

THE USE OF APPROPRIATE TECHNOLOGIES FOR BIOMASS
WASTE CONVERSION IN SMALL COMMUNITIES

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^aFormerly employed by Brown and Caldwell
presently employed by
Santina and Thompson, Inc.
1040 Oak Grove Road
Concord, California 94518

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Brown and Caldwell Consulting Engineers
1501 North Broadway
Walnut Creek, California, USA, 94596

ABSTRACT

This paper will describe several simple, appropriate technologies for biomass waste conversion which can be applied in rural or small community settings. Technologies to be discussed include ethanol production from cannery wastes with a mobile fermentor/still, production of medium-energy fuel gas from animal manures, and production of low-energy fuel gas from agricultural and municipal wastes. Each of the technologies will be briefly discussed below.

Ethanol Production From Wastes

Ethanol can be produced from cannery wastes using conventional fermentation and distillation technology. Cannery wastes such as fruit wastes that contain significant quantities of sugar are the most suitable since sugar ferments directly to ethanol without extensive preprocessing. However, the capital cost of an ethanol production facility may be cost prohibitive in the case of canneries which run on a seasonal basis. The use of a mobile ethanol distillation system allows these costs to be shared among several canneries. This paper discusses pilot testing such a system. The mobile system was installed at a sewage treatment plant near the cannery. The stillage by-product from fermentation was fed to the existing methane digesters at the sewage plant, and the resulting methane used to produce steam for distillation. The benefits of the project included both 190-proof fuel alcohol and a reduction in the disposal costs of the cannery wastes.

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Methane Production From Manure

Medium-energy gas, consisting of methane and carbon dioxide (biogas), can be produced from the anaerobic digestion of animal wastes. The paper will describe a project at a beef feedlot in which a full-size digester was designed to provide biogas to a steam boiler used in the feed processing equipment. The manure is mechanically scraped from the feedlot, slurried with water, and loaded into a 567,750-liter digester tank. Steam injection maintains the digester temperature at 35 degrees C, and the resulting biogas is fired in a steam boiler. The digested slurry then is used as fertilizer for the farmland surrounding the feedlot.

Gasification

Low-energy gas can be produced in relatively low cost gasifiers from a wide variety of biomass waste feedstocks including wood chips, crop residues, and waste paper. While some biomass wastes can be directly gasified, most types require preprocessing, including shredding and densification. The paper will describe experimental results from a pilot-scale gasifier operated on all three types of biomass and discuss the status of commercial-scale gasifiers.

INTRODUCTION

This paper will discuss several appropriate technologies for the conversion of biomass wastes into gaseous and liquid fuels. Technologies discussed include ethanol production from cannery wastes, the generation of medium-energy fuel gas from animal manures, and the production of low-energy fuel gas from agricultural and municipal wastes. The discussion is limited to the conversion of biomass wastes as opposed to the conversion of biomass crops specially grown for energy conversion such as sugar cane.

This paper employs the metric system of units. Table 1 is a summary of conversion factors to United States customary units for those readers more familiar with that system.

Benefits

The production of fuels from waste materials provides two significant benefits. First, the fuel can be sold or used by the producer thereby producing revenue or eliminating the cost of buying other fuel. Second, the cost to dispose of biomass waste is reduced or eliminated. The relative economics of waste conversion are dependent on the value of the fuel, the cost of waste disposal, the cost of financing, the cost of local manufacturing, and local tax laws. Thus, the determination of economic feasibility of a particular project must be made on a country-by-country basis.

Comparison Between Biological and Physical Processes

Biomass waste materials can be converted to useful energy products by either biological or physical processes. Selection of the appropriate process is a complex undertaking with many variables. For this presentation, the variables are grouped into the chemical and physical characteristics of the biomass wastes and the operational characteristics of the conversion process.

For example, wastes with a high moisture content tend to be amenable to biological processes such as anaerobic digestion. Wastes with a low moisture content can best be processed by physical processes such as combustion or gasification. Typical characteristics of such systems are summarized in Table 2.

The three biomass waste processing systems discussed in this paper were selected to match the characteristics of the biomass waste with the processing system. Ethanol production, a biological process, is ideally matched to cannery wastes with a high sugar content. Anaerobic digestion, also a biological process, is an optimum conversion process for cattle feedlot manures. Gasification, a physical process, is well suited to dry agricultural and municipal wastes.

Table 1 Metric Conversion Factors

Multiply the metric unit	By	To obtain the U.S. customary unit
Centimeter (cm)	2.54	Inch (in)
Cubic meter (m ³)	35.3147	Cubic foot (ft ³)
Degrees Celsius (C)	1.8C + 32	Degrees Fahrenheit (F)
Dollars (U.S.) per megagram (\$/Mg)	0.9072	Dollars (U.S.) per ton (\$/ton)
Hectare (ha)	2.471	Acres (ac)
Kilogram (kg)	2.2046	Pound (lb)
Kilometer (km)	0.6214	Mile (mi)
Kilopascal (kPa)	0.1450	Pound force per square inch (lb/in ²)
Liter (L)	0.2642	Gallon (gal)
Liters per megagram (L/Mg)	0.2397	Gallons/ton (gal/ton)
Megagram (Mg) or metric ton (tonne)	1.1023	Ton
Megajoule (MJ)	947.8	British thermal unit (Btu)
Megajoule per cubic meter (MJ/m ³)	26.839	British thermal unit/cu ft (Btu/cf)
Megajoule per kilogram (MJ/kg)	429.9	British thermal unit/lb (Btu/lb)
Meter (m)	3.2808	Foot (ft)

