

**RETROFIT OF A WTE FACILITY WITH  
SCR FOR NO<sub>x</sub> and PCDD/F CONTROL  
AND  
Na<sub>2</sub>S<sub>4</sub> INJECTION FOR MERCURY CONTROL**

**A. John Chandler**

A.J. Chandler & Associates Ltd.  
Willowdale, ON Canada

**Jim Gallant**

KMS Peel Energy  
Brampton ON Canada

**Hans-Ulrich Hartenstein**

KWH of North America  
c/o Licata Energy  
Yonkers, NY

**ABSTRACT**

The potential expansion of an existing municipal waste-to-energy [WTE] facility located in Canada prompted an evaluation of the alternatives available for upgrading the air pollution control [APC] system. The facility, which had sufficient capacity in the existing APC system to meet the anticipated flue gas flow from the increased throughput, required upgrading to meet more stringent air emission limitations than were in place during initial design. The expansion was to be combined with facility improvements including the processing of bottom ash for utilization, and the addition of a natural gas fired combustion turbine to provide additional energy to the grid.

The community that is served by the facility is growing rapidly. Its existing landfill has limited capacity and new landfills are increasingly difficult to site in the immediate area. For these reasons, the municipality had commissioned studies to determine how best to cope with the pressures of waste management over the next 20 years, and concluded that both increasing the size of the facility and finding an alternative to manage bottom ash would be beneficial. Opportunities for utilizing bottom ash had been investigated several years ago and it was determined that most users required that the material be at least partially dried before leaving the facility. Thus, it was concluded that dried and processed material offered the greatest potential for re-use. Of course, drying the ash required that a source of heat be identified. Without extra heat in the existing system, any

alternative required capital investment and increased energy expenditures, however when this requirement was combined with the opportunity to generate electrical power for sale using a gas-fired turbine/generating set a unique alternative was developed to meet all requirements.

The project team considered various ways of achieving the desired improvement in APC performance and decided that SCR control offered the best chance of meeting the new NO<sub>x</sub> emission standards. Taking advantage of the heat from the exhaust of the combustion turbine to reheat the flue gases to a SCR operating temperature of 265°C offered a lower capital cost than could be realized with heat exchanger equipped SCR systems and provided utilization of the waste heat from the turbine. The SCR application provides an additional option for the control of PCDD/PDF and allowed consideration of alternative mercury control measures. Without the need to control PCDD/PCDF with powdered activated carbon, the sodium tetrasulphide mercury control system could be employed.

This paper outlines the principle of this patented German technology as well as the design of the injection system for the common duct leading to the existing APC system. The paper will detail the process and reaction mechanisms of this European proven technology as well as describing the design and set-up of the SCR reactor.

The paper presents the process technology and basic design of the system which, to the best of the authors' knowledge,

will be the first SCR system retrofitted to a WTE facility in North America.

## INTRODUCTION

A municipal waste-to-energy (WTE) facility located in Canada has been in operation since 1992. The facility was constructed with a state-of-the-art air pollution control system designed to meet emission standards that include < 20 mg/Rm<sup>3</sup> @ 11% O<sub>2</sub> particulate emissions and 0.5 ng TEQ/Rm<sup>3</sup> @ 11% O<sub>2</sub> PCDD/PCDF. The facility has operated at an average 91% availability since start-up and consistently met the emission standards during annual and semi-annual testing.

Having demonstrated that the facility could operate and meet the existing environmental standards, the WTE facility has become an important part of the waste management process in the local municipality. Rapid increases in waste volumes brought on by population growth and the impending closing of the local landfill forced the Regional council to consider additional waste disposal options in 1997. While diversion activities were championed as one potential option, it was also recognized that both increasing the size of the facility and finding an alternative to manage bottom ash would reduce the need for landfill capacity.

The operators of the facility commissioned studies to determine how to meet their client's needs. Air emission limitations have changed since the facility was commissioned, therefore expanding the EFW facility required upgrading the APC systems. Various options for this upgrade were examined. These and the eventual preferred solution are the main subject of this paper. The facility examined bottom ash utilization opportunities and decided that processed material offered the highest potential for re-use. To that end, they developed a plan to process and dry the ash. This plan had a direct bearing on the selection of the preferred APC upgrade.

Drying the ash requires energy and with it attendant energy costs. The preferred option, tapping waste heat streams of sufficient quality, was not possible. But, using an opportunity open to it through its energy supply contract with the local power utility, the facility chose an alternative that did not involve the existing facility, or the expansion. The power supply contract allowed the installation a co-generation facility. Using the exhaust of a gas fired turbine to supply the dryer provided an opportunity to improve the heat rate of the turbine.

