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**AN ENGINEERING AND ECONOMIC EVALUATION OF
THE METHANE de-NOXSM TECHNOLOGY**

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AN ENGINEERING AND ECONOMIC EVALUATION OF THE METHANE de-NOXSM TECHNOLOGY

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ABSTRACT

The Institute of Gas Technology (IGT) and Ogden Martin Systems, Inc. (OMS) are conducting a joint engineering and economic evaluation of IGT's METHANE de-NOXSM technology for its application to new, as well as retrofit, municipal waste combustors (MWCs). It is anticipated that this new technology offers a technically and economically attractive alternative to existing selective noncatalytic reduction (SNCR) systems for new facilities, as well as in retrofit applications. Consequently, IGT and OMS are considering pursuing a long-term demonstration of this technology on an OMS MWC.

The METHANE de-NOX approach was developed based on extensive full-scale MWC in-furnace characterization and pilot-scale testing using simulated combustion products. The approach involves injection of natural gas, together with recirculated flue gases (for mixing), above the grate to provide oxygen-deficient combustion conditions that promote the destruction of NO_x precursors, as well as NO_x. Extensive pilot-scale testing, using both simulated combustion products and actual municipal waste (MW), showed that significant NO_x reduction could be achieved. The results were used to define the key operating parameters for a field evaluation of the process.

A full-scale METHANE de-NOX system was designed and retrofitted to a 100-ton/day Riley/Takuma mass burn system at the Olmsted County Waste-to-Energy facility for this field evaluation. The results of the field evaluation tests demonstrated the reduction of up to 60% in NO_x emissions and up to 50% in CO emissions. Further benefits included a reduction of up to 50% in excess air requirements and boiler efficiency improvements.

This paper describes the METHANE de-NOX technology and discusses the results to date of the IGT/OMS engineering and economic study. The focus is on the discussion of the benefits and drawbacks of this new technology in comparison with existing SNCR systems, which is the only other commercially demonstrated NO_x control technology for municipal waste combustors in the United States.

INTRODUCTION

The United States generates over 180 million tons of municipal solid waste (MSW) each year, of which the majority is landfilled. About 29 million tons of MSW is, however, incinerated,¹ primarily in waste-to-energy facilities. Because of the increasing restrictions being placed on landfilling, the amount of MSW incinerated is expected to grow. By the year 2000, 24% of the MSW generated in the United States, representing over 40 million tons/year of MSW, and 4×10^{14} Btu's of energy, could be incinerated in Municipal Waste Combustors (MWCs). There are two major types of MWCs: mass burn and refuse derived fuel (RDF) – differing primarily in the extent of waste preparation. The majority of the MWCs in the United States currently in use or in the planning stages are of the mass burn type.

Over the last 2 decades, significant advances have been made to make municipal waste combustion a cleaner and more controllable, as well as acceptable, alternative. However, waste-to-energy facilities, in many cases, still face stiff opposition, primarily because of concerns for the air pollutant emissions. Other problems facing the waste-to-energy industry include high-temperature corrosion of the boiler tubes and the superheaters,² slagging, and fouling.

To address the air emission concerns, the U.S. Environmental Protection Agency (U.S. EPA) has been developing new air pollution rules that apply to all new and existing MWCs. These rules require MWCs to comply with emission limits for acid gases (HCl and SO₂), trace metals (measured

as total particulates, Hg, Cd, and Pb), organics (measured as CO, PCDD, and PCDF), and NO_x. Table I summarizes the New Source Performance Standards for MWCs that were issued by the U.S. EPA in February 1991. These may be further revised in 1993. Also, local regulations (California, New Jersey, etc.) that are being placed on the MWCs, in many cases, require significantly greater emission controls than those mandated by the Federal regulations. Strict emission controls are also being applied to MWCs in Europe³ and Japan.

Table I. New source performance standards
(MWCs over 250 tons/day).

	New Units	Existing Unit ^c
NO _x , vppm at 7% O ₂	180	None
HCl ^a Removal, %	95	50
SO ₂ ^b Removal, %	80	50
CO, vppm at 7% O ₂	100	100
THC	None	None
Dioxins/Furans, ng/dscm	30	125

a Or 25 vppm at 7% O₂.

b Or 30 vppm at 7% O₂.

c Up to 1100 tons/day.

