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NATURAL GAS APPLICATIONS IN WASTE MANAGEMENT

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IGT

INTRODUCTION

The Institute of Gas Technology (IGT) is engaged in several projects related to the use of natural gas for waste management. These projects can be classified into four categories:

- Cyclonic incineration of gaseous, liquid, and solid wastes
- Fluidized-bed reclamation of solid wastes
- Two-stage incineration of liquid and solid wastes
- Natural gas injection for emissions control.

CYCLONIC INCINERATION

A cyclonic combustor provides an ideal device for waste incineration. Its unique flow pattern, which combines both tangential swirl and axial flow recirculation (Figure 1), promotes excellent mixing of fuel and waste. This, in turn, improves the rate of incineration while ensuring uniform temperature distribution. Thus, cold spots, which cause ineffective incineration, are avoided, as are hot spots, which produce excess NO_x. Both cause air pollution.

IGT operates a 3 million Btu/h (MMBtu/h) cyclonic incinerator test facility at its Energy Development Center (EDC).[1] This facility includes equipment for the controlled feeding of all types of waste and an exhaust gas treatment system that consists of a direct quencher, air heater, baghouse, and scrubber. Semiautomatic computer-assisted controls tie the individual components together and provide computerized data acquisition by a full range of analytical instruments that continuously monitor incinerator operation and flue gas emissions.

The heart of the facility, the cyclonic waste incinerator (Figure 2), features a cylindrical combustion chamber that provides high specific-heat densities and promotes the turbulence required for high waste-destruction efficiency. The unit incorporates interchangeable cylindrical sections that sit atop a refractory-lined base that also serves as an ash/slag receiver.

For versatility, the interchangeable sections incorporate a water-cooled annulus and an interior refractory lining. Most of the sections provide openings for collecting data or for viewing the firing operation. These

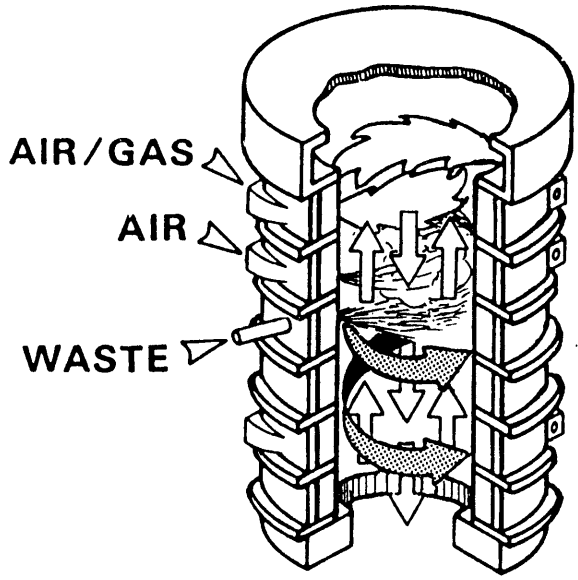

Figure 1. MIXING PATTERNS IN A CYCLONC INCINERATOR

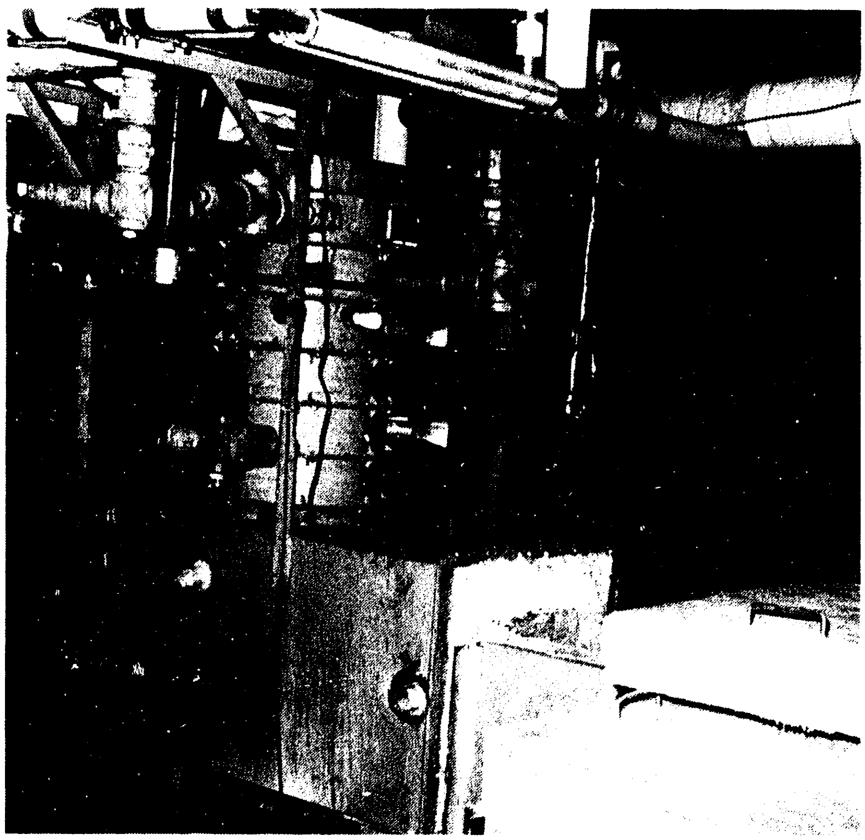

Figure 2. CYCLONIC INCINERATOR TEST FACILITY

openings allow the use of water-cooled probes to measure incineration temperatures or collect gas samples.

Incineration of Low-Btu Gas

Prior to construction of the 3 MMBtu/h test facility, IGT tested a 3 MMBtu/h two-stage cyclonic incinerator for incinerating low-Btu gases containing hydrogen and carbon monoxide (CO). These gases were doped with hydrogen sulfide and ammonia to simulate sulfur and fuel-bound nitrogen. The results of these early tests show that stable operation was obtained at the 3 MMBtu/h firing rate with a waste gas of 67 Btu/SCF using gas and combustion air preheats of 335° and 750°F, respectively. These preheats were used to stabilize the combustion. Higher gas preheat (490°F) and a lower firing rate (2 million Btu/h) were needed to stabilize combustion of a 54 Btu/SCF waste gas.

As shown in Figure 3, CO concentrations below 50 ppm, which indicate good burnout, were achieved in the exhaust gases when excess air greater than 15% was used. Low NO_x emissions, below 300 ppm, on the other hand, required the use of less than 7% excess air and, hence, resulted in poorer burnout. Although this incinerator did not simultaneously achieve low NO_x and low CO (good burnout) because of insufficient residence time in the first stage, it did provide the data and experience needed to design and construct IGT's current test facility. Subsequent testing on other IGT facilities, described below, shows that the simultaneous reduction of NO_x and CO is possible with natural gas injection.

Incineration of a PCB Surrogate

Carbon tetrachloride (CCl_4) was selected as a surrogate to simulate the combustion of polychlorinated biphenyls (PCBs), one of the more ominous hazardous wastes facing the natural gas industry today.

To measure the effectiveness of CCl_4 incineration, a modified U.S. Environmental Protection Agency (EPA) analytical train was used to collect flue gas samples for subsequent analyses by gas chromatography/mass spectrometry. This method provides a sensitivity of about 99.9999% (also known as "six-9's") in the measurement of the destruction and removal efficiency (DRE), at a CCl_4 feed rate of 1 lb/min and a natural gas firing rate of 1 MMBtu/h.

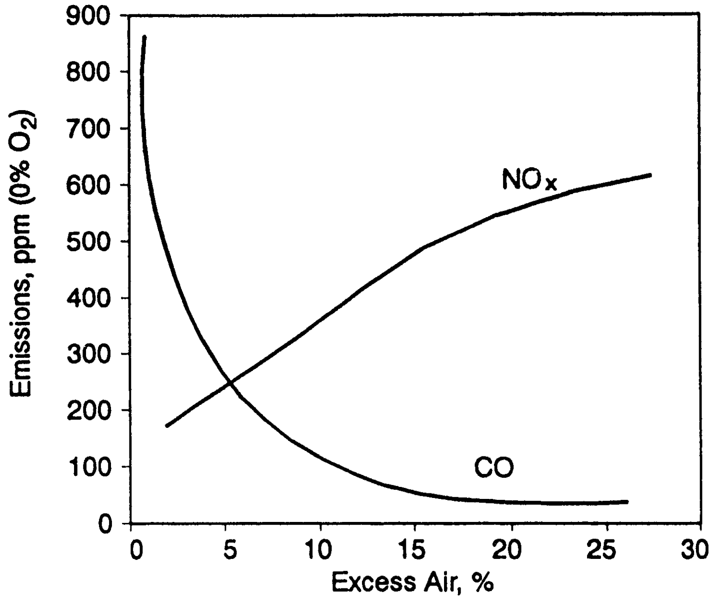

Figure 3. CYCLONIC INCINERATION OF A TYPICAL LOW-Btu GAS (67 Btu/SCF)

In most tests, a combustion air preheat of 800°F was used:

Firing Rate, MMBtu/h	CCl_4 Flow, lb/min	Exhaust Gas Temperature, °F	DRE
0.8	1.44	2098	99.99997
0.8	3.26	2163	99.99997
0.8	1.05	2032	99.99996
0.8	1.05	2485	99.99992

In all cases, a DRE greater than six-9's was achieved with a hot gas residence time of only 0.25 seconds, clearly demonstrating the effectiveness of cyclonic incineration for destroying toxic wastes.

The system was also equipped with caustic injection to neutralize the hydrochloric acid (HCl) resulting from the destruction of the CCl_4:

$$CH_4 + CCl_4 + 2O_2 \longrightarrow 2CO_2 + 4HCl$$

$$HCl + NaOH \longrightarrow H_2O + NaCl$$

The caustic was injected directly into or immediately downstream of the incinerator, thereby converting the acid to a harmless salt and avoiding acid corrosion of downstream equipment. Although this technique requires further testing, it holds good promise for eliminating a downstream gas scrubber and all of its attendant corrosion problems.

Incineration of Industrial Wastewaters

Industry produces millions of gallons of wastewater daily, a practice which is becoming less acceptable to the clean earth initiatives now being implemented throughout the U.S.A. One way to dispose of these wastewaters is on-site cyclonic incineration with natural gas. If it is done properly, most of the energy value in the natural gas, as well as any in the waste, can be recovered from the exhaust gases.

For these reasons, IGT conducted several tests to determine the optimum conditions for incinerating typical dairy product wastewaters. These wastewaters contained 35% to 44% solids with dry heating values of 3000 to 6000 Btu/lb and ash fusion (fluid) temperatures of 2700° to 2800°F. Typical operating conditions for these tests were --

Type	Solids Concn., wt %	Heating Value, Btu/lb-wet	Wastewater Feed Rate, gal/h	Natural Gas Firing Rate, MMBtu/h
Wastewater A	35	3270	15	0.5
Wastewater B	39	1600	9	0.6
Wastewater C	44	2600	14	0.8

The results of these tests demonstrate that low-heating-value wastewaters can be effectively incinerated using a natural gas-fired cyclonic incinerator. In general, stable operation was obtained and combustion efficiencies exceeding 99.9% were attained at total firing rates exceeding 1 MMBtu/h, 20% to 60% of which was contained in the wastewater feed. Combustion intensities of 250,000 Btu/h-ft^3 were also achieved. The data generated in the test facility were used to design, construct, and operate a 40-gal/h demonstration unit at a midwest dairy processing plant.

IGT is currently teamed with a major aluminum producer and an incinerator manufacturer to continue the development of this technology to process spent aluminum potliners. The cyclonic incinerator will be operated in the slagging mode to destroy the organics in the potliners while converting the inorganics into a benign glassy solid residue.

FLUIDIZED-BED RECLAMATION

During the energy crises years, when coal gasification was in vogue, IGT developed a fluidized-bed gasifier that relied upon a sloping gas distribution grid to create the intense mixing needed to avoid sintering of the hot coal/ash particles being gasified. This concept was later applied to incineration where the intense mixing is used instead to provide the gas/solids contact needed for complete burnout. (See Figure 4.) In operation, the sloping grid acts as an aerated slide feeding the bed solids into a central throat, where they are recirculated to the top of the bed by a natural gas/air jet (flame) that also incinerates combustible materials contained in the bed solids. The jet can be controlled to allow some of the bed solids to exit through the throat, thus serving as a nonmechanical pneumatic solids discharge valve, as well as an incineration flame.

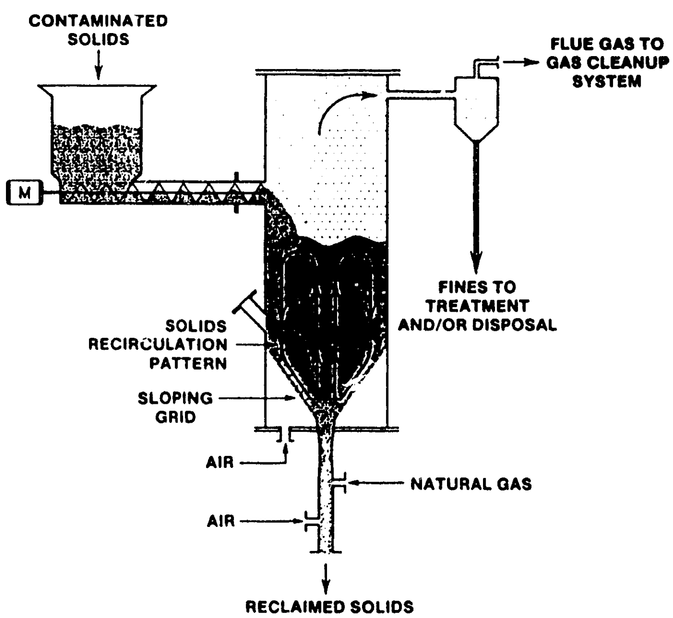

Figure 4. FLUIDIZED-BED SLOPING-GRID RECLAIMER

This system is especially useful for decontaminating inert solids, such as spent foundry sand, used blasting grit, or contaminated soils.

IGT has tested a 1-ton/h, 3-foot-diameter sloping-grid reclaimer for reclaiming both spent foundry sand and used blasting grit.[2] Because the sand contains about 1% organic residues and the grit 1% to 2% paint chips; both are classified as hazardous wastes in many states. In addition to achieving successful burnout of the organic matter, the sloping-grid reclaimer removes other undesirable materials, such as clay fines in the foundry sand and heavy metals in the grit. These materials are ultimately elutriated from the top of the fluidized bed because they are too small (do not have the gravitational force) to exit against the upward jet velocity at the solids discharge throat. Thus, the sloping grid serves two purposes, providing the mixing needed for burnout and, coupled with the central jet, the valving action needed to control both the quantity and type of solids discharged.

The effectiveness of decontaminating spent foundry sand can be characterized by the decrease in both clay content and organic matter. (Organics are measured as loss on ignition, or LOI analysis). Two types of foundry sand were reclaimed at IGT:

	Clay, %			LOI, %		
	Before	After	% Removal	Before	After	% Burnout
Sand A	2.2	0.1	95	1.0	0.02	98
Sand B	1.1	0.1	91	0.9	0.06	93

These results show a 91% to 95% clay removal and a 93% to 98% organic matter burnout. Also, the decontaminated sand was found to be acceptable for reuse, as determined by core strength tests conducted at the foundry. Thus, in addition to averting a hazardous waste problem, the reclaimed sand offsets considerable foundry expense. (New foundry sand costs up to $100/ton, and landfill costs for contaminated foundry sand range from $20 to $40 per ton.)

Used blasting grit can also be reclaimed using the fluidized-bed reclaimer. Eight U.S. Navy shipyards generate about 100,000 tons of used blasting grit every year. The anticorrosive and antifoulant coatings used to protect the underwater hulls and ballast spaces of oceangoing vessels must be removed every 2 to 5 years. Several different types of grit, including power plant coal slag and copper sinter slag costing $50 to $100/ton, are used to grit-blast these coatings.

Tests with both types of grit show that both can be reclaimed for reuse. After burnout in the fluidized-bed reclaimer, the Navy conducted extensive testing with both the coal and the copper slag and found that the reclaimed materials perform almost as well as new grit. Paint-removal efficiency and grit consumption were comparable to new grit. On the basis of these results, the Navy is planning to construct a 5-ton/h commercial demonstration unit at the Mare Island Naval Shipyard in California. If successful, this new technology could reduce the amount of new grit purchased and used grit landfilled by as much as 80%.

TWO-STAGE INCINERATION

IGT is now developing a two-stage incinerator that incorporates the features of both the cyclonic incinerator and the fluidized-bed reclaimer.[3] (See Figure 5). Waste materials are fed to the first-stage fluidized-bed, where they are incinerated at temperatures in the range of 2000° to 3000°F (hot zone). Fine solid materials or easily vaporized liquids contained in the feed, which would normally be carried out of the bed in the flue gas, are further incinerated at 1600° to 2200°F in the second-stage cyclonic after-burner located above the fluidized bed. This combination incinerator is able to process a wide variety of solid, liquid, and/or gaseous wastes in a single incinerator system. This system, because of its dual operating temperatures, ensures both high waste DRE and low gas emissions (CO, SO_x, and NO_x).

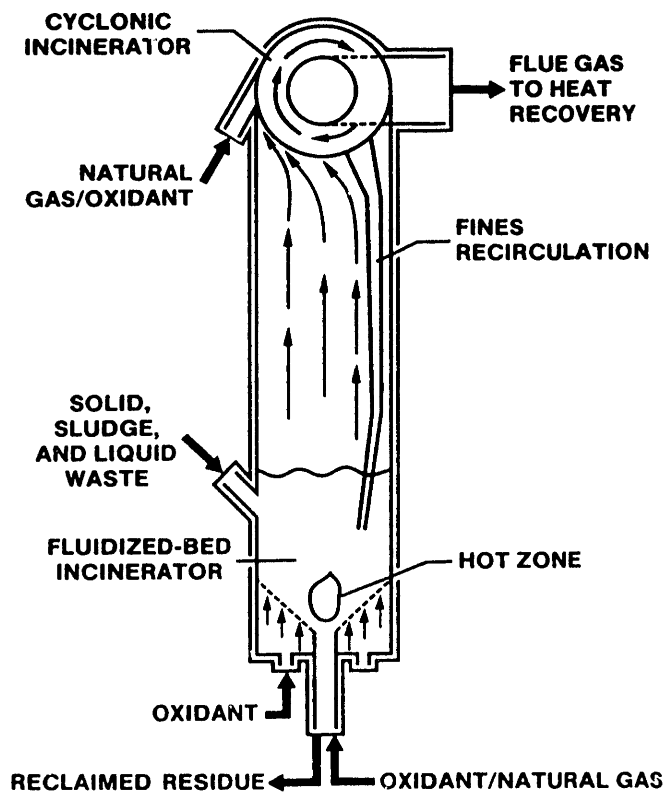

Figure 5. TWO-STAGE INCINERATOR

EPA and the Gas Research Institute (GRI) are co-funding the design, construction, and testing of a pilot two-stage incinerator for the thermal treatment of contaminated soils. These soils contain highly volatile hazardous liquid wastes that could easily vaporize and escape in the flue gas of single-stage incinerators. Operation of the pilot incinerator is scheduled for next year.

NATURAL GAS INJECTION

There are over 100 municipal waste-to-energy plants in the U.S.A., most of which emit about 200 ppm NO_x. As a result, EPA has announced its intention to limit NO_x emissions from MSW incinerators to be equal to or less than that obtained by the thermal de-NO_x process, which uses ammonia injection to reduce NO_x in the stack.

Natural gas injection is another promising method to reduce NO_x. Natural gas is injected into the furnace above the stoker grate, where it partially burns with the excess air normally used at the grate. (See Figure 6.) This injection creates a uniform reducing atmosphere, which decomposes the nitrogen compounds, such as ammonia (a typical NO_x precursor), formed at the grate into harmless nitrogen gas before these compounds can be oxidized to NO_x by the overfire air (OFA). Because the natural gas is injected upstream of the heat recovery (boiler) zone, essentially all of the heating value of the added gas can be recovered as steam.

IGT began a municipal solid waste (MSW) natural gas reburn project in 1987.[4] The project was divided into four phases:

- Commercial combustor characterization
- Furnace simulator tests
- Pilot combustor tests
- Field evaluation.

Commercial Combustor Characterization

Baseline data were obtained on one of the Riley-Takuma MSW combustors at the Olmsted County Waste-to-Energy facility in Rochester, Minnesota. This unit burns about 100 tons/day of MSW and produces about 25,000 lb/h of 625-psi steam.

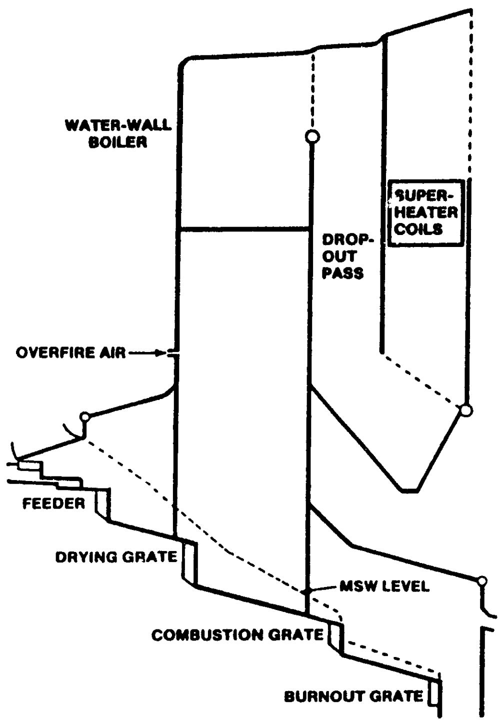

Figure 6. RILEY-TAKUMA MSW COMBUSTOR/BOILER

In normal operation, this unit produces about 125 to 175 ppm NO_x at the furnace exit. This high NO_x level is principally due to the use of excess air at the grate and additional OFA just above the grate. MSW combustors operate with 60% to 80% excess air to ensure complete combustion. Without OFA and at lower excess air, NO_x emissions can be reduced, but CO levels increase greatly:

		Furnace Exit, ppm (12% O_2)	
OFA	Excess Air, %	NO_x	CO
Normal	60-80	125-175	20-30
None	57	88	130
None	23	45	1300

These baseline data show that most MSW incinerators can reduce NO_x by eliminating OFA and reducing excess air. However, this results in incomplete combustion, as indicated by the high CO levels. The goal of natural gas injection is to reduce NO_x emissions without the corresponding increase in CO.

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 MSW stoker:

Component, %	Simulator	Baseline
O_2	8	8
CO_2	10	10
N_2	71	71
H_2O	12	11
NO_x, ppm	100-350	130
Temperature, °C	1065-1315	1215
Residence Time, s	1-5	3

In typical excess air operation (without natural gas injection), the furnace simulator produced relatively steady NO_x 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 eliminate NO_x precursors. As shown in Figure 7, in the first 3 seconds after natural gas injection, the NO_x emissions decreased from 225 to 75 ppm. Longer residence times produce very little additional NO_x reduction. These data show that if natural gas injection is to be effective, it must be injected into the MSW incinerator such that sufficient residence time is provided before the gas is cooled by the boiler tubes. (Temperatures above 1000°C are needed for effective natural gas injection.)

Pilot Combustor

Because of the encouraging furnace simulator tests, follow-up tests were conducted in the pilot MSW combustor at Riley Stoker's Research Center. A pulverized coal combustor was modified to simulate the commercial unit at Olmsted. Several different batches of MSW were tested at Riley Stoker.

Without natural gas injection, NO_x emissions ranged from 110 to 165 ppm, a fairly good simulation of the baseline results obtained in the commercial combustor. With 10% to 15% (percent of total heat input) natural gas injection, NO_x emissions were reduced by as much as 70%, depending on the

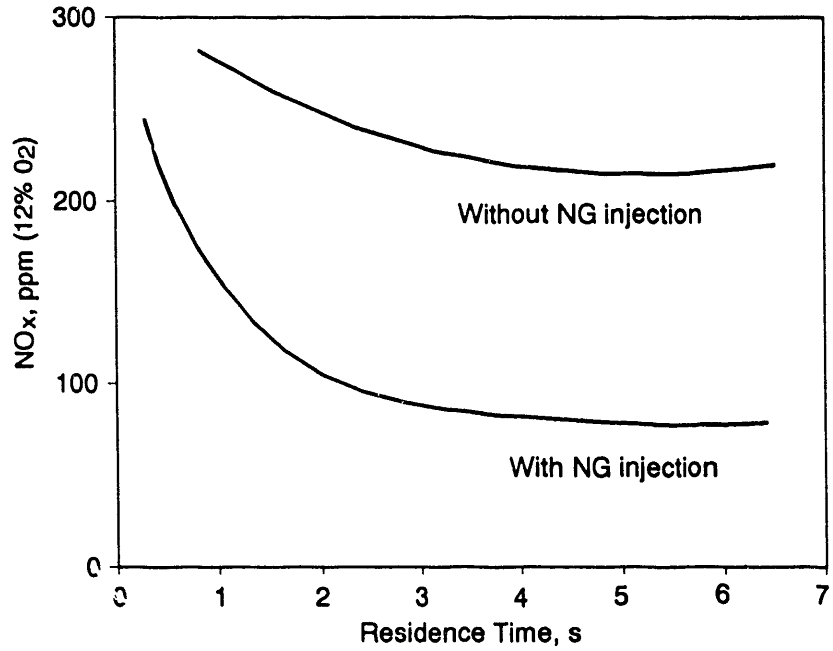

Figure 7. RESIDENCE TIME REDUCES NO_x IN THE FURNACE SIMULATOR

natural gas and OFA injection points and residence time in the reducing zone. As shown in Figure 8, NO_x emissions decreased from 100 to 130 ppm at a 0.6 seconds residence time to 40 to 80 ppm at a 1.2 seconds residence time. These results verify the beneficial effects of increased residence time observed in the furnace simulator tests.

Field Evaluation

Because of the promising results in the pilot combustor, the Olmsted combustor was modified to test natural gas injection. The results of these tests are very encouraging.[5] Natural gas injection simultaneously reduced both NO_x and CO. Furthermore, reductions to below 50 ppm NO_x and 32 ppm CO were achieved in several tests. These results were obtained using a residence time of about 2 seconds and 12% natural gas injection. Even less natural gas injection might have been effective had more residence time been possible. Conversely, even lower emissions might have been achieved with more residence time using the same natural gas injection.

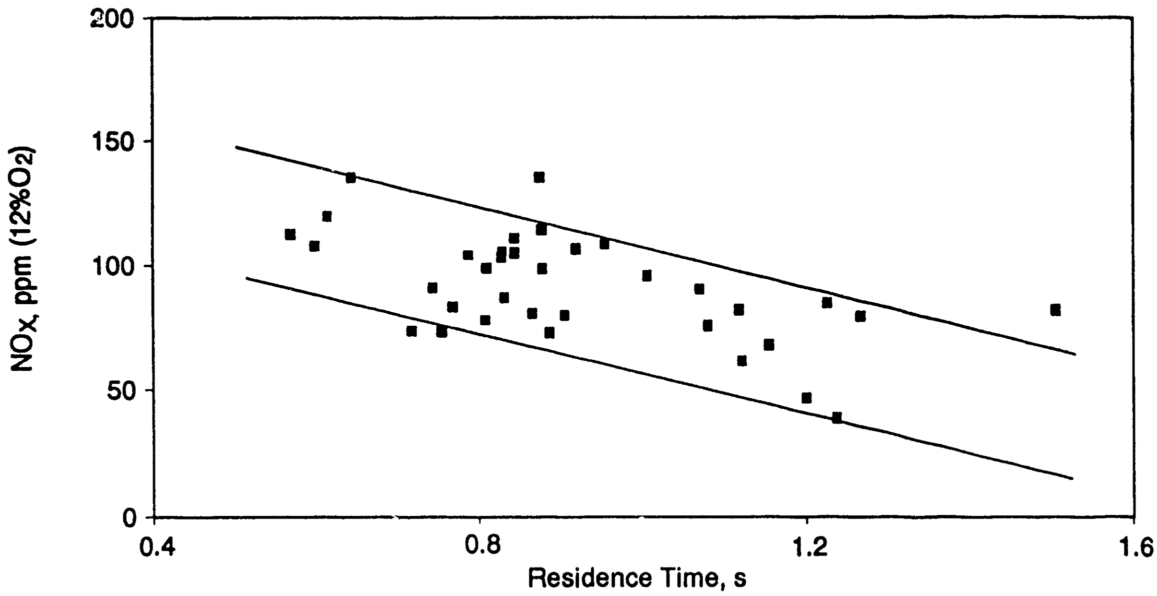

Figure 8. RESIDENCE TIME PLAYS AN IMPORTANT ROLE IN THE METHANE de-NOX PROCESS

The results of this test program demonstrate the effectiveness of natural gas injection for reducing NO_x while maintaining high combustion efficiency in MSW combustors. IGT believes that this new METHANE de-NOX process can be extended to refuse-derived fuel and other types of waste combustors, creating a new market for natural gas.

ACKNOWLEDGMENT

Many sponsors played important roles in the development of IGT's cyclonic incinerator and METHANE de-NOX process. Manpower and equipment were provided by Riley-Stoker Corporation and Takuma Company, Ltd. Considerable funding and guidance were provided by the Gas Research Institute, Brooklyn Union Gas Company, Minnegasco, Northern Illinois Gas Company, Northern Natural Gas Company, Peoples Gas Light and Coke Company, Southern California Gas Company, and IGT's Sustaining Membership Program member companies.

The Olmsted County Waste-to-Energy officials and plant personnel warrant special thanks for interrupting commercial operations to not only accommodate but also vigorously assist IGT researchers in the birth of a new process that can serve both the waste-to-energy and natural gas industries.

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