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Gasification of Municipal Solid Waste in a Fluidized Bed Reactor

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GASIFICATION OF MUNICIPAL SOLID WASTE
IN A FLUIDIZED BED REACTOR

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Abstract

Results of pilot plant municipal solid waste gasification studies conducted at the Adolph Coors Company, Golden, Colorado, are presented. The nominal one ton per hour, 150 psig, fluidized bed gasification system was operated during 1973-1974 using steam and air as oxidants and fluidizing media. These studies show the feasibility of a one-stage, air blown, fluid bed MSW conversion system.

1. INTRODUCTION

Technologies for the production and use of Refuse Derived Fuels are emerging as local and state governments grapple with pressing solid waste problems. Conventional landfill operations are being curtailed in many areas of the country because the additional acreage needed to sustain these disposal sites is either unavailable or too expensive. This problem is most intense near large metropolitan areas where municipal and commercial solid wastes are concentrated. New government regulations (federal and state) covering siting, permitting and operation of sanitary landfills are increasing the cost and decreasing the attractiveness of this conventional disposal option. As a result of these and other obstacles, private companies, in concert with government bodies having various jurisdictional responsibilities, are intensifying efforts to develop solid waste processing, recycling, and energy recovery technologies. Studies of this nature were conducted by the Adolph Coors Company during 1973 and 1974 on low-Btu gasification of solid waste. The intent of these studies was to provide an alternative disposal option for the Denver Metropolitan Area, while providing a supplementary fuel source for the Coors companies. Results of pilot plant scale gasification tests will be presented, as well as our concept of a larger scale facility.

2. SOLID WASTE PROCESSING OVERVIEW

2.1 THE SOLID WASTE RESOURCE

Solid wastes potentially represent only a small portion of our nation's raw materials and energy requirements. However, the contributions that can be made through material recycling and energy recovery programs can go a long way toward solving the waste disposal and energy shortage related problems faced by our larger metropolitan areas. It is estimated that the U.S. generates about 136 million tons of mixed municipal and commercial solid wastes each year, which enter the municipal collection and disposal systems. Table 1 shows the various components of this waste stream in tons per year. Based on the approximate breakdown of this stream, shown in Table 1, this represents about 75 million tons per year of organic matter, on a dry basis, with a heating value between 7,000 and 8,500 Btu's per pound. This is comparable to a low rank sub-bituminous coal. Accounting for collection and processing inefficiencies, about 85%, or 65 million tons

Table 1

Annual U.S. Production of Municipal Solid Wastes

Component	Million Tons per Year	Percent of Total
Organics:		
Paper	47.6	35
Yard wastes	21.8	16
Food wastes	20.4	15
Textiles, plastics, rubber, etc.	12.2	9
Total organics	(102.0)	(75)
Inorganics:		
Metal	13.6	10
Glass	13.6	10
Total inorganics	(27.2)	(20)
Miscellaneous	6.8	5
Total U.S. Production	136.0	100

Note: Does not include source separated-internally recycled industrial wastes.

Source: National Center for Resource Recovery, Inc.

per year of this organic fraction, could be available as feedstock to a variety of energy conversion processes after initial recovery of the inorganic metal and glass components. Significant technical and economic obstacles exist to the recovery of this potential energy resource -- obstacles that begin with the initial collection and waste processing operations. The organic or fuel fraction becomes an end product along with aluminum, steel, and glass. While it is possible to collect and recycle certain select components of municipal wastes (magnetic metals, for example) prior to land filling, it becomes an economic necessity to recycle all components to sustain the cost of the final fuel or energy recovery step. In addition, it appears that a total waste processing operation would require additional revenue in the form of a disposal fee such as that paid to landfill operators. Obviously the disposal fee must be less than that paid to the present disposal contractor for the recycling operation to be attractive. The fee would be dependent on the volume of waste to be processed and the option chosen for energy recovery.

2.2 ENERGY CONVERSION OPTIONS

Options currently available for conversion of organic wastes to other useful energy forms on a large scale include direct incineration producing steam for space heating or process uses or co-combustion with coal in conventional power generating systems. Both of these approaches are currently being applied; however, not without problems. Combustion of municipal wastes in conventional coal fired equipment requires modification of the coal storage, conveying, and ash recovery systems. Organic wastes may be burned with coal up to about 20% without exceeding boiler design temperatures. These options, or others under development, are predicated on the availability of the prepared waste feed and the reliable operation of a waste processing facility.

