



Project Summary

Performance and Economic Feasibility of a Sludge/Wastepaper Gasifier System

N. W. Sorbo, G. Tchobanoglous, J. R. Goss, and S. A. Vigil

Thermal gasification of densified sludge/wastepaper fuels has been shown to be technically feasible for the co-disposal of sludge and source-separated wastepaper. The performance and economic feasibility of a downdraft packed-bed gasifier system fueled with densified sludge/wastepaper and wastepaper fuels has been evaluated.

To assess the performance of the gasifier, a series of gasifier runs were conducted at various air input rates with the use of various densified fuels. In eight of the runs, a densified fuel consisting of 20 percent lagoon-dried sludge and 80 percent recycled wastepaper was used; in five runs, densified wastepaper cubes were used. Gaseous and particulate emissions resulting from the combustion of producer gas were measured. Char, a by-product of the gasification process, was evaluated as a substitute for powdered activated carbon. The performance of a small dual-fuel diesel engine combusting producer gas generated from the gasification of densified wastepaper was also demonstrated.

The cost of sludge disposal in a sludge-wastepaper gasification system, using wood chips as an auxiliary fuel, was found to be competitive with the cost of sludge disposal by landfilling if the electricity generated by the gasification system can be sold at a cost of \$0.12/kWh, \$0.09/kWh, and \$0.085/kWh for communities sizes of 10,000, 30,000, and 50,000 persons, respectively. The economic feasibility of sludge/wastepaper gasification is highly sensitive to the cost of wood chips, the solids content of the dewatered sludge, the percentage of wastepaper collected, and the resale cost of electricity.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The disposal of sewage sludge and solid wastes in an economic and environmentally acceptable manner is a problem common to many communities. The co-disposal of sludge and wastepaper in a common facility is a potential solution to both of these problems. This research project deals with the application of the gasification process for the co-disposal of sludge and wastepaper. To reduce the volume of sludge, densified mixtures of sludge and source-separated wastepaper are gasified in a simple packed-bed reactor (downdraft gasifier) that uses air as the oxidant.

Experimental Gasification System

Gasification results when a carbonaceous fuel is partially combusted by injecting 20 to 30 percent of the stoichiometric oxygen requirement. The products of the gasification process are a low-energy gas (producer gas) and char. Producer gas can be used to fuel boilers, heaters, engines, or turbines; the char can, in some cases, be used as a source of powdered activated carbon.

To evaluate the performance of sludge/wastepaper gasification, a pilot-scale gasification system was designed and constructed. The complete system consists of three subsystems: batch-fed downdraft gasifier and producer gas burner, data acquisition, and shredding/densification system.

The pilot-scale batch-fed downdraft gasifier used in this experimental program was designed and constructed for work previously reported. A producer gas burner was designed and constructed to provide a facility from which particulate and gaseous measurements of both the producer gas and the flue gas (combined producer gas) could be taken. A schematic diagram of sludge/wastepaper gasification system is shown in Figure 1.

The data acquisition system consisted of an automated temperature measurement system and a producer gas analysis system. Temperatures and elapsed time from Type T, K, and R thermocouples were recorded automatically and printed on the paper tape output of a Digilog Model 1000 Datalogger.* The Papakube Corporation densification system was used to shred and densify all fuels. Key features of the Papakube system include an integral shredder, a metering system, and a modified John Deere Cuber equipped with dies developed by the Papakube Corporation.

Experimental Results

The experimental gasifier runs were conducted at various air input rates with the use of different densified fuels. A mixture of 20 percent sludge and 80 percent recycled newspaper was the fuel used for eight gasifier runs; five gasifier runs were conducted using densified, recycled newspaper fuel cubes. The gasifier operational data, gaseous and particulate emissions testing, the feasibility of using gasifier char as a source of powdered activated carbon, and the operation of a small diesel engine with producer gas are summarized below.

Summary of Gasifier Operational Data

During each gasifier run, data were collected on fuel and char characteristics (physical and chemical), process rates, temperatures and pressures, and producer gas composition. From these data, energy balances were calculated.

