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Project Summary

Co-Gasification of Densified Sludge and Solid Waste in a Downdraft Gasifier

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Thermal gasification is a new process for the co-disposal of densified sludge and solid waste in a co-current flow, fixed bed reactor (also called a downdraft gasifier). The advantages of this technology include lower costs than other incineration or pyrolysis technologies, simple construction and operation, and the ability to use a variety of fuels including agricultural wastes and other biomass materials in addition to densified sludge and solid waste.

Essentially, the gasification process involves the partial combustion of a carbonaceous fuel to generate a low energy combustible gas and a char. Operationally, fuel flow is by gravity with air and fuel moving co-currently through the reactor. The low energy gas is composed primarily of carbon monoxide, hydrogen, and nitrogen and of trace amounts of methane and other hydrocarbons.

Although fixed bed gasifiers are mechanically simpler than other co-disposal reactors, such as multiple hearth furnaces or mass fired incinerators, they have more exacting fuel requirements which include: moisture content, ≤20 percent; ash content, ≤6 percent; and relatively uniform grain size. Without front end processing, neither municipal solid waste nor dewatered sludge meet these criteria. Demonstrating that a suitable gasifier fuel could be made with a simple front end system consisting of source separation for solid waste, a sludge dewatering system, and fuel densification system has been one of the objectives of this project.

To demonstrate the gasification process, a pilot scale gasifier was constructed. A broad range of fuels have been tested with the gasifier including an agricultural residue, densified waste paper, and densified waste paper and sludge mixtures containing up to 25 percent sludge by weight. The sludge fuels were made from mixtures of lagoon-dried primary and secondary sludge and from recycled newsprint (in full scale systems a mixed paper fraction of solid waste could be used). Mixtures were densified using commercially available agricultural cubing equipment.

The gasifier was operated with each fuel, and measurements of the variables needed to characterize the process were made. The results of gas, fuel, and char analyses were used to compute energy balances. These data were also used to calculate efficiencies for each run. Hot gas efficiency, which include the sensible heat of the gas, ranged from 40.0 to 85.2 percent. The cold gas efficiency, which does not include the gas sensible heat, ranged from 37.1 to 80.7 percent. The dry low energy gas produced during the tests ranged in a higher heating value (HHV) from 4.52 to 6.79 MJ/m^3.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincin-

nati, 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 co-disposal of sludge (the solid residues of wastewater treatment) and solid waste in a joint facility is acceptable from an environmental, economic, and energy standpoint. However, the trend in development of such projects has been towards very large systems. It has been assumed that the economics of scale precludes the use of such technology by small communities (less than 50,000 population). The ever increasing costs of energy and disposal of sludge and solid waste make small scale co-disposal attractive.

This report presents the development of a new process for the co-disposal of sludge and solid waste that, unlike existing co-disposal technology, can be implemented on a small scale. This air-blown gasification process has been widely applied to coal, wood, and agricultural wastes but has never before been used for the co-disposal of sludge and solid waste. Co-gasification of densified mixtures of sludge and source separated solid waste occurs in a simple fixed bed reactor, also known as a moving packed bed reactor. Energy, in the form of a low energy gas (LEG) produced by the process, can be used to fuel boilers, heaters, engines, or turbines.