Technologies are commercially available, both in the United States and abroad, to control many of the air pollutant emissions — electrostatic precipitators or baghouses for particulates; selective noncatalytic reduction (SNCR) and selective catalytic reduction (SCR) for NO_x; and dry injection of lime slurry (dry scrubber), as well as wet scrubber for acid gases. These technologies are not, however, free from drawbacks.

IGT, together with industrial partners, is actively pursuing the development of alternate pollution control technologies for MWCs that are lower in cost and/or have fewer drawbacks. The initial focus has been on reducing NO_x emissions because of the deficiencies in the current technologies.

As discussed, the SNCR and SCR technologies for reducing NO_x emissions from MWCs, as well as other sources, have been commercially available for many years.^{4,5} SNCR generally involves the injection of reducing agents, such as NH₃ or urea, into the flue gases at temperatures of 1600° to 1900°F for about 50% NO_x reduction, while SCR generally involves injection of NH₃ at temperatures of 500° to 800°F in the presence of a catalyst for even greater NO_x reductions. Both techniques, however, have several drawbacks.

- SNCR (using anhydrous ammonia): High capital and operating costs, ammonia slip, ammonium chloride plume, requirement to store and handle pressurized toxic gas, increased particulate emissions, and potential for increased N₂O emissions.
- SNCR (using urea): High capital and operating costs, ammonia slip, ammonium chloride plume, and potential for increased CO and N₂O emissions.
- SCR: Very high initial and operating costs, ammonia slip, flue gas reheating requirement, catalyst pluggage, spent catalyst disposal requirements, and potential for increased N₂O emissions.

IGT believes that a technology based on natural gas could overcome many of the drawbacks, while also offering certain benefits. Figure 1 illustrates the concept selected for MWCs. Termed METHANE de-NOX, this technology involves the injection of natural gas, together with recirculated flue gases (for mixing), above the grate to provide oxygen deficient combustion conditions that promote the destruction of NO_x precursors, as well as NO_x. Overfire air (OFA) is then injected at a higher elevation in the furnace, after sufficient residence time at these oxygen deficient conditions, to burn out the combustibles.

IGT, together with Riley Stoker Corporation (Riley) and Takuma Company Ltd. (Takuma), has successfully field evaluated the METHANE de-NOX technology on a 100-ton/day MWC. The results show simultaneous reductions of 60% in nitrogen oxides and 50% in carbon dioxide with natural gas injection equal to 15% of total waste heat input. Excess air requirements were also

Figure 1. The METHANE de-NOX process.

reduced by 50% thus increasing the overall waste-to-energy plant efficiency. The next step toward commercialization of this technology is a long-term performance test to ensure sustained operability without any adverse effects on the boiler performance – increased slagging, fouling, corrosion, etc.

IGT and Ogden Martin Systems (OMS) have teamed to pursue this demonstration at an OMS site provided a joint study confirms its engineering and economic feasibility. The remainder of this paper describes the current development status and the results to date of the engineering and economic study.

METHANE de-NOX DEVELOPMENT

To assess and develop the concept, a program was undertaken by the team of IGT, Riley, and Takuma with funding support from GRI and several gas utilities. The development steps were 1) characterization of the in-furnace conditions of a commercial MWC to define the variability of operation, the gas temperatures within the furnace, and the distribution patterns for oxygen, CO, NO_x, and other combustion product species; 2) evaluation of the gas-phase chemistry in laboratory furnace simulation experiments (1.7×10^6 Btu/h) to define the regions of operation in which METHANE de-NOX could be effective; 3) design and construction of a pilot combustor (2.5×10^6 Btu/h) firing actual MSW, in which the METHANE de-NOX process could be developed and tested; and 4) a full-scale evaluation of the process on a commercial MWC.

The baseline data were acquired on one of the two units at the Olmsted County Waste-to-Energy (W-T-E) Facility located in Rochester, Minnesota. Each unit is designed to burn MSW at the rate of 100 tons/day, producing about 24,000 lb/h of 615-psig superheated steam. Test details and results have been presented earlier from the commercial combustor characterization, as well as the pilot-scale efforts.⁶⁻⁸ Briefly, the baseline data confirmed the possibility for creating the desired NO_x reducing conditions within the furnace. The results of pilot-scale assessments showed that 10% to 15% (percent of total heat input) natural gas, reduced NO_x emissions by as much as 70%, depending on the natural gas and OFA injection points and the residence time in the reducing zone.