When it was determined that one option for the preferred APC upgrade would require additional heat to achieve its operating temperature, the co-generation system was

enlarged to meet those needs. This has resulted in the selection of an APC control option for the facility that is unique to North America.

## EXPANSION PROPOSAL AND IMPLICATIONS

During deliberations on the expansion several alternatives were considered. It was concluded that adding to the existing combustion equipment and upgrading the APC system through add-on technology offered the most cost effective means of providing additional disposal capacity at the facility.

A conventional flat tipping floor inside a pre-fabricated steel building forms the basis of the waste receipt and handling system. Waste from the floor is fed to a National Recovery Technology fuel enhancement system [NRT] that homogenizes the waste while removing glass, fines and a limited amount of metal before a series of conveyors return it to the storage area. Front end loaders are used to charge the furnaces. There are four Consumat 110 Mg/d furnaces each with dedicated heat recovery boilers. The flue gases from the 4 furnace/boiler systems are collected in a common duct leading to the APC system. The APC system consists of two parallel APC trains which include:

- a wet spray humidifier or evaporative cooling tower [ECT] where water is injected and the gases are cooled,
- a venturi reactor or dry scrubber [DS] where powdered lime is added to remove acid gases, and
- a fabric filter baghouse [FF] where the particulate matter is removed from the gas stream.

Each APC train discharges through an induced draft (ID) fan into a single flue stack.

Originally the NRT system consisted of two processing lines, however, during the first 6 years of operation it was determined that, given the effects of a local source separation initiative and changing characteristics of the waste stream, this system was over-sized for the needs of the operation. In fact, operating one line for 2 shifts daily produced sufficient material. The second line was essentially moth-balled. Since the second line was not required, it was decided that the space would be used to install a 5<sup>th</sup> identical furnace/boiler combination. This allowed the new furnace to be installed inside the existing building.

Each of the existing APC trains had been designed to accommodate the flue gases from three operating furnaces. The system was approved to operate in this mode and was tested while operating in this mode on several occasions

during the first two years of operation. No statistically significant change in emissions were found when the test data were examined <sup>1</sup> suggesting that no changes were required to incorporate the 5<sup>th</sup> furnace into the existing system. However, with more stringent emission limitations additions were required on the APC.

When the regulators rescinded a ban on WTE facilities introduced in the early 1990s they tightened air emission standards for new facilities to the equivalent to the US EPA large facility standards promulgated in 1995. Existing facilities, such as the one in question, were exempt from tighter control provided no changes were made in the facility. Expanding the capacity however triggered the need to comply with the tighter standards. The new guideline lowered allowable emissions for PCDD/PCDF, particulate matter, HCl, and SO<sub>2</sub>, and imposed new emission limitations for mercury, cadmium, lead and NO<sub>x</sub>. The present APC system meets all the new emission limitations with the exception of the ones for PCDD/PCDF, mercury and NO<sub>x</sub> while operating in the high flow mode. Thus the owners needed to find control measures that would be suitable for reducing mercury, PCDD/PCDF and NO<sub>x</sub> emissions to the newly required levels if the facility was to be expanded.

While several alternative measures were available as add-ons to the existing system to control mercury and PCDD/PCDF emissions, the biggest technical challenge was to find a reasonably priced system to reduce NO<sub>x</sub> emissions. This had to be accomplished within the constraints offered by the existing furnace configuration and the required emission limitations.

## CONTROL ALTERNATIVES FOR MERCURY

Mercury is present in the waste and removing this mercury would reduce emissions; however, such bans are unlikely to be sufficient to reduce mercury emissions to the regulatory level because much of the mercury found in MSW arises from materials such as yard and garden waste <sup>2</sup>. In fact, when yard waste bans are put into effect at incinerator facilities, noticeable reductions in mercury emissions occur <sup>3</sup>. A downward trend exists in the concentration of mercury in consumer products. The manufacturers have reformulated products such as batteries and fluorescent light bulbs to significantly reduce their mercury concentration.

The ECT/DS/FF systems operating at temperatures below 160°C are generally assumed to provide mercury removal efficiencies of up to 50 % but this is insufficient to meet the new standards. Even the apparent success of source reduction measures, reflected by a drop of about 30% in the average Hg emission levels at the facility over the last 3

years, is insufficient to achieve the desired target without additional intervention.

