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**READINESS THROUGH RESEARCH**

**DEVELOPMENT OF NATURAL GAS INJECTION  
TECHNOLOGY FOR NO<sub>x</sub> REDUCTION FROM  
MUNICIPAL WASTE COMBUSTORS**

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## ABSTRACT

Natural gas injection (NGI) technology for reducing  $\text{NO}_x$  emissions from municipal waste combustors (MWCs) is being developed in a joint program between the Gas Research Institute (GRI), the Institute of Gas Technology (IGT), Riley Stoker Corporation (Riley), Olmsted Waste-to-Energy (Olmsted), and Takuma Company, Ltd. (Takuma). The approach developed by IGT and Riley (termed METHANE de- $\text{NO}_x$ ) is based on extensive, full-scale, MWC in-furnace characterization followed by pilot-scale testing using simulated combustion products that would result from the firing of  $1.7 \times 10^6$  Btu/h (0.5 MWth) municipal solid wastes (MSW). The approach involves the injection of natural gas, together with recirculated flue gases (for mixing), above the grate to provide reducing combustion conditions that promote the destruction of  $\text{NO}_x$  precursors, as well as  $\text{NO}_x$ . Extensive development testing was subsequently carried out in a  $2.5 \times 10^6$  Btu/h (0.7 MWth) pilot-scale MWC firing actual MSW. Both tests, using simulated combustion products and actual MSW, showed that 50% to 70%  $\text{NO}_x$  reduction could be achieved. These results were used to define the key operating parameters.

A full-scale system has been designed and retrofitted to a 100-ton/day Riley/Takuma mass burn system at the Olmsted County Waste-to-Energy facility. The system was designed to provide variation in the key parameters to not only optimize the process for the Olmsted unit, but also to acquire design data for MWCs of other sizes and designs. Extensive testing was conducted in December 1990 and January 1991 to evaluate the effectiveness of NGI. This paper concentrates on the METHANE de- $\text{NO}_x$  system retrofit and testing. The results show simultaneous reductions of 60% in  $\text{NO}_x$ , 50% in CO, and 40% in excess air requirement with natural gas injection.

### UTILIZATION OF NATURAL GAS IN MUNICIPAL WASTE COMBUSTORS (MWCs)

In 1986, following GRI's successful pilot-scale testing of natural gas reburning for  $\text{NO}_x$  reduction in coal-fired applications, GRI and IGT began an investigation of the potential for utilizing natural gas in MWCs for the control of  $\text{NO}_x$  emissions. At that time the control of  $\text{NO}_x$  was required in the State of California; however, it was not yet being seriously discussed elsewhere in the United States. By 1989, the U.S. Environmental Protection Agency had announced its intention to set limits for  $\text{NO}_x$  emissions from all MWCs. The limits being evaluated were based on the performance of the thermal de- $\text{NO}_x$  process, which uses ammonia injection to reduce  $\text{NO}_x$  emissions. The thermal de- $\text{NO}_x$  process has been installed on three MWCs operating in California.

Figure 1 illustrates the  $\text{NO}_x$  reduction approach proposed for MWCs. This approach (termed METHANE de- $\text{NO}_x$ ) involves the injection of natural gas, together with recirculated flue