In light of the favorable test results obtained from both the IGT and Riley pilot-scale investigations, a field evaluation was undertaken at the Olmsted W-T-E facility. The retrofit METHANE de-NOX system was designed based on the pilot-scale results.⁹ It included installation of a flue gas recirculation (FGR) system and modification of the furnace walls to accommodate nozzles and sampling/observation ports at multiple levels. The design also provides for acquisition of the necessary in-furnace gas composition and temperature data, as well as other relevant data. Recirculated flue gas, taken from the economizer outlet, was used to introduce natural gas above the

grates. OFA injectors are installed in two locations in the upper half of the furnace for combustible burnout. The two elevations enabled testing of different residence times for the reducing zone. Residence time has a significant effect on NO_x reduction and combustible burnout. Inserts were employed during the testing to evaluate different injection velocities for the OFA, natural gas, and FGR. The system was instrumented to provide an extensive data base for the impacts of METHANE de-NOX on both the furnace side, as well as the steam side parameters. Due to space and time constraints, the results here will focus on NO_x and CO emissions measured at the ESP inlet and their relationships with some of the significant operating parameters.

Table II summarizes the average values of selected operating data, as well as CO and NO_x emissions from the field evaluation tests. Data are also presented from the 1987 baseline tests and for one test with METHANE de-NOX that was carried out at a higher steam flow rate to maintain the MSW rate at the current normal baseline value of 7000 lb/h. It must be noted that the steam flow during the 1991 baseline test was about 28,400 lb/h or 6% higher than the current normal baseline steam flow of 26,700 lb/h, and 20% higher than the 1987 baseline level of 23,500 lb/h. During most of the tests with natural gas injection, the steam flow rate was maintained between 28,100 and 29,000 lb/h or 9% higher than the current normal baseline level (as there was no need for the additional steam), which automatically decreased the MSW feed rate to the 1987 baseline value. As shown, however, one test was carried out with the MSW rate maintained very close to the current normal baseline level by increasing the steam flow by about 14%. This was to prove that METHANE de-NOX retrofits do not necessarily require a decrease in MSW feed rate. Table II shows that 13% to 15% (total heat input) natural gas injection allowed a reduction in excess air from over 100% (10.5% excess O₂) to about 50% (6.5% excess O₂), which as discussed later, allows a higher firing rate and increases the boiler thermal efficiency. The data presented in the table also show that compared to the 1991 baseline test, METHANE de-NOX decreased the NO_x emissions by about 60% and CO emissions by about 50%. The NO_x emissions were decreased by 20% with FGR alone, however, the CO emissions were more than double compared with the average CO with METHANE de-NOX.

Figure 2 illustrates the relationship between NO_x and CO emissions for the Olmsted combustor that was found in 1987 for the baseline operation. The data represents operation at different air flow distributions and excess air levels. The 1991 baseline data appear to follow the 1987 baseline trend. The data with natural gas injection in the non-optimum configurations show considerable scatter, but in general, some show NO_x and CO reduction. On the other hand, the data with the optimum METHANE de-NOX configuration and with 12.5% or higher natural gas injection, illustrated by solid triangles, distinctly show a significant reduction in both NO_x and CO emission levels. The average baseline NO_x at 50 vppm CO was about 215 vppm, while the average NO_x with METHANE de-NOX was about 80 vppm at an average CO level of 35 vppm. Figure 3 illustrates that decreasing the oxygen concentrations in the secondary zone decreased NO_x emissions. The figure shows that

Table II. Average operating data – field evaluation tests.