Fuel Characteristics

The higher heating values and wastepaper fuel for the sludge/wastepaper fuel were 18.78 and 19.42 MJ/kg. The bulk density of these fuels varied between 284 to 595 kg/m³, with the bulk density of the sludge/wastepaper fuel being significantly higher than that of the wastepaper fuels. The fuel ash content is one of the most critical parameters in any downdraft gasifier application. The percentage of fuel ash (dry basis) was 4.6

percent in the sludge/wastepaper fuels and 1.0 percent in the wastepaper fuels.

Char Characteristics

The major constituents of gasifier char, the major waste product of the gasification process, are carbon and ash. Char production should be minimized it represents an energy loss as well as a waste product that must be disposed. Reducing the carbon content of the char improves the gasification process efficiency as well as lowers disposal costs. The physical and chemical properties of the gasifier char are presented in Table 1.

Slag Formation

Slag is formed in the gasifier when the fuel ash, upon reaching its melting point, flows together and cools. Excessive slag formation in downdraft gasifiers can block the flow of fuel and char through the gasifier, and thus cannot be permitted. Because of the relationship between the fuel ash content and reactor temperature, there has been concern about the technical feasibility of gasifying sludge in downdraft gasifiers. Based on a series of eight experimental gasifier runs, it can be concluded that fuel mixtures of 20 percent sludge and 80 percent wastepaper can be gasified without prohibitive slag formation.

Distribution of Gaseous Constituents

Producer gas is the desired product of the gasification process. Three gaseous constituents make up the combustible fraction of producer gas: CO, H₂, and total hydrocarbons. The concentration of each gaseous constituent did not vary much despite a large change in the air input rate (Figure 2).

Energy Balances

Temperature, process rate, and gas analysis were used to calculate energy balances. Gasifier efficiencies (obtained from the energy balance calculations) as a function of air input rate are graphically summarized in Figure 3. If the producer gas can be used hot (in a boiler), the gasifier process efficiency is the sum of the cold gas energy and the sensible heat.

Feasibility of Using Gasifier Char as a Source of Powdered Activated Carbon

Char samples from eight gasifier runs were analyzed for the effectiveness as a replacement for powdered activated carbon. The following tests were conducted on ground and classified char samples: proximate analysis, ultimate analysis, apparent density, methylene blue number, iodine number, rate of adsorption of TOC (total organic carbon),

relative TOC reduction factor (TOC RF), settling tests, and scanning electron microscopy. The most important char characterization test is the relative TOC RF, which is used as an indicator of the relative efficiency of removal of TOC with respect to a reference activated carbon.

In most cases, the adsorptivity of the char varies inversely with the percentage of sludge in the fuel used to generate the char and directly with the carbon content of the char. Because high gasifier efficiencies are attained when the carbon content of the char is minimized and high char adsorptivity is attained when the carbon content of the char is maximized, the production of char that has good adsorption properties is not feasible when the gasifier is operated to maximize the production of high quality gas.

Gaseous and Particle Emissions

Four tests were done to determine the gaseous and particle emissions from the combustion of producer gas. The producer gas, generated by the gasification of densified sludge/wastepaper cubes, was combusted in the producer gas burner. Both gaseous and particle emissions data were collected from the flue gas sample ports shown in Figure 1.

The following values from the gaseous emissions measurements were obtained: NO_x concentrations varied between 60 and 115 ppm, noncondensable hydrocarbon concentrations (based on hexane) were generally less than 1 ppm, SO₂ concentrations (corrected to 12 percent CO₂) ranged from 0.091 to 0.227 grams per dry standard cubic meter (g/dscm). When the total particle emission rate was measured (by the EPA Method 5 protocol), the particle concentration in the flue gas (corrected to 12 percent CO₂) range from 0.068 to 0.164 g/dscm. Based on these measurements, the producer gas burner system meets federal standards for particle emissions from incinerators (0.189 g/dscm) without any cleanup equipment. From an impactor study, it can be concluded that the cut diameter for particles in the flue gas is approximately 8 microns.