Table 2 Characteristics of Biological and Thermal Biomass Conversion Systems

Parameter	Type of system	
	Biological	Thermal
Residence time	Long (3 to 60 days)	Short (10 seconds to 1 hour)
Start-up time	Long (9 to 180 days)	Short (20 minutes to 1 hour)
Operational temperature	Low (20 to 35 degrees C)	High (300 to 1,100 degrees C)
Operational complexity	Moderate	Low to high
Potential for automation	Moderate	Very high
Preferred feedstock	Nutritionally balanced, wet slurry	Dry
Residue	Biologically active, wet slurry	Dry, sterile ash or char

ETHANOL PRODUCTION FROM CANNERY WASTES

Each year about 14,515 megagrams (Mg)^a of solid waste are produced by two major fruit canneries in Sunnyvale, California (near San Francisco). The wastes consist of fruit peelings and cull fruit. Currently, this waste is trucked to a sanitary landfill 64 kilometers (km) away at a cost of \$10.03/Mg.

The wastes have a high sugar content and would be ideal feedstock for ethanol fermentation. However, due to the relatively short canning season, 3 to 4 months, installation of a conventional fermentor and still is not cost-effective.

As an alternative to a permanent fermentor installation, a mobile ethanol fermentation and distillation system was tested during the 1981 canning season. The mobile ethanol facility was temporarily installed at the City of Sunnyvale Sewage Treatment Plant, about 3.2 km from the fruit canneries. This location has the further advantage that stillage wastes produced during ethanol distillation can be disposed of into the sewage treatment plant's sludge digesters, enhancing existing biogas production. This extra biogas can be burned in a portable boiler, producing steam for ethanol distillation.

System Description

The mobile system consists of three major groups of equipment: front-end processing, a fermentor, and the distillation columns. Figure 1 is a schematic diagram of the system.

Front-End Processing. Wastes from the canneries are first unloaded into two open-top fiberglass tanks, of about 9,463 liters (L) capacity each. Propeller mixers installed in the tanks prevent fruit solids from settling out. A submersible, chopper-type pump is also used to macerate the wastes. Finally, a food processing finisher is used to further process the wastes. Output from the finisher is a thin slurry about the consistency of tomato juice or apricot nectar.

Fermentor. The fermentor is a 24,603-L closed circular fiberglass tank. Fermentation is a biological process in which the canning wastes are converted into ethanol (dissolved in water) and carbon dioxide. A recirculating pump installed in the fermentor prevents solids from settling out.

Distillation. The distillation unit is a trailer-mounted portable unit. It consists of two stainless steel distillation

^a1 Mg equals 1 metric ton equals 1,000 kg.

