EPRI-AP--2567

DE82 905493

Technical Evaluation of Wood Gasification

AP-2567
Research Project 986-10

Final Report, August 1982

Prepared by

SYNTHETIC FUELS ASSOCIATES, INC.
Two Palo Alto Square, Suite 528
Palo Alto, California 94304

Principal Investigator
E. D. Oliver

Prepared for

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
S. M. Kohan

Engineering and Economic Evaluations Program
Advanced Power Systems Division

ABSTRACT

Gasification of biomass (wood, wood waste, agricultural residues, etc.) is an often-discussed option that may permit utilities to obtain a portion of their fuel requirements from renewable resources. However, the technical state of this option is unclear at present, and this study was initiated to provide documented performance information of commercial biomass gasifiers to the electric utility industry.

Biomass gasification was to be assessed in terms of operability and technical performance by investigating installed commercial gasifiers. Only one gasifier installation, the Omnifuel gasifier at Hearst, Ontario met the criteria selected to identify commercial installations able to provide operating data for engineering analysis. Although the data contained gaps and inconsistencies, a reasonably consistent picture of gasifier operation was derived. The gasifier was observed to be responsive to controls, but no long-term operating and maintenance data were available. Thus, biomass gasification is an emerging technology with potential applications, but the technical performance of large-scale gasifiers is not yet fully defined.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This final report under RP986-10, Technical Evaluation of Wood Gasification, presents an analysis of the early commercial performance of the Omnifuel biomass gasifier installed at the Levesque Plywood plant at Hearst, Ontario, Canada. Omnifuel Gasification Systems, Ltd., the technology developer and licensor, provided field data for the technical analysis and hosted a visit by the project team members to the plant site.

The Omnifuel installation is a single-train, fluid bed, atmospheric pressure, air-blown gasifier feeding mill residues generated at the plant. It is designed to feed 156 short tons per day of a 27% moisture content feedstock varying in size from 2-inch chips to sanderdust.

As a result of past and ongoing EPRI studies (e.g., EPRI Final Report AP-2320, Small System Generation Requirements: Fuels and Technologies; EPRI Special Report AP-1713-SR, Electric Utility Solar Energy Activities: 1980 Survey), a small but growing interest in biomass gasification on the part of some U.S. electric utilities was perceived. The first step was to define the state of the art of biomass gasification. Fred C. Hart Associates, Inc., (RP986-9) is preparing a worldwide state-of-the-art review of biomass gasification, emphasizing commercial applications in North America. Using preliminary information from their study and applying a series of agreed upon screening criteria, Synthetic Fuels Associates (SFA) recommended and EPRI agreed that the Omnifuel gasifier would be able to furnish the most complete information base for a technical gasifier performance analysis.

PROJECT OBJECTIVE

A principal objective of this study is to provide the utility industry with documented technical performance information for a biomass gasifier used in a commercial setting. Field data from the biomass gasifier were to be analyzed from a chemical engineering perspective, and comments were to be prepared on the adequacy and reliability of the data base.

PROJECT RESULTS

The key findings of this study are as follows:

- As is often the case where field data are concerned, SFA observed several gaps or inconsistencies in the data provided by Omnifuel. Consequently, several assumptions had to be made in the course of the analysis, and the calculated performance results could not be completely confirmed by direct experimental measurements.
- Regarding performance measures using a 5% moisture content woody feedstock, the following were calculated using the best set of assumptions:

—Carbon Conversion	97.4%
--Gasifier Thermal Efficiency	
1. Including sensible heat in gas stream from 60°F (base) to 1390°F (gasifier exit temperature)	86.6%
2. Excluding sensible heat	75.2%

- Gasifier heat loss was calculated to be about 11% of the energy input and appears high.

The analyses presented in this report represent a snapshot of the commercial performance of one type of biomass gasifier in the late-1981 time frame. The on-site industrial application of the gasifier may be attractive in that gasification simultaneously solves a waste disposal problem, provides a clean energy form that can substitute for conventional oil and gas fuels at the lumbermill, and incurs no feedstock transportation costs.

This biomass gasifier appears to satisfactorily operate in the commercial setting for which it was designed. Reflecting on the assumptions and limitations of the analyses, the data and calculated results are judged to lie in the 85 to 90% confidence range. Three possible technical drawbacks of this information from a utility perspective are: (1) the absence of long-term operating and maintenance histories (this would be true of any biomass gasifier today), (2) the absence of load-following information, and (3) the absence of information related to changes in gasifier performance as feed quality and moisture content change. Future EPRI studies may address these issues.

Stephen M. Kohan, Project Manager
Advanced Power Systems Division

CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

BACKGROUND

Interest in renewable sources of energy has increased in recent years as a possible alternative to increasingly expensive conventional fuels such as coal, oil, and gas. Wood and wood wastes are renewable sources that are inexpensive in some locations. Although wood and wood wastes can be burned in facilities designed for their use, they cannot be used directly in most existing systems designed for oil or natural gas. However, gasification of these materials can provide a combustible gas that can be burned in existing facilities designed for oil or gas with relatively minor modifications. In new facilities, simplicity would generally favor direct combustion over gasification followed by combustion of the gas. However, specific comparisons could favor wood gasification even in new facilities.

Small wood gasifiers have been widely used in the past, but utility applications have been minimal. Detailed performance information is largely non-existent in the literature. EPRI undertook the present study to attempt to document the technical performance of existing available wood gasifiers, because of a perceived small but growing interest in biomass gasification by some U.S. electric utility companies.

The method used to determine feasibility of the gasification option entailed two principal steps. First, criteria were established to determine if a gasifier were in commercial operation and capable of providing engineering data on its performance. By this approach, only one type of gasifier was identified as being suitable for engineering analysis, but two other gasifiers justified a state-of-the-art review. Second, data were acquired from the identified gasifier licensor and analyzed to determine the reliability of the data and the performance of the gasifier.

TYPES OF GASIFIERS AND SELECTION CRITERIA

The principal criteria leading to the selection of these gasifiers for analysis and review were that a unit be installed in an industrial setting, intended for commercial use, and potentially available for further testing and for licensing of new units, preferably with performance guarantees. Two years of experience were desired but not found in any existing units.

The gasifier studied most extensively in this project is licensed by Omnifuel Gasification Systems Limited of Toronto, Ontario, Canada (herein called Omnifuel). Wood-type fuel is injected into a bed of inert sand fluidized by combustion air insufficient for complete combustion. Combustible gas leaves from the top of the bed, along with entrained ash. Combustible components in the gas include carbon monoxide, hydrogen, methane, and hydrocarbon gases, but very little condensable tar and oil. The Omnifuel gasifier at the Levesque Plywood Company plant in Hearst, Ontario, rated at 80 million Btu/hr input, was chosen for data analysis in this report.

The second type of gasifier is the fixed-bed updraft gasifier. Such a gasifier operates in countercurrent flow; wood is fed at the top and air through a grate at the bottom. Ash is removed from the bottom and fuel gas from the top. Because the gas is cooled by the entering wood, the gas contains tars and oils in addition to the components found in gas from fluidized bed gasifiers. The fixed-bed gasifier is not suitable for sander dust, the type of wood waste used in the Omnifuel gasifier test. The most commercially advanced fixed-bed type of gasifier in North America appears to be one licensed by Applied Engineering Company of Orangeburg, South Carolina. One unit is installed at the Northwest Regional Hospital in Rome, Georgia, but it is not instrumented to provide engineering data. A more advanced unit with instrumentation is being installed and tested by Florida Power Corporation at the Suwannee Power Station; this unit will be a prime candidate if studies such as this one are undertaken in the future. Large fixed-bed gasifiers have also been installed by Westwood Polygas Ltd. of Vancouver, British Columbia. These are developmental units not fully commercial nor instrumented for data collection.

