APPLICATION OF PACKED BED GASIFIERS TO THE REDUCTION OF SOLID WASTES AND THE RECOVERY OF ENERGY

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History of Gasification

Gasification is an energy efficient technique for reducing the volume of solid wastes and the recovery of energy. Essentially, the process involves the partial combustion of a carbonaceous fuel to generate a combustible gas rich in carbon monoxide and hydrogen. The inventor of the process is unknown, but stationary gasifiers were used in England in the early 1800's (Skov and Papworth, 1974). By the early 1900's, gasifier technology had advanced to the point where virtually any type of cellulosic residue such as rice hulls, olive pits, straw, and walnut shells could be gasified. These early gasifiers were used primarily to provide the fuel for stationary gasoline engines.

Portable gasifiers emerged in the early 1900's. They were used for ships, automobiles, trucks, and tractors. The real impetus for the development of the portable gasifier technology was World War II. During the war years, France had over 60,000 charcoal burning, gasifier equipped cars while Sweden had about 75,000 wood burning cars. With the return of relatively cheap and plentiful gasoline and diesel oil, after the end of World War II, gasifier technology was all but forgotten. However, in Sweden research has continued into the use of wood fueled gasifiers for agriculture (Horsfield, 1975), and currently downdraft gasification of peat is being pursued actively in Finland (Jantunen and Asplund, 1979).

In the United States, gasification technology was, until recently, virtually ignored. In the early 1970's, work was started in the U.S. on "pyrolysis" systems for energy recovery from solid wastes. Many of these "pyrolysis" systems are actually complex adaptations of the simple gasification process. For example, the BSP/Envirotech multiple hearth pyrolysis system (Brown and Caldwell, 1977) and the PUROX process (Fisher, et al, 1976) are in reality gasification systems. The reader is referred to Jones, 1978 and Jones, Phillips, et al, 1978 for an in-depth review of current research into pyrolysis and gasification systems.

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Gasification Theory

In the gasification process, six principal reactions occur:

1.	$C + O_2 \rightarrow CO_2$	exothermic
2.	$nC + \frac{n}{2} O_2 \rightarrow nCO$	exothermic
3.	$C + 2\,H_2O \rightarrow CO_2 + 2\,H_2$	endothermic
4.	$C + H_2O \rightarrow CO + H_2$	endothermic
5.	$C + CO_2 \leftrightarrow 2\,CO$	endothermic
6.	$C + 2\,H_2 \leftrightarrow CH_4$	exothermic

The heat to sustain the process is derived from reactions (1) and (2), while the combustible components of the gas are generated by reactions (2) through (6). The actual composition of the gas is dependent upon the temperature of the reactor and the fuel moisture. Typically, the gas contains about 10% $CO2$, 20% CO, 15% $H2$, 2% $CH4$, with the balance being N_2. The energy content of the gas is in the range of 140-160 BTU/scf.

Reactor Types

Four basic reactor types are used in gasification:

1. vertical packed bed
2. multiple hearth
3. rotary kiln
4. fluidized bed

Most of the early gasification work in Europe was with the packed bed type reactors. The other types are favored in current U.S. practice, with the exception of the PUROX oxygen blown gasifier.

The simple vertical packed bed type reactor has a number of advantages over the other types including simplicity and relatively low capital cost. However, it is more sensitive to the mechanical characteristics of the fuel. Eggen and Kraatz, 1974, discussed the merits and limitations of vertical bed gasifiers in detail.

Research at the University of California, Davis has concentrated on co-current flow, packed bed vertical reactors (also called downdraft gasifiers). As shown in Figure I, fuel flow is by gravity with air and fuel moving co-currently through the reactor. At steady state, four zones form in the reactor. In the hearth zone, where air is injected radially into the reactor, exothermic combustion and partial combustion reactions predominate. Heat transfers this zone upward into the fuel mass, causing pyrolysis reactions in the distillati zone and partial drying of the fuel in the drying zone. Actual productio the fuel gas occurs in the reduction zone, where endothermic reactions predominate, forming CO and H . The end products of these reactions are a carbon rich char and the low BTU gas.

Gasification Research at the University of California, Davis

Gasification work started at UCD in 1975. Researchers in the Agricultural Engineering Department designed and built several laboratory and pilot scale downdraft gasifiers for use with agricultural wastes. The gasifiers were operated successfully on a broad range of agricultural and forest industry residues including corn cobs, wood chips, peach and prune pits, and tree trimmings.

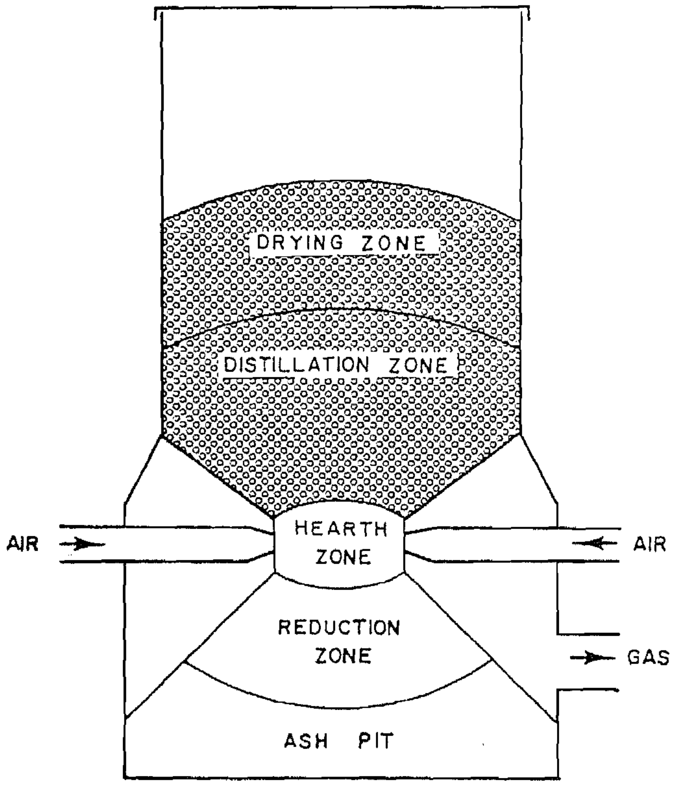

FIGURE I - DOWNDRAFT GASIFICATION

The work is described in detail in Williams, Goss, et al, 1978, and Williams and Horsfield, 1977.

In 1978, a project was started by the Civil Engineering Department at UCD to investigate the application of gasification technology to small communities. The project is co-sponsored by the University of California Appropriate Technology Program and the U.S. Environmental Protection Agency.

Laboratory Scale Solid Waste Gasifier

A 100 lb/hr laboratory scale solid waste gasifier was constructed in 1978 (see Figure II). The unit is batch fed through a hatch on the top of the fuel hopper. The gasifier consists of the reactor shown in Figure II, a ten channel scanning thermocouple system, and a small air blower.

Gasification of Solid Waste

As mentioned earlier, downdraft gasifiers are simpler to construct and operate than the other reactor types, but they have more exacting fuel requirements which include:

1. moisture content < 30%
2. ash content < 5%
3. uniform grain size

Since wastes can be dried prior to gasification, excessive moisture can be overcome. However, ash content and grain size are more difficult to handle. When the ash content is higher than 5%, clinkers tend to form which can cause severe maintenance problems. Excessive fine material in the fuel can cause mechanical bridging in the fuel hopper. One method of overcoming these problems is to use more complex reactors such as the Envirotech Multiple Hearth System or a high temperature slagging gasifier, such as the PUROX process, in which the ash is melted. Although these approaches work, they are costly and complex.

A lower cost approach is to utilize the simplest reactor type, the downdraft gasifier, and tailor the fuel accordingly. This can be accomplished by densifying the paper fraction of source separated solid waste thus producing a densified refuse derived fuel (d-RDF) that has low moisture content, low ash content, and uniform grain size. Many cities already operate source separation systems to recycle newsprint and cardboard. In northern California, such systems are operated by Sacramento County and the cities of Davis, El Cerrito, and Santa Rosa. Collection of a fuel quality paper fraction would be more profitable to a community than existing recycling programs since food wrappers, magazines, paper bags, and other paper waste could be collected in addition to newsprint and cardboard. More importantly, the value of a waste paper fuel would be constant compared to the wildly fluctuating markets for recycled newsprint.

Production of the d-RDF would require a community source separation system, a shredder, and a densification system. In gasification research at the University of California, a hand-fed 5 HP cutter head mill is being used to shred newsprint. Densification of the shredded paper is accomplished with a Cal-Cube agricultural cubing machine. Originally designed to produce animal feeds, the fuel "cubes" produced with this machine are about 3" x 1" x 1" (7.6 cm x 2.5 cm x 2.5 cm). Other d-RDF systems have also used agricultural cubing machines, including the city of Ft. Wayne, Indiana (Hollander and Cunningham, 1972) and Papakube Corporation of San Diego (Waste Age, 1977).

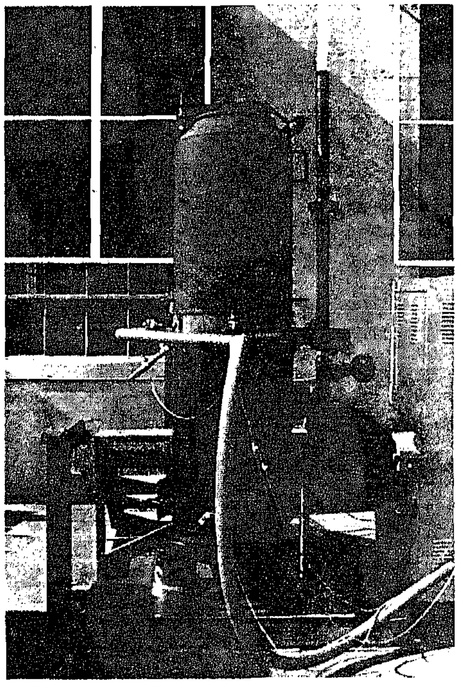

FIGURE II - UCD SOLID WASTE GASIFIER

TABLE I - PRELIMINARY GASIFIER DATA

A. Operations Summary

Run No. 02-78	24 Oct 78
Net Run Time	140 Min
Fuel Consumption	25.4 Kg/Hr (56 Lb/Hr)
Char Production	2.7 Kg/Hr (6 Lb/Hr)
Condensate Production	0.19 Kg/Hr (0.43 Lb/Hr)
Air Input Temperature	33°C
Reduction Zone Temperature	900°C
Gas Outlet Temperature	210°C
Fuel Weight Reduction	89%
Fuel Volume Reduction	89%

B. Fuel Summary

Type	Pine Wood Chips
Moisture Content	9%
Ultimate Analysis*	59% C
	7.2% H
	37% O
	1.1% Ash
Energy Content* (HHV dry basis)	$24,300 \frac{KJ}{Kg}$ $(10,450 \frac{BTU}{LB})$

(*Typical values for pine after Skov and Papworth, 1974)

Operating Data from the UCD Gasifier

The densification portion of the system was being installed and tested during the writing of this paper, thus test results with d-RDF were not available. However, tests have been run with wood chips and other agricultural wastes. A summary of these results is attached as Table I.

Estimated Costs of Gasifying Solid Waste

Since there are no full-scale down draft gasifiers currently operating on solid waste, the estimated costs below are based on projections for agricultural waste gasification (Goss, 1978). The costs shown do not include collection costs for the source separated solid waste or the energy conversion system (diesel-generator or gas turbine-generator).

Gasifier	\$0.90/10^6 BTU
Densification of Fuel	\$0.57/10^6 BTU
Cooling and Cleaning of Gas	\$0.20/10^6 BTU
Energy Losses	\$0.15/10^6 BTU
	\$1.82/10^6 BTU

(Capital and operating costs, mid 1977, includes 10% interest, depreciation over 10 years, 3% maintenance per year, and tax and insurance.)

The above costs compare favorably to diesel fuel at \$3.57/10^6 BTU, gasoline at \$5.00/10^6 BTU, and natural gas at \$2.40/10^6 BTU (mid 1977). In view of the current costs of gasoline and diesel oil, the relative economics of low-BTU gasification are improving. The low-BTU gas from a gasifier system is, of course, not as versatile as the other energy sources since it must be used on-site. The economics of gasification in a municipally operated system are currently being evaluated in the project. A municipal system would have the advantages of tax exemption, lower interest rates, and longer amortization periods. However, the additional costs to collect a fuel quality paper fraction are not known at this time. A municipal system would also gain credit for the extension of landfill life.

Conclusions

Downdraft gasifiers have been operated successfully on a broad range of fuels for over 100 years. Operation of these systems with d-RDF is beneficial both from the viewpoint of energy recovery and the extension of landfill life. Generation of low-BTU gas with source separated solid waste may be a low cost alternative source of energy for small communities.

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