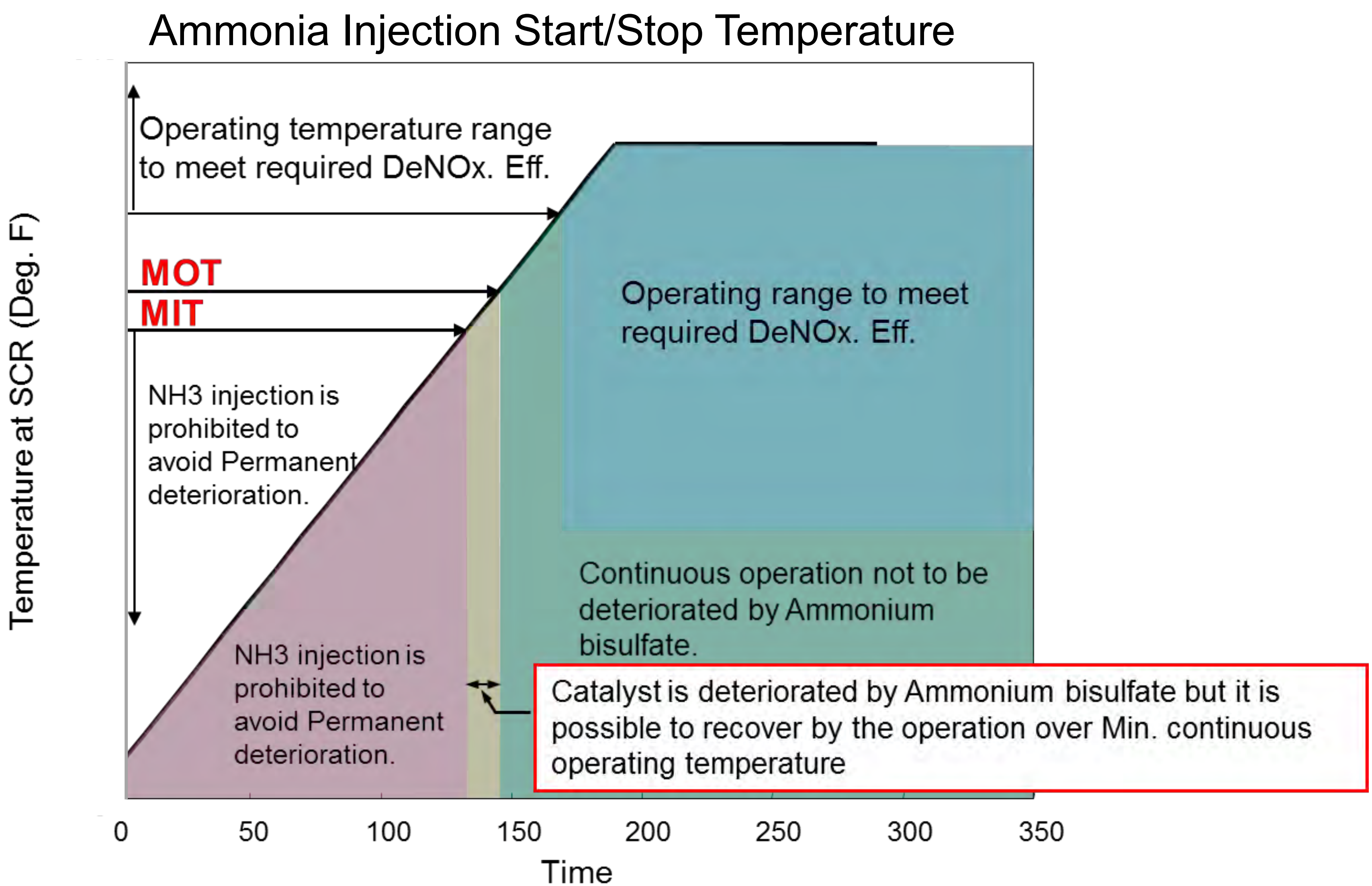
Not All Catalyst Pore Structures Respond the Same Way

