Proceedings of NAWTEC16
16th Annual North American Waste-to-Energy Conference
May 19-21, 2008, Philadelphia, Pennsylvania, USA

NAWTEC16-1903

A Case Study of the Selective Catalytic Reduction (SCR) System at the Algonquin Power Energy-From-Waste Facility

Principal Author: Janice Hatton
Technical Analyst, Waste Management, Region of Peel
7795 Torbram Road
Brampton, ON L6T 0B6
janice.hatton@peelregion.ca

Co-Author: Peter Bulionis, P. Eng.
Senior Project Manager, Thermal Power, Algonquin Power Systems Inc.
7656 Bramalea Road
Brampton, ON L6T 5M5
peter.bulionis@algonquinpower.com

Abstract

The Algonquin Power Energy-From-Waste (APEFW) facility is located in the suburban Toronto, Ontario city of Brampton. It receives approximately 140,000 metric tonnes (154,000 tons) of MSW per year from the Region of Peel (Region) and approximately 10,000 metric tonnes (11,000 tons) per year of international airport waste from the area's two international airports. The APEFW facility commenced initial operations in 1992 and included four, 91 tonne (100 ton) per day Consumat two stage incinerators with heat recovery boilers and a dual-train air pollution control (APC) system consisting of evaporative cooling towers, venturi reactors and fabric filter baghouses.

The APEFW facility expanded its capacity in 2001 with the addition of a fifth 91 tonne (100 ton) per day modular incinerator and heat recovery boiler. One of the stipulations in the permitting process was that the entire expanded facility meet more stringent emission standards that included a significantly lower nitrogen oxides (NOx) emission rate. After a review of several available NOx control technologies, the APEFW facility chose to install a Selective Catalytic Reduction (SCR) system. While SCR systems are fairly common on EFW facilities in Europe, the APEFW facility is the only EFW facility in North America that currently operates with an SCR system and as such has gained valuable insight into the application and performance of this technology that is very relevant to the North American EFW industry.

This paper discusses the operation and maintenance of the SCR system, compares pre- and post- SCR NOx emissions and presents capital and operating costs for the SCR including the cost per tonne of waste processed and the cost per tonne of NOx removed.

Introduction

With the planned closure of the Region's Britannia Road landfill in 2002, the Region was interested in having more of its waste processed within its borders rather than shipping waste outside the region. This led to a decision to add a fifth modular combustion unit and waste heat boiler to the APEFW facility, which was placed into operation in 2001. The Ministry of the Environment allowed the expansion under the condition that the entire facility meet tighter emission limits.

Prior to 2001, the average NOx emission at the APEFW facility was 233 ppmdv at 11% O_2 (326 ppmdv at 7% O_2) using typical combustion control technologies. The new NOx emission limit that the expanded APEFW facility was expected to meet was 110 ppmdv at 11% O_2 (154 ppmdv at 7% O_2). Prior to expansion, there was no stack emission limit. It was determined that the APEFW facility could not achieve the required, lower emission rate using only combustion control technology and that an add on control system would be required. Two technologies, Selective Non-Catalytic Reduction (SNCR) and SCR, were determined to represent the best options for NOx control.

Both SNCR and SCR are based on the reduction of NOx to nitrogen gas. SNCR involves the addition of urea or ammonia at high furnace temperatures, while SCR involves the addition of ammonia at lower temperatures but in the presence of a catalyst. Compared to SCR systems, SNCR systems have more limited removal capabilities and can result in ammonia slip and the formation of ammonia bisulphate. Another major concern related to employing a SNCR system at the APEFW facility was the feasibility of applying this technology to the refractory walled Consumat units since it had previously only been employed on waterwall type combustors.

A decision was eventually made to install a low dust and low temperature SCR configuration because it could be easily retrofitted to the back end of the APEFW downstream of the existing fabric filter baghouses. Low dust SCR systems require relatively clean flue gases that have to be re-heated to operate around 230 °C (446 °F). In evaluating the technology options, it was suggested that the operating costs for SNCR would be lower than for SCR. However, the SCR system had the potential advantage of dioxin and furan destruction. Thermal oxidation of PCDD/F in the presence of a catalyst produces water, carbon dioxide and hydrogen chloride. Therefore SCR was the chosen technology after the evaluation of pollution control options was complete.