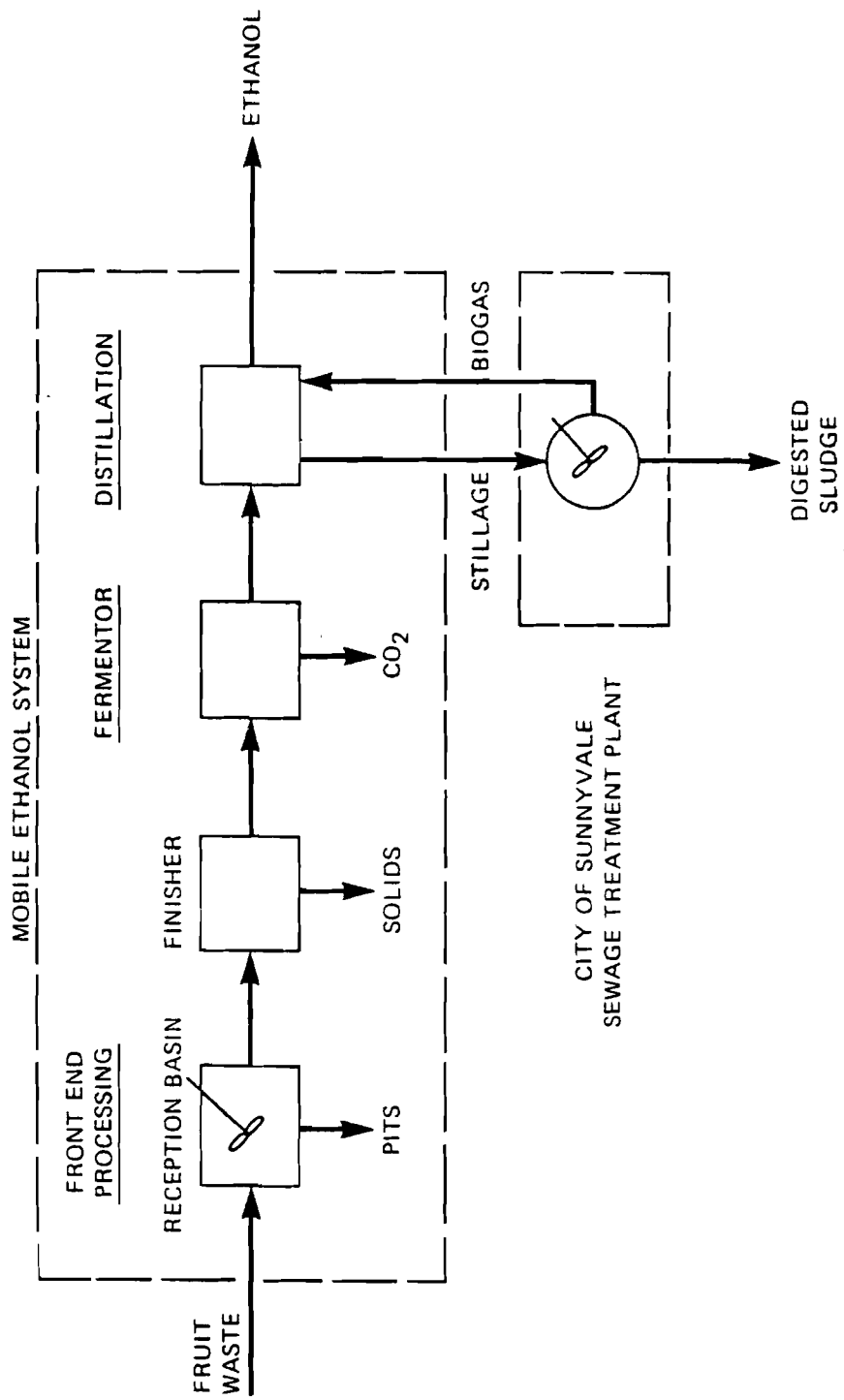


Figure 1 Schematic Diagram - Mobile Ethanol System

columns, a dual fuel boiler (natural gas/biogas), a tube-in-shell condensor, recirculating pumps, electrical controls, and flow meters.

Experimental Results

The mobile ethanol system was installed on August 12, 1981. A total of 11 truckloads of fruit canning wastes were processed between August 22 and October 5, 1981. Experimental results for the tests are summarized below.

Ethanol Production. Table 3 summarizes production data on the 11 batches of fruit wastes processed. Some of the earlier batches in the test series did not produce ethanol due to equipment problems and unsuitable characteristics of the fruit waste. For the batches which produced ethanol, a total of 1,215 L were produced from 88,569 L of fruit waste. Ethanol yield on a volume basis was 1.32 percent, or 15.6 L/Mg.

Materials Flow. Table 4 summarizes mass balance data for batches 6 and 7. From Table 4, it can be seen that yeast is added at the rate of 1.36 kilograms (kg) per 16,654 L batch of fruit waste. Total fermentation time is about 48 hours. In the present experimental pilot system, individual process steps are not well matched. For example, the front-end processor can handle 5,299 L/hour of raw waste, while the fermentor can only process 314 L/hour (15,140 L of slurry for 48 hours) and the still, 2,650 to 3,028 L/hour over a 6-hour period. In a commercial system, these flow rates would be balanced.

Energy Balance. Table 5 compares energy consumption in the process with the energy content of ethanol produced. Note that the key to a self-sustaining process is methane production from the stillage. (Methane output was estimated from bench-scale laboratory tests.) Total energy output of the system would be 12,009 megajoules (MJ) (5,088 MJ for the ethanol and 6,921 MJ for methane). Thus, the energy output to input ratio for the system is 1.71.

Conclusions

Based on the pilot-scale test program conducted during the 1981 canning season, the following conclusions were drawn:

1. Ethanol production (180 proof) will be 1.3 percent by volume or 15.6 L/Mg of fruit waste processed.
2. The limiting factors for processing fruit waste include fermentation time and the capabilities of the front-end system.

Table 3 Summary of Ethanol Production

Parameter	Cannery waste batch numbers										
	1	2	3	4	5	6 ^a	7 ^a	8	9	10	11
<u>Cannery waste</u>											
Liters	12,870	17,030	12,870	12,870	12,870	8,330	8,330	19,310	17,030	12,870	15,140
Megagrams	12.7	16.3	12.7	12.7	12.7	8.2	8.2	16.3	16.3	12.7	14.5
Percent sugar	-	-	8	5	5	4.5	4	8.9	5.5	8.2	4.8
<u>Fermented slurry</u>											
Liters	-	-	-	11,360	-	9,460	5,110	17,030	9,650	16,280 ^b	12,110
Megagrams	-	-	-	11.3	-	9.1	5.0	16.3	16.3	15.4	11.8
<u>Alcohol distilled</u>											
Liters	-	-	-	151	-	144	106	250	151 ^c	197	216
Proof	-	-	-	180	-	165	172	188	180 ^c	180 ^c	180 ^c

^aBatches 6 and 7 were combined in the fermentation tank, and this mixture was then distilled in two batches.

^bBatch number 10 showed more fermentation slurry than cannery waste. This was because some of the slurry from batch number 9 was left in the fermentation tank when batch 10 was added.

^cEstimate.

