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ADVANCED TWO-STAGE INCINERATOR

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IGT

ADVANCED TWO-STAGE INCINERATOR

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ABSTRACT

The Institute of Gas Technology (IGT) is developing an advanced incinerator that combines the fluidized-bed agglomeration/incineration and cyclonic combustion/incineration technologies that have been developed separately at IGT over many years. This combination results in a unique and extremely flexible incinerator for solid, sludge, liquid, and gaseous wastes. This system can operate over a wide range of conditions in the first stage, from low temperature (desorption) to high temperature (agglomeration), including gasification of high-Btu wastes. In the combined system, solid, liquid, and gaseous organic wastes would be easily and efficiently destroyed [>99.99% destruction and removal efficiency (DRE)], whereas solid inorganic contaminants would be contained within a glassy matrix, rendering them benign and suitable for disposal in an ordinary landfill. This technology is different from other existing technologies because of its agglomeration and encapsulation capability and its flexibility with respect to the types of wastes it can handle. Both the fluidized-bed as well as the cyclonic incineration technologies have been fully developed and tested separately at pilot scales.

INTRODUCTION

There is an ever increasing need for the treatment and safe disposal of a wide variety of organic and inorganic wastes. Most notably, the cleanup of sites under Superfund, the U.S. Department of Defense, and the U.S. Department of Energy has triggered an enormous interest in this area. There are now hundreds of sites on the EPA National Priority List. The types of wastes encountered include one or more of the following:

- Soils contaminated with organic and inorganic (metal) contaminants
- Contaminated debris, including drum carcasses, wood, rocks, concrete, scrap metal, and brush
- Sludges and tars, some of which are extremely viscous and non-pumpable

- Pumpable organic and aqueous slurries
- Aqueous liquids
- Organic liquids.

At sites where a retrieval and treatment approach is required, available treatment technologies include soil washing, biological degradation, steam or air flushing, and thermal desorption as well as incineration. Biological treatment methods perform best in an aqueous media and are similar in this respect to soil washing systems. Slurry preparation and handling equipment are generally involved, and additional treatment of a contaminated water stream is often required. Biological systems operate at relatively low rates, requiring long processing times in large equipment. They operate best with organic contaminants in the 2000 to 5000-ppm range, and with aliphatic (straight-chain and branched) or polyaromatic hydrocarbons (PAH's) of 3 to 4 rings or less.[1] Methods for biological treatment of heavy metal contamination are currently under development. As with steam or air flushing, biological treatment for metals will require further processing for metals concentration and recovery or stabilization.

Of these treatment technologies, incineration is the most versatile and most widely practiced. Incineration offers complete destruction of organic contaminants to innocuous products of combustion and the ability to stabilize inorganic and heavy metal contaminants in a continuous manner at high treatment rates.

ADVANCED TWO-STAGE INCINERATOR

IGT's advanced two-stage incinerator, shown schematically in Figure 1, is based on combining a fluidized-bed agglomeration/gasification technology and a cyclonic combustion technology developed at IGT over many years. This combination results in a unique and extremely flexible incinerator for solid, liquid, and gaseous wastes. 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 high-Btu wastes. In the combined system, organic wastes are easily and efficiently destroyed (>99.99% DRE), while solid inorganic contaminants are captured within a glassy matrix, rendering them benign and suitable for disposal in an ordinary landfill.

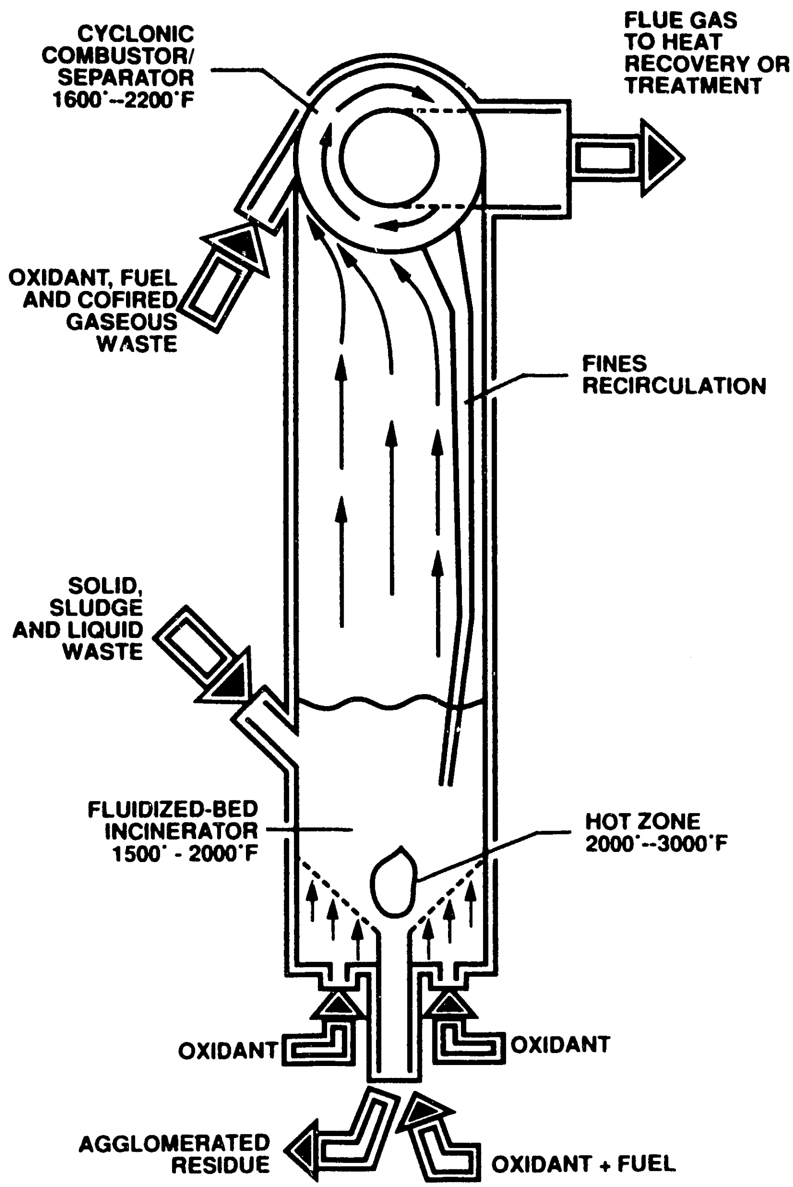


Figure 1. SCHEMATIC DIAGRAM OF IGT'S TWO-STAGE FLUIDIZED-BED/CYCLONIC AGGLOMERATING INCINERATOR

First Stage -- Fluidized Bed Incinerator

The first stage of the incinerator is a sloped-grid, agglomerating fluidized-bed reactor (Figure 2), which can operate under either substoichiometric or excess air conditions. The reactor includes a sloping grid, 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. With a unique distribution of fuel and air, the bulk of the fluidized bed is controlled at a temperature of 1500° to 2000°F while the central spout temperature can be varied from 2000° to 3000°F. The hot zone thus formed is localized and very distinct in terms of temperature and size, and can be altered by changing the gas flow distribution. This feature is the key to it's ability to produce and control the rate of soil vitrification in the fluidized bed. The ability of the fluidized bed to produce solid wastes that meet leachability standards has been demonstrated in coal gasification tests.

Contaminated soils and sludges fed into the fluidized bed undergo rapid gasification/combustion, producing gaseous components. The large inorganic fraction is softened and oxidized in the hot zone, producing glassy, essentially non-leachable, environmentally benign agglomerates. These agglomerates are ejected from the fluidized bed through the classification zone via a terminal velocity mechanism. This solid product is expected to meet the EPA standards for leachability (TCLP) and should be suitable for normal disposal in landfills or for return to the site as fill. Additives or fluxes, such as calcium carbonate and sodium carbonate, may be added to this stage of the incinerator to help the agglomeration process as well as for capture of any sulfur and chlorine present in the waste being treated.

Because of the large volume of R&D activity being conducted for various in-situ treatment methods, a considerable amount of information is available on the physical and chemical properties of the various soil types encountered at contaminated sites. In-situ vitrification (ISV) research has determined that most soils melt in the range of 1100° to 1600°C.[2,3,4] It is therefore expected that the first stage of the incinerator will be able to vitrify the majority of soils found at contaminated sites.

Previous work by IGT and others in the areas of gasification, combustion, and incineration has shown that metals volatilized in gasifiers and combustors are closely associated with fine particulates carried over in the flue gas.

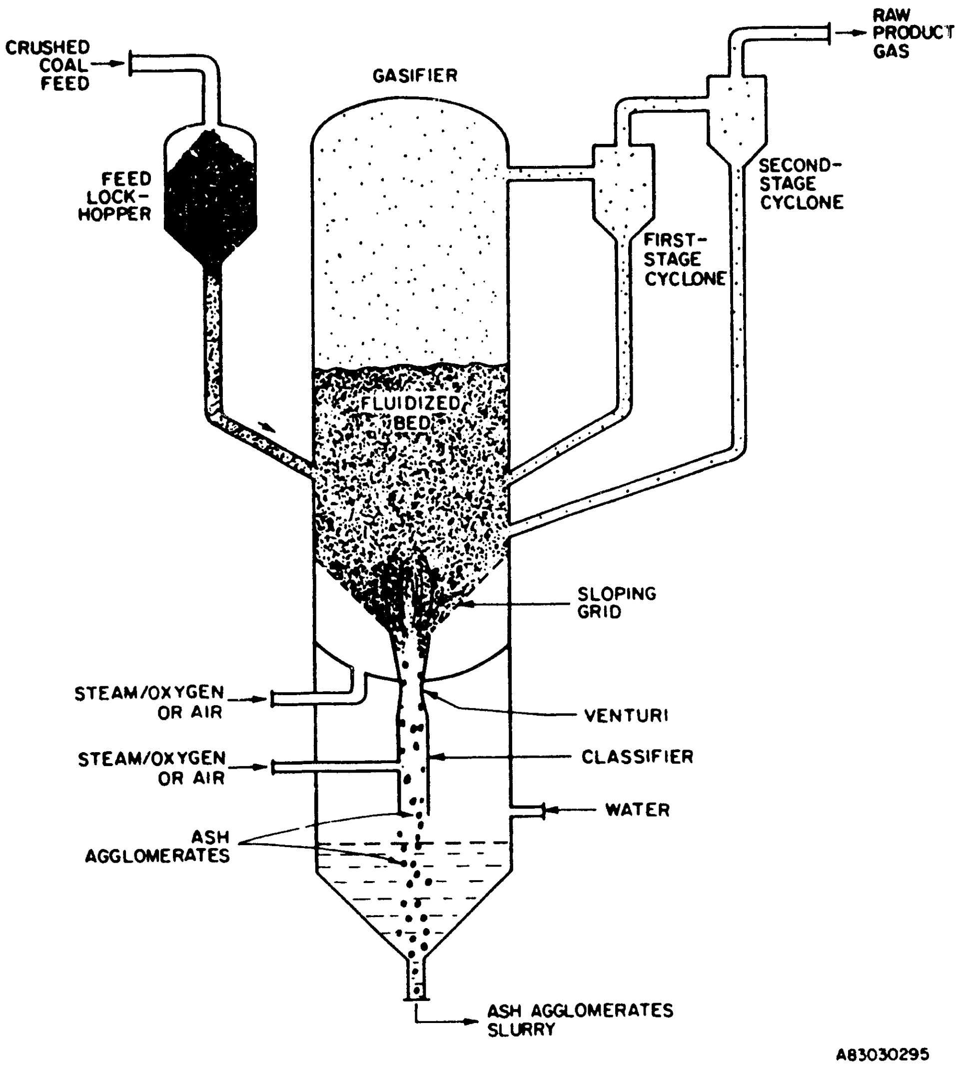


Figure 2. IGT'S U-GAS FLUIDIZED-BED GASIFIER/INCINERATOR
(Basis for First Stage of Incinerator)

Collection and return of fine particulate from the flue gas back to the fluidized bed will increase the quantity of metals captured in the vitrified soil discharged from the bottom of the fluidized bed. The addition of flue-gas cooling upstream of the cyclone will further increase metals capture in the discharge by partially condensing the more volatile metal vapors, a portion of which will be returned to the bed with the captured fines.

Second Stage -- Cyclonic Incinerator

The cyclonic combustor, shown in Figure 3, is the second incinerator stage 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, giving 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 Incinerator is a novel approach to staged incineration/combustion technology[5] with the following unique features:

- The ability to process solid, liquid, and gaseous wastes in a single system
- A patented sloped grid that enhances solids-circulation patterns within the fluidized bed, promotes complete gas-solids mixing and even temperature distribution for higher contaminant DRE
- An ash-discharge port with no moving parts, which provides precise discharge rate control and size classification proven in over 10,000 hours of service in a 3-foot-diameter, 24-ton/day coal gasification unit
- A central air/fuel jet, which permits efficient combustion of natural gas within the fluidized bed, while producing a hot zone of controlled size and temperature for the production of agglomerates
- A central hot zone, which agglomerates and encapsulates the solids while the cooler surrounding bed scrubs the more volatile inorganics for ultimate removal with the agglomerates
- The recycling of elutriated fines to minimize particulate and volatile metals emissions
- Staged processing, which insures high organic component DRE and low CO, THC, SO_x, and NO_x in spite of changing feed conditions

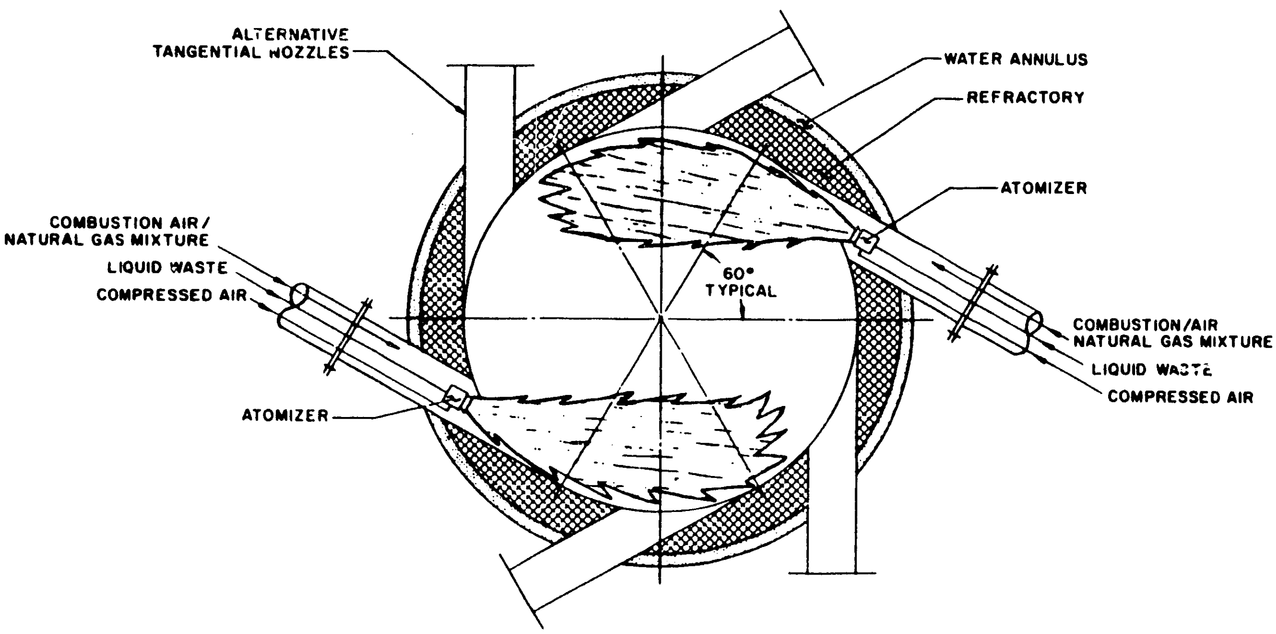


Figure 3. IGT'S CYCLONIC COMBUSTOR/INCINERATOR
(Basis for Second Stage of Incinerator)

- High heat-transfer rates and low air/fuel ratios that allow high treatment capacities in relatively compact, transportable equipment.

Thus, for a soil contaminated with organics and inorganics, the two-stage incinerator captures and immobilizes inorganics and heavy metal contaminants in soil in the first stage, while operating in a continuous-feeding mode, by vitrifying the inorganic soil matrix. Some destruction of organic contaminants will also take place in the first stage; however, high organic DRE is expected to be accomplished in the second-stage cyclonic incinerator. The Advanced Two-Stage Incinerator should be most effectively applied at sites --

- Where a removal and treatment approach is required
- Which contain combined organic and inorganic or heavy metals contamination, with or without the presence of radionuclides
- Which contain medium to high contaminant concentrations (5000 ppm and above).

The incinerator is being developed in two steps. In the first step, the operating data from its individual stages are being analyzed to establish the capability of each stage separately. Then, 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 data already obtained from the fluidized-bed agglomerating pilot unit as well as from the cyclonic combustor/incinerator pilot unit.

DATA AND RESULTS TO DATE

Extensive data have been obtained in two key components of the two-stage incinerator while operating separately.

Results of First-Stage Fluidized-Bed Incinerator

The fluidized-bed reactor has demonstrated its wide application with gasification and agglomeration of various coals, reclamation of foundry sands, and for destruction of organic contaminants present in spent blast grits.

Agglomeration and Encapsulation of Trace Metals

IGT's fluidized-bed gasification and incineration system for non-hazardous and hazardous wastes based on its sloped-grid, fluidized-bed (SGFB) concept is in the advanced stage of development. A key feature of the process is its ability to agglomerate the ash, entrapping a majority of the trace metals. These agglomerated ash particles produced from a variety of coals (Figure 4) have been tested and have been found to comply with EPA toxicity standards for leachability. Over a 10-year period, IGT has processed many fossil fuels, oil shales, and biomass, and generated several designs based on the SGFB ash agglomerating concept.[6,7] Over 10,000 hours of data has been accumulated with this device. The experience associated with entrapment of trace metals from coals in glassy, essentially non-leachable ash agglomerates can be readily extended to the treatment of contaminated soils and sediments. Another important aspect of these agglomerates is that despite the abundant presence of organic compounds in coals, these agglomerates were completely devoid of any of the organics.

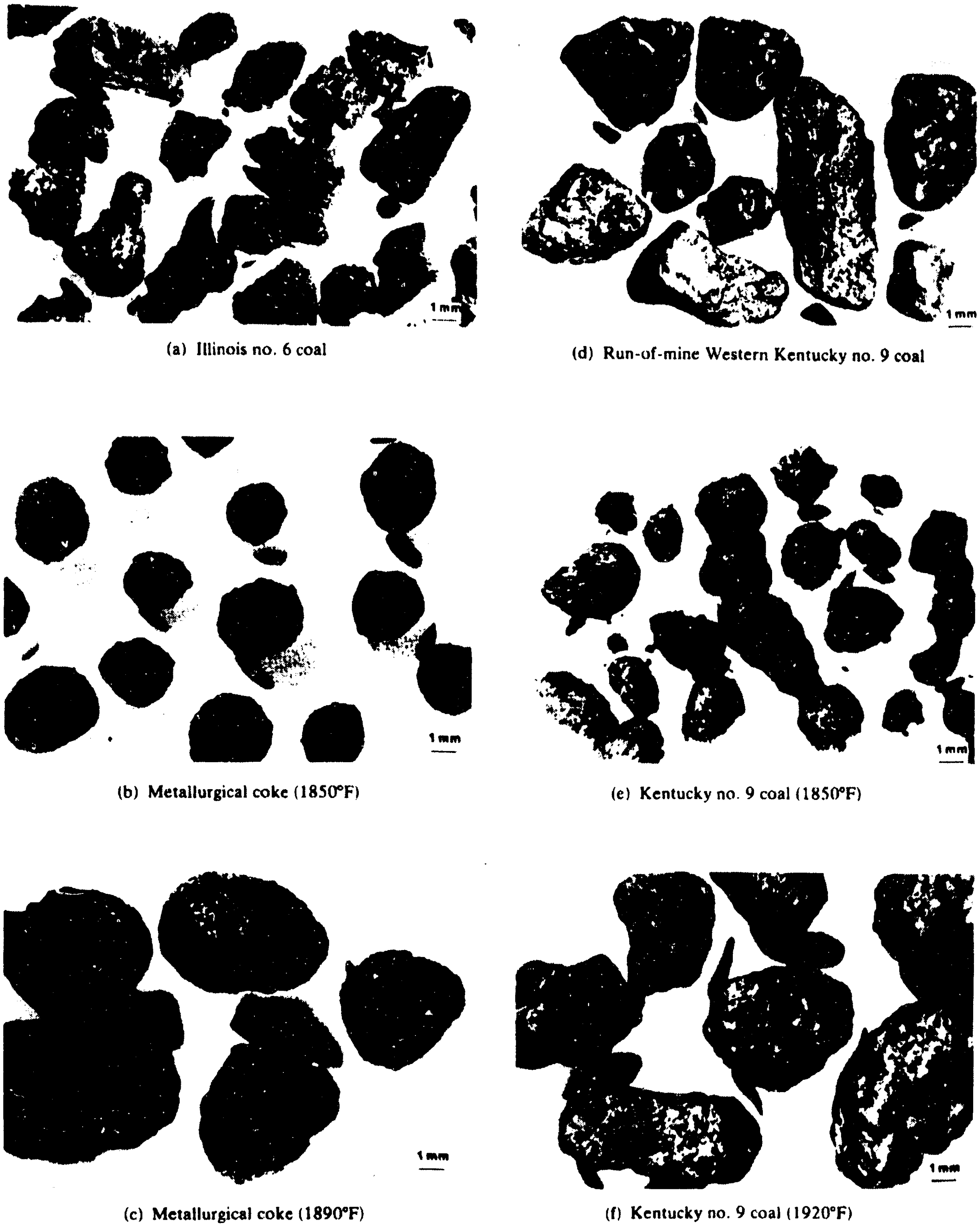
Incineration and Reclamation of Spent Foundry Sands

A growing need for spent foundry sand reclamation is spurred by the Resource Conservation and Recovery Act (RCRA) sand classification regulations. When a foundry's used sand is classified as a hazardous waste, the dumping costs increase dramatically. This reclassification is occurring with increasing frequency, and some foundries are setting schedules to terminate dumping.

Spent foundry sand containing 1% to 2% organic resins and binders was successfully processed at IGT in the 3-foot-diameter pilot unit using natural gas as supplemental fuel.[8] Bench-scale fluidized-bed studies were first conducted to establish residence time and operating temperature to reduce the organic binder level in the spent foundry sand (measured as Loss on Ignition) to 0.2 weight percent. These tests established the basis for conducting a large-scale, continuous test with 40 tons of sand.

The SGFB pilot plant was then operated at 1 ton/h for approximately 50 hours to incinerate used clay-bonded sand containing crushed resin-bonded core butts from a major automobile manufacturer. The processed sand was then mechanically scrubbed (by others) to remove trace quantities of clay and returned to the foundry for core rebonding and strength testing. The core strength data for the three resin-bonding systems tested were quite favorable.

IGT also participated in the American Foundry Society 4S Committee's thermal reclamation study of clay-bonded sands in 1984. IGT's effort, financed in-house, included the incineration in the SGFB Process Development



(a) Illinois no. 6 coal

(b) Metallurgical coke (1850°F)

(c) Metallurgical coke (1890°F)

(d) Run-of-mine Western Kentucky no. 9 coal

(e) Kentucky no. 9 coal (1850°F)

(f) Kentucky no. 9 coal (1920°F)

Figure 4. TYPICAL ASH AGGLOMERATES FROM DIFFERENT FEEDSTOCKS

Unit (PDU) of 1 ton each of clay-bonded sand from a General Motors and a John Deere foundry. These sands were then scrubbed (by others) and samples were sent to the resin manufacturing companies. Each company used its own bond formulations and conducted rebond core strength tests. The reclaimed sand was found to be suitable for reuse, thus achieving the test objectives. Some of the results from the test are shown in Table 1.

Table 1. SPENT SAND THERMAL RECLAMATION TEST RESULTS

	Loss on Ignition, %		Clay, %	
	Before	After	Before	After
Sand I	1.0	0.16	2.2	1.1
Sand II	5.6	0.4	12.3	1.6
Sand III	0.9	0.06	1.1	0.1

Incineration and Reclamation of Used Blast Grit

Naval shipyards and other domestic port facilities generate thousands of tons of used blast grit annually and dispose of it in landfills. Also, there are thousands of steel bridges in the United States that are on a repaint maintenance schedule that requires grit blasting for surface preparation; this used grit also goes to landfills. Nevertheless, for environmental reasons it is becoming prohibitively expensive to landfill used blast grit containing paint residues. IGT has conducted test work to develop a process to clean blast grit to make possible its recycling for reuse. Essentially, IGT applied a transfer/adaptation of fluidized-bed incineration system developed for the reclamation of foundry sand. This SGFB incinerator affords processing advantages that include a pneumatic size classification of the reclaimed grit. In addition, the sloped-grid incinerator design facilitates the removal of any tramp material fed or fusible lumps formed.

Under its own Internal R&D program, IGT conducted feasibility tests on the use of fluidized beds for thermal reclamation of blast abrasives. These tests showed that, at fluidization velocities above 3 ft/s and temperatures in the range of 1200° to 1500°F, both organic contaminants and fines can be removed from the abrasives in a single-stage fluidized bed. Based on these results, a program to reclaim spent abrasives in IGT's 3-foot-diameter pilot-scale fluidized-bed incinerator was undertaken for the U.S. Navy.

The overall objective of this test program was to evaluate the use of the SGFB incinerator for the thermal reclamation of used blasting abrasives. 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 pilot 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 2. 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. Also, analyses for organics, organotin, total tin, and size distribution were conducted for the coal/TBT test. The results of these analyses, shown in Table 3, indicated that the reclaimed materials were suitable for reuse in blasting operations.

The performance testing clearly demonstrated that the reclaimed abrasive's performance was comparable with fresh abrasive. The laboratory results proved that the SGFB incinerator produced reclaimed abrasives conforming to the requirements of MIL-A-22262A for fresh blasting abrasives.

Results of Second-Stage Cyclonic Incinerator

The second stage of the two-stage incinerator, the cyclonic incinerator, has demonstrated the following advantages relative to commercially available incineration equipment:

Table 2. BLAST ABRASIVE TEST BURN SUMMARY

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

* Measured as carbon and hydrogen.

** Indicates detection limit of analytical procedure.

- Improved DRE
- Dry-ash operation
- Benign bottom ash
- Higher combustion intensity
- Lower excess air requirements
- Reduced supplementary fuel demand
- Wider range of operating temperatures
- Higher turndown ratio
- Extremely stable operation
- Longer refractory life
- Reduced size and capital cost
- Reduced operating cost.

The cyclonic combustion system is capable of incinerating a wide variety of solid, liquid, and gaseous wastes and offers great operational flexibility.

Table 3. RESULTS OF LABORATORY ANALYSES OF RECLAIMED ABRASIVES

	Results			
Test	Coal Slag Requirement	Coal Slag/ Copper Paint	Copper Slag/ TBT Paint	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 & 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

Three pilot-scale test programs involving cyclonic incineration have amply demonstrated its capability:

- A low-Btu gaseous waste (55 to 65 Btu/SCF) from an industrial process using H_2, CO, CH_4, and NH_3 was combusted.[9] Combustion was stable at 1900°F (achieved through air and waste preheat), NH_3 conversion to NO_x was as low as 5% (the NO_x level with no NH_3 in feed was below 10 ppm), and CO levels were in the range of 25 to 30 ppm. The test unit was operated at a 3×10^6 Btu/h rate; no supplemental fuel was required because of the intense mixing that occurs in the cyclonic incinerator.

- Carbon tetrachloride was destroyed as a surrogate for PCB's at a combustion rate of approximately 1×10^6 Btu/h. In a two-phase program, the carbon tetrachloride was processed at both high and low concentrations.

- Three nonhazardous wastewaters from a typical food process were successfully incinerated in a 1×10^6 Btu/h pilot-scale unit; one of these was also incinerated on a 3×10^6 Btu/h demonstration system.[10,11] This wastewater was a solution of 25% to 45% organic material and 5% to 20% inorganic material in water. The waste was incinerated with supplemental natural gas fuel at temperatures of about 2000°F in the dry-ash mode. Combustion was stable and complete, with less than 100 ppm CO in the exhaust.

Table 4 summarizes the results obtained in the cyclonic combustion/incineration testing programs. The details of these studies are provided by Khinkis.[12]

Table 4. SUMMARY OF DATA IN CYCLONIC COMBUSTION/INCINERATION SYSTEM

Feed Material	Supplemental Contaminant	Fuel	DRE
Carbon Tetrachloride	100% pure	Natural gas	>99.9999%
Carbon Tetrachloride	0.5% in Hexane	None	>99.999%
Carbon Tetrachloride	1.0% in Hexane	None	>99.9999%
Low-Btu Gaseous Waste 1.7% CO, 3.7% CH_4 24.1% CO (67 Btu/SCF)	9% H_2, 61.3% N_2,	None <10 ppm NO_x	<50 ppm CO
Industrial Wastewater dissolved solids, up to 3270 Btu/lb HHV	35% to 50%	Natural gas	N/A

In addition, IGT has recently been awarded a contract from a consortium of companies including GRI, IGT-SMP, gas companies, aluminum producers, and incinerator manufacturers to evaluate the applicability of IGT's natural gas-fired cyclonic incinerator to industrial waste incineration with molten (benign) ash discharge, using spent aluminum potliners as an example. In this application, the incinerator, with the addition of various fluxing agents, will operate in a slagging mode. The vitreous slag will render the inorganic constituents that cannot be destroyed into a non-leachable form capable of being landfilled without special precautions.

CURRENT STATUS

The data obtained from the two individual components of the two-stage 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, GRI, IGT-SMP, 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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