The third type of gasifier is the travelling-grate gasifier, offered by Forest Fuels, Inc. of Marlborough, New Hampshire. Wood is carried by a travelling grate and is gasified by a cross flow of air. These gasifiers are close-coupled to package boilers. They are not instrumented for data collection. Although several have been installed, insufficient information was available to warrant inclusion in this report.

FINDINGS

The Omnifuel gasification system at Hearst gasifies plant wastes to supply fuel gas to heat a hot oil system used for plant heat requirements. The system includes pneumatic wood collectors, storage silos, gasifier and auxiliaries, an 800 ft pipeline distribution system, burners, and a flare stack. The gasifier is approximately 12 ft OD by 40 ft high. Air is compressed, heated by exchange, and injected into the gasifier below a grid that supports the fluidized bed of sand. Feed is injected into the bed, which operates at about 1400° F. Fuel gas leaves from the top and is cooled by exchange but is kept above about 800° F to prevent condensation of any tars and oils that it may contain. Design conditions are for 13,000 lb/h feed of 27% moisture (wet basis) varying in particle size from 2 in chips to sander dust.

Omnifuel provided test data that included fuel and ash rates and compositions, dry fuel gas composition, and an estimate of water vapor content of the fuel gas. The air rate and composition and gas rate were not reported. The reported dry fuel gas percentages did not add up to 100%. To define the performance of the gasifier, it was therefore necessary to make assumptions and check their plausibility by trial-and-error calculations. These calculations are fully documented in the report; only the most plausible results and conclusions are summarized here.

The trial calculations eventually gave a material balance at a 5 short ton per hour feed rate which was deemed most plausible because of closure of elemental balances within about 5% for important elements. Unfortunately, the results cannot be confirmed because Omnifuel did not report air or fuel gas rates. The following table summarizes performance based on this material balance and heat balances.

OMNIFUEL GASIFIER AND PLANT PERFORMANCE

Carbon Utilization	97.4%
Gasifier Cold Gas Efficiency[a]	75.2
Gasifier Hot Gas Efficiency[b]	86.6
Plant Cold Gas Efficiency[c]	74.2
Plant Hot Gas Efficiency[c]	85.3

[a] Higher heating values only as inputs and outputs of gasifier

[b] Higher heating values plus enthalpies as inputs and outputs of gasifier

[c] Analogous efficiencies counting gasifier auxiliary power at 10,000 Btu/kWh (for energy self-sufficient plant) as inputs, excluding feedstock comminution and hauling

CONCLUSIONS

The Omnifuel gasifier at Hearst was visited during this project and was observed to respond rapidly to controls. The cold gas efficiency probably equals or exceeds 75% with a wood feed of 5% moisture, but the calculated performance cannot be confirmed by independent measurements. No long-term operating and maintenance experience exists.

The Applied Engineering gasifier has reportedly operated well, but no operating data are available for engineering analysis. No long-term operating and maintenance experience exists. Likewise, insufficient information is available for technical analysis of any other gasifiers for potential use by utilities.

Wood gasification is a potentially suitable method of providing a clean fuel gas for utility use. For retrofitting, however, unit-specific analysis is necessary to determine the degree of derating and other performance changes that might result from changes in pressure drop and heat transfer due to the properties and volume of the fuel gas and flue gas compared with the corresponding values for the design fuel.

Section 1

INTRODUCTION

Price increases in conventional fossil fuels such as coal, oil, and natural gas have rekindled interest in renewable energy sources. Wood is a renewable resource, and a possible source of clean fuel gas. Although small wood gasifiers have been widely used in the past, utility applications have been minimal. A principal objective of this project is to provide the utility industry with documented technical performance information for commercial-scale biomass gasifiers including an indication of the adequacy and reliability of the field data used in the analysis.

The approach to determining the commercial availability of a particular wood gasifier was to investigate installed gasifiers operating in commercial settings, as opposed to development projects, and to evaluate their technical performance. The technical evaluations include heat and material balances, determination of gasification efficiencies, and discussions of the apparent technical state of development of the gasifier. However, wood gasification economics is outside the scope of the project.

A review of historical developments is necessary to understand the current status and potential of wood gasifiers in the energy picture. About a century ago, wood was the most extensively used fuel in the U.S. before alternative fossil fuels (coal, oil, gas) became readily available. Early in this century, the discovery, development, and distribution of large reserves of oil and gas generally made other fuels uncompetitive. Convenience and costs both favored oil and gas. In recent years, large increases in oil and gas prices have made wood competitive again in some cases, especially where wood wastes or noncommercial timber are available. However, existing equipment designed to burn oil or gas is not generally capable of directly burning wood. Therefore, systems capable of converting wood to a combustible gas compatible with oil/gas-designed equipment (such as may be owned by a small utility) are of interest. These systems are the subject of this report.

For new installations, wood can be used as the energy source for either gasification followed by combustion of the gas or by direct combustion of wood in a boiler or furnace. Thus, another option can be considered for new units.

Wood can also be gasified with oxygen and steam to make a synthesis gas for the production of liquid fuels. The requirements for synthesis gas differ from those for fuel gas, and the choice of gasifier may differ. No commercial-scale oxygen-blown wood gasifiers are believed to exist at present, although demonstration units have been proposed.

Section 2 of this report discusses different types of gasifiers and the rationale for the choice of the Omnifuel gasifier for data analysis. Section 3 presents the data analysis. Section 4 briefly discusses the state of the art of other gasifiers. Section 5 lists references.

Section 2

TYPES OF GASIFIERS AND CHOICE FOR DATA ANALYSIS

Wood gasifiers require a reaction chamber for the partial oxidation of wood with air or oxygen and perhaps steam. As opposed to direct combustion, the gaseous products are poisonous and flammable, and leakage must be prevented. To meet these basic requirements, many configurations have been proposed.

Most gasifiers contact air with what is usually called a fixed bed of wood, although the wood slowly descends as it is consumed. The air may flow up (counter-current) or down (cocurrent). The differences in operation are fundamental. In upflow, the fuel gas is cooled by the incoming feed before it leaves the gasifier. The materials of construction in the outlet piping therefore face a moderate environment. The heat transferred to the wood and heat recovery from the ash improve the thermal efficiency of the gasification. However, condensable pyrolysis products are carried out with the gas. Unless removed by scrubbing or other means, these tars and oils may foul or corrode downstream piping and equipment and create a pollution control problem. The Westwood Polygas and Applied Engineering gasifiers are of the upflow type.

In downflow gasifiers, the hot gas leaves from the same region as the hot ash. An advantage of the system, which is most important in the production of synthesis gas, is the near elimination of cordensable liquids by reactions in the bed of hot char and ash. Less development effort has been applied to downflow gasifiers than to upflow gasifiers.

In fluidized bed gasifiers, wood is fed to a fluidized bed of inert solids supported by an upflowing stream of air or oxygen and perhaps steam. A fluidized bed is violently mixed and nearly uniform in temperature. Because the fluid bed can operate at elevated temperatures, condensable liquids of the kind formed by fixed-bed gasifiers are cracked and nearly eliminated from the product gas. At least one fluidized bed gasifier has been installed for commercial use: the Omnifuel gasifier in Hearst, Ontario.

