Reduction of NO_x Emissions From MSW Combustion Using Gas Reburning

by

Craig A. Penterson and D. C. Itse
Riley Stoker Corporation, USA

Hamid A. Abbasi
Institute of Gas Technology, USA

Yasujiro Wakamura
Takuma Company Ltd., Japan

David G. Linz
Gas Research Institute, USA

Presented at the

1989 Joint Symposium on Stationary Combustion NO_x Control

San Francisco, California
March, 6-9, 1989

RST 77

RILEY STOKER CORPORATION
BOX 15040, WORCESTER, MA 01615-0040

Reduction of NO_X Emissions From MSW Combustion Using Gas Reburning

by

Craig A. Penterson and D. C. Itse
Riley Stoker Corporation, USA

Hamid A. Abbasi
Institute of Gas Technology, USA

Yasujiro Wakamura
Takuma Company Ltd., Japan

David G. Linz
Gas Research Institute, USA

ABSTRACT *A program has been initiated to evaluate the potential for reducing air pollutant emissions from Municipal Solid Waste (MSW) combustion systems using natural gas reburning. The program is being conducted jointly by the Institute of Gas Technology, the Gas Research Institute, Riley Stoker Corporation and Takuma Company Ltd.*

Three major tasks are included in the program: (1) acquisition of baseline data from a commercial operating facility, (2) pilot-scale development and testing of the reburning technology, and (3) field demonstration testing of the technology. This paper focuses on the results to date of the first two tasks: baseline data acquisition and pilot scale testing.

The gas reburning concept being evaluated for MSW combustion is similar to the reburning technique being investigated to reduce NO, emissions from fossil fuel combustion systems. Natural gas is introduced above the main combustion zone to create a reducing environment where significant amounts of NO, and other fixed nitrogen species (NHi, HCN), generated in the main combustion zone, are reduced to molecular N_2.

Results of the pilot scale testing have demonstrated up to 70% reduction in NO, emissions using gas reburning. The effects of gas injection location, reburning zone stoichiometry and residence time, overall boiler excess air and the amount of natural gas reburning on NO, emissions are characterized. The impact of gas reburning on reducing other emissions such as CO, unburned THC and dioxin is also discussed.

INTRODUCTION

With the expanding waste-to-energy market today, the need to understand more about the combustion characteristics and behavior of municipal solid waste (MSW) and refuse derived fuel (RDF) has increased dramatically. Of primary concern are the air pollutant emissions produced during the combustion process and the ability to control these emissions. Flue gas scrubbers are generally employed in modern facilities at the boiler exit to control the acid gas emissions such as HC1 and SO_2. Baghouses or electrostatic precipitators are used to remove the particulate emissions as well as the reacted lime from the scrubber. Other emissions could potentially be controlled during the combustion process. These include NO_N, CO, unburned THC, polychlorinated dibenzodioxins (PCDD's) and polychlorinated dibenzofurans (PCDF's).

In April, 1987, the Institute of Gas Technology (IGT), the Gas Research Institute (GRI), Riley Stoker Corporation (Riley) and Takuma Company Ltd. from Japan (Takuma) began work on a research program to evaluate the potential for reducing pollutant emissions from MSW combustion systems using natural gas. The primary objective of the overall program is to investigate the use of natural gas reburning in combination with low excess air operation to minimize the production of NO_x emissions. As conceptually shown in Figure 1, natural gas would be introduced above the main combustion zone in a MSW combustor to create a strong fuel rich or reducing zone where NO_x and other fixed nitrogen species (NHi, HCN), generated in the main combustion zone, would be reduced to harmless molecular nitrogen. Natural gas reburning might also serve to reduce other pollutant emissions such as CO, unburned HC, PCDD's and PCDF's by creating a more uniform and stable thermal environment in the combustor.

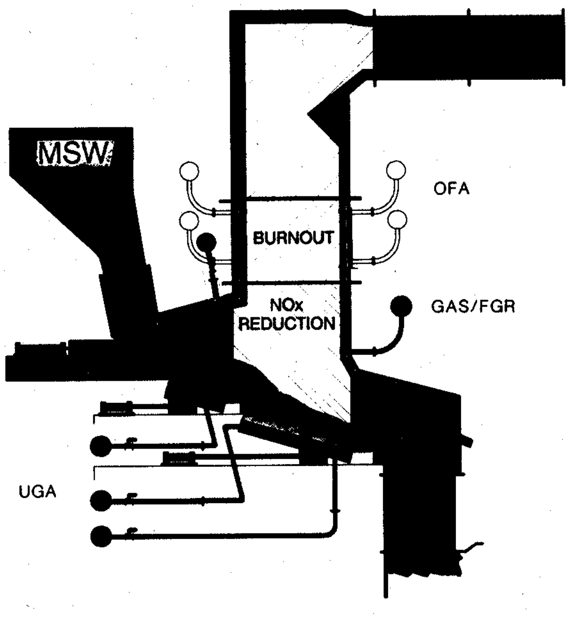


Figure 1. MSW Gas Reburning Concept

Other benefits expected from this type of boiler operation are improved combustion efficiency, increased boiler efficiency and more stable, reliable operation of the system. As outlined below, the research program is divided into three major tasks. Task 1 was completed in the fall of 1987 while Task 2 is nearly complete.

Task 1 — Acquisition of Baseline Data From a Field Operating Unit.

Task 2 — Pilot Scale Development and Testing of the Gas Reburning Technology.

Task 3 — Field Demonstration Testing at a Commercial Installation

This paper discusses the results to date of Tasks 1 and 2. Due to the initial favorable results incurred during the pilot scale testing at both IGT and Riley, preliminary plans are currently being formulated for a field demonstration test of the gas reburning technology.

GAS REBURNING TECHNOLOGY

The gas reburning technology being developed in this program is similar to the reburning techniques being investigated to reduce NO_x emissions from coal fired combustion systems. As shown in Figure 1, gas would be injected into the furnace through multiple openings above the main combustion zone at 10-15% of the total heat input. Recirculated flue gas, equal to 10-20% of the total boiler flue gas approaching the take off point, would be used to convey the natural gas and achieve the proper penetration and mixing required in the furnace. Overfire air (OFA), would then be added above the gas reburning zone to complete the combustion process.

The reburning zone created by the natural gas would provide the H and OH radicals necessary to react with and reduce the NO_x and other fixed nitrogen species, generated in the main combustion zone to molecular N_2. As discussed later in this paper, the NO_x emissions being produced from a typical Riley-Takuma mass burn system [1] average 150 PPM[1]. Our goal is to reduce the NO_x emissions to 50 PPM, comparable to the levels currently attainable only by selective catalytic reduction (SCR) or urea injection [2, 3].