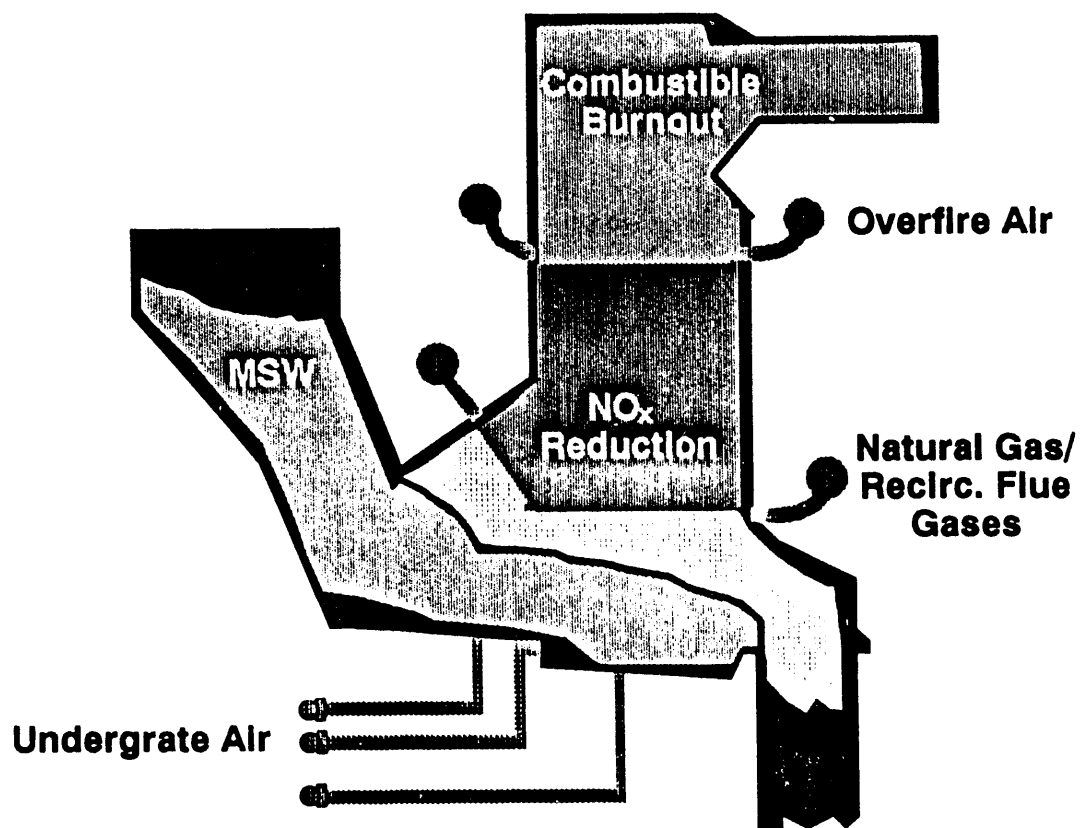


Figure 1. THE METHANE DE-NO<sub>x</sub> PROCESS

gases (for mixing), above the grate to provide reducing combustion conditions that promote the destruction of  $\text{NO}_x$  precursors, as well as  $\text{NO}_x$ . Secondary overfire air (OFA) is then injected at a higher elevation in the furnace, after sufficient residence time at these reducing conditions, to burn out the combustibles. Applying this approach to MWCs is challenging because of the low heat content of the waste being fired, the presence of significant amounts of  $\text{NO}_x$  precursors (for example,  $\text{NH}_3$ ,  $\text{HCN}$ ) above the grate, and the high excess air levels that are typically used in these types of combustors. These conditions result in relatively low temperatures and high oxygen and  $\text{NO}_x$  precursor levels in the primary combustion zone compared with conditions in the same location in a coal-fired boiler. Further complexities include the distribution of air, which includes a relatively large amount through the burnout grate at the discharge end of the combustor, and a large amount of air infiltration due to the negative operating pressure of the combustor. Also, because of the variability of the waste being burned, conditions in the furnace are typically variable. The initial concern, therefore, was that if NGI could be made to work at all in MWCs, it might require either large amounts of natural gas, or extended furnace zones to increase the residence time, or both.

The objectives of the development program were to 1) characterize the in-furnace conditions of a commercial MWC to define the variability of operation, the gas compositions within the furnace, and the flow distribution patterns for oxygen, CO,  $\text{NO}_x$ , and other flue gas species, 2) evaluate the gas-phase chemistry in laboratory furnace simulation experiments (0.5 MWth) and define regions of operation in which NGI could be effective using simulated MWC flue gases, 3) design and build a pilot combustor (0.7 MWth) firing actual MSW, in which the NGI process could be developed and tested, and 4) design and conduct a full-scale evaluation of the NGI process on a commercial MWC.

The experimental program was conducted from 1987 to 1989. The installation of the full-scale field evaluation was completed in late 1990, and NGI testing was completed in January 1991. The remainder of this paper summarizes the research conducted over the last 3 years that led to the design of a full-scale system and the results of NGI testing on the full-scale commercially operating MWC.

## RESULTS OF COMMERCIAL COMBUSTOR CHARACTERIZATION

The baseline data were acquired on one of the two units at the Olmsted County Waste-to-Energy Facility (Figure 2) located in Rochester, Minnesota. The design of the combustor is an integration of the Takuma MWC stoker and combustion control technology with the Riley waterwall furnace technology. Each unit was designed to burn MSW at the rate of