In Europe, wet scrubber systems have added TMT reagent to trap the mercury and remove it from the gas stream. To meet the emissions limits in its permit, the Burnaby, B.C. facility injected sodium sulphide into the APC for a period of time. This was replaced by activated carbon injection to reduce the risks to plant workers who were handling the sorbent <sup>4</sup>. Activated carbon has been used for mercury removal in facilities in many countries with the added benefit that it reduces PCDD/F emissions. Fixed activated carbon bed adsorbers, generally termed activated char reactors [ACR], have also been installed at the end of APC systems to polish the gases and remove trace organics and mercury. Their removal efficiencies for many chemicals are reported to be in excess of 99.9%. A relatively new innovation is the use of sodium tetrasulphide to remove mercury <sup>5</sup>. This approach has been used to provide a mercury sink in ACR installations where the carbon is burned in the furnace.

Wet scrubbers and fixed bed carbon filters were not considered appropriate add-ons for additional mercury control in the facility and the alternatives evaluated were PAC and Na<sub>2</sub>S<sub>4</sub> injection.

PAC is a very effective mercury sorbent and can improve removal efficiencies to the mid 90% range if sufficient material is used. PAC provides surfaces on which the mercury is adsorbed. The more surface area provided the better the process. Literature data suggests that at PAC feed rates of 0.25 kg/Mg of waste, overall mercury removal efficiencies could improve to 85%. This should be sufficient to meet the existing emission limitations <sup>6 7</sup> for mercury. Furthermore, the US EPA <sup>8</sup> suggests that current PCDD/PCDF emission levels could be reduced by a further 50% if PAC were injected at this rate. This would bring the facility into compliance with the new PCDD/PCDF emissions limitations.

Residence time of the PAC in the system is important because the adsorption reaction requires time. Thus, fabric filter systems have a distinct advantage over ESP installations because PAC is retained in the filter cake. This also improves its utilization. Site specific tests would be required to optimize the PAC injection rate and some data suggests that injection rates could be as low as one third of that assumed above.

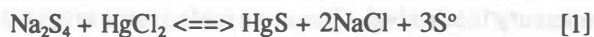
Studies have indicated that the PAC tends to preferentially remove the HgCl<sub>2</sub> present in the flue gas stream and has less effect on the elemental mercury. This has been explained as being a function of the difference in the size of

the atoms. Thus elemental mercury can still be released from systems equipped with PAC injection.

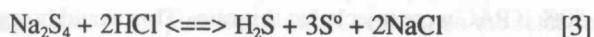
Furthermore, the characteristics of the APC residues generated when using activated carbon are a concern. It is known that carbon is a reducing agent and it can, therefore, be presumed that mercury may be released from the carbon unless the disposal process fixes the carbon and lime. In addition, Lanier<sup>9</sup> has reported, in limited tests of PAC injection at a hazardous waste incineration facility, an increase in PCDD/F's in the APC residue greater than the amount of PCDD/F removed from the gas stream. This suggests that the addition of PAC may increase the production of PCDD/F's in some APC systems. This is similar to performance noted by Sierhuis and Born when they examined test data from the new Amsterdam facility<sup>10</sup>.

Unlike activated carbon and lime which provide sites for surface adsorption to take place, the alternative reagents used for mercury removal, sodium sulphide as used in Burnaby, and sodium tetrasulphide, participate in a chemical reaction that produces sulphur compounds of mercury that are inherently stable. Of the two, only sodium tetrasulphide has an ability to affect high levels of control on elemental mercury.

The following two equations are credited with explaining the majority of the reactions that take place when Na<sub>2</sub>S<sub>4</sub> is injected into the stack gases:



however, a third reaction can also liberate sulphur to take part in the reaction of equation 2:



Injected as an aqueous solution, the droplets of the Na<sub>2</sub>S<sub>4</sub> reagent dissolve the HCl in the stack gases and create sodium chloride along with H<sub>2</sub>S and elemental sulphur. The sulphur liberated then combines with the elemental mercury to form mercury sulphide. However, not all the Na<sub>2</sub>S<sub>4</sub> is decomposed by the HCl because the effectiveness of the process is limited by competitive reactions. For instance, oxidation of Na<sub>2</sub>S<sub>4</sub>, H<sub>2</sub>S, or S into Na<sub>2</sub>SO<sub>3</sub>, SO<sub>2</sub>, SO<sub>3</sub>, or S<sub>2</sub>O<sub>3</sub> can take place and the sulphur can also combine with certain trace metals in the gas stream to form sulphides.