SCR Design

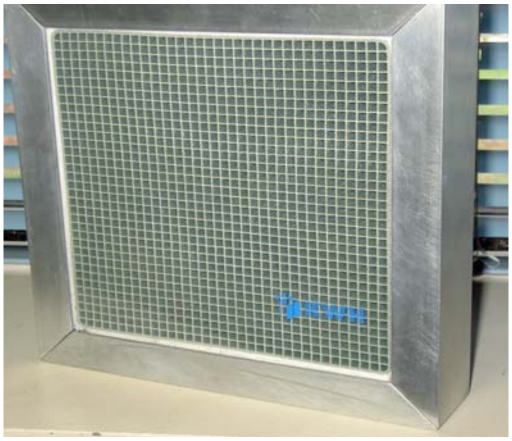
Installing a full SCR (versus an in-duct SCR) at the APEFW facility required a separate reacting chamber and additional ductwork. This ductwork allows for the mixing of air and ammonia prior to entering the reactor. Since the additional ductwork and SCR reactor added to the overall system pressure drop, an upgrade to the induced draft (ID) fans was required. This was already being contemplated as part of the addition of the fifth incinerator. The ID fans were increased from two 400 horsepower units to two 500 horsepower units.

The SCR reactor is enclosed in a fabricated steel housing measuring 5.76m x 5.76m x 9.1 m (18.9ft x 18.9ft x 29.9 ft) with a new stack built on top of the reactor measuring 35.18 m (115 ft) high. A picture of the SCR unit and stack is shown in Figure 1. Anhydrous ammonia and dilution air are injected into the inlet plenum or mixing chamber prior to the catalyst area and the flue gas temperature is increased to 230 °C (446 °F) using natural gas burners. These burners span the width of the plenum and together with profile plates, provide turbulent mixing by accelerating the flue gas over the plates. The ammonia dosing rate is controlled by the NOx and oxygen levels, which are measured in the combined gas stream before and after the SCR. The ammonia injection manifold is located downstream of the duct burners and consists of six, 2 inch diameter Inconel tubes spread across the plenum. These tubes are equally spaced horizontally in the plenum. Thorough dispersion of the ammonia into the flue gas is achieved prior to the first catalyst layer using a total of 168 nozzles, which are equally divided across each tube face. The nozzles face into the incoming flue gas stream 15 degrees above and below the centerline of each tube. A manifold arrangement equally feeds the ammonia to the six tubes. The mixed flue gas then flows through two layers of catalyst.

Figure 1: SCR Unit and Stack

The catalyst used at the APEFW facility consists of titanium dioxide elements arranged in a honeycomb pattern. An element is a ceramic honeycomb section with a defined pore structure that is 80% titanium dioxide, 4.5% vanadium pentoxide, 13% tungsten trioxide and 1.8% aluminum orthophosphate. A picture of one of the honeycomb sections is shown in Figure 2 and the full specifications for the catalyst are presented in Table 1.

Figure 2: An Element of Honeycomb Catalyst



Each of the two layers of catalyst contains 18 modules and each module contains 72 elements. Each module consists of an acid resistant steel frame that houses the individual honeycomb elements. The module is 1,907 mm x 970 mm x 1,390 mm (75 in x 38 in x 55 in) and the individual catalyst elements are 150 mm x 150 mm x 1,100 mm (5.9 in x 5.9 in x 43 in) in dimension. The module protects the elements from damage and keeps them in place. This design also allows for easy handling during cleaning or replacement. Flow straighteners are placed in front of the catalyst to equalize the temperature profile and gas distribution across the catalyst.

The temperature of the catalyst has to be maintained at a minimum of 230°C (446 °F) but below 300 °C (572 °F). If the temperature falls below 228 °C (442 °F), ammonia injection will be interrupted automatically to prevent catalyst damage from the formation of ammonia hydrogen sulphate. Ammonia addition will also cease if the temperature passes 300°C (572°F) and is not reduced within 15 minutes.

Table 1: AP Catalyst Details

Catalyst Specifications				
Catalyst Composition	80%	titanium dioxide		
	4.5%	vanadium pentoxide		
	13%	tungsten trioxide		
	1.8	aluminum orthophosphate		
Catalyst Volume	32.08	m^3	1130	ft^3
Total Number of Elements	1,296			
Number of Modules	18			
Module Dimension	970	mm length	38	Inch
	1907	mm width	75	Inch
	1390	mm height	55	Inch
Module Weight including Catalyst	1550	Kg	3,417	Pds
Arrangement of Modules	3 x 6			
Number of Layers	2			
Cross Sectional Area	29.16	m^2	314	ft^2
Elements per Module	72			
Catalyst Element Dimension	1,100	mm length	43	Inch
	150	mm width	5.9	Inch
	150	mm height	5.9	Inch
Pitch	4.3	Mm	0.17	Inch
Channel Width	3.59	Mm	0.14	Inch
Number of Channel	35 x 35			
Operating Temperature	230	degrees Celsius	446	degrees Fahrenheit
Gas Velocity	3.93	m/s	13	ft/s
Gas Velocity in Channel	5.6	m/s	18	ft/s
Total Pressure Drop	4.5	mbar, clean catalyst	0.065	Psi