Table 4 Mass Balance: Batches 6 and 7

Parameter	Mass, kilograms					
	Front-end processing		Fermentation		Distillation	
	Input	Output	Input	Output	Input	Output
Cannery waste	16,103	-	-	-	-	-
Yeast	1.4	-	-	-	-	-
Nutrient	0.6	-	-	-	-	-
Screened solids	-	1,681	-	-	-	-
Thin slurry	-	14,424	14,424	-	-	-
Carbon dioxide, CO ₂	-	-	-	227	-	-
Fermented slurry	-	-	-	14,197	14,197	-
Steam	-	-	-	-	2,268	-
Ethanol, C ₂ H ₅ OH, 168 proof	-	-	-	-	-	207
Stillage	-	-	-	-	-	16,258

Table 5 Energy Consumption and Production: Batches 6 and 7

Item	Energy flow in MJ	
	Consumption (input)	Production (output)
<u>Front-end processing</u>		
Flygt submersible pump (5 hp at 3 hours)	15.8	-
Finisher (5 hp at 1 1/3 hours)	7.4	-
Marlow centrifugal pump (7 1/2 hp at 24 hours)	31.7	-
<u>Fermentation</u>		
Marlow centrifugal pump (7 1/2 hp at 24 hours)	569.7	-
<u>Distillation</u>		
All of distillation motors (4 hp at 4 hours)	53.8	-
Natural gas (1,266 MJ/hr, at 5 hours)	6,330	-
Stillage pump (7.5 hp at 1 hour)	24.3	-
<u>Ethanol production</u>		
(250 L at 20.35 MJ/L)	-	5,088
<u>Methane production from stillage</u>		
(assuming methane content of biogas at 68 percent)	-	6,921
Total	7,033	12,009

3. A positive energy balance results only from a dual fuel production system which combines fermentation and distillation to produce ethanol and anaerobic digestion of stillage to produce methane gas.

METHANE PRODUCTION FROM CATTLE MANURE

In the United States and many other countries, beef cattle are fattened for market on cattle feedlots. In a typical feedlot, feeder cattle weighing 340 kg are fed for approximately 150 days to increase their weight to 500 kg. This results in the production of large quantities of manure, typically 26 kg per head per day. Management of the manure is a major problem for feedlots, especially those with limited land available for surface spreading.

As an alternative to conventional disposal techniques, feedlot manure can be anaerobically digested to produce biogas. Brown and Caldwell has recently designed such a system for Fat City Feedlots, Incorporated, which operates a 30,000-head feedlot located in Gonzales, California. The cattle produce an estimated 80,000 kg of manure each day. This manure is currently routed to a waste lagoon. Most of the manure is ultimately sold as soil amendment. The cattle are primarily fed steam-flaked corn. This requires 72,600 MJ/day of natural gas for the steam-flaking process. The anaerobic digester will utilize the manure and produce biogas as a substitute for the natural gas currently used in the steam-flaking process.

Process Description

Anaerobic digestion is a biological treatment process which has been used for decades for the treatment of sludges from wastewater treatment plants for the purpose of sludge stabilization and the reduction of pathogenic bacteria. Biogas (typically 60 percent methane and 40 percent carbon dioxide), is produced as a by-product.

The digester system comprises four subsystems which include manure collection and slurry mixing, the digester feed system, the digester, and the effluent management. These areas are described below. A schematic diagram of the system is shown as Figure 2. Design parameters of the system are summarized in Table 6.

Manure Collection and Slurry Mixing. Manure will be collected from the concrete apron of the cattle pens using a

