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Reverse-Burn Gasification for Treatment of Hazardous Wastes: Contaminated Soil, Mixed Wastes, and Spent Activated Carbon Regeneration

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■ A unique reverse-burn gasification process (the ChemChar process) employing secondary combustion of the product gases is described. The process has been applied to a variety of hazardous and nonhazardous wastes. Thermochemical destruction of these wastes is accomplished in a primarily reducing atmosphere induced by reactions of carbon, oxygen, and water. This paper describes the results from selected studies involving application of reverse-burn gasification to soil contaminated with polychlorinated biphenyls (PCBs), activated carbon regeneration, and mixed waste treatment. The process is especially useful in destroying hazardous wastes because of the unique characteristics of reverse-burn gasification, which is particularly effective for dehydrohalogenating organohalide compounds without producing undesirable byproducts, such as dioxins, in retaining acid gases, such as hydrogen chloride produced in the destruction of organohalides, and in retaining radionuclides during the destruction of the organic constituents of mixed waste. With second-stage combustion of the product gas, destruction/removal efficiency of greater than 99.9999% ("six nines") is readily achieved.

Introduction

Reverse-burn gasification (Figure 1), patented for waste treatment as the ChemChar Process (1, 2), provides a means to treat wastes thermochemically in the forms of solids, liquids, sludges, and soils on a devolatilized coal char matrix (3). Organic constituents of the waste are converted to a combustible gas and to a dry, inert, carbonaceous solid. The solid can be readily mixed with cement to prevent leaching of radioactive or heavy metal constituents retained in the char residue after gasification, or the solid can be converted to a much reduced volume of poorly leachable slag by a subsequent forward-burn gasification (4). Therefore, reverse-burn gasification can be a very effective method for treating mixed wastes (organic waste containing radioactive metals) (5).

Spent activated carbon can be regenerated by reverse-burn gasification. A previous study (6) had indicated that, in addition to destroying sorbed hazardous constituents, partial gasification of spent activated carbon by the reverse-burn process restores the sorptive capacity of the carbon, retains heavy metals on the carbon, and (for alkaline carbons) retains HCl on the carbon matrix.

Figure 1 shows a diagram of the batch-mode version of the reactor used for reverse-burn gasification (a continuous-feed version is under development). For gasification the reactor is charged with the coal char/waste mixture. Water, which aids gasification and provides a source of hydrogen for waste-destroying free radical induced reactions, such as dehydrohalogenation, may be present on the solid or introduced as steam into the oxidant stream. Oxygen was used as the oxidant in all experiments described in this paper.

As reverse-burn gasification occurs with movement of the flame front counter to the oxidant flow, a combustible synthesis gas is evolved from the gasifier. This gas consists of combustible components, CO₂, H₂O vapor, and trace volatile organic constituents. The combustible fraction is approximately 45% CO, 45% H₂, and 10% CH₄. The carbonaceous solid residue retains heavy metals and, when alkaline, acid gases, such as HCl. If the flame front is not extinguished by stopping the oxidant flow when the front reaches the top of the solids reactor charge, or when the front is initiated at the top of the reactor charge, forward-burn gasification occurs as the flame front travels in the same direction as the oxidant flow, consuming all combustible material and leaving only the inorganic constituents of the reactor charge. The characteristics of the flame front and the hot reducing zone immediately downstream from it determine the characteristics of reverse-burn gasification that are crucial to its success as a waste treatment process.

Figure 2 further explains the thermochemical reactions occurring in the region just above the flame front, within the flame front, and in the reducing zone immediately