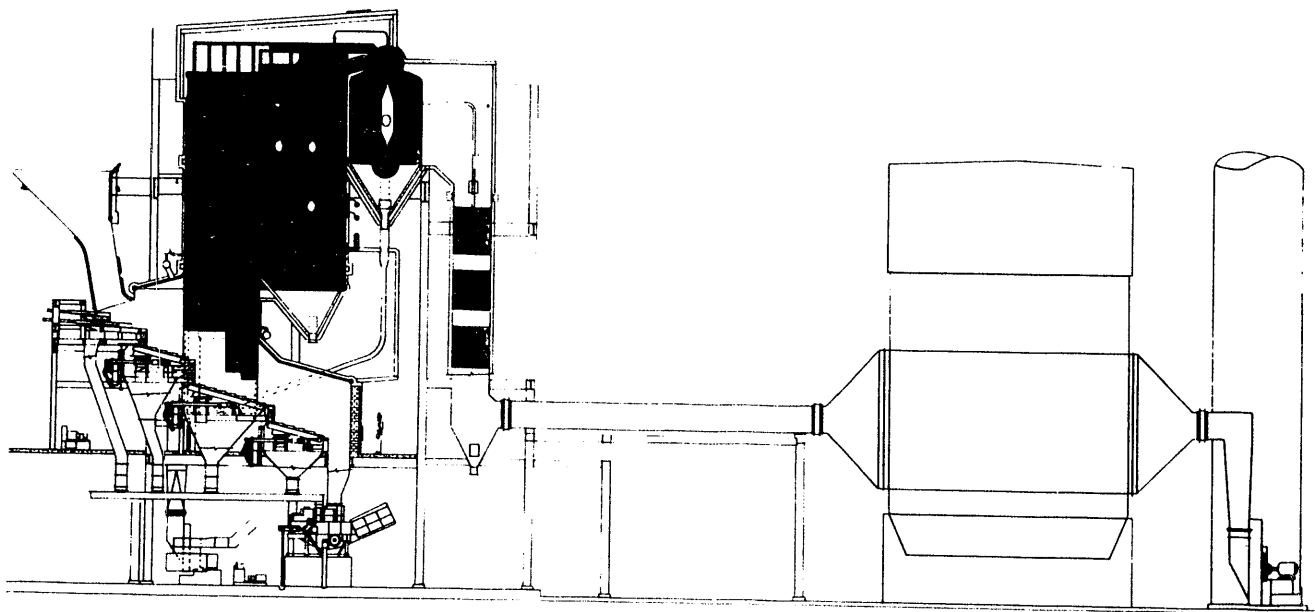


Figure 2. OLMSTED WASTE-TO-ENERGY FACILITY

100 tons/day (90 metric tons/day), producing about 24,000 lb/h (11,000 kg/h) of 615-psig (42-bar) superheated steam.

The unit was tested while varying load, total stoichiometric ratio (TSR), allocation of undergrate air (UGA) flow, and OFA location. Two general types of tests were conducted: in-furnace measurements by IGT and overall system performance data acquisition by Riley. Test details have been presented earlier<sup>1</sup> and the results are briefly described below.

In normal operation, with 60% to 80% excess air to ensure complete combustion, this unit produced about 125 to 175 ppm\* NO<sub>x</sub>. Without OFA and at lower excess air, NO<sub>x</sub> emissions were reduced significantly, but CO and total hydrocarbon (THC) emissions increased greatly. The baseline data show that NO<sub>x</sub> can be reduced by eliminating OFA and reducing excess air; however, incomplete combustion results – as indicated by the high CO levels. The goal of NGI is to reduce NO<sub>x</sub> emissions without the corresponding increase in CO emissions. The furnace characterization data that were acquired also show that it would be possible to create the substoichiometric NO<sub>x</sub> reducing conditions within the furnace with NGI.

#### Furnace Simulator

A pilot furnace at IGT was fired with No. 2 fuel oil using preheated air and adding appropriate amounts of oxygen, moisture, and ammonia (to simulate fuel-bound nitrogen). Thus, the pilot furnace closely simulated the baseline combustion products from the stoker firing 1.7 X 10<sup>6</sup> Btu/h (0.5 MWth) of MSW. These test details have also been presented earlier.<sup>2,3</sup>

In typical excess air operation (without NGI), the furnace simulator produced relatively steady NO<sub>x</sub> levels of 200 to 225 ppm – independent of residence time. Residence time, however, plays an important role when natural gas is injected, because sufficient time must be available for the natural gas to decompose NO<sub>x</sub> precursors. The first 3 seconds after NGI reduced NO<sub>x</sub> from 225 to 75 ppm. Longer times produce very little additional NO<sub>x</sub> reduction. The results showed that if NGI is to be effective, it must be injected into the MWC such that sufficient residence time at high temperatures is provided before OFA is injected for combustible burnout.