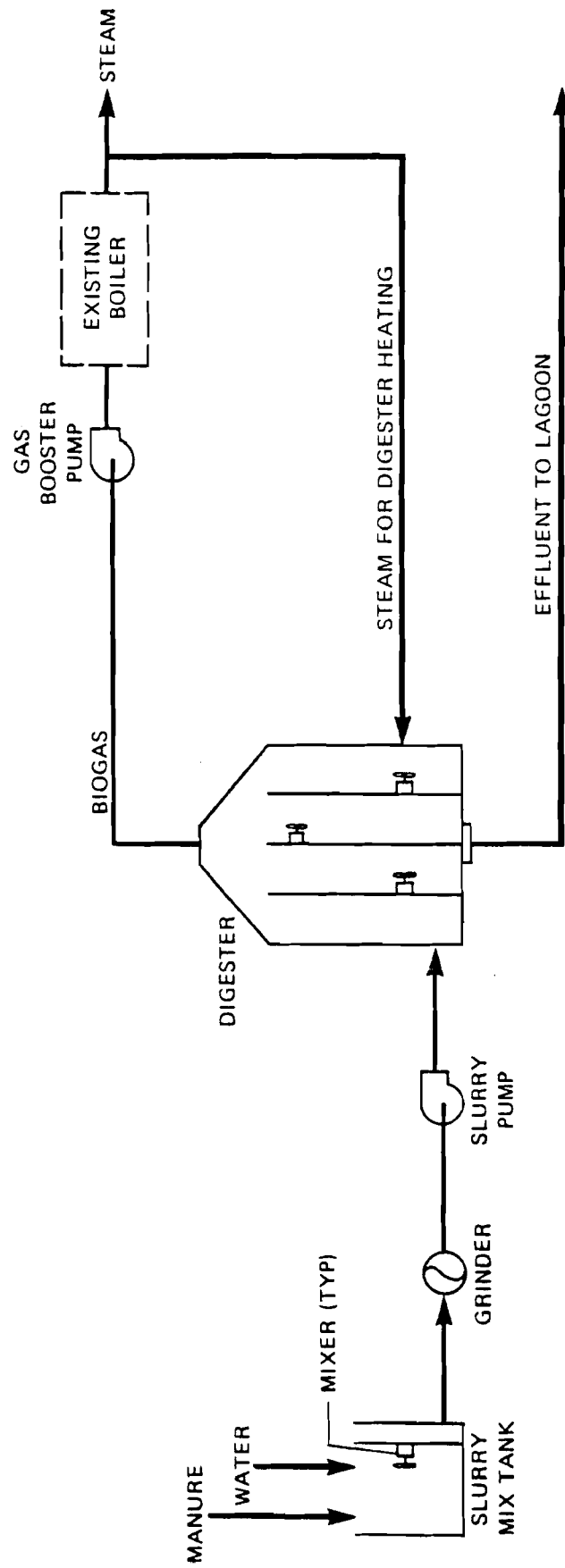


Figure 2 Schematic Diagram – Fat City Digester

**Table 6 Design Parameters for Fat City
Feedlot Manure Digesters**

Parameter	Value
Manure capacity	6,800 to 11,300 kg/day
Biogas output	1,020 m ³ /day
Biogas energy output	22,800 MJ/day
Digester volume	567,750 liters
Diameter by height	9.4 m x 8.5 m
Residence time	10 days

self-loading scraper which will transport the material to a concrete pad located at the slurry mixing tank. A front-end loader will load the manure into the mixing tank. This tank is sized to store the amount of slurry produced in 1 day. About 6,800 to 11,300 kg of manure will be added to the mixing tank once a day and diluted to a 10 percent slurry with water. A submersible mixer will be used to blend the manure and water into a consistent slurry.

Digester Feed Subsystem. The digestion process will operate continuously. The digester feed system will consist of a rotary lobe pump for feeding the slurry into the digester and a grinder located directly upstream of the pump to provide size reduction of large solids in the slurry.

Digester Design and Operation. The digester will be a 9.4-meter (m) diameter, 8.5-m sidewall depth standard size, glass lined, bolted steel tank with concrete foundation and floor and a capacity of 567,750 L. The tank will be manufactured and installed by A. O. Smith Harvestore, Incorporated. The digester walls and cover will be insulated to reduce heat losses to the environment. Modifications to the tank will include two additional manways and two pipe sleeves in the steel cover, plus sidewall pipe sleeves for the slurry feed pipeline, the direct steam injection pipeline, and the overflow pipeline. Digester mixing will be provided by three submersible mixers to ensure that heat introduced into the digester in the form of steam will be uniformly distributed throughout the tank. The mixers will be lowered into the digester through three manways in the cover located 120 degrees apart. A guide rail for each will extend to the bottom of the tank, providing flexibility for initially experimenting with the depth of each mixer to obtain optimum tank mixing. The two mixers at the bottom will serve to keep solids from settling out at the tank bottom (particularly at the periphery) and will direct the contents toward the center of the tank where the slurry feed and steam are injected. In addition to improving heat circulation, these mixers will help to promote increased contact between the new food source (slurry feed) and the microorganisms in the tank. The mixer near the top will break up scum as well as promote good mixing.

Effluent Management Subsystem. The digester overflow subsystem will consist of an overflow hopper inside the digester and overflow piping through the sidewall to a surge tank located outside the digester. The tank will drain into an agricultural spreader mounted on a flat-bed truck. The spreader is sized to provide 8 hours of effluent storage. The slurry will be spread onto nearby fields or manure piles three times a day.

Biogas Management System

For the Fat City Feedlot, it was determined that direct utilization of the biogas in existing boilers was the best use of the gas. These boilers provide steam for the steam flaking of cattle feed. A gas management system consisting of boiler modifications, digester heating, and gas transport was designed to utilize the gas. These subsystems are described below.

Boiler Modification/Operation. Gas production for one digester will average 1,020 cubic meters per day (m^3/day) of biogas, containing approximately 610 m^3/day of methane. This represents about 22,800 MJ/day, while the average annual daily feedmill fuel demand equals 72,600 MJ/day. Thus, gas production from one digester will yield approximately 31 percent of the process fuel demand, the remaining 69 percent to be provided by natural gas. After an in-depth study of the existing boiler, it was concluded that only one of the existing boilers should be modified to accept digester gas. In order to burn digester gas, a new forced-draft burner will replace the existing natural gas induced draft burner which does not provide adequate air control for burning biogas, which has a lower energy content.

Digester Heating--Direct Steam Injection. A study was performed to determine whether it would be more cost-effective to heat the digester using an economizer to recover waste heat from the boiler stack or to use direct steam injection utilizing steam from the boiler. It was discovered that direct steam injection is substantially more cost-effective due to boiler exhaust stack temperatures, which were lower than expected.

An insulated, black, steel steam header will be connected to the existing steam manifold for transporting steam to the digester. The manifold will be sized to provide for future digester heating requirements. Steam will be injected at a point near the bottom center of the digester in close proximity to the slurry feed injection point. A manual steam modulating valve will be periodically throttled by operating personnel to maintain the digester design temperature of 35 degrees C.

Gas Transport System. Because the fuel train of the existing natural gas fired boilers was designed for 2 kPa pressure, a gas booster pump was included to increase biogas pressure to this value. A gas flowmeter was also included in the design to monitor gas production. Automatic controls on the boiler will add natural gas to supplement biogas if required to meet the steam demand.