Anhydrous ammonia is fed from a storage tank through a half inch line at a pressure of 6 barg (87 psig). A pressure reducing station supplies a regulated feed of 1.2 barg (17.4 psig) to the injection system. The flow is monitored by mass flow meters which also supply a signal to the control system. A control valve receives instructions from the control loop to adjust the ammonia flow rate as necessary. The ammonia injector can deliver a maximum of 25 m^3/hr (882 ft^3/hr) at a pressure of 1.2 barg (17.4 psig). Dilution air is supplied at a constant rate by two dilution air fans. One fan is in constant operation, while the second fan serves as a back up. The discharge piping for the dilution air fans is equipped with check valves to prevent “blow back” from the operating fan and the ammonia/air mixture. Lances inject ammonia and air into the mixing chamber at a rate of 70 m/s (230 ft/s).

Ammonia gas is explosive in the range of 15 to 28 percent in air. However, even at maximum ammonia, the dilution air flow and mass flow will produce a mixture below the explosive range.

Nitrogen oxides react with ammonia as the reducing agent to form nitrogen (N_2) and water vapour. Nitrogen oxides in the flue gas are primarily present as NO and react in the following manner:

$4\ NO + 4\ NH_3 + O_2 \text{ -> } 4\ N_2 + 6\ H_20$

When both NO and NO_2 are present, the following reaction occurs simultaneously:

$NO + NO_2 + 2\ NH_3 \text{ -> } 2\ N_2 + 3\ H_20$

Flue Gas Reheating

The original plan at the APEFW facility was to reheat the flue gas with the exhaust from a 5.3 MW gas turbine. Unfortunately, it was not cost effective to operate the gas turbine A decision was then made to rely on the natural gas burners originally installed as a back up system as the primary method of reheating the flue gases and to add a second layer of catalyst to lower the reheat temperature requirements from 260°C (500°F) to 230 °C (446 °F).

The reheat burner system consists of two modulating natural gas fired burners originally that are located in the SCR inlet plenum below the catalyst area, Each burner is rated at 8 million Btu/hr and includes a combustion air blower rated at 90.6 m^3/min (3,200 ft^3/min). The burners are regulated by the temperature of the gas leaving the catalyst bed. The burners use approximately 1.84 m^3 to 2.13 m^3 (65 ft^3 to 75 ft^3) of natural gas per tonne of waste processed or on average 22,653 m^3 (800,000 ft^3) of natural gas per month.

Pre and Post SCR NOx Emissions

The pre-SCR average NOx emission was 233 ppmdv at 11% O_2 (326 ppmdv at 7% O_2) while the post SCR average NOx emission was 74 ppmdv at 11% O_2 (104 ppmdv at 7% O_2). Therefore the removal efficiency is approximately 68%. During the summer smog season, the APEFW facility has been able to reduce NOx emissions to 50 ppmdv at 11% O_2 (70 ppmdv at 7% O_2) by injecting more ammonia. This increases the removal efficiency to 79%.

Table 2: NOx Emissions (ppmdv at 11% O_2)

Pre-SCR NOx						SCR NOx					
1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
244	238	235	230	224	225	97	50	50	50	95	99

Table 3: NOx Emissions (ppmdv at 7% O_2)

Pre-SCR						SCR NOx					
1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
342	333	329	322	314	315	136	70	70	70	133	139

Table 4: Average NOx Removal Efficiency

Pre SCR NOx Average	Post SCR NOx Average	Removal Efficiency%
233	74	68

Table 5: SMOG Season NOx Removal Efficiency

Pre SCR Average NOx	SMOG Season NOx	Removal Efficiency%
233	50	79

The estimated amount of NOx removed by the SCR system is 227 tons per year calculated as follows:

Table 6: Tonnes of NOx Emitted Pre-SCR

Pre SCR N0x Emissions		
Year	**Total Waste Processed (tonnes)**	**Total N0x Emitted tonnes**
1998	147,977	372
1999	141,682	356
2000	136,825	346

Table 7: Tonnes of NOx Emitted Post-SCR

Post SCR N0x Emission		
Year	**Total Waste Processed (tonnes)**	**Total N0x Emitted tonnes**
2001	155,660	167
2002	168,208	96
2003	162,537	94
2004	153,035	82
2005	141,424	160
2006	151,436	186

Table 8: Average Tonnes of NOx Emitted Post-SCR

Pre-SCR Average Tonnes N0x Emitted	Post-SCR Average Tonnes N0x Emitted	Average Tonnes N0x Removed
358	131	227

Capital and Operating Costs

The SCR system installed at the APEFW was supplied by KWH. The SCR system was quoted as a turnkey system where KWH was responsible for the design, supply and installation of the complete SCR system including a new stack. The old stack was retained for use as an emergency by-pass.

The total capital cost for installation of the SCR system was $5,606,000 in 2001 dollars. A breakdown of the capital cost is included in Table 9. The annual cost to operate and maintain the SCR system is $1,472,500 in 2007 dollars inclusive of the cost for amortization of the capital cost. A breakdown of the annual operating cost is presented in Table 10. The annual capital recovery included in Table 10 is based on an interest rate of 4 percent and an amortization period of 25 years.

Table 9: SCR Capital Costs

SCR Capital Costs (2001)	
Turnkey	$5,071,000
Ammonia system	$25,000
Catalyst conditioning	$11,000
ID Fan Upgrade	$499,000
Total	**$5,606,000**
Present Day Costs	**$6,511,000**

Table 10: SCR Annual Operating Costs

Typical Annual Operating Costs (2007)	
Natural Gas	$800,000
Repairs	$16,800
Ammonia	$64,000
Additional Power for ID Fans	$110,000
Catalyst Cleaning	$5,000
Catalyst Replacement	$60,000
Annual Capital Recovery	$416,700
Total	**$1,472,500**

On a cost per tonne of waste processed basis, the annual operating cost equates to $10.52 per tonne of waste processed. Based on an estimated 227 tonnes of NOx removed per year by the SCR system, the cost to remove each tonne of NOX equates to approximately $6,487 per tonne NOx.

Operating Issues

The APEFW facility has 6 years of experience operating the SCR system. To date, replacing the catalyst is the only major maintenance issue. The suggested replacement frequency for the catalyst according to the manufacturer is every 5 years. The APEFW is now operating beyond this and has not noticed any appreciable decrease in performance or increase in ammonia usage. NOx emissions have consistently been below the permit limit of 110 ppmdv at 11% O_2 (154 ppmdv at 7% O_2) during this period. AP needs to clean the catalyst layers every other year to remove any particulate that can accumulate in this area as a result of fabric filter bag leaks. The presence of particulate can adversely affect the performance of the catalyst and also leads to increased pressure drop and higher power consumption. Cleaning is achieved by removing the individual modules from the catalyst bed and vacuuming them. The only routine repairs needed to the SCR system are primarily related to the natural gas burners. They include the burner controls, the burner shields and the ductwork that is housed outside of the SCR unit.

Ammonia Slip

The APEFW tested the ammonia slip during peak ammonia usage to ensure that unreacted ammonia was not an issue at any time. When NOx emissions were around 50 ppmdv at 11% O_2 (70 ppmdv at 7% O_2) the ammonia slip was measured at 1.4 ppm. Therefore, ammonia slip has not been an issue for the SCR system.

Conclusion

SCR technology has proven to be a reliable alternative to the conventional SNCR technology used to date on EFW plants in North America. Although capital and operation costs for the SCR system are higher than SNCR systems, this type of system is capable of achieving higher removal efficiencies than SNCR systems. SCR systems are also more flexible to changing emission standards and based on experience at the APEFW can meet a 50 ppmdv at 11% O_2 (70 ppmdv at 7% O_2) NOx emission limit if additional ammonia is used. Unreacted ammonia leaving the SCR reactor has not been an issue with the SCR system.

Table 11: SCR Annual Capital and Operating Costs

Summary of SCR Costs at Algonquin Power	
Annual Capital and Operating Cost	$1,472,500
Cost Per Tonne of Waste Processed	$10.52
Tonnes of N0x Removed	227
Cost Per Tonne of N0x Removed	$6,487

Assumptions

- 25 year amortization period with 4% annual capital recovery
- Power consumption for the ID fans was estimated to be one-third of the total increased for expansion and the SCR pressure drop.
- Catalyst is cleaned every two years.
- From 2002 to 2006 AP used an average of 73 tonnes of ammonia per year.
- Catalyst replacement was based on every 5 years, although AP has used the current catalyst for over 6 years.
- Assumed 140,000 tonnes of waste processed annually based on limited throughput in 2007.

Acknowledgements

The authors gratefully acknowledge Frank Amaral of Algonquin Power EFW and Anthony LoRe of Camp Dresser and McKee for sharing their insight and knowledge.