A fourth type of gasifier uses a travelling grate to carry wood across an upflowing stream of air. Forest Fuels gasifiers are of this type, and several have been sold.

Other gasifiers use horizontal or inclined flow, often assisted by an auger or tumbling action. Sometimes gasification is combined with pyrolysis. These gasifiers pose pontentially serious mechanical problems such as abrasion; no information is available to indicate that such problems have been solved to permit routine commercial use. Some gasifiers use a staged combination of gasification methods.

It was agreed at the onset of this study that representative data for EPRI purposes would be requested from plants with the following desirable features:

- recent sustained gasifier operation for at least two years in a commercial setting, and prospects for the continuing use of the gasifier in this setting
- the general absence of potentially high-maintenance items
- use of a wood-type feedstock (municipal solid waste is not considered)
- gasifiers of this type offered for sale, preferably with performance guarantees.

In this context, commercial operation means operation in an industrial setting not primarily for development. The period of two years was chosen to show an apparent commitment by the owner to use the gasifier in the conduct of his normal business. Although large scale is desirable, no minimum size was set. Additionally, any practical gasifier type was to be included.

A survey in this project and more extensive investigation by Fred C. Hart Associates under a companion EPRI contract (RP #986-9) indicated that no gasifier extant completely satisfied all these criteria. The Omnifuel gasifier at the Levesque Plywood plant in Hearst, Ontario came the closest, having been operated commercially only a few months instead of two years. It was reportedly the only plant with an installed data logging system capable of providing heat and material balance data. The fuel gas is used in the production of plywood and particle board.

One commercial-scale Applied Engineering fixed-bed gasifier is installed and another is under construction. The one installed in Rome, Georgia is a 25 million Btu/h (output) demonstration unit providing fuel gas for raising steam for the Northwest Georgia Regional Hospital. Mechanical problems were solved at this unit. It is understood that only fuel input and steam output are measured to characterize performance, and operating heat and material balance information is unavailable. A "second generation" Applied Engineering gasifier is nearing start-up at the Florida Power Corporation Suwannee generating station near Lake City, Florida; it will provide a portion of the fuel for a natural-gas-fired boiler. The Lake City gasifier will have a measuring and metering system designed to interface with the rest of the plant and will be a prime candidate for data analysis if a future project of this type is undertaken.

Forest Fuels, Inc. has supplied several small gasifiers that use predried wood chips or wastes as feedstocks. These units are installed principally in the Northeast. Six sizes with ratings from 1.6 to 17.5 million Btu/h output are offered. The fuel is supported on a travelling grate through which air rises. The units are close-coupled to package boilers. Boiler pressure controls grate speed, and the temperature at the gasifier outlet controls the fan. These units are not instrumented to provide operational heat and material balance data.

Westwood Polygas Ltd. has a 10 ft diameter demonstration gasifier at Chasm, British Columbia at the Ainsworth Lumber Company sawmill. It has operated sporadically, supplying gas to a kiln and in one period operating continuously for two weeks. Business conditions have limited its use, and it is not instrumented to gather heat and material balance data.

From these considerations, the Omnifuel gasifier was chosen for detailed analysis and the Applied Engineering and Westwood Polygas gasifiers for state-of-the-art review. Little information was available about the Forest Fuels gasifier; however, it is reviewed in the companion report by Fred C. Hart Associates.

Section 3

ANALYSIS OF OMNIFUEL GASIFIER

OMNIFUEL SYSTEMS

Omnifuel offers complete system designs in four general areas (1):

- Fuel drying, storage, and delivery to the gasifier
- The proprietary Omnifuel gasification system
- Pipeline distribution system
- Gas utilization

Fuel drying is not needed in most cases. Storage and delivery depend on the supply of fuel and the demand for gas from the gasifier. The Omnifuel gasification system consists of several components:

- Wood feeder system
- Fluidizing air or oxygen blower (the Hearst system uses air; use of oxygen may necessitate steam injection)
- Start-up burner
- Ash handling and emission control
- Air preheater
- Instrumentation

The wood feeder system includes a patented sealing device to prevent the escape of gas and permit operation under pressure. Thus only a forced-draft air blower is required for air-blown gasification. If the feeder system were not sealed, an induced-draft fan would be required to operate on a hot dusty gas of greater volume than the volume of air to a forced-draft fan. Simplicity and low power requirements result from the use of the feed seal.

For cold startup, a startup burner is provided to heat the gasifier and the contained bed of inert sand before wood can be gasified (partially burned) in the bed. Oil or natural gas may be burned for this purpose. The bed loses heat slowly when shut down because of its low thermal conductivity and because the gasifier is insulated. Gasification can be restarted rapidly in a hot bed without use of auxiliary fuel.

Cyclone separators have been used to remove particulates from the gas. These have been adequate to meet emission regulations at Hearst. Other applications may require more complete removal. Current plans call for cleaning the gas in a wet scrubber for testing in a diesel engine.

If desirable, an air preheater can be installed to heat the fluidizing air by exchanging heat with the hot gas from the gasifier. Air preheating has several advantages: it improves the thermal efficiency by recovering heat that may otherwise be wasted, it cools the product gas so that materials of construction are subjected to less severe conditions, and it improves the quality of the product gas. This quality improvement results from a reduction in the heat release necessary to maintain heat balance at the bed temperature that is required to achieve a desired degree of carbon conversion. That is, preheating the air reduces the amount of heat required to raise the temperature of the reactants to the bed temperature. If the incoming air is cold, a portion of the necessary heat may be supplied by burning carbon monoxide to carbon dioxide and hydrogen to water, which reduces the heating value of the product gas. These advantages, of course, result in increased capital and maintenance costs attributable to the preheater that would be the subject of tradeoff studies for specific projects.

The typical Omnifuel system is instrumented to permit automatic operation without continuous supervision. A control panel displays major operating parameters and facilitates startup and shutdown. According to Omnifuel literature, if a hazardous condition arises when the gasifier is unattended, the system will shut down the gasifier and switch from wood to auxiliary fuel automatically to maintain production.

The pipeline distribution system is kept as short as possible to conserve sensible heat of the gas. The gas is kept hot also to prevent condensation of liquid by-products. Dual-fuel burners are used. Wet wood produces a low-Btu gas that may require an auxiliary fuel pilot flame to maintain combustion when such gas is burned.

Omnifuel systems use feed of less than 2 in size with no minimum size. According to Omnifuel literature (1), turndown is typically 2:1, but proprietary design modifications can increase it to 5:1. Feeds of up to 50% water can be processed, but increased water content decreases the heating value of the wet gas.

OMNIFUEL SYSTEM ADVANTAGES

Conversion efficiency said to exceed 98% carbon utilization in some tests is claimed (97.4% was calculated for the test analyzed herein). Since the ash and unburned carbon leave the bed by entrainment, coarse particles stay in the bed until nearly consumed. Conceptually, the small particle size of the feed makes possible higher specific capacity (mass of feed to gasifier per hour per unit cross section) than fixed bed gasifiers, although no comparative data can be cited.

The heat capacity of the bed material (primarily sand) provides a "thermal flywheel" that helps the gasification proceed smoothly without temperature excursions. As previously discussed, it also facilitates hot startup. The high degree of mixing in a dense-phase fluidized bed promotes uniformity of temperature and composition.

Omnifuel claims low maintenance for its system, but no long-term experience is available. Besides providing a fuel gas, the Omnifuel system can be used to dispose of wastes that are suitable for feedstock while simultaneously reducing the amount of oil or gas necessary to supply plant heat requirements.