The difference between using sodium sulphide and sodium tetrasulphide is principally that there is more sulphur available for reactions such as those in equation 3. This ensures that the conversion of HgCl<sub>2</sub> and Hg<sup>0</sup> to HgS can

proceed. Studies have suggested that with Na<sub>2</sub>S<sub>4</sub> the elemental mercury removal efficiency is on the order of 98%. This reaction proceeds faster than the reaction with HgCl<sub>2</sub> and, since these two reactions would be expected to compete, the additional sulphur provided by the Na<sub>2</sub>S<sub>4</sub> results in much higher elemental mercury removal efficiencies and similar ionic mercury removal efficiencies to those reported for sodium sulphide.

The removal efficiency guaranteed in the supplier's quotation for using Na<sub>2</sub>S<sub>4</sub> in conjunction with the existing APC system installed is 85%. To achieve this performance level 16 kg/h of 34% Na<sub>2</sub>S<sub>4</sub> solution will need to be injected into the system. This would be sufficient to meet the emission guideline value for mercury. Should lower emission limitations be imposed, an increase in the Na<sub>2</sub>S<sub>4</sub> injection rate will bring about a corresponding decrease in the emission concentrations. As with PAC, site specific studies will need to be conducted to determine the optimum injection rate. This might vary by season when the system becomes operational.

The reaction of mercury and sulphur forms cinnabar, the red stable form of HgS. The stability of the red cinnabar is better than that of mercury containing PAC residues. Thermal decomposition does not occur below about 400°C and the chemical has an extremely low water solubility.

## CONTROL ALTERNATIVES FOR PCDD/PCDF

These organic compounds are principally controlled through good combustion practices. The facility's Consumat furnaces are similar to those tested by Environment Canada during the P.E.I. NITEP program and found to be very effective at controlling PCDD/PCDF emissions<sup>11</sup>. Regardless of the level of control afforded by the combustion process not everything is destroyed. Residual organic compounds entering the boiler can become involved in a *de novo* synthesis or gas-solid phase reaction on the surface of fly ash that creates PCDD/PCDF. To meet the stringent emission limitations imposed in most countries further steps must be taken to remove the residual amounts of PCDD/PCDF from the flue gas stream before it is released to the atmosphere.

The presence of finely divided reagent used for acid gas control provides surface adsorption potential for collecting organic and inorganic species. Removing the reagent, or its reaction products, from the gas stream results in reducing PCDD/PCDF concentrations in the cleaned gas stream. The facility currently meets its permit conditions with PCDD/PCDF emission concentrations less than 0.5 ng TEQ/Rm<sup>3</sup> at 11% O<sub>2</sub> however, it does not consistently meet the new emission limitation value of 0.14 ng TEQ/Rm<sup>3</sup> at



11% O<sub>2</sub>. To ensure the latter limitation can be met on a consistent basis additional removal is required.

There are several options for providing the additional PCDD/PCDF removal required:

- inject PAC as discussed in the mercury section above;
- employ an activated char reactor such as discussed previously; or
- utilize catalytic destruction of residual organics in the clean gas stream.

The performance potential for the PAC injection and ACR systems was discussed above, as were their limitations. A brief discussion of applying catalytic destruction follows.

PCDD/PCDF are organic compounds that can be destroyed by oxidation, producing CO<sub>2</sub> and water vapour, however trace amounts of HCl are also generated. Normally such oxidation takes place at high temperatures to take advantage of faster reaction times. Of course, raising the gas temperature requires the expenditure of energy making this approach impractical for large MWC installations. To overcome this limitation, catalysts such as platinum and oxides of vanadium and titanium which promote thermal oxidation at low temperatures can be employed. Such catalysts have been used to reduce the emissions of oxides of nitrogen at various MSW incinerator facilities. This process has been noted to reduce the concentration of PCDD/PCDF in the stack gases.

There are some limitations to using catalysts including:

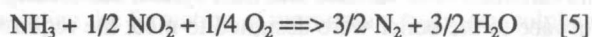
- sintering where the microsurface disappears as the catalyst's pores collapse due to elevated temperature reformation of titanium;
- poisoning when a molecule or atom of an alkali metal permanently attaches to an active catalyst site;
- plugging by capillary condensation or dust blockage; or,
- erosion due to HCl attack.

For these reasons catalytic systems are best employed with a relatively clean flue gas stream, i.e. as the last step in APC control systems. The operating temperature for such catalysts is normally an optimized one based upon the cost of the catalyst and the temperature available. The higher the activity rate of the catalyst, or the more catalyst available for the reaction, the lower the operating temperature. When used in conjunction with NO<sub>x</sub> control, limitations on the operating temperature are normally imposed by the level of sulphur in the gas stream as discussed in the next section. Catalytic oxidation systems work best at temperatures in excess of 225°C.