Operation of a Small Diesel Engine with Producer Gas

The performance of a small diesel engine operated in a dual-fuel mode with producer gas was evaluated in a series of three gasifier runs. The producer gas, generated from the gasification of densified wastepaper, was cleaned by a fiber glass filter and a condenser. The gas was fed to the engine with a modified natural gas engine carburetor. The practical output of the dual-fuel engine operated with producer gas was 71 percent

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

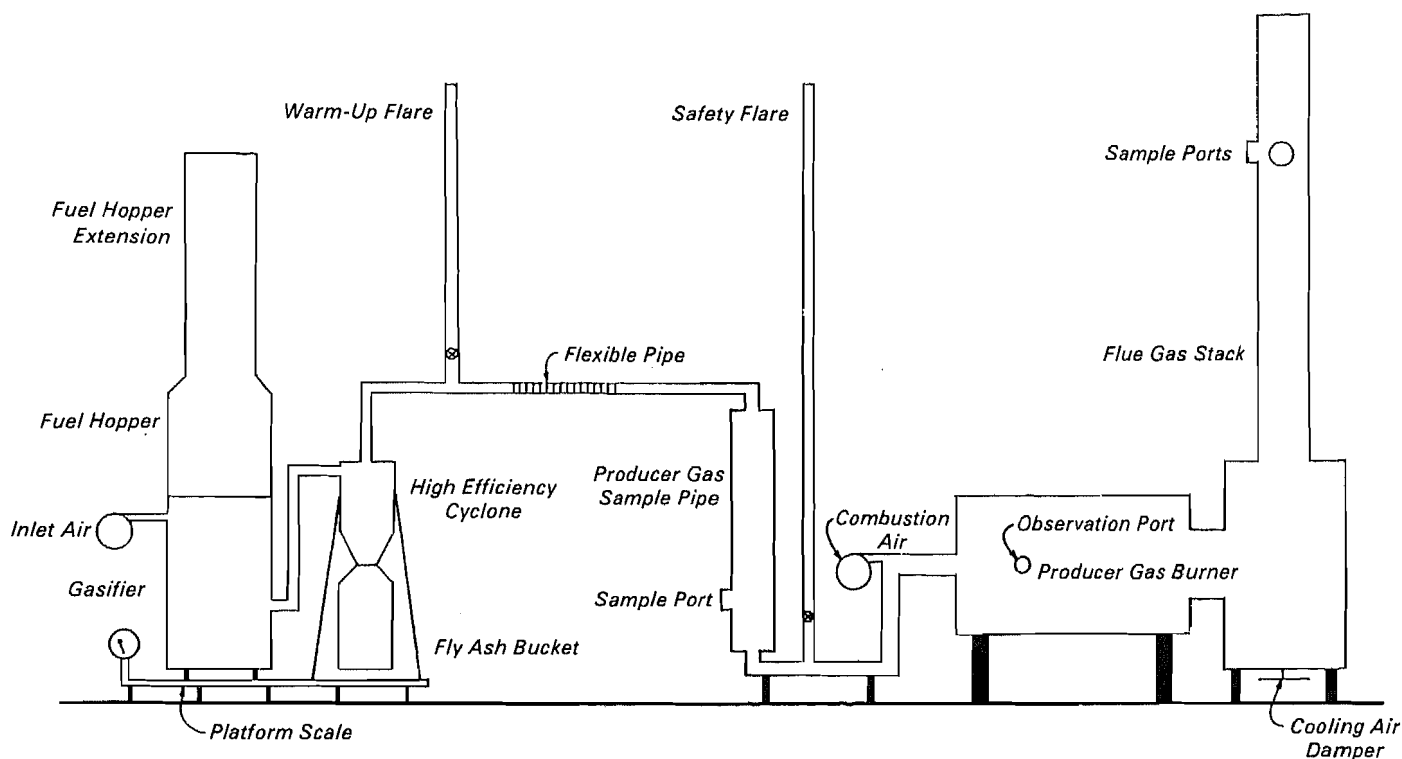


Figure 1. Schematic diagram of the experimental sludge/wastepaper gasification system.

