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IGT

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ABSTRACT

The Institute of Gas Technology (IGT) is conducting an experimental program to develop and test through pilot-plant scale of operation, IGT's two-stage fluidized-bed/cyclonic agglomerating incinerator (TSI). The 2-year program is sponsored by the U.S. Environmental Protection Agency (SITE program), Gas Research Institute, American Combustion, Inc., and IGT's Sustaining Membership Program. The TSI is based on combining the fluidized-bed agglomeration/gasification technology and the cyclonic combustion/ incineration technology, which have been developed at IGT over many years.

The TSI is a unique and extremely flexible combustor that can operate over a wide range of conditions in the fluidized-bed first stage from low temperature (desorption) to high temperature (agglomeration) including gasification of high-Btu wastes. The TSI can easily and efficiently destroy solid, liquid and gaseous organic wastes, while containing solid inorganic contaminants within an essentially non-leachable glassy matrix, suitable for disposal in an ordinary landfill.

This paper presents the results of tests conducted in a batch, fluidized-bed bench-scale unit (BSU) with commercially available "clean" top soil and the same soil spiked with lead and chromium compounds. The objectives of these tests were to determine the operating conditions necessary to achieve

soil agglomeration and to evaluate the leaching characteristics of the soil agglomerates formed. Typical operating conditions tested included a bulk bed temperature of 1500°F (816°C) and a superficial fluidization velocity in the range of 2.5 to 3.5 ft/s (0.8 to 1.1 m/s).

Agglomerates have been produced in the BSU at several different operating conditions with samples of both "clean" and spiked soil. The agglomerates are firmly consolidated and have a dark brown to black, glassy appearance. Tests to determine the leaching characteristics (TCLP) of the agglomerates for comparison with the untreated soil are in progress. The TCLP results are expected to demonstrate that the agglomeration process encapsulates metals within the glassy matrix and significantly reduces leachability. This expectation is based on leaching tests performed by IGT on agglomerates formed from coal ash.

INTRODUCTION

Incineration (thermal destruction) has been recognized as one of the best demonstrated and available technologies for waste destruction. The ultimate goal of incineration is the complete destruction of the waste. Thermal energy is used to break the chemical structures of organic compounds, thus, reducing the volume and toxicity of the residual material. Other applications for combustion processes include reclamation/recycling of solid wastes, and combustion of RDF (refuse-derived fuel), sludges and other organic residues for energy recovery.

Incineration of wastes (hazardous and nonhazardous) continues to be strongly favored in the United States and abroad as one of the best alternatives to landfilling. As legislation regarding the disposal of hazardous wastes becomes more stringent, disposal costs continue to climb. The diminishing capacity of existing landfills (and reluctance by local communities to approve new ones) has already resulted in increased tipping fees. Most observers expect that incineration will become more firmly established in the U.S. as a means of reducing the amount of material that must be landfilled, as has been the case in Europe and Japan. The benefits of thermal destruction compared to other disposal methods are even more pronounced with falling or unstable fuel prices. Hence, there is an enormous potential for more incineration capacity in the near future.

IGT's Two-Stage Incinerator

The Institute of Gas Technology (IGT) is developing the two-stage fluidized-bed/cyclonic agglomerating incinerator (TSI), shown schematically in Figure 1, which is based on combining fluidized-bed agglomeration/gasification and cyclonic combustion technologies. This two-stage combination results in an extremely flexible incinerator for solid, liquid, and gaseous wastes including municipal sludges. The system can operate over a wide range of conditions. In the system, these wastes are efficiently destroyed (>99.99% Destruction and Removal Efficiency [DRE]), while solid inorganic contaminants or solid residues are captured within a glassy matrix, being rendered benign and suitable for disposal in ordinary landfills.

The first stage of the incinerator is a sloping-grid, agglomerating fluidized-bed reactor that 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. 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 (816 to 1093°C), while the central spout temperature can be varied from 2000 to 3000°F (1093 to 1649°C). 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 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 largely depend upon the calorific value of the waste being incinerated. Municipal sludges typically contain 1000 to 3000 Btu/lb (2.3 to 7.0 MJ/kg), all of which is released during combustion. With these wastes, besides obtaining significant volume reduction, the noncombustibles are vitrified into glassy agglomerates that can be then safely used for construction-related industry. The ability of the fluidized bed to produce solid wastes that meet leachability standards has already been demonstrated by IGT in coal gasification tests.

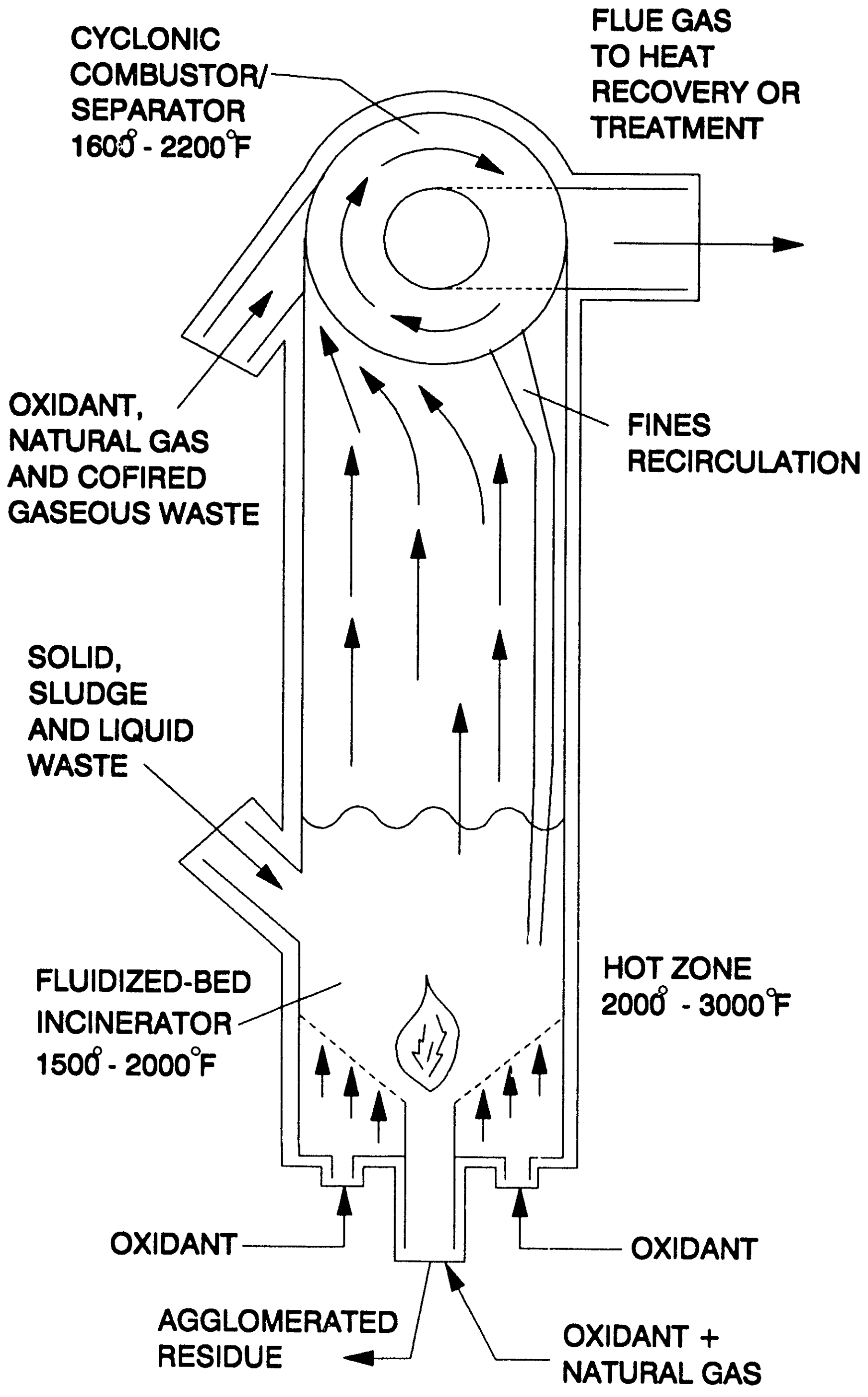


Figure 1. IGT's TWO-STAGE FLUIDIZED-BED/CYCLONIC AGGLOMERATING INCINERATOR

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

The second stage of the TSI is the cyclonic combustor in which flue gas from the fluidized bed is further combusted at temperatures of 1600 to 2400°F (871 to 1316°C). 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 Two-Stage Incineration System is a novel approach to staged incineration/combustion technology (1) with the following unique features:

- The ability to process solid, liquid, and gaseous wastes including municipal sludges in a single system.
- A patented sloping 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 insures high organic component DRE and low CO, hydrocarbons (HC), SO_x, and NO_x emissions despite changing feed conditions.
- The system allows high combustion temperature (1500 to 1800°F [816 to 982°C]) for sufficient time (1-3 sec) to mitigate trace HC emissions, which constitute good combustion practice for municipal sludges and solid wastes.
- 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 agglomerating 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.

Current Program

The overall objective of the 2-year program is to develop and test through pilot-plant scale operation, IGT's Two-Stage Incinerator. The data obtained during the program will be used for evaluating TSI performance, for process and engineering design of commercial-scale units, and for assisting in the permitting process. The TSI technology will be available for permanent cleanup of Superfund sites.

The program is divided into two phases. During Phase I, tests were conducted in a batch, 6-inch (15.2-cm)-diameter bench-scale unit to bracket the operating conditions necessary to achieve soil agglomeration. A 6-ton/day (5.4-metric ton/day)-TSI pilot plant will also be designed and built during Phase I. Testing of the TSI pilot plant with soil will be carried out during Phase II.

The program is co-sponsored by the U.S. Environmental Protection Agency (EPA), the Gas Research Institute (GRI), IGT's Sustaining Membership Program, and American Combustion, Inc. This paper presents the work performed by IGT during Phase I of the current program, in which batch, bench-scale soil agglomeration tests were conducted with clean and spiked samples of soil. Research performed during the development of the individual stages of the TSI, including the fluidized bed agglomeration of coal ash, thermal reclamation of spent blasting abrasives and foundry sand, and cyclonic combustion of carbon tetrachloride (CCl_4), liquid waste, and low-Btu gases are briefly described.

Development of the Sloping Grid Fluidized-Bed First Stage

The ability of IGT's sloping grid, fluidized-bed (SGFB) technology to produce agglomerated ash from coal has been amply demonstrated during the development of the U-GAS coal gasification process. The U-GAS process incorporates agglomeration as the method for discharging ash from the fluidized bed. The tests were conducted in a 3-foot (0.91-m)-diameter reactor equipped with a sloping grid, a jet for creating a hot zone within the fluidized bed, and an ash discharge nozzle (Figure 2). Fluidization was maintained by using steam or mixtures of steam, oxygen, and air. The hot zone was established by introducing streams of air or steam enriched with oxygen into the central jet. The localized zone of relatively high temperature resulted from the reaction of oxygen with carbon and hydrogen present in the

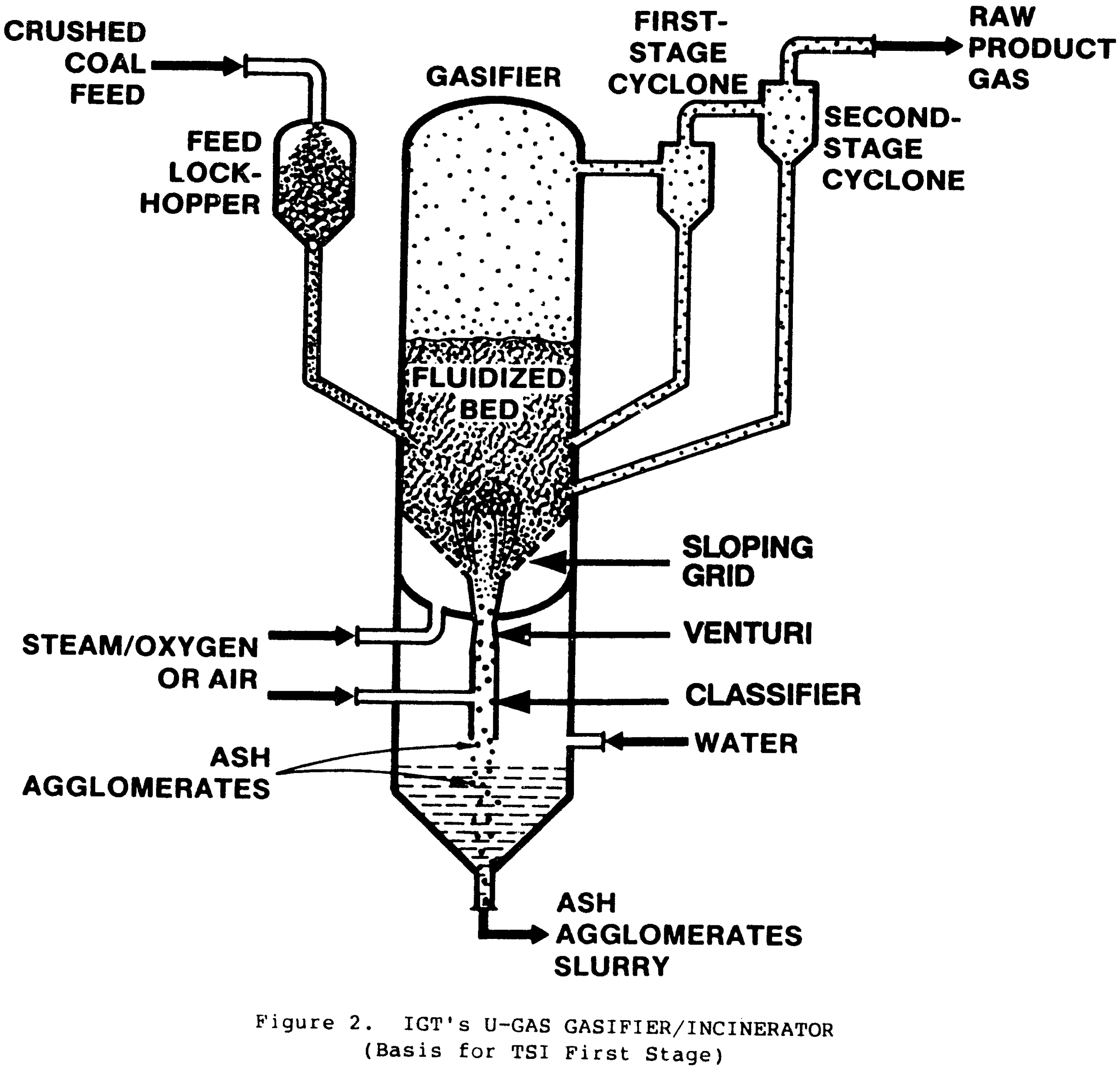
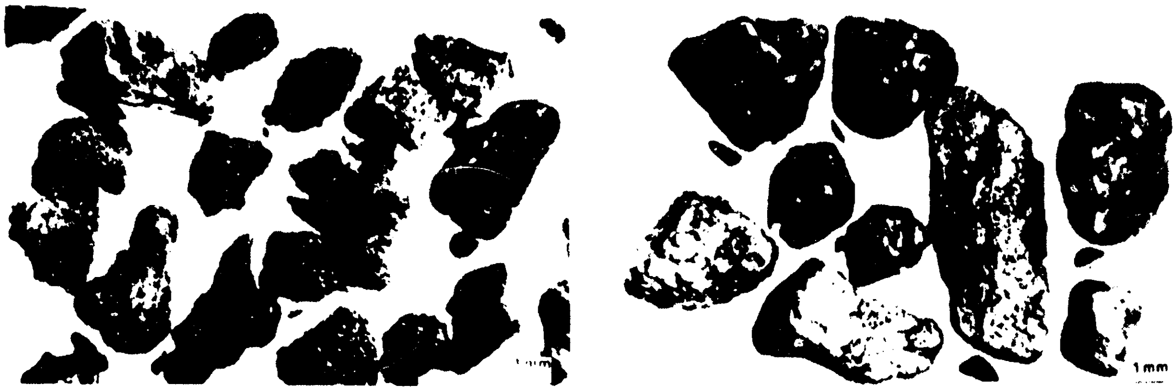


Figure 2. IGT's U-GAS GASIFIER/INCINERATOR
(Basis for TSI First Stage)

coal. In tests with coal, the addition of supplemental fuel was not necessary.

As particles of ash within the hot zone are heated to temperatures above their softening points, their surfaces become sticky. Collisions with other particles result in particle growth through accretion. As the agglomerates grow in size, the fluidizing gases can no longer support them in the bed. Thus, agglomerates are removed from the bed via a terminal-velocity mechanism. During the development of the U-GAS process, many types of coals (2,3) were tested in the 3-foot diameter unit to determine the effects of different ash properties (composition and softening temperature) on agglomeration characteristics. Agglomerates produced from the ash of different feedstocks are shown in Figure 3. When subjected to the EP Toxicity Test (EPA 1310), these agglomerates were found to be in compliance with the regulations. The encapsulation of trace inorganic metals from coal in glassy, essentially nonleachable ash agglomerates can be readily extended to the treatment and incineration of other wastes. Another important aspect was that despite the presence of abundant organic material in coals, the agglomerates were completely devoid of any organic compounds - indicating that the fluidized bed, while producing agglomerates, is capable of stripping off organics from the waste. These organics are partially combusted in the fluidized-bed stage; the balance in the cyclonic stage.

In another application of the SGFB technology, IGT is developing a thermal process for reclamation of spent blasting abrasives from U.S. Naval Shipyards (4). Each year, the eight U.S. Naval Shipyards produce about 100,000 tons of spent blasting abrasive during repainting operations, which must be reclaimed or otherwise disposed of. This is one of the major hazardous waste streams generated at Naval Shipyards. Paint and rust removed from the surface of the ship during blast cleaning, as well as marine biota (crustaceans, seaweed, etc), accumulates in the spent blast abrasive. Occasionally, material from other vessel servicing operations accumulates as tramp with the spent blast abrasive. Because of this contamination and the generation of fines during blasting, the blast abrasive is not reusable. The used blast abrasive is either stockpiled onsite, or, in some states, is landfilled at special hazardous waste sites.



(a) Illinois no. 6 coal

(d) Run-of-mine Western 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 COAL FEEDSTOCKS

IGT conducted bench-scale and pilot plant-scale calciner tests with samples of spent blasting abrasive (provided by the U.S. Navy) contaminated with copper-based or tributyl tin (TBT)-based paints. The tests were conducted at bulk-bed temperatures of 1470 to 1500°F (799 to 816°C) with five different samples of spent abrasives. Complete analyses for organics, total and soluble metals, major oxides, and size distribution for the feed and output streams from the calciner tests were performed. Analyses for organics, organotin, total tin, and size distribution were also conducted for the coal/TBT test. The results of these analyses indicated that the reclaimed materials were suitable for reuse in blasting operations. Further, Modified Method 5 sampling of the stack gas during the coal/TBT test confirmed that the calciner destroyed TBT to greater than 99.99%.

Reclaimed abrasive was returned to the U.S. Navy in bulk for performance evaluation. The performance of the reclaimed abrasive was comparable to that of fresh abrasive. The results demonstrated that the SGFB calciner produced reclaimed abrasives conforming to the requirements of MIL-A-22262A for fresh blasting abrasives(4).

Because the preliminary economic evaluation for spent blasting abrasive reclamation using the SGFB calciner was very favorable, the U.S. Navy has decided to proceed with the design, construction, and operation of a 5-ton/hour prototype calciner at a Navy Shipyard (4).

In a similar project, IGT employed the SGFB calciner to reclaim used foundry sand for an automobile manufacturer. Tests with the reclaimed foundry sand demonstrated comparable performance to that of new foundry sand (5).

Development of the Cyclonic Combustor Second Stage

The cyclonic combustor second stage of the TSI has been extensively tested and developed at IGT. A schematic diagram of the cyclonic combustor/incinerator is shown in Figure 4. Tests have been conducted with CCl_4 - a PCB (polychlorinated biphenyl) surrogate -- as well as liquid wastes and a low-Btu gas. The cyclonic combustor readily destroys organic compounds with high DRE and also minimizes emissions of CO and HC. IGT's Combustion Facility for the cyclonic incinerator includes a waste storage and supply system, combustion air and natural gas systems, atomization assembly, cooling water system, compressed air system and drum heating system.

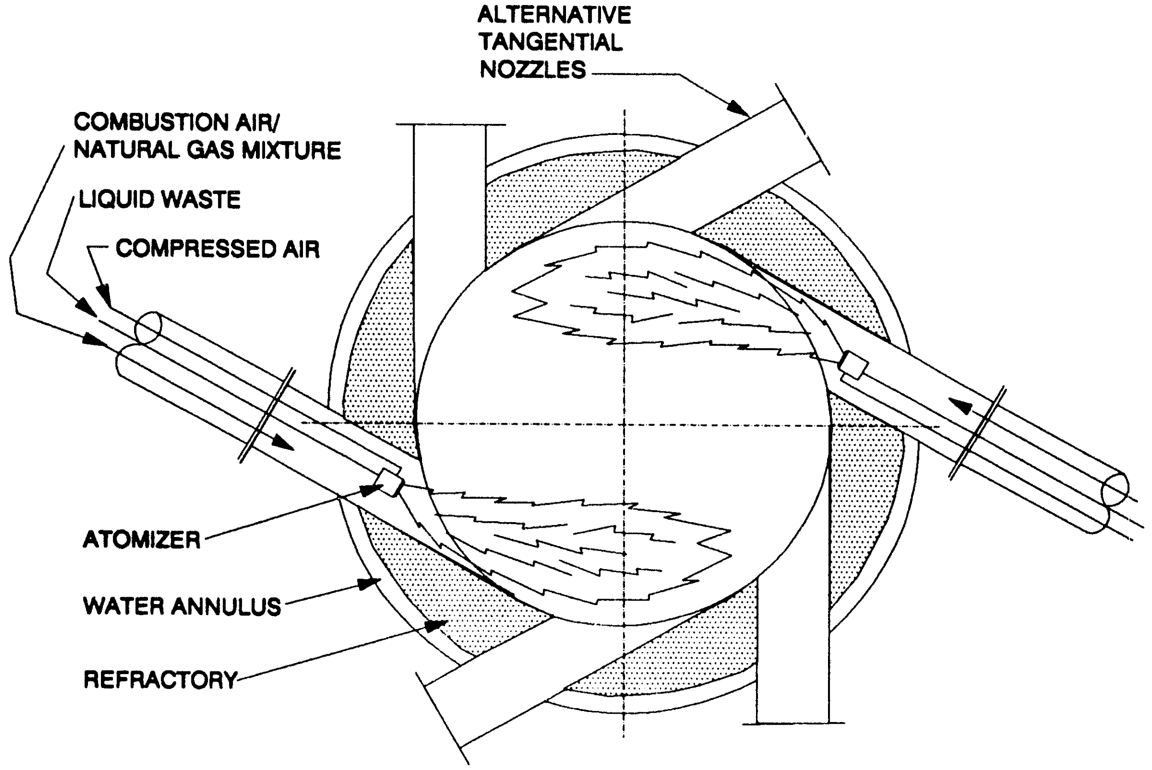


Figure 4. IGT's CYCLONIC COMBUSTOR/INCINERATOR
(Basis for TSI Second Stage)

CCl_4 was selected as the surrogate material for testing PCB incineration capability in the cyclonic combustor, because it is generally believed to be more stable than PCB's, has a lower relative toxicity, and will not result in products of incomplete combustion that are highly toxic.

To determine the DRE of CCl_4, high-temperature gas samples were drawn from the combustion system through a Modified Method 5 analytical train, and the residual CCl_4 was trapped in double Tenax beds in series.

In most of the tests, the unit was operated with combustion air preheated to 800°F (427°C) and a gas firing rate of about 0.8 million Btu/h (0.234 MJ/s). The gas sampling probe was located immediately beneath the cyclonic section of the combustor, with a hot-gas residence time of about 0.25 seconds. Temperatures were taken by a suction pyrometer near the exhaust of the combustor base, after a gas residence time of about 0.75 seconds.

The cyclonic combustor tests demonstrated that CCl_4 could be destroyed to greater than six-9's DRE by incineration with methane and preheated air at a residence time of 0.25 seconds. Under these conditions, the emissions of NO_x were relatively high at 130 to 330 ppm. By reducing the air preheat from 800 to 450°F (427 to 232°C), NO_x emissions dropped to 60 ppm, but CCl_4 DRE was slightly reduced. Abbasi et al.(6) and Crimmins et al.(7) provide other test results.

A summary of the contaminants and concentrations subjected to testing in the two separate stages of the TSI are presented in Table 1.

Development of the Two-Stage Fluidized-Bed/Cyclonic Agglomerating Incinerator

The data obtained from the two individual components of the TSI have shown that each is capable of meeting its respective performance expectations. In the current program, the operating conditions necessary to agglomerate a soil sample are being determined. Further, the ability of the SGFB to capture and encapsulate inorganic contaminants present in the soil is being evaluated on samples of soil that have been spiked with selected metallic compounds.

Table 1. SUMMARY OF CONTAMINANTS AND CONCENTRATIONS SUBJECTED TO TESTING

Stage	Feed Material	Contaminant	Supplemental Fuel	DRE, %
Fluidized Bed	Spent Foundry Sand	1-2% organic resins & binders	Natural gas	Up to 98
	Spent Blast Abrasive	1-2% organics, 100 ppm TBT	Natural gas	>99.99
	Coal	Coal, ash, S, organics, metals	None	*
Cyclonic	CCl_4	100% pure	Natural gas	>99.9999
	CCl_4	0.5% in Hexane	None	>99.999
	CCl_4	1.0% in Hexane	None	>99.999
	Industrial Wastewater	15-50% dissolved solids, 3270 Btu/lb (HHV)	Natural gas	N/A
	Low-Btu Gas (67 Btu/SCF)	9.2% H_2, 61.3% N_2 1.7 CO, 3.7% CH_4, 24.1% CO_2	None	<50 ppm CO <10 ppm CO_x

Analysis and Preparation of Feed Soil

The feedstock for the bench-scale unit (BSU) tests was a bulk sample (20 yd^3 [15.3 m^3]) of commercially available "clean" top soil. Grab samples of the soil "as delivered" indicated a moisture content of about 20 weight percent.

Because the desired feedstock moisture content for BSU tests is less than 10 weight percent, about 800 pounds (365 kg) of the soil were dried in a direct-flame rotary dryer at IGT. The soil exiting the dryer was in the form of 1/4-inch (6-mm) diameter spheres, which were subsequently crushed and screened to -1/8 inch (-3 mm) in a hammer mill. The dried and screened soil was stored in three 55-gallon drums.

Grab samples of the dried and crushed soil were taken for proximate and selected elemental analyses. The results of the sample analyses are presented in Table 2. The moisture content of three samples taken after drying averaged 7.9 wt % (0.25% standard deviation [SD]). The elemental concentrations of arsenic, chromium, and lead averaged 11 (1.7), 32 (2.7), and <10 ppm (0 ppm

Table 2. PHYSICAL ANALYSES OF DRIED, CRUSHED AND SCREENED GRAB SAMPLES OF TOP SOIL

Sample No.	1	2	3
Proximate Analysis		wt %	
Moisture	7.86	7.65	8.15
Volatile Matter	7.61	7.80	7.81
Mixed Carbon	0.60	0.52	0.48
Ash	83.93	84.03	83.56
Total	100.00	100.00	100.00
Element (dry basis)		μg/g	
Arsenic	10	10	13
Chromium	29	34	33
Lead	<10	<10	<10
Calorific Value		Btu/lb (MJ/kg)	
	390 (0.39)	443 (1.03)	414 (0.96)

SD), respectively. These elements were selected based on discussions with the EPA to be the focus of the capture and encapsulation studies. The gross calorific value of the three samples averaged 416 Btu/lb (0.97 MJ/kg, dry basis) with a SD of 26.5 Btu/lb (62 kJ/kg).

The ash fusion temperatures (oxidizing atmosphere) of the three grab samples were also determined and are presented in Table 3. The initial deformation temperature for this sample of top soil is 2400°F (1316°C); the fluid temperature is about 2700°F (1482°C). The initial deformation (softening) temperature provides and indication of the temperatures required for

Table 3. ASH FUSION TEMPERATURES FOR BULK TOP SOIL SAMPLE (Oxidizing)

Sample No.	1	2	3
Ash Fusion Temperature		F (C)	
Initial Deformation	2405 (1318)	2400 (1316)	2410 (1321)
Softening	2515 (1379)	2502 (1372)	2510 (1377)
Hemispherical	2620 (1438)	2600 (1427)	2620 (1438)
Fluid	2700+ (1482+)	2700 (1482)	2700+ (1482+)

forming agglomerates in the fluidized-bed reactor. Thus, at a minimum the temperature in the fluidized-bed hot zone should be about 2400°F (1316 °C).

Tests to determine the fluidization characteristics of the soil were conducted in a 6-inch (15.2-cm)-diameter Plexiglas column. The results (Figure 5) showed that the complete fluidization velocity for the -1/8-inch soil sample was 1.25 ft/s (0.38 m/s).

Preparation of Spiked Feed Soil

The BSU tests were conducted with the -1/8-inch soil sample described in Table 2. When soil agglomerates were generated, tests to determine the capture and encapsulation efficiency of the SGFB stage were to be conducted. Because the levels of Pb and Cr in the soil were relatively low, the soil was spiked to increase the concentration of these metals to about 90 ppm to facilitate subsequent analyses. The spiking solution (about 400 mL) contained lead oxide (PbO) and chromium nitrate hydrate ($Cr(NO_3)_3 \cdot 9H_2O$) dissolved in nitric acid. (The As concentration was about 10 ppm, and no spiking of this carcinogenic material was necessary.)

Further, for the encapsulation tests with spiked soil, the fines fraction (-20 mesh) of the soil was removed by screening. This was done to reduce the amount of spiked soil that would be conveyed out of the BSU by elutriation without experiencing any significant temperature. As described later, the fines collected by the cyclone were not returned to the BSU fluidized bed, but were collected in a hopper. The complete fluidization velocity of the soil with the 20 mesh fraction removed is higher than the value reported above. A 20-kg batch of soil was carefully weighed into a 30-gallon drum with plastic liner. The drum was placed into a cylinder spinner and rotated at a speed of about 10 rpm and inclined at an angle of about 45°. The spiking solution was slowly sprayed onto the soil sample as it rotated by this procedure. After the solution was applied, three grab samples were taken for chemical analyses to determine the uniformity of the spiking procedure. The tests are in progress.

Description of Equipment

The BSU shown schematically in Figure 6 is constructed of a 108-inch (2.74-m) piece of 6-inch Schedule 40 stainless steel pipe. Feed material is stored in a 6-inch diameter hopper and is fed into the BSU freeboard through a screw calibrated with the feed material. The soil drops through the freeboard

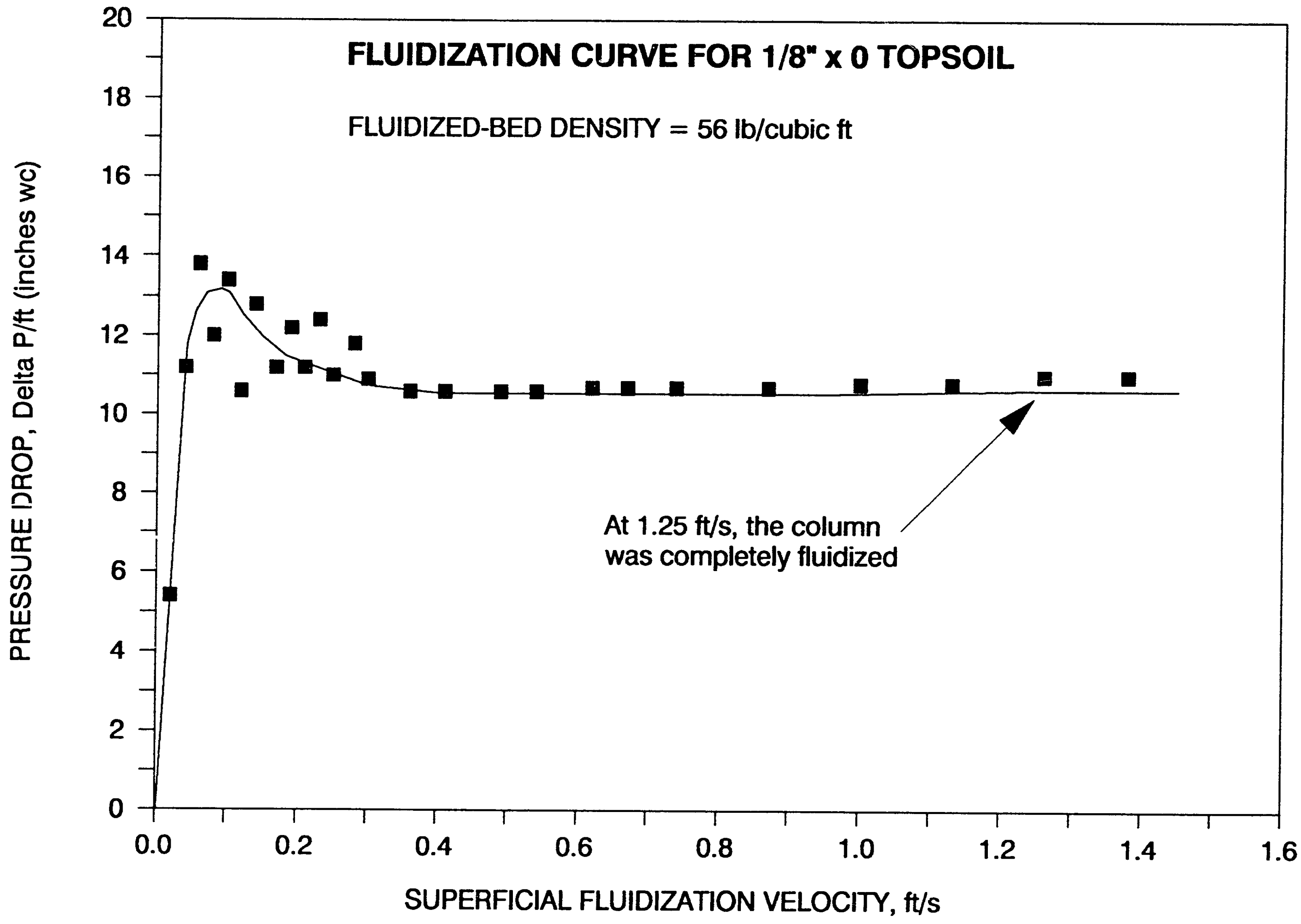


Figure 5. FLUIDIZATION CURVE FOR DRIED AND SCREENED SOIL SAMPLE (-1/8 INCH)

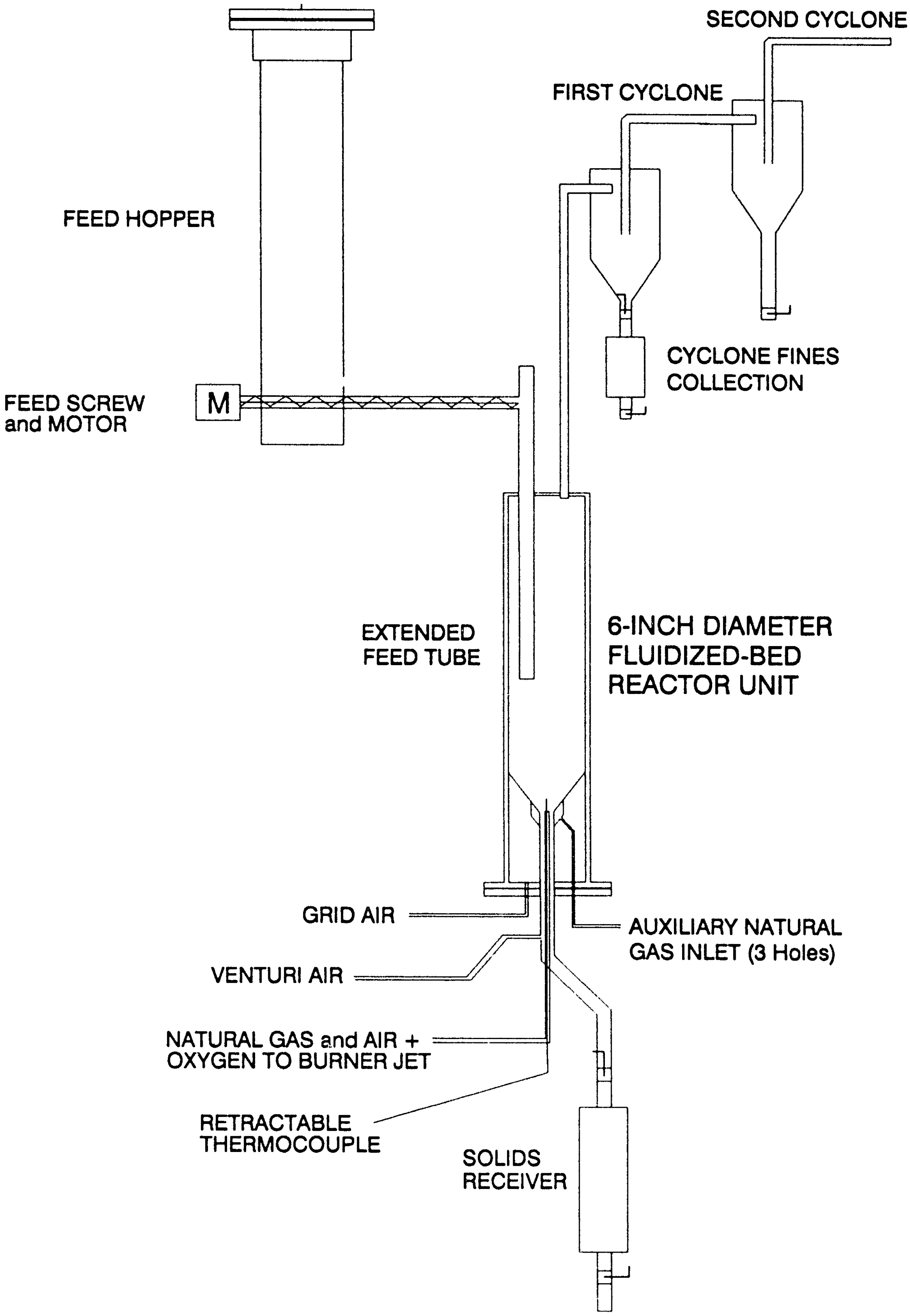


Figure 6. BENCH-SCALE UNIT (BSU)

into the bed via a 1-3/8-inch diameter tube. Two cyclones are installed downstream of the BSU to collect fine particles elutriated from the fluidized bed. The fines removed from the flue gas by the cyclones are collected in a hopper. A product gas scrubber is also used to capture fine particles that may elude the cyclones. The BSU is equipped with external electric heaters for achieving temperatures up to 2000°F (1093°C) as well as means for preheating feed gases.

For these tests, the bottom section of the BSU was replaced with a sloping-grid, fluidized-bed gas distributor, including venturi discharge and central burner jet. The flows of air, natural gas, and oxygen to the burner jet can be used to adjust the flame temperature. Soil discharged from the bed is collected in a stainless steel vessel that is 15.2 cm in diameter, 48.3 cm long with a 5.1-cm-top opening and a 3.8-cm drain. Thermocouples indicate temperatures at different levels in the fluidized bed including the air preheat and material being discharged. Differential pressure taps located in the bed provide an indication of the bed level during the test.

A retractable thermocouple assembly was installed for sensing flame temperatures at the burner jet. Its normal position is inside the burner tubing at the burner tip; however, it can be extended beyond the tip into the fluidized bed a total of 8 inches (20.3 cm). Type K thermocouples were used for the tests.

BSU Test Procedure

Prior to each test, the BSU was reassembled and pressure tested. A weighed quantity of dried and sized soil was then loaded into the feed hopper. Appropriate flows of air were started through the venturi, grid and burner jet. The BSU temperature was increased to about 1000°F (538°C) by the electric furnaces. The feed screw was then activated to deliver soil at about 20 lb/h (9.1 kg/h) to the BSU. Once the differential pressure taps indicated that a bed had formed, stoichiometric flows of natural gas and air were started to the burner jet. The furnace controllers were then set to the desired temperature for the test. The screw was stopped after about 1 hour of soil feeding. Fifteen pounds (6.8 kg) of soil yielded a fluidized bed with an aspect ratio (L/D) of about 2, which was suitable for these tests.

Upon achieving the targeted operating conditions, the flow of oxygen to the burner jet was increased incrementally for short periods of time to increase the hot zone temperature. The flow of air was concurrently decreased to maintain stoichiometry. Estimated flame temperatures for natural gas combustion with different enriched oxygen concentrations are presented in Table 4. The flame temperatures exceed the soil fusion temperatures at all oxygen concentrations. However, because of the solids circulation patterns within the fluidized bed, the particles are exposed to the hot zone temperatures for only brief periods. The rate of agglomerate formation and growth must be balanced against the size and temperature of the hot zone.

Table 4. EFFECT OF OXYGEN CONCENTRATION IN AIR ON THEORETICAL NATURAL GAS FLAME TEMPERATURES*

at Stoichiometric Conditions

% Oxygen	Temperature, °F	(°C)
21 (air)	3562	(1961)
30	4127	(2275)
40	4520	(2493)
50	4765	(2629)
60	4918	(2714)
65	4976	(2747)

*Assumes no feed-gas preheat and no heat loss to surroundings.

The appearance of the material discharged from the venturi provided an indication of the approach to conditions required for soil agglomeration. Once agglomerates appeared in the discharge, other operating conditions were tested to determine the effects on agglomerate production and quality.

In the tests conducted with spiked soil, safety precautions were observed to minimize the exposure of the operating staff to airborne particulates that may be enriched in As, Cr, or Pb. During sample collection, the technician wore a disposable suit and gloves, and was provided breathable air through an enclosed helmet by an ambient air blower. Other staff present wore gloves, particulate masks, and safety glasses.

Data Collection and Sample Analysis

BSU temperature and differential pressure data were recorded on strip chart recorders throughout the test. The operators recorded other data in the project notebook as well as special data sheets. All data were transferred to the notebook after the test. Samples were weighed immediately after collection and kept in sealed stainless steel cans with appropriate labels.

Samples of raw feed soil and soil agglomerates were subjected to the Toxicity Characteristic Leaching Procedure (TCLP) to determine leachability. The samples collected during the spiked soil test included grab samples of spiked feed soil, spiked soil agglomerates, and spiked cyclone fines. The As, Cr, and Pb contents of each spiked sample were determined and a TCLP was conducted on the spiked feed soil and spiked soil agglomerates. The analyses were conducted with specific quality assurance and quality control procedures as required by EPA.

RESULTS

A summary of the operating conditions and qualitative results of the tests conducted in the BSU with "clean" and spiked soil are presented in Table 5. In the first test, operating conditions were established for the fluidized bed to operate between bubbling mode and entrained mode. Much of the soil fed to the BSU was entrained into the flue gas. In the second test, the limits of flame temperature were determined with different stoichiometric ratios of natural gas and air entering the jet. However, no apparent hot zone was formed. In Test 3, flame temperatures using oxygen-enriched air were determined. Excessive temperatures generated in the flame damaged the central jet and the retractable thermocouple.

The fourth test was not successful because of a plug in the feed soil dip tube, which caused the feed screw to jam. In the fifth test, a hot zone was formed in the fluidized bed using oxygen-enriched air. The soil was vitrified into a large mass consisting of tiny agglomerates.

Distinct soil agglomerates were first produced in the BSU during Test 6. Figure 7 is a photograph of the agglomerates from this test juxtaposed with a photograph of the feed soil. The agglomerates were of varied shape and ranged in size from 1/4 to 1 inch (6 to 25 mm). The agglomerates were dark brown to black in color and well consolidated. For comparison, the feed soil was gray and the nonagglomerated material discharged from the BSU was light brown to rusty.

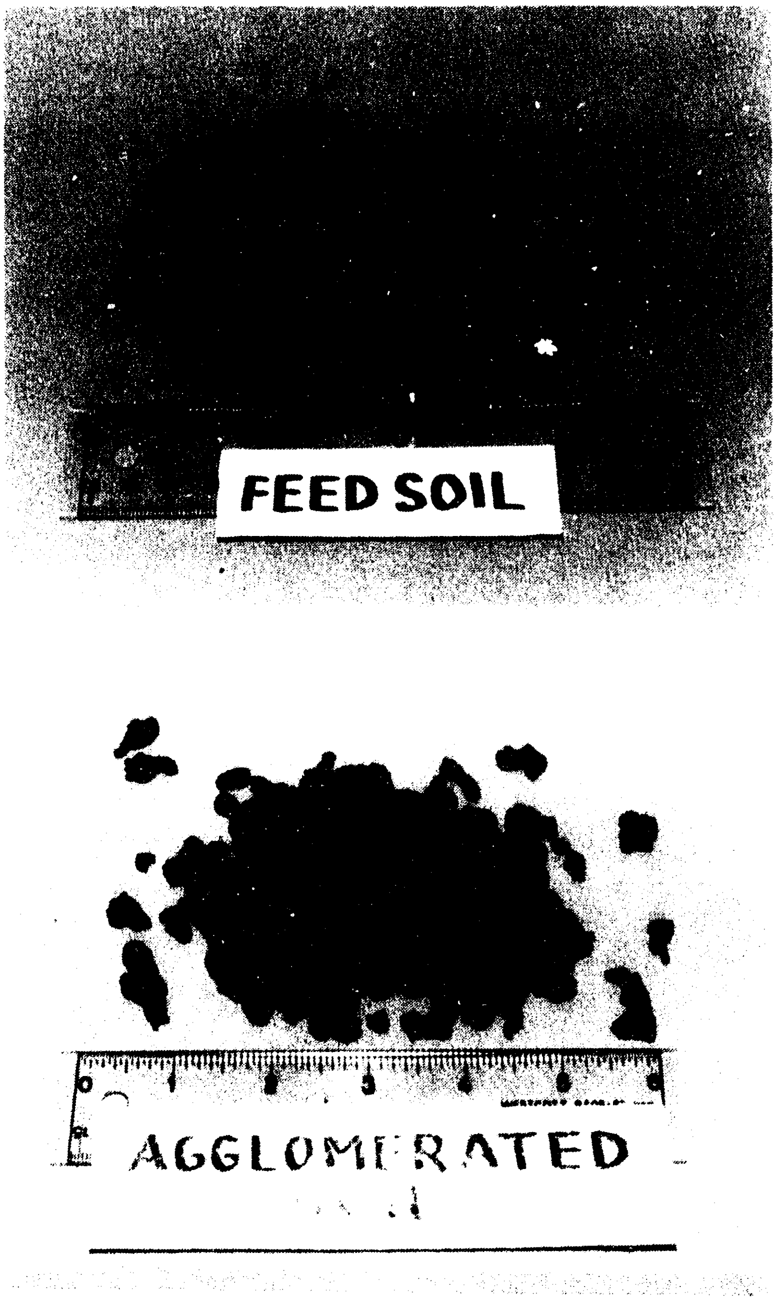


Figure 7. RAW FEED SOIL AND AGGLOMERATED SOIL FROM THE BSU TESTS

Table 5. SUMMARY OF OPERATING CONDITIONS AND RESULTS OF SOIL AGGLOMERATION TESTS CONDUCTED IN THE BSU

Test No.	2	3	5	6			7*	8*
Bulk Bed Temp., °F	1500	1277	1500	1300	1490	1490	1480	1450
Superficial Fluidization Velocity, ft/s	2.03	1.88	1.96	3.37	3.39	3.73	3.28	3.36
Burner Jet								
Velocity, ft/s	40	59	132	137	113	99	137	117
O_2 Conc., mol %	21.0	71.6	59.5	47.8	65.7	59.2	71.4	59.1
Flame Temp. (theoretical) °F	3652	5029	4918	4716	4982	4908	5027	4908
Comments	No Aggl.	TC Melt	Vtrfd+ Soil	Some Aggl.	Many Aggl.	Good Aggl.	Few Aggl.	Good Aggl.

*Spiked soil sample.
+Vtrfd = vitrified.

Samples of the raw "clean" soil and agglomerates from this test were analyzed for As and Cr content and subjected to the TCLP for As and Cr as well (Pb was below the analytical detection limit as indicated in Table 2). The results in Table 6 show that Cr remained with the soil while As was apparently volatilized. Neither the As or Cr was leached into the TCLP extraction media above the detection limit.

Table 6. TCLP RESULTS AND ELEMENTAL ANALYSIS OF "CLEAN" RAW AND AGGLOMERATED SOIL SAMPLES

Sample	Raw Soil	Agglomerates	TCLP Limit
TCLP Leachate		mg/L	
Arsenic	<0.010*	<0.010	5.0
Chromium	<0.050	<0.050	5.0
Element		µg/g	
Arsenic	11 (avg.)	<1.0	
Chromium	32 (avg.)	32.9	

*Indicates detection limit of analytical procedure.

In Test 7, a sample of spiked soil was prepared and charged to the feed hopper to test metals capture and encapsulation efficiency. The burner jet was relocated to the side of the venturi to facilitate the removal of agglomerates from the fluidized bed. Many of the same operating conditions from Test 6 were duplicated in this test, however, only a few agglomerates were formed.

In the eighth test, the BSU was returned to the configuration of Test 6. Spiked soil was again prepared and charged to the feed hopper. In this test however, instead of increasing the oxygen content to the burner jet as was done previously, the natural gas flow was increased. Agglomerates were again formed from the spiked soil sample in sufficient quantities for detailed analyses. The chemical analyses of the spiked feed soil, agglomerated soil, and cyclone fines from this test are in progress. Samples of the spiked feed soil and agglomerated soil have been subjected to the TCLP to determine the leachability of As, Cr, and Pb from the samples.

Summary and Current Program Status

Agglomerates have been produced from a typical sample of soil in a batch, BSU that simulates the first stage of IGT's Two-Stage Incinerator. These agglomerates are the first to be formed from soil with the objective of capturing and encapsulating inorganic materials and rendering the contaminated soil essentially nonleachable.

Tests to determine the operating conditions necessary to agglomerate soil in the bench-scale unit have been completed. The results of chemical analyses and TCLP tests are required before quantitative conclusions can be reached concerning the capture and encapsulation efficiency of the TSI for the metals tested.

IGT has completed the design and specifications for a nominal 6-ton/day (5.4-metric ton/day) TSI pilot plant. The TSI pilot plant design incorporates provisions for feeding natural gas, air, oxygen to both stages. It will be equipped to test natural gas reburning for emission control. It also has provisions for adequate sampling and on-line analysis. When completed, the TSI pilot plant will be extremely versatile and could be used for testing a variety of soils contaminated with inorganic as well as organic contaminants, and other feedstocks, such as RDF, petroleum coke, and auto fluff.

The TSI will be located at IGT's Energy Development Center. The TSI will be installed and connected to existing feeding equipment and downstream product gas cleaning equipment, which include a wet scrubber and bag house.

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DISCLAIMER

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