Conversion processes at various stages of development include:

(1) Gasification to low or medium Btu fuel gas.

(2) Pyrolysis to a gas/liquid fuel mix.

(3) Anaerobic digestion.

Of these three, gasification is the more advanced. Several large gasification and pyrolysis plants have been operated with encouraging results. These

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technologies, however, are also predicated on large scale total waste processing and recycling systems. Combustion of fuel gas produced from wastes or coal allows higher pressure boiler operation and higher superheater surface temperatures than incineration, in accordance with utility practice. Combustion of fuel gas can provide 30-40% higher water-tube boiler capacity than direct combustion. Penalties are paid, however, in increases in induced-draft fan capacity and modifications to burners to accommodate low Btu gas at rated boiler output. Gas turbine combined cycle power plants using low Btu gas allow higher overall thermal efficiencies than conventional power plants, while allowing use of up to 100% refuse derived clean fuel.

3. COORS PILOT PLANT

3.1 PLANT DESCRIPTION

A pilot plant was constructed and operated by the Adolph Coors Company in Golden, Colorado, during 1973 and 1974 to develop and test a municipal solid waste gasification process. Nominal capacity of the plant was one ton per hour of prepared municipal waste. Primary pilot plant equipment included:

(1) Fluidized bed reactor.

(2) Screw feeder to handle shredded wastes.

(3) An air compressor.

(4) A gas fired superheater to preheat process air and steam.

(5) A wet product gas scrubber.

(6) A high temperature product gas incinerator.

The scrubber subsystem included an ash settling tank, recirculating pump, and an induced draft heat exchanger to cool recycle scrubber water. The pilot plant process flow is shown in Figure 1.

Feed preparation was accomplished with a hammermill shredder, air classifier, and a pneumatic conveying system for handling the classified organic material. The feed preparation system provided the reactor section of the plant with minus 3-inch light organic components of general packer-truck refuse. The classifier separated the shredded refuse into light and heavy fractions. The heavy fraction was approximately 30% by weight of shredder feed and contained the recyclable materials. The remaining 70% was the classifier organic light fraction which contained about 30% moisture and

5,000 Btu per pound. The air classification tended to dry this organic fraction which was sent forward to gasification.

3.2 GASIFICATION - REACTIONS/EQUILIBRIA

The development of processes for the gasification of solid wastes parallels very closely developments in coal gasification. These two gasification feedstocks are similar in chemical constituents and therefore undergo the same chemical reactions at gasification conditions. The striking differences between these feedstocks are the relative amounts of carbon, hydrogen, and oxygen they contain, and the chemical structures that link them together. The principal reactions in a gasification system are shown in Table 2. The first reactions that take place are those reactions that produce char while the refuse is rapidly heated to reaction temperature upon entering the fluid bed reactor. These endothermic pyrolysis and cracking reactions receive their heats of reaction primarily from the combustion of a portion of the char as shown in reaction (3). The steam-carbon reaction, producing CO and H_2, also requiring a great deal of heat, likewise is sustained by char combustion. The water gas shift and methanation reactions add heat to the system too, but to a lesser extent as dictated by reaction product equilibriums.

The water vapor required for char gasification, reaction (4), is supplied as refuse moisture and as a product of combustion. Moisture content of the system influences the hydrogen-to-carbon ratio, a key factor determining product gas equilibrium concentrations. The empirical formula for refuse, shown also in Table 2, gives a hydrogen-to-carbon ratio of 1.6 on a dry basis. Coal typically has such a ratio of less than 1.0. Because the inherent moisture of the refuse feed is available during gasification, the H/C ratio may be as high as 2.5. Thus, refuse is a more favorable gasification feedstock than coal and may be gasified without steam addition as is necessary in coal systems.

These basic reactions define equilibrium concentrations of the principal products; methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), and hydrogen (H_2). The reaction mechanisms in the refuse gasification system are complex and not well defined. However, of
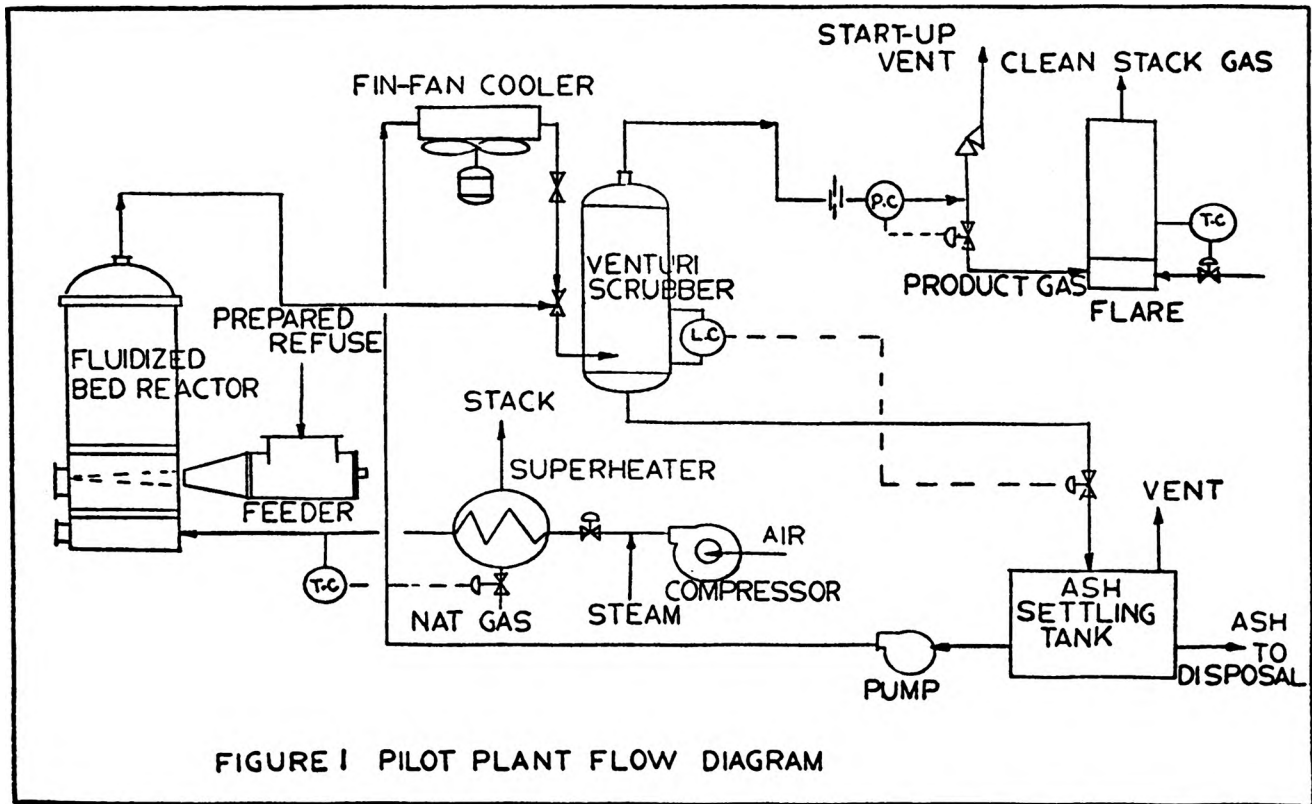
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FIGURE I PILOT PLANT FLOW DIAGRAM

Table 2

Principal Gasification Reactions

		Heat of Reaction @ 291°K ΔH (Kcal/gram mole)	
Pyrolysis (over 850°F):			
Refuse	→ Gas + Liquid + Char (Endothermic)	-	(1)
Pyrolysis liquids	→ Gas + Char + H_2O (Endothermic)	-	(2)
Char Combustion:			
$C + O_2$	→ $CO_2 + H_2O$ (Strongly Exothermic)	-94.4	(3)
Steam Carbon:			
$C + H_2O$	→ $CO + H_2$ (Strongly Endothermic)	+31.3	(4)
Watergas Shift:			
$CO + H_2O$	→ $H_2 + CO_2$ (Exothermic)	-10.1	(5)
Methanation:			
$C + 2H_2$	→ CH_4 (Strongly Exothermic)	-18.1	(6)
An empirical formula for solid wastes:	$C_{30}H_{48}O_{19}N_{0.5}S_{0.05}$ (dry basis)		