Catalysts are not inexpensive and their life is not infinite, however, the simplicity of the operating system is such that only limited maintenance is required. Catalytic reduction of organics is most practical when it can be combined with NO<sub>x</sub> reduction because of the high cost of constructing and operating such equipment. However, catalytic reduction of PCDD/PCDF ensures that the materials are destroyed, not just transferred to another media such a PAC which ultimately must be disposed.

## EMISSION CONTROL ALTERNATIVES OF NO<sub>x</sub>

While reburning and wet chemical techniques can be used to reduce NO<sub>x</sub> emissions, the only control options that were seriously considered for this application were selective catalytic reduction (SCR), and selective non-catalytic reduction (SNCR). Both control systems rely on the use of ammonia or a similar chemical (urea) to supply the nitrogen needed for the following reactions:



Generally SNCR processes utilize NH<sub>3</sub>, injected with a carrier gas, either air or steam, at a point specifically selected to provide optimum reaction temperature and residence time. The injection is accomplished with specially designed nozzles strategically placed in the walls of the furnace to achieve adequate mixing<sup>12</sup>.

The SNCR process relies on the fact that the reaction of NO<sub>x</sub> and NH<sub>3</sub> that results in the conversion of NO<sub>x</sub> to N<sub>2</sub> occurs quickly and with high efficiency if conditions are appropriate. At CO levels less than 20 ppm, the optimal temperature for the reaction is 982°C and the temperature range between 90+% removal and no removal is 42°C in either direction. Unfortunately, under some circumstances at higher temperatures the ammonia can be oxidized to actually create more NO<sub>x</sub> than was originally present in the flue gas. If the CO level increases in the flue gas, the optimal removal temperature decreases and the whole range moves with it causing a decrease in efficiency. Since the process is a chemical reaction that utilizes the NH<sub>3</sub> added to the gas stream some of the inefficiencies can be overcome by adding excess NH<sub>3</sub>. Typically ammonia addition stoichiometry ranges from 1.1 to over 2.0 depending upon the application. At the higher addition rates considerable ammonia is wasted. Some of this material is discharged as ammonia with the stack gases, the balance combines with the fly ash.

While SNCR techniques were generally considered less costly and acceptable given the desired removal efficiencies

in the early 1990s, as the millennium approaches they are falling out of favour. They have limited removal capabilities given a desire to minimize the potential for excess emissions of  $\text{NH}_3$  and can create numerous operating problems such as ammonia slip, visible plumes and odours from residues removed from the boiler. In addition, ammonia in the gas stream generates ammonia sulphate which can block the boiler's flue gas passages. In areas where the soot blowers are ineffective this can create major operational problems.

SNCR application is also very furnace specific. For instance, the ammonia added to the furnace must be distributed uniformly throughout the gas stream and, given the narrow temperature window for optimized performance, the temperature must be at the correct level. The use of aqueous solutions of ammonia type reagents further complicates the application because the water in the mixture must be evaporated before the reaction can go to completion. This was a significant consideration for the existing systems. The residence time requirements of the SNCR system did not match well with the permitted operating conditions for the furnaces. The furnace and duct system connecting the furnace to the boiler were designed to meet the required 1 second after the last air injection port residence time at  $1000^\circ\text{C}$ . Time requirements quoted by suppliers suggested that either modifications might have to be made to the furnace configuration or the performance might be compromised. Such restrictions, coupled with low removal guarantees (56%) and high operating costs, suggested that the untried application of SNCR to the Consumat furnaces at the facility might be problematic.

Selective catalytic reduction systems reduce  $\text{NO}_x$  emissions by injecting ammonia ( $\text{NH}_3$ ) into the exhaust gas stream upstream of a catalyst. The exhaust gas must contain a minimum amount of  $\text{O}_2$  and be within a particular temperature range (typically  $260$  to  $320^\circ\text{C}$  on MWC facilities) in order for the SCR system to operate properly. The limitations of catalysts mentioned in the previous section: sintering; poisoning; plugging; and, erosion; are also considerations for SCR  $\text{NO}_x$  control systems.

The operating temperature range is a site specific consideration dictated by the volume and type of catalyst used and the quality of the gas being treated as will be discussed in the specific facility details section. If the exhaust gas is at temperatures greater than the upper limit, the  $\text{NO}_x$  and unreacted ammonia will pass through the catalyst without reacting and the catalysts can be damaged.

Two components are required to apply SCR: an ammonia delivery system and the catalyst bed. Ammonia, either in the form of liquid anhydrous ammonia or aqueous ammonia hydroxide, is injected into the gas stream upstream of the

catalyst. The catalyst volume and catalyst housing tend to be very large to provide very high surface area to volume ratio for the high exhaust flow rates and long residence times required for the reactions. Most catalysts are configured in a parallel-plate or "honeycomb" design to maximize the surface area-to-volume ratio.

