Retrofit Application and Operation of the Shell Low Temperature SCR Technology on Gas Turbines, Ethylene Cracker Furnaces and Process Heaters.

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Abstract

The Shell low temperature selective catalytic reduction (SCR) technology has been successfully retrofitted on gas turbines, ethylene cracker furnaces and process heaters. Typical SCR operating temperatures are 325° - 450°F with low pressure drop. The low temperature capability of the Shell SCR technology allowed retrofit installation after the existing heat recovery equipment with no modification or impact on the existing combustion equipment and minimum down time. Design NOx conversions of over 90% have been achieved at low ammonia slip.

This paper will discuss the design criteria, the Shell low temperature SCR technology, and the retrofit installation and operating experience on these three applications.

Introduction

Since its introduction in Japan in the 1970's, Selective Catalytic Reduction (SCR) of nitrogen oxides (NOx) has gained wide acceptance as the most effective and technologically proven method for deep NOx removal from flue gases. The Shell DeNOx System (SDS) operates on the SCR principal using ammonia (NH_3) as the reductant and a catalyst to promote the reaction of NH_3 with the NOx to form nitrogen and water (Fig.1). Unlike conventional SCR systems, the Shell system is able to operate at lower temperatures and lower pressure drop. Consequently the SCR system can be installed immediately before or in the stack, thereby avoiding any modification to combustion or heat recovery equipment or negative effects on other upstream plant operations. This makes the Shell DeNOx System very suitable for retrofit SCR applications. To date this system has been successfully applied to combustion and chemical process operations including gas turbines, refinery heaters, boilers and ethylene cracker furnaces.

Typical Application Conditions and Performance of the Shell Low Temperature SCR Technology:

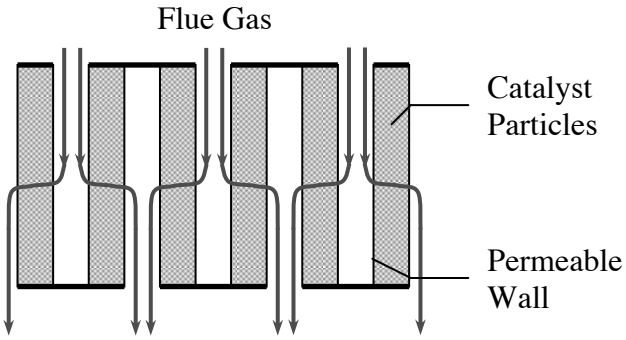
Operating Temperature	
Typical Application	325-450° F
Range	325-700° F
Pressure Drop	
Typical Application	2-3" H_2O
Range	as low as 1" H_2O
Performance	
NOx Conversion	>90%
NH_3 Slip	10 ppm or lower

The Shell DeNOx System (SDS)

The Shell DeNOx System differs from conventional honeycomb SCR systems in two important aspects: the catalyst and the catalyst reactor module. The catalyst is in the form of porous pellets (extrudates) and can be produced in a range of sizes and shapes to meet specific performance requirements. Due to the high activity of the catalyst, high NOx removal efficiencies with simultaneous control of NH_3 slip can be obtained at relatively low temperatures.

The catalyst reactor module is based on the so-called Lateral Flow Reactor (LFR) principal [Fig 2].

Fig 2. LFR Principle



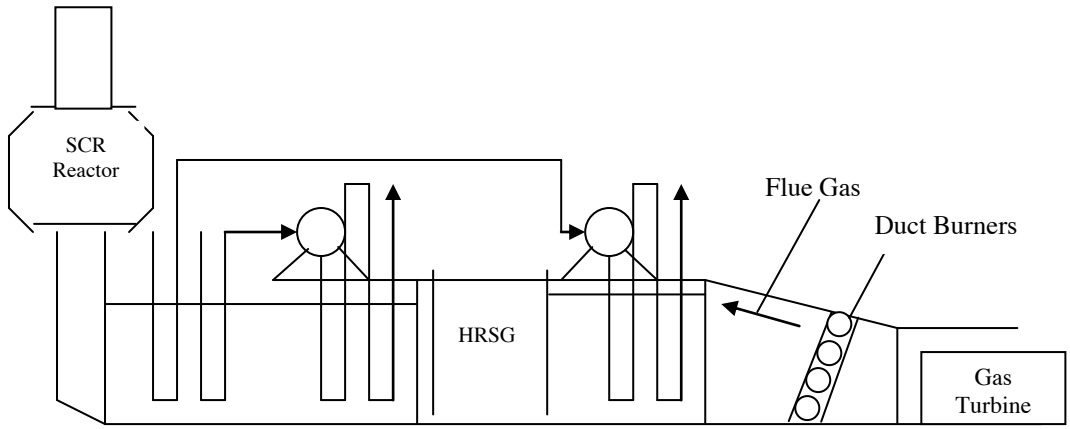
The LFR is a packed-bed type reactor which offers the advantage of low-pressure drop, even at high space velocities. A low-pressure drop over the SCR reactor reduces power consumption or power loss depending on the application. Furthermore, the LFR design makes possible the use of relatively small catalyst pellets, which reduces the amount of catalyst required, and additionally facilitates fast loading and unloading of catalyst from the reactor.

Development of the LFR technology has resulted in a modular construction system, thereby providing a large degree of flexibility in the design of SCR systems for specific applications, particularly retrofit. As a consequence of the high catalyst activity and the flexibility of the LFR module design, the most optimal solution can be found for each application with respect to NOx removal, NH_3 slip, temperature, pressure drop and available plot or duct space.

Application of the Shell Low Temperature SCR System to Gas Turbines

The Shell Low Temperature technology has been retrofitted on nine gas turbines, including six in California and one in Houston. All of the turbines had existing HRSG's with insufficient space within the boiler section for installation of SCR catalyst. Economic analysis of each of the facilities determined that the lowest cost option was to install a low temperature SCR downstream of the HRSG. Two possible options for installation of low temperature SCR catalyst exist: (1) In the HRSG duct between the economizer and the stack where the flue gas flow through the SCR is horizontal, provided there is sufficient space, or (2) in the stack where the flue gas flow through the SCR is vertical. In all nine installations, the SCR was installed in the stack (Fig. 3). Stack gas temperatures for these installations range from 325 - 375°F.

Figure 3 – Gas Turbine Installation



The design basis for these installations is summarized in Table I.

Fuel to the turbines, and duct burners if present, is natural gas or in one case a blend of natural gas and refinery fuel gas. The oldest unit has been in continuous operation for 6 years, and all of the SCR systems are still operating on the original charge of catalyst. A major advantage of installing the SCR in the stack is that most of the SCR system can be pre-fabricated and much of the civil, structural and installation can be done while the turbine/HRSG is still in operation. Several of the low temperature SCR systems were installed during a normal turbine outage period of 2-3 weeks.

Case Study:

In 1997, three Turbo Power FT4 gas turbine/HRSG units at a Bay Area, California location were retrofitted with Shell low temperature SCR systems. The SCR was designed for a maximum flue gas flow of 1,030,000 #/hr and a minimum operating temperature of 375°F. The fuel to these turbines is natural gas. Design performance was 9 ppmvd maximum NOx outlet from a maximum of 135 ppmvd NOx inlet or a 93% NOx reduction. NH_3 slip limit was 10 ppmvd.

The SCR units started up in March 1997 and have operated continuously since then, other then normal shutdowns. Recent data (Table II) shows that the units continue to meet NOx emission and NH_3 slip requirements.

Table II

Gas Turbine Installation

	Design	**Start Up 3/97**	**12/01**
Months Since Start Up	-	0	57
SCR Operating Temperature (°F)	375 min.	377	411
Flue Gas Flow (#/hr)	1,030,000 max.	920,000	ca. 920,000
Nox Inlet (ppmvd corrected)	135 max.	121	110
Nox Outlet (ppmvd corrected)	9 max	5	4
Nox Conversion (%)	93.3%	95.9%	96.3%
NH_3 Slip (ppmvd corrected)	10 max.	-	5

Application of the Shell Low Temperature SCR System to Ethylene Cracker Furnaces

The Shell Low Temperature SCR System can be installed at three different locations on cracking furnaces –

(1) Between the superheater and the economizer sections within the convection section
(2) Immediately after the economizer section with the SCR integrated into the existing duct configuration
(3) Downstream of the furnace in a separate reactor house

Each location has its own features and is more or less suitable for installing a low temperature SCR system.

Location	Approximate Temperature	Advantages	Disadvantages
1	500 - 600ºF	* Smaller catalyst quantity * No additional reactor house required	* Difficult and expensive to retrofit on existing furnaces * Long downtime for installation * Long, narrow duct requires more sophisticated ammonia distribution system
2	320 - 420ºF	* No additional reactor house required * Shorter downtime for installation	* More catalyst required * Long, narrow duct requires more sophisticated ammonia distribution system
3	320 - 420ºF	* Easy, simple tail end solution for existing furnaces * Allows for prefabrication of SCR system, resulting in minimum down time for installation	* More catalyst required * Additional reactor house required

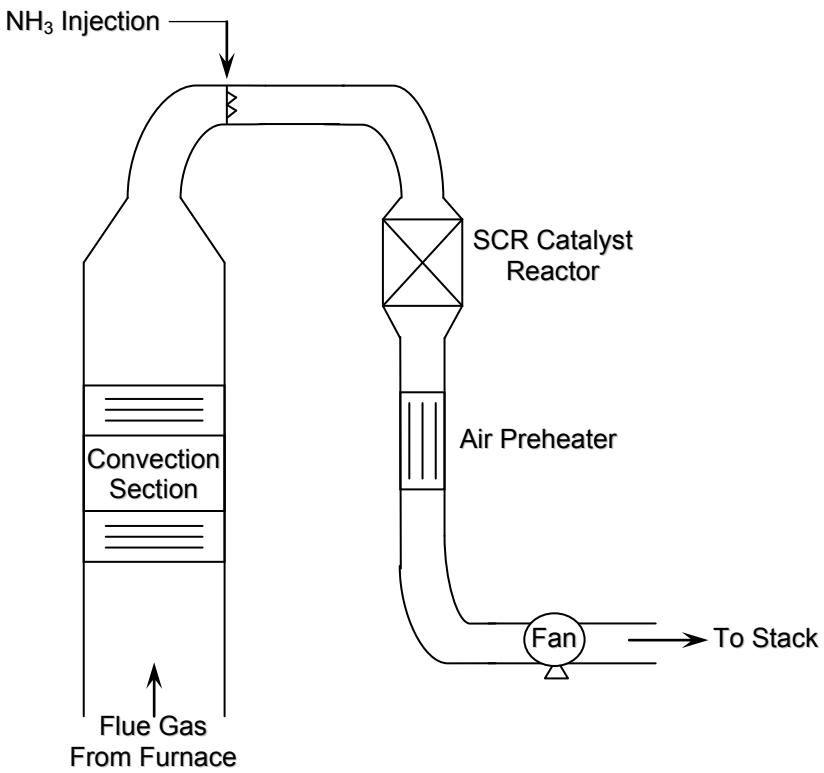
		* Simpler ammonia injection and distribution system.	

For existing cracking furnaces, because of the difficulty and high costs for breaking into the existing convection section to install SCR catalyst, locations 2 and 3 are usually the most economically attractive.

The Shell Low Temperature SCR System has been retrofitted on two ethylene cracker furnace facilities, six furnaces in Germany and two furnaces in The Netherlands.

At both facilities the SCR reactors were installed in an existing duct section downstream of the furnace convection section before the air preheater. [Fig 4]

Fig. 4 – Ethylene Cracker Furnace Installation



The fuel to the furnaces is either fuel gas produced on site (which is mainly methane) or natural gas.

The furnaces process multiple feed stocks, so minimum stack gas temperatures can range from a low of 320°F up to 415°F during normal operation, with maximum temperatures up to 700-750° F during decoke. The oldest unit (on LFR technology) has been in operation over four years, and all of the SCR systems are still operating on the original charge of catalyst.

The design basis for these units is summarized in Table III.

Case Study:

In 2000, two ethylene cracker furnaces at Shell Nederland Chemie (SNC) in Moerdijk, Netherlands were retrofitted with low temperature SCR to bring the site into compliance with lower total NOx emission requirements. SNC had commissioned a study, conducted by a major independent EPC contractor, which determined that the Shell low temperature SCR technology had the highest tonnage NOx removal and the lowest cost per ton of NOx removed over several competing technologies, including retrofit of the furnaces with state of the art low NOx burners.

The SCR reactors were installed in the duct section downstream of the furnace before the air preheater (refer to Fig 4). The SCR reactor and NH_3 injection grid were pre-fabricated and designed to fit on existing flanges in the duct. Installation occurred during a scheduled maintenance outage for the furnaces. Start-up was in June 2000 and the units have operated continuously since then.

The SNC furnaces process two types of feedstocks, resulting in different SCR operating temperatures, 415ºF and 540ºF respectively. The fuel is natural gas. The SCR units were designed to treat a flue gas flow of approximately 190,000 #/hr and achieve 91% minimum NOx reduction with 5 ppm maximum NH_3 slip.

Performance data for this installation is summarized in Table IV.

Table IV

	Design	**Start-up 6/00**	**1/01**
Months Since Start-up	-	0	6
SCR Operating Temperature (ºF)	410 min.	404	392
O_2 (vol%)	2.4	Typical	1.4
H_2O (vol%)	19	Typical	Typical
Inlet NOx (ppmvd @ 3% O_2)	102 max.	75-80	95
Performance			
Outlet NOx (ppmvd @ 3% O_2)	9.7 max.	2-4	3.5
% NOx Reduction	90.5	94.6-97.5	96.2
NH_3 Slip (ppmvd @ 3% O_2)	6.6 max.	1-1.5	1.5

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Application of the Shell Low Temperature SCR System to Refinery Heaters

The Shell low temperature technology has been retrofitted on three refinery heaters/furnaces, two in California and one in Sweden. Fuel to all of the units is primarily refinery fuel gas which contains varying levels of sulphur. SCR operating temperatures for these units range from 350°F to 440°F, which are somewhat higher than the typical range for natural gas fired units to compensate for the higher sulphur content in the flue gas. The oldest unit has been operating for over ten years.

The design basis for these installations is summarized in Table V.

Case Study:

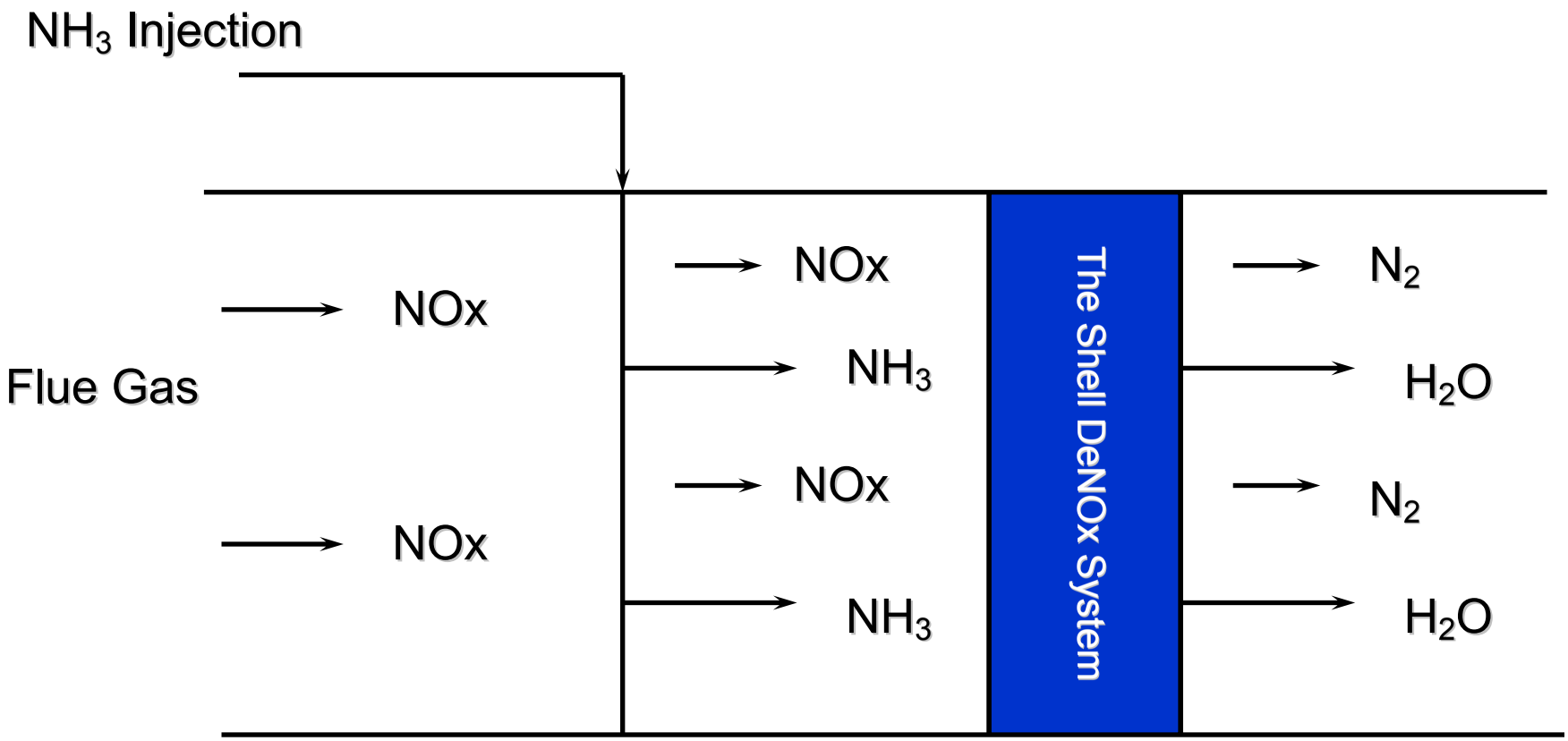
In 2000, a large hydrogen reforming furnace at a major California refinery was retrofitted with a Shell low temperature SCR system. The SCR was designed for a maximum flue gas flow of 706,000 #/hr. The fuel to the furnace is RFG, so the minimum SCR operating temperature is 440°F in order to keep the SCR system above the dew point for ammonium bisulphate salt formation. Design performance was 20 ppmvd maximum NOx outlet from a maximum of 200 ppmvd inlet (90% NOx conversion) with a NH3 slip limit of 10 ppmvd.

The SCR unit started up in November 2000 and has operated continuously since then other then normal scheduled shutdowns. Recent data (Figure 5) shows that the unit is routinely meeting NOx emission and NH_3 slip requirements.

Summary

The Shell low temperature SCR technology has been successfully retrofitted onto gas turbines, ethylene cracker furnaces and refinery heaters to achieve over 90% NOx reduction at low NH3 slip. The low temperature capability of the Shell systems allowed installation after the heat recovery section with no modification on the existing equipment.

Fig 1



The Shell Denox SCR System

Table I

Shell Low-Temperature SCR Systems
Operating Units – Gas Turbines

Location	No. of Units	Turbine	Start-up Date	Fuel	Flue Gas Flow #/hr	SCR Oper. Temp.	Design Max. N0x Conc. Outlet	Design N0x Conversion	Design NH_3 Slip
California	3	Westinghouse W-191	1/96 3/96 12/96	RFG/ NG Blend	1,050,000	360°F	9 ppm	91%	10 ppm
Texas	1	Allison 501-KB5	5/96	NG	135,000	350°F	9 ppm	90%	10 ppm
California	3	TurboPower FT4	3/97	NG	1,000,000	375° F	9 ppm	93%	10 ppm
Netherlands	2	GE Frame 5	11/97 5/99	NG	750,000	340° F	9 ppm	86%	5 ppm

Table III

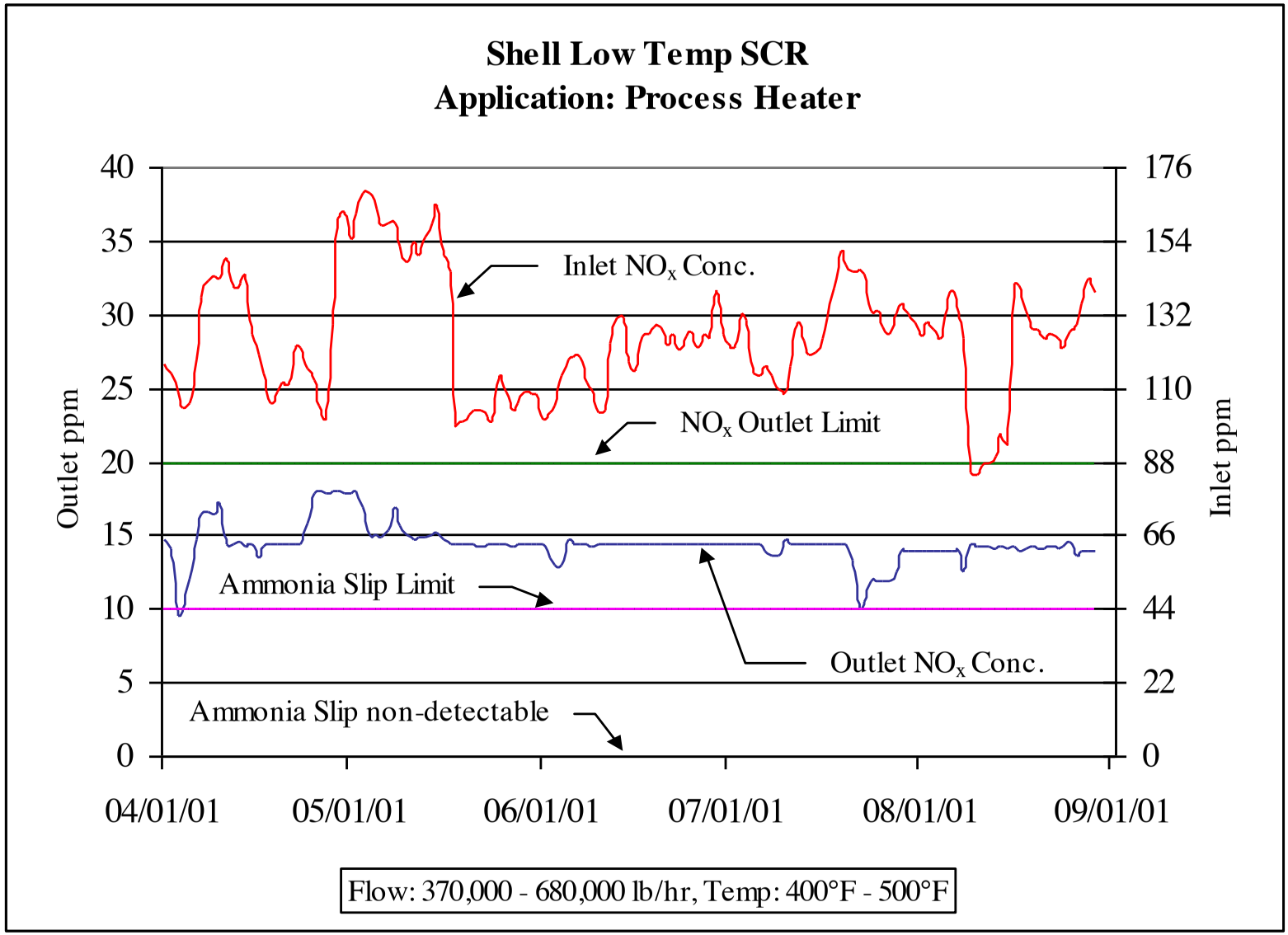
Shell Low-Temperature SCR Systems
Operating Units – Ethylene Cracker Furnaces

Location	No of Units	Start-up Date	Fuel	Flue Gas Flow #/hr	SCR Operating Temperature Operating	SCR Operating Temperature Decoke	Design Max. N0x Conc. Outlet	Design N0x Conversion	Design NH_3 Slip
Germany	6	3-'89 1 – 3Q/'97 2- 1Q/'98	NG/ Fuel gas	155,000	320°F	700°F	34 ppm	66%	5 ppm
Netherlands	2	6/2000	NG	183,000	410°F	750°F	9 ppm	91%	5 ppm

Table V
Shell Low-Temperature SCR Systems
Operating Units – Refinery Heaters/Furnaces

Location	No. of Units	Start-up Date	Fuel	Flue Gas Flow, #/hr	SCR Operating Temp	Design Max. N0x Conc. Outlet	Design N0x Conversion	Design NH_3 Slip
California	1	3/91	RFG	60,000	420°F	9 ppm	87%	10 ppm
California	1	11/00	RFG	700,000	440°F	20 ppm	92%	10 ppm
Sweden	1	10/98	RFG	275,000	350°F	9 ppm	90%	5 ppm

FIGURE 5


Shell Low Temp SCR
Application: Process Heater
Outlet ppm
Inlet ppm
40
35
30
25
20
15
10
5
0
176
154
132
110
88
66
44
22
0
Inlet NOx Conc.
NOx Outlet Limit
Ammonia Slip Limit
Outlet NOx Conc.
Ammonia Slip non-detectable
04/01/01
05/01/01
06/01/01
07/01/01
08/01/01
09/01/01
Flow: 370,000 - 680,000 lb/hr, Temp: 400°F - 500°F