Installed Costs

Total installed cost for the system in January 1982 was estimated at \$273,500. This is a firm price, based on final design drawings and bidder quotes on equipment. It should be noted that this cost includes elements which are particular to the Fat City Feedlot. These particular elements include:

1. Site road development
2. Burner modifications
3. Piping to existing boilers
4. Effluent spreader tank

If these elements were deleted, and if the digester construction was managed by the owner himself, (saving the overhead and profit of a general contractor), the installed cost would be reduced to about \$222,700. These costs are summarized in Table 7.

It should be noted that the digester was designed for the construction environment of the United States. Extensive use was made of prefabricated components to minimize construction labor costs. In other countries, it may be more cost-effective to utilize field erected tanks and locally procured materials.

Conclusions

The design of a full-scale anaerobic digester for cattle manure has been described. The digester system will process 6,800 to 11,300 kg of manure per day, producing 1,020 m³ of biogas per day. Total installed cost of the system is \$222,700. In countries with lower labor rates, these costs could be substantially lower.

GASIFICATION

Gasification is a physical process in which solid fuels such as biomass (any material derived from growing organisms) and coal are converted into gaseous fuels. This section will discuss several types of gasifiers and how they can be used for the conversion of biomass wastes into useful fuels. This discussion is limited to a technical review of gasification and a brief description of pilot-scale and commercial systems.

Table 7 Installed Costs for 567,750-Liter Manure Digester^a

Discipline	Cost, United States dollars		
	Materials	Labor	Total
Civil	6,900	7,800	14,700
Mechanical	112,100	9,300	121,400
Structural	2,500	1,500	4,000
Valves and piping	9,200	9,300	18,500
Electrical	21,100	8,000	29,100
Subtotal	151,800	35,900	187,700
Engineering design	-	35,000	35,000
Total	-	-	222,700

^aCosts based on Final Design for Fat City Feedlot completed in January 1982.

Overview

The gasification process involves the partial combustion of a carbonaceous solid fuel to generate a combustible fuel gas containing carbon monoxide and hydrogen. The historical development, the basic theory of operation, and the types of reactors used in the gasification process are discussed briefly below.

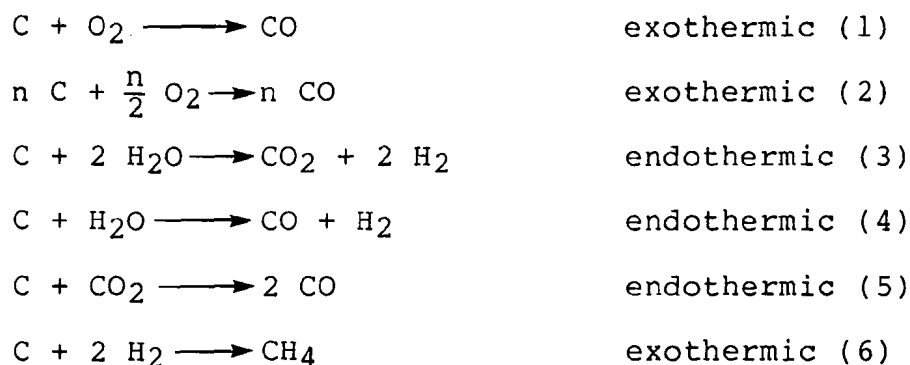
Definition. Gasification can be defined as the thermal processing of waste where a fraction of the stoichiometric oxygen required by the waste is admitted directly into the fuel bed to liberate the heat required for the endothermic gasification reactions. The volatile portion of incoming waste is pyrolyzed by the heat of the fuel gases, and the outlet gas composition reflects both processes.

Historical Development. Gasifiers have been used since the 19th century. The first coal gasifiers were built by Bischof in Germany, 1839; Ebelman in France, 1840; and Ekman in Sweden, 1845. This was followed by the Siemens brothers in Germany, 1861. The Siemens' gasifiers were used primarily to fuel heavy industrial furnaces. The development of gas cooling and cleaning equipment by Dowson in England, 1881, extended the use of gasifiers to small furnaces and gas engines.

By the early 1900s, 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. During World War II, France had over 60,000 charcoal burning cars while Sweden had about 75,000 wood burning gasifier equipped cars. With the return of relatively cheap and plentiful gasoline and diesel oil after the end of World War II, gasifier use and research decreased to a few locations in Northern Europe.

In the United States, gasification technology got little attention until fuel prices increased in the early 1970s. Pyrolysis systems for energy recovery from solid wastes were popular because of the potential benefit of both a fuel and waste disposal. The pyrolysis systems for energy recovery from solid wastes are complex adaptations of the simple gasification process. Both the PUROX system¹ and the Envirotech multiple-hearth pyrolysis system² are gasification systems which were aggressively developed during this period.

Gasification Theory. A gasifier is basically an incinerator operating under reducing conditions. During the gasification process, six principal reactions occur:



The heat to sustain the process is derived from the exothermic reactions while the combustible components of the low energy gas are primarily generated by the endothermic reactions. Although the reactions kinetics of the gasification process are quite complex, the actual operation of air blown gasifiers is straightforward. An in-depth discussion of gasification theory and reaction kinetics may be found in References 3, 4, and 5.

Reactor Types. Five basic types of reactors are used in gasification. They are (1) downdraft fixed bed, (2) updraft fixed bed, (3) multiple hearth, (4) rotary kiln, and (5) fluidized bed. Most of the early gasification work in Europe was with the fixed bed reactors. The other types are favored in current United States practice, with the exception of the PUROX oxygen blown gasifier (an updraft reactor). The fixed bed reactors (both updraft and downdraft) have a number of advantages over the other types including simplicity and relatively low capital cost. However, they are more sensitive to the mechanical characteristics of the fuel.