The gas produced can be burned with less excess air than is normally used in burning wood. According to Omnifuel literature, adiabatic flame temperatures of about 3000° F can be attained with hot fuel gas. This is important in some applications such as for lime kilns and radiant boilers (1).

As with any low-Btu gas, the requirements of specific applications must be considered. Some applications may require more complete particulate removal, removal of sulfur compounds (H_2S, COS), or derating of existing equipment designed for firing oil or gas because of the increased flue gas volume from the diluents in the Omnifuel gas.

DESCRIPTION OF HEARST GASIFICATION PLANT

The Hearst Gasification Plant was installed in 1981 at the Levesque Plywood Company veneer and particle board plant in Hearst, Ontario. It was installed for the twin purposes of disposing of plant wastes and reducing the expense of burning natural gas used to heat a hot oil system used for plant heat requirements.

The equipment required for wood collection, gasification, and gas use include the following, as shown in Figure 3-1:

- Pneumatic wood collectors
- Storage silos
- Gasification system
- Pipeline distribution system (800 feet)
- Burners
- Flare stack

Wood waste is collected from several operations and is pneumatically conveyed to two storage silos about 26 ft OD x 60 ft high. The wood waste is withdrawn from the silos and fed into the feed injector, which forces the feed into the fluidized bed in the gasifier. The fluidized bed contains inert sand, ash, and unconverted wood waste. The sand improves the thermal and dynamic stability of the bed. The bed is maintained in the fluidized state by air entering through a proprietary distributor near the bottom of the gasifier vessel. The air is compressed by a blower and preheated to 700-800° F by exchange with product gas before entering the vessel below the distributor. A characteristic of fluidized beds is that the bed is well mixed and of relatively uniform temperature, in this case in the neighborhood of 1400° F. Air reacts with the wood waste, forming a combustible gas, which entrains the ash and a small amount of degraded sand, and leaves the top of the vessel under a small positive pressure.

The use of a dense inert bed material such as sand creates a bed that provides buoyancy for wood particles so that fluidization is less sensitive to variations in size and density of wood particles in the feedstock. Furthermore, the turbulence of the sand bed promotes heat and mass transfer and abrades the wood, thus increasing the gasification rate. Finally, the heat capacity of the sand helps maintain steady temperatures in the bed. Inert materials are used in other reactors, such as in the multi-solid fluidized bed combustor (MS-FBC) (2) and the solids circulation boiler (3) used to burn coal.

The hot gas passes through two cyclone separators in series. The particulates are removed from the system by a screw conveyor to a covered box. The gas leaving the second cyclone preheats the incoming air in the aforementioned heat exchanger and then enters the distribution pipeline. The gas is cooled to 900 to 1000° F in the heat exchanger and is kept above 800° F in the pipeline to prevent condensation. Part of the gas is burned in an oil heater nearby; the hot oil is used by the particle board plant. The rest of the gas is piped over 800 feet to other oil heaters.

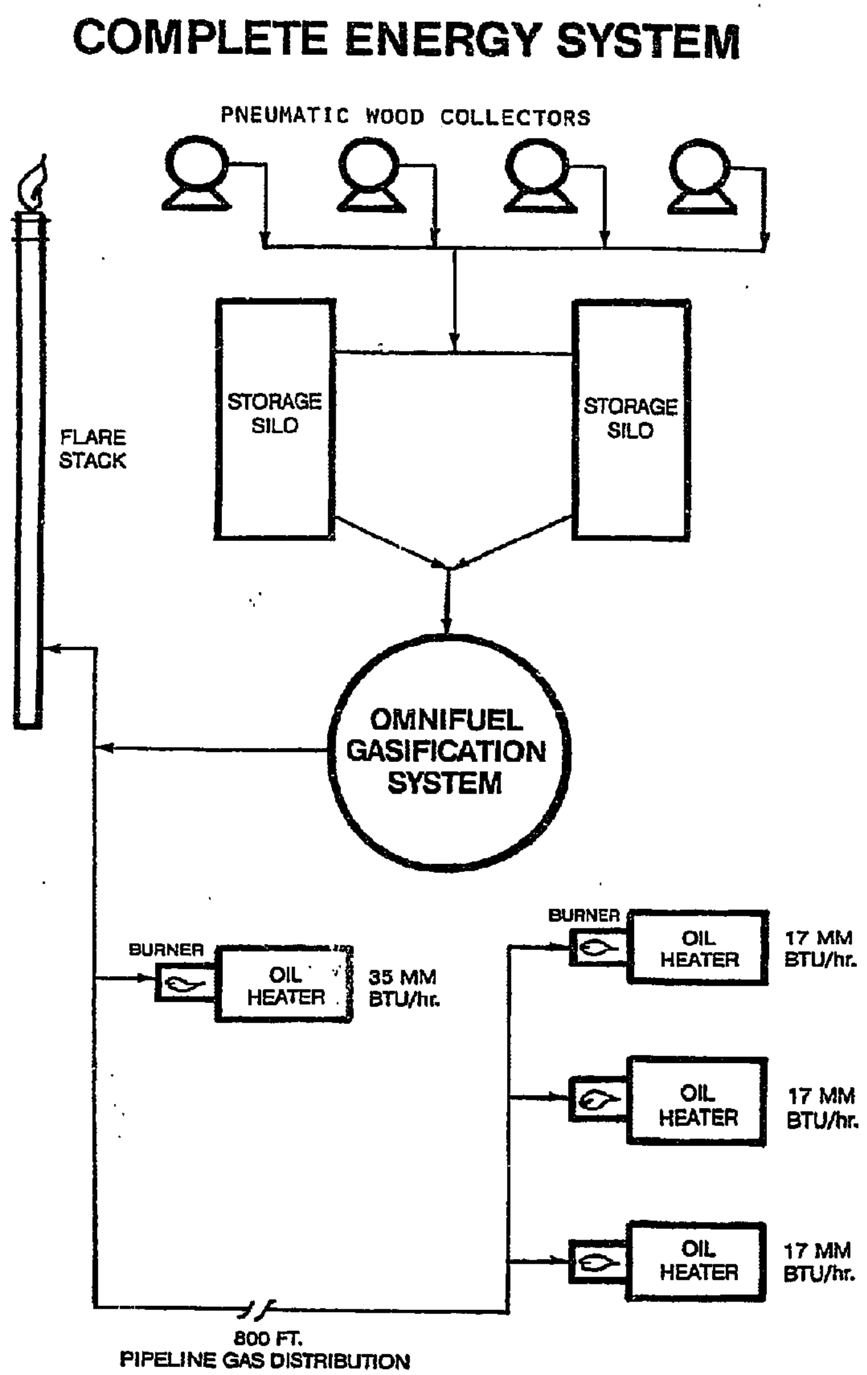


Figure 3-1. Complete Energy System

Source: Reference 5.

Wood waste is fed through a rotary valve; the rate is determined by diverting the entire stream for a measured period of time and weighing the amount collected. The feedstock is sampled at this point. The air rate is controlled by the speed of the blower. The ash rate is determined by weighing the amount collected in a certain time. There is no direct measure of the product gas rate. Various measurements are recorded on a strip chart. During some operating periods, the hot product gas withdrawn from the pipeline was filtered and analyzed by a gas chromatograph in a cabinet on the roof of the building.

Glue is used in the products of this plant. As a result, feed containing sander dust from products is higher in nitrogen than wood or other biomass feedstocks.

The gasifier vessel itself is approximately 12 ft OD by 40 ft high and is internally insulated. Gasifier internals are proprietary. During startup, the bed is heated by a propane burner.