	Baseline		FGR Only	FGR plus NGas	
	1987 Test	1991 Test		at Normal 1987 Baseline MSW Input (Avg. Data)	at Normal 1991 Baseline MSW Input Test
MSW, * lb/h	6,500	7,900	7,400	6,600	7,000
Natural Gas, %	0	0	0	14.8	12.9
Total Heat Input, * 10 ⁶ Btu/h	33.4	40.9	38.6	40.2	42.6
FGR, %	0	0	7.9	8.7	10.6
Total Fuel Gas, lb/h	46,000	59,000	46,000	48,000	45,000
Steam Flow, lb/h	23,500	28,400	27,300	28,600	30,600
Economizer Exit Temp, °F	417	424	430	423	423
Precipitator Inlet					
O ₂ , %	9.3	10.5	8.9	6.5	5.9
CO, vppm, at 7% O ₂	47	72	100	35	33
NO _x , vppm, at 7% O ₂	210	185	150	75	75

* Estimated.

Figure 2. Natural gas injection simultaneously decreases NO_x and CO emissions.

Figure 3. Effect of reduced oxygen concentration on NO_x formation.

proper injection of natural gas can significantly reduce NO_x without requiring highly fuel-rich conditions in the oxygen deficient zone.

In summary, proper injection of 12% to 15% (heat input basis) natural gas simultaneously decreased the NO_x emissions by 50% to 60% and CO emissions by 40% to 50% compared to the 1991 baseline test values. It also allowed a reduction in excess air by 50% and increased the boiler thermal efficiency by 2.5%. Furthermore, because of the reduced excess air requirement, it was possible to maintain the MSW feed rate at the baseline level by increasing the steam output to accommodate the additional heat input with natural gas.

METHANE de-NOX ECONOMIC EVALUATION

Based on the excellent results obtained during the field evaluation tests, IGT decided to pursue further development and commercialization of the METHANE de-NOX technology as an alternative to SNCR. Toward this end, IGT and Ogden Martin Systems (OMS) have teamed together to conduct a joint engineering and economic evaluation of METHANE de-NOX for OMS's Waste-to-Energy Facilities. If the results warrant, IGT and OMS will retrofit an OMS MWC for a long-term performance test. This will prove the sustained operability of the technology and identify any adverse effects on the boiler performance, such as increased slagging, fouling, or corrosion of the water tubes.

The MWC selected for this evaluation is one of two 264-ton/day units at an existing resource recovery facility. The units operate at about 80% of the rated capacity, which permits METHANE de-NOX retrofit without exceeding the system heat release capacity. The unit will also be tested with METHANE de-NOX at the design MSW feed rate to determine whether the system can handle the additional load.

Both MWC's at this facility utilize water wall furnaces equipped with Martin reverse-reciprocating grates and an ash handling system. Each unit can burn municipal, residential, and commercial solid waste to produce 64,000 lb/h of 865-psig/830°F superheated steam. The units are equipped with semi-dry flue gas scrubbers and fabric filter baghouses. The facility generates up to 14.5 MWth of electricity, which is sold to the local utility. OMS owns and operates the facility.

Retrofit Description

The retrofit system has been designed to allow operation at the rated MSW throughput. It incorporates flexibility in 1) changing the injection velocities of natural gas, FGR, and OFA, and 2) distributing natural gas and FGR. It also incorporates additional ports and instrumentation for test data acquisition. The METHANE de-NOX retrofit consists of the following major components:

- A natural gas supply and injection system to inject up to 750 lb/h of natural gas through the existing OFA injectors above the grate in the front or rear wall of the furnace (in any proportion) to create oxygen deficient conditions that promote destruction of NO_x precursors and NO_x .
- A flue gas recirculation system to withdraw up to 15,000 lb/h of flue gases from downstream of the ID fan using an FGR fan and inject these through the existing OFA injectors above the grate in the front or rear wall of the furnace (in any proportion) to properly mix the natural gas with the MSW combustion products.
- A modified OFA injection system for the injection of OFA at a higher furnace elevation to burnout the combustibles present in the oxygen deficient zone.

Performance Comparison

Table III compares the current baseline operation of the facility with estimated performance using SNCR and METHANE de-NOX. SNCR would require injection of 70-lb/h urea together with 550-lb/h water and an additional 2-kW electricity consumption to reduce NO_x by approximately 50%. The CO level will probably increase, and about 5 to 10 ppm NH_3 is expected to slip through. METHANE de-NOX would require injection of 610-lb/h natural gas together with 12,000-lb/h FGR and an additional 5-kW electricity consumption to reduce NO_x by up to 60%. The CO level will most likely decrease, and there will be no NH_3 slip. The steam generation will increase by 17%, while combustion and total flue gas flow rates will decrease because of the reduction in the level of excess air. METHANE de-NOX is, therefore, expected to provide better emission performance compared to SNCR, together with an increase in steam generation and system thermal efficiency.

Table III. Performance comparison of METHANE de-NOX with current baseline operation and SNCR.

	Baseline	SNCR	METHANE de-NOX
MSW Input, lb/h	18,000	18,000	18,000
Natural Gas Input, lb/h	0	0	610
Total Heat Input, 10 ⁶ Btu/h	90	90	103.5
Urea Input, lb/h	0	70	0
FGR, lb/h	0	0	12,000
Water Input, lb/h	0	550	0
Electricity Consumption, kW	0	2	5
Excess Air, %	100	100	50
Total Combustion Air, lb/h	126,000	126,000	110,000
Total Flue Gases (Wet), lb/h	139,000	139,000	122,000
Steam Produced, lb/h	52,000	52,000	65,000
Super Heater Inlet Temp, °F	----- No Change -----		
System Thermal Efficiency	70	70	74
Stack Emissions			
NO _x , vppm @ 7% O ₂	300	150	TBD
CO, vppm @ 7% O ₂	30	same or higher	TBD
NH ₃ , vppm @ 7% O ₂	0	5-10	0

Cost Comparison

Table IV compares the estimated costs of METHANE de-NOX with SNCR. The capital costs for METHANE de-NOX include all equipment, installation, foundations, ductwork, piping, instruments, controls, wiring, tie-ins to existing facility, as well as design engineering, required initial spare parts, construction and environmental permits, and bid bonds. As is clear from the tables, the costs of natural gas, the sale price of electricity produced, and the tipping fee are all significant contributors to the overall system operating costs. Because these values vary widely from one region to the other, each case needs to be individually evaluated. The estimates presented in the table are based on \$2.50/1000 ft³ natural gas, \$0.06kWh electricity, and \$50/ton for tipping fee – which can be considered average, although probably not typical. It is clear from Table IV that METHANE de-NOX is very cost-effective, if the facility can accommodate the additional steam and sell it at a reasonable price. The economics are not very good, however, if the turbine cannot accommodate the additional steam flow, and the power sales are lost. In these cases, the extra steam will be condensed in the dump condenser.

For new facilities, the economics are expected to be even more favorable for METHANE de-NOX. The capital cost increases somewhat to accommodate the increased steam produced, however, if the electricity can be sold at a reasonable price, METHANE de-NOX can offer a significant cost advantage over SNCR. Combined with the additional benefits of lower CO emissions and no NH₃ slip, METHANE de-NOX could be both technically and economically attractive in retrofit and new applications. Based on this analysis, OMS and IGT have decided to pursue the long-term performance testing of METHANE de-NOX retrofit to an OMS MWC and are seeking funding support from outside agencies.

CONCLUSIONS

Based on the engineering and economic evaluation carried out jointly by IGT and OMS, it is concluded that the METHANE de-NOX technology could offer a technically and economically attractive alternative to SNCR for new facilities, as well as in retrofit applications. OMS and IGT have a definite interest in pursuing a long-term demonstration of the technology on an OMS MWC.

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Table IV. Cost comparison with SNCR^a in retrofit applications
(Basis: 264-ton/day unit).

Costs	SNCR (With Urea)	METHANE de-NOX
Capital	\$1,200,000	\$1,100,000
Annual Operating ^b		
Urea (\$210/ton-46%)	60,000	--
Natural Gas (\$2.5/1000 cuft)	--	360,000
Power Consumed (\$0.06/kWh)	1,400	3,200
Water (\$0.6/ton)	1,400	--
Power Produced (\$0.06/kWh)	--	(-)960,000
Total Operating	\$62,800	(-)596,800
Total Annualized Capital ^c and Operating	\$302,800	(-)376,800

^a Change from baseline.

^b Excludes labor, maintenance, and other costs that are estimated to be similar.

^c 20% of capital costs.

in the development of the METHANE de-NOX process. The authors also would like to thank Mr. James Schnieder and Mr. Richard Potter of Ogden Martin Systems, and Mr. David Cygan of IGT for their efforts.

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