The downdraft fixed bed reactor is the best reactor type for producing a relatively tar free gas suitable for operating engines. In the downdraft gasifier, fuel flow is by gravity with air and fuel moving cocurrently through the reactor (see Figure 3). 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 from this zone upward into the fuel mass, causing pyrolysis reactions in the distillation zone and partial drying of the fuel in the drying zone. Actual production of the fuel gas occurs in the reduction zone, where endothermic reactions predominate, forming CO and H₂ and small amounts of methane. The end products of the process are a carbon rich char and the low energy gas.

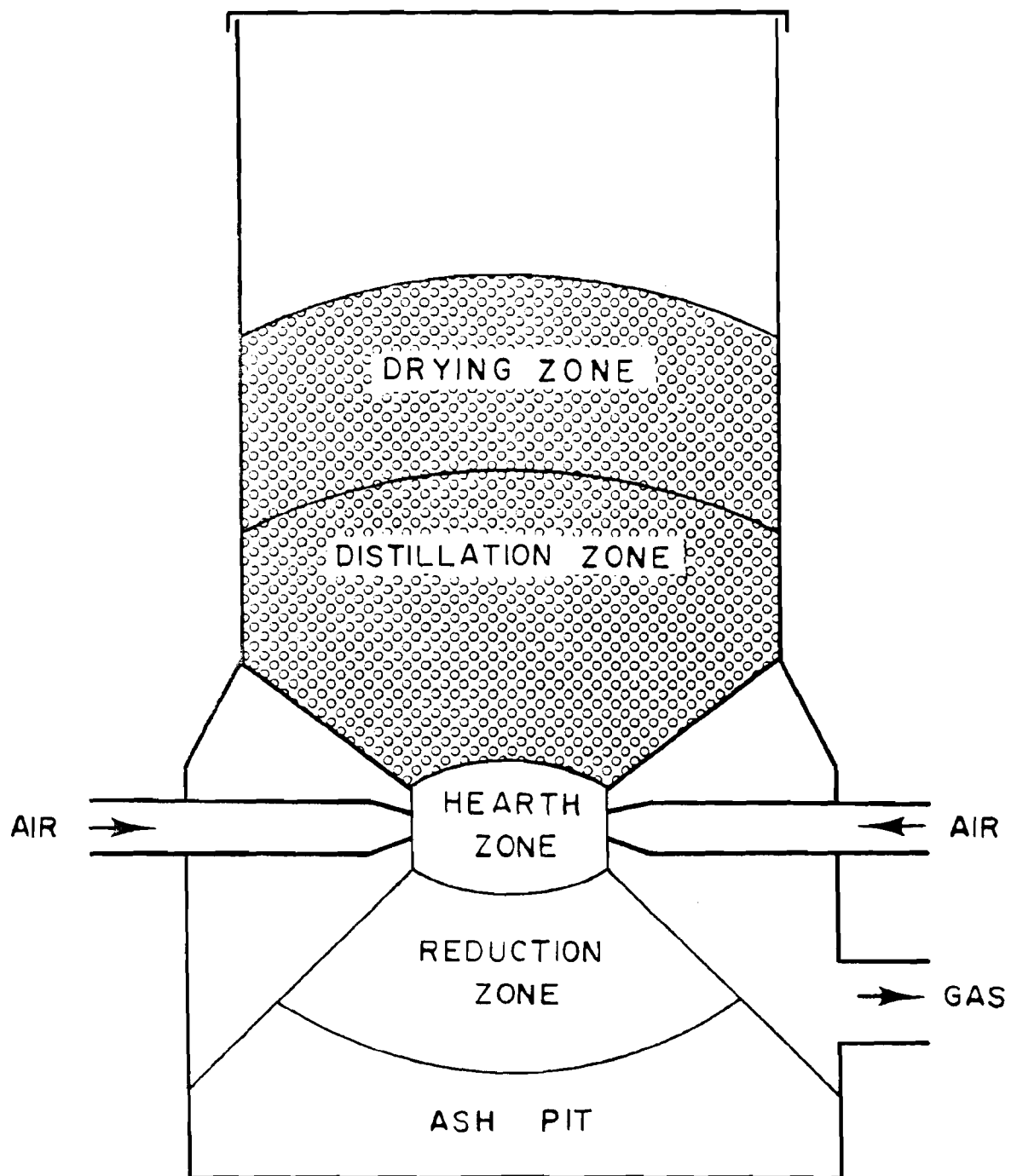


Figure 3 Schematic Diagram - Downdraft Fixed Bed Gasifier

The updraft fixed bed gasifier operates in a similar fashion except that the air flow is upward through the fuel bed, with gas extraction at the top of the reactor. This essentially reverses the order of the reaction zones shown on Figure 3. Updraft fixed bed gasifiers tend to be lower in cost than downdraft gasifiers, but produce a gas with more tars (condensable hydrocarbons). Thus updraft fixed bed gasifiers are typically used to fuel boilers, an application where tars in the gas are not critical. Rotary kiln, multiple hearth, and fluidized bed gasifiers also operate in the updraft mode.