Design basis and some performance data published by Omnifuel are given for the Hearst gasifier in Table 3-1. Design calls for 99% carbon conversion at 80 million Btu/h input (design feedstock wood with 29% moisture, wet basis). Performance data show that the design rate can be considerably exceeded, but carbon conversion may fall short. The thermal efficiency* depends on the moisture content of the feed; according to Table 3-1, it is about 84% with 27% moisture in the feed. The heating value of the wet gas decreases with increasing moisture content of the feed and therefore of the gas because of the diluent effect. Cooling to condense water would increase the heating value of the remaining gas.

The Hearst Gasification Plant was accepted by Levesque Plywood Ltd. by letter in July 1981. This acceptance was conditional on additional engineering support as needed. The plant operated continuously from May to July 1981 and in recent months plant availabilities in excess of 90 percent have been reported (15). Plans call for installation of a wet scrubber to clean the gas sufficiently for testing in diesel and spark ignition engines.

*Thermal Efficiency =

$$\frac{\text{Total heat of combustion of gas at } 60^\circ\text{ F plus sensible heat at } 1400^\circ\text{ F above } 60^\circ\text{ F}}{\text{Total heat of combustion of wood feed at } 60^\circ\text{ F}}$$

Table 3-1

DESIGN AND PERFORMANCE OF OMNIFUEL GASIFIER AT HEARST, ONTARIO

	Design	Measured and Calculated Data Reported by Omnifuel		
Input Capacity (10^6 Btu/h)	80[a]	a	95[b]	144[b]
Fuel - size	2 in chips to sanderdust			
- moisture content (% wet basis)	27	5-40	25	11
- flow (lb/h)	13,000	design	15,000	19,000
Gas Production - temp. (° F)	1,400	design		
- pressure (psig)	2.5	design		
- gas heating value (Btu/scf wet basis)	142[d]	134[c, d]	137[d]	195[d]
- gas sensible heat above 60° F (Btu/scf wet basis)	18[d]	18[c, d]		
Gas Analysis (vol %) CO	11.9	11[c]	12.2	17.8
H_2	8.6	7.5	7.8	9.4
CH_4	4.5	4.8	4.6	6.9
C_2H_x	1.9	1.5[c]	1.6	2.3
N_2, CO_2, H_2O	Balance	Balance	Balance	Balance
Gas Production (scf/lb dry wood)	45.2[d]	45.5[c, d]		
Sensible Heat Loss (% of heating value)	1.0[d]	1.8[d]		
Ash Content of Char (%)	up to 50	25-50		
Carbon Conversion (%)	99[d]	98-99[d]		
Thermal Efficiency of Gasifier (%) (including evaporation of moisture and heat loss from gasifier)		84.3[d]		

---

[a] All data in this column from Reference 4

[b] All data in this column from Reference 5

[c] Average for 27% moisture content feed

[d] Calculated values

ANALYSIS OF HEARST GASIFICATION PLANT DATA

This section presents estimates of the performances and efficiencies of the Hearst Gasification Plant. These conclusions are documented in Appendix B by the analysis and descriptions of various trials that unsuccessfully attempt to rationalize discrepancies and gaps in the data. As noted below, the calculated thermal efficiency of about 75% is believed to be within 5% of the true value.

Table 3-2 gives the elemental material balances for the most successful trial based on minimum root mean square of percentage error in closure for all elements and a thermal efficiency that is reasonable in comparison with coal gasification thermal efficiencies for low-moisture coal and with anticipated heat losses. Closure is less than one half percent for nitrogen, oxygen, and carbon. As elsewhere noted, Table 3-2 requires several assumptions, since neither air rate nor gas rate was reported. The most serious error is about 5% for hydrogen, although this amounts to only 31 lb/h. Argon and mineral ash are both inert and low in amount, so the errors are not important. The indicated carbon utilization is 97.4%, somewhat less than the design value of 99%. Table 3-3 gives molar rates of air and gas streams on a particulate-free basis, as well as other properties and heat quantities. The higher heating value of 202 Btu/scf wet gas is relatively high and results from the high concentrations of methane and ethylene, which in turn are the result of relatively low operating temperatures. Condensables were not reported by Omnifuel but should be expected to accompany the high hydrocarbon concentrations. Omnifuel states that condensables are typically 0.1% by weight of gas. Hydrocarbon formation is desirable when producing fuel gas; it not only increases the heating value but also the thermal efficiency because formation is exothermic and less combustion with oxygen is necessary to attain the operating temperature. C_2 and heavier hydrocarbons are assumed to be ethylene as in Omnifuel practice; no analysis was reported.

Table 3-2

ELEMENTAL MATERIAL BALANCES

Stream Rates in lb/h

Element	1 Wood	2 Air	Total In	3 Ash	4 Gas	Total Out	% Error $\left(\frac{\text{Out-In}}{\text{Out}}\right)$
Carbon, C	4,520	0	4,520	90	4,449	4,539	0.4
Hydrogen, H	638	5	643	5	607	612	-5.1
Oxygen, O	4,549	2,705	7,254		7,242	7,242	-0.2
Nitrogen, N	484	8,673	9,157		9,157	9,157	Basis
Argon, Ar	0	149	149		164	164	9.1
Mineral Ash	41	0	41	39	11	50	18.0
Total	10,232	11,532	21,764	134	21,630	21,764	

Basis: Wood and ash total rates measured, others calculated.
Nitrogen as tie element.
Missing reported dry gas percentage is CO_2.
Wet gas 10% H_2O by volume (estimated by Omnifuel).
Unremoved ash in Stream 4 is same composition as Stream 3.
Reported carbon on ash is actually 5% hydrogen.
Moist air contains 0.004 lb H_2O/lb dry air.
Air composition from Reference 6 with minor components included with N_2.

Notes: Calculated dry air/dry fuel ratio 1.182.
Air supplied 21.1% of stoichiometric.
Carbon utilization 97.4%.

Table 3-3

MOLAR STREAM FLOWS AND PRODUCT ENERGY DATA

					Gas Energy Quantities				
	2 Air		4 Gas[a]		Chemical Heat of Combustion	Sensible Heat above 60° F [c]	Latent Heat of Water 60° F	Total By Component	Total By Component
Component	mol % dry	lb mol/h	mol % dry	lb mol/h	Btu/lb mol	Btu/lb mol	Btu/lb mol	Btu/lb mol	10^6 Btu/h
H_2			6.70	49.02	122,850	9,366	-	132,216	6.48
CO			21.66	158.46	121,641	9,838	-	131,479	20.84
CH_4			9.49	69.43	382,828	17,491	-	400,319	27.80
C_2H_x [b]			2.34	17.12	606,773	23,315	-	630,088	10.79
CO_2			14.55	106.45	-	15,160	-	15,160	1.61
N_2	78.07	309.73	44.7	327.02	-	9,741	-	9,741	3.19
Ar	0.94	3.73	0.56	4.10	-	6,517	-	6,517	0.03
O_2	20.99	83.27	0.00	0.00	-	-	-	-	
Subtotal	100.00	396.73	100.00	731.60					
H_2O		2.54		81.28	-	11,807	18,919	30,726	2.50
Total		399.27		812.88					73.24
Flow, lb/h		11,532		21,592					
Flow, scfm		2,522		5,135					
Calculated HHV, Btu/scf wet gas				202					

[a] Excluding particulate matter
[b] Assumed C_2H_4
[c] At 1390° F raw gas exit temperature

Basis of heat of combustion: 60° F, water as liquid

Condensables may be desirable if hot raw gas can be burned because they increase the heating value. However, they pose operating and pollution difficulties when they condense, whether by cooling or by scrubbing the gas.

