NATURAL GAS REBURNING TECHNOLOGY FOR NO_x REDUCTION FROM MSW COMBUSTION SYSTEMS

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ABSTRACT

A technology for reducing emissions from municipal solid waste combustion systems through advanced combustion techniques is being developed in a joint program between the Gas Research Institute, Institute of Gas Technology, Riley Stoker Corporation and Takuma Company, Ltd. Pilot testing of natural gas reburning was first performed in the Institute of Gas Technology's pilot-scale furnace under conditions simulating the firing of 1.7×10^6 Btu/hr (0.5 MWth) of MSW. Pilot testing then continued in Riley Stoker Corporation's 3×10^6 Btu/hr (0.88 MWth), 7 ton/day, pilot-scale MSW combustor using actual MSW. In both test series, injection of up to 15% (HHV basis) natural gas reduced NO_x by 50–70% while maintaining or improving combustion efficiency as measured by CO and hydrocarbon emissions and temperature stability. This paper will review the test results and discuss the status of the full-scale field demonstration testing that is planned for 1990.

INTRODUCTION

The Gas Research Institute (GRI), the Institute of Gas Technology (IGT), Riley Stoker Corporation (Riley) and Takuma Ltd. of Japan (Takuma) have been developing natural gas reburning technology for reducing NO_x emissions from municipal solid waste (MSW) combustors. The goal of this program is to reduce NO_x emissions by more than 50% under the conditions found in MSW combustors. Because this is a cofiring technology, reductions in products of incomplete combustion (PIC) and a more constant thermal environment were also expected.

Development of this technology is being carried out in three phases:

(a) Task 1, Technology Assessment and Baseline Field Testing.

(b) Task 2, Pilot-Scale Development Testing at IGT and Riley Stoker.

(c) Task 3, Field Demonstration.

Baseline field testing was initially conducted during Task 1, at the Olmsted County Waste to Energy Facility in Rochester, Minnesota. This unit, rated at 100 ton/day, was designed and built by Riley Stoker Corporation. Baseline testing determined the current emission levels as well as the design guidelines or requirements for the gas reburning system. Flue gas recirculation (FGR) to the lower furnace replacing overfire air (OFA), may be necessary to maintain adequate gas mixing. Available residence times anticipated for the reburning zone are 1.0–2.5 sec. Available reburning temperature was estimated from this testing to be between 2000°F and 2200°F (1090°C and 1200°C).

The technology assessment conducted during

Task 1 also showed that the process is applicable to most mass burning MSW combustion systems. OFA near the grate is replaced with FGR to minimize oxygen availability while maintaining adequate gas mixing. Natural gas is injected with the FGR to create a fuel rich zone for NO_x destruction. OFA is added in the upper furnace to complete burnout. Pilot-Scale testing was first conducted at IGT under Task 2 in an oil fired furnace designed to simulate the chemical and thermal environment of MSW combustion. The purpose of these tests was to determine the feasibility of using natural gas reburning to control emissions. Results showed that natural gas reburning reduced NO_x by as much as 70% at the residence time and temperature typical of MSW Combustors. Results of the IGT testing along with the baseline field testing at Olmsted County are discussed in greater detail in Refs. [2–5].

Based on these favorable results pilot-scale testing continued under Task 2 with process development testing conducted at Riley Stoker. An engineering evaluation of retrofitting natural gas reburning to the commercial facility used in the baseline tests was also performed during the later part of Task 2. Results of this analysis were used in an economic comparison of natural gas reburning to an ammonia injection process (Thermal $DeNO_x$) used to also reduce NO_x emissions from MSW combustors. This paper discusses the final results of Task 2 and the results of the economic analysis. Plans are outlined for the field demonstration test of the gas reburning technology during Task 3 in 1990.

RILEY STOKER PILOT-SCALE MSW COMBUSTION FACILITY

In support of this research program, Riley Stoker modified their Pilot-Scale Combustion Facility (PSCF) to burn MSW. The lower sections of the furnace were removed and replaced with a mass fed, reciprocating grate stoker. The stoker is a model of the grate developed by Takuma Ltd. and licensed by Riley Stoker for use in the United States [1]. The furnace above the stoker is designed to simulate the chemical, thermal and mixing environment found in the field unit. Figure 1 shows the Pilot-Scale MSW Combustion Facility.

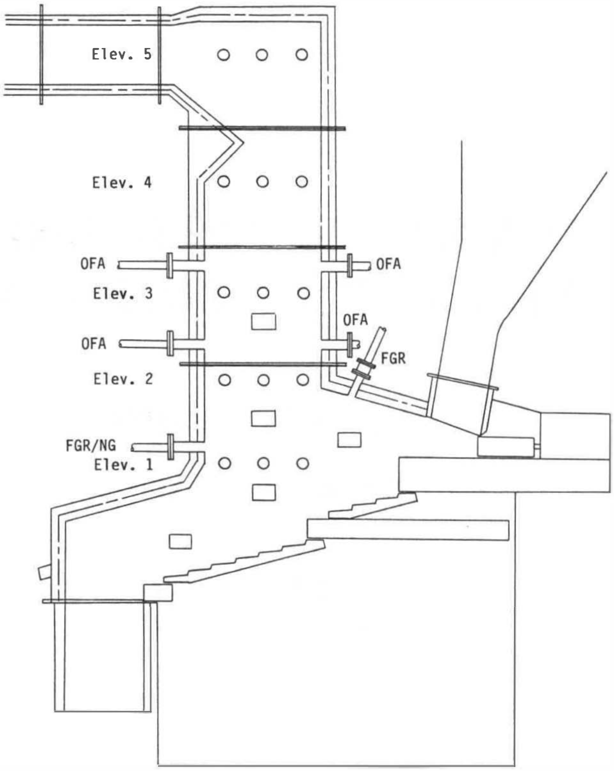

FIG. 1 RILEY STOKER PILOT MSW COMBUSTION FACILITY

Refuse enters the unit through a hopper and drops onto the feeder table. A single ram feeder pushes the refuse onto the drying and ignition grate. Fuel dries and pyrolyzes on the drying and ignition grate. Burning refuse falls onto the combustion grate where most of the combustion occurs. A small portion of this grate is partitioned off to act as a burnout grate. The burnout grate operates with high excess air to complete burnout.

The system was designed to burn processed MSW at a capacity of 3×10^6 Btu/hr (0.88 MWth). Fuel comes from a refuse facility in Biddeford, Maine. It has been shredded, magnetically separated, and air classified. The size (6 in. top size) is appropriate for the small scale of the pilot combustor and the absence of metals alleviates some fuel feed problems. Table 1 compares the test fuel to the MSW burned at Olmsted.

Flue gas is analyzed for the following gases: O_2, CO_2, CO, NO_x, SO_2, and HC. Flue gas samples are normally withdrawn from the exit of the convection section. However, during selected tests, samples were withdrawn from the furnace and analyzed for composition. Gas temperatures were measured using a suction pyrometer. Solid circles on the furnace section in Fig. 1 shows the location of the in-furnace sampling ports.

RILEY STOKER PILOT-SCALE RESULTS

The facility was first run at a condition to simulate baseline operation in a commercial facility. Table 2

TABLE 1 FUEL ANALYSIS COMPARISON

	Olmsted County Raw MSW	Riley Unit Processed MSW
Moisture, %	16.88	18.19
Volatile Matter, %	29.12	57.90
Fixed Carbon, %	13.95	11.70
Ash, %	40.05	12.21
Sulfur, %	0.64	0.21
Carbon, %	27.52	34.49
Hydrogen, %	2.96	4.48
Nitrogen, %	0.81	0.35
Oxygen, %	11.14	30.07
HHV, Btu/lb (as rec'd)	5192	5447
Paper, %	70.0	75.8
Plastic, %	15.0	6.0
Miscellaneous, %	10.0	18.2