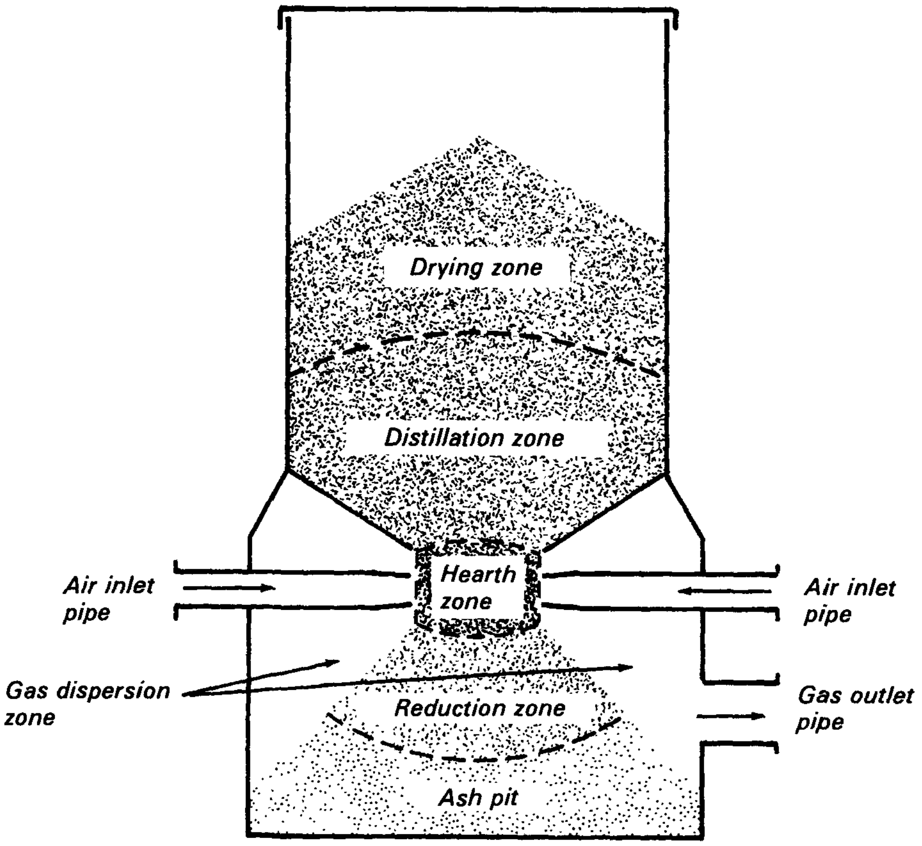

Figure 1. Schematic of a downdraft gasifier.

Experimental Gasification System

To investigate the co-gasification of densified sludge and solid waste, a pilot scale gasification system was designed and constructed. The complete system consists of three subsystems: batch fed downdraft gasifier, data acquisition, and solid waste shredding and densification.

Batch Fed Downdraft Gasifier

A pilot scale batch fed downdraft gasifier was designed and constructed for the experiments. The design of the gasifier is based on laboratory and pilot scale gasifiers built by the Department of Agricultural Engineering at the University of California, Davis.

As shown in Figure 1, the gasifier is built in three main assemblies, fuel hopper, firebox, and ashpit. The fuel hopper is a double walled cylinder. The inner wall is in the form of a truncated cone to reduce the tendency for fuel bridging. The double wall acts as a condenser to remove water vapor from the fuel before gasification. Condensed vapor is collected in a condensate gutter and drained off after each run. The fuel hopper is mounted on the firebox with quick-release clamps to allow easy inspection after experimental runs.

The firebox is also a double walled cylinder. The inner cylinder is the actual firebox. Air is supplied by four air tubes to the annular space between the walls that acts as an air plenum to distribute air evenly to the six tuyeres (air nozzles), which supply air for partial combustion of the fuel. A choke plate acts as a large orifice, replacing the Venturi section previously used in earlier gasifier designs. The firebox assembly is flange mounted to the ashpit.

Char is collected in the ashpit during an experimental run. A rotating eccentric grate is located in the ashpit immediately below the choke plate. The grate supports the fuel bed, and allows passage of char and gas into the ashpit. Gas is drawn off continuously through a pi on the side of the ashpit.

The choke plates and tuyeres we constructed from Type 304 stainle steel. A temperature resistant allo ASTM Type A515*, was used for t firebox and rotating grate. The remai der of the gasifier was constructed fro Type 1040 mild steel.

The rolled cylindrical sections, inn and outer walls of the firebox, ash and inner and outer walls of the f hopper were fabricated by commerc machine shops. All other cutting, a welding, and assembly were done in t College of Engineering shops. Full siz gasifiers could easily be constructed relatively unsophisticated machi shops since exotic materials or comp machining are not required.

Data Acquisition

The data acquisition subsystem is automated temperature measurem system. Temperatures are measu with Type K thermocouples located shown in Figure 2. A Type T thermocouple is used in the air inlet line and a Type K thermocouple is installed in the gas outlet pipe. Provision is made for three magnetically mounted Type K thermocouples for surface temperature measurements. Thermocouple number, temperature, and elapsed time are printed on the paper tape output of a Digitec Model 1000 Datalogger.

Solid Waste Shredding and Densification

Based on the successful cubing test with the John Deere cubing machine at the University, the Papakube Corporation was contracted to prepare sludge/solid waste cubes. Key features of the Papakube system include an integral shredder, a metering system that maintains optimum moisture content of the newspaper, and a modified John Deere Cuber. The extrusion dies of the machine have been modified with a proprietary coating and finishing treatment that is said to allow the densification of many materials without binding agents.