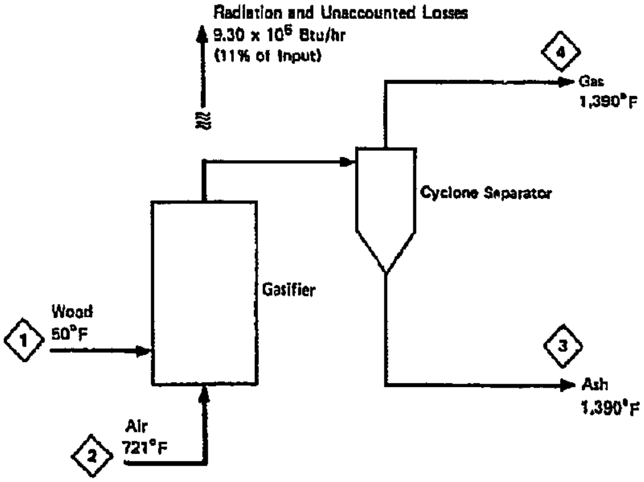
These analyses report no sulfur. Woods commonly contain up to a few tenths of a percent of sulfur.

Figure 3-2 is a sketch showing overall flows and heat rates for the gasifier. The air and product gas rates are calculated as described above, not obtained from Omnifuel. The heat rates are total enthalpies referred to 60° F, with water as liquid, and higher heating values. Although the latent heat of water is not generally available for recovery, the enthalpy definition is consistent with the use of higher heating values. Radiation and unaccounted losses are calculated as 11.0%, which is higher than would be expected from a well-insulated system. Table 3-4 gives the heat balance in more detail. The heat balance is summarized as follows:

Input, 10^6 Btu/h			Output, 10^6 Btu/h		
Wood	82.7	97.8%	Ash	1.6	1.9%
Air	1.9	2.2	Gas and entrained particulates	73.7	87.1
Total	84.6	100.0	Loss	9.3	11.0
			Total	84.6	100.0

Basis: 60° F reference temperature, water as liquid

Table 3-5 gives Synthetic Fuels Associates (SFA) estimates of energy requirements for auxiliaries. These were not supplied by Omnifuel but are given as the prospective requirements in a defined situation, namely, appropriately sized wood or wood waste at the plant site, excluding delivery and disposal energy, and product gas available at 3 psig, assuming environmental regulations are met without further treatment. This is a conservative case for a plant self-sufficient in energy, providing electricity at 10,000 Btu/kWh. The energy for chipping wood is also shown.



CONDITIONS	STREAM				
	◇1	◇2	◇3	◇4 (Gas)	◇4 (Solid)
Flow (lb/hr)	10,232	11,532	134	21,592	38
Total Heat Content Above 60°F (10^6 Btu/hr)[a]	-0.03	1.88	0.05	10.97	0.01
Total Heat of Combustion (10^6 Btu/hr)[a]	82.77	0.00	1.57	62.27	0.45

a) Water as Liquid

Figure 3-2. Overall Flow and Heat Rate Sketch

Table 3-4

OMNIFUEL GASIFIER HEAT BALANCE, HEARST, ONTARIO

(10^6 Btu/h)

HEAT IN	HHV	Sensible	Latent	Radiation & Unaccounted	Total
Wood	82.77	-0.03	0.00	-	82.74
Air		1.83	0.05	-	1.88
Total	82.77	1.80	0.05	-	84.62
HEAT OUT					
Gas (only)	62.27	9.43	1.54	-	73.24
Particulates in gas	0.45	0.01	0.00	-	0.46
Ash	1.57	0.05	0.00	-	1.62
Losses				9.30	9.30
Total	64.29	9.49	1.54	9.30	84.62

Basis: HHV and latent heat at 60° F, sensible heat above 60° F.

Table 3-5

ESTIMATED ENERGY REQUIREMENTS FOR PLANT AUXILIARIES

Auxiliary	Requirement	Horsepower	Energy[a], 10^6 Btu/h
Air blower	2,522 scfm at 10 psig	133	1.10
Feedstock:	12,500 lb/h		
Pneumatic conveyor		5	0.04
Screw unloader and conveyor		3	0.02
Injector		5	0.04
Ash screw conveyor	500 lb/h	Neglect	
Total		146	1.20
Not Included:			
Feedstock hog (for wastes)		140	1.16
Feedstock chipper (for whole trees)		350[b]	2.23

[a] At typical 10,000 Btu/kWh and 90% motor efficiency for self-sufficient plant providing its own electricity

[b] Assuming engine efficiency of 40%

Table 3-6 gives the derivation of several efficiencies as defined. The gasifier cold gas efficiency, 75.2%, is simply the ratio of the total heat of combustion of the fuel gas to the total heat of combustion of the feed, i.e.,

$$\text{cold gas efficiency} = \frac{(\text{Gas } \Delta H_c\text{, Btu/lb})\ (\text{lb/h gas})}{(\text{Feed} \Delta H_c\text{, Btu/lb})\ (\text{lb/h feed})}$$

in which ΔH_c = higher heating value.

The fuel gas contains a small amount of entrained particulates containing char; the heating value of the char is not included in the efficiency calculations because of two factors. First, the particulates may have to be removed for environmental reasons. Second, the char is difficult to burn completely. The heating value of the entrained char at the exit from the gasifier amounts to 0.5% of the heat input.

The gasifier hot gas efficiency, 86.6%, is based on both heating values and enthalpies above 60° F (water as liquid) of the fuel gas and the input streams (wood and air). As in all cases, the entrained particulate matter is excluded. Analogous cold gas and hot gas efficiency, 74.2 and 85.3%, are also calculated with the energy related to plant auxiliaries counted as input.

As previously mentioned, the radiation and unaccounted losses seem higher than would be expected, meaning calculated efficiencies are probably somewhat lower than actual. One reason is probably the relatively poor closure of the hydrogen material balance. If arbitrary adjustments were made to the output to close the hydrogen, carbon, and oxygen balances, the increase in heating value would increase the calculated efficiencies by 1.8% of the heating value of the wood. Similarly, assuming the fuel gas contained 0.1% by weight of condensables with a heating value of 20,000 Btu/lb it would be equivalent to 0.5% of the input.

Besides errors in elemental balances and compositions, errors in measured feed rates, product rates, temperatures, heats of combustion, and specific heats may lead to errors in the calculated heat losses (heat in minus heat out). However, in this analysis no objective standard can be applied to the results as in the case of the elemental balances.

Table 3-6
EFFICIENCIES

	Input		Output		Efficiency	
	Stream	Energy	Stream	Energy	Type	Value
Heating Values Only	Wood	82.77	Fuel Gas	62.27	Gasifier	
					Cold Gas	75.2%
Heating Values and Enthalpies	Wood H	-0.03	Fuel Gas H	10.97		
	HHV	82.77	HHV	62.27		
	Air H	1.88				
	Total	84.62		73.24	Gasifier	
					Hot Gas	86.6%
Heating Values and Auxiliaries	Wood HHV	82.77	Fuel Gas HHV	62.27	Plant	
	Auxiliaries	1.20			Cold Gas	74.2%
	Total	83.97				
Heating Values, Enthalpies, and Auxiliaries	Wood H	-0.03	Fuel Gas H	10.97		
	HHV	82.77	HHV	62.27		
	Air H	1.88				
	Auxiliaries	1.20			Plant	
	Total	85.82	Total	73.24	Hot Gas	85.3%

The efficiencies depend on the moisture content of the feed as well as heat losses and performance of the gasifier. For the test run analyzed herein, feed wood waste with 5% moisture, the gasifier cold gas efficiency appears to be somewhat above 75%, perhaps 2 or 3% above. Efficiencies may not be of as great importance in disposing of wastes as are operating reliability, maintenance, and costs. It is unfortunate that the performance derived from this analysis cannot be confirmed by actual experimental measurements. No commercial data on wood gasifiers of other types are available for comparison, but upflow gasifiers would be expected to show about 5% higher efficiency, if no channelling occurs, because of the countercurrent flow.

