CONF-9106296--1

TI92 002493

READINESS THROUGH RESEARCH

THERMAL TREATMENT OF WASTES IN AN ADVANCED CYCLONIC COMBUSTOR

by

Hamid A. Abbasi
Mark J. Khinkis
Walter Kunc

Paper Presented at the

15TH ANNUAL ARMY ENVIRONMENTAL R&D SYMPOSIUM

Williamsburg, Virginia

June 25-27, 1991

INSTITUTE OF GAS TECHNOLOGY

3424 South State Street Chicago Illinois 60616

MASTER

IGT

THERMAL TREATMENT OF WASTES IN AN ADVANCED CYCLONIC COMBUSTOR

H. A. Abbasi, M. J. Khinkis and W. Kunc
Institute of Gas Technology
4201 West 36th Street
Chicago, IL 60632

ABSTRACT

IGT is developing an advanced waste combustion concept, based on cyclonic combustion principles, for application to a wide range of industrial wastes. In IGT's cyclonic combustor, a mixture of fuel and combustion air is fed tangentially at a relatively high velocity into a cylindrical chamber. The waste is injected either tangentially with the fuel or separately in a tangential, radial, or axial configuration. This approach provides high combustion intensity with internal recirculation of combustion products, which results in extremely stable and complete combustion, even at relatively low temperatures.

Compared with other types of waste combustors, the cyclonic unit offers several important advantages: better mixing and temperature uniformity, higher destruction and removal efficiency (DRE), a wider operating range, greater flexibility to variations in waste properties, molten-ash discharge capability, and more efficient heat recovery at reduced capital and operating costs.

IGT has performed three successful test programs involving cyclonic waste combustion for industrial clients. In one program, industrial wastewaters containing 40% to 50% organics and inorganics with heating values of 1600 to 3270 Btu/lb were combusted to 99.9% completion at only 2000°F. The low combustion temperature minimized the supplemental fuel required. In another program, simulated low-Btu industrial off-gases (55 to 65 Btu/SCF) were successfully combusted with stable combustion at 1900°F using air and waste preheat. Supplemental fuel was unnecessary because of the mixing that occurs in the cyclonic combustor. The conversion of fuel-bound nitrogen to NO_x was as low as 5%, and CO levels were in the range of 25 to 30 ppm. In the third program, CCl_4 (as a test surrogate for PCBs) was efficiently destroyed by firing natural gas or hexane. With 100% CCl_4 and natural gas firing, the DRE at 2200°F and a 0.25-second residence time ranged from 99.9999% to 99.99999%.

These successful tests have led to the design and construction of a modular test facility at IGT's Energy Development Center. The 1 to 3 million Btu/h facility uses an improved,

second-generation cyclonic waste combustor and is complete with gaseous, liquid, and solid fuel feeding systems as well as downstream gas conditioning equipment. It also includes a cold-flow aerodynamic model capable of studying both liquid and gaseous fluids.

IGT is currently using this facility to develop a slagging cyclonic combustor for a class of industrial solid wastes. The first waste being evaluated is a spent aluminum potliner product. The process is being designed to produce a molten (i.e., benign) ash while emitting a flue gas stream that contains less than 25 ppm carbon monoxide and total hydrocarbons.

INTRODUCTION

The U.S. Federal Government responded to the critical waste problem with the enactment of the Resource Conservation and Recovery Act (RCRA) in 1976, the Toxic Substance Control Act (TSCA) in 1976, the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) in 1980, the RCRA Amendment of 1984, and the most recent Superfund Amendments and Reauthorization Act of 1986 (SARA) to ensure the reliable management of hazardous/toxic waste disposal operations and dump site cleanup. The enactment of these laws has intensified interest in the thermal destruction of organic/inorganic wastes.

Thermal treatment of wastes has long been recognized as one of the best demonstrated and available technologies for waste disposal. It is an engineered process, with waste destruction being the ultimate goal. Its function is to use heat to break the chemical structures of organic compounds, thus reducing the volume and toxicity of the residuals.

Thermal treatment of wastes (hazardous and nonhazardous) continues to be strongly favored in the U.S. and abroad as one of the best alternatives to landfilling. Many observers expect that this mode of waste disposal will become more firmly established as a means of minimizing landfilling in the U.S.; this has certainly been the case in Europe and Japan. The benefits of thermal treatment over other disposal methods are even more pronounced in the U.S. with relatively low fuel prices. Hence, there is an enormous potential for more capacity to be built over the next 2 to 10 years.

Commercially available technologies for the thermal treatment of hazardous and nonhazardous liquid, gaseous, and solid wastes use a variety of methods that include combustion chambers with low swirl, rotary kilns, multiple hearths, and moving grates.

Significant technological advances have been made during the past few decades; however, these commercial technologies still suffer from a variety of drawbacks:

- High excess combustion air requirement to achieve high DRE
- Low combustion intensity
- Inability to efficiently separate ash from combustion products in the combustion chambe
- Inability to maintain stable, continuous operation
- Short refractory life when molten ash is present in the products of combustion
- Low thermal efficiency of heat recovery equipment
- High capital cost because of relatively large combustion chamber and/or design complexity
- High operating cost because of high auxiliary fuel usage.

There is a need, therefore, for advanced thermal treatment technologies that can overcome these drawbacks. One such advanced technology, under development at IGT for the past few years, is based on the cyclonic combustion concept. As illustrated in Figure 1, it involves the injection of a mixture of auxiliary fuel (natural gas) and combustion air at a relatively high velocity into a cylindrical combustion chamber. The waste is injected either tangentially with the auxiliary fuel or separately in a tangential, radial, or axial configuration. This approach provides high combustion intensity with internal recirculation of combustion products, which results in extremely stable and complete combustion, even at relatively low temperatures. Compared with other types of waste combustors, the cyclonic unit offers several important advantages:

- Lower excess air requirement
- Higher combustion intensity
- Lower supplementary fuel requirement
- Better mixing and temperature uniformity
- Wider operating range
- Greater flexibility to variations in waste properties
- Dry ash or molten (vitrified) ash discharge
- Longer refractory life
- Higher efficiency of heat recovery equipment
- Lower capital and operating costs.

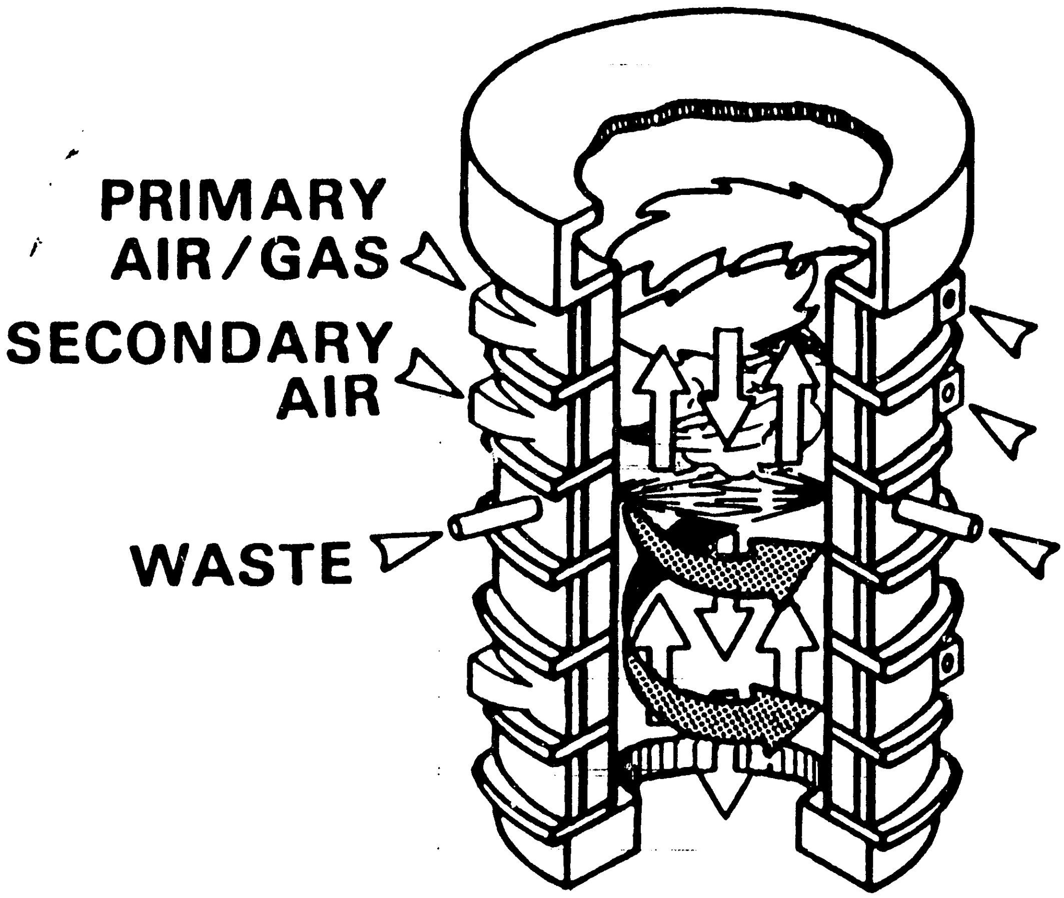

Figure 1. TANGENTIAL SWIRL AND INTERNAL RECIRCULATION PATTERNS

IGT has performed three test programs involving cyclonic combustion for industrial clients. In one program with a pilot-scale unit, several industrial wastewaters containing 39% to 50% organics and inorganics were treated at a rate of 1 X 10^6 Btu/h. The wastewaters, with heating values of 1600 to 3270 Btu/lb, were combusted in the dry ash mode at combustion temperatures of 2000°F using natural gas as the supplementary fuel. The major results can be summarized as follows:

- For a selected wastewater, stable operation was demonstrated for 48 continuous hours.
- High combustion intensity (0.25 X 10^6 Btu/h-ft^3) and excellent combustion completion (>99.9%) were achieved.
- Excess combustion air levels ranged from 10% to 25%.
- Ash accumulation on the combustor and exhaust duct surfaces was relatively low.
- The combustor chamber refractory lining performed well with no observed damage.

Subsequently, one of the wastewaters was treated on-site in a 3 X 10^6 Btu/h demonstration system. Another wastewater was successfully treated in the slagging mode with molten ash discharge by premixing it with 5% glass cullet to reduce the ash fusion temperature.

In another program, IGT treated a simulated low-Btu industrial off-gas (55 to 65 Btu/SCF) with stable combustion at 1900°F using air and waste preheat. The gas contained H_2, CO, CH_4, and NH_3. The test unit was operated at a rate of 3 X 10^6 Btu/h. Supplemental fuel was unnecessary because of the mixing that occurs in the cyclonic waste combustor. The conversion of NH_3 to NO_x was as low as 5%, and CO levels were in the range of 25 to 30 ppm. The NO_x level with no NH_3 added was below 10 ppm.

For the third program, CCl_4 (as a test surrogate for PCBs) was efficiently destroyed by firing natural gas or hexane at an approximate rate of 1 X 10^6 Btu/h. With 100% CCl_4 and natural gas firing, the DRE at 2200°F and a 0.25-second residence time ranged from 99.9999% to 99.99999%. The CCl_4 remaining in the combustion products was at the parts-per-trillion levels.

These successful tests led to the design and construction of a cyclonic waste combustion modular test facility at IGT's Energy Development Center. It is currently being configured to evaluate the treatment of spent aluminum potliners, to produce benign vitrified ash. This paper describes the test programs that have been undertaken on the cyclonic waste combustor, describes the modular cyclonic waste combustion test facility, and discusses the current program to treat SPL.

PILOT-SCALE CYCLONIC COMBUSTION OF LIQUID WASTES

The original pilot-scale system, as illustrated in Figure 2, consisted of the following major components:

- Highly flexible cyclonic waste combustor
- Waste storage and supply subsystem
- Combustion air and natural gas subsystem
- Atomizer assembly
- Cooling water subsystem
- Compressed air subsystem
- Drum heating subsystem.

The cyclonic waste combustor was designed for a nominal firing rate of 3×10^6 Btu/h and consisted of interchangeable cylindrical sections atop a base section that served as an ash/slag receiver. Each cyclonic chamber section incorporated a water-cooled annulus and an interior refractory lining. The approximate height and diameter of the combustor unit were 3.50 and 2 feet, respectively.

The key section in the combustion chamber was located at the top of the chamber; it contained six evenly spaced tangential nozzles through which primary combustion air (preheated up to 800°F), natural gas, and waste might enter the chamber. Primary combustion air and natural gas were mixed prior to entering the tangential nozzles while the liquid waste and compressed air were introduced using injectors positioned inside and along the axis of the tangential nozzles.

A second important chamber section was the refractory orifice section located at the bottom of the incineration chamber immediately above the base. The orifice had a smaller inside diameter than the major portion of the chamber, which enhanced the cyclone swirl and promoted the recirculation of combustion products to the top of the cyclonic chamber.

Other sections of the chamber served various purposes. Beneath the section containing the six tangential nozzles was a section featuring four tangential nozzles for the introduction of secondary combustion air (also preheated up to 800°F) or waste or both. Below this was a section containing four radial nozzles through which waste could enter the chamber. The remaining sections of the chamber served to satisfy the height-to-diameter ratio required for satisfactory combustion of the waste.

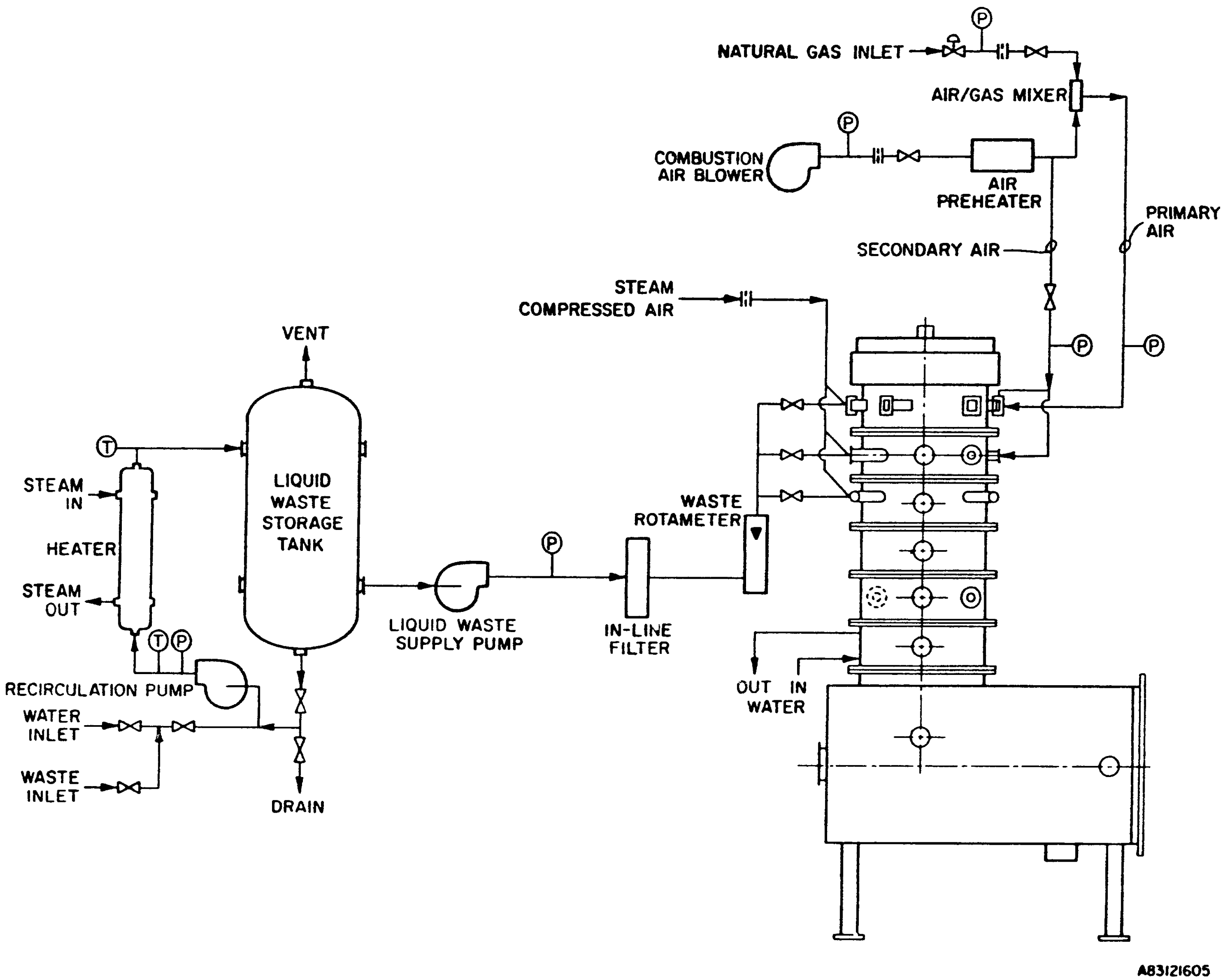

Figure 2. SIMPLIFIED SCHEMATIC DIAGRAM OF THE IGT PILOT-SCALE CYCLONIC WASTE COMBUSTION SYSTEM

Except for the top nozzle section, all sections of the cyclonic combustor unit, including the base, incorporated openings for the gathering of data or viewing of the incinerator interior. These openings allow entry of water-cooled probes for composition sampling or temperature measurements of combustion products.

The waste combustion chamber was designed so that molten slag will freeze on the refractory lining because of the cooling effect of the water, thereby protecting the refractory from both the erosive and corrosive actions of high-velocity molten slag.

The key components in the design of the combustor were the geometry, nozzle orientation, injection technique, and injector type used to introduce the liquid waste into the combustion chamber.

Tests With Industrial Wastewater No. 1

Waste Characteristics

The typical wastewater used in the tests contained about 50% dissolved solids and had a higher heating value (HHV) of approximately 3270 Btu/lb. The chemical composition of one of the "as-received" dewatered waste samples is shown in Table 1; the fusion characteristics of the inorganics in the wastewater are presented in Table 2. The ashing temperatures are temperatures used to "burn out" the organic material in the dewatered sample.

The data show that the ash fluid temperature is approximately 2750° to 2800°F, regardless of the ashing temperature. In addition, the fluid temperatures are very similar for both oxidizing and reducing conditions.

The chemical composition of the 1000° and 1900°F ash samples is shown in Table 3. The 1900°F ash sample was analyzed for chloride content and contained less than 0.01% chloride by weight (dry basis).

Table 1. PROXIMATE/ULTIMATE ANALYSIS OF DEWATERED WASTE

Proximate Analysis	wt, %	Ultimate Analysis	wt, % (Dry Basis)
Moisture	0.88	Ash	4.7
Ash	4.66	Carbon (Total)	37.45
		Hydrogen	6.28
		Sulfur	0.14
		Nitrogen	0.76
		Oxygen (by Difference)	50.67
		Total	100.00

Table 2. SUMMARY OF FUSION TEMPERATURE OF ASH

Ashing Temperature, °F	1000	1300	1600	1900
Oxidizing Atmosphere, °F				
Initial Deformation	1730	1720	2360	2385
Softening	2585	2590	2550	2770
Hemispherical	2730	2715	2765	2790
Fluid	2740	2745	2795	2800
Reducing Atmosphere, °F				
Initial Deformation	1780	1870	2505	2490
Softening	2695	2710	2690	2695
Hemispherical	2725	2735	2735	2720
Fluid	2750	2755	2775	2785

Table 3. CHEMICAL COMPOSITION OF ASH

Composition	Sample Ashed at 1000°F	Sample Ashed at 1900°F
SiO_2	0.48	0.41
Al_2O_3	0.11	0.13
Fe_2O_3	0.06	0.14
TiO_2	0.09	0.09
P_2O_5	18.45	33.66
CaO	9.74	22.90
MgO	2.48	5.0
Na_2O	11.41	14.61
K_2O	27.21	16.00
SO_3	6.3	7.5
Totals	76.3	100.4

Dry Ash Test Results

Some of the performance test results are shown in Table 4. The data indicate that stable and complete combustion was achieved. The waste/natural gas heat contribution ratio was 59:41 for Test No. 1 and 63:37 for Test No. 2.

Following the performance tests, a final 48-hour continuous test was conducted. For this test, however, the waste used contained approximately 35% solids.

During the 48-hour test, data were collected approximately every hour; some results are shown in Table 5. As expected, the data indicate a higher natural gas consumption than in previous tests. The average waste/gas heat contribution ratio was 41:59. About 25% of the total heat input was removed by the cooling water. Most of this heat would be usable in a commercial system, which would either not use any cooling water or employ a heat recovery boiler. Test Nos. 36 through 41 were performed at a turndown ratio of 1.6:1 (35% below normal operation) and reduced combustion temperature (1900°F).

A total of 750 gallons of wastewater was treated during the 48-hour test. There were no shutdowns, and the operation was generally free of difficulties.

The major results of the pilot-scale tests can be summarized as follows:

- Stable operation was demonstrated for 48 continuous hours using a feed rate of approximately 15 gallons per hour.
- The optimum ratio of waste heat input to natural gas heat input was approximately 60:40 (for 50% solids concentration), producing a total firing rate of approximately 0.8 X 10^6 Btu/h.
- High combustion intensity (0.25 X 10^6 Btu/h-ft^3) and excellent combustion efficiency (>99.9%) were achieved.
- Excess combustion air levels ranged from 10% to 25%.
- The ability to combust wastewaters of various concentrations was demonstrated (varied from roughly 35% to 55% solids).
- Ash accumulation was relatively low on the combustor walls, orifice, base, and exhaust duct.
- The combustion chamber refractory lining performed well with no observed damage.

Slagging Test Results

It had been proven (using laboratory samples) that it is possible to lower the fusion temperatures of the ash by using additives that do not interfere with the pumping and combustion characteristics of the wastewater. Lowering the fusion temperatures allows the

Table 4. RESULTS FOR INDUSTRIAL WASTEWATER NO. 1

Test No.	Natural Gas Firing Rate, 10^6 Btu/h	Primary Air/Natural Gas Mixture Temperature, °F	Secondary Air Temperature, °F	Exhaust Gas Analysis O_2, %	Exhaust Gas Analysis CO, ppm	Exhaust Gas Analysis CO_2, %	Base/Slag Receiver Wall Temperature, °F
1	0.34	490	728	2.1	150	14.0	1745
2	0.33	439	745	2.1	40	14.3	1820

Table 5. SYSTEM OPERATING PARAMETERS DURING 48-HOUR PERFORMANCE TEST

Test No.	Natural Gas Firing Rate, 10^6 Btu/h	Primary Air/Natural Gas Mixture Temperature, °F	Liquid Waste Flow, gal/h	Secondary Air Temperature, °F	Exhaust Gas Analysis O_2, %	CO, ppm	CO_2, %	Base/Slag Receiver Wall Temperature, °F
1	0.465	477	15.7	725	2.3	50	--	2010
5	0.475	485	15.7	727	2.2	50	--	2085
12	0.48	477	13.5	727	2.9	50	13.0	2093
16	0.48	480	14.8	726	3.2	150	13.25	2111
21	0.49	478	13.9	724	2.6	50	13.5	2098
25	0.45	467	13.9	724	2.4	75	13.5	2086
27	0.455	464	13.9	723	2.2	50	12.75	2095
36	0.32	392	8.7	694	4.8	275	10.75	1818
41	0.35	347	8.7	682	4.3	100	10.75	1886
44	0.30	384	13.9	700	3.0	150	13.25	2072

combustor to operate in a slagging mode at lower temperatures and with lower natural gas consumption. The two additives, microfine glass cullet (99.9% minus 325 mesh) and Apex 700 powder, had been examined by IGT's Analytical Laboratory (Table 6) and were found to lower the initial deformation temperatures by 750° and 100°F and the fluid temperatures by 400° and 300°F, respectively. The glass cullet, which showed a higher temperature reduction, was selected for testing on the pilot unit.

Table 6. ASH FUSION TEMPERATURE CHARACTERISTICS IN ADDITIVE/WASTE MIXTURE

	Microfine Glass Cullet	Apex 700 Powder
Oxidizing Atmosphere, °F		
Initial Deformation	1610	2260
Softening	2030	2390
Hemispherical	2250	2410
Fluid	2420	2520
Reducing Atmosphere, °F	1560	2230
Initial Deformation	1860	2380
Softening	1860	2380
Hemispherical	2240	2400
Fluid	2370	2510

The unit was preheated to about 2300°F using natural gas before wastewater was injected. When stable operation was achieved, the microfine glass cullet was slowly added into the preheated (160°F) waste tank. A total of 26.2 lb of glass cullet was mixed into a barrel containing approximately 510 lb of waste. The data collected during the test run are shown in Table 7.

The operation of the combustor throughout the testing was stable and without any difficulties. The formation and presence of slag on the interior surfaces of the combustor could not be observed during operation. After the unit was cooled, however, the following was observed:

- A thin layer of the frozen slag was present on the walls and orifice of the combustion chamber and floor of the slag receiver.
- The slag covered the entire wall surface of the combustor, starting at the level of the waste injection and progressing to the orifice at the bottom of the combustor.

The average waste/gas heat contribution ratio during these tests was 13:87 and the glass cullet/liquid waste ratio was 5:95 (on weight basis).

Table 7. RESULTS FOR MIXTURE OF WASTEWATER AND GLASS CULLET

Test No.	Natural Gas Firing Rate, 10^6 Btu/h	Primary Air/Natural Gas Mixture Temperature, °F	Liquid Waste Flow, gal/h	Exhaust Gas Analysis O_2, %	CO, ppm	CO_2, %	Base/Slag Receiver Wall Temperature, °F
1	1.06	621	3.8	1.4	90	12.0	2305
2	1.06	623	3.9	1.1	95	12.0	2344
3	1.06	626	3.9	1.7	60	11.3	2318
4	1.06	--	4.4	1.5	75	11.5	2369
5	1.06	--	4.4	1.3	90	11.5	2383
6	1.06	628	4.4	0.7	105	11.5	2395
7	1.06	628	4.1	0.8	110	12.3	2395
8	1.06	628	4.0	1.3	80	11.5	2382

Tests With Industrial Wastewater No. 2

Waste Characteristics

Wastewater No. 2 contained approximately 61% water, 26.5% dissolved organics (HHV about 6000 Btu/lb), and 12.5% dissolved inorganics. Its HHV (wet, as tested) was about 1600 Btu/lb.

During the mixing and preheating of the waste, it was found that the waste thickens or coagulates when heated. After some sample tests in the laboratory, it was decided not to preheat the waste.

Test Results

The performance test results with this waste are presented in Table 8. During the tests, the unit operated without any difficulties. The combustion was stable, and no unburned liquid waste was observed on the combustor walls. The flow of wastewater into the combustor was stable, and the waste atomizers did not show any signs of overheating. The flame inside the combustor was observed to be very luminous and stable.

The major results can be summarized as follows:

- The wastewater was effectively and completely combusted.
- Low excess air (10% to 15%) operation was achievable and sustainable.

Tests With Industrial Wastewater No. 3

Waste Characteristics

The dry waste sample was analyzed for chemical composition as well as for ashing/fusion temperature characteristics. Wastewater No. 3 contained 56% water. The HHV of its organics content was 7200 Btu/lb and of the waste as tested was 2600 Btu/lb. The fusion tests were conducted in an oxidizing atmosphere for 1000°F and oxidizing and reducing atmosphere for 1600° and 1900°F. The results, presented in Table 9, show that the fluid temperature of the ash is approximately 2640° to 2740°F, regardless of the ashing temperature and atmosphere in which the fusion takes place; however, the ash percent in the sample does vary with the ashing temperature. At 1000°F ashing temperature, the amount of ash was found to be 16.5%; at 1900°F ashing temperature, the amount of ash dropped to only 6.0%.

Table 8. RESULTS FOR INDUSTRIAL WASTEWATER NO. 2

Test No.	Natural Gas Firing Rate, 10^6 Btu/h	Primary Air/Natural Gas Mixture Temperature, °F	Liquid Waste Flow, gal/h	Exhaust Gas Analysis O_2, %	Exhaust Gas Analysis CO, ppm	Exhaust Gas Analysis CO_2, %	Base/Slag Receiver Wall Temperature, °F
1	.05	385	2.6	2.2	60	10.0	1240
2	.06	400	10.9	4.4	70	8.0	1595
3	.06	400	12.5	3.0	45	–	1736
4	.06	400	12.5	2.9	140	10.0	1845

Table 9. SUMMARY OF FUSION TEMPERATURE OF ASH

Ashing Temperature, °F	1000	1600	1900
Oxidizing Atmosphere, °F			
Initial Deformation	1660	2550	2590
Softening	2020	2570	2610
Hemispherical	2580	2620	2630
Fluid	2640	2680	2700
Reducing Atmosphere, °F			
Initial Deformation		2630	2660
Softening		2700	2710
Hemispherical		2710	2720
Fluid		2730	2740
Ash Content, %	16.5		6.0

The ashes with an ashing temperature at 1000° and 1900°F were analyzed for chemical composition. For a better understanding of the variations in percentage of ashes at 1000° and 1900°F ashing temperature, the chemical constituents found in the ashes were recalculated to the original sample bases. The results, presented in Tables 10 and 11, show that the NaCl and KCl evaporated, lowering tho amount of ash from 16.5% at 1000°F to 6% at 1900°F.

Test Results

Table 12 presents the results of tests with industrial wastewater No. 3. The unit operated without any difficulties. Combustion was stable and complete. The flow of the waste into the combustor was stable as well, and the waste atomizers did not show any signs of overheating. The flame inside the combustor was very luminous and appeared to be stable. The average waste/gas heat contribution ratio during these tests was 30:70.

After completion of the testing, the interior of the chamber was inspected. The following observations were made:

- A thin layer of powdery, golden-colored ash covered the walls of the combustor and hearth of the base.
- No ash deposition was found on the top portion of the chamber walls at the level of the primary combustion air/natural gas nozzles.
- The chamber wall area downstream of the atomizer level was relatively clean, with ash deposits evenly distributed around the chamber.

Table 10. CHEMICAL COMPOSITION OF ASH

Composition	Sample Ashed at 1000°F	Sample Ashed at 1900°F
SiO_2	0.17	0.25
Al_2O_3	0.05	0.05
Fe2O_3	0.05	0.10
TiO_2	<0.09	<0.09
P_2O_5	16.10	41.29
CaO	6.37	18.68
MgO	1.89	5.23
Na_2O	7.10	27.41
K_2O	--	2.50
SO_3	1.8	4.43
NaCl	25.65	--
KCl	33.10	--

Table 11. CHEMICAL COMPOSITION OF ASH CALCULATED TO ORIGINAL SAMPLE BASES

Composition	Sample Ashed at 1000°F	Sample Ashed at 1900°F
Si	0.013	0.007
Al	0.004	0.002
Fe	0.009	0.004
P	1.16	1.08
Ca	0.75	0.79
Mg	0.188	0.188
Na	2.53	1.21
K	2.86	0.13
Cl	5.16	0.001
F	0.008	0.006

Table 12. RESULTS FOR INDUSTRIAL WASTEWATER NO. 3

Test No.	Natural Gas Firing Rate, 10^6 Btu/h	Primary Air/Natural Gas Mixture Temperature, °F	Secondary Air Temperature, °F	Liquid Waste Flow, gal/h	Exhaust Gas Analysis O_2, %	Exhaust Gas Analysis CO, ppm	Exhaust Gas Analysis CO_2, %	Exhaust Gas Analysis NO_x, ppm	Base/Slag Receiver Wall Temperature, °F
1	0.7	289	377	12.6	3.6	25	13.3	300	2084
2	0.8	286	372	13.5	3.6	35	12.8	380	2110
3	0.8	285	371	10.9	3.4	195	12.8	--	2133
4	0.8	290	372	15.9	2.6	105	13.8	--	2188

Tests With Carbon Tetrachloride

Carbon tetrachloride (CCl_4) was selected as the surrogate material for testing the polychlorinated biphenyl (PCBs) treatment capability. CCl_4 is generally believed to be more stable than PCBs, is relatively nontoxic, and will not result in products of incomplete combustion (PICs) that are highly toxic.

To determine carbon tetrachloride's DRE, high-temperature gas samples were drawn from the combustion system, through a modified EPA Method 5 analytical train, and the residual CCl_4 was trapped in double Tenax beds in series. Sample volumes of 20 liters were drawn and measured by a meter that was calibrated and temperature-compensated. Double tubes of absorbent were used in the traps to assure complete recovery; a system of blanks and sample spikes was used to verify the analytical technique.

The sample traps were analyzed by gas chromatography/mass spectrometry (GC/MS) techniques. This approach was shown to have a sensitivity of about 0.7 micrograms of CCl_4 in the sample (0.9 micrograms sensitivity was used for data reduction). The sensitivity was sufficient to measure six-9's destruction efficiency.

The destruction of CCl_4 in a methane-fueled combustor requires no additional oxygen. The chemistry at two stoichiometric ratios of CCl_4/CH_4 is as follows:

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

$$2CH_4 + CCl_4 + 4O_2 \rightarrow 3CO_2 + 4HCl + 2H_2O$$

The heat effect of the CCl_4 is nearly negligible. Specifically, at a CCl_4/CH_4 ratio of 0.5, the heat of reaction is essentially identical to the heat of combustion of methane alone.

The system incorporated scrubbing, with neutralization of the spent scrub liquor, and an ID fan to maintain a slight vacuum in the combustion chamber.

The tabulated results of the tests are summarized in Table 13.

In most of the tests, the unit was operated with an 800°F* combustion air preheat and a gas firing rate of about 0.8×10^6 Btu/h. The gas sampling probe was located immediately beneath the cyclonic combustion chamber, with a hot gas residence time of approximately 0.25 seconds. Temperatures were measured by a suction pyrometer near the exhaust of the combustor base, after a gas residence time of about 0.75 second.

---

* This degree of air preheat approximately counteracts the combustor cooling attributable to the cooling water. In the production unit, it is anticipated that this water cooling would not be required, and the preheat was used to account for this effect.

Table 13. CCl_4 COMBUSTION TEST SUMMARY

Test No.	Firing Rate, 10^6 Btu/h	NG/Air Temp., °F	Suction Pyrometer Base Temp., °F	Exhaust Gas Analysis as Measured O_2, %	Exhaust Gas Analysis as Measured CO_2, %	Exhaust Gas Analysis at 0% O_2 CO, ppm	Exhaust Gas Analysis at 0% O_2 NO, ppm	CCl_4 Flow, lb/min.	CCl_4/NG Ratio	CCl_4 Recovered, μg/20 L	Destruction Efficiency, %	Comments
1	1.0	695	2338*	2.5	10.25	68	--	--	--	--	--	NG Only.
2	0.8	685	2098*	3.7	10.5	55	--	1.44	0.270	<0.9	99.99997	
6	0.8	715	2520	3.7	12.5	36	170	3.3	0.618	2.7	99.99996	
10	0.7	704	1950	1.2	12.0	21	498	0.83	0.178	<0.9	>99.99996	Caustic Injection in Incinerator.
14	0.8	712	2458**	3.6	10.5	60	--	1.05	0.190	1.8	99.99992	
16	0.8	693	2533**	0.7	13.5	398	134	2.15	0.393	1.8	99.99996	Caustic Injection in Base.
17	0.8	406	2408**	3.5	11.5	60	60	2.15	0.393	5.1	99.99988	

* Suction pyrometer downstream.
** Thermocouple data.

The initial test was run with natural gas combustion only, without injection of CCl_4. A blank sample was taken for CCl_4 analysis through GC/MS as part of the data quality assurance program.

The second two samples were run at approximately a 0.3 and a 0.6 molar ratio of CCl_4 to CH_4. At the lower carbon tetrachloride feed rate, the CCl_4 remaining was below the limits of detection; at the higher rate, the CCl_4 remaining was 1.8 microgram in the 20-liter gas sample. Both of these results indicate significantly better than six-9's destruction. Therefore, downstream sample ports for improved destruction as a function of time were unnecessary.

Operation at low excess air did not significantly impair the destruction efficiency, nor did variations in the location of the sampling probe, across the diameter of the orifice plate, cause a noticeable effect.

For the next series of tests, a 40% caustic solution was injected directly into the combustion chamber to neutralize the hydrochloric acid as it was formed. With this direct caustic injection, a liquid scrubber was not required. Rather, the exhaust was ducted directly to the refractory-lined stack. During operation, the stack had no objectionable odor of either acid or caustic.

Relatively low temperatures were recorded by suction pyrometer directly under the combustor orifice during this series. Test conditions employed lower CCl_4/CH_4 ratios (about 0.14 to 0.2) and relatively low excess air ratios (O_2 about 1.2% to 1.7%).

In the last series of tests, the caustic solution was injected into the base about 2-1/2 feet downstream from the point where the gas composition and temperature data were acquired. For this series of tests, the temperature was measured by a small bare-bead thermocouple.

The tests investigated impacts of variations in excess air utilization, CCl_4/CH_4 ratio, and combustion air preheat. Test 17, with lower combustion air preheat, showed slightly less than six-9's CCl_4 destruction.

The major results of the tests with carbon tetrachloride can be summarized as follows:

- Carbon tetrachloride was destroyed in the cyclonic combustor, generally at greater than six-9's removal – with air preheated to 700°F, exhaust temperatures of 2400° to 2500°F, and a residence time of 0.25 seconds.
- Emissions of NO_x were 130 to 330 ppm under these conditions. With reduced air preheat (450°F), NO_x emissions dropped to 60 ppm, but CCl_4 destruction was slightly impaired.

- Generally, the destruction efficiency was high, regardless of the excess air level, combustor exhaust temperature, or CCl_4/CH_4 ratio. No correlations with these parameters could be determined.
- The direct injection of alkali into the combustor or into a hot zone downstream of the combustor appears to hold promise for HCl removal but requires further development.

Tests With Hexane Mixed With Carbon Tetrachloride

No natural gas was used during these tests. The analytical technique called Volatile Organic Sampling Train (VOST) was used in these tests utilizing two sorbent tubes connected in series. The sorbent tubes were thermally desorbed, and the content was analyzed by GC/MS technique. The approach was shown to have a sensitivity of 1 nanogram of CCl_4 per sample (20 liters). The sensitivity was sufficient to measure six-9's destruction efficiency.

Selected test results with 0.5% CCl_4 in hexane are presented in Table 14 and with 1% CCl_4 in hexane in Table 15. In most of the tests, the gas sampling probe was located beneath the combustor orifice, with a hot residence time of approximately 0.25 seconds.

The major results of the tests with this waste can be summarized as follows:

- Combustion efficiency of hexane was very high (CO not detectable) even at a low excess air level of about 10%.
- Carbon tetrachloride was destroyed, generally at greater than five-9's DRE, with combustion air preheated to 400°F, at exhaust temperatures of 2100° to 2200°F and a residence time of 0.25 seconds.
- NO_x emissions were relatively low under these conditions (90 to 130 ppm). With ambient combustion air, NO_x emissions dropped to 70 ppm.
- Generally, the DRE was high regardless of the excess air ratio and CCl_4 concentration in the hexane. Reduced air preheat had a slightly negative effect on the CCl_4 DRE.

LOW-BTU OFF-GAS TESTING

The combustion characteristics of low-Btu off-gases (from shale gasification) and the operating performance of a horizontal cyclonic combustor were tested to evaluate emissions and heat recovery potential. The basic flow diagram for the tests is shown in Figure 3, and the combustor setup is shown in Figure 4. Table 16 shows the composition of the low-Btu off-gases tested. The 54 Btu/SCF off-gas composition represents the minimum heating value expected, and the 67 Btu/SCF represents the average of the minimum and maximum heating value. It was also anticipated that the off-gas would contain up to 0.56% NH_3 and 0.15% H_2S.

Table 14. RESULTS FOR HEXANE MIXED WITH 0.5% CCl_4 (by Weight)

Test No.	Firing Rate, 10^6 Btu/h	Thermocouple Base Temp., °F	Exhaust Gas Analysis, as Measured: O_2, %	Exhaust Gas Analysis, as Measured: CO_2, %	Exhaust Gas Analysis, at 0% O_2: CO, ppm	Exhaust Gas Analysis, at 0% O_2: NO/NO_x, ppm	CCl_4 Flow Rate, lb/h	CCl_4 Recovered, 10^{-9} μg/20 L	Destruction Efficiency, %
1*	1.0	1808	3.0	11.50	0	64/64	--	250	--
2	1.0	1862	4.1	11.00	0	55/55	0.255	300	99.99580
4	1.1	1947	2.1	12.25	0	75/75	0.255	190	99.97630
8	0.9**	1957	3.1	9.75	0	103/103	0.214	12	99.99984
9	0.8**	1970	2.3	10.50	0	121/121	0.195	8	99.99990
12	1.0**	1860	4.2	11.50	0	90/90	0.234	19	99.99973
14	0.9**	1911	2.0	13.25	0	125/125	0.223	50	99.99936

* Hexane only, 5 X 10^{-9} g spike.
** Combustion air preheated to 400°F.

Table 15. RESULTS FOR HEXANE MIXED WITH 1% CCl_4 (by Weight)

Test No.	Firing Rate, 10^6 Btu/h	Thermocouple Base Temp., °F	Exhaust Gas Analysis, as Measured: O_2, %	Exhaust Gas Analysis, as Measured: CO_2, %	Exhaust Gas Analysis, at 0% O_2: CO, ppm	Exhaust Gas Analysis, at 0% O_2: NO/NO_x, ppm	CCl_4 Flow Rate, lb/h	CCl_4 Recovered, 10^{-9} μg/20 L	Destruction Efficiency, %
1*	0.9**	2001	0.4	11.50	0	84	--	28	--
3	0.9**	1916	2.8	12.25	0	92	0.450	7	99.99995
6†	0.9**	2029	1.9	13.25	0	97	0.413	19	99.99988
9	1.0	2003	2.9	12.25	0	64	0.493	8.4	99.99994
10	1.1	2034	2.0	13.00	0	72	0.536	11	99.99993
12†	1.1	2055	2.2	13.00	0	71	0.550	24	99.99985

* Natural gas fire, no CCl_4, 9×10^{-9} g spike.
** Combustion air preheated to 400°F.
† Downstream sample.

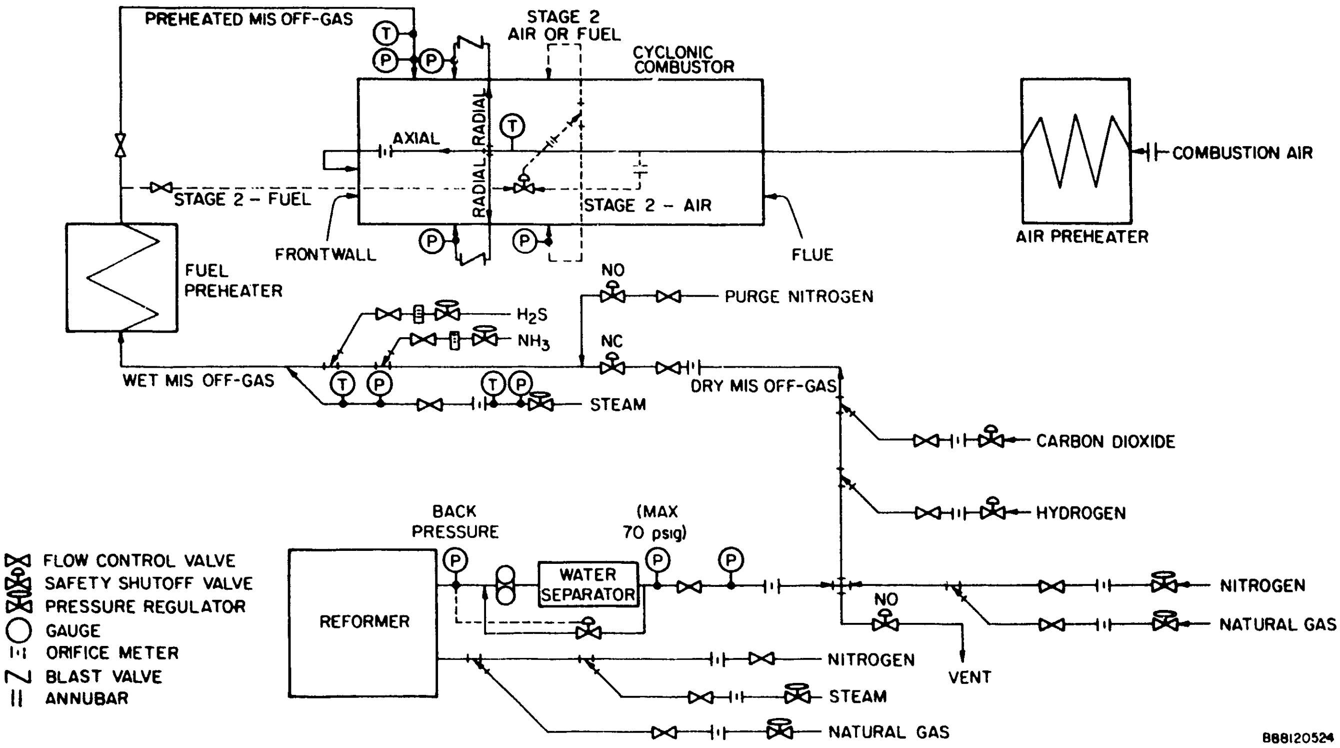

Figure 3. FLOW DIAGRAM FOR LOW-BTU GAS TESTS

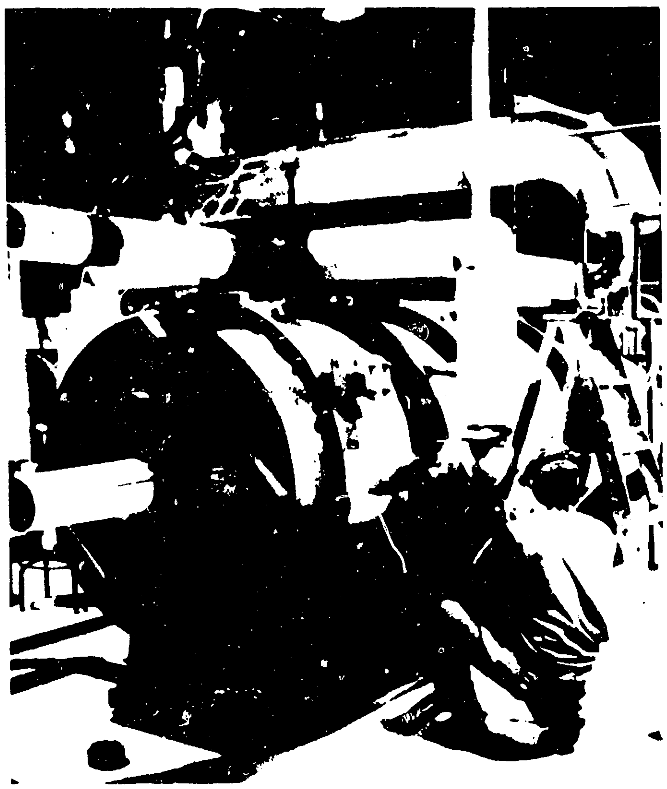

Figure 4. CYCLONIC LOW-BTU GAS COMBUSTOR

Table 16. COMPOSITIONS OF LOW-Btu GASES TESTED

	H_2	N_2	CO	CH_4	CO_2	H_2O,	HHV,
			% Dry			% Wet	Btu/SCF
Average	9.2	61.3	1.7	3.7	24.1	7.3	67
Minimum	7.0	59.8	0.5	3.4	29.3	8.7	54

The off-gases for the combustion tests were made first by reforming natural gas and steam in a reformer over a catalyst at 1800°F to generate hydrogen and carbon monoxide. The product gas containing H_2, CO, CO_2, unused H_2O, and small quantities of unused natural gas was quenched in water-cooled heat exchangers. The resulting saturated mixture at about 100°F was compressed to 70 psig, and the condensed water was removed in a water separator. Nitrogen, natural gas, carbon dioxide, hydrogen, steam, ammonia, hydrogen sulfide, and carbon disulfide were blended with the product gas to achieve the required low-Btu gas composition. The higher hydrocarbons were replaced by natural gas.

Combustion air and waste were individually preheated in independent natural gas-fired preheaters.

Test Results

At the design firing rate of 3 X 10^6 Btu/h, the flame with the average heating value gas was unstable until the gas and combustion air were preheated to 335° and 750°F, respectively. At these conditions the combustor wall temperatures stabilized; therefore, a gas temperature of 350°F, an air temperature of 750°F, and a firing rate of 3 X 10^6 Btu/h were selected as the nominal firing conditions for the combustor performance tests.

Figure 5 shows the effect of excess air on CO and NO_x emissions in the flue corrected to 0% oxygen. The CO concentration decreased rapidly with an increase of excess air (up to 15% excess air) and then slowly leveled off, whereas the NO_x concentration increased with excess air throughout the range tested. These results are similar to those generally observed with conventional burners.

Figure 6 shows the effect of fuel ammonia concentration on CO and NO_x emissions. The loss in the heating value of the gas at reduced NH_3 concentrations was made up by adding an equal amount (heating value) of natural gas through a calibrated rotameter. The results show that NO_x decreased slowly with a decreasing NH_3 concentration at high waste NH_3 levels and rapidly at low waste NH_3 levels. For example, an 80% reduction in the fuel NH_3 concentration (from 0.5% to 0.1%) reduced NO_x by 40%.

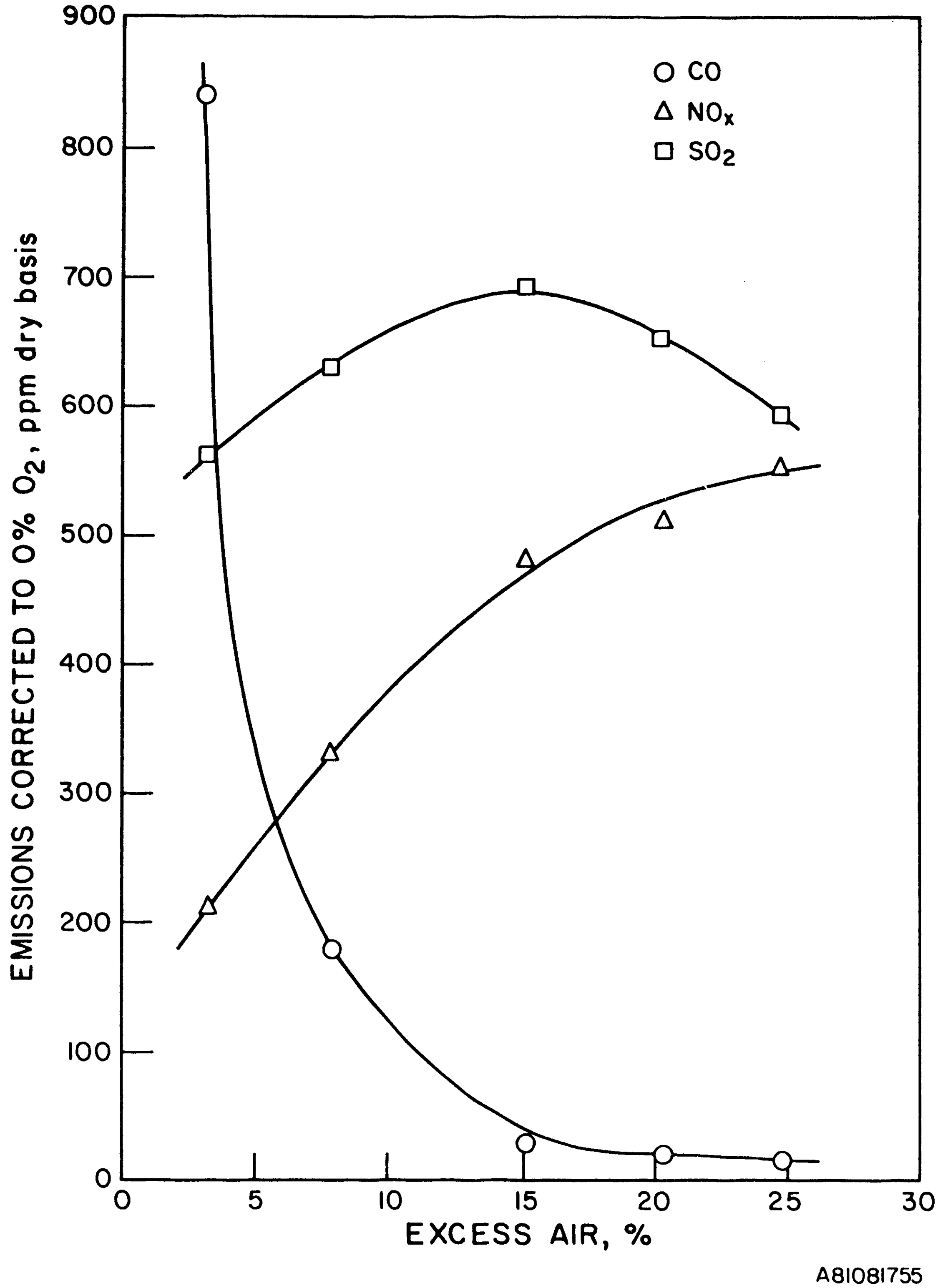

Figure 5. EFFECT OF EXCESS AIR ON GASEOUS EMISSIONS FOR AVERAGE GAS

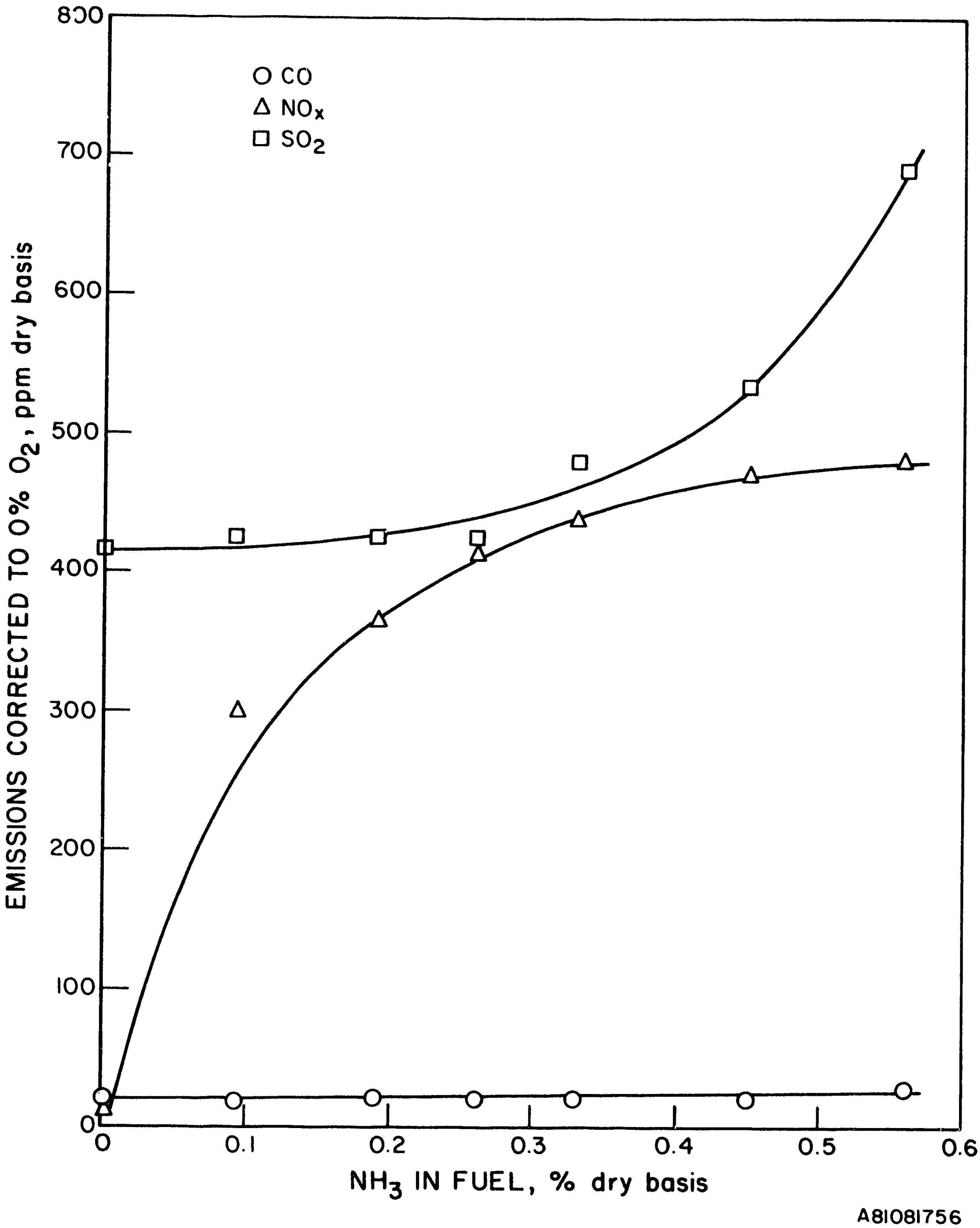

Figure 6. EFFECT OF FUEL NH_3 CONCENTRATION ON EMISSIONS FOR AVERAGE GAS WITH 15% EXCESS AIR

Following the combustor performance tests with the average heating value gas, stability tests were conducted to determine if the cyclonic combustor was capable of burning the minimum heating value gas. The waste gas temperature was increased to 490°F, and the firing rate was reduced to 1.9 X 10^6 Btu/h. The flame was stable up to 11.3% moisture in the waste, which represents a heating value of 50 Btu/SCF. The waste gas temperature was then slowly reduced. The flame lifted off at a waste gas temperature of 350°F.

The NO_x reduction techniques of combustion air staging and fuel staging were also evaluated separately but were found to be relatively ineffective at the conditions tested.

The major results of the tests with low-Btu off-gas can be summarized as follows:

- The combustor tested is capable of operating on the 67 Btu/SCF off-gas with a stable flame and with low CO (<50 ppm) at the exit at 15% excess air when the combustion air is heated to approximately 750°F and the off-gas is heated to approximately 350°F.
- For NO_x emissions to be below 0.7 lb NO_2 per 10^6 Btu fuel input, either the combustor should be operated below 7% excess air, which resulted in more than 200 ppm CO, or the off-gas NH_3 concentration should be reduced below 0.1% (dry basis).
- A stable flame can be obtained with an off-design gas (higher moisture content) or a lower heating value gas if the combustor is downrated.
- Fuel staging was not effective in reducing NO_x in that it increased the CO emissions.
- Combustion air staging, as tested, was ineffective in significantly reducing NO_x emissions; however, this technique may be effective if the combustor design is modified for higher first stage temperature and/or larger residence time.
- The test results suggest that the cyclonic combustor performance can be significantly improved by providing better air/waste mixing and by making aerodynamic refinements to the combustor.
- The test results also suggest that the cyclonic combustion approach is well suited for developing an advanced, highly efficient afterburner design for fluidized-bed, rotary kiln, and moving-grate waste combustors, including starved-air designs.

DESIGN AND OPERATION OF THE DEMONSTRATION SYSTEM FOR INDUSTRIAL WASTEWATER NO. 1

Demonstration Cyclonic Waste Combustion System

The development of the cyclonic waste combustor demonstration system was based on the successful results on the pilot-scale unit that were described earlier. On the basis of these data, the demonstration system was jointly designed, constructed, tested, and operated by IGT, York-Shipley, Inc. (Y-S), and an industrial client.

The demonstration system features a compact combustion chamber (Figure 7) with an ash/slag receiver, capable of operating either in dry or slagging mode. The demonstration system has a wastewater handling subsystem and is equipped with a heat recovery boiler, an air heater, and a baghouse. A flow diagram of the demonstration system is shown in Figure 8. Wastewater feeding is automatically controlled by a micromotion flowmeter in the jacketed wastewater conveying jacketed line, traced with 180° to 190°F hot water.

The heat available in the combustor exhaust gases is partially recovered in a two-pass Scotch Marine boiler. Soot blowers, installed for final system operation at the entrance to the convective pass of the boiler, are of concurrent flow, operated on compressed air. In addition, a 12-foot-long, retractable rotary soot blower has been installed to provide for cleaning of the Morison tube and return box of the boiler.

Further heat recovery is provided by an air heater of the basic shell-and-tube heat exchanger design. Preheated combustion air is then conveyed to the combustor and separated into a primary and secondary air stream. The primary air stream is mixed with natural gas, and the gas-air mixture is then injected into the combustor through the top-row tangential nozzles. Secondary combustion air is injected into the combustor through the second row of tangential nozzles. Flow control is accomplished either manually or automatically using an O_2 analyzer installed in the boiler exhaust duct.

Flue gases from the air preheater are cleaned in a baghouse. An induced draft fan mounted on the baghouse support structure pulls exhaust gases through the boiler, air heater, and baghouse. The outlet damper of the ID fan is adjusted manually or controlled automatically to maintain the desired pressure at the inlet of the boiler. Flue gases are then exhausted through the stack to the atmosphere.

System Operation and Test Results

A total of about 175,000 pounds of wastewater was treated during the final 500-hour continuous system operation. Some of the data collected are shown in Table 17. The wastewater averaged a 48.25% solids concentration; its average flow rate was 6.5 lb/min. Therefore, the average waste firing rate was 1.21 X 10^6 Btu/h. The average natural gas flow was 988 ft^3/h for a gas firing rate of 1.04 X 10^6 Btu/h. The average wastewater/natural gas ratio calculated was 54:46 (Btu basis). It should be noted that a somewhat lower concentration of solids in the wastewater resulted in a significantly higher natural gas consumption. Raising the concentration from 44.2% to 49.2% resulted in about a 26% lower gas consumption.

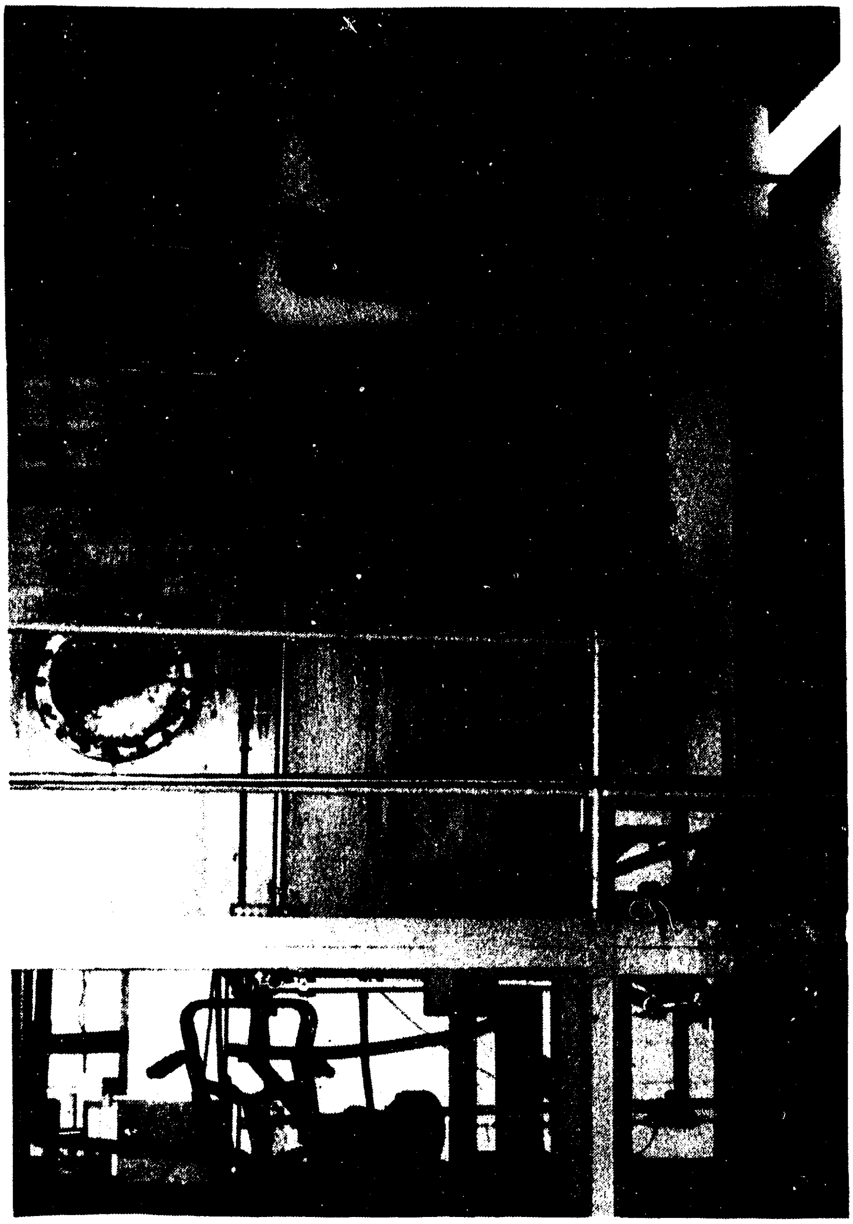

Figure 7. CYCLONIC WASTE COMBUSTION DEMONSTRATION SYSTEM

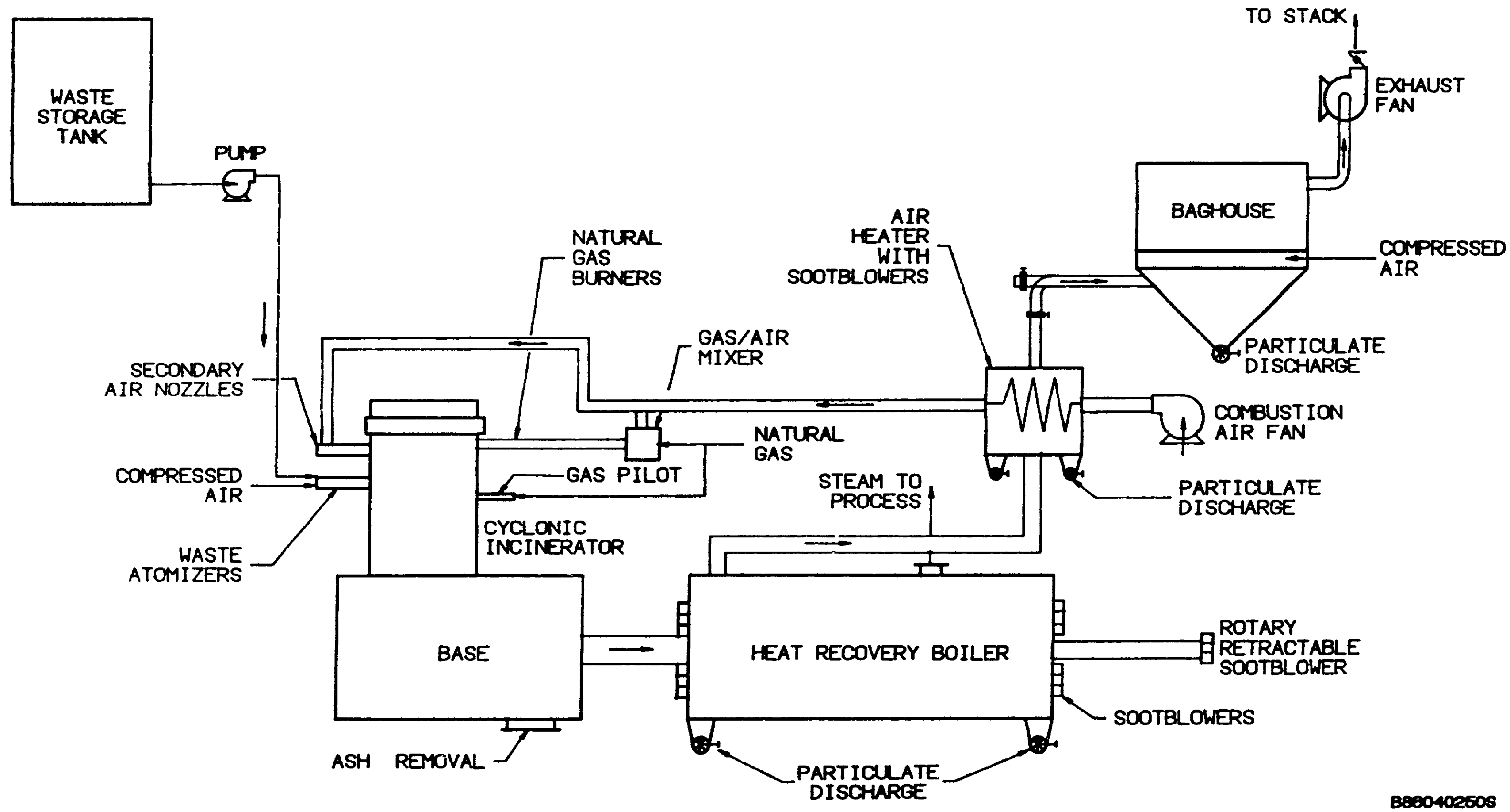

Figure 8. CYCLONIC WASTE COMBUSTION DEMONSTRATION SYSTEM FLOW DIAGRAM

Table 17. DATA COLLECTED DURING THE 500-HOUR CONTINUOUS SYSTEM OPERATION

Test No.	Natural Gas Firing Rate, SCF/h	Liquid Waste Flow, lb/min	Temperature, °F: Incinerator Base	Temperature, °F: Boiler Morison Tube Exit Thermocouple	Temperature, °F: Boiler Exit	Temperature, °F: Baghouse Inlet	Temperature, °F: Combustion Air	Temperature, °F: Combustion Air/Natural Gas Mixture	Flue Gas Analysis: O_2, %	Flue Gas Analysis: CO, ppm
1	1300	6.7	1970	1110	559	320	329	294	4.1	20
3	1195	6.7	2020	1065	526	335	284	252	3.6	10
5	840	7.0	2080	1090	561	350	287	257	3.6	10
7	836	6.5	2200	1075	546	330	274	238	3.9	45
10	851	6.6	2150	1644	532	320	281	241	3.8	20
12	851	6.5	2000	1006	488	310	278	216	3.8	55
16	933	6.5	2130	955	519	320	284	248	3.4	20
18	963	6.5	2100	1150	537	320	298	262	4.1	20
20	1088	6.5	2175	5954	511	330	297	259	3.6	11
21	1163	5.0	2150	950	493	310	278	239	--	--
22	961	6.0	2190	950	498	310	277	229	--	--
23	922	6.0	1950	950	477	315	284	225	--	--

To avoid incomplete combustion, the combustor base temperature (Figure 9) was maintained at a higher level than in the past. The temperature of the flue gases exiting the Morison tube was monitored continuously.

The major results of the system operation can be summarized as follows:

- The demonstration system proved to be a reliable and highly efficient operation, with low-emission combustion of wastewater with an HHV of about 3000 Btu/lb.
- The heat contribution ratio of wastewater to auxiliary fuel averaged 55:45.
- Major operating parameters during the final operation included 2.15 X 10^6 Btu/h total firing rate, 2050°F combustion temperature, air preheat of 325°F, and specific heat release of 0.12 X 10^6 Btu/h with 20% excess air. Carbon monoxide concentration in the flue gas was usually below 100 ppm.
- It was demonstrated that the flue gas temperature control after the radiative chamber (appropriate surface area and surface cleaning) is a key element in eliminating the fouling and slagging of the first convective pass.
- For the last 24 hours of the final operation, mechanical wastewater atomizers operating at 100 psig were used. There was no apparent problem with the mechanical atomization during this period. Mechanical atomization has a good potential for commercial cyclonic waste combustion systems.

  Data collected provide a sufficient data base for a larger size commercial system design (from 10 X 10^6 to 25 X 10^6 Btu/h total firing rate).

IGT CYCLONIC WASTE COMBUSTION MODULAR TEST FACILITY

The successful results described above have led to the design and construction of a modular cyclonic waste combustion test facility at IGT's Energy Development Center. As illustrated schematically in Figure 10, it consists of the following subsystems:

- Advanced, highly flexible, cyclonic waste combustor
- Liquid waste feeding system
- Gaseous waste feeding system
- Solid waste feeding system
- Main auxiliary fuel system (natural gas)
- Combustion air system (air temperature from ambient to 1200°F)
- Oxygen enrichment system

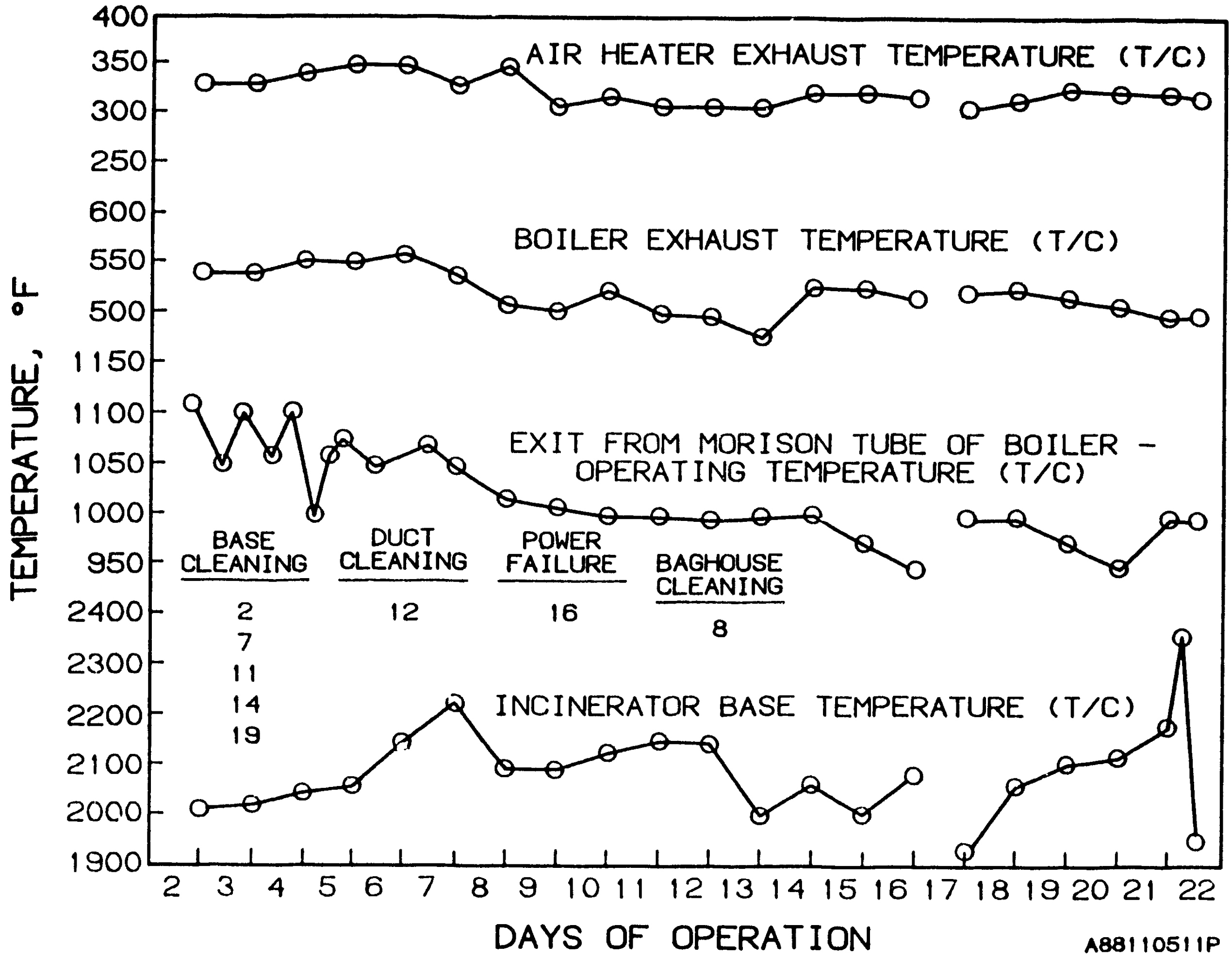

Figure 9. COMBUSTOR BASE, BOILER, AND AIR HEATER FLUE GAS TEMPERATURES AS A FUNCTION OF OPERATING TIME (500-hour Operation)

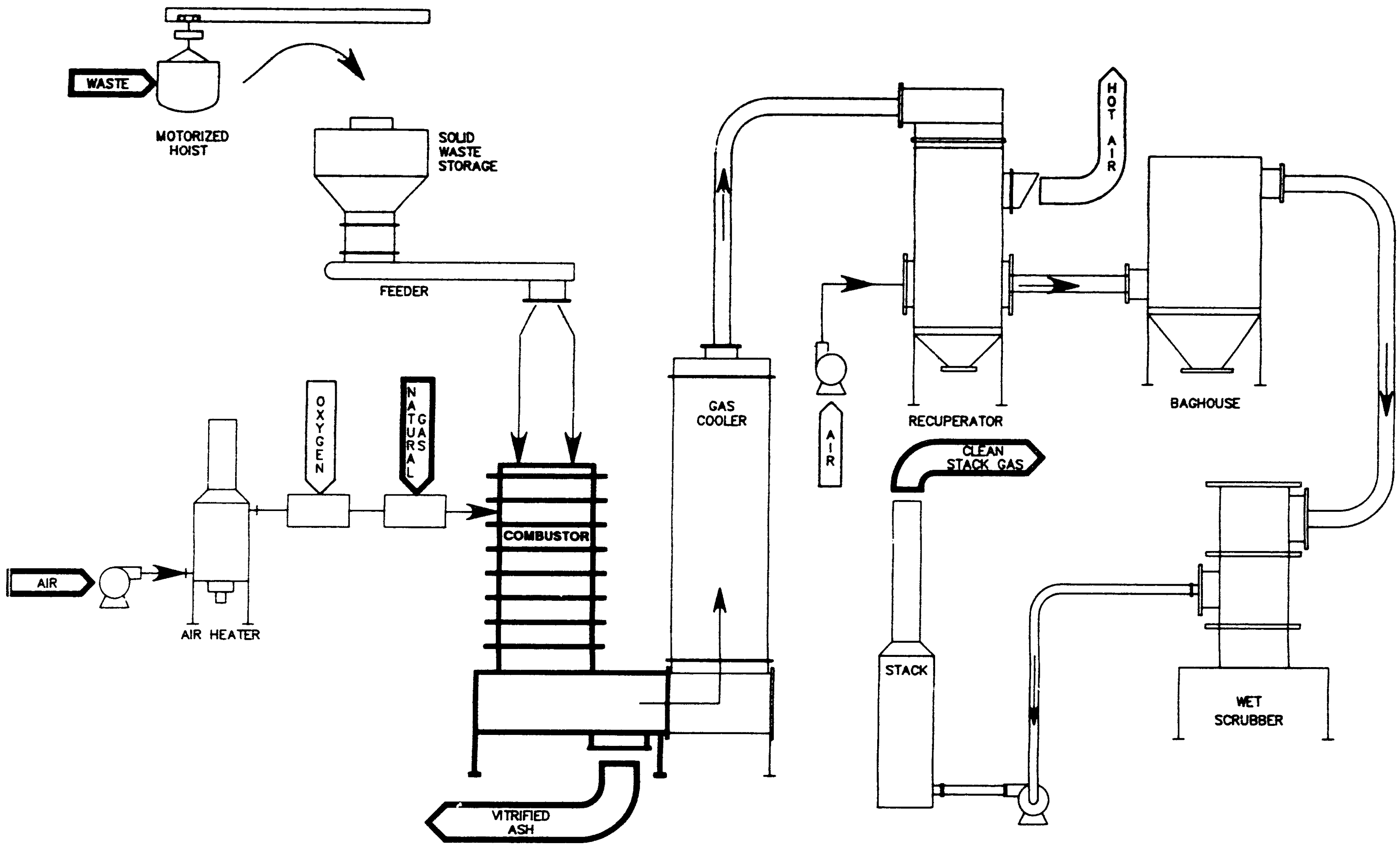

Figure 10. SIMPLIFIED FLOW DIAGRAM OF THE CYCLONIC WASTE COMBUSTOR TEST FACILITY

- Exhaust gas treatment system
  - Direct quencher
  - Recuperator
  - Baghouse
  - Scrubber

- Ash (slag) removal system

- Control systems
  - Semiautomatic control
  - Probes and instrumentation
  - Computer data acquisition.

The heart of the test facility is the cyclonic waste combustor (Figures 10 and 11). For versatility, similar to the earlier pilot unit, the design incorporates the use of interchangeable cylindrical sections to evaluate combustion performance, depending on the characteristics of the specific waste being combusted. Some of the sections are refractory-lined, and other sections incorporate a water-cooled annulus and an interior refractory lining.

The waste feeding systems associated with the cyclonic combustion unit consist of a solid waste feeding system and a liquid waste feeding system. The solid waste feeding system (Figure 12) is an automatic waste delivery system that meters the amount of solid waste being combusted. The waste is delivered to the combustor through ports located in the lid of the combustor. The liquid waste feeding system is also an automated system. The feed storage includes mixing, recycle, and heating capabilities to assure uniformity of the waste being incinerated. The waste is then delivered for injection into the combustor via liquid waste atomizers. Compressed air or steam for pneumatic atomization, or a high-pressure pump for mechanical atomization, are also available. Tangential or radial injection ports of the combustor are selected, depending on the quality (amount of water, heating value, etc.) of the waste being treated.

An auxiliary fuel system provides a natural gas supply that can be either premixed with air or injected through the appropriate nozzles. If required, oil can be used as an auxiliary fuel.

The combustion air system provides ambient or preheated primary and secondary air with a preheat temperature up to 1200°F. The oxygen enrichment system provides delivery and injection of pure oxygen to the primary and secondary air supply lines.

Downstream of the cyclonic combustion unit is exhaust gas treatment equipment (Figures 10 and 11) consisting of a direct quencher, convective air heater, baghouse, and scrubber. Provisions were made to add a heat recovery boiler and a high-temperature radiative recuperator to the exhaust gas treatment system at a later date.

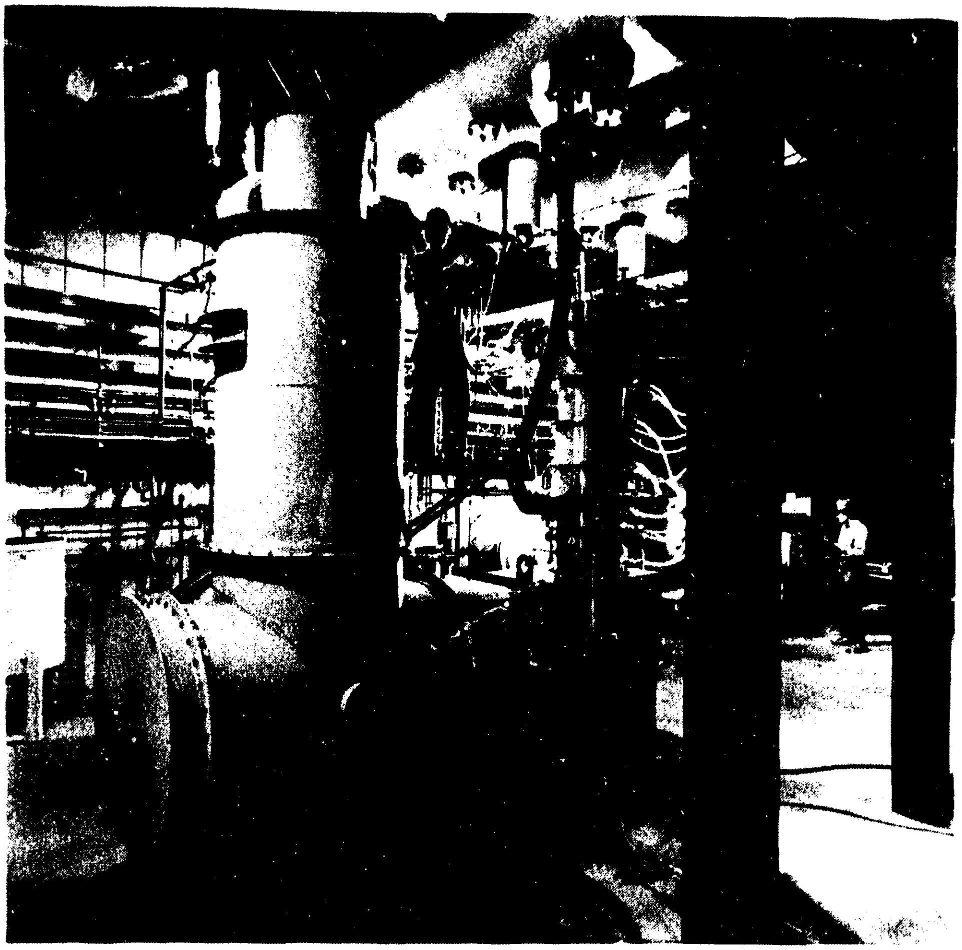

Figure 11. CYCLONIC WASTE COMBUSTOR AND EXHAUST GAS DIRECT QUENCHER

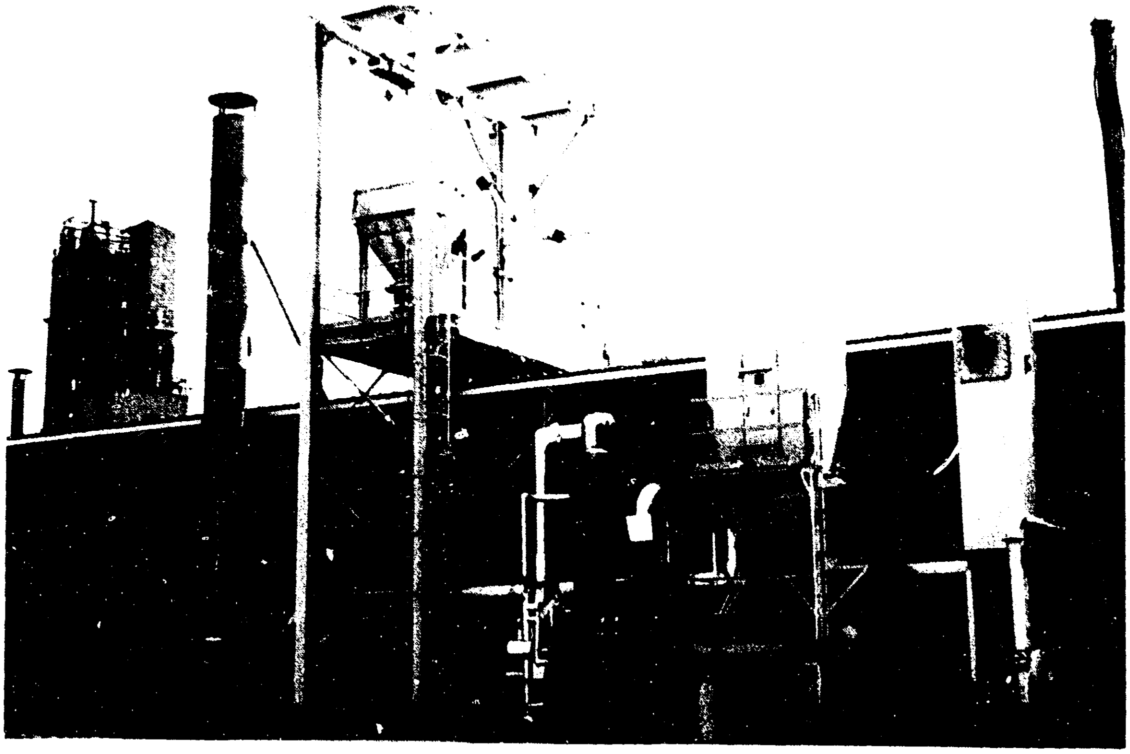

Figure 12. SOLID WASTE FEEDING SYSTEM, SCRUBBER, BAGHOUSE, AND AIR HEATER

A semiautomatic, computer-assisted control system ties the individual components and subsystems of the test facility connects and provides computerized data acquisition. It is centrally located in the control room, where the desired operation and safety aspects of every component of the facility are being initiated and monitored.

The facility is equipped with a full range of analytical instrumentation for continuous monitoring of the flue gas emissions: O_2, CO, total hydrocarbons (THC), NO_x, SO_x, etc.

THERMAL TREATMENT OF SPENT ALUMINUM POTLINERS

The efforts thus far had been directed toward the development of a general cyclonic waste combustion system for industrial applications. The focus had been on dry ash discharge; however, as discussed earlier, exploratory tests with molten ash discharge also showed good potential. To further evaluate this mode of operation, a project was initiated with funding support from the gas industry.*

The objective was to evaluate the waste combustor using a solid feed-type waste, with both organic content and inorganic content, to demonstrate its destruction capability and the slagging performance.

Solid feed-type wastes are anticipated to be a major portion of the candidate wastes for application of this technology. Specifically, spent potliners (SPL), a major waste product of the aluminum smelting industry were selected for the proof-of-concept testing. Potliners, comprising carbon and refractory material, are used as an electrolytic cathode and insulating material in large reinforced steel cells or pots that contain cryolite (Na_3AlF_6), alumina (Al_2O_3), and various additives. In these pots, calcined alumina is electrolytically reduced to molten aluminum metal and subsequently drawn off. During this process, carbon in the potliner combines at high temperatures with nitrogen to form cyanide that is absorbed in the liner itself.

After a few years, the potliners crack and must be replaced. In addition to cyanides, the SPL contain a significant amount of leachable fluorides. Table 18 shows the composition of SPL from two aluminum producers that annually amounts to roughly 150,000 tons of waste material, which must be either discarded, destroyed, or reclaimed in a manner that prevents the cyanides, fluorides, and other organic and inorganic impurities from reaching the environment. For many years, SPL were recycled to recover cryolite, using one or more of several different recovery schemes. Landfill disposal is not acceptable environmentally.

---

* GRI, Enron Corp., Northwest Pipeline Corp., Tenneco, and IGT Sustaining Membership Program.

Table 18 . REPORTED COMPOSITIONS OF SPL

Constituent	Alcoa	Reynolds
C	28.6	42.7
Al	14.2	4.7
Si	4.76	0.11
Fe	3.23	0.27
Na	13.9	20.0
F	18.2	17.6
CN	0.09	0.135
Al Carbide	0.46	--

In recent years, indoor storage has provided a temporary means of accumulating SPL at some smelter locations until an acceptable or final disposal option becomes available. Thermal treatment using fluidized-bed techniques has been tried in the past, but with little success; thermal decomposition of cyanide is successful, but leachable fluoride content has not been reduced to environmentally acceptable levels. Recently it has become a federally listed hazardous waste.

The slagging mode treatment of SPL is shown conceptually in Figure 13. In this mode, the waste is burned and the inorganic content (ash) is melted primarily in the space. The resultant particulates and droplets are separated from the combustion products and thrown on the combustion chamber walls by the centrifugal forces created by the cyclonic motion. Final burnout and melting occurs on the refractory walls, producing a thin layer of slag that flows down into the slag received and is removed by gravity.

In this mode, the cyclonic combustor is believed to be capable of treating a wide variety of solid, liquid, and gaseous wastes and offers great operational flexibility. The thermal and combustion characteristics are controllable and can be tailored to specific wastes. The controlling parameters are the injector configurations, the amounts of the primary air, secondary air, natural gas, and waste, and the orifice size and location. The sectional design of the pilot-scale combustor with multiple injection ports simplifies the adjustments of these parameters.

The specific performance goals of the test program are to achieve a DRE of 99.999% of cyanides and 90% ash removal as slag, while operating with less than 20% excess air and producing air emissions of less than 25 ppm carbon monoxide and less than 25 ppm total hydrocarbons.

Current Status

The system has been configured for the treatment of SPL with molten ash discharge, and a system shakedown (without waste feed) has been carried out firing natural gas. Two

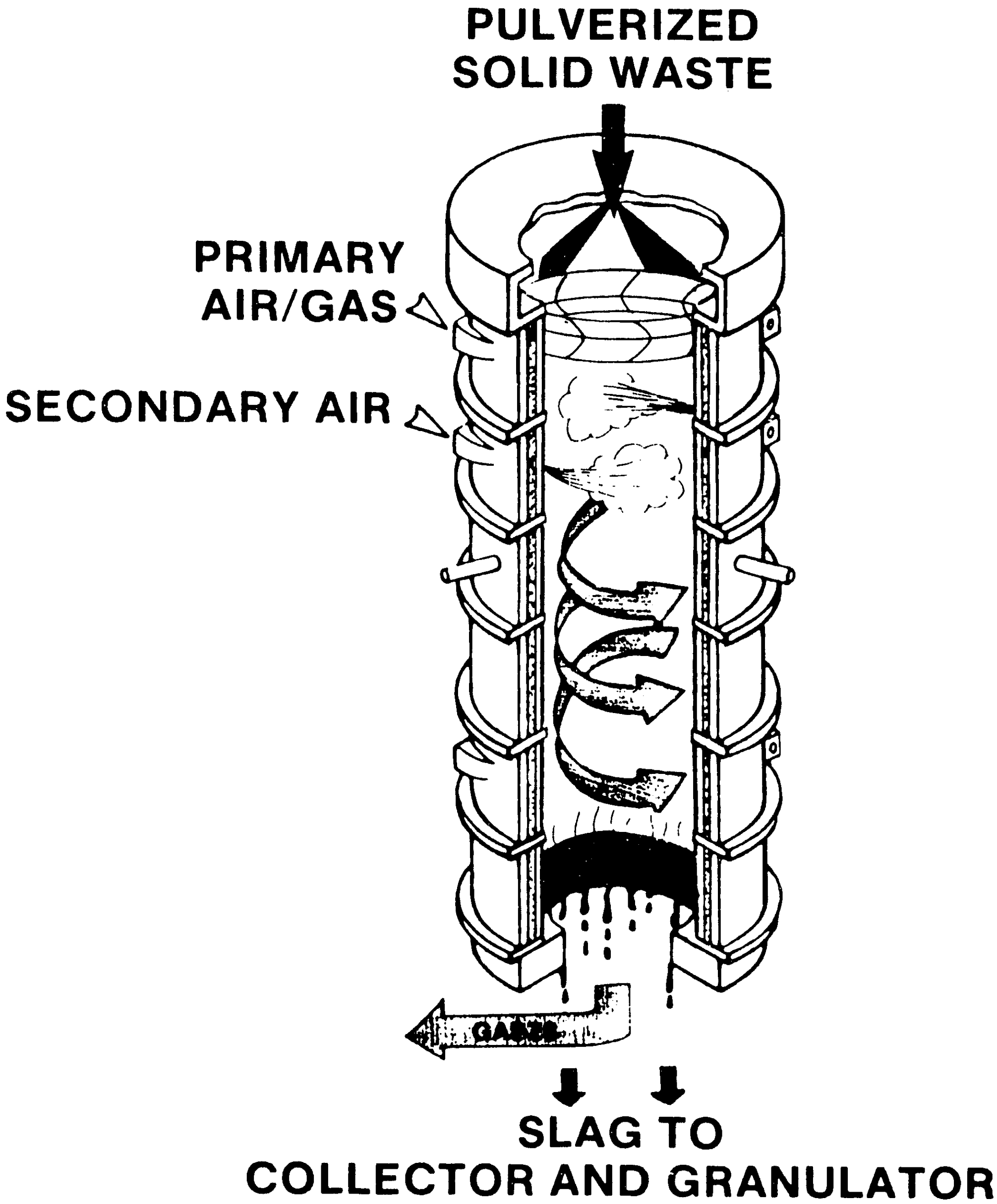

Figure 13. SLAGGING CYCLONIC WASTE COMBUSTION

relatively inexpensive fluxes have also been identified, through analytical studies, that could significantly reduce the SPL ash melting temperatures. Testing is expected to be completed during 1991. If successful, a full-scale field evaluations would be undertaken during 1992/93.

END

DATE
FILMED
12/3/91