more immediate interest than reaction mechanisms are equilibrium gas compositions which are well understood. Factors influencing equilibrium concentrations are primarily temperature and pressure, while the degree to which equilibrium is approached is primarily controlled by residence time at reaction conditions. Temperature increases in the system tend to retard the exothermic water gas shift and methanation reactions while enhancing the endothermic steam-carbon reaction. Thus, a balance is struck in the system between low temperature levels near 800°F favoring methane formation and higher temperatures favoring char conversion. Gasification temperatures between 1200°F and 1400°F are common, giving acceptable reaction rates and gas compositions. Theoretically, increasing system pressure favors methane formation dramatically up to about 20 atmospheres, increasing product gas heating value. However, experimental data by others for refuse systems have shown that system pressure does not affect overall gas composition as significantly as theory might predict. The benefits of pressured systems are found practically to be increased system capacity and compatability with gas-turbine power cycles.

3.3 TEST RESULTS
Experimental refuse gasification runs made at the Coors pilot plant were of two basic types:

(1) Runs using superheated steam to supply the heat of pyrolysis.

(2) Runs using air to supply the heat of pyrolysis by partial combustion of feed material.

In both cases the steam or air served as the fluidizing media for the reactor bed material. During all runs the reactor operated at 1200°F and 10 psig, with a prepared refuse feed rate of about 500 lb/hr. During the steam runs the weight ratio of steam to dry feed was held near 4.5, or a steam rate of 1800 lb/hr. The product gas contained between 220 and 360 Btu/scf, depending on steam temperature. While the gas produced during steam-only runs contained no nitrogen and therefore had a relatively high heat content, this mode of operation appeared to be thermally unfavorable. This led to the decision to investigate air gasification.

During the air runs the nominal weight ratio of air to dry feed was 2.0, or an air rate of 1100 lb/hr at 1000°F. This allowed partial combustion of refuse char to maintain bed temperature at 1200°F. The product gas contained between 80 and 130 Btu/scf, depending on the air-to-feed ratio. As feed moisture increased much over 20%, the air-to-feed ratio increased to maintain thermal balance and reactor temperature. This resulted in lower gas quality.

Table 3 shows typical gas and refuse feed analyses during air runs. Note that the methane concentration of 5.5 volume percent is very close to the equilibrium value that would be predicted for this reaction temperature and pressure. This indicates that the reactor configuration and feed residence time allowed an overall approach to equilibrium for this system.

The thermal efficiency of the process appears to be about 75% based on a heat content of 5,000 Btu/lb for feed refuse, 0.07 mm Btu/hr heat leak, and 1.80 mm Btu/hr in the product gas. The apparent gas yield was 36.0 scf per pound of feed, or feed conversion of 93%.

The primary conclusion of these refuse gasification runs is the generation of the heat of pyrolysis by partial combustion of feed char in a single stage fluid bed reactor afforded by air gasification is more efficient than transferring the heat required to the reactor with superheated steam. The recoverable heat in the product gas is sufficient to preheat the process air to 1000°F. The superheater used to preheat the process air in these tests simulated product gas waste heat recovery. The addition of a recycle product gas stream to the pilot plant flow scheme would allow greater turn-down of preheated air while maintaining proper gas velocities through the reactor bed.

3.4 CONCEPTUAL LARGE-SCALE ENERGY RECOVERY PLANT
Conceptual engineering studies were conducted at Coors in parallel with pilot plant testing to define the general configuration of a large-scale energy from refuse facility. This facility, as envisioned, would utilize the fluid bed gasification process described in conjunction with commercially available material recovery and separation technology. A block diagram of the major

Table 3

Typical Gas and Refuse Feed
Analyses During Air Runs
(Dry Basis)

Product Gas:

CO_2	13.8	vol %
CO	17.9	
CH_4	5.5	
C_2H_4	0.5	
H_2	8.3	
N_2	54.0	(corrected to zero O_2)
	100.0	

Refuse Feed:

Carbon	46.88 Wt %
Hydrogen	7.40
Nitrogen	0.11
Sulfur	0.27
Ash	3.49
Oxygen	41.85
	100.00

components of this facility producing fuel gas sufficient to generate 300 mw of electrical power is shown in Figure 2. Fluidized bed gasification can be easily adapted to both refuse and coal, thus providing a standby fuel which can be used to replace refuse when it is unavailable and for peak loads. Coal can provide primary capacity for larger plants. This system offers several advantages:

(1) Utilizes a wide variety of feed materials, including refuse, coal, or waste organic liquids.

FIGURE 2 INTEGRATED REFUSE ENERGY RECOVERY SYSTEM
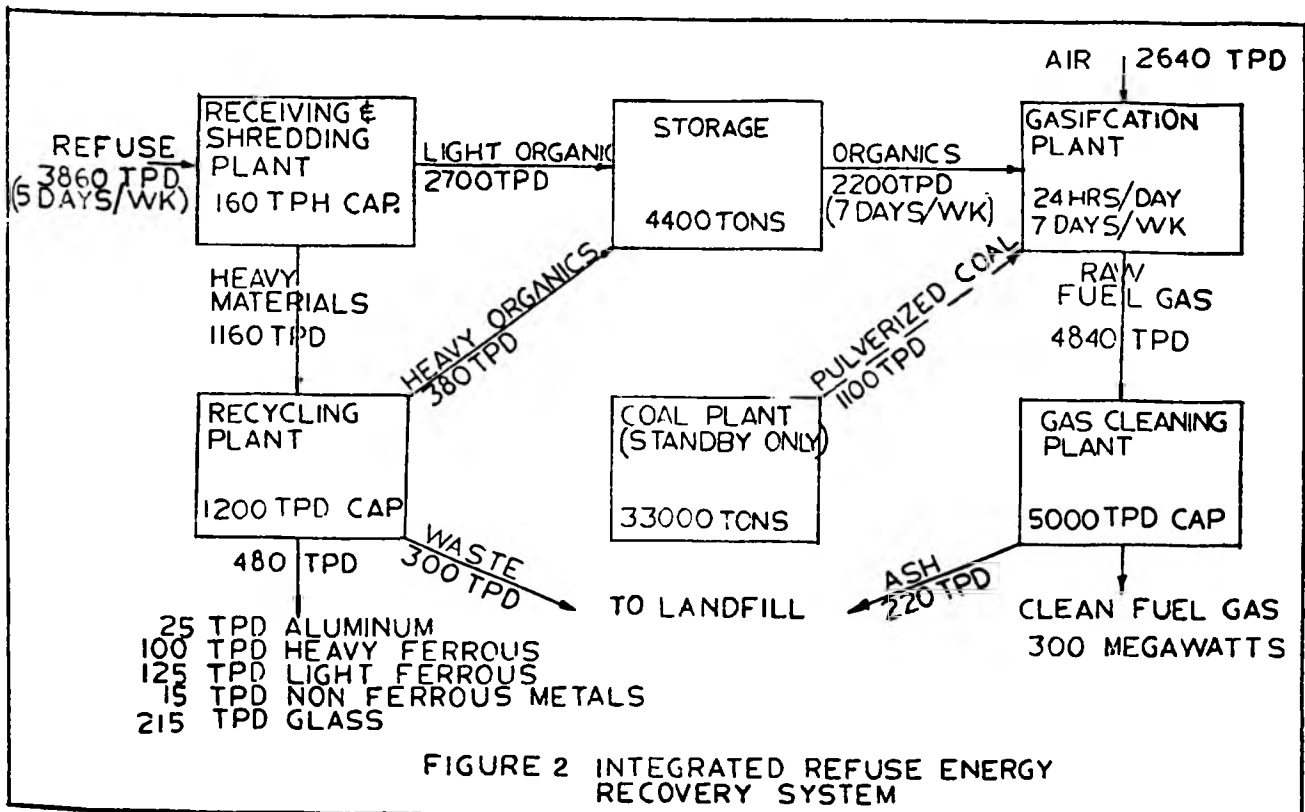
(2) Allows the use of air for gasification heat requirements rather than oxygen;

(3) Catalyst addition to the bed is a possibility to provide higher overall thermal efficiencies.

(4) Limited waste effluents other than a dry sterile ash.

(5) Provides the reliability of modular redundancy and high turn-down.

(6) Allows high pressure gasification for pipelining and combined cycle power applications.

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