Fluidized bed coal gasifiers are likely to show cold gas efficiencies in the range of 80 to 82%, based on SFA experience, when dried coal is fed. Therefore, the cold gas efficiency calculated for the Hearst gasifier is probably within about 5% of the true value.

The balance of this trial has one apparent discrepancy in that the calculated equilibrium constant for the CO shift reaction is 0.405, much lower than would be expected (thermodynamic equilibrium about 1.2 at the operating temperature of about 1400° F):

$$\frac{(\text{mol } H_2)\ (\text{mol } CO_2)}{(\text{mol } H_2O)\ (\text{mol } CO)} = K = 0.405$$

The cause of the low value has not been determined. However, reactions approach equilibrium at rates dependent on the reactivity of the components, the temperature, and the presence of catalysts. Compositions may deviate from equilibrium because the mechanism of the reaction results in a non-equilibrium mixture which does not have time to equilibrate. The temperature of the Omnifuel gasifier and absence of effective catalysts may result in reaction rates too low to approach equilibrium. Also, a component such as H_2O may bypass the reaction zone. Of course, all the data are subject to error: the concentrations, the temperature, the equilibrium constant. The calculated K corresponds to a temperature above 2100° F, more than 700° F above the measured temperature. The approach to equilibrium is commonly expressed as the difference between the measured temperature and the temperature corresponding to the equilibrium constant. The difference here is unusually large.

IMPLICATIONS OF HEARST GASIFIER DATA TO UTILITIES

Some implications to utilities can be derived from the data for the Hearst gasifier. Gasifiers may provide all the fuel to small units or a portion of the fuel to large units. Applications to small units are considered first.

Small oil-fired or gas-fired boilers could be retrofitted to burn fuel gas derived from wood. Such retrofitting would in some cases permit substituting waste or low-cost wood for expensive oil or gas. (Gas is expected to increase in price as price controls are removed.) The Hearst gasifier was observed to start up quickly when hot. Cold startup and load-following ability can only be inferred from claims by Omnifuel at this point. Furthermore, no long-term maintenance or operating experience is available. Costs of retrofitting burners suitable for low-Btu gas are expected to be minor; the principal capital costs would be for the gasifier, wood or wood waste handling, and possibly emission controls, in a plant area that may lack adequate space. However, substantial derating of capacity may be required in some cases, as discussed below. Consequently, if a utility is heavily dependent on units to be converted, derating of existing equipment could be a serious disadvantage of a wood gasifier producing low-Btu gas.

The most likely need for derating relates to the volume of flue gas and perhaps the heat transfer capacity. Some package boilers have a large excess of flue gas handling capacity and may require no derating. However, some investigators suggest severe derating; an experimental and theoretical study for EPA suggests 25 to 35% derating of high-Btu gas capacity even for a 150 Btu/scf gas when burned in equipment designed for high-Btu gas (7). This study, which focuses mostly on coal gasification for large power plants, concludes that the major concerns of retrofitting are the load factor, heat transfer control, pressure drop, and dependability.

An experimental and theoretical study sponsored by EPRI considered the following factors for low- and medium-Btu gases: flame stability, flame length, flame emissivity, pollutant emissions, detailed temperature profiles, and calculated changes in heat transfer in radiant and convection section of a boiler (8). Briefly, flame stability was established for all coal-derived gases studied, flame length was usually less than for natural gas, emissivity did not vary radically, adiabatic flame temperatures were not greatly affected for medium-Btu gases, but were much lower for low-Btu gases, and projected NO_x emissions correlated with adiabatic flame temperatures. Heat transfer was reduced in the radiant section by lower flame temperatures, but increased in the convection section by increased gas flow, posing control problems for a steam power plant.

The increased flue gas volume from low-Btu gas is a matter of simple arithmetic and stoichiometry (9, 10). Down to about 300 Btu/scf, which is in the neighborhood of the heating values of hydrogen and carbon monoxide, the effect is small. Heating values lower than this imply that the fuel gas contains diluents, and the flue gas volume rises sharply as the heating value decreases. Air preheater and convection pass draft losses increase, exit temperature increases, and efficiency falls off, compared with design values.

Since the effects are relatively minor at heating values of 300 Btu/scf or above (medium-Btu gas) the possibility of producing such a gas by wood gasification may be considered. This would require gasification with oxygen rather than with air. Although the cost of cleaned coal-derived medium-Btu gas is often comparable with the corresponding low-Btu gas, low-Btu gas from wood would probably cost appreciably less than medium-Btu gas, because little or no gas cleaning is required. Wood is low in sulfur content, but sulfur removal may be necessary at some installations, depending on the wood and the regulations. Particulate removal greater than achievable by cyclone separators may be required. If so, an oil-fired unit (industrial or utility) with an electrostatic precipitator (ESP) installed might be a favorable location for a wood gasifier retrofit. A few oil-fired units have ESPs, but they are not common.

The above-cited studies concern gases whose heating values are reduced by the presence of diluents that are mainly nitrogen and carbon dioxide. The Omnifuel gasifier produces gas from wood or wood waste th[illegible] ig amounts of water. Since it is desirable and often fea[illegible] hot from the gasifier without first condensing the water, [illegible] be reduced in heating value by the presence of water vapor [illegible] be noted: the sensible heat of the gas probably makes flame [illegible]ty easier to attain and raises the flame temperatures, but the water vapor affects the results because its specific heat is greater than the specific heat of nitrogen. This tends to lower flame temperatures. Thus specific analysis would be required to determine the effects of heat transfer and draft losses in the light of system capabilities. One option, of course, is to predry the wood or wood waste to improve the gas quality. Gasifier efficiencies are also increased if the feed is dried. The tradeoff would be between increased capital and operating costs for the feed dryer on the one hand and the value of increased efficiency and operability on the other hand.

Wood gasifiers may also be used to provide a small part of the fuel for a large boiler, as in the Florida Power Corporation, Suwannee plant, in areas where cheap wood or wood waste is available. A small proportion of such gas might not require derating or significant changes other than for the low-Btu gas burner system. Feedstock availability is too limited to supply all the fuel to large units.

Because of the capital cost of the gasifier system, gasification would be most favorable for base-load plants or in steady-load operation supplying part of the fuel to a large unit. The prospects for use of gasification dedicated to simple cycle gas turbines are poor, because gas turbines require very low particulate loadings and usually operate only for peak loads.

If wood or wood waste is considered as a replacement or supplemental fuel, other options may be considered: direct combustion (especially for a new unit) or use in a coal-fired boiler, if feasible.

To summarize, utilities may consider wood gasifiers as sources of all the fuel for small units or a portion of the fuel for large units. The latter appears to pose a less difficult retrofit problem.