#### Pilot MWC Combustor

Because of the encouraging furnace simulator test results, it was decided to make follow-up tests in the pilot combustor at Riley's Research Center. A pulverized coal combustor

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\* All of the NO<sub>x</sub> and CO emission values presented here are on a 12% O<sub>2</sub> and dry basis. For a 3% O<sub>2</sub> basis, multiply values by 2 and for a 7% O<sub>2</sub> basis, multiply by 1.56.

at Riley was modified to simulate the commercial unit at Olmsted, and several different batches of MSW were tested. The results<sup>3,4</sup> show that without NGI, NO<sub>x</sub> emissions ranged from 110 to 165 ppm – a fairly good simulation of the baseline results obtained in the commercial combustors. With 10% to 15% (percent of total heat input) NGI, NO<sub>x</sub> emissions were reduced by as much as 70%, depending on the natural gas and OFA injection points and the residence time in the reducing zone. NO<sub>x</sub> emissions decreased to 100-130 ppm at 0.6 seconds residence time and to 40-80 ppm at 1.2 seconds residence time. These results verify the beneficial effects of residence time as observed in the furnace simulator tests.

### FIELD EVALUATION OF NATURAL GAS INJECTION

In light of the favorable test results obtained from both the IGT and Riley pilot-scale investigations of NGI, a field evaluation was undertaken. The NGI technology was retrofitted to one of the Olmsted units. This facility was also used to acquire all the baseline data reported here.

The pilot-scale work had demonstrated the potential of NGI for reducing the emissions of NO<sub>x</sub>, CO, and THC. A number of issues remained, however, before it could be commercialized as a viable emissions reduction technology. The major issues were as follows:

- Can NGI be as effective on a commercial unit, considering the actual conditions of high excess oxygen and the variability of feed quality and operating temperature?
- Can the already low CO and THC levels (<50 ppm) be further lowered and stabilized on the full-scale unit, as evidenced in the pilot unit?
- Can proper furnace aerodynamics be maintained or improved? In other words, can adequate distribution of natural gas in the reducing zone and OFA in the burnout zone be accomplished in full-scale systems?
- What would be the impact on thermal efficiency, slagging, corrosion, steam superheat, and other boiler performance parameters?
- What are the costs and advantages over thermal de-NO<sub>x</sub> and/or other alternative NO<sub>x</sub> control measures?

The results of the field evaluation would help resolve many of these issues. As with the experimental program, this 15-month effort was conducted jointly by IGT and Riley in consultation with Olmsted and Takuma. The work effort was divided into three major activities. The first involved finalization of site selection and engineering and design of a flexible NGI retrofit system. The second was the procurement and installation of the retrofit system. The

third was the field evaluation testing of NGI for emissions reduction, as well as other impacts, which began in early December 1990 and was completed in late January 1991.

The primary goal was to reduce  $\text{NO}_x$  to below 70 ppm from the current uncontrolled level of over 140 ppm without adversely affecting other emissions such as CO and THC. Additional goals were to maintain or improve the steam capacity while increasing the boiler thermal efficiency.

The retrofit METHANE de- $\text{NO}_x$  system was designed by IGT and Riley based on the pilot-scale testing results. The primary variables (determined during the pilot testing) for design of the NGI system are –

- 15% natural gas above grates to create substoichiometric conditions
- 15% flue gas recirculation (FGR) above grates for mixing the natural gas with the furnace gases
- Variability in reducing zone stoichiometry; reducing zone residence time; and natural gas, FGR and OFA flows, injection locations, and velocities.

The retrofit included installation of an FGR system and modification of the furnace walls to accommodate several nozzles and sampling/observation ports at multiple levels. The design also provides for acquisition of the necessary in-furnace and flue gas composition and temperature data, as well as other relevant data. Recirculated flue gas, taken from the economizer outlet, is used to introduce natural gas above the stoker.

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  $\text{NO}_x$  reduction and combustible burnout. Inserts were employed during the testing to evaluate higher injection velocities for the OFA, natural gas, and FGR.

#### FIELD EVALUATION TESTS

Extensive testing was carried out on the 100-ton/day commercially operating MWC during December 1990 and January 1991. These tests investigated the impacts of the following variables.

- OFA location – to change the residence time in the reducing zone
- OFA amount, injector size, and number of injectors – to optimize combustible burnout

- Natural gas and FGR amounts, distribution, injector sizes, and injector locations – to modify reducing zone mixing
- UGA amount and distribution – to modify MSW combustion profiles.

As indicated earlier, the objective of the testing was twofold:

1. To prove the effectiveness of natural gas in reducing the  $\text{NO}_x$  emissions on a full-scale commercial unit without any adverse effects
2. To acquire design data for the application of the NGI technology to MWCs of other sizes and designs.

As a result, the system was instrumented to provide an extensive data base for the impacts of NGI on both the furnace side, as well as the steam side parameters. The following is a list of measurements made during the tests.

- Full spectrum of furnace and steam side operating data including temperatures, flows, pressures, etc. through a specially installed computer data acquisition system and manually
- Gas composition ( $\text{O}_2$ , CO, THC,  $\text{CO}_2$ ,  $\text{NO}_x$ ) and temperature profiles in the reducing zone below the OFA injectors and at the furnace exit above the OFA injectors
- Flue gas composition ( $\text{O}_2$ , CO,  $\text{CO}_2$ ,  $\text{NO}_x$ ) at the electrostatic precipitator (ESP) inlet
- Flue gas composition ( $\text{O}_2$ , CO,  $\text{NO}_x$ ) in the recirculated flue gases
- Oxygen concentration in the reducing zone (continuously)
- Ash samples
- MSW samples.

The in-furnace gas composition and temperature measurements were made using water-cooled gas sampling and suction pyrometer probes that were installed at various elevations to traverse the furnace. Two sets of continuous emission monitors were employed. One set of  $\text{O}_2$ , CO,  $\text{CO}_2$ , and  $\text{NO}_x$  analyzers was installed near the ESP to measure the gas composition at the ESP inlet; and another set of  $\text{O}_2$ , CO, THC,  $\text{CO}_2$ , and  $\text{NO}_x$  analyzers was installed in the control room to measure the gas compositions inside the furnace and in the recirculated flue gases. The gas composition at the ESP inlet was measured continuously for the duration of each test, while the gas composition in the recirculated flue gases was measured periodically between the in-furnace traverses. The moisture contents of the flue gases and the flue gas flow rates were also measured during some of the tests.

The extensive data that were acquired during the field evaluation tests have not been fully reduced and analyzed at this writing. The composition of the actual MSW burned during

the tests is also not yet available. Consequently, the data presented here are limited. The results will focus on NO<sub>x</sub> and CO emissions measured at the ESP inlet and their preliminary relationships with some of the significant operating parameters. In general, these relationships were consistent with the pilot-scale results. The data presented here are further limited to the configurations that provided the optimum results with NGI. Data are presented for three types of tests. First, these data are presented with the baseline configuration as the unit is normally operated; second, in the NGI configuration with FGR injected into the lower furnace and OFA moved up to a higher elevation; and third, also in the NGI configuration with both FGR and natural gas injected into the lower furnace and OFA injected at the higher elevation.

Table 1 summarizes the average values of selected operating data, as well as CO and NO<sub>x</sub> emissions for these three test configurations. Data are also presented from the 1987 baseline testing and for one test with NGI that was carried out at a higher steam flow to maintain the MSW rate at the current normal baseline value of 7000 lb/h. The MSW feed rate and the total flue gas flow rate shown have been estimated assuming typical MSW composition and heat content. The actual values might be somewhat different, but the trends are expected to be unaltered. It must be noted that the steam flow during the 1991 baseline test was about 28,250 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 NGI, the steam flow rate was maintained at 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. However, as shown, 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 NGI retrofit may not necessarily require a decrease in MSW feed rate. Table 1 shows that 12.5% to 14% (total heat input) NGI allowed a reduction in excess air from over 70% to about 40% which may increase the boiler thermal efficiency.

The data presented in the table also show that, compared to the 1991 baseline test, NGI decreased the NO<sub>x</sub> emissions by 60% and CO emissions by 50%. The NO<sub>x</sub> emissions were decreased by 40% with FGR alone, however, the CO emissions were more than double compared with the average CO with NGI. The CO level with FGR was comparable to the 1991 baseline test value, but higher than the average value for the 1987 baseline tests. Figure 3 illustrates the relationship between NO<sub>x</sub> and CO emissions for the Olmsted combustor that was found in 1987 for the baseline operation. The relationship represents baseline operation at different UGA and OFA flow distributions and excess air levels. The current (1990-1991) data at baseline configuration, as well as with FGR, show scatter but appear to follow the 1987 trend. The average NO<sub>x</sub>/CO values with FGR fall close to the average baseline curve. This suggests

Table 1. AVERAGE OPERATING DATA – 1990/1991 FIELD EVALUATION TESTS

	Baseline		FGR Only (Average Data)	FGR + NGas	
	1987 Test	1991 Test		At Normal 1987 Baseline MSW Input (Average Data)	At Normal 1991 Baseline MSW Input Test
MSW,* lb/h	6,450	7,760	--	6,500	7,000
Natural Gas, %	0	0	0	14.0	12.4
Total Heat Input,* 10 <sup>6</sup> Btu/h	33.5	40.3	--	39.9	41.9
FGR, %	0	0	9.5	9.5	10.0
Excess Air, %	73	76	54	37	41
Total Flue Gas,* lb/h	44,800	54,100	47,100	45,400	48,500
Steam Flow, lb/h	23,500	28,250	27,670	29,000	30,500
Economizer Exit Temperature, °F	417	425	423	422	422
Precipitator Inlet					
O <sub>2</sub> , %	9.3	10.5	7.6	6.5	5.9
CO, ppm at 12% O <sub>2</sub>	30	46	47	22	21
NO <sub>x</sub> , ppm at 12% O <sub>2</sub>	135	117	70	48	48

\*Estimated.

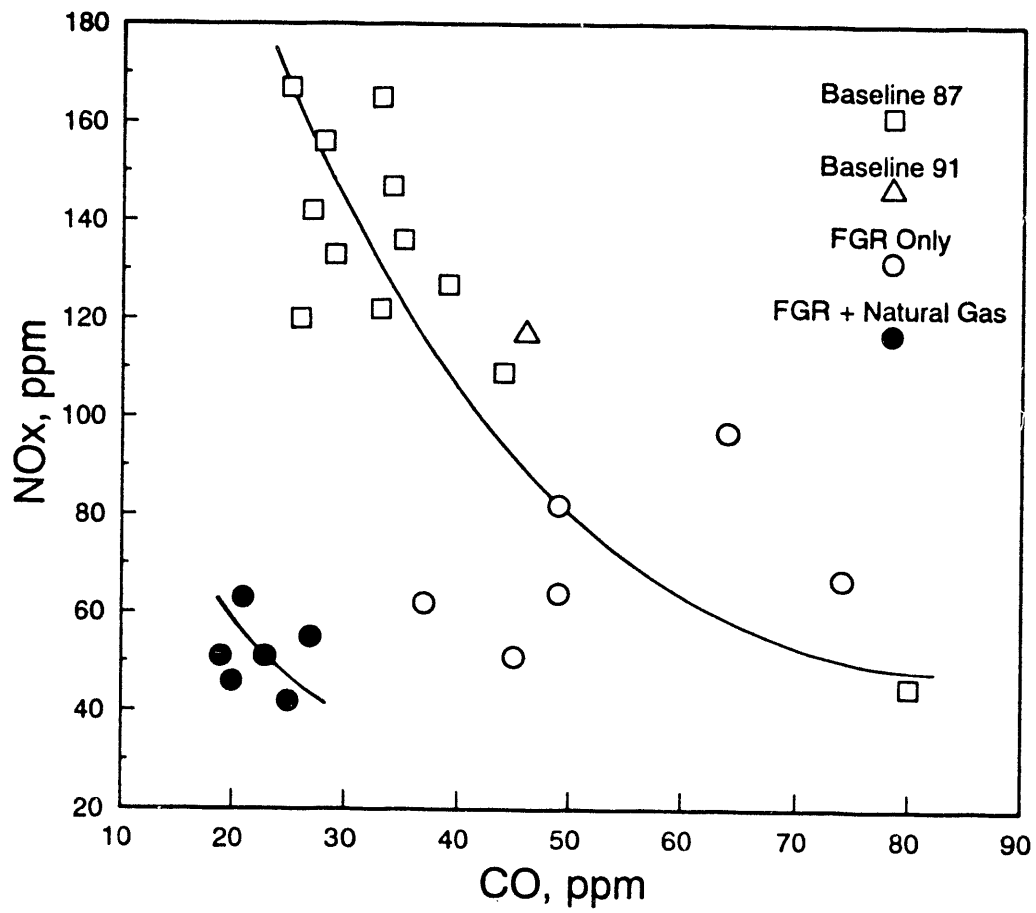


Figure 3. NATURAL GAS INJECTION SIMULTANEOUSLY DECREASES NO<sub>x</sub> AND CO EMISSIONS

that the effectiveness of FGR in reducing NO<sub>x</sub> may not be significantly better than some of the other simpler combustion modifications that were tested in 1987. The figure also illustrates the effectiveness of NGI in controlling both NO<sub>x</sub> and CO emissions simultaneously. Both NO<sub>x</sub> and CO emissions were significantly lower with NGI. The average baseline NO<sub>x</sub> at 32 ppm CO (expected regulatory limit) was about 137 ppm while the average NO<sub>x</sub> with natural gas was about 50 ppm at an average CO level of about 22 ppm.

Figure 4 shows the NO<sub>x</sub> data (for tests with  $\leq 32$  ppm CO) as a function of the amount of natural gas injected into the furnace. Here the data point with no natural gas is the average baseline value from the previous figure. The figure shows that an NO<sub>x</sub> level of 50 ppm required injection of about 14% natural gas. If it is assumed that the NO<sub>x</sub> level could be further reduced to 35 ppm (at 14% natural gas, through extrapolation of the data in Figure 3) by combustion modifications (that would increase CO to 32 ppm), then the amount of natural gas required for 50 ppm NO<sub>x</sub> would decrease to 12%.

Figure 5 illustrates the impact of reducing zone residence time on NO<sub>x</sub> and CO emissions. The data again are limited to tests with  $\leq 32$  ppm CO. A residence time ratio of 1 represents the average baseline condition, while the other data represent 12% to 15% NGI. The data show that a residence time ratio of about 2.5 is required in the Olmsted unit for NO<sub>x</sub> reduction to 50 ppm. A higher residence time could further decrease the NO<sub>x</sub> emissions, but it appears that the CO level would increase.

## SUMMARY OF RESULTS

As discussed, the data acquired during the field evaluation tests have not yet been fully reduced and analyzed. Based on the current analysis, however, the following can be stated:

- In general, the relationships between the significant operating parameters and the emissions were consistent with those found on the pilot-scale units.
- Proper injection of 12% to 15% (heat input basis) natural gas simultaneously decreased the NO<sub>x</sub> emissions to below 50 ppm and the CO emissions to below 25 ppm, which represents a 60% reduction in NO<sub>x</sub> and a 50% reduction in CO compared to the 1991 baseline test values.
- NGI also allowed a reduction in excess air to 40% (from the baseline levels of 70% to 80%), which may provide an increase in boiler thermal efficiency.
- An FGR level of 6% to 8% was sufficient to inject and effectively mix the natural gas with the furnace gases.

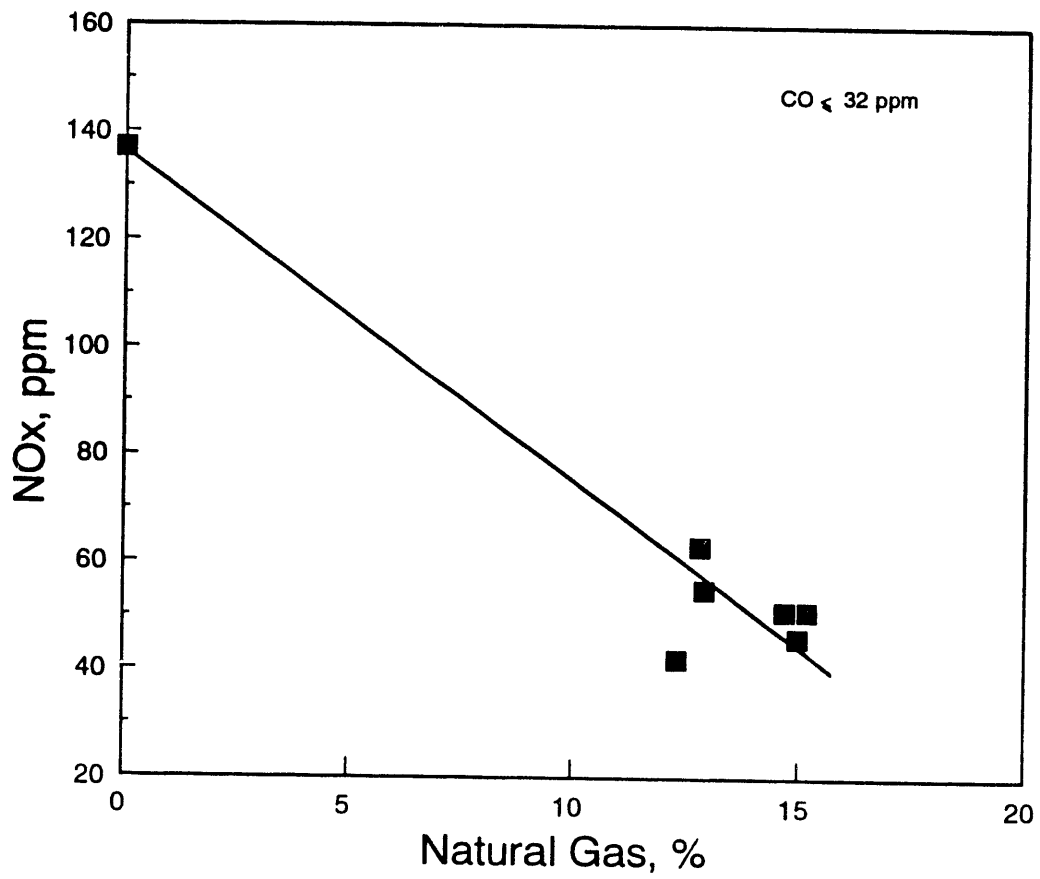


Figure 4. INJECTION OF 12% TO 15% NATURAL GAS SIGNIFICANTLY DECREASES NO<sub>x</sub> EMISSIONS

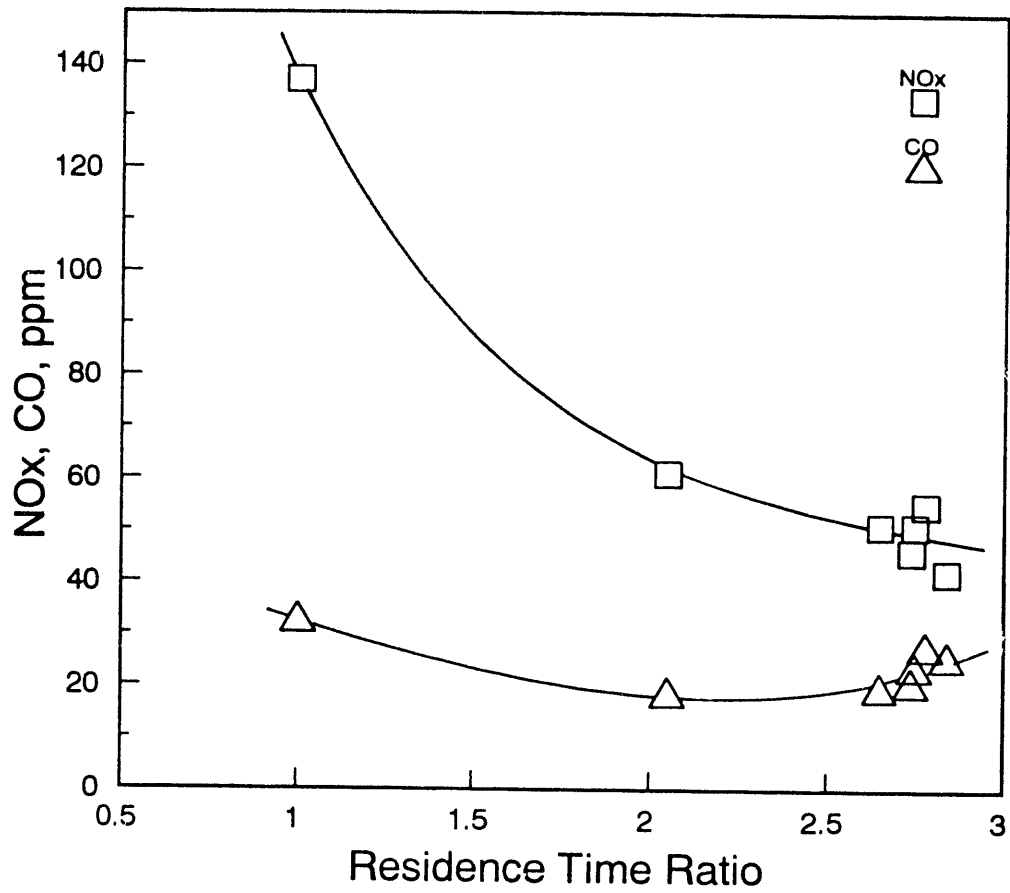


Figure 5. RESIDENCE TIME PLAYS A SIGNIFICANT ROLE IN THE EFFECTIVENESS OF NATURAL GAS

- Because of the reduced excess air requirement, it was possible (as demonstrated in one test) to maintain the MSW feed rate at the baseline level by increasing the steam output to accommodate the additional heat input with natural gas.
- Optimization of the residence time is important for the simultaneous reduction in NO<sub>x</sub> and CO emissions.

In conclusion, the effectiveness of the METHANE de-NO<sub>x</sub> process for controlling NO<sub>x</sub> and CO emissions from MWCs has now been demonstrated on a commercially operating MWC. Further analysis of the data should provide additional information for application of this process to MWCs of other sizes and designs, including refuse derived fuel (RDF).

#### ACKNOWLEDGMENT

Many sponsors played important roles in the development of the METHANE de-NO<sub>x</sub> process. Considerable funding and guidance were provided by the Gas Research Institute, Brooklyn Union Gas Co., Minnegasco, Northern Illinois Gas Co., Northern Natural Gas Co., Peoples Gas Light and Coke Co., Southern California Gas Co., and IGT's Sustaining Membership Program member companies

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