Table 1. Properties of Gasifier Char

Run #	Fuel Type	Energy Content (Dry Basis, HHV) (MJ/Kg)	Ultimate Analysis (% by weight)						Proximate Analysis* (% by weight)			
			C	H	O	N	S	Residue	MC	VCM	FC	Ash
14	wastepaper	25.31	70.93	0.59	2.78	0.18	0.02	25.5	0.3	5.4	70.8	23.5
15	wastepaper	26.19	73.29	0.69	2.69	0.19	0.04	23.1	0.2	4.4	74.7	20.7
16	wastepaper	30.44	86.62	0.92	2.64	0.09	0.03	9.7	0.6	4.0	84.0	11.4
17	20% sludge/ wastepaper	24.62	70.53	0.51	1.06	0.18	0.12	27.6	0.3	2.9	71.0	25.8
18	20% sludge/ wastepaper	25.50	71.97	0.76	0.94	0.25	0.08	26.0	0.7	3.2	71.6	24.5
19	20% sludge/ wastepaper	26.20	76.27	0.65	1.52	0.27	0.09	21.2	0.6	3.3	74.1	22.0
20	20% sludge/ wastepaper	21.82	62.98	0.27	1.70	0.13	0.02	34.9	NA [†]	NA	NA	NA
21-A	20% sludge/ wastepaper	25.69	68.71	1.59	6.79	0.36	0.05	22.5	NA	NA	NA	NA
21-B	20% sludge/ wastepaper	26.60	73.46	2.59	9.70	0.53	0.12	13.6	NA	NA	NA	NA
26	20% sludge/ wastepaper	15.88	50.68	0.40	0.0	0.18	0.01	49.3 [‡]	NA	NA	NA	NA
27	20% sludge/ wastepaper	17.73	51.98	0.30	0.34	0.17	0.01	47.2	NA	NA	NA	NA
28-A, 28-B	20% sludge/ wastepaper	15.62	48.18	0.30	0.0	0.20	0.01	51.4 [‡]	NA	NA	NA	NA

*MC = Moisture content, VCM = Volatile combustible matter, FC = Fixed carbon.

[†]NA = Not available.

[‡]As oxides, therefore total is greater than 100%.

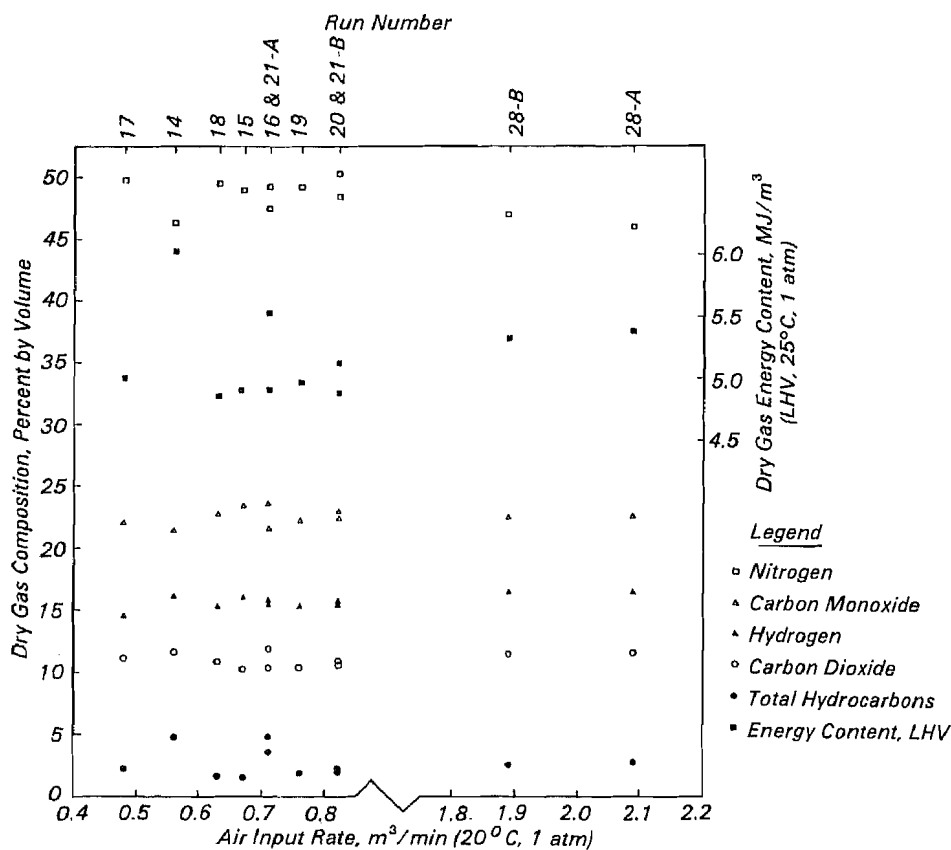


Figure 2. Producer gas composition vs. air input rate.

of the engine power output operated with diesel fuel alone.

Economic Feasibility of Sludge/Wastepaper Gasification

To estimate costs of a full-scale sludge/wastepaper gasification system, a model to evaluate the economic feasibility was developed. Important technical factors that influence the design and cost of a full-scale system are fuel density, fuel ash content, quantity of wastepaper collected, and the moisture content of dewatered sludge. Based on these factors, a full-scale sludge/wastepaper gasification system would have three process elements: collection, fuel processing, and energy conversion. The collection process consists of collecting source separated wastepaper, dewatering sludge, and procuring wood chips. (To maintain an acceptable fuel ash content for operation without disruptive slag formation, wood chips need to be added to the sludge/wastepaper mixture.) Fuel processing consists of mixing, shredding, densifying, and drying the sludge/wastepaper/wood chip mixture. Converting the chemical energy in the den-

sified fuel cubes into electricity is done with the use of a downdraft packed-bed gasifier, a dual-fuel diesel engine, and an electric generator.

Because of the large number of variables (technical, economic, and site specific) that affect the economic feasibility of sludge/wastepaper gasification in small communities, an economic sensitivity analysis was performed. The resale value of electricity, cost of wood chips, and community size were varied, and the costs of sludge/wastepaper gasification were compared with estimated costs for sludge disposal by landfilling. Assuming 40 percent of the wastepaper is collected, the cost of sludge/wastepaper gasification is competitive with the cost of sludge disposal by landfilling when the resale cost of electricity is greater than: \$0.12/kWh for communities of 10,000 persons, \$0.09/kWh for communities of 30,000 persons, \$0.085/kWh for communities of 50,000 persons.

Conclusions

Based on the work described in this report the following conclusions can be made:

1. The gasification of densified sludge/wastepaper cubes consisting of 20 percent dewatered sludge and 80 percent recycled wastepaper has been demonstrated.
2. Results of tests to measure gaseous and particle emissions are: NO_x concentrations varied between 60 and 115 ppm; noncondensable hydrocarbon concentrations were usually less than 1 ppm; SO_2 concentration (corrected to 12 percent CO_2) ranged from 0.091 to 0.227 g/dscm; particle concentration (corrected to 12 percent CO_2) ranged from 0.068 to 0.164 g/dscm; federal standards for particle emissions for incinerators were met without emission control devices.
3. If the gasifier is operated to produce a char high in carbon, the resulting char can be used as an acceptable substitute for powdered activated carbon.
4. A dual-fuel diesel engine was operated successfully at 71 percent of the rated power output with producer gas.
5. Depending on the resale value of electricity and the cost of woodchips, sludge/wastepaper gasification systems can be economically competitive with sludge disposal in landfills.

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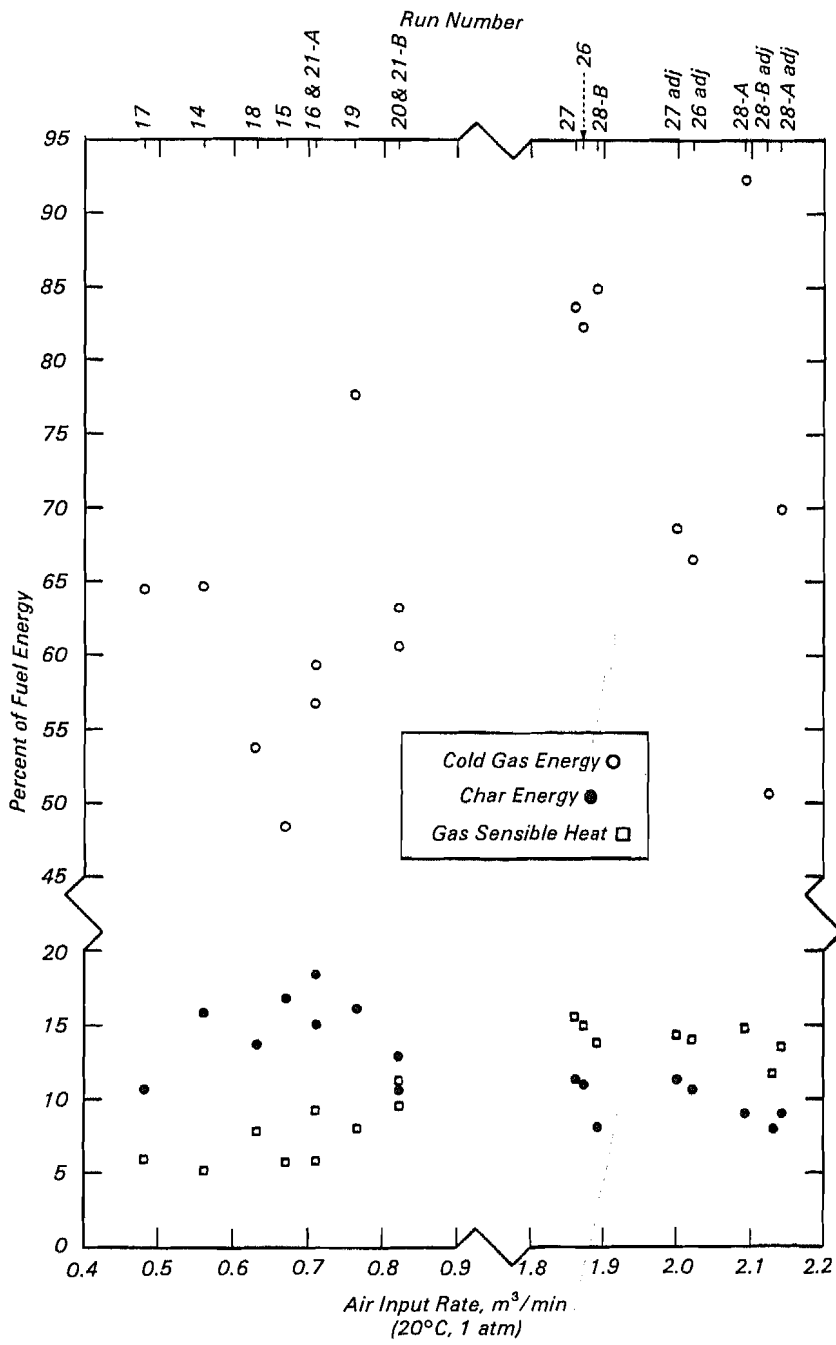


Figure 3. Gasifier efficiencies vs. air input rate.

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Howard O. Wall is the EPA Project Officer (see below).

The complete report, entitled "Performance and Economic Feasibility of a Sludge/Wastepaper Gasifier System," (Order No. PB 84-169 317; Cost: \$17.50, subject to change) will be available only from:

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