MHPS Approach to Low Temperature SCR Operation

MHPS Traditional Approach to MIT and MOT

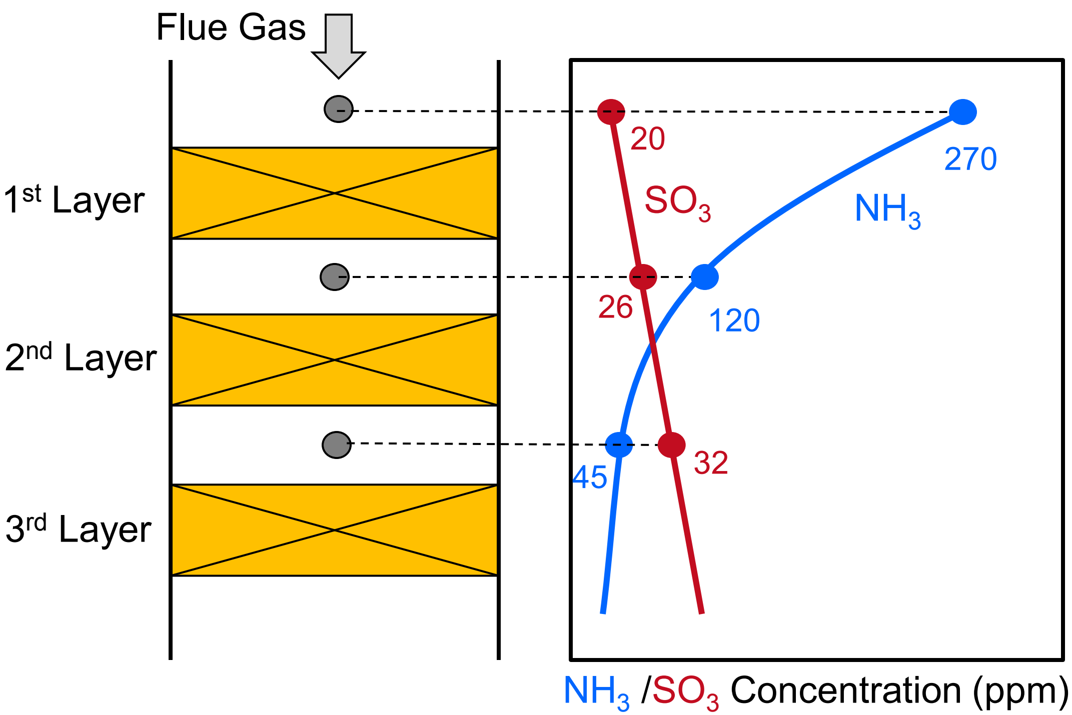


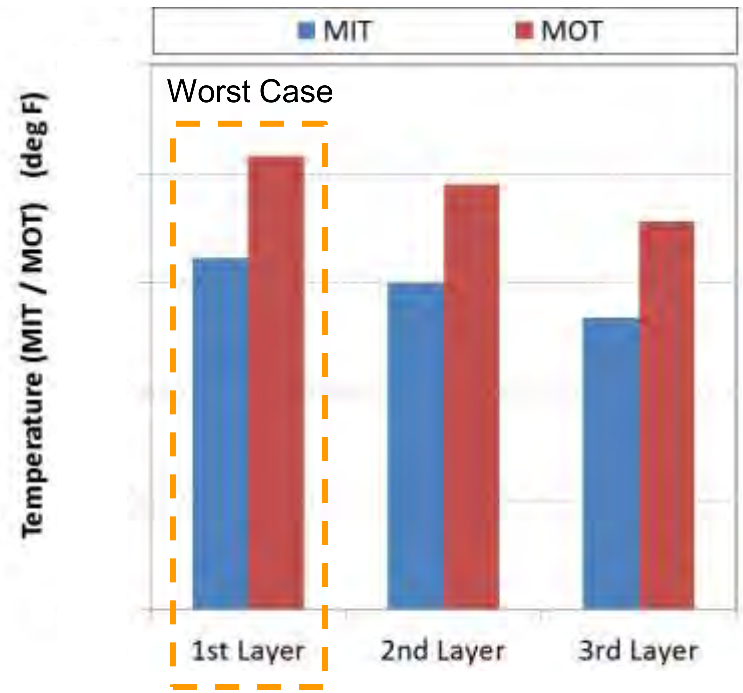
MHPS SCR Operating Standard (Startup Example)



What Temperature Should Be Monitored

Gas Composition: NOx = 300 ppm, SO_3 = 20 ppm, NH_3 = 270 ppm, SO_2 = 2,000 ppm
SCR Performance: NOx removal = 88%, SO_2 Conversion Rate = 0.9%





Leading Edge of Top Catalyst Layer is the Critical Point

MHPS Bench Test Study

on Catalyst MOT and MIT

&

MHPS Standard MOT and MIT Procedure

Review of MIT/MOT by Bench Scale Test

Pattern #1:

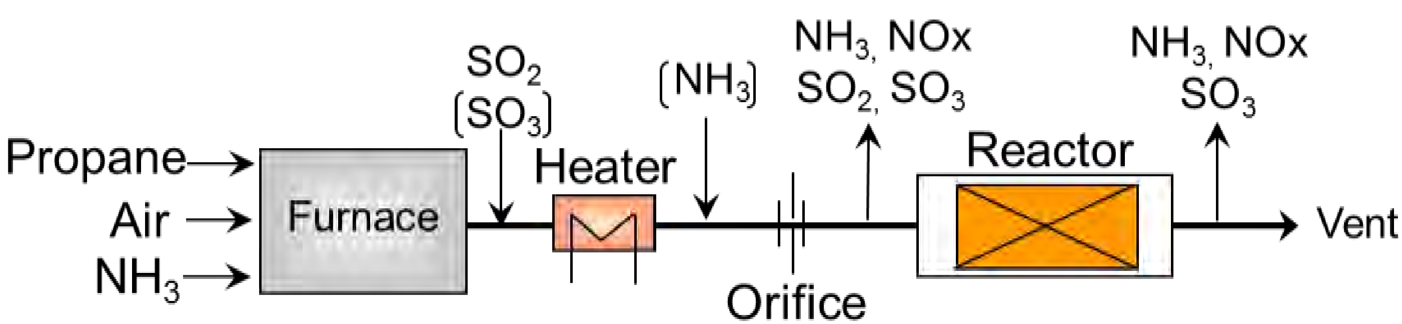
Test the effect of operating at between MOT and MOT-36 (still above MIT)

Pattern #2:

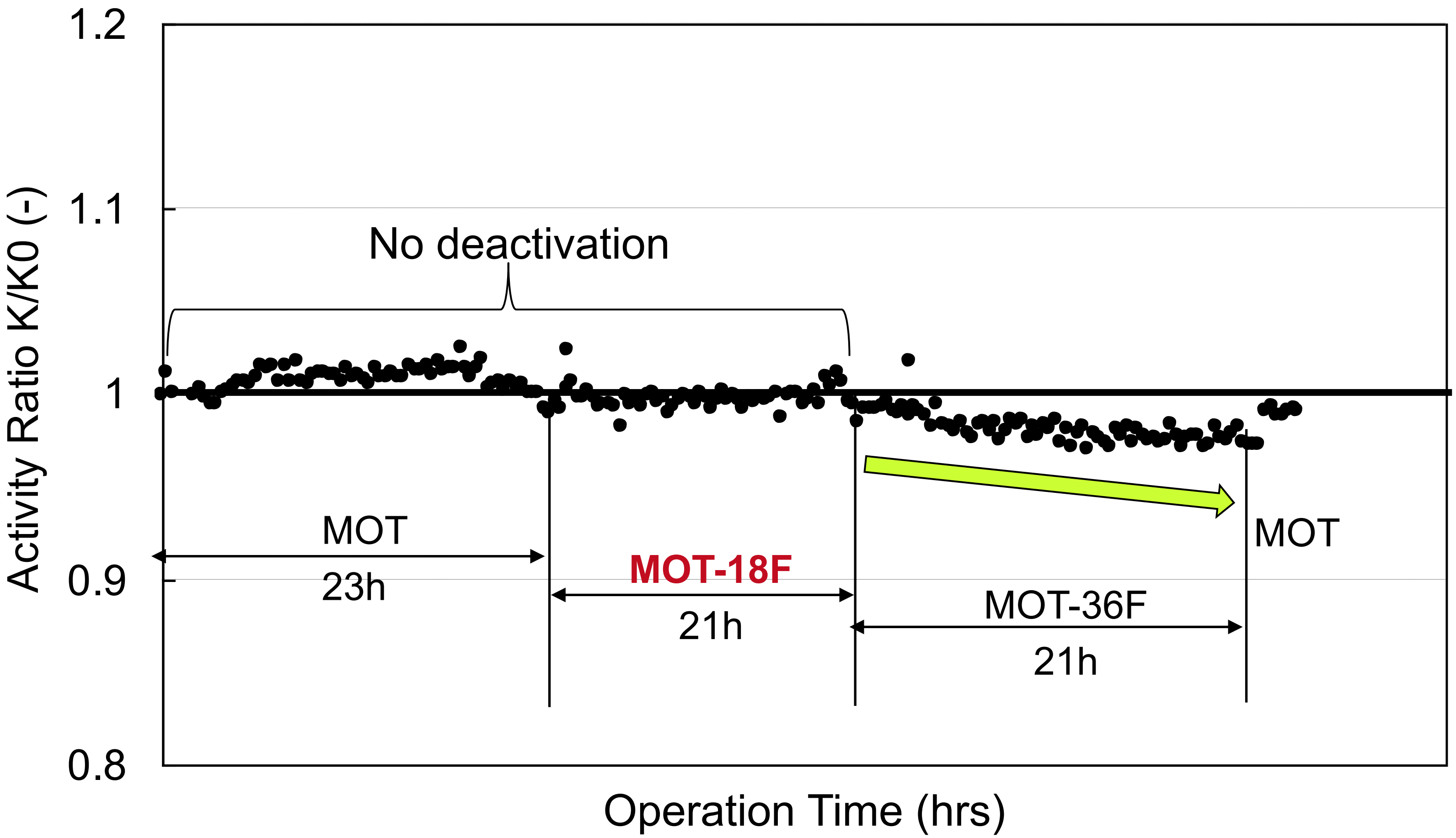
Test the effects of running for different cycle times at MIT to determine how long is required to run at MOT to recover catalyst activity.

Pattern #3, 4, 5

Test the effects of running below MIT for different cycle times and determine what times and what temperatures are required to run to recover catalyst activity.

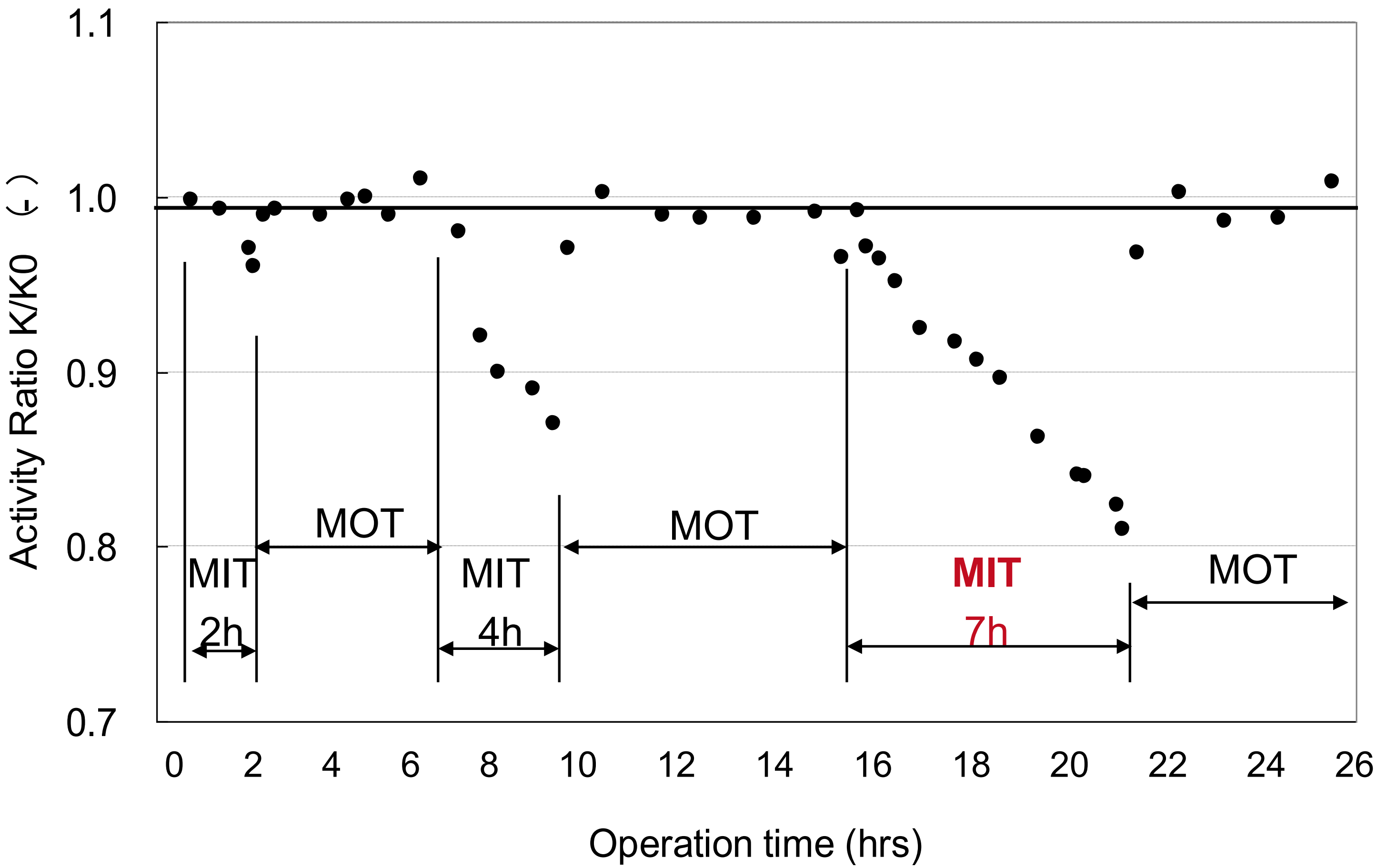


Bench Scale Test (Pattern #1)