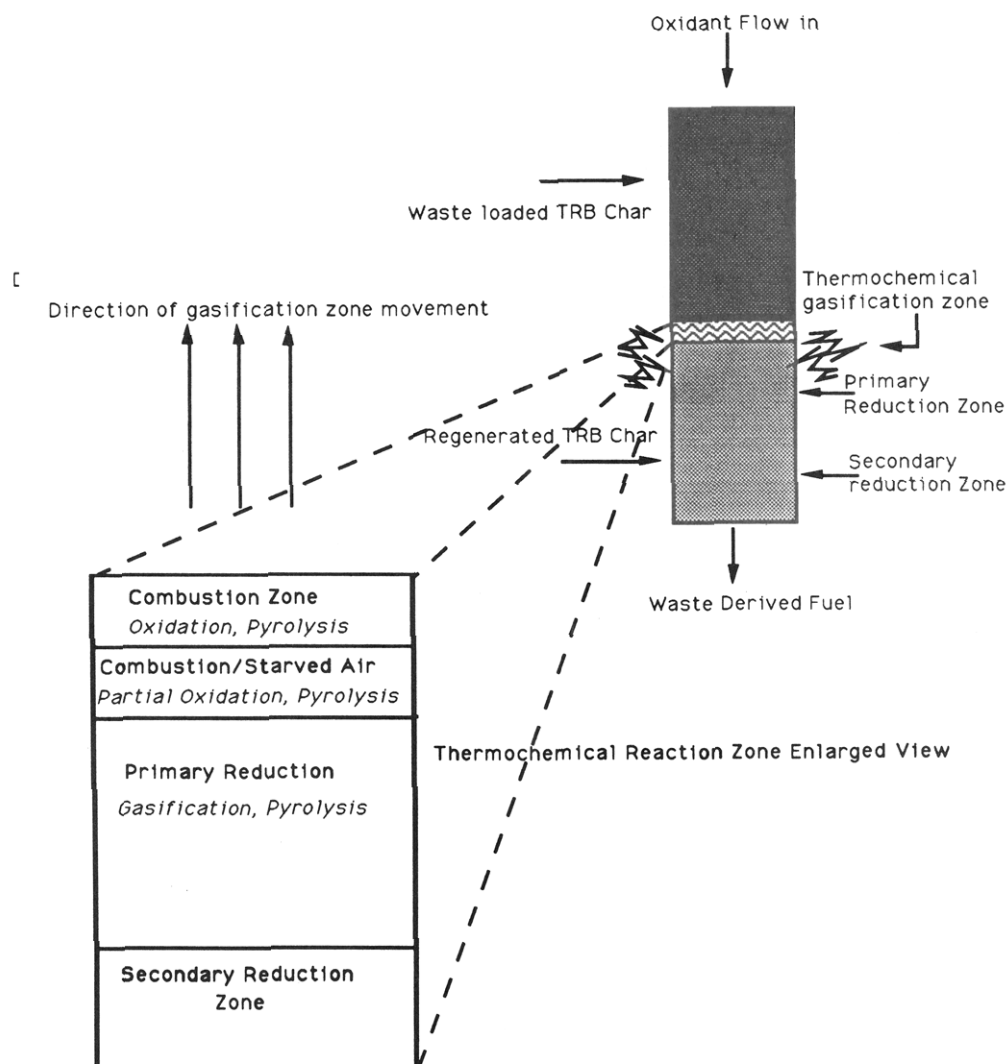


Figure 1. Schematic of gasifier in reverse-burn gasification. The enlarged view of the gasification zone is shown.

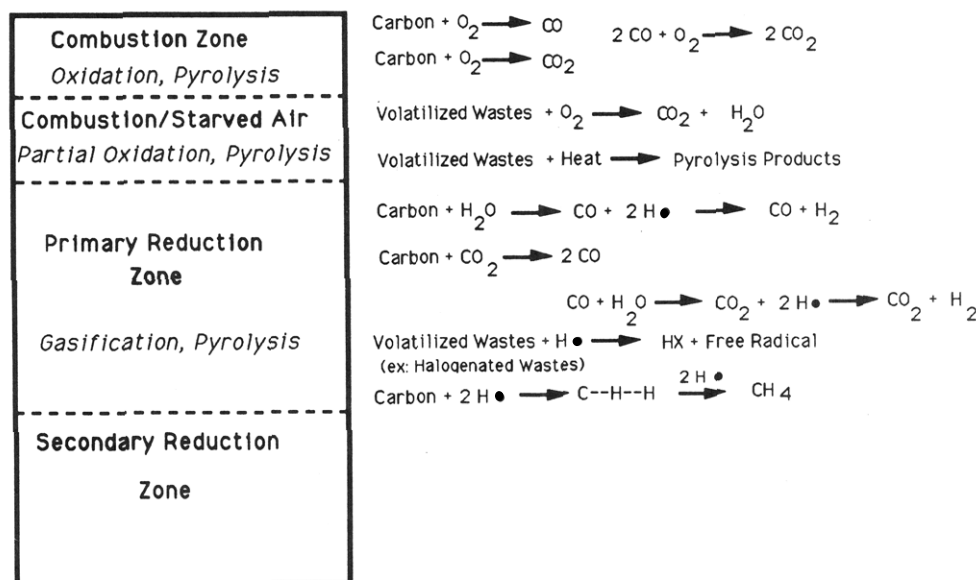


Figure 2. Thermochemical reaction zone showing pertinent gasification reactions of the oxidant with sorbed wastes and carbon.

downstream from the flame front.