Another benefit anticipated from using gas reburning is the ability to create a more uniform and stable thermal environment within the furnace, thus eliminating localized low temperature zones and pathways. As described later, furnace temperature fluctuations on the order of ±150°F, over a one minute period, were measured during the baseline testing at a commercial facility while burning only MSW. Temperature differences as large as 160°F between the front and rear walls were also measured. These erratic temperature profiles may contribute to products of incomplete combustion (PIC) emissions by allowing the reactions to occur at insufficient temperature. Work by Duvall shows that below

[1] All emissions have been corrected to 12% O_2 unless stated otherwise.

approximately 1500°F, thermal destruction of many PIC's begins to rapidly decrease [4]. Gas reburning should, therefore, enhance the burnout of CO, unburned THC, PCDD's and PCDF's by creating a more uniform temperature environment in the furnace.

Gas reburning, in combination with low excess air operation, should also improve boiler efficiency. Reducing the overall excess air requirement from the current 80% to 40% could potentially increase boiler efficiency by 1.5%.

BASELINE FIELD TEST RESULTS

In July 1987, parametric field tests were performed during Task 1 by Riley and IGT on Unit 1 of the Olmsted County Waste-to-Energy facility in Rochester, Minnesota. This 100 ton/day unit, shown in Figure 2, was designed and constructed by Riley to incorporate the Japanese technology for mass burning that Riley licenses from C. Itoh Takuma Ltd., Japan. As shown in Figure 3, the Takuma stoker consists of four separate sections: feeder table, drying and ignition grate, combustion grate and burnout grate.

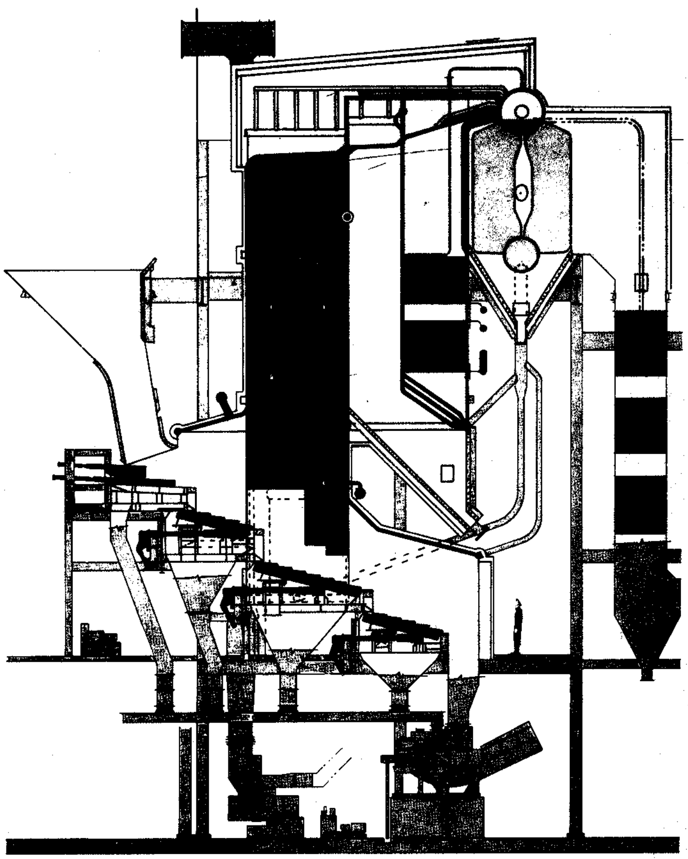


Figure 2. Riley-Takuma Waste to Energy Facility Olmsted County, Minnesota

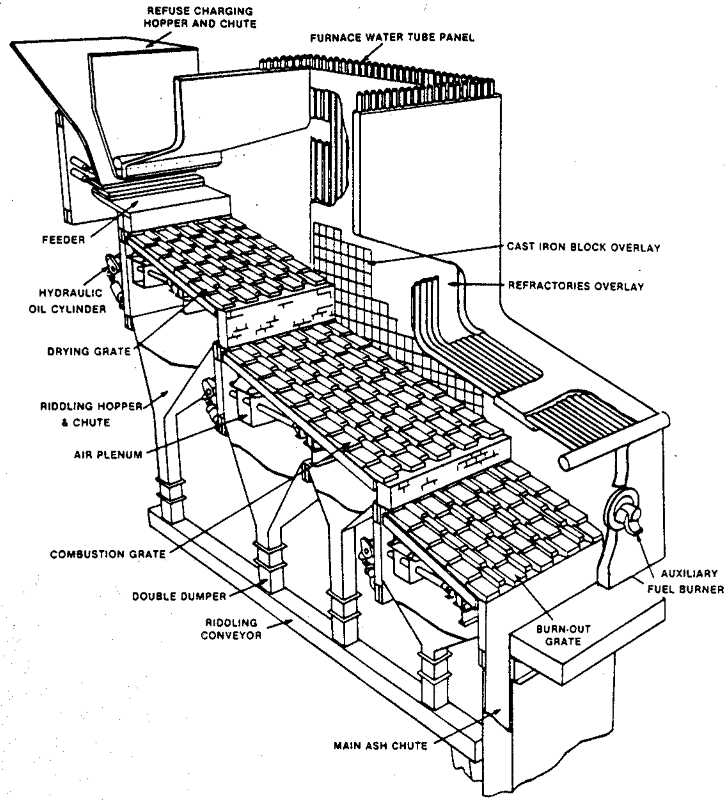


Figure 3. Riley-Takuma MSW Stoker Grate

Between the grate sections are two to three foot drops or steps which reduce top to bottom fuel stratification and help to break up any large agglomerations of the fuel. By hydraulically reciprocating every other individual grate row, the fuel cascades and moves down the various grate sections. Fuel drying, pyrolysis and ignition occur on the drying and ignition grate. About 95% of the fuel combustion occurs on and over the combustion grate. The burnout grate provides time for carbon burnout and reduction of putriscibles under locally high excess air conditions. The Riley-Takuma systems are designed to handle refuse throughputs from 100-1000 tons per day.

During the field tests at Olmsted County, pollutant emissions were measured at the economizer exit or precipitator inlet as well as at critical locations in the furnace. These emissions included NO_x, SO_2, CO, unburned THC and putriscibles in the ash. Tests were conducted while varying the amount and location of OFA, undergrate air (UGA), excess air and boiler load. Using suction pyrometers, furnace gas temperature measurements were also collected in the upper furnace and furnace backpass. However, attempts to measure furnace gas temper ature in the lower furnace immediately above the grates were unsuccessful due to probe plugging.

Results of the testing showed that operation of the overfire air (OFA) system had the most significant effect on controlling NO_x, CO and unburned THC emissions. The amount of OFA had the greatest impact. Since excess air is automatically controlled by the amount of OFA [1], increasing excess air would cause an increase in the NO_x and a decrease in CO emissions, typical of most combustion systems. This is shown in Figure 4. At design excess air operation, NO_x emissions entering the electrostatic precipitator averaged 150 PPM while CO was 28 PPM. Unburned THC emissions measured at this same location averaged less than 5 PPM. In general, the CO emissions would only increase at very low levels of excess air (<30%) when OFA was completely closed. But, the level would still remain below 200 PPM.

Detailed in-furnace gas composition measurements showed the effect of OFA in controlling emissions. Figure 5 summarizes the gas composition history measured at various locations throughout the entire unit during full load normal operation. NO_x increases following the addition of OFA while CO and unburned THC are reduced significantly. Less than 50% of the total NO_x emission is formed immediately above the grate while the remaining NO_x is formed in the OFA region. In addition, since the predicted peak furnace temperature in this area remains below 2400°F, NO_x is primarily formed from the conversion of fuel bound nitrogen.

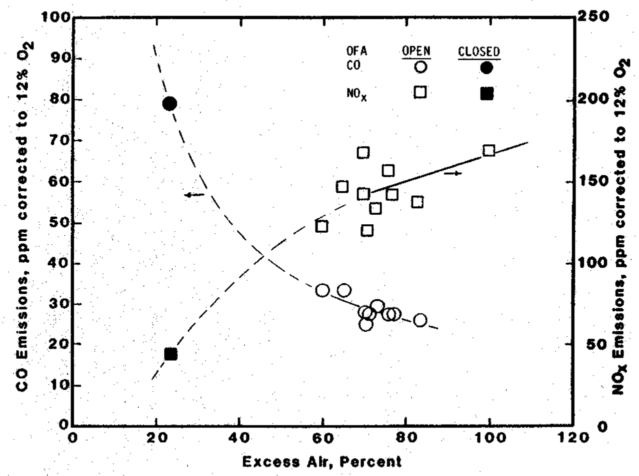
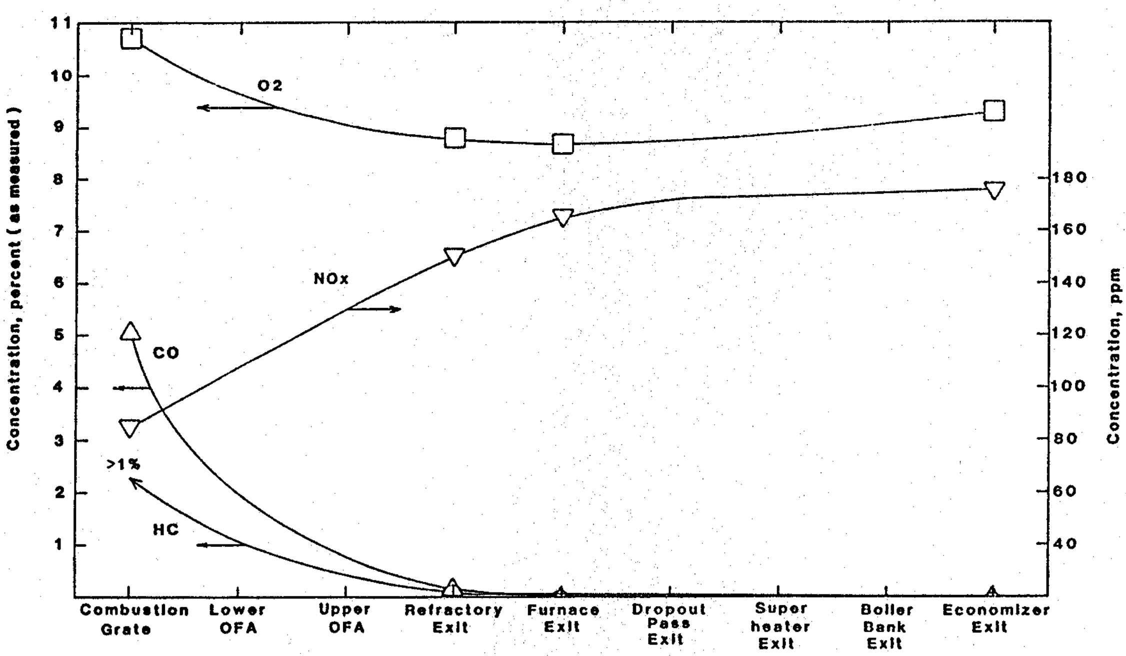


Figure 4. NO_x and CO Emissions as a Function of Excess Air, Olmsted Waste to Energy Facility — Economizer Exit

Figure 5. Furnace Gas Composition History Through the Olmsted Waste to Energy Facility During Normal Full load Operation



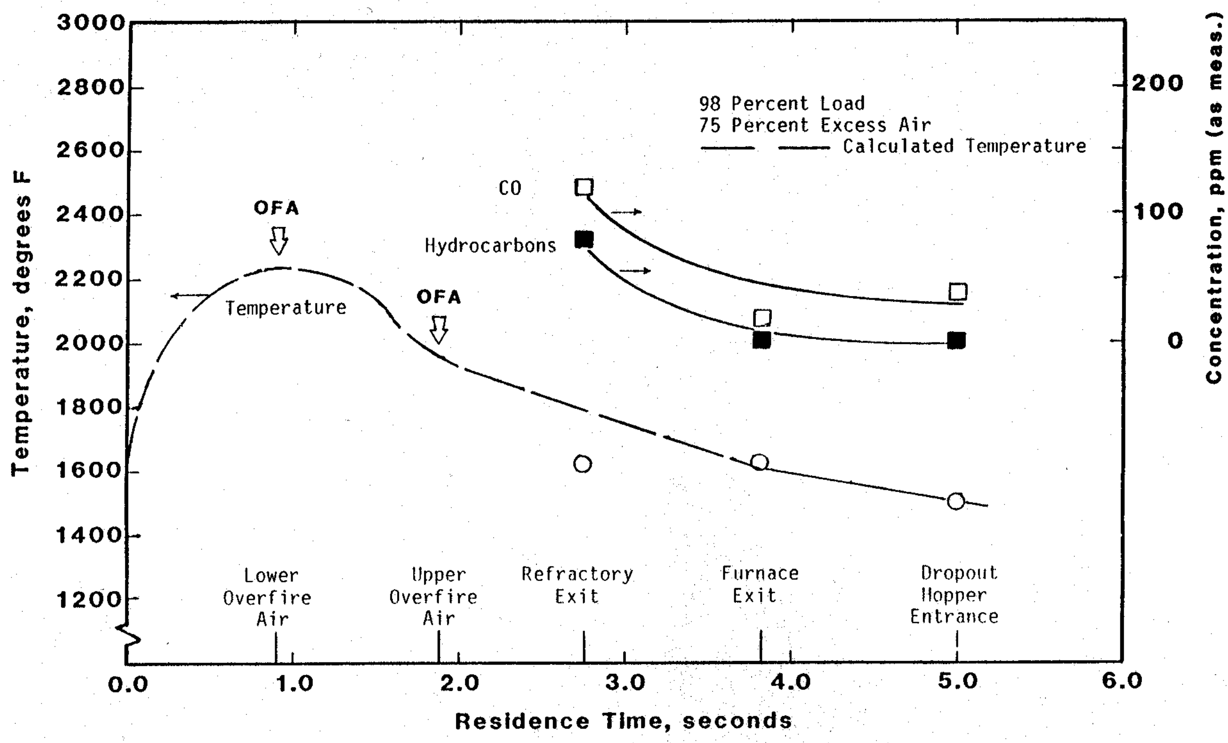


Figure 6. Temperature and Products of Incomplete Combustion Profiles through Olmsted Waste to Energy Facility