KJ/Kg = Btu/lb x 2.326

TABLE 2 COMPARISON OF PILOT-SCALE TEST DATA WITH BASELINE FIELD TEST DATA

	Field Test Unit	Riley Pilot Unit
MSW Heating Value, Btu/lb	5192	5447
Load, 10^6 Btu/hr	33.5	2.36
Excess Air, %	73	70
OFA Flow, %	34	38
OFA Configuration	Standard	Standard
Combustion Products		
O_2, %	9.3	8.7
CO_2, %	10.1	10.9
NO_x, ppm	134	142
CO, ppm	29	27
THC, ppm	0	0
Furnace Exit Temperature, °F	1620	1570
Reburn Zone Temperature, °F(1)	2220	2181
Residence Time to Furnace Exit, S	3.8	2.0

[1] Calculated from Measured Furnace Exit Temperature

KJ/Kg = Btu/lb x 2.326
MWth = Btu/hr x 0.293
°C = (°F - 32) ÷ 1.8

compares the operation and emissions of the pilot-scale facility to the baseline field test results. Excess air and the overfire air (OFA) configuration and amount were similar during both sets of tests. NO_x concentration was within 10 ppm of the commercial system and CO was nearly identical. Therefore, scaling the results from the pilot-scale facility to a commercial facility was not a major concern. Note that all NO_x emissions are corrected to 12% O_2. The next set of tests in the pilot facility was to evaluate gas reburning.

During the gas reburning tests, the stoichiometric ratio at the grate was reduced to less than 1.10. Flue gas replaced the overfire air in the region just over the fuel bed. Natural gas entered with the flue gas, through the center jet of coaxial jets. The resulting reburn zone had a stoichiometry between 0.85 and 0.95. Residence time in the fuel rich zone was varied by changing the overfire air elevation.

Figure 2 shows the effect of reburn zone residence time on NO_x emissions. Longer residence time increased NO_x reduction. NO_x emissions were about 70 ppm (50% reduction) with a reburn zone residence time of 0.9 sec. Increasing the reburn zone residence time to 1.4 sec reduced NO_x to 45 ppm (70% reduction).

Figure 3 shows the effect of reburn zone stoichiometry on NO_x emissions for three different residence times. NO_x decreases as the reburn stoichiometry is reduced. At a reburn stoichiometry of 0.9 NO_x was between 45 and 70 ppm depending on reburn zone residence time. Up to 50% NO_x reduction was achieved with a superstoichiometric reburn zone. This was substantiated during tests with only FGR, and no natural gas. Similar results have been achieved with FGR in commercial units by Takuma Ltd, in Japan. Natural gas reburning improves NO_x reduction, and reduces CO emissions which are a problem with FGR alone.

Figure 4 shows NO_x versus CO with and without reburning. NO_x as a function of CO was similar for the field unit and pilot-scale system in the baseline configuration. The NO_x versus CO curve was lower during reburning than for the baseline. Thus low CO emissions can still be maintained when NO_x is reduced by 50–70%.

Furnace observations and in furnace measurements indicate that combustion occurs in a narrow flame at the interface of fuel-rich pyrolysis gases and air from the combustion and burnout grates. There is a tendency toward stratification of gas composition from the drying and ignition grate to the burnout grate. Therefore, the location for natural gas injection, was as im-

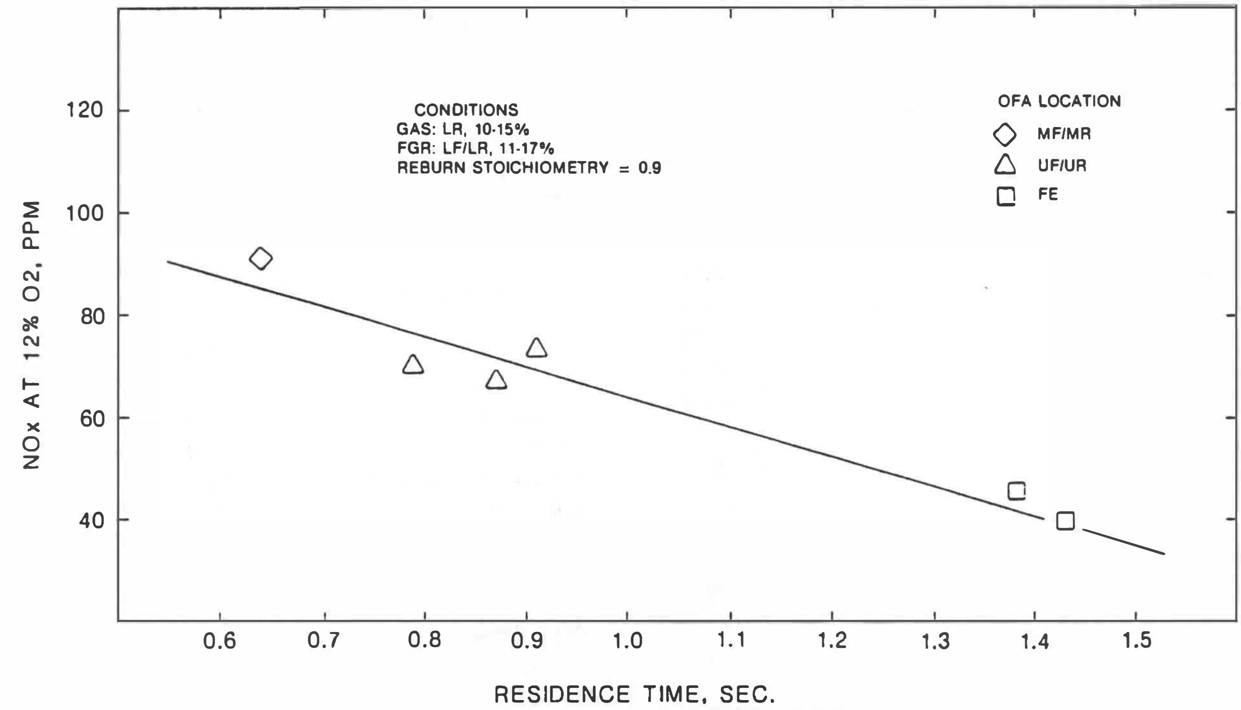

FIG. 2 THE EFFECT OF REBURN ZONE RESIDENCE TIME ON NO_x EMISSIONS

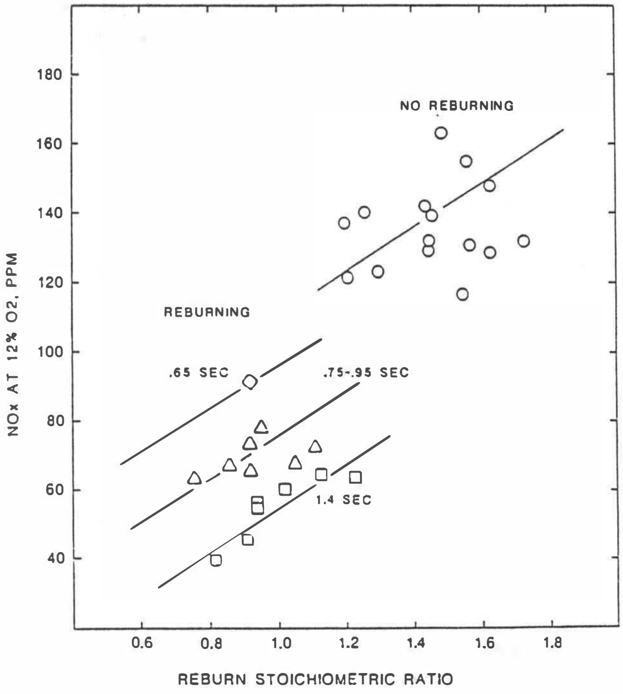

FIG. 3 THE EFFECT OF REBURN ZONE STOICHIOMETRY ON NO_x EMISSIONS

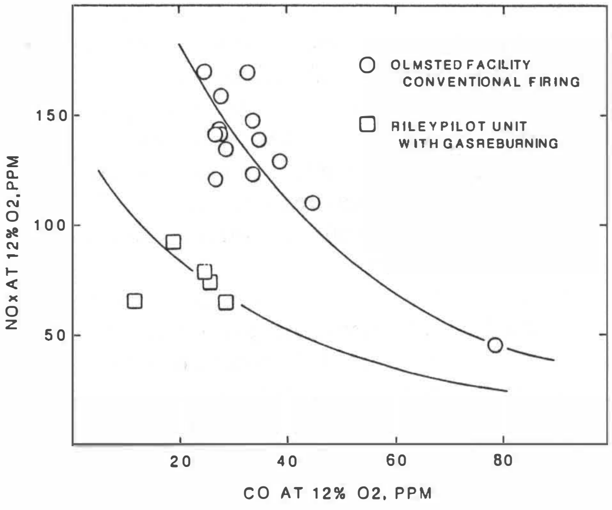

FIG. 4 COMPARISON OF NO_x AND CO EMISSIONS FOR BASELINE AND REBURNING OPERATION

portant as the reburn zone stoichiometry for reducing NO_x emissions.

Figure 5 shows effect of natural gas injection location. Natural gas quantity had less effect on NO_x reduction when natural gas was injected through the lower rear ports over the burnout grate. Injecting natural gas through the lower front ports, adds fuel to an already fuel rich region of the furnace, requiring more gas to affect local stoichiometry. Injecting natural gas through the lower rear ports mixes the natural gas with the flame from the fuel lean side of the furnace. Less gas was required to affect the stoichiometry of the near stoichiometric flame.

In addition to low NO_x emissions, reburning improves the stability of operation. Figure 6 shows traces of O_2 and CO measured at the furnace exit with and without natural gas reburning. The addition of reburn natural gas dampened the excursions, providing a more constant combustion environment.

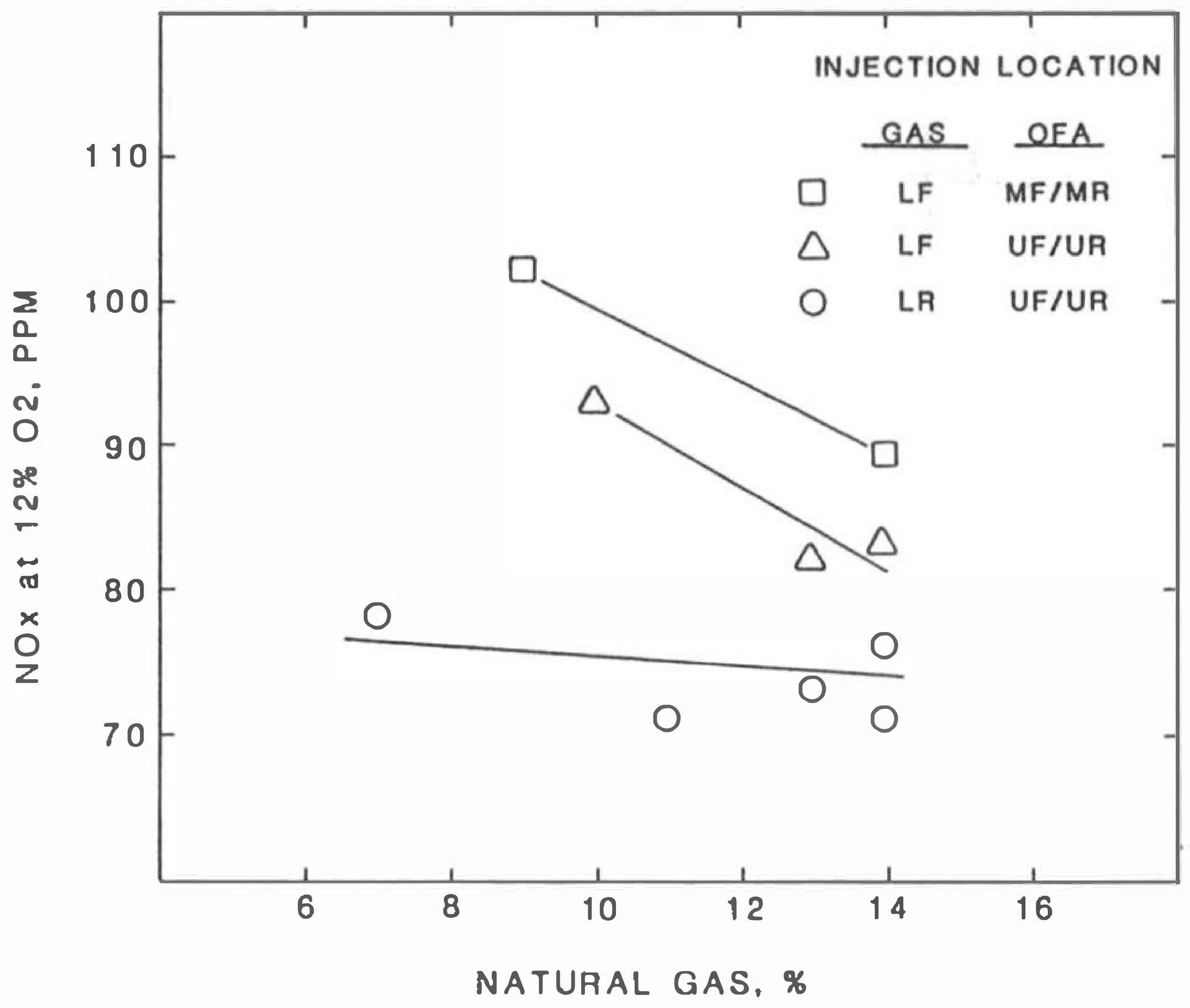

FIG. 5 THE EFFECT OF NATURAL GAS INJECTION LOCATION ON NO_x EMISSIONS

ENGINEERING AND ECONOMIC EVALUATION

Retrofitting natural gas reburning to the Olmsted County facility was evaluated for its impact on boiler performance. Major equipment is as follows:

(a) Flue Gas Recirculation Fan
(b) Flue Gas Recirculation Ductwork
(c) Natural Gas Injection and Control System
(d) New Overfire Air Ductwork
(e) New Overfire Air Ports

Calculations of the furnace and backpass heat transfer were run for MSW alone. The calculations agreed with the results of the baseline field tests to within 1.5%. Performance predictions for reburning were then made using the calibrated models. Table 3 shows the results of this study.

Reduced excess air during reburning increases unit efficiency by nearly 2.0%. The furnace exit gas temperature (FEGT) and superheater inlet temperature increased by about 25°F (15°C). The maximum temperature limit at the superheater inlet is 1400°F (760°C) to minimize corrosion. For the reburn case shown, this temperature was 1378°F (748°C). It is our intent during the demonstration test to maintain the same MSW input in addition to the reburning gas. In order to maintain acceptable superheater inlet gas temperatures, flue gas recirculation will be introduced at the superheater inlet. Steam production would then increase. The predicted performance analysis for this case was not complete at the time this paper was written.

An economic analysis of the reburning condition with the higher steam flow production was performed. The results are summarized in Table 4. Table 4 compares the natural gas reburning retrofit cost to the cost of retrofitting Thermal $DeNO_x$ to the Olmsted County unit. Installation costs of the two systems are comparable.

Neither process requires significant maintenance. However, natural gas and FGR are significant operating costs, which are not found in Thermal $DeNO_x$. If the additional steam produced in the reburn design can be used as process steam or for electricity production, the income derived from this extra steam more than compensates for the increased operating costs. Assuming the MSW processing remains constant, and the increase in steam production can be used, the process can provide an operating cost credit of $27,012/year. Thermal $DeNO_x$ results in a $50,200/year operating cost debit.

This evaluation was based on retrofitting these NO_x control technologies to existing systems. Economics for the application of natural gas reburning should improve for new units designed for reburning.

CONCLUSIONS

Pilot-scale combustion studies showed that natural gas reburning can reduce NO_x emissions by 50% or more. During pilot-scale testing other benefits were also observed. Emissions of CO and total hydrocarbon emissions were comparable to, or lower than during baseline operation.

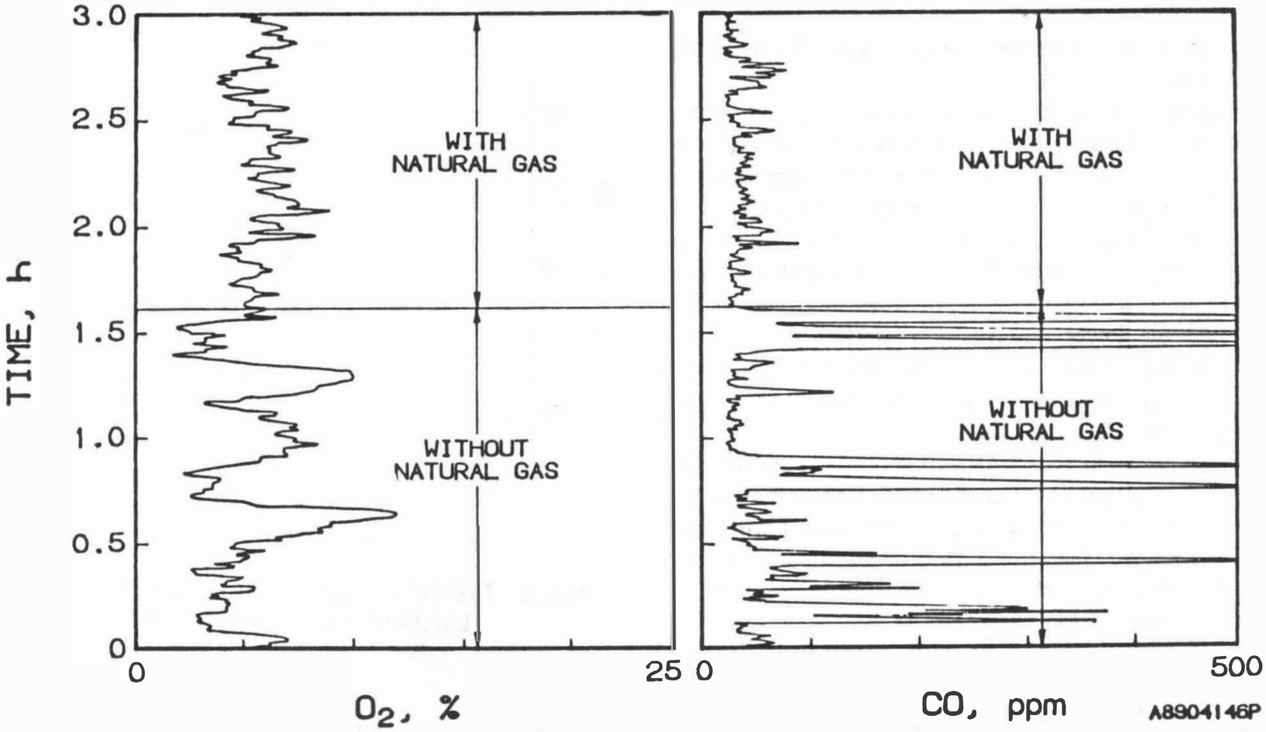

FIG. 6 THE EFFECT OF REBURNING ON STABILITY OF OPERATION

TABLE 3 BOILER PERFORMANCE IMPACT OF RETROFITTING OLMSTED COUNTY WITH GAS REBURNING
(Predicted Performance)

CONDITION	BASELINE 2/86 DESIGN	 8/87 MEASURED	REBURN
Gas Reburn, %	- -	- -	15
Excess Air, %	80	73	40
FGR, %	- -	- -	15
Total Heat Input, x 10^6 Btu/hr	37.5	33.5	32.6
Full Load, %	100	98	98
MSW Input, lb/hr	8340	6456	5347
Gas Input, lb/hr	- -	- -	224
Total Air Flow, lb/hr	49500	38798	33196
OFA Air , lb/hr	9910	13056	11262
OFA Elevation	Std.	Std.	New
OFA, %	20	34	34
Steam Flow, lb/hr	24095	23500	23500
FEGT, °F	1381	1619	1647
SH Inlet Gas, °F(1)	1170	1360	1378
Econ. Exit Gas, °F	400	420	407
Total Flue Gas Flow, lb/hr	55800	55456	54013
SH Spray Flow, lb/hr	332	218	139
Reburn Residence Time, Sec	- -	- -	2.3
Reburn Stoichiometry	- -	- -	0.9
Reburn Temperature, °F	- -	- -	2125
Boiler Efficiency, %	67.2	74.96	76.94

(1) Maximum Allowable Gas Temperature = 1400°F.

KG/hr = lb/hr x 0.4536

°C = (°F - 32) ÷ 1.8

TABLE 4 RETROFIT COST COMPARISON BETWEEN NATURAL GAS REBURNING AND THERMAL DENO$_x$

NATURAL GAS REBURNING			THERMAL DeNOx		
			Purchased Equipment:	-	$127,710
			Exxon Field Labor:	-	$104,500
			Exxon Indirect Cost:	-	$220,590
Purchased Equipment:	-	$257,000	Exxon Royalty Fee:	-	$ 37,150
Installation & Startup:	-	$226,000	Riley Engineering Cost:	-	$ 33,960
Design Engineering:	-	$111,000	Riley Site Engineer:	-	$ 40,400
N.G. Reburning System Cost:	-	$594,000	DeNO$_x$ System Cost:	-	$564,310
Natural Gas Cost:	-	$148,750/yr	Ammonia Cost:	-	$ 8,300/yr
Steam Credits:	+	$207,844/yr	Carrier Steam Cost:	-	$31,400/yr
Maintenance Cost:	-	$ 8,305/yr	Maintenance Cost:	-	$10,000/yr
Power Cost:	-	$ 23,777/yr	Power Cost:	-	$ 500/yr
Operating Credit:	+	$ 27,012/yr	Operating Cost:	-	$50,200/yr

Natural gas reburning improved the operational characteristics of the pilot-scale unit. Excursions of O_2 and CO concentrations in the flue gas were virtually eliminated. More consistent combustion provides better steam production control and a more constant thermal environment. Eliminating spikes in CO results in lower average CO emissions. Under these favorable combustion conditions, emissions of dioxins and furans may also be reduced.

Natural gas reburning can be a cost effective alternative to Thermal DeNO$_x$. For the case studied reburning provides an operating credit of $27,012/year. Economic benefit of reburning depends on available steam demand, natural gas and electricity costs, and the ability to operate the system at higher than designed heat input.

Pilot-scale testing demonstrated that natural gas reburning can achieve the program goals for NO$_x$ reduction. And, an additional benefit is reduced CO and unburned HC emissions. The process should be economically competitive with other NO$_x$ reduction technologies. The program is now ready to move forward to a field demonstration. Design of the full-scale system has begun and testing is scheduled for 1990.

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Key Words: Aluminum; Combustion; Emissions; Mass Burn; Pilot Scale; Refuse; Testing