Gas Composition. When a gasifier is operated at atmospheric pressure with air as the oxidant, the principal end products of the gasification process are a low energy gas (LEG) typically containing (by volume) 10 percent CO_2 , 20 percent CO , 15 percent H_2 , 2 percent CH_4 , with the balance being N_2 . A carbon rich char is also produced. Due to the diluting effect of the nitrogen in the input air, the LEG has an energy content in the range of 5.2 to 6.0 MJ/m^3 . When pure oxygen is used as the oxidant, a medium energy gas (MEG), with an energy content in the range of 12.9 to 13.8 MJ/m^3 , is produced.¹ Because of their complexity and high capital cost, oxygen blown gasifiers have not yet been applied commercially.

The low-energy gas from a downdraft gasifier can be utilized in several ways. The simplest technique is to burn the gas with stoichiometric amounts of air in a standard boiler designed for natural gas. This requires minor modifications to the burner head to allow for more combustion air and enlargement of the gas feed pipes to account for the lower energy content of the gas (about 5.6 MJ/m^3) as compared to natural gas (about 37.3 MJ/m^3). Another approach is to cool and filter the gas and utilize it as an alternative fuel for internal combustion engines. Reference 6 describes the operation of gasoline engine powered trucks, buses, and agricultural equipment in Europe with gas produced using portable wood fueled gasifiers. Gasifiers can also be used to operate diesel engines.^{7,8}

Fuel Specifications. Fixed bed gasifiers have stringent fuel requirements including low moisture content (preferably below 30 percent), low ash content (less than 10 percent), and a uniform size distribution. Wood chips, charcoal, coal, and certain agricultural residues (i.e., olive pits, peach pits) can be used "as is" without further processing. Other biomass materials such as tree prunings and straw may require densification into pellets or cubes prior to utilization.

Present Applications

Gasification is an emerging technology. Although units are available from several manufacturers, gasification must be

considered to be in the developmental stages. This section describes several existing experimental and commercial scale gasifier systems.

Experimental Systems. Researchers at the Agricultural Engineering Department of the University of California, Davis Campus, have demonstrated that downdraft fixed bed gasifiers can gasify a wide variety of biomass waste materials.^{9,10,11} They successfully gasified many common agricultural wastes including wood chips, almond shells, walnut shells, and tree prunings, and operated spark ignition and diesel engines with low energy gas.

Another group at the Civil Engineering Department of the University of California, Davis Campus, demonstrated the gasification of densified waste paper and densified waste paper and sewage sludge.^{12,13,14,15} This technology could be applied to small communities as an alternative to conventional solid waste disposal practices.

Existing Commercial Scale Gasifiers. Two full-size gasifier systems are now in operation in North America. The first unit is an updraft fixed bed unit installed at a hospital in Rome, Georgia. The gasifier was designed and built by the Applied Engineering Company of Orangeburg, South Carolina. The gasifier produces an estimated 20,000 MJ/hr of low energy gas from 1,620 kg/hr of wood chips purchased from local lumber mills. The gas is burned onsite in existing boilers.

A somewhat larger fluidized bed gasifier has been installed at a plywood mill in Hearst, Ontario, Canada. The unit was constructed by Omnifuel Gasification Systems Limited of Toronto, Canada. The unit produces 81,240 MJ/hr of low energy gas from 5,900 kg/hr of wood waste. The gas is used on site for plywood and veneer drying. The Hearst, Ontario gasifier system is an ideal application because it combines waste disposal savings as well as natural gas savings.

Future Commercial Scale Installations

Three full-scale gasifiers are known to be under construction in the United States. The first will be a fluidized bed gasifier for the State of California in Sacramento, California. The system will produce low energy gas for combustion in a central steam plant which heats several downtown Sacramento buildings. The unit will be fueled with wood chips and shredded municipal garden wastes. Brown and Caldwell designed the shedding system for this gasification project.

The second gasifier will be an updraft fixed bed unit for Florida Power Corporation in Clearwater, Florida. The unit will apparently be similar to the Rome, Georgia gasifier. The system will be fueled with wood chips and provide low energy gas to an existing fuel oil fired electric generating station.

The third gasifier is a downdraft fixed bed system being built for Southern California Edison Company and WCS Incorporated at Highgrove, California. The system will be fueled with wood wastes collected by WCS Incorporated as part of their existing solid waste collection business. The system consists of two 1.5 m diameter gasifiers in parallel with a combined output of 18,900 MJ/hr of low energy gas. The gas will be scrubbed, cooled, and fed to an adjacent Southern California Edison 40 MW steam/electric power station. The low energy gas will produce an estimated 1.8 MW of the total plant output. Startup of the gasifier system is scheduled for September 1982.

Recommendations for Future Gasifier Applications

Operation of several commercial scale gasifiers in North America is a reality. All of these gasifiers will generate low-energy gas for firing of boilers. Although operation of gasifiers for use with internal combustion engines was widely practiced during World War II, reliable, commercial scale operation of such systems has not been demonstrated today.

Gasifiers can be effectively used if low cost sources of suitable fuel can be found. Since biomass wastes have a relatively low density in the as-discarded state, hauling them great distances is not economical.

The Hearst, Ontario and Southern California Edison gasifiers are examples of ideal applications because they have "free" fuel. Sites such as these with access to wood wastes or suitable agricultural wastes are good candidates for gasifier systems.

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