Section 4

STATE OF THE ART OF OTHER GASIFIERS

APPLIED ENGINEERING GASIFIER

Overview of Status and Operability

Although its capabilities and performance are not currently publicly documented, the Applied Engineering updraft gasifier may be considered in applications that can use a low-energy gas and where wood is cheap. According to telephone discussions with Applied Engineering personnel, a unit rated at 15 million Btu/h output has operated sporadically for a year and reliably for several months in an unattended mode (i.e., without an engineering crew in attendance). The average output has not been reported. The unit was designed to operate on green whole tree chips. Capacities to 35 million Btu/h output (hot gas) are offered. Performance guarantees are not stated but can be negotiated. However, no long-term maintenance experience (e.g., two years or more) exists at the time of writing this report.

Additional information to document the capabilities and performance of this gasifier should become available in 1982 from the new Florida Power Corporation unit, which is being instrumented to provide data in an electric utility setting. Applied Engineering is currently developing a second generation gasifier with a single train capacity of 50 million Btu/h output and is also working on manifolding several reactors.

Description of Installations

Data related to the Rome, Georgia unit, designed and manufactured by Applied Engineering Company of Orangeburg, South Carolina, are given in Table 4-1. A sketch of the unit is given in Figure 4-1. Besides internals to promote uniform flow of fuel and gases, the system design requires attention to the following:

- the feeding system
- ash removal
- steam injection
- transportation gas
- a burner system capable of burning tars and oils along with gas

Table 4-1

WOOD GASIFIER FACILITY PLANT PERFORMANCE SUMMARY

Northwest Regional Hospital
Rome, Georgia

RAW MATERIAL REQUIREMENTS

Type: Whole tree wood chips (coniferous and deciduous)

Size: Individual chips to average 3 in x 3 in x ½ in with occasional chips being no larger than 3 in x 3 in x 1 in

Quantity: 75 tons/d (24 h/d)

Moisture Content: Maximum of 50% (wet basis)

PLANT OUTPUT

Output: Low-Btu Gas

Quantity: 25×10^6 Btu/h (hot)

Heating Value: 150-165 Btu/scf

PLANT UTILITIES

Electrical

Service Required: 460V, 3 phase, 60 Hz

Connected HP: 125

Operating HP: 110

Water

Fire water supply adequately sized to comply with local codes

Cooling water supply to gasifier - 10 gpm

Steam

Plant steam required for grate cooling of gasifier and enhancing Btu content of the gas (500 lb steam/h)

Sewage/Drainage

10 gpm at 120° F

Ash Disposal

500 lb/d

Source: Reference 11

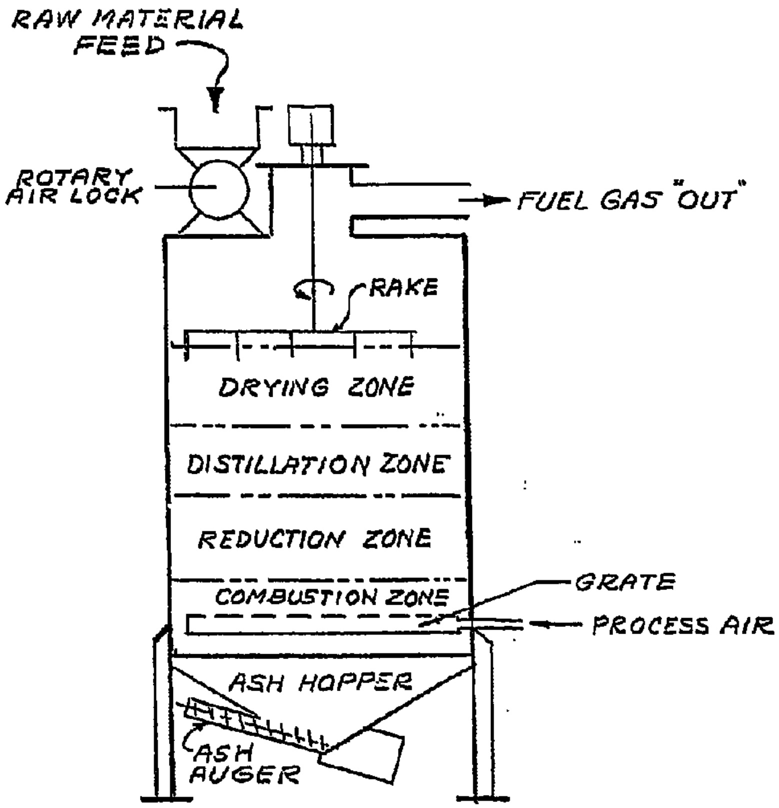


Figure 4-1. Applied Engineering Gasifier

Source: Reference 12.

A rotary valve meters fuel into the reactor vessel and also seals against leakage. A rake system continuously stirs the top layer of chips to prevent channelling. The grate is activated to dump ash into the ash hopper when the temperature in the region of the grate falls a proprietary preset amount, indicating a deep bed of ash. Although not shown on Figure 4-1, steam is injected below the grate (0.16 lb/lb dry feed) to cool the grate and increase the heating value of the gas by the steam carbon reaction. (Moisture in the feed is evaporated at the top and cannot react with carbon in an upflow gasifier.)

If possible, fuel gas should be transported to burners without condensing tars and oils. However, a liquid collection tank is provided to prevent slugs of liquids from entering the gas burner. The collected liquids are pumped separately to the dual-fuel burner and atomized, achieving complete combustion in the fuel gas flame.

The Rome, Georgia unit is retrofitted to one of three 19,000 lb/h type "O" watertube boilers which supplies heating and cooling needs of the Northwest Georgia Regional Hospital. Project specifications required that the unit be operational on green wood (50% moisture) at least 3,000 hours a year. The fuel is trucked in from northern Georgia logging sites in standard chip vans. The fuel is predominantly 2 inch by 2 inch chips with some pine needles, leaves, twigs, and bark. The typical moisture content is 40 to 50%, and the heating value is 4,000 to 5,000 Btu/lb.

The chips are dumped into a live bottom pit and are conveyed to a storage silo of 3.5 days capacity. The silo has a bottom unloader that feeds a reclaim conveyor that in turn feeds the rotary feed valve.

The cylindrical gasifier vessel is insulated with firebrick enclosed in a carbon steel shell. The dimensions are not given for this unit, but a photograph gives an idea of the size (13). The metal around the grate is water cooled.

No detailed description of the Lake City, Florida gasifier is available, but the gasifier itself is understood to be basically similar to the Rome gasifier.

In its development program, Applied Engineering installed and tested a prototype gasifier. The dimensions are given as 6 feet diameter by 11 feet high. Originally wood pellets rather than chips were fed through a lock system. The bed was supported by a cast iron grate. The gas was either burned in a 50 hp

Cleaver-Brooks firetube boiler or flared. Later in development, whole tree wood chips were gasified, and different methods of feeding chips and removing ash were tested.

Costs

Although economics is not the subject of this report, it is worth noting that the cost of a 25 million Btu/h system is estimated by the developer as $6,000,000 in 1981 dollars (12).

WESTWOOD POLYGAS GASIFIER

Overview of Status and Operability

The Westwood Polygas gasifier appears to be a slightly earlier state of development than the Applied Engineering updraft gasifier. In 1981, the gasifier was operated 63 days mainly in June, July, September, and October at less than half the design rate on wood chip feed, ending with a two-week continuous run. Reliable operation on sawmill waste was not demonstrated, even at a low fraction of expected capacity of 20 to 30 million Btu/h. Seventy-three operating days were achieved in 1980. Development has lagged because of labor strikