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DEVELOPMENT OF ADVANCED FLUID-BED AGGLOMERATION AND CYCLONIC INCINERATION FOR SIMULTANEOUS WASTE DISPOSAL AND ENERGY RECOVERY

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IGT

DEVELOPMENT OF ADVANCED FLUID-BED AGGLOMERATION AND CYCLONIC INCINERATION FOR SIMULTANEOUS WASTE DISPOSAL AND ENERGY RECOVERY

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ABSTRACT

The Institute of Gas Technology (IGT) is currently developing a two-stage fluidized-bed/cyclonic agglomerating incineration system for waste disposal that is based on combining the fluidized-bed agglomeration/incineration and cyclonic combustion technologies. Both technologies have been developed individually at IGT over many years. This combination has resulted in a unique and extremely flexible incinerator for solid, liquid, and gaseous wastes including municipal sludges. The system can operate over a wide range of conditions in the first stage, from low temperature (desorption) to high temperature (agglomeration), including gasification of wastes. In the combined system, solid, liquid, and gaseous organic wastes are incinerated with ease and great efficiency [>99.99% destruction and removal efficiency (DRE)], while solid inorganic contaminants contained within a glassy matrix are rendered benign and suitable for disposal in an ordinary landfill. The heat generated within the incinerator can be recovered using the state-of-the-art boilers. The development of the two-stage incinerator is a culmination of extensive research and development efforts on each stage of the incinerator. The variety of data obtained with solid, liquid, and gaseous wastes for both stages includes agglomeration of ash, incineration and reclamation of used blast grit and foundry sand, partial combustion of carbonaceous fuels, in-situ desulfurization, combustion of low-Btu gases, incineration of industrial wastewater, and incineration of carbon tetrachloride.

DEVELOPMENT OF ADVANCED FLUID-BED AGGLOMERATION AND CYCLONIC INCINERATION FOR SIMULTANEOUS WASTE DISPOSAL AND ENERGY RECOVERY

INTRODUCTION

The U.S. Government responded to the critical waste problem with the enactment of the following laws: 1) the Resource Conservation and Recovery Act (RCRA) in 1976; 2) the Toxic Substance Control Act (TSCA) in 1976; 3) the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) in 1980; 4) the RCRA Amendment of 1984; and, most recently, 5) the Superfund Amendments and Reauthorization Act (SARA) of 1986. These laws intensified interest in the thermal destruction of organic/inorganic wastes and ensure the reliable management of hazardous/toxic waste disposal operations and dumpsite cleanup. Also, the current dratt regulations (40 CFR Part 503) proposed by the U.S. Environmental Protection Agency (EPA) for municipal sludge and solid waste incineration and the increasing scrutiny in renewing permits for the emissions from such incineration dictate sophisticated disposal options.

Incineration ("thermal destruction") has been recognized as one of the best demonstrated and available technologies for waste destruction. Incineration is an engineered process, with waste destruction being the ultimate goal. It uses heat to break the chemical structures of organic compounds, thus reducing the volume and toxicity of the remaining residuals.

Incineration of hazardous and nonhazardous wastes continues to be strongly favored in the United States and abroad as one of the best alternatives to landfilling. Most observers expect that incineration will become more prevalent as a means of minimizing landfilling in the U.S.; that has certainly been the case in Europe and Japan. The benefits of incineration compared with other disposal methods are even more pronounced with falling fuel prices. Hence, there is an enormous potential for more incineration capacity in the near future.

IGT's advanced multipurpose incinerator, shown in Figure 1, combines fluidized-bed agglomeration/gasification technology and a cyclonic combustion technology. This two-stage system is an extremely flexible incinerator for solid, liquid, and gaseous wastes, including municipal sludges, that can operate over a wide range of conditions. In the combined system, these wastes

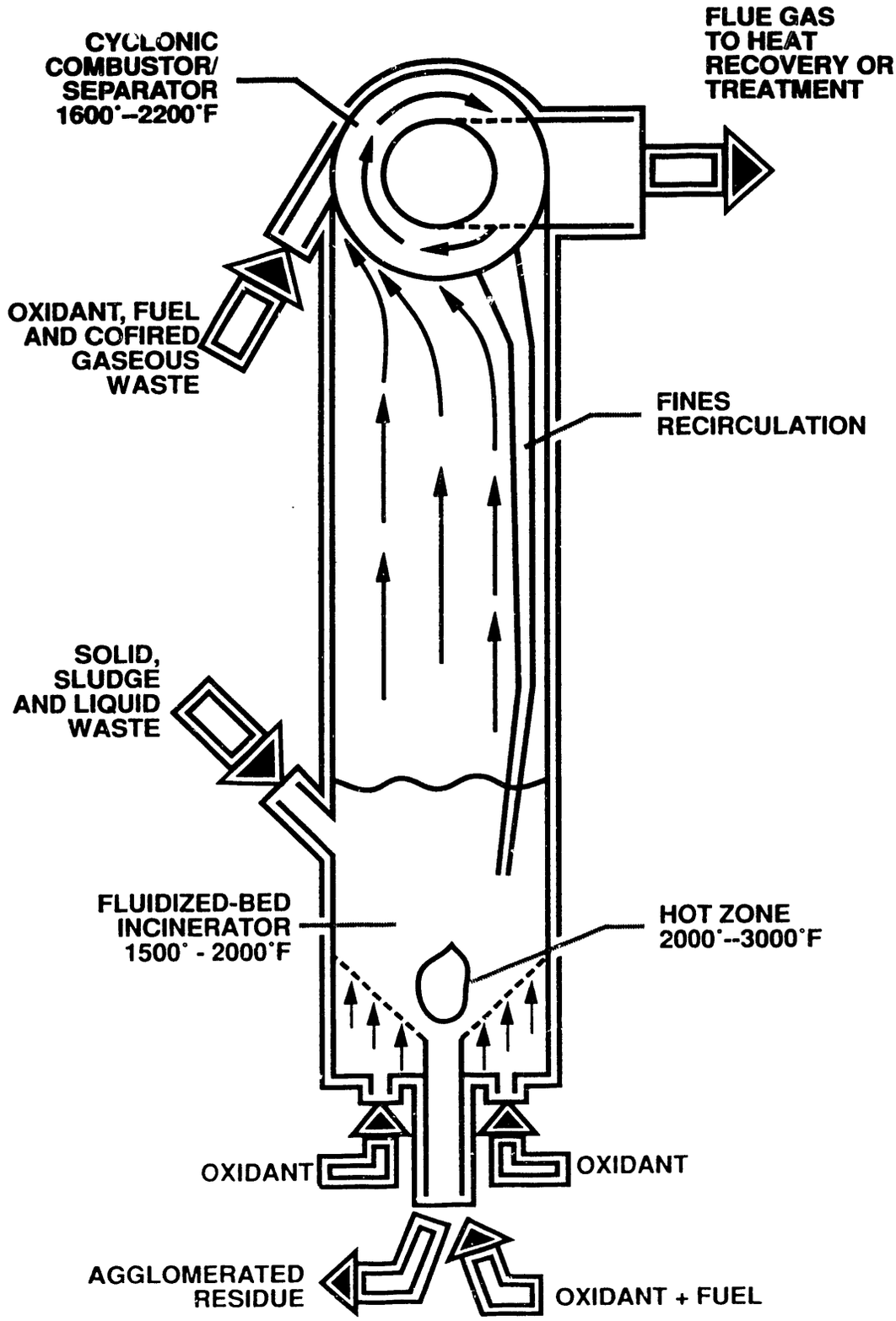

Figure 1. SCHEMATIC DIAGRAM OF THE ADVANCED TWO-STAGE INCINERATOR

are efficiently destroyed (>99.99% DRE), while solid inorganic contaminants or the solid residues are captured within a glassy matrix and rendered benign and suitable for disposal in an ordinary landfill.

The first stage of the incinerator is a sloped-grid (SG) agglomerating fluidized-bed reactor that can operate under either substoichiometric or excess air conditions. Besides the sloped grid, the reactor has a central jet and a classification section. Fuel gas and air enter the central jet, while only air is admitted through the grid and the classifier. The waste to be incinerated is introduced directly into the fluidized bed. With a unique distribution of fuel and air, the bulk of the fluidized bed is controlled at a temperature of 1500° to 2000°F, whereas the central spout temperature can be varied from 2000°F to 3000°F. The hot zone thus formed is localized and very distinct in terms of temperature and size; it can be altered by changing the gas-flow distribution. This feature is the key to its ability to produce and control the rate of ash and solid waste in the fluidized bed. The amount of fuel required to maintain the operating temperatures depends largely on the calorific value of the waste being incinerated. The municipal sludges are typically 1000 to 3000 Btu/lb, all of which is released during combustion. With these wastes, not only is the volume reduced, but the noncombustibles are vitrified in glossy agglomerates that can then be safely used for construction-related industry. The ability of the fluidized bed to produce solid wastes that meet leachability standards has already been demonstrated in coal gasification tests.

Collection and return of fine particulates from the flue gas to the fluidized bed increases the quantity of metals captured in the vitrified solid residue discharged from the bottom of the fluidized bed.

The second incinerator stage is the cyclonic combustor, where flue gas from the fluidized bed is further combusted at temperatures of 1600° to 2200°F. Either secondary air or a natural gas/air mixture is fed to this incinerator stage as needed. The cyclonic combustor provides sufficient residence time at operating conditions to oxidize all carbon monoxide (CO) and organic compounds to CO_2 and water vapor, yielding a combined DRE greater than 99.99%. The gaseous effluent from the cyclonic combustor can be cleaned using available technologies (fabric filters, scrubbers, etc.).

IGT's Advanced Two-Stage Incineration System, a novel approach to staged incineration/combustion technology (5) has the following unique features:

- The ability to process solid, liquid, and gaseous wastes, including municipal sludges, in a single system
- A patented sloped grid that enhances solids-circulation patterns within the fluidized bed and promotes complete gas-solids mixing and even temperature distribution for destruction of organic components
- Staged processing, which ensures a high organic component DRE and low CO, THC, SO_x, and NO_x emissions despite changing feed conditions
- The ability to operate at a high combustion temperature (1500° to 1800°F) for a sufficient length of time (1 to 3 seconds) which is good combustion practice for municipal sludges and solid wastes to mitigate emissions of trace organic compounds
- A central air/fuel jet, which permits efficient combustion of natural gas or other fuels within the fluidized bed while producing a hot zone of controlled size and temperature
- A central hot zone, which agglomerates and encapsulates inorganics into glassy pellets while the cooler surrounding bed scrubs the more volatile inorganics for ultimate removal with the agglomerates
- An ash-discharge port with no moving parts, which provides precise discharge-rate control and size classification
- The recycling of elutriated fines into the agglomerates zone to minimize particulate and volatile metals emissions
- High heat-transfer rates and low air/fuel ratios that allow high treatment capacities in relatively compact, transportable equipment.

A boiler appears to be the most attractive way to recover energy when wastes such as municipal sludge are processed through the system. The waste, auxiliary fuel, and air are admitted in a controlled manner in two stages by which heat and gaseous products are liberated. As these hot gases pass through the two different combustion stages, a portion of this heat is transferred to the waterwall enclosure. The design of the incinerator could include direct firing into the boiler at a power generation facility whereby most of the residual heat is recovered as steam.

Research and development on the incinerator is being conducted in two steps. In the first step, the operating data from the individual stages are being analyzed to establish the capability of each stage separately. In the second step, an integrated unit will be designed, constructed, and operated to

obtain the performance data and control characteristics of the integrated unit. This paper highlights the research data obtained individually from the fluidized-bed unit and from the cyclonic combustor/incinerator unit. It presents the research results from the agglomeration of inorganic constituents of coal ash and thermal reclamation of blast grit conducted in the fluidized-bed unit and the combustion of liquid waste, low-Btu gases, and carbon tetrachloride in the cyclonic unit.

AGGLOMERATION OF INORGANIC ASH

Ash agglomeration tests were conducted in a 3-foot-diameter reactor equipped with a sloped grid, a jet for creating a hot zone within the fluidized bed, and an ash discharge nozzle (venturi), as depicted in Figure 2. Different types of coals (3,4) were used in this investigation to vary the ash properties in terms of composition and softening temperature. A partial list of coals along with ash content and ash fusion temperature is shown in Table 1. The fluidization was maintained by using steam or steam/ oxygen/air mixtures, whereas the hot zone was maintained by introducing streams of air or steam enriched with oxygen into the central jet. The localized zone of relatively high temperature was caused by the combustion of oxygen with carbon and hydrogen contained in the coal. The temperature created was sufficient to melt the ash and cause the agglomeration through collision of like particles. The addition of supplemental fuel was not necessary in this case. The typical ash agglomerates produced from some of these feedstocks are shown in Figure 3. These agglomerates were found to be in compliance with EPA toxicity standards for leachability.

The experience with entrapment of trace inorganic metals from coal in glassy, essentially non-leachable ash agglomerates can be readily extended to the treatment and incineration of other wastes. Another important aspect of these agglomerates was that, despite the abundance of organic compounds in the coals, these agglomerates were completely devoid of any of the organics -- indicating that the fluidized bed, while producing agglomerates, is capable of stripping off organics from the waste. A portion of these organics is combusted in the fluidized-bed stage and the balance in the cyclonic stage.

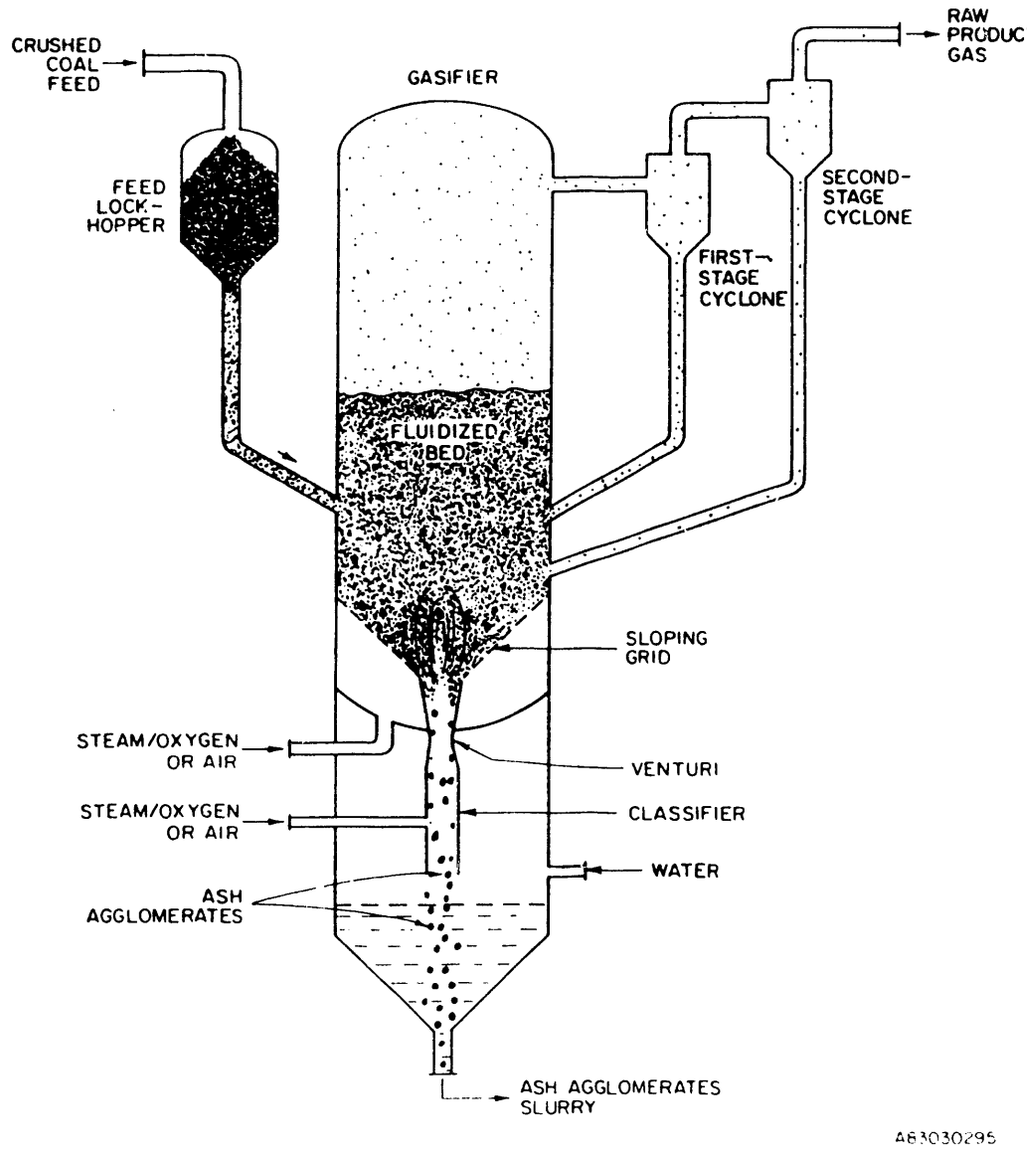

Figure 2. FLUIDIZED-BED INCINERATOR

Table 1. FLUIDIZED-BED FEEDSTOCK PROPERTIES

	Ash, %	VM, %	Sulfur, %	FSI	IDT, °F	STD, °F
Bethlehem Coke Breeze	11	3	0.6	0	2085	2155
Montana Subbituminous	8	32	0.6	0	2050	2110
Illinois No. 6 Bituminous	11	35	3.9	3-4	1960	2120
ROM W. Kentucky No. 9 Bituminous	19	35	4.6	5-6	1975	2105
Washed W. Kentucky No. 9, Bituminous	12	37	3.1	3-5	1995	2110
Pittsburgh No. 8 Bituminous	13	34	1.8	7-8	2200	2325
Australian Coal	10	33	0.8	1	2330	2490
Wyoming Subbituminous	6	42	1.0	0	1915	2035
Polish Coal	13	30	0.8	1	2180	2330
French ROM Bituminous	32	24	0.6	1	2240	2325
Utah Bituminous	10	41	0.6	1	2210	2370
Finnish Peat	4.5	42	0.2	0	1960	2010

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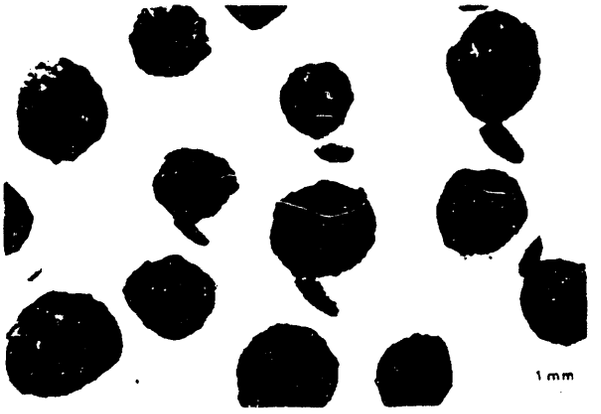
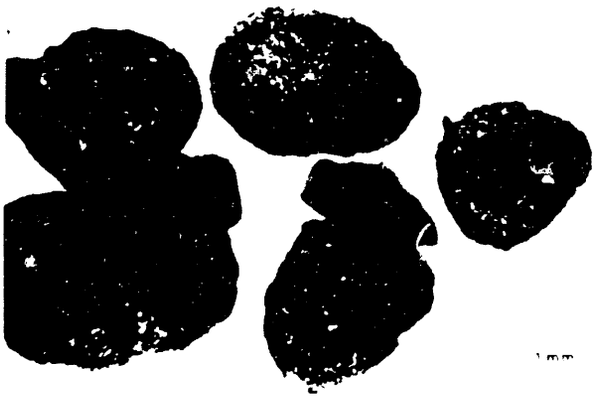
(a) Illinois No. 6 Coal

(d) Run-of-Mine W. Kentucky No. 9 Coal



(b) Metallurgical Coke (1850°F)

(e) Kentucky No. 9 Coal (1850°F)



(c) Metallurgical Coke (1890°F)

(f) Kentucky No. 9 Coal (1920°F)

Figure 3. TYPICAL ASH AGGLOMERATES FROM DIFFERENT FEEDSTOCKS

RECLAMATION OF BLAST GRIT

The U.S. Naval Shipyards produce about 100,000 tons of used blast grit annually and dispose of it in landfills. During blast cleaning, the paint and rust removed from the ship's surface accumulates in the used or spent blast grit (slag). Occasionally, material from other vessel-servicing operations accumulates as tramp with the used blast grit. Because of this contamination and the generation of grit fines during blasting, the blast grit is not reusable and therefore must be reclaimed or carefully discarded. Because it contains metals and organics from the paint coatings, the used blast grit is stockpiled onsite or landfilled at special hazardous waste sites in certain states. This material is one of the major hazardous wastes generated in the eight Naval shipyards.

Figure 4 shows a suggested SG calciner system for blast grit reclamation. As the air enters the preheater, the air dries the grit, which is then fed into the calciner by a metering screw feeder or drag feeder. The grit is heated to a temperature of 1200° to 1600°F by burning natural gas directly in the fluidized bed. The organic content of the paint chips is converted to water vapor and carbon dioxide, and the inorganic and metallic components are elutriated out of the calciner with the flue gases. Rough particle sizing of the reclaimed media, free of paint residue and grit fines, can be achieved through adjustments in air flow to the discharge line from the fluidized bed. Sensible heat from the calcined grit can be used to generate low-pressure steam and/or provide hot air for drying the spent grit. The cooled, reclaimed grit can then be stored for reuse. The majority of fines and inorganic paint residues can be removed from the calciner flue gases by a cyclone separator. A flue-gas heat-recovery system downstream of the cyclone can preheat the fluidization and combustion air supplied for the calciner.

Bench-Scale Tests

Four tests were conducted with the used blast grit in the 2-inch fluidized-bed reactor. A charged batch of grit was brought to the desired temperature by both the preheat coil fluidizing air and direct radiation from the furnace. Hot air, CO_2, and water vapor from the paint and fine particles leaving the reactor passed through a cyclone where fines were separated and the gas vented. The operating conditions for the four tests are given in

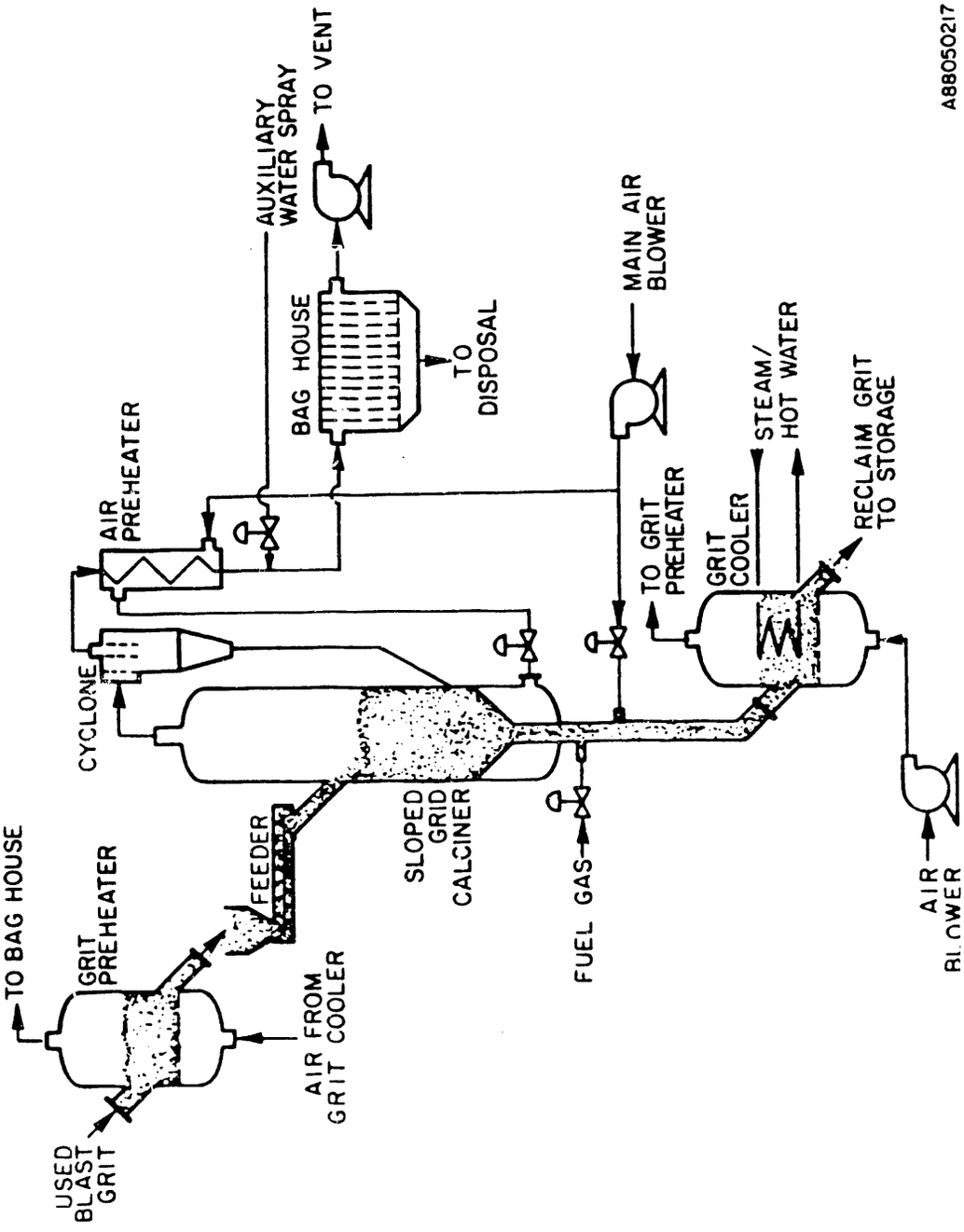


Figure 4. FLUIDIZED-BED INCINERATOR FOR BLAST GRIT RECLAMATION

Table 2. Table 3 lists the weight fractions of calcined grit retained in the reactor and carried to the cyclone.

To evaluate the results of the four calcining tests, samples of the calcined grit and the cyclone fines were analyzed (using the same criteria for the virgin and used grit) for metals and major oxide content plus sieve-size distribution. These analytical results are shown in Tables 4, 5, and 6. The same information on fresh grit and used grit is also listed for comparison.

The analyses presented in Table 4 show that common constituents of paint such as organics, zinc, barium, titanium, and copper were removed from the grit and carried to the cyclone fines collector. The greater concentration of these metals in the fines fraction confirms that fluidized-bed calcining incinerates the paint chips and entrains the inorganic oxides to the fines fraction. The fines fraction also contains degraded grit generated during blasting. The organic content of the reclaimed grit readily meets the low specification level of the virgin grit. The organic content of the fines is high in Test Nos. 1, 2, and 4, but not in Test No. 3 because the higher fluidization velocity of the latter test provided more intensive mixing, and thereby more complete combustion of the paint.

Table 5 lists the analysis for major oxide components of the blast grit. These data show that there is no significant difference in the general chemical analysis of the virgin, used, and reclaimed grit. However, the major oxide content of the fines indicates that concentrations of Na_2O, SO_3, CaO, and TiO_2 increased. Some of these compounds are paint components; others may have been volatilized at the calcining temperature.

As shown in Table 6, the reclaimed grit from all the tests is lower in fines (<80 mesh) than the used grit but does not meet the virgin grit specifications. Operating velocity limitations for the laboratory reactor prevented the use of higher fluidization velocities needed to remove sufficient fines to meet virgin grit size specifications.

A cursory observation of the data shown on Table 6, however, reveals that a larger fraction of the fines collected exceeded the 100-mesh sieve size during Test No. 3 than in Test Nos. 1, 2, and 4. Test No. 3 operated at a fluidization velocity 50% higher than that of Nos. 1 and 2, and 33% higher than that of No. 4. A calciner can be operated at any velocity compatible

Table 2. TEST OPERATING CONDITIONS

Run No.	Test Temperature, °F	Fluidization Velocity, ft/s	Test Period, h
1	1500	2	2
2	1200	2	2
3	1500	3	2
4	1200	2.3	2

Table 3. MATERIAL DISTRIBUTION

Run No.	Used Grit wt, grams	Reclaimed Grit wt, grams	Fines wt, grams	Percent Reclaimed
1	534.5	493.3	30.8	92.3
2	535.5	513.5	16.4	95.9
3	537.5	512.7	19.0	95.4
4	535.9	504.5	26.9	94.1

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Table 4. BLAST GRIT TEST RESULTS OF METAL CONTENT ANALYSES

Metal	Virgin Grit	Used Grit 1	Used Grit 2	Test No. 1 Reclaimed Grit	Test No. 1 Fines	Test No. 2 Reclaimed Grit	Test No. 2 Fines	Test No. 3 Reclaimed Grit	Test No. 3 Fines	Test No. 4 Reclaimed Grit	Test No. 4 Fines
Copper (CU)	980	1000	200	1100	5700	2000	6200	600	860	1400	11900
Zinc (Zn)	3400	3700	3700	3700	9000	3400	7200	2800	6800	3100	6400
Titanium (Ti)	1900	1600	1400	1000	4000	1100	5200	1000	4900	1000	4600
Barium (Ba)	590	790	670	360	4100	400	4400	290	4600	320	4300
Chromium Vi (Cr)	2900	4000	3900	4000	3300	4000	3100	4400	3300	3800	3200
Nickel (Ni)	2000	2700	2200	1700	1800	2700	1600	2700	660	1400	5600
Lead (Pb)	840	320	320	300	480	310	550	240	440	300	510
Tin (Sn)	160	120	130	60	110	160	80	100	140	100	100
Arsenic (As)	210	220	230	92	170	130	220	160	210	220	170
Cadmium (Cd)	8	6	6	4	12	6	9	6	11	6	11
Organics*	1000	5800	4900	800	35400	900	2900	700	4100	700	42300

* Measured as carbon and hydrogen in the sample.

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Table 5. BLAST GRIT TEST RESULTS OF MAJOR OXIDE ANALYSES

Major Oxide	Virgin Grit	Used Grit 1	Used Grit 2	Test No. 1 Reclaimed Grit	Test No. 1 Fines	Test No. 2 Reclaimed Grit	Test No. 2 Fines	Test No. 3 Reclaimed Grit	Test No. 3 Fines	Test No. 4 Reclaimed Grit	Test No. 4 Fines
Na_2O	0.45	0.35	0.30	0.26	0.70	0.28	0.76	0.27	0.69	0.26	0.85
MgO	15.50	20.60	20.70	21.50	18.70	21.50	17.80	21.50	17.90	22.60	18.00
Al_2O_3	3.23	2.55	2.49	2.60	3.27	2.65	3.48	2.72	3.27	2.70	3.19
SiO_2	41.90	47 80	47.60	46.50	41.00	44.40	43.20	48.10	44.70	48.90	43.90
P_2O_5	0.12	0.07	0.05	0.07	0.14	0.07	0.14	--	--	--	--
SO_3	0.52	0.55	0.47	0.612	1.85	0.52	1.22	0.5	1.30	0.50	0.87
K_2O	0.54	0.40	0.39	0.34	0.54	0.35	0.52	0.36	0.51	0.34	0.51
CaC	2.32	1.30	1.32	1.27	3.19	1.40	3.78	1.26	3.37	1.26	3.44
TiO_2	0.32	0.27	0.23	0.17	0.67	0.18	0.87	0.17	0.77	0.17	0.82
Fe_2O_3	30.30	24.60	24.40	24.30	24.80	24.30	24.80	23.70	24.80	23.70	23.50
Total	95.10	98.49	97.75	97.69	94.86	95.65	96.57	98.58	97.26	100.43	95.08

lWP/hazard-5/PAP

Table 6. BLAST GRIT TEST RESULTS OF PARTICLE-SIZE ANALYSIS

U.S. Sieve No. Retained On:	Virgin Grit	Used Grit 1	Used Grit 2	Test No. 1 Reclaimed Grit	Test No. 1 Fines	Test No. 2 Reclaimed Grit	Test No. 2 Fines	Test No. 3 Reclaimed Grit	Test No. 3 Fines	Test No. 4 Reclaimed Grit	Test No. 4 Fines
6	0.0	0.2	0.003	0.0	1.3	0.0	1.9	0.0	0.0	0.0	0.0
8	0.1	0.1	0.2	0.1	1.0	0.1	0.6	0.0	0.0	0.10	0.0
12	2.7	0.8	1.1	1.1	1.0	1.2	0.6	2.2	0.5	1.1	0.4
20	49.0	25.0	30.9	28.2	2.7	31.4	0.6	36.9	0.0	28.5	0.4
30	25.9	18.6	20.4	2.2	0.7	23.2	.0	23.1	0.0	22.2	0.0
40	12.9	18.5	18.7	19.9	0.3	19.3	0.6	16.9	0.5	20.1	0.0
50	3.5	13.2	12.1	14.5	0.7	13.1	0.0	11.5	0.0	14.5	0.4
80	2.3	12.0	9.8	10.9	1.3	8.9	0.6	7.9	4.3	10.4	1.5
100	0.8	3.1	2.2	2.3	6.4	1.5	2.5	1.2	12.9	2.0	5.8
200	1.8	5.9	2.9	0.5	65.7	1.0	57.1	0.3	54.3	0.9	55.8
270	0.4	1.1	0.6	0.1	6.1	0.1	10.8	0.0	8.6	0.0	9.6
325	0.4	0.7	0.2	0.1	4.0	0.1	6.2	0.0	6.5	0.0	6.9
Pan	0.2	0.8	0.6	0.1	8.8	0.1	16.5	0.0	12.4	0.09	19.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Bulk Density, lb/ft^2	122.5	118.6	123.7	123.2	96.0	118.6	89.1	121.8	97.8	122.2	105.5
Moisture, wt %	--	14.9	14.9	--	--	--	--	--	--	--	--

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with elutriation constraints; therefore, if required, a commercial unit can be designed at higher velocities to yield a reclaimed grit more closely approaching the virgin grit sieve-size specifications.

Pilot-Scale Tests

Five kinds of blast grit materials were received for the study:

1. Spent coal slag with copper-based paint (coal/Cu)
2. Spent coal slag with tributyl tin-based paint (coal/TBT)
3. Spent copper slag with copper-based paint (Cu/Cu)
4. Fresh coal slag abrasive
5. Fresh copper slag abrasive.

The two fresh abrasives and the spent coal/Cu and Cu/Cu abrasives were analyzed for total and soluble metals, major oxide components, sieve and subsieve particle-size distribution, and organics measured as carbon and hydrogen. The spent coal/TBT abrasive was analyzed for organics, particle-size distribution, total tin, and organotin specification.

Approximately 30 tons of spent abrasives were processed in the 3-foot-diameter pilot fluidized-bed incinerator system at abrasive feed rates of about 800 to 1500 lb/h. using supplemental natural gas. No attempt was made to agglomerate the material because it was expected to be reused for blasting.

A summary of the operating conditions and results of the pilot-scale test burns with the three abrasives is given in Table 7. Complete analyses for organics, total and soluble metals, major oxides, and size distribution for the coal/Cu and Cu/Cu feed and output streams were performed. In addition, analyses for organics, organotin, total tin, and size distribution were conducted for the coal/TBT test. The results of these analyses, shown in Table 8, indicated that the reclaimed materials were suitable for reuse in blasting operations.

The testing clearly demonstrated that the performance of the reclaimed abrasive and that of the fresh abrasive were comparable. The laboratory results proved that the SG fluidized-bed incinerator produced reclaimed abrasives that conform to the requirements of MIL-A-22262A for fresh blasting abrasives.

Table 7. BLAST ABRASIVE TEST BURN SUMMARY

Abrasive Type	Coal Slag/ Copper Paint	Coal Slag/ TBT Paint	Coal Slag/ Copper Paint
Abrasive Feed Rate, lb/h	840	1120	1510
Incinerator Temperature, °F	1480	1470	1475
Incinerator Pressure, psig	10.3	11.5	13.5
Organics,*)g/g (ppm)			
Feed	12,300	15,000	7,200
Discharge	1,500	200	200
Total Tin/Organotin,)g/g (ppm)			
Feed	--	50/32	--
Discharge	--	30/<0.00005**	--

* Measured as carbon and hydrogen.

** Indicates detection limit of analytical procedure.

lWP/hazard-7/PAP

Table 8. RESULTS OF LABORATORY ANALYSES OF RECLAIMED ABRASIVES

Test	Coal Slag Requirement	Results: Coal Slag/Copper Paint	Results: Coal Slag/TBT Paint	Results: Copper Slag/Copper Paint
Moisture, wt %	0.5 max	<0.05	<0.05	<0.05
Weight Change on Ignition, %	-1.0 to +5.0	<0.1	<0.1	<0.1
Chloride, %	0.03 max	<0.001	<0.001	<0.001
Free Silica, %	1.0 max	<1.0	<1.0	<1.0
Free Flow, %	99.0 min	>99.0	>99.0	>99.0
Specific Gravity	2.5 min	2.86	2.85	3.43
Carbonates and Gypsum	None	CONFORMS	CONFORMS	FAILS*
Conductivity, Imhos/cm	100 max	24.5	10.0	120*
Oil Content, %	0.030 max	<0.001	<0.001	<0.001
Metal Content (STLC and TTLC)	CA Title 22	CONFORMS	CONFORMS	CONFORMS
Hardness, Mhos Scale	6 min	>6	>6	>6
Radioactivity, Gross Gamma, pCi/g	20 max	16	15	165*
Cobalt, pCi/g	0.05 max	<0.02	<0.02	<0.02
Sieve Analysis, % 70 mesh (CA)	<1.0 passing	16.9	4.3	3.6
* PASS/FAIL	MIL-A-22262A	PASS	PASS	FAIL

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TESTS WITH THE CYCLONIC INCINERATOR

The key feature of the cyclonic stage of the incinerator -- to destroy organics as well as minimize emissions -- was demonstrated in tests with a liquid waste, low-Btu gases, and carbon tetrachloride. The cyclonic incinerator is shown in Figure 5. The complete facility for the cyclonic incinerator, in addition to the incinerator itself, included a waste storage and supply subsystem, a combustion air and natural gas subsystem, an atomizer assembly, a cooling water subsystem, a compressed air subsystem, and a drum heating subsystem.

Incineration of Liquid Waste

The liquid waste used in the tests contained about 35% to 55% dissolved solids and had a higher heating value (HHV) of approximately 3270 Btu/lb. The chemical composition of the "as-received" dewatered waste samples is shown in Table 9. The 48-hour test operation was generally free of difficulties, and there were no shutdowns. The test parameters are given in Table 10.

Some of the data collected involved heat removal via the water-cooled annulus of the incinerator chamber. The results indicate that about 190,000 Btu/h (25% of the total heat input) was transferred through the walls.

During the 48-hour test, 750 gallons of wastewater were incinerated. The major test results 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 0.8×10^6 Btu/h.
- High combustion intensity (250,000 Btu/h-ft^3) and excellent combustion efficiency (>99.9%) were achieved.
- Excess combustion air levels ranged from 10% to 25%.
- Preheated combustion air improved the performance and reduced auxiliary fuel consumption by about 5%.
- The ability to combust wastewaters of various concentrations (varied from roughly 35% to 55% solids) was demonstrated.

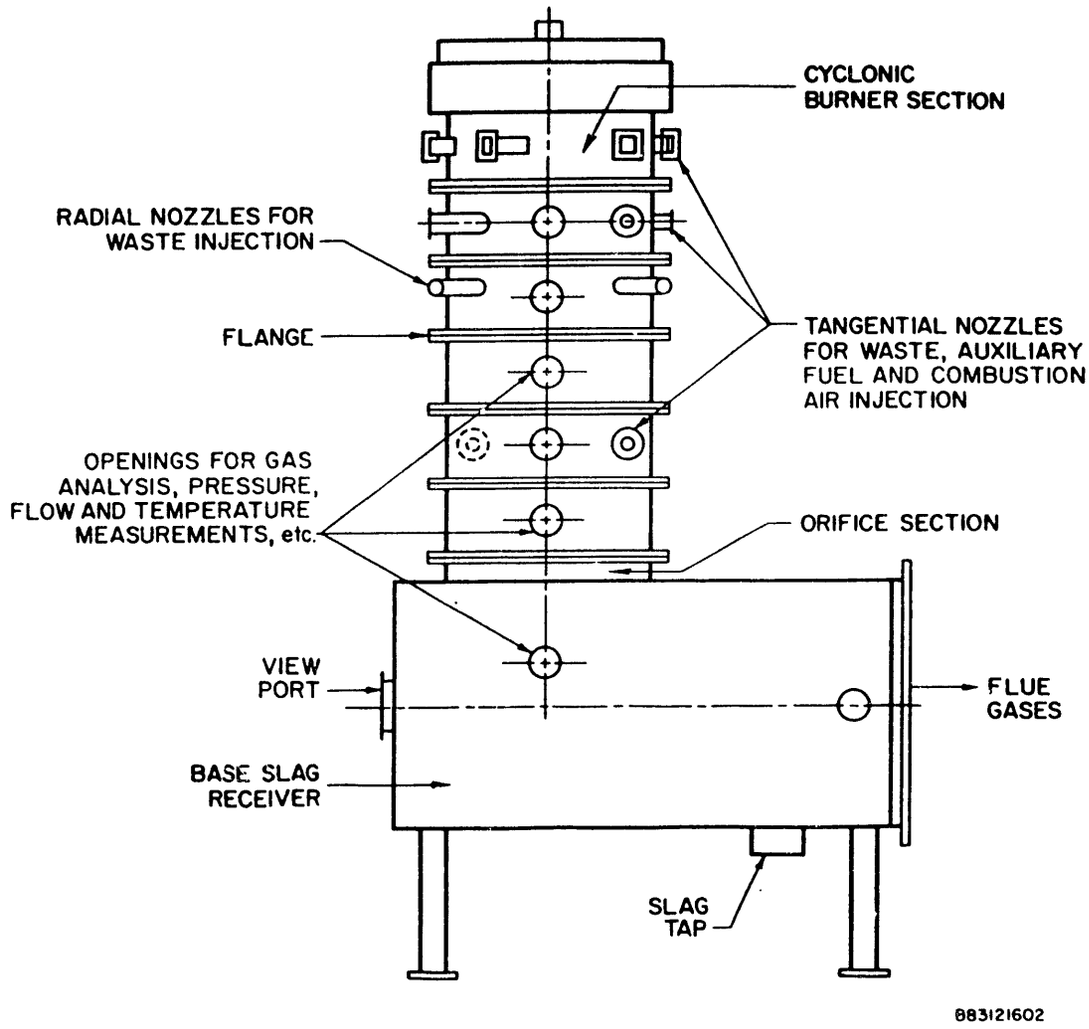

Figure 5. CYCLONIC INCINERATOR UNIT

Table 9. PROXIMATE AND ULTIMATE ANALYSES OF DEWATERED WASTE

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

Table 10. SYSTEM OPERATING PARAMETERS DURING 48-HOUR PERFORMANCE TEST

Test No.	Primary Air/Natural Gas Mixture: Firing Rate, 10^6 Btu/h	Primary Air/Natural Gas Mixture: Air Flow, SCF/h	Primary Air/Natural Gas Mixture: Static Pressure, in. wc	Temp, °F	Liquid Waste Flow, gal/h	Secondary Air: Static Pressure, in. wc	Secondary Air: Temp, °F	Exhaust Gas Analysis: O_2, %	Exhaust Gas Analysis: CO, ppm	Exhaust Gas Analysis: CO_2, %	Base/Slag Receiver Wall Temp, °F
1	0.465	4960	6.4	477	15.7	16.5	725	2.3	50	--	2010
5	0.475	5070	6.4	485	15.7	17.0	727	2.2	50	--	2085
12	0.48	5120	5.8	477	13.5	16.0	727	2.9	50	13.0	2093
16	0.48	5120	5.6	480	14.8	16.0	726	3.2	150	13.25	2111
21	0.49	5230	7.3	478	13.9	17.0	724	2.6	50	13.5	2098
25	0.45	4800	5.8	467	13.9	17.0	724	2.4	75	13.5	2086
27	0.455	4850	5.9	464	13.9	16.5	723	2.2	50	12.75	2095
36	0.32	3410	1.8	392	8.7	11.5	694	4.8	275	10.75	1818
41	0.35	3730	1.7	347	8.7	12.0	682	4.3	100	10.75	1886
44	0.30	3200	--	384	13.9	16.0	700	3.0	150	13.25	2072

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- Ash accumulation was relatively low on the incinerator chamber walls, orifice, base, and exhaust duct.
- Heat losses through the water-cooled walls were approximately 25% of the total heat input.
- The incinerator chamber refractory lining performed well with no observed damage.
- Sufficient data were collected to design and build a cyclonic incineration demonstration system.

TESTS WITH LOW-Btu GASES

The organics, which are partially combusted in the fluidized-bed stage of the incinerator, are expected to yield low-Btu gases, which are in turn expected to combust in the cyclonic stage. Therefore, the cyclonic incinerator was tested to observe the combustion characteristics of these gases. Table 11 shows the composition of the low-Btu off-gases tested. The 54 Btu/SCF gas composition represents the minimum heating value, and the 67 Btu/SCF represents the average of the minimum and maximum heating values. The gas also contained up to 0.56% NH_3 and 0.15% H_2S.

Table 11. COMPOSITIONS OF LOW-Btu GASES TESTED

	H_2	N_2	CO	CH_4	CO_2	H_2O, % Wet	HHV, Btu/SCF
	% Dry						
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

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 6 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,

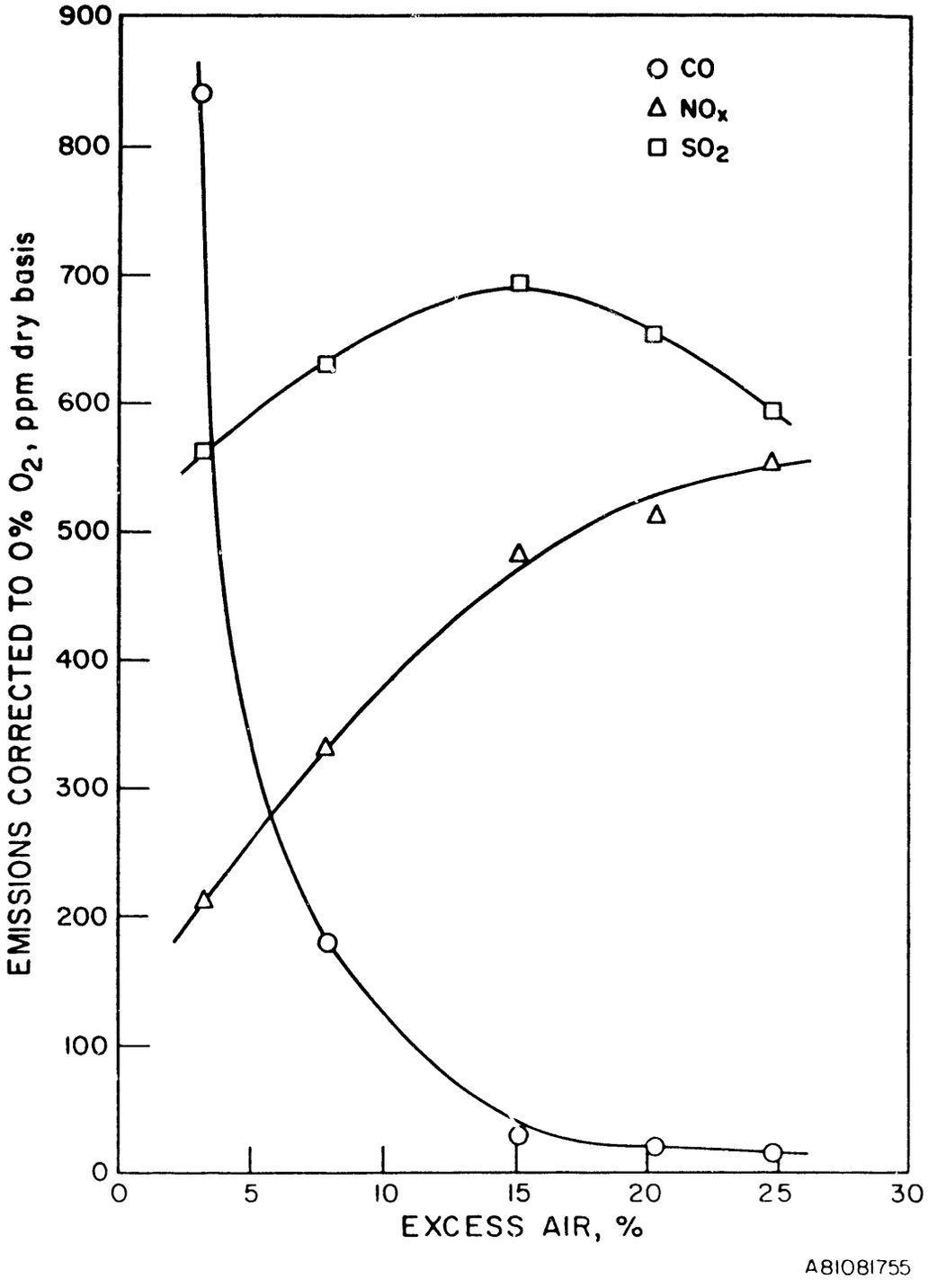

Figure 6. EFFECT OF EXCESS AIR ON GASEOUS EMISSIONS FOR AVERAGE GAS

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 7 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 NH_3 levels and rapidly at low 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%.

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

TESTS WITH CARBON TETRACHLORIDE

Carbon tetrachloride (CCl_4) was selected as the surrogate material for testing polychlorinated biphenyl (PCB) incineration capability in the cyclonic incinerator. 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.

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

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

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

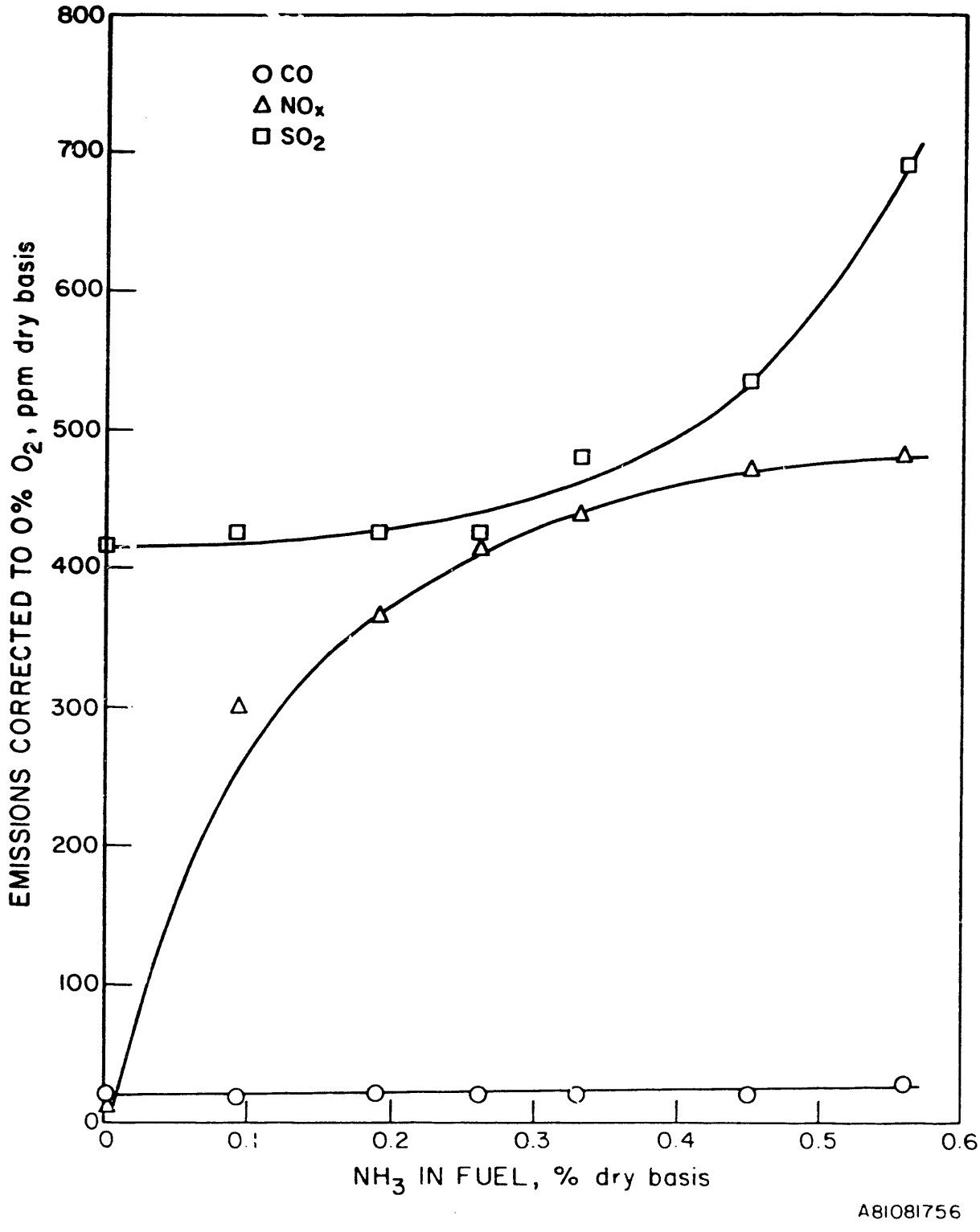

Figure 7. EFFECT OF FUEL NH_3 CONCENTRATION ON EMISSIONS FOR AVERAGE GAS WITH 15% EXCESS AIR

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.

A summary of the test results is presented in Table 12. 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 MMBtu/h. The gas sampling probe was located immediately beneath the cyclonic section of the incinerator, with a hot-gas residence time of approximately 0.25 seconds. Temperatures were taken by suction pyrometry near the exhaust of the incinerator base, after a gas residence time of about 0.75 seconds.

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, IGT's Analytical Laboratory reported that the CCl_4 remaining was below the limits of detection; at the higher rate, the CCl_4 remaining was 1.8 micrograms in the 20-liter gas sample. Both of these results indicate a destruction efficiency significantly better than six-9's. 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 incinerator 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 pyrometry directly under the cyclone orifice during this series. 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%) were used.

Table 12. CCl_4 INCINERATION TEST SUMMARY

Test No.	Firing Rate, 10^6 Btu/h	Suction Natural Gas/Air Temp, °F	Pyrometer Base Temp, °F	Exhaust Gas Analysis As Measured O_2, %	As Measured CO_2, %	Al O% O_2 CO, ppm	Al O% O_2 NO, ppm	CCl_4 Flow, lb/min	CCl_4/Nat. Gas Ratio	CCl_4 Recovered,)g/20 L	Destruc. Eff., %	Comments
1	1.0	695	2338*	2.5	10.25	68	--	--	--	--	--	N.G. Only
2	0.8	685	2098*	3.7	10.5	55	--	1.44	0.270	<0.9	99.99997	
3	0.8	700	2183*	3.6	12.0	54	--	3.26	0.610	1.8	99.99997	
5	0.8	700	2433	0.6	14.75	139	329	3.3	0.618	3.8	99.99995	Scrubber
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 Rejection
11	0.8	736	2032	1.7	11.25	11	511	1.05	0.197	<0.9	>99.99996	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**	.6-.8	13.5	398	134	2.15	0.393	1.8	99.99996	Caustic Injection in Base
17	0.8	406	2406**	3.5	11.5	60	60	2.15	0.393	5.1	99.99988	

* Suction pyrometer downstream.

** Thermocouple data.

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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 thermometry was used for the temperature and CCl_4 data. For this series of tests, the temperature was measured by a small bare-bead thermocouple.

The data points include variations in excess air utilization, CCl_4/CH_4 ratio, and combustion air preheat. Test 17, with lower combustion air preheat, showed a CCl_4 destruction efficiency slightly lower than six-9's.

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

- Carbon tetrachloride was destroyed in the cyclonic incinerator, generally at greater than six-9's destruction, by incineration with methane and air preheated to 800°F at exhaust temperatures of 2400° to 2500°F and a residence time of 0.25 seconds. Data were acquired with an incineration of 100% CCl_4; the impact of CCl_4 dilution was not tested.
- Emissions of NO_x were relatively high at 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 impaired.
- Generally, the destruction efficiency was high, regardless of the excess air ratio, cyclone exhaust temperature, or CCl_4/CH_4 ratio.
- The direct injection of alkali into the incinerator or into a hot zone downstream of the incinerator appears to hold promise for HCl removal but requires further development.
- Staged combustion can be evaluated for both NO_x control and chlorine control. Staged combustion for NO_x control requires temperature reduction before final CO burnout; alkali injection, or perhaps steam injection, may be desired approaches.

Additional test results are reported by Abbasi et al. (1) and Crimmins et al.(2)

CURRENT STATUS

The data obtained from the two individual components of the multipurpose fluidized-bed/cyclonic incinerator have shown that each of the components is capable of meeting its respective performance expectations. The first-stage sloped-grid, fluidized-bed reactor has demonstrated its ability to produce agglomerates and to desorb and destroy organics from the contaminated wastes. The second-stage cyclonic incinerator has demonstrated its ability to

combust and destroy practically all organic compounds. To provide further flexibility in the treatment of difficult and hazardous wastes, the two-stage incineration design will undergo a development and pilot plant demonstration with funding from the U.S. Environmental Protection Agency, The Gas Research Institute, IGT's Sustaining Membership Program, and American Combustion, Inc.

This integrated unit will be used to obtain performance data and design data for a commercial-sized plant. The unit would be used for a variety of applications, including the cleanup of various Superfund sites.

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