Experimental Results

In the experimental phase of the project the gasifier was operated at a constant air flow rate but fueled with five different types of fuel: wood chips, almond shells, densified source separated solid waste (two types), and densified mixtures of sludge and solid waste (10, 15, 20, and 25 percent sludge by weight). The characteristics of the fuels, operational data from the test runs, and energy balances for two typical runs (RUNS 11 and 12) are presented and discussed below.

Fuel Characteristics

All fuels were tested for proximate analysis, ultimate analysis, and energy content (Table 1). In general, the gasifier fuels tested were all relatively high in volatile combustible matter (VCM), low in carbon content, and low in energy content as compared with coal, but similar to most woods. Both bulk and individual particle densities of the fuels were also measured (see Table 1). Bulk density as it relates to storage and transportation is a significant parameter, and the bulk density of densified fuels is twice that most natural fuels (e.g., wood chips).

Operational Data

The results of the gasification test series are given in Table 2. All test runs were conducted at the same air flow rate, 0.41 m^3/min (1 atmosphere, 0°C). Thus, the flow rate of fuel through the gasifier, the efficiency, and gas quality are a function of the gasification characteristics of the fuel.

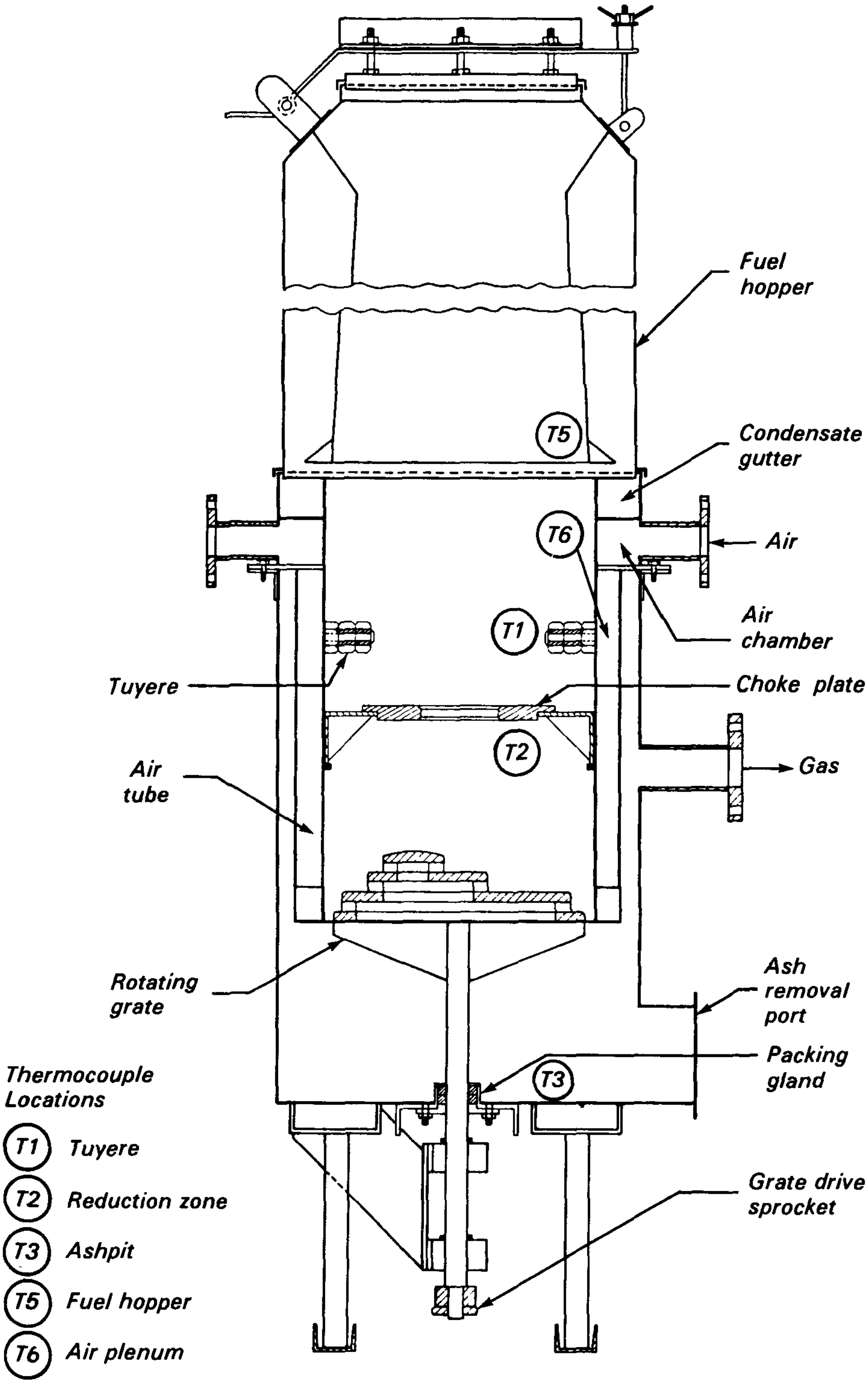

Figure 2. Cross section — UCD sludge/solid waste gasifier.