For optimal efficiency, both in terms of the performance of the system and its cost, the SCR should be operated at temperatures in the range of  $300^\circ\text{C}$ . Even with heat exchangers to transfer the heat in the exhaust gas to the gas going to the SCR, energy still needs to be added to the incoming gas stream. This is usually done by adding gas fired heaters to the system. These systems perform very well with quoted efficiencies as high as 90%.

Recent advances in SCR technology have responded to the energy needs of the SCR system by developing low temperature SCR systems that operate below  $250^\circ\text{C}$ . These offer performance levels up to 75% to 95% removal and have been successfully employed in MWC facilities achieving outlet concentrations of 15 to 50 ppmdv ( $28 - 94 \text{ mg/Rm}^3$ ) @ 11%  $\text{O}_2$ <sup>13</sup>. Unfortunately, the low temperature systems are more susceptible to contaminants and reaction products in the gas stream and good gas quality must be maintained. Such systems were not considered appropriate for the facility in question given the sulphur levels in the stack gases.

One major advantage of SCR systems is vastly reduced  $\text{NH}_3$  usage. Unlike the SNCR systems where ammonia slip can be appreciable when attempting to achieve high removal efficiencies, SCR systems can be operated at stoichiometric  $\text{NH}_3$  addition levels very close to 1 while maintaining high removal levels.

As discussed earlier, SCR systems have also been used to destroy organics by catalytic oxidation. Such systems combine both the  $\text{NO}_x$  reduction capabilities with the ability to destroy organics and are designed to operate from  $260$  to  $320^\circ\text{C}$ . This implies that auxiliary heat is required and this is the major impediment to the system's application in many MSW incinerator applications.

Typical APC systems, such as the one installed at the facility, are designed to operate in the range of  $150$  to  $170^\circ\text{C}$ . With the SCR having to be operated at elevated temperature to ensure limited operating problems with sulphur products, it was estimated that over 6 MW of heat would need to be added to the flue gas stream. Existing applications have employed a massive regenerative heat exchanger coupled with a natural gas burner or steam reheat to achieve the desired operating temperature. Initial cost estimates for such a system were rejected as being too

high largely because of the cost of the heat exchanger. While the desired temperature could have been achieved using a natural gas burner the operating cost was significant. Thus it was that it was decided to integrate the co-generation combustion turbine that was to supply the heat for the ash dryer with the SCR system.

## PROJECT CONFIGURATION

The SCR configuration provided proven technology for the removal of  $\text{NO}_x$  in a low maintenance package that minimized reagent usage while attaining high levels of performance. With the decision to incorporate SCR into the APC system, it became obvious that the preferred PCDD/PCDF reduction strategy was thermal oxidation because it destroyed the organic compounds. Without the need for PAC to control PCDD/PCDF,  $\text{Na}_2\text{S}_4$  became the method of choice for mercury control.

Selection of the desired sodium tetrasulphide injection location was simple. The hot gas duct connecting the furnaces to the APC system provided a single location where the combined gases could be treated. Sufficient duct length was available to allow proper mixing and ports originally incorporated in that duct to permit inlet/outlet sampling across the APC provided an ideal location for the  $\text{Na}_2\text{S}_4$  injection lance. Temperatures in this duct are high enough to ensure that the solution can be properly distributed into the flue gas stream and still have sufficient time for the reaction to continue before the reaction products are collected on the fabric filter.

In developing the SCR system configuration, a number of issues were considered. Gas flow from the furnaces and the existing APC was a given and its characteristics defined the minimum SCR operating temperature. The power supply agreement the facility had obtained in 1990 allowed it to sell up to an additional 6 MWe to the grid at prices based upon the heat rate of the chosen system. This effectively capped the turbine capacity and thus the amount of heat that was available from the turbine exhaust. With these two limitations, an optimized configuration for the catalyst based upon temperature and desired performance could be developed.

As noted earlier, the high operating temperatures of SCR systems is a disadvantage. It is necessary to maximize conversion efficiency for a given volume of catalyst and thus there are trade-off between temperature and catalyst volume for a given performance level. As an alternative, the reactivity of the catalyst can be increased. In systems equipped with regenerative heat exchangers, the increase in catalyst volumes and reactor costs is partially compensated for by a decrease in the size of the heat exchanger surface

area. The pressure drop across the catalyst and the heat exchanger are similar so net changes in pressure drop and thus operating costs are minimal. A third factor governing cost is the expected lifetime of the catalyst. This depends upon the purity of the flue gas entering the catalyst and the operating temperature.

The flue gas purity at the facility was governed by the performance of the existing APC system as the intent was to add the SCR after the baghouse. While concentrations of trace metals such as arsenic and alkaline elements such as potassium and sodium were well within the desired levels, sulphur in the flue gas was a concern. Emissions data indicated that  $\text{SO}_2$  and  $\text{SO}_3$  levels could be 44 and 0.55  $\text{mg/Rm}^3$  @ 11%  $\text{O}_2$  respectively.

The catalyst can be poisoned by the deposition of ammonium salts such as ammonium chloride and ammonium sulphate. These salts are formed when residual  $\text{HCl}$  and  $\text{SO}_3$  combine with the ammonia injected into the system. Moreover, partial oxidation of  $\text{SO}_2$  to  $\text{SO}_3$  leads to the formation of additional  $(\text{NH}_4)_2\text{SO}_4$ . Most critical is to minimize the formation of ammonium hydrogen sulphate  $[\text{NH}_4\text{HSO}_4]$  which condenses and deposits on surfaces at temperatures below  $240^\circ\text{C}$ . The exact temperature for any application depends upon the relationship between ammonia and sulphate in the system. While the deposition is reversible at high temperatures by evaporating the salts, such a process is expensive and time consuming and should be avoided. Given the available sulphur data, caution dictated that the operating temperature for the system should be greater than  $260^\circ\text{C}$ .

The dry volumetric flow rate of flue gas from the existing APC was assumed to be  $116,524 \text{ Nm}^3/\text{h}$  at a temperature of  $165^\circ\text{C}$ . Given the desired operating temperature and the temperature of the turbine exhaust,  $490^\circ\text{C}$ , a 5.3 MWe turbine/generator set was selected. This adds  $57,836 \text{ Nm}^3/\text{h}$  of gas to the combined flow entering the SCR and will raise the operating temperature to  $265^\circ\text{C}$ .

The resulting SCR reactor configuration will be:

- width x depth 5.76 x 5.76 m / 18.9 x 18.9 ft.
- height 6.7 m / 22 ft.
- material Carbon Steel
- flow direction vertical

The reactor will house the catalyst:

- Elements per module 6 x 12 = 72
- Number of modules/level 3 x 6 = 18
- Number of levels 1 double layer
- Module size 1885x940x1330mm

A total of 32 m<sup>3</sup> of catalyst will be installed in the system initially, with provision to add a second layer of the same size. Performance specifications for the system limit the ammonia slip to less than 14 ppm<sub>v</sub>. Should the ammonia slip increase while the NO<sub>x</sub> outlet concentration remains the same it would indicate that the effectiveness of the catalyst has been diminished. To overcome this, the second layer of catalyst can be introduced into the reactor on top of the first layer. The added catalyst should restore performance levels and allow the life of the lowest layer of catalyst to be extended to the maximum.

Physically the existing APC is arranged with the stack west of the fabric filter housing and between the two ID fans. The motors for the ID fans are west of the fans and form a physical boundary to close coupling the SCR to the ID fan outlets. Because the turbine exhaust will be mixed with the flue gas from the furnaces, the volumetric flow rate will be too large to accommodate in the existing stack and a new stack had to be added. This will be mounted on top of the SCR. The SCR center line will be located approximately 12 m west of the existing stack. It will be elevated above an existing access road used by ash trucks leaving the site. The location of the turbine and ash dryer are on the other side of the road so the SCR conveniently acts as the connection between the two systems and limits the need to carry ductwork across the road. The top of the SCR has an additional opening to allow 40,400 Nm<sup>3</sup>/h of 260°C gas to be split off to feed the ash drying system.

## ANTICIPATED PERFORMANCE

An important criteria to the selection of the add-on APC equipment was the anticipated performance, not just in terms of removal efficiencies, but also the potential to meet anticipated changes in legislation. Canada, through the Canadian Council of Ministers of the Environment, a joint federal provincial body, has recently initiated a process for developing Canada Wide Standards for various chemicals. Canada-Wide Standards [CWS] can include qualitative or quantitative standards, guidelines, objectives, and criteria for protecting the environment and reducing the risk to human health.

CWS will include a numeric limit (for example, ambient, discharge or product standard), a commitment and timetable for attainment, a list of preliminary actions to attain the standard, and a framework for reporting to the public. The initial short list of chemicals being addressed by this process includes mercury, benzene, PCDD/PCDF, petroleum hydrocarbons, and particulate matter and ground level ozone

as related to smog<sup>14</sup>. The latter category will also include NO<sub>x</sub> as it is generally considered a contributor to such problems. Thus, the CWS initiative has the potential to ratchet emission standards to a lower level than was contemplated during the initial evaluation stages of this project.

Within the context of the CWS proposals are currently circulating to lower mercury emission limits for MWC sources to concentrations in the range of 20 ug/Rm<sup>3</sup> @ 11% O<sub>2</sub>. This would be less than half the current limit. While the existing limit for PCDD/PCDF is 0.14 ng/Rm<sup>3</sup> @ 11% O<sub>2</sub>, this could be reduced by an additional 30% to compare to European levels (0.1 ng/Rm<sup>3</sup> @ 11% O<sub>2</sub>). NO<sub>x</sub> limits may be lowered as well. These measures have some impact on the costs of the project.

A comparison of existing performance, interim guideline levels and potential CWS emission limitation criteria are shown in Table 1. The existing performance was defined by the upper confidence level of the test data collected over the 6 years of operation however a design basis for the system was selected as well. The design basis was the highest average values of the test data collected in any test period. The 1996 standard represents the latest emission limitations for MWC that are applied in the jurisdiction. The NO<sub>x</sub> performance guarantee from the supplier includes the allowance for the dilution effect of the turbine exhaust being mixed with the furnace flue gases. It is assumed that the turbine exhaust has 150 ppm<sub>v</sub> NO<sub>x</sub> @ 15% O<sub>2</sub> and its emissions must meet a 25 ppm<sub>v</sub> @ 15% O<sub>2</sub> emission limit, whereas the furnace must meet the limit shown in the table. The emission limit for PCDD/F at the stack, assuming no addition from the turbine, should show the influence of the dilution, about 35%, so it should be on the order of 0.09 ng ITEQ/Rm<sup>3</sup> @ 11% O<sub>2</sub>. Similarly, the mercury number, again assuming no contribution from the turbine, should be 37 ug/Rm<sup>3</sup> @ 11% O<sub>2</sub>. The anticipated emission limits that might result from the CWS process are in the last column.

To meet the guaranteed performance based upon the average input values, reagent consumption is estimated at 16 kg/h of 34% Na<sub>2</sub>S<sub>4</sub> and 18.5 kg/h of NH<sub>3</sub> at 100%. It is estimated that to meet the lower mercury emission limitation the injection rate for Na<sub>2</sub>S<sub>4</sub> will need to be increased to approximately 25 kg/h.

## CURRENT PROJECT STATUS

After much discussion and evaluation the project was deemed to be viable. It addresses the need to meet the current emission limitations imposed in the jurisdiction while providing the owner with a performance margin that



should allow the facility to meet the emission limits that might result from the CWS process. Furthermore, since the NO<sub>x</sub> and PCDD/PCDF control efficiency can be increased by either adding the second layer of catalyst, or in the case of NO<sub>x</sub> increasing the reagent flow and adding more catalyst, the facility should be able to meet, at a reasonable additional cost a more stringent NO<sub>x</sub> standard.

Based upon these factors a contract for the supply and installation of both the Na<sub>2</sub>S<sub>4</sub> injection system and the NO<sub>x</sub>/DeDiox SCR system has been awarded. The co-generation turbine that will supply the heat to the system is currently on order with start-up of that system scheduled for late 1999. It is anticipated that the SCR system will be hot commissioned in the middle of 2000. Testing of the completely operational system on the expanded facility will likely be in the fall of 2000.

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Table 1 Performance Data for Facility

Chemical	Units *	Performance Criteria					
		UCL of Test Data	Maximum Design Value	Average Design Value	1996 Standard	Average Guaranteed** with Dilution	CWS Potential
HCl	mg/Rm <sup>3</sup>	17.7			27		
SO <sub>2</sub>	mg/Rm <sup>3</sup>	37.3			56		
NO <sub>x</sub>	mg/Rm <sup>3</sup>	464	563	451	206	160	
PCDD/PCDF	ng ITEQ/Rm <sup>3</sup>	0.3	2.7	0.9	0.14	<0.09	<0.1
Cadmium (Cd)	ug/Rm <sup>3</sup>	4.1			14		
Lead (Pb)	ug/Rm <sup>3</sup>	11.6			142		
Mercury (Hg)	ug/Rm <sup>3</sup>	290	366	160	57	33	<30
Particulate Matter	mg/Rm <sup>3</sup>	5.6			17		

Note: \* all concentrations corrected to 25°C, 101.3 kPa, and 11% O<sub>2</sub>  
 \*\* includes allowance for turbine exhaust diluting the gas stream.