Triple-Reverse-Burn Char (TRB Char). A key constituent of the ChemChar waste treatment process is the granular char matrix on which waste materials are held and immobilized for gasification. The char is prepared by gasification of subbituminous coal in a larger version of

the reactor shown in Figure 1 (7). The subbituminous coal that is suitable for this application is nonswelling, low-sulfur, high-alkalinity material. It is subjected to three consecutive reverse-burn gasifications to produce a material called triple-reverse-burn (TRB) char (8). As shown by the electron micrograph in Figure 3, TRB char is a

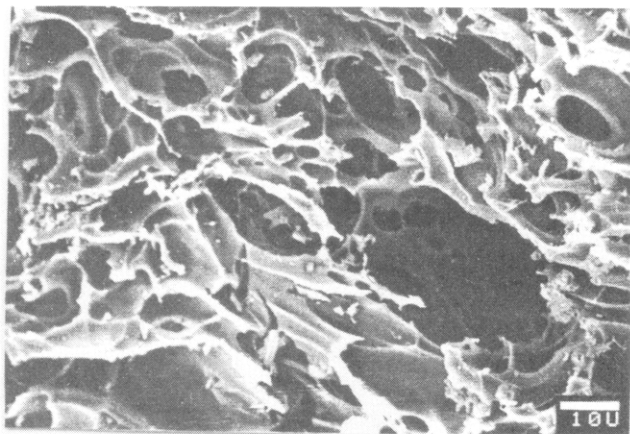


Figure 3. Electron micrograph of TRB char generated by triple-reverse-burn gasification of subbituminous coal and used as a support matrix for waste gasification.

highly porous material with macropores of the order of several tens of micrometers in size. The porous network enables TRB char to soak up as much as its own mass of liquids and sludges. Because of the capillary action of the macropores, TRB char also serves as a drying agent for some kinds of sludges, rejecting water while retaining organic and nonvolatile components. In contrast to the starting materials immobilized on it, the waste-laden char is a dry, granular, readily handled material. It is a low-grade activated carbon with a surface area of approximately 100–200 m²/g.

Waste Treatment by Reverse-Burn Gasification.

Destruction of wastes by reverse-burn gasification is accomplished with the gasification reactor shown in Figure 1 (9). A generalized waste treatment system involves the following steps: (1) macerated solid wastes mixed directly with char (char can be used to sorb and dry aqueous liquid and solid wastes to produce a dry, granular, readily handled material); (2) gasification of the char/waste mixture; (3) removal from the gas stream of aqueous condensate containing impurities and gasification byproducts; (4) filtration of the gas stream through a bed of TRB char; (5) combustion of the gas product; (6) recycle to the gasifier of aqueous condensate and char from the filter.

The following section describes experiments designed to determine the efficiency of reverse-burn gasification applied to treatment of polychlorinated biphenyl- (PCB-) contaminated soils, destruction of mixed waste, and regeneration of activated carbon.

Experimental Section

Soil Gasification Study. Reagents. All reagents were analytical grade. Solvents were Optima HPLC grade from Fisher Scientific. XAD-2 resin was purchased from Aldrich Chemical. Double-distilled deionized (DI) water was used to prepare all aqueous solutions. The PCB and furan standards were purchased from ULTRA Scientific.

Triple-Reverse-Burn (TRB) Char. The TRB char (20–80 mesh) was prepared by reverse-burn gasification of subbituminous coal. Particle diameter is approximately 180–850 μm.

Instrumentation. A Hewlett-Packard GC-MSD system was used to analyze the sample extracts. A Dionex ion chromatograph was used to measure the chloride concentrations in the base-trapping solutions and solid residue extracts.

Apparatus. All parts and connections used in the sampling trains and the process were of either quartz or Pyrex glass. All fittings were constructed out of ball and socket

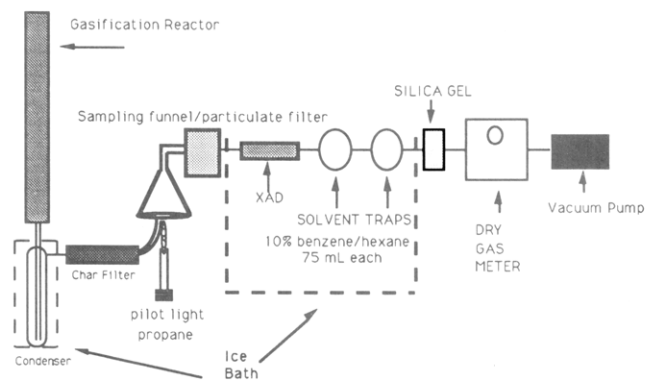


Figure 4. Schematic of sampling train designed to collect combusted effluent from reverse-burn gasification.

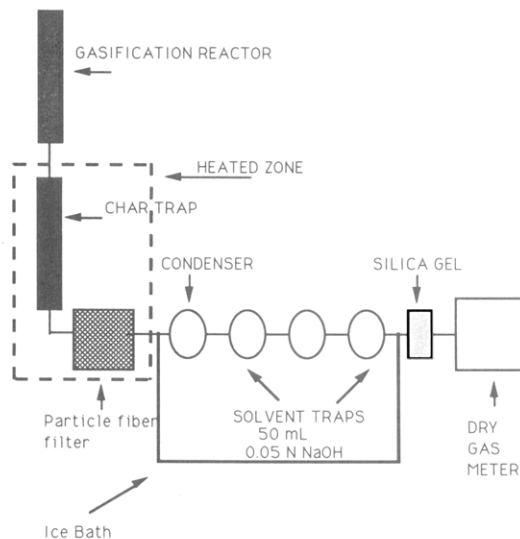


Figure 5. Schematic of process configuration and sampling train for the collection of HCl.

type connections to form leak-free seals. No sealing grease was used in these studies. The capacity of the reactor in the laboratory-scale process is ~25 g. An Omega Engineering rotameter was employed to measure the flow rate of the incoming oxygen, and a Rockwell 415 dry gas meter was used to meter gas sample volume. A Universal Electric vacuum pump was used to pull the combusted effluent through the sampling train via a sampling funnel.

Construction of Laboratory-Scale Reactor. The laboratory-scale batch reactor was constructed from a 2.2 cm inside diameter, 30 cm long tube composed of optically transparent Vycor tubing to which steel fittings were bonded with heat-resistant J-B Weld epoxy resin cement. The charge was held in the reactor by plugs of silica wool at both ends. Oxidant flow to the reactor was measured with a rotameter. In some cases the percentage of water vapor in the oxidant was varied by bubbling the gas through water contained in a flask and heated with a variable-temperature heating mantle.

Gasifier Configuration and Sampling Trains. The two gasifier configurations used in these experiments are depicted in Figures 4 and 5. In all cases, the sampling train was checked for leaks by observing changes in pressure after sealing and evacuating the system. It is important to note that the *process* refers to all system components up to the flame in the PCB-contaminated soil experiments, and refers to the reactor and the char filter in the chloride experiments.

Sampling Train/Laboratory Glassware Preparation. All sampling train glassware and laboratory glassware

coming into contact with the samples were extensively cleaned. Teflon connecting tubing was replaced with new tubing after each experiment. Glass components were rinsed with acetone and hexane, then soaked and washed in hot soapy tap water, and rinsed three times with DI water. The glassware was dried and baked in a 300 °C oven and allowed to cool before a final hexane rinse. Background checks of glassware cross-contamination were done by rinsing with hexane, reducing the volume to 1 mL, and screening by GC/MS for PCBs.

Preparation of Laboratory Waste Soil. In the soil gasification experiments a standard laboratory waste (LW) soil was prepared from a locally collected loam type soil having the following characteristics: pH 7.1, 387 ppm potassium, 206 ppm magnesium, and 2685 ppm calcium. The soil was crushed and dried, and a 20% loading by weight of mineral oil and 233 ppm PCBs was applied to it with thorough mixing. To simulate contamination by Aroclor 1248, three PCB congeners were spiked on this soil in the following ratios: PCB 10 (2,6-dichlorobiphenyl), 83 ppm (ppm = μg of PCB/g of soil); PCB 18 (2,2',5-trichlorobiphenyl), 83 ppm; PCB 47 (2,2',4,4'-tetrachlorobiphenyl), 67 ppm; total added, 233 ppm.

Three experiments were done using LW soil to determine the process destruction efficiency under the configuration in which water is condensed from the gas stream prior to char filtration and combustion of the effluent. The LW soil was applied to TRB char at a 45.5% loading by total weight, then split into three equal portions, and gasified with a reverse burn followed by a forward burn (RB/FB), after removing a portion for analysis of actual loading.

In order to determine actual loading of the polychlorinated biphenyls on the soil and on the loaded char, extraction of the untreated materials was done using a Soxhlet extractor charged with solvent composed of equal volumes of benzene and hexane. These extracts were reduced to 2 mL in hexane by rotoevaporation and solvent exchange. The extracts were subjected to a cleanup procedure involving extraction with dimethyl sulfoxide (DMSO), and back-extraction with hexane (10). The resultant extract was reduced to a 2-mL volume and chromatographed on a multilayer column designed to selectively remove interfering compounds from the PCBs. Volume reduction in vacuo and nitrogen blowdown of the eluate to 1 mL affords an extract free of interferences. This cleanup procedure applies only to untreated soil or soil/char samples.

Gasification of Laboratory Waste Soil/Char Mixture. To study PCB destruction, laboratory waste soil was applied at a 45.5% loading on TRB char (37.5 g of laboratory waste soil applied to 45.0 g of TRB char) and thoroughly mixed using added moisture. After drying until only 10% residual moisture remained, the mixture was split into three equal portions, and three experiments using identical conditions were performed. The waste soil/char mixture was reverse-burn/forward-burn gasified at a rate of 0.824 L/min until only the inorganic portion of the mixture remained. The resultant gasification residues were pulverized and analyzed along with the other process samples and sampling train components.

Gasification of Waste-Contaminated Soil. To study the fate of chloride during gasification, contaminated soil from an existing waste site was applied to TRB char at a 20% loading by total weight (5.0 g of soil on 20.0 g of TRB char) and gasified. Three experiments were performed using this mixture to determine the amount of chloride retained in the process, and that which escapes the process. This soil

was analyzed by the method previously described and found to have an Aroclor 1248 concentration of 518 ppm.

Sample Recovery and Cleanup. After reverse-burn/forward-burn gasification of the reactor charge, the sampling train components, process glassware, and corresponding connecting tubing were rinsed three times each with acetone followed by hexane to remove all analytes within the sampling train. The process samples were analyzed separately, and the sampling train components were combined with the exception of the last trap, which was analyzed separately in order to determine if breakthrough of the PCBs had occurred.

For the sampling train in the PCB studies, the solvent traps and corresponding rinses were dried by filtration over sodium sulfate and concentrated to a 1-mL volume. The condensate was extracted three times with hexane and this extract filtered over sodium sulfate prior to volume reduction to 1 mL. The XAD-2 resin was Soxhlet extracted with equal volumes of hexane and benzene and concentrated to a 1-mL volume.

For the process samples in the PCB studies, the solid gasification residue and spent char from the char filter were Soxhlet extracted using equal volumes of hexane and benzene. The process glassware rinses were added to the extraction solvent. These extracts were concentrated to 1 mL by rotoevaporation and nitrogen blowdown.

All 1-mL samples were subjected to alumina column chromatography to isolate the PCBs, taking the following two fractions: one hexane only and the other a 50:50 mixture of methylene chloride and hexane. Since polychlorinated dibenzofurans (PCDFs) are reported to form under some thermal conditions (11), both fractions from this procedure were analyzed using methods described in the following section. This method was validated by application of a standard of PCB and furan isomers to the alumina column and application of the eluting solvents. A 100% separation of these classes of compounds was obtained for the two fractions by this method.

All chromatographed extracts were reduced to a 300- μL volume by gentle evaporation using nitrogen, rinsing the sides of the vial, and reconstituting to 300 μL by addition of isooctane. An equal volume of bromobenzene was added to all sample extracts as a volume internal standard.

This recovery method was applied to a sampling train in which individual components were spiked with different PCB isomers. The expense and unavailability of ^{13}C -labeled standards prevented their use as internal standards; therefore, this procedure was substituted in order to verify the recovery of the PCBs throughout the process and sampling train.

For the process samples in the chloride generation experiments, the gasification residues from these experiments were pulverized by a mortar and pestle. These and the char filters were extracted three times with a wrist-action shaker using 50-mL volumes of 0.05 N NaOH. The first two extracts were combined, and the last was analyzed separately in order to determine extraction efficiency.

For the sampling train samples in the chloride generation experiments, the sampling train components were rinsed three times using 0.05 N NaOH and combined, with the exception of the last trap, which was analyzed separately to determine if breakthrough had occurred.

For analysis in the PCB experiments, a standard mixture of individual PCB isomers was prepared to obtain response factors for each degree of chlorination at different concentrations. A standard composed of ditetra PCBs [2,6-dichlorobiphenyl (10) 2,2',5-trichlorobiphenyl (18), and 2,2',4,4'-tetrachlorobiphenyl (47)] was used. Selected ion

Table I. Results from the RB/FB Gasification of PCB-Contaminated Soil

run no.	1	2	3
gasification conditions ^a	RB/FB	RB/FB	RB/FB
soil loading, ^b % LW soil on soil/char mixture	45.5	45.5	45.5
ΣPCBs detected in process samples, ng			
gasification residue	0.013	0.150	0.065
condensate	140	183	164
char filter	19	35	27
condensate plus char filter	159	218	191
ΣPCBs detected in process effluent			
combined train, ^c pg	93.7	95.8	88.3
penetration and destruction efficiency			
% penet of PCBs through process into sampling train	<0.0001	<0.0001	<0.0001
destruction efficiency, ^d %	>99.9999	>99.9999	>99.9999

^aRB/FB is a reverse-burn gasification followed by forward-burn gasification. ^bPCBs present in gasification reactor at 45.5% soil loading: 666 μg of 10, 666 μg of 18, 533 μg of 47 for total of 1865 μg. ^cThe results for the combined train are for the traps with the exception of the last trap, which was analyzed separately to ensure no breakthrough. In all cases, no PCBs were detected in the last trap. ^dDestruction efficiency is defined as [(amount PCBs in - amount PCBs out)/amount PCBs in] × 100.

monitoring (SIM) for the respective *m/z* ion pairs, 222/224, 256/258, 290/292, and 157, for bromobenzene was used. Monochlorobiphenyl and pentachlorobiphenyl standards were also prepared in order to determine whether the spiked PCBs in the laboratory soil were undergoing thermal degradation to less highly chlorinated species or undergoing rearrangements to form more highly chlorinated congeners (12). The response factors for each individual congener were used to construct a calibration curve to measure the PCB concentration of each compound in the samples. The minimum instrumental detection limit (MDL) for the di-tetrachloro PCB standard using this method was 10–12 pg. The data are reported as total PCBs calculated by adding the amount from each degree of chlorination and totaling these to give a figure for total PCB concentration.

The second fractions from the alumina column chromatography were analyzed using the SIM technique for the ion pairs *m/z* 236/238, 270/272, and 304/306, for ditetra chlorofurans. Retention times from furan standards were used for the windows of ion monitoring. The MDL was approximately 9–12 pg.

For determination of chloride concentration in the chloride generation experiments, extracts were analyzed using ion chromatography. The chloride concentration was then multiplied by the total volume of the extract to give the total amount of HCl converted by gasification of the chlorinated wastes, which was measured as chloride with a detection limit of 100 parts per billion (ppb).

Spent Activated Carbon Regeneration. *Reagents.* The granular activated carbons used were (1) Darco, Norit Co., 20–40 mesh; Cekarbon GAC 40, Atochem, 12–40 mesh; and ChemChar TRB char, 20–60 mesh. All solvents were purchased from Fisher Scientific. All aqueous solutions were prepared with double-distilled dionized water.

Instrumentation. A Waters high-pressure liquid chromatography pump, coupled with an Altex 152 dual optical flow-through cell (20-μL capacity, quartz cells) to measure absorbance at 254 nm was used in this set of experiments. A Quantasorb QS-10 surface area analyzer (QuantaChrome Corp., Syosset, NY) was employed for measurement of surface area.

Spending and Reactivation of Carbon. Carbons were deaerated by boiling in water and cooling. The carbons were suspended in water and loaded over a 24-h time period in contact with 0.11% hexachlorobenzene (HCB) applied as a benzene solution of HCB. After oven-drying at 120 °C until free flowing, the carbons were regenerated by reverse-burn gasification at an oxygen flow of 2 L/min. After removal of a 2.0-g sample for breakthrough assay

with phenol, the process was repeated three times for subsequent regenerations.

Breakthrough Curve Assay. For flow-through measurement of sorptive capacity, carbons were ground to a powder and a 0.5-g portion was loaded into a 3 mm inside diameter stainless steel column through which a 1000 ppm phenol solution was pumped at 0.5 mL/min with a Waters high-pressure liquid chromatography pump. Absorbance of phenol was measured at 254 nm and sorptive capacity calculated at the point where the plot of absorbance vs volume rose abruptly from baseline.

Surface area measurements were performed by the nitrogen adsorption isotherm (BET).

Mixed Waste. *Ion-Exchange Resin.* The organic constituent of the simulated mixed waste studied was Amberlite IRN-78, a strongly basic nuclear grade anion-exchange resin in the OH form. The particle size of this resin ranges from 16 to 50 mesh, corresponding to an effective size of 0.38–0.45 mm. The maximum moisture content is 60%.

Technetium-99m. This radioisotope was produced from the decay of ⁹⁹MoO₄²⁻ on an activated alumina column. ^{99m}Tc is eluted from the column with normal saline solution as ^{99m}TcO₄⁻. The activity of ^{99m}Tc was counted with a well-type NaI(Tl) solid scintillation detector to measure the 140.5-keV γ emission.

Gasification of Technetium-99m. A sample containing radioactive ^{99m}Tc as TcO₄⁻ loaded onto anion-exchange resin was slurried with water and mixed with char in a 1:3 ratio. The resin/char mixture was air-dried and charged into the reactor configured so that the gas flowed upward, rather than the conventional downflow configuration shown in Figure 1. A TRB char filter was added to the column downstream from the char/resin mixture as a precautionary measure for adsorption of volatilized components. The resin/char mixture was subjected to reverse-burn gasification (in the configuration used, the flame front was initiated at the top of the resin/char mixture plug, the oxygen flowed upward, and the flame moved downward), and the activities of 1-cm³ volumes of resin/char product, glass wool, and filter char were measured.

Results and Discussion

Soil Gasification Experiments. The data for gasification of PCB-contaminated soil given in Table I illustrate the following points pertaining to PCB destruction by gasification of a PCB-contaminated soil mixed with char: (1) Only 4 × 10⁻⁶% of the PCBs remained unreacted on the ash residue from a reverse burn followed by forward-

Table II. Inorganic Chloride Production from PCB Gasification

run no.	1	2	3
gasification cond ^a	10.0 g of char, RB only	2.5 g of 518 ppm Aroclor 1248 on 10.0 g of char, RB only	2.5 g of 518 ppm Aroclor 1248 on 10.0 g of char, RB/FB
sample vol, m ³	0.005	0.005	0.005
chloride as Cl ^{-b}			
in traps, ng	nd ^c	156	183
in residue + char filter, µg	nd	560	535

^aRB is a reverse-burn gasification only; RB/FB is a reverse-burn gasification followed by forward-burn gasification. ^bThe 2.5 g of 518 ppm Aroclor 1248 corresponds to a total of 1.29 mg of Aroclor present in the gasification matrix. Since Aroclor 1248 contains 48% chlorine, this corresponds to 0.619 mg of available chloride to be evolved as HCl (619 µg of chloride). ^cnd, not detected.

burn gasification. (2) Essentially all of the unreacted PCBs, amounting to 0.01% of the total PCBs, were collected in condensate plus char filter. These can be recycled to the gasifier so that they do not count as "undestroyed" wastes in the overall process. Therefore, gasification alone achieves 99.99% destruction of PCBs. (3) Less than 0.0001% of the PCBs penetrated into the sampling train. (4) Calculated in the standard manner, greater than 99.9999% destruction efficiency of PCBs was achieved overall.

The chloride recovered in runs 2 and 3 for inorganic chloride production from PCB gasification (Table II) accounted for 89% of the original chloride placed in the system, a reasonable recovery given the small quantities involved. Of the inorganic chloride found, only 0.03% penetrated into the traps. This value, alone, reflects high retention and low emission of chloride, indicating that virtually all of the chloride produced remains with dry solids contained in the gasification reactor and heated char trap shown for the configuration employed in Figure 5. In an operational process, liquid condensate and an alkali-treated char filter included as part of the process and not as emission control per se, as shown in Figure 4, should reduce chloride emissions dramatically. (The effects on chloride emissions of condensation of water from product gas and passage of the gas over an alkali-treated char filter are the subject of future studies in our laboratory.)

Analysis of the second fractions from alumina column chromatography indicated that, within the detection limits of the method, no PCDFs were formed. The high destruction efficiency and ability to retain acid gases in the process clearly indicate that reverse-burn gasification is an alternative thermochemical treatment for the destruction of PCB-contaminated soils. This is a particularly attractive means for destruction of these refractory compounds, considering the amount of soil contaminated with PCB-containing transformer oils. The process is self-sustaining with regard to energy consumption due to the carbonaceous char matrix on which the wastes are sorbed. It not only provides the fuel for gasification but also a highly reactive surface on which important thermochemical reactions occur which serve to destroy the sorbed wastes by gasification in a reducing atmosphere. The reducing atmosphere is an important aspect of this process, as it serves to prevent the formation of unwanted byproducts such as polychlorinated dibenzofurans.

Spent Activated Carbon Regeneration. Carbon regeneration data are given in Table III. The data show that, for the most part, capacity as measured by phenol sorption is retained in regeneration; in the case of TRB char, it is significantly enhanced. Surface area is essentially unchanged through two successive regenerations. The physical integrity of the carbons remained intact and adequate for use in all cases through three successive regenerations. Scanning electron microscopy of CeCarbon showed that it changed from a very closed structure for

Table III. Capacity and Surface Area (SA) of Carbons before and after Successive Regenerations^a

no. of regens	TRB char		Darco		Cecarbon	
	capac, mg/g	SA, m ² /g	capac, mg/g	SA, m ² /g	capac, mg/g	SA, m ² /g
0	85.7	104	58.4		256	1000
1	85.7	70	204		181	1025
2	243	76	180		228	907
3	293		180		177	

^aAll values for regenerated carbons were for carbons spent with HCB, except for surface area measurements for first and second regenerations of Cecarbon, in which the carbon was spent with toluene.

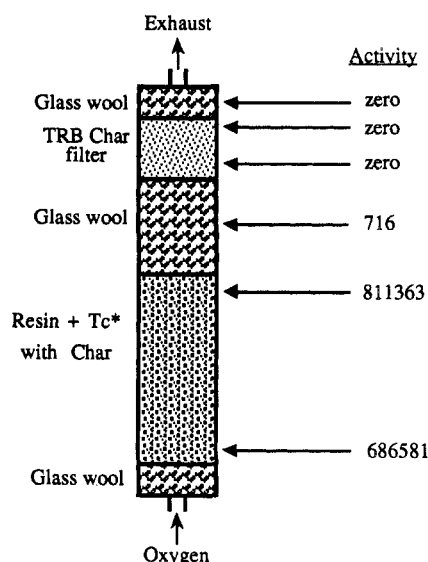


Figure 6. Retention of ^{99m}Tc in the gasification of a mixture of char and anion-exchange resin laden with ^{99m}Tc. Activity is in units of counts per minute. Oxygen flow in this case is upward, and the flame front was initiated at the top of the "resin + Tc" with char" plug and moved downward the length of the plug.

the original material to a significantly more porous material with numerous surface crevices for the regenerated material. The carbon itself provided all the fuel needed for regeneration. For each regeneration cycle the mass loss of carbon was approximately 10%, which is acceptable from an economic viewpoint.

Mixed Waste. Radionuclide retention in waste treatment was measured using radioactive technetium-99m. In addition to being a significant contaminant nuclear fission byproduct, this radionuclide is a standard one used for a wide range of radiotracer and imaging studies because of its optimum half-life and radiation characteristics.

The results obtained in the radiotracer experiment are illustrated in Figure 6. The reactor retained all of the radioactivity detected, of which 99.9% remained on the char/resin residue. The remaining 0.1% activity was re-

tained in the glass wool immediately downstream from the mixture gasified and located between the char/resin column and the char filter, which became moist from the gases evolved during gasification, and the moisture probably carried with it the small amount of activity that was found on the glass wool plug. No activity was detected in the char filter immediately downstream from the glass wool plug. These results demonstrate the superb ability of the char to retain metals while the organic portion of the waste ion-exchange resin is destroyed.

Summary

One of the greater challenges facing professionals in the area of hazardous waste management is the treatment and destruction of wastes in a manner that is effective, affordable, and environmentally acceptable, particularly from the standpoint of emissions (13) and in consideration of the production of highly toxic byproducts of treatment processes (14). Despite the euphoria in some circles for alternative approaches, such as biotreatment, for some kinds of wastes, only the high temperatures and chemically severe conditions of thermochemical treatment processes are adequate for effective treatment. However, conventional incineration suffers some severe disadvantages in the thermochemical treatment of wastes, particularly in the areas of emissions and byproduct generation (15). Gasification offers some distinct advantages over incineration, especially because it operates under reducing conditions and produces a combustible gas that can be burned very efficiently under carefully controlled conditions to destroy any remaining traces of wastes or gasification byproducts.

The high destruction efficiency and ability to retain acid gases in reverse-burn gasification clearly indicate that this approach offers an alternative thermochemical means for the destruction of PCB-contaminated soils. Reverse-burn gasification is a particularly attractive means for destruction of refractory PCBs, considering the amount of soil contaminated with PCB. The process is energy self-sufficient due to the carbonaceous char matrix on which the wastes are sorbed. In addition to providing fuel for gasification, the char matrix also offers a highly reactive surface on which thermochemical reactions occur which destroy the sorbed wastes by gasification in a reducing atmosphere. The reducing atmosphere generated by gasification reactions on the char surface is a crucial attribute of this process because it serves to prevent the formation of unwanted byproducts such as polychlorinated dibenzofurans.

This paper has summarized the uses of reverse-burn gasification for several important waste treatment applications. Refractory organohalide wastes (PCBs) were destroyed to an extent of at least 99.9999% without production of undesirable byproducts or evolution of significant amounts of hydrogen chloride. Destruction of wastes on contaminated soil was demonstrated. The organic

constituents of mixed wastes containing both organic substances and radioactive materials were destroyed with complete retention of radionuclides, which can be incorporated into a nonleachable slag with ~5% of the volume of the original waste. In addition, spent activated carbon was regenerated and reactivated by reverse-burn gasification without unacceptable loss of mass, sorptive capacity, or physical integrity.

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