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

Table 1 *Summary of Fuel Characteristics*

Item	*RUN 11, 20% Sludge Cubes*	*RUN 12, 25% Sludge Cubes*
Proximate analyses		
Volatile combustible matter, %	*74.54*	*73.66*
Fixed carbon, %	*13.05*	*13.70*
Ash, %	*3.07*	*4.08*
Moisture, %	*9.34*	*8.56*
Ultimate analyses (Dry basis)		
C, %	*45.24*	*45.27*
H, %	*5.81*	*5.77*
N, %	*0.13*	*0.42*
S, %	*0.11*	*0.16*
O, %	*46.81*	*44.18*
Residue	*1.90*	*4.20*
Energy content, MJ/kg (Dry basis, HHV)	*18.93*	*18.49*
Densities		
Bulk kg/m^3	*536*	*1010*
Unit, kg/m^3	*486*	*1014*

Table 2. *Operational Summary*

Item	*RUN 11, 20% Sludge Cubes*	*RUN 12, 25% Sludge Cubes*
Fuel consumption rate, kg/hr	*17.5*	*16.3*
Char production rate, kg/hr	*2.47*	*1.71*
Condensate production rate, kg/hr	*0.50*	*0.73*
Net run time, min	*265*	*262*
Gas flare ignition time, min	*24*	*44*
Air input rate, m^3/min (0°C, 1 atm)	*.407*	*.415*
Gas output rate, m^3/min (0°C, 1 atm)	*.749*	*.735*
Average reduction zone temperature, °C	*779.8*	*734.7*
Average gas outlet temperature, °C	*197.6*	*180.6*
Volume reduction, %	*64*	*74*
Weight reduction, %	*82*	*83*

Gas Analyses

Gas samples were collected for analysis in Tedlar gas sampling bags and analyzed off-line with a Leeds and Northrup multicomponent gas analyzer system. Gas moisture content was determined by the condensation method. Dry gas composition, gas moisture content, and gas energy content are summarized in Table 3. The dry gas compositions measured during RUNS 11 and 12 were within the normal range expected for air blown gasifiers.

Energy Balances - RUNS 11 and 12

Energy balances were calculated using computer programs "GASEN," "GASHEAT," and "ENERGY." The output from the programs "GASEN" and "GASHEAT," the fuel and char characteristics, and the operational data from each run are used as input to the program "ENERGY," which, in turn, is used to compute energy balances. Listings of the programs and printouts for each run are attached as Appendixes A, B, and C to the report. A summary of the energy balances is shown in Table 4.

In Table 4, energy balances for each run are given both in energy units (MJ/hr) and percentages, assuming the fuel net energy as 100 percent. Gas chemical energy is the most significant energy output, ranging from 72 to 81 percent of the input energy. Gas sensible heat is relatively minor, contributing only 5 percent to the energy output. The gas sensible heat could probably be increased in insulating the ashpit and gas piping to the flare. A far more significant energy output is the char energy, which ranges from 16 to 25 percent of the input net energy. As char generation is sensitive to fuel residence time and air flow rate, char energy could be minimized by optimizing operation. Condensate energy is very minor varying from 0.9 to 1.4 percent of the input net energy.

Energy losses for most runs ranged from 9 to 49 percent, with 20 percent being typical. Hot and cold gas efficiencies were 40 and 37 percent, respectively, for RUN 08, and 85 and 81 percent, respectively, for RUN 12. Hot gas efficiencies in the upper 60 percent range are typical for the runs.

The negative energy losses shown in Table 4 in RUNS 11 and 12 are likely the result of errors made in determining the amount of char generated during each run. Because of the relatively large storage volume for char in the gasifier above the grate, it was difficult to determine accurately the amount of char generated during a short (2 to 3 hour) run.

Limitations to the Co-gasification Process

Although gasification itself is an old technology, the application of gasification to municipal uses is a relatively new concept. Hardware needed to implement the concept is manufactured by several firms, but the equipment still must be considered to be in the developmental stage. Questions on the environmental effects of gasification still need to be resolved. Finally, the limitation inherent in the prooduction of LEG mus be recognized. The gas should be use onsite, most efficiently in a boiler, a though it can also be used, with a acceptable loss in efficiency, in a ga turbine or internal combustion engine

Conclusions and Recommendations

The technical feasibility of operating fixed bed gasifier with densified sludge solid waste mixtures has been demonstrated. Densified sludge/solid was mixtures were successfully prepared a full scale pilot facility, and a pilot sca downdraft gasifier was designed and constructed.

The gasifier was operated with various fuels including an agricultur waste (almond shells), wood chips, de sified source separated solid waste, an densified mixtures of sludge and source separated solid waste (10, 15, 20, and 25 percent sludge by wet weight). LEG was produced during the tests with an energy content ranging from 4.19 to 6.26 MJ/m^3 at hot gas efficiencies from 40 to 85 percent.

The co-gasification of densified sludge and source separated solid waste may be a new approach to co-disposal that could be used by smaller communities.

Before the co-gasification process can be considered operational, however, several key issues must be addressed in future work:

1. The optimum conditions for gasifier operations in terms of fuel consumption, air flow, gas quality, and efficiency need to be defined. These parameters can be used to develop loading factors and specifications for the design of full scale systems.
2. Conditions causing slagging should be determined. Slag control measures such as steam or water injection, or continuous grate rotation should be investigated.
3. The fate of heavy metals during the gasification process should be determined.
4. Mass emission rates and particle size distributions for particulates in the LEG should be measured to provide data for the design of gas cleaning equipment.
5. Emission data from engines, burners, and boilers fueled with LEG should be measured. Emissions should also be analyzed for potentially toxic compounds.
6. Manufacturers of system components should be identified.

The full report was submitted in fulfillment of Grant No. 805-70-3010 by the University of California at Davis, under the sponsorship of the U.S. Environmental Protection Agency.

Table 3. *Composition and Energy Content of Low Energy Gas*

Item	*RUN 11, 20% Sludge Cubes*	*RUN 12, 25% Sludge Cubes*
Dry gas composition (by volume)		
CO, %	*20.9*	*21.5*
H_2, *%*	*14.5*	*13.7*
CH_4[a], *%*	*2.3*	*2.5*
C_2H_6[a], *%*	*0.1*	*0.1*
CO_2, *%*	*11.9*	*11.0*
O_2, *%*	*0.3*	*0.3*
N_2[b], *%*	*50.0*	*50.9*
Gas moisture content (by volume), %	*14.15*	*12.31*
Gas energy content MJ/M^3 (dry gas, LHV, 0°C, 762 mm Hg)	*5.11*	*5.17*

[a] *Measured as Total Hydrocarbons, (THC),* CH_4 *assumed to be 95% of THC,* C_2H_6 *assumed to be 5% of THC.*

[b] N_2 *includes nitrogen, argon, and trace amounts of nitrogen oxides.* N_2 *is determined by difference,* $N_2 = 100\% - (CO + H_2 + THC + CO_2 + O_2)$.

Table 4. *Energy Balances*

	RUN 11, 20% Sludge Cubes		*RUN 12, 25% Sludge Cubes*	
Item	*MJ/hr*	*%*	*MJ/hr*	*%*
Gross energy, dry fuel	*269.49*		*268.08*	
Latent heat, combined water	*18.48*		*16.26*	
Latent heat, fuel moisture	*4.15*		*4.07*	
Net energy, fuel	*273.86*	*100.00*	*247.75*	*100.00*
Gas chemical energy	*197.15*	*71.99*	*199.93*	*80.70*
Gas sensible heat	*12.37*	*4.52*	*11.03*	*4.45*
Heat loss condenser	*21.16*	*7.73*	*19.27*	*7.78*
Char energy	*69.00*	*25.20*	*41.45*	*16.73*
Condensate energy	*2.38*	*0.87*	*3.33*	*1.34*
Energy losses	*-28.19*	*-10.30*	*-27.25*	*-11.00*
Hot gas efficiency		*76.51*		*85.15*
Cold gas efficiency		*71.99*		*80.70*

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

The complete report, entitled "Co-Gasification of Densified Sludge and Solid Waste in a Downdraft Gasifier," (Order No. PB 82-230 293; Cost: $13.50, subject to change) will be available only from:

National Technical Information Service
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The EPA Project Officer can be contacted at:

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