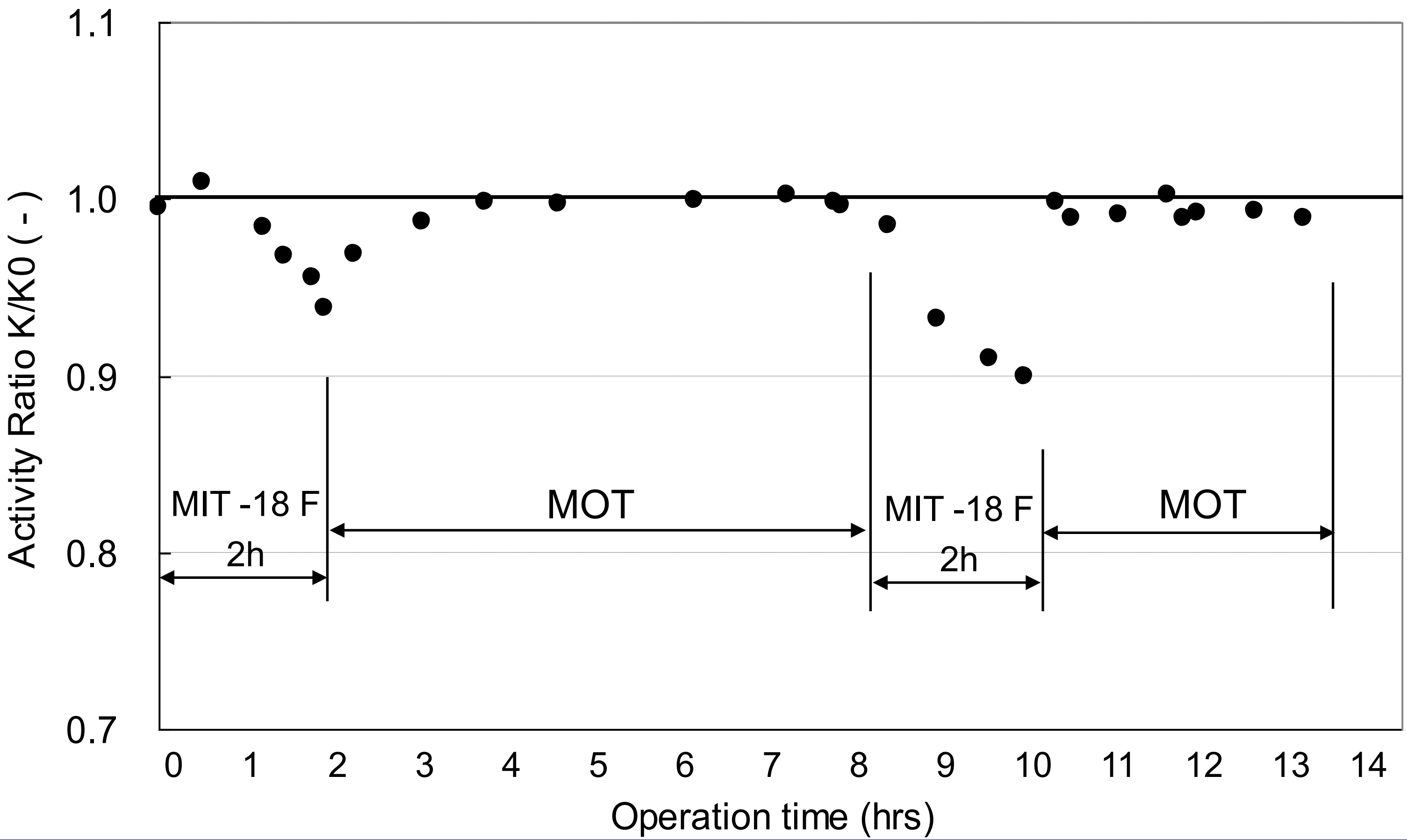
No Deactivation was Observed at MOT-18F
Steady Deactivation was Observed at MOT-36F

Bench Scale Test (Pattern #2)



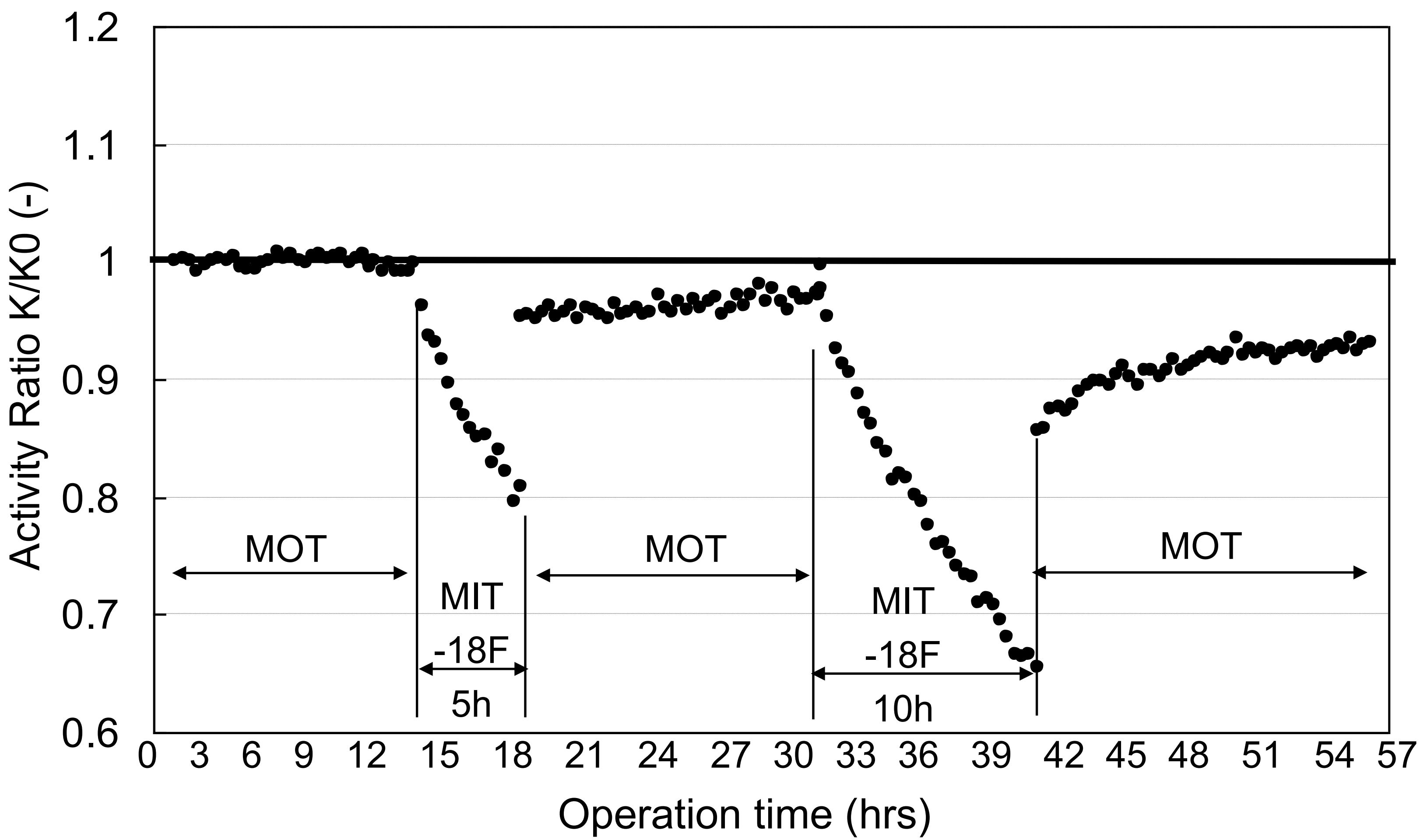
Rapid Deactivation was Observed at MIT, but fully recovered after operation at MOT

Bench Scale Test (Pattern #3)



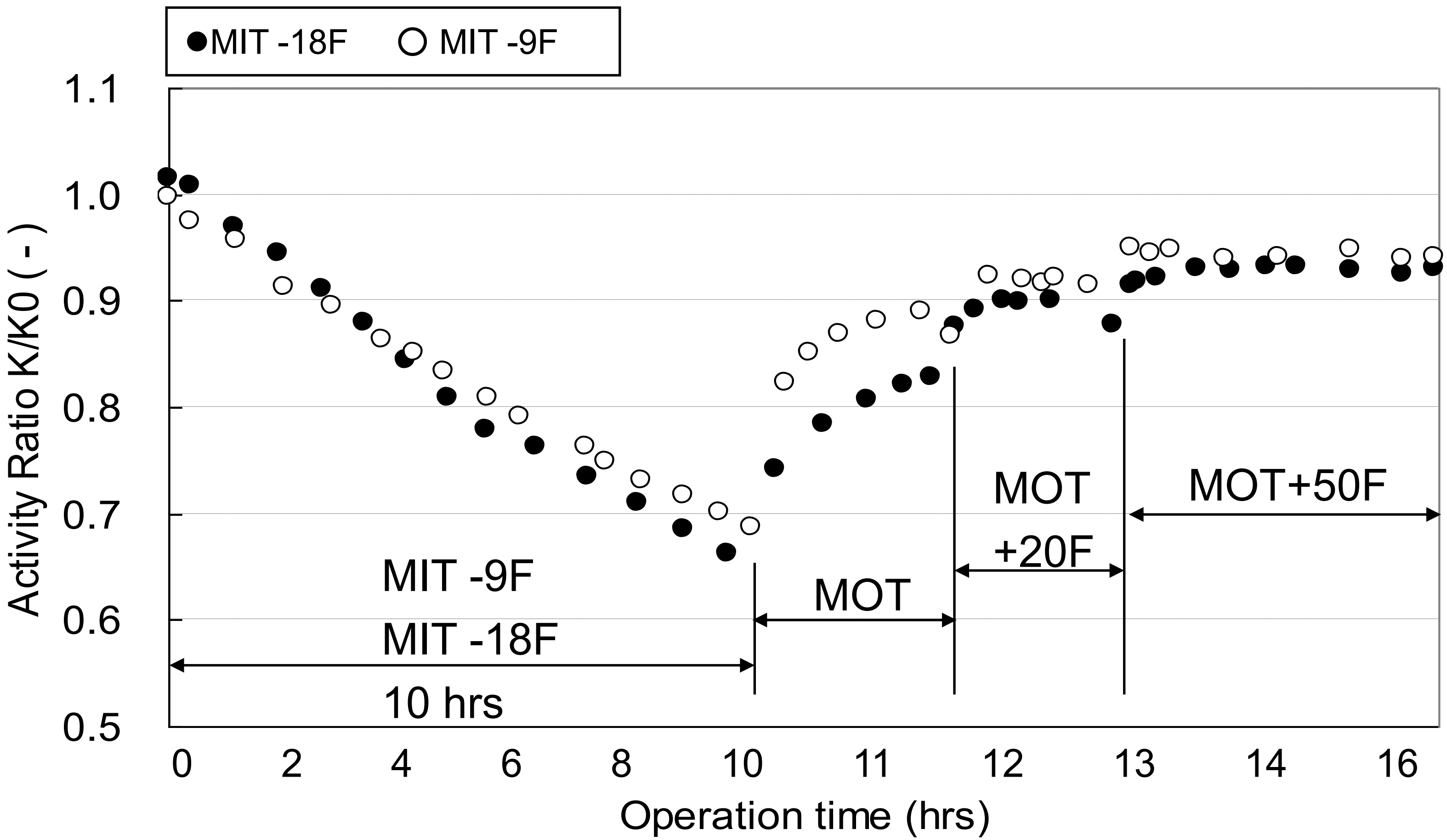
After short operation below MIT, catalyst activity was fully recovered by operating at MOT

Bench Scale Test (Pattern #4)



After longer operation below MIT, catalyst activity was NOT fully recovered by operating at MOT

Bench Scale Test (Pattern #5)



After longer operation below MIT, catalyst activity was NOT even fully recovered by operating above MOT

Summary of Bench Scale Test Results

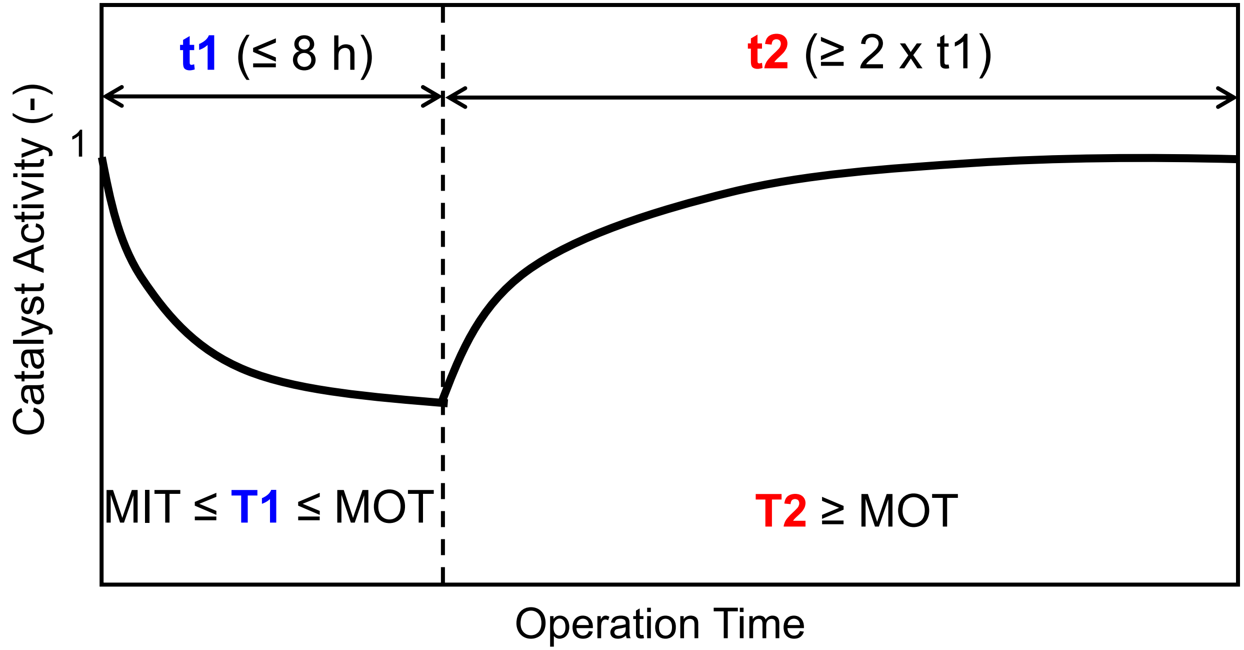
Temperature	Bench Test Results
MOT	Not Deactivated
<MOT & >MIT	**Not Deactivated at MOT-18 F**
MIT (Short Time)	Deactivated at MIT (7 hours) Fully recovered by MOT
< MIT (Short Time)	Deactivated at MIT-18F (2 hours) Fully Recovered by MOT
< MIT (Long Time)	Deactivated at MIT-18F (10 hours) Not able to be fully recovered by MOT/MOT+50F

MHPS Standard Procedure of Low Load Operation

· Operation of SCR under MIT shall be prohibited.

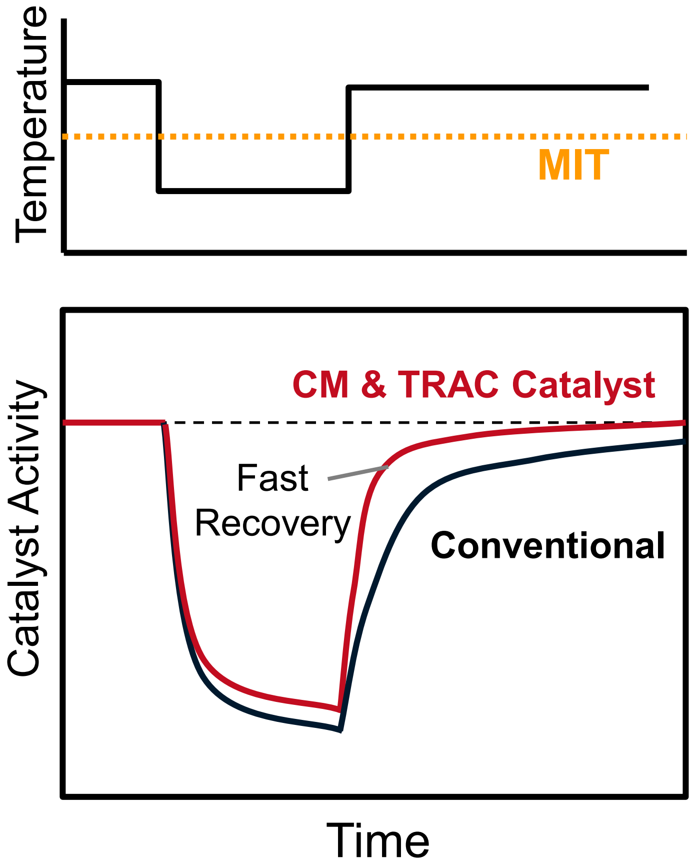
· The maximum continuous operating time (**t1**) of lower temperature (**T1**) operation (where **T1** is between MOT and MIT) shall be 8 hours.

· In order for the catalyst to recover the activity drop, it is required to operate the SCR with higher gas temperature than MOT (**T2**) for at least two times longer (**t2**) than the amount of time (**t1**) of the lower temperature operation.



Laboratory Scale (Micro-reactor) Test

MHPS catalyst developed in late 2000's, CM and TRAC, show better recovery characteristics than Conventional catalysts.



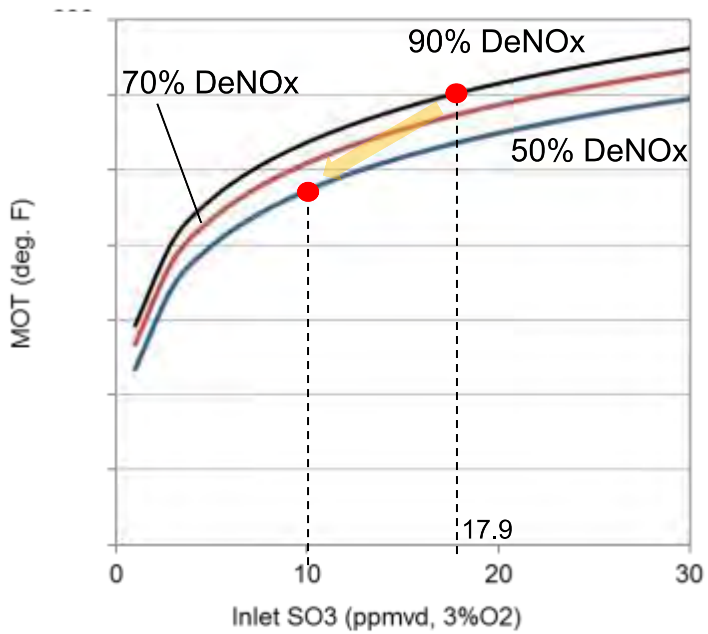
How can MOT and MIT be Reduced Further?

What is the Potential Cost Savings?

Consideration of Low Load Conditions

EXAMPLE

Item	Unit	Full Load	Lower Load	MOT/MIT
Temperature	deg F	700	↓	-
Required DeNOx	%	90	↓ ?	⬇
O2	%	3.9	↑	-
SO3	ppm act O2	17.9	↓ ?	⬇



MOT and MIT Calculations based on Low Load Conditions may reduce catalyst operating temperatures

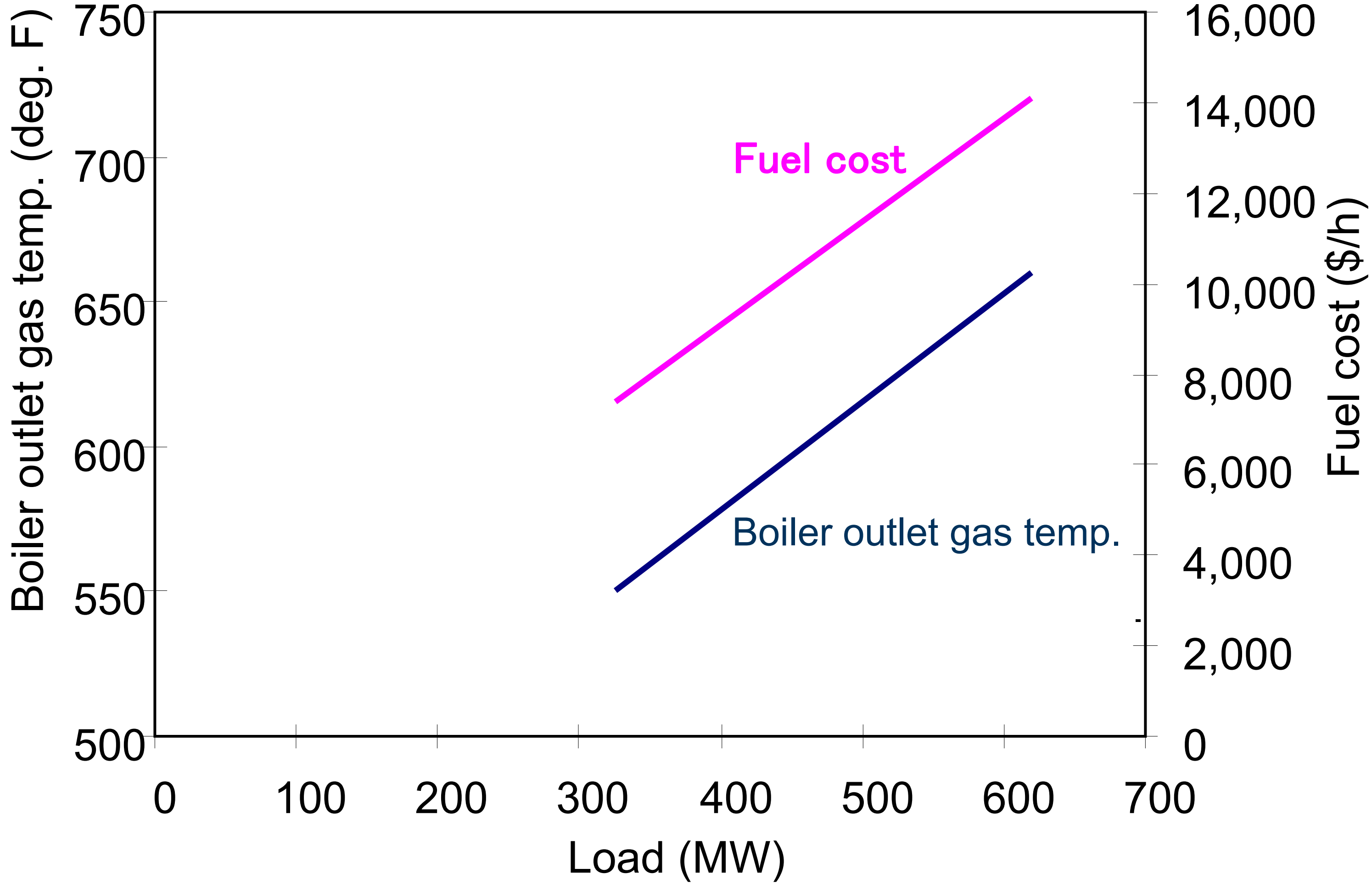
SO3 Mitigation Upstream of the SCR

Items to Consider

- Reduces the SCR inlet SO3, which reduces the catalyst MOT and MIT.
- Adds particulate loading through the SCR.
- Many SO3 sorbents contain known catalyst poisons.
    - May impact catalyst performance guarantees and life
- To minimize impact on catalyst deactivation, may require implementation of SCR layup procedure during outages to keep catalyst dry.

Potential Cost Savings of Lower SCR Temperature Operation

Assumption:
Coal: Bituminous, Fuel Consumption: 650lb/MW, Fuel Cost: $0.035/lb



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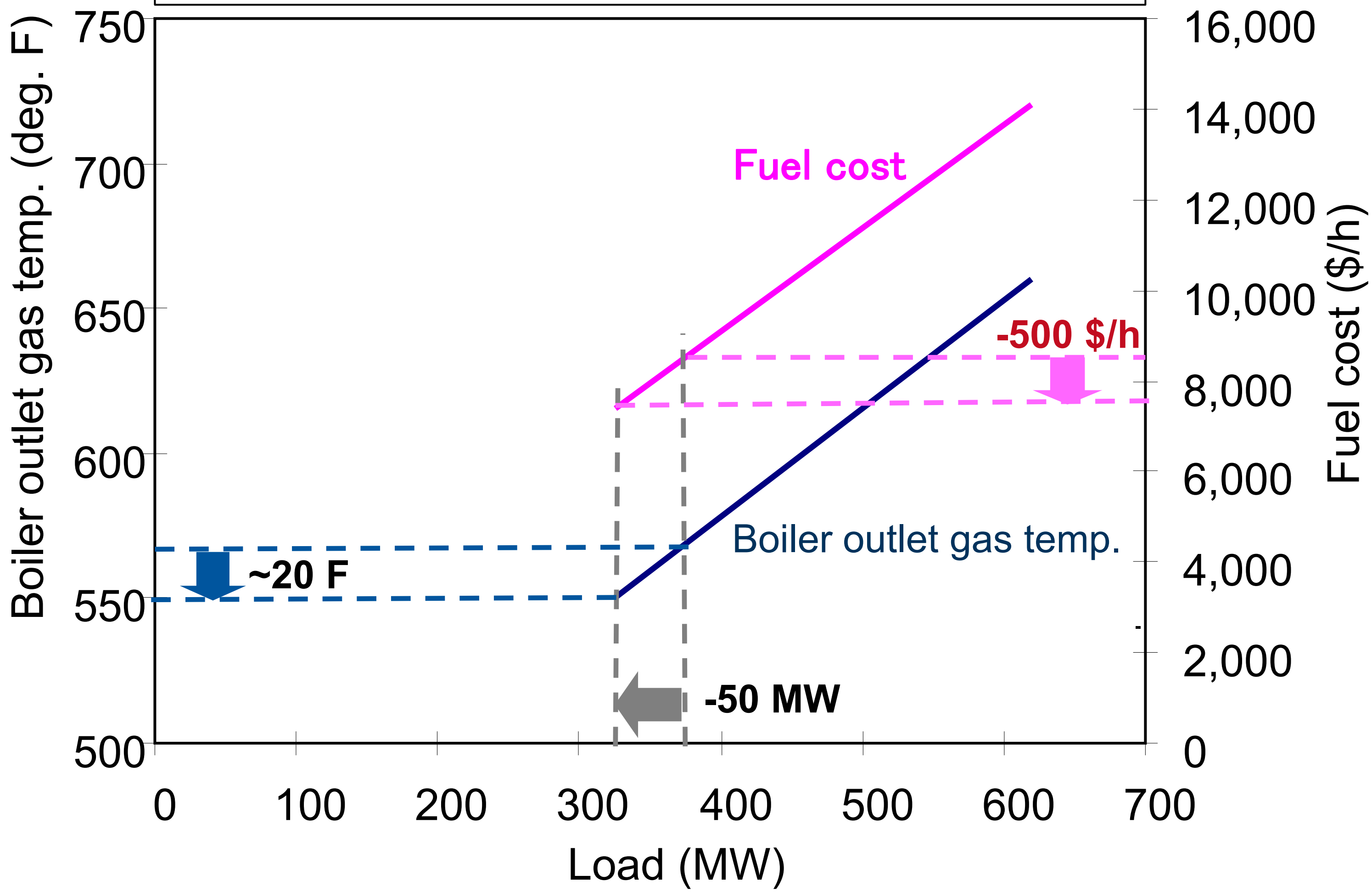

3,000 operating hours/year at reduced temperatures can save $1.5M annually

What if NH_3 is Injected below MIT?

What if NH3 is Accidently Injected below MIT?

- Immediately Stop NH3 Injection
- Try to keep catalyst as hot as possible
- Operate SCR at highest temperature possible without exceeding catalyst maximum operating temperature. Attempt to burn off ABS formation.
- Delay restart of NH3 injection as long as possible.
- When NH3 injection is restarted, increase injection rate slowly and monitor the SCR performance closely.

Combination of Time and Temperature are the Best Medicine

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