Figure 6 shows the gas temperature history of the unit based on actual furnace temperature measurements and calculated flue gas flows. Furnace temperatures are typically less than 2400°F. However, not shown on the figure, are the significant temperature fluctuations and stratification measured in the furnace. During several tests, fluctuations of ±150°F over a one minute period were measured while the temperature difference between front and rear furnace walls was as large as 160°F. Though the CO and unburned THC emissions remain relatively low with this type of thermal environment, the benefit of using natural gas reburning to stabilize this environment may potentially reduce these emissions even further as well as provide the environment for reductions in PCDD's and PCDF's.

The results of the testing at Olmsted County were then used to form the basis for the pilot scale testing performed initially at IGT in a furnace simulator and then at Riley in an actual pilot MSW combustion facility. The purpose of the testing at IGT was to initially investigate the feasibility of using gas reburning to reduce NO_x emissions and to identify those variables which had the most significant impact on controlling NO_x. The test variables included:

- reburning zone residence time
- reburning zone stoichiometry
- reburning zone temperature
- amount of natural gas reburning fuel
- amount of flue gas recirculation (FGR) for natural gas transport
- overall stoichiometry leaving the furnace

Subsequent testing at Riley Stoker was then performed to further characterize and define an optimum gas reburning strategy that would be directly transferrable to a commercial installation. The following section briefly describes the major results of the pilot scale testing at IGT followed by a more detailed discussion of the initial process development tests conducted at Riley Stoker.

IGT PILOT SCALE TESTING (TASK 2)

One of the pilot-scale furnaces, at IGT's Applied Combustion Research Facilities, was modified to simulate the combustion products measured in the lower furnace section of the Olmsted County MSW

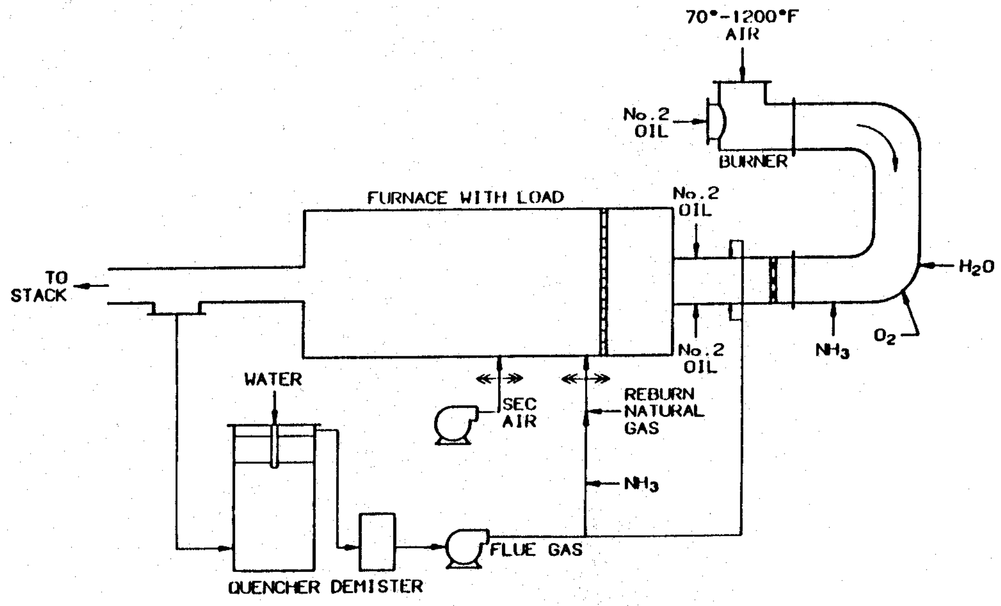


Figure 7. Schematic of IGT's Pilot-Scale Facility

combustor. As shown in Figure 7, combustion products, that would result from firing MSW at a rate of 1.7 x 10^6 Btu/hr, were simulated by firing No. 2 fuel oil into preheated combustion air with subsequent blending of water, ammonia and oxygen. The hot combustion products were introduced into one end of the 4.5 ft wide x 3 ft high x 14 ft long furnace chamber and distributed across the furnace cross section using a refractory grid. The furnace chamber was refractory lined and equipped with cooling tubes to simulate the thermal environment measured in the field.

In the combustion chamber, the natural gas for reburning, conveyed by recirculated flue gas, was introduced through holes in the top and bottom of a 4″ diameter stainless steel pipe. This injector, extending the full width of the combustor, was placed at the centerline of the combustion chamber just downstream of the distribution grid. Secondary air, simulating overfire air, was also introduced through a similar injector design, downstream of the reburning zone, to complete the burnout. The furnace is equipped with 32 removable doors along the length which allowed for significant flexibility in the placement of these injectors and probes.

The reburn zone stoichiometry and temperature were changed by varying the amount and temperature of the preheated combustion air, while reburn zone residence time was varied by placing the secondary air injector at various locations along the furnace length. Test measurements focused on gas composition (O_2, CO, THC, CO_2 and NO_x) and temperature in both the reburn zone and at the furnace exit.

Table I shows a comparison of the gas composition measured without gas reburning in the IGT furnace simulator with the gas composition measured

Table 1
Comparison of IGT Pilot Data with Field Data — Baseline Testing

	Baseline Field Test Unit	IGT Furnace Simulator
Test	Typical	Typical
Combuston Products[1]		
O_2, %	7.9	7.9
CO_2, %	10.2	9.8
N_2, %	71.2	70.7
H_2O, %	10.7	11.6
NO_x, PPM	130	100-300
Reburn Zone Temp., °F	~2220[2]	1950-2400
Reburn Zone Residence Time, sec.	1.0-3.0	1.0-4.5

[1]Wet basis.
[2]Estimated from actual measurements of FEGT

in the baseline test furnace at Olmsted County, The pilot scale results showed good agreement in regards to gas composition, furnace temperature and residence time. NO_x emissions varied (100–300 PPM) primarily depending on the amount of NH_3 injected into the flue gas products.

Testing the affect of gas reburning on reducing NO_x emissions showed very promising results. NO_x reductions of up to 70% were measured. The most significant variable was the stoichiometric ratio of the reburning zone. As shown in Figure 8, NO_x decreased with decreasing stoichiometry. NO_x emissions were reduced significantly down to a reburn zone stoichiometry of approximately 0.6-0.9, depending on residence time. A stoichiometric ratio of 0.9 utilized 15% natural gas for reburning in combustion products that originally had a stoichiometric ratio of 1.1.

Figure 8 also shows the effect of the reburn zone residence time on NO_x reduction. The results show that longer residence times are more beneficial in reducing NO_x. The difference between 1.0-1.4 seconds and 4.0-5.2 seconds was 40-50 PPM more NO_x reduction for the longer times. The shorter residence times are, however, more practical for commercial applications. Residence times on the order of 2.0-2.5 seconds in the reburn zone of a Riley-Takuma system are possible. As shown in Figure 9, at 2.5 seconds residence time, NO_x reductions of 50% were measured.

The furnace temperature in the reburn zone was not a critical factor in reducing NO_x emissions

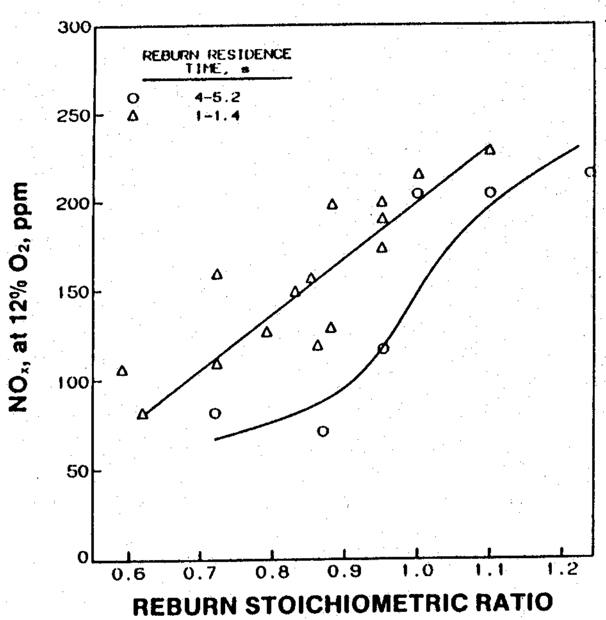


Figure 8. The Effect of Reburn Zone Stoichiometric Ratio on NO_x Emissions in IGT Pilot Unit

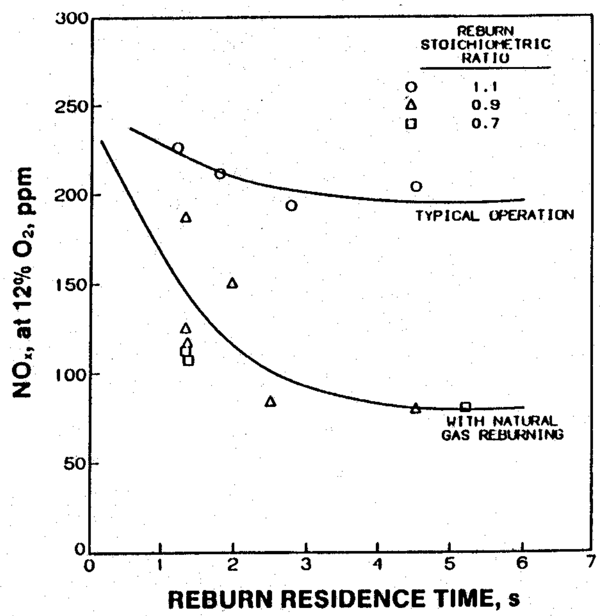


Figure 9. The Effect of Reburn Zone Residence Time on NO_x Emissions in IGT Pilot Unit

within the temperature range tested, 1950°F–2400°F. Any temperature effects were dominated by other more significant parameters. In regards to other emissions, though, CO was reduced from 30-40 PPM without gas reburning to <20 PPM with 15% gas reburning.

The major findings drawn from this initial testing of the gas reburning concept, on IGT's Pilot-Scale Furnace Simulator, are summarized below:

- Up to 70% NO_x reduction was achieved with 15% gas reburning and 4.0-5.2 seconds residence time in the reburning zone.
- Residence times of approximately 2-2.5 seconds in the reburning zone appears to be sufficient for 50-60% NO_x reduction.
- Reburn zone temperatures are less critical than residence time and stoichiometry for NO_x reduction.
- Reburn zone stoichiometry of 0.9 is effective in controlling NO_x and is attainable in commercial installations.
- There is potential for reducing CO emissions using gas reburning.

RILEY STOKER PILOT SCALE TESTING (TASK 2)

Following the initial pilot scale testing at IGT, process development tests were conducted at Riley in a 3 × 10^6 Btu/hr Pilot MSW Combustion Facility. The pilot scale step grate stoker design is an actual prototype of a full scale Riley-Takuma system for mass burning. As conceptually shown in Figure 10, the combustor section is 17′-0″ tall × 11′-9″ long x 3′-0″ wide and is designed to burn processed MSW at a rate of approximately 450 lb/hr or 5.5 tons/day.

Processed MSW, from an RDF plant in Biddeford, Maine, rather than raw MSW is burned. The majority of the glass and metals content has already been removed and the refuse has been reduced in size. This was done to avoid mechanical operating problems which would result from raw MSW. Table II shows a comparison of the processed MSW with the MSW from Olmsted County.

The pilot facility includes a 10 ton storage trailer, 45 ft long drag chain conveyor, refuse feed chute, stoker grate and hydraulic drive system, ash discharge hopper, overfire air nozzles, natural gas injection nozzles, undergrate air, a flue gas recirculation system and a startup gas burner. The furnace walls of the combustor are water cooled with high insulating refractory attached to the inside surface to produce a thermal environment typical of field operating conditions.

Figure 11 shows a photograph of the main combustor section. Combustion products exit the main combustor and pass through heat recovery equipment, a gas analysis sampling train, baghouse, acid gas scrubber system and finally exhaust out the stack. The gas analysis train at the furnace exit is used to continuously monitor flue gas composition including NO_x, O_2, CO, THC, CO_2 and SO_2. The facility is currently being equipped to monitor HCl.

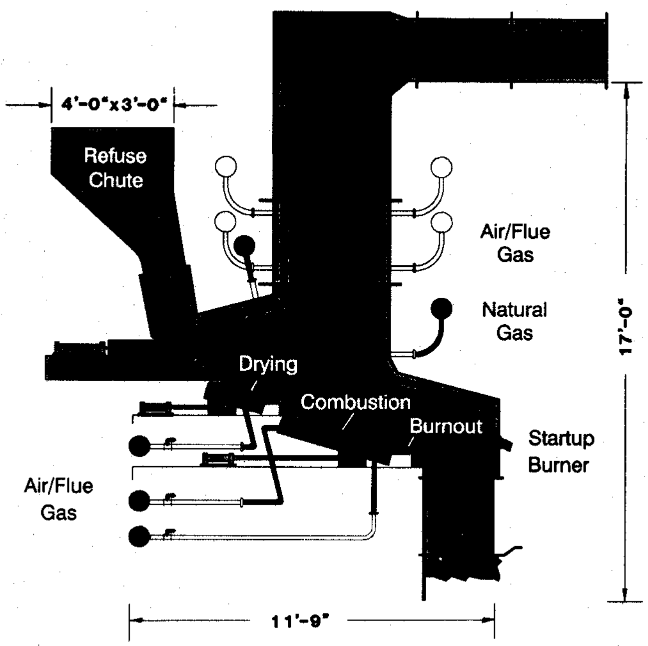


Figure 10. Riley Pilot MSW Combustion Facility

Table II
Typical Fuel Analysis Comparison

	Olmsted Cty. Raw MSW	Riley Unit Processed MSW
Moisture, %	3.35	18.19
Volatile Matter, %	33.86	57.90
Fixed Carbon, %	16.22	11.70
Ash, %	46.57	12.21
Sulfur, %	0.75	0.21
Carbon, %	32.00	34.49
Hydrogen, %	3.44	4.48
Nitrogen, %	0.95	0.35
Oxygen, %	12.94	30.07
HHV, Btu/lb (as rec'd.)	6037	5447
Paper, %	70.0	75.8
Plastic, %	15.0	6.0
Miscellaneous, %	10.0	18.2

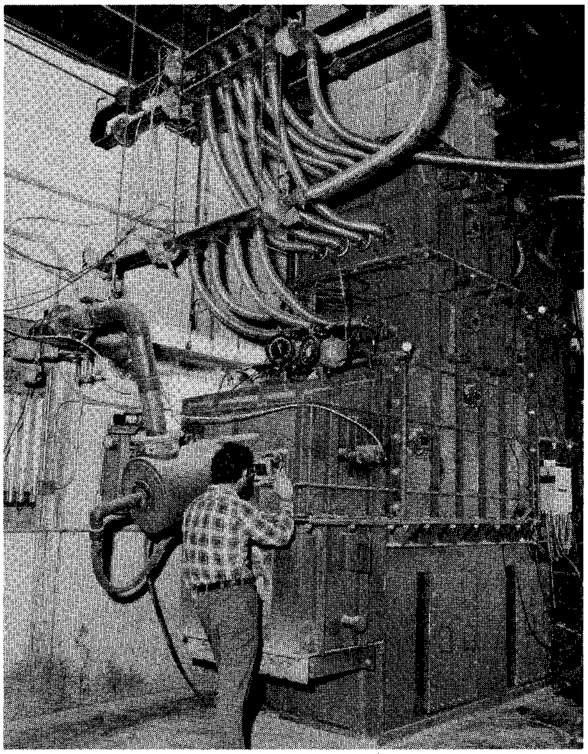


Figure 11. Riley Pilot MSW Combustion Facility — Combustor Section

Table III
Comparison of Riley Pilot Data with Field Data — Baseline Testing

	Field Test Unit	Riley Pilot Unit
Test	21	7
Load, MBtu/hr	37.5	2.36
Excess Air, %	73	70
OFA Flow, %	34	38
OFA Configuration	Std.	Std.
Combustion Products		
O_2, %	9.3	8.7
CO_2, %	10.1	10.9
CO, PPM	29	27
THC, PPM	0	0
NO_x, PPM	134	142
Reburn Zone Temp., °F[1]	2220	2181
Residence Time to Furnace Exit, sec.	~3.8	~2.0

[1]Estimated from actual measurements of FEGT.

In-furnace gas composition and temperatures are measured as desired through various sampling ports located throughout the combustor. A data acquisition and computer system is used for direct on-line data analysis of various test conditions.

Similar to the testing performed at Olmsted County, baseline testing was first conducted in the Pilot MSW Combustion Facility to ensure the results were comparable to the field data. Normal operating conditions were simulated in regards to excess air, % OFA flow, OFA and UGA flow distribution and the burning profile of the processed MSW on the grates.

Figure 12 shows the computer output for a typical baseline performance test during normal or standard operating conditions. Pertinent information regarding load, flue gas composition, furnace zone stoichiometric ratios (SR), temperatures (T) and residence times (t) are identified as well as the actual fuel and air flows. NO_x, CO and THC emissions for this one test measured 142, 27 and 0 PPM, respectively. For all the baseline testing under normal operating conditions the NO_x, CO and THC emissions varied as follows:

NO_x	120-165 PPM
CO	10- 50 PPM
TCH	0- 2 PPM

The furnace exit temperature indicated in Zone 5 (1570°F) was actually measured with a high velocity temperature (HVT) probe while all the other furnace temperatures were calculated based on the amount of heat removed in each furnace section.

Comparing these results with the field data collected at Olmsted in Table III showed good agreement in regard to flue gas emissions and furnace temperatures. The only discrepancy discovered was with furnace residence time. The residence times at Olmsted were calculated to be approximately twice as long as the pilot unit because of the physical scale differences. However, based on the pilot testing performed at IGT, longer residence times are more beneficial for NO_x reduction. So, the test results obtained in the Riley Pilot unit, when testing the effects of gas reburning, should be conservative.

Additional baseline testing was performed in the Riley Pilot unit to evaluate the impact of varying OFA injection location on NO_x emissions. The normal or standard configuration is to introduce approximately 35% of the total combustion air through the lower front (LF), middle front (MF) and lower rear (LR) OFA nozzles. Refer to Figure 12 for the location of these nozzles. NO_x emissions during normal operation with 70% excess air averaged 120-165 PPM. However, introducing the same amount of OFA through only one location (LF or LR) caused an increase in NO_x to 200-220 PPM. CO emissions remained unchanged. The higher NO_x is attributed to greater turbulence and mixing in the lower furnace and a subsequent increase in fuel NO_x conversion.

Conversely, the lowest NO_x can be produced by completely closing the OFA and maintaining 50-60% total excess air. Tests showed that NO_x could be reduced to 109 PPM but CO emissions increased significantly to 150 PPM and THC emissions were measured to be 6 PPM. Again, similar to the field operating unit, operation of the OFA system in the pilot unit had a significant effect on controlling NO_x, CO and unburned THC emissions. Variations in excess air, unit load and undergrate air distribution had no appreciable effect on combustion performance and emissions.

Tests were then performed to evaluate the impact of gas reburning on reducing emissions. The primary variables focused on natural gas and FGR quantity, natural gas, FGR and OFA injection location and furnace stoichiometries. As summarized in Table IV, the initial results were very encouraging. This data was collected at 2.0-2.5 x 10^6 Btu/hr unit load with approximately 32-34% OFA. From a baseline NO_x level of 120-165 PPM, NO_x could be reduced to approximately 70-80 PPM or nearly 50%. Figure 13 shows the effect of reburn zone stoichiometric ratio on NO_x emissions both with and without gas reburning. Typically, this ratio averaged 1.4 without and 0.9 with gas reburning.

Riley Research Pilot Scale Combustion Facility
Reduced Data Page 1

Date: 11/29/88 Time: 11:00 Test Pt 7 .1 Min
Test Comment: RE-ENTERED DATA = FEST CORR
Fuel Comment: MSW
Combustor Comment: NONE

```
Heat Input (O2):   2.36 MBtu/Hr
  MSW (O2):        2.36 MBtu/Hr    100 %       433 lb/Hr
  Gas:                0 MBtu/Hr      0 %         0 lb/Hr
```

GAS	Meas.	@7%O2	@12%O2
O2 %	8.7	---	---
CO2 %	10.9	12.42	7.95
CO ppm	37	42	27
HC ppm	0	0	0
NOx ppm	194	221	142

```
                 ------------------
                 |   ZONE 6      .
                 | SR=   1.7    .--//---> CO ppm
                 | T=  1459 F   .--//---> HC ppm
                 | t=    .37 s _._        NOx ppm
                 | . . . . . . /
                 |   ZONE 5 /
                 | SR=   1.7\
                 | T=  1570 F\
                 | t=    .18 s |
                 | . . . . . . |
                 |   ZONE 4    |
                 | SR=   1.7   |
                 | T=  1620 F  |
                 | t=    .26 s |
        UFOFA--->| . . . . . . |<--UROFA
                 |   ZONE 3    |
                 | SR=   1.7   |
                 | T=  1711 F  |
                 | t=    .26 s |
        MFOFA--->| . . . . . . |<--MROFA
      LFOFA     _/   ZONE 2    |
            \_/    SR=  1.42   |
           __/     T=  2181 F  |
Feed    __/        t=    .44 s |
|    |_/. . . . . . . . . . . .|<--LROFA
|     . . . .      ZONE 1   \____
|_____      . .   SR=  1.06    . \__
     |       . . . T=  2525 F  .    |
     |\______   . . t=   .46 s .    \
     |      |    . . .         .     |<--Burner
     |  DGA |\____   . . . .   .    /
            |     \________ . . .   |
            |              \_____   |
            |     CGA      |     |  |
                           |BGA  |  |
```

Stream	MSW lb/Hr	Natural Gas lb/Hr	Heat Input MBtu/Hr	Air lb/Hr	FGR lb/Hr
Feed	433	----	2.36	----	----
Burner	----	0	0	0	----
DGA	----	----	----	0	----
CGA	----	----	----	1795	----
BGA	----	----	----	268	----
LFOFA	----	0	0	576	0
LROFA	----	0	0	121	0
MFOFA	----	----	----	554	----
MROFA	----	----	----	0	----
UFOFA	----	----	----	0	----
UROFA	----	----	----	0	----
Total	433	0	2.36	3313	0

Figure 12. Typical Computer Output from Riley Pilot Unit — Baseline Testing

Table IV
RILEY PILOT MSW COMBUSTION FACILITY
GAS REBURNING TEST RESULTS

	Stoichiometry					Injection Location			PPM @ 12% O_2			% NO_X
Test	Grate	Reburn	Total	% FGR	% NG	OFA	FGR	NG	NO_X	CO	THC	Reduction
7[1]	1.06	1.42	1.70	0	0	MF/LF/LR	—	—	142	27	0	—
37	1.26	1.10	1.48	13	13	UF/UR	LF	LF	97	25	2	32
38	1.18	1.01	1.48	15	15	"	"	"	74	60	0	48
39	0.95	0.86	1.27	15	10	"	"	"	56	106	5	60
40	0.97	0.87	1.28	13	10	"	"	"	76	32	1	46
41	1.04	0.90	1.32	15	14	"	LR	LR	76	82	4	46
42	1.05	0.91	1.34	13	14	"	"	"	71	98	6	50
43	1.05	0.94	1.37	15	11	"	"	"	71	84	1	50
44	1.36	1.15	1.69	13	15	"	LF	LF	88	93	0	38
45	1.09	0.94	1.37	15	14	"	"	"	83	29	1	42
46	1.10	0.99	1.45	15	10	"	"	"	93	31	1	35
47	0.95	0.86	1.31	15	9	MF/MR	"	"	102	35	2	28
48	1.09	0.94	1.43	15	14	MF/MR	"	"	89	26	1	37
49	0.97	0.85	1.29	17	13	UF/UR	LF/LR	LF	82	73	4	42
50	1.31	1.07	1.61	18	19	"	"	LF/LR	84	33	1	41
51	1.03	0.90	1.35	17	13	"	"	LF/LR	83	19	1	42
52	1.02	0.95	1.44	17	7	"	"	LR	78	25	1	45
53	0.99	0.87	1.31	17	13	"	"	LR	73	26	1	49

[1]Typical Baseline Test

The scatter in the data is due to variations in load, overall excess air, grate stoichiometry and gas injection location.

Gas reburning was indeed effective in controlling NO_X. The low levels of CO and THC emissions measured during the baseline testing would also remain low using gas reburning. CO emissions were measured at <25 PPM while THC emissions would remain at only a trace.

However, these favorable results were very dependent on the injection method and type of operation being used. The best approach for maximum emission reduction evaluated during this initial testing was to operate the reburning system as outlined below, which corresponds to Test 53.

- 17% FGR through LF and LR nozzles
- 13% natural gas through LR nozzles only
- 34% OFA through upper front (UF) and upper rear (UR) nozzles
- 31% overall excess air

All other system operating conditions remained the same as during the baseline testing. The resulting reburn zone stoichiometry for Test 53 was 0.87 while reburn zone residence time was calculated to be .91 seconds.

Introducing natural gas through the lower rear nozzles, immediately above the combustion grate, was also very effective during earlier tests (41-43) in reducing NO_X but CO emissions exceeded 80 PPM. The reason for this is because FGR was only being introduced through these same nozzles, and the high degree of turbulent mixing, resulting from introducing FGR through both the LF and LR nozzles, was not as pronounced.

Test 52 demonstrated that low levels of NO_X could still be produced when using only 7% natural gas for reburning. However, as shown in Figure 14, this occurred only when natural gas was introduced through the LR nozzles. Introducing gas through the LF nozzles for reburning would create a situation where the degree of NO_X reduction was much more dependent on the amount of natural gas being burned.

Tests 47 and 48 evaluated the effect of introducing OFA through the middle front (MF) and middle rear (MR) nozzles. This would produce shorter residence times for NO_X reduction reactions to occur in the reburning zone. Residence times for these tests were calculated to be only 0.65 seconds as compared to >0.90 seconds when introducing OFA

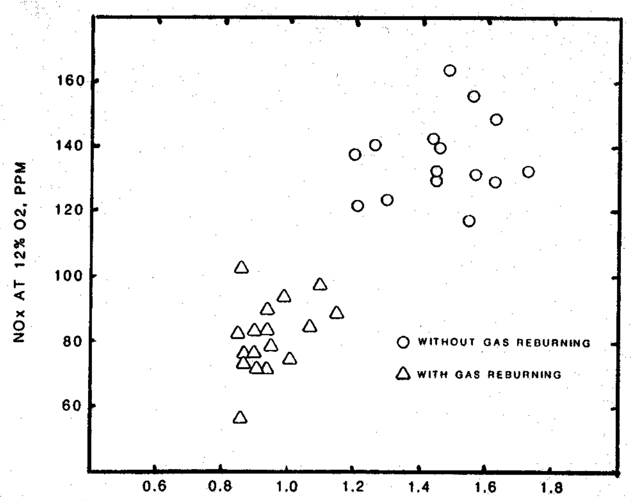


Figure 13. The Effect of Reburn Zone Stoichiometric Ratio on NO_x Emissions in Riley Pilot Unit

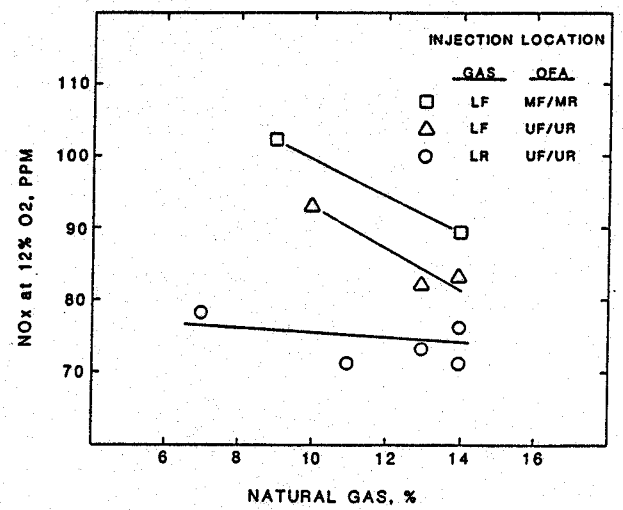


Figure 14. The Effect of Natural Gas Quantity on NO_x Emissions in Riley Pilot Unit

through the UF and UR nozzles. During these tests, NO_x emissions were only reduced 28-38% depending on the amount of gas reburning being used. This showed the importance of reburn zone residence time on NO_x reduction. Figure 15 graphically shows the effect of reburn zone residence time on NO_x emissions from this testing. As discussed later, additional testing, to study the effect of increasing this residence time to levels approaching 1.5 seconds, will be performed, since residence times of 2.0-2.5 seconds can be obtained in commercial installations.

Further analysis of the data to evaluate the effects of grate stoichiometry and overall excess air is currently being performed. Preliminary indications are that these variables do not have as significant an impact on emissions reduction as reburn zone stoichiometry, residence time and gas injection strategy. The data does show that low NO_x levels can be achieved without having to operate the grates at sub-stoichiometric combustion air levels.

The major findings based on initial testing of the gas reburning concept are as follows:

- 50% NO_x reduction was achieved with 7-15% natural gas reburning. Introducing the gas through the lower rear nozzles was the most effective.
- Effective burnout of CO and THC emissions can be achieved using gas reburning.
- The ability to control emissions using gas reburning is very dependent on injection location, residence time and reburn stoichiometry.
- A reburn zone stoichiometry of approximately 0.9 is effective in reducing NO_x while residence times >.85 seconds are required for sufficient reactions to occur, i.e. >40% NO_x reduction.
- It appears excess air levels can be reduced from the normal 70% to 30% using gas reburning without adverse effects on emissions.
- No significant increase in furnace exit gas temperature was measured with gas reburning operating.
- Operating with 7-15% natural gas improved furnace heat input stability resulting in less variation in the measured O_2 concentration at the furnace exit. The variation decreased from ±2% without to ±1% with gas reburning.

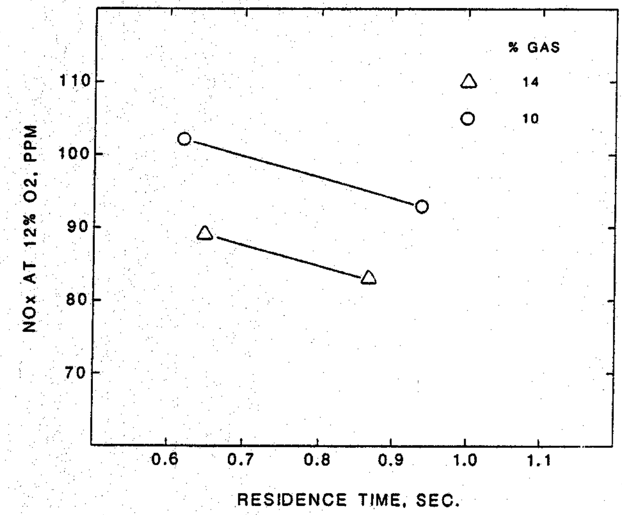


Figure 15. The Effect of Reburn Zone Residence Time on NO_x Emissions in Riley Pilot Unit — Lower Front Gas Injection

FUTURE WORK

Testing in Riley Stoker's Pilot MSW Combustion Facility will continue to further optimize the gas reburning system. Test variables will focus primarily on increasing reburn zone residence time and modifying lower furnace mixing in an effort to obtain >50% NO_x reduction while maintaining low CO and THC emissions. Modifications will be made to introduce OFA as high in the furnace as possible in order to maximize residence time. This will provide the capability of testing residence times >1.5 seconds. The best injection strategy determined during the initial testing will continue to be studied along with variations of this approach such as reducing the amount of FGR and changing FGR injection locations.

Following determination of the final gas reburning configuration, more detailed in-furnace testing will be performed to better characterize the gas composition and temperature history throughout the furnace both with and without gas reburning. Dioxin measurements will also be collected.

Assuming success with the final pilot scale testing, plans for a field demonstration test of this technology in a commercial operating facility will be finalized during Task 3. A detailed economic analysis of the gas reburning technology will be conducted to determine the economic advantage of utilizing natural gas for emissions control. Boiler performance analysis will also be performed to quantify the impact of a gas reburning system on overall boiler performance. If these final analyses are encouraging, a field demonstration program of the gas reburning technology will be implemented.

REFERENCES

1. Itse, D.C. and Penterson, C.A., "Riley-Takuma Technology for Refuse Combustion Plants," presented at the AFRC International Symposium on Incineration of Hazardous, Municipal, and Other Wastes, Palm Springs, California, November, 1987.
2. Yamagishi, M., Yokohama, T., Shibuya, E. and Nippon Kokan K.K., "Air Pollution Control for Waste-to-Energy Plants," presented at the AFRC International Symposium on Incineration of Hazardous, Municipal, and Other Wastes, Palm Springs, California, November, 1987.
3. Fleming, D.K., Khinkis, M.J., Abbasi, H.A., Linz, D.G. and Penterson C.A., "Emissions Reduction from MSW Combustion Systems Using Natural Gas," presented at the Energy from Biomass Conference, New Orleans, Louisiana, February, 1988.
4. Duvall, D.S. and Ruby, W.A., "Laboratory Evaluation of High-Temperature Destruction of Polychlorinated Biphenyls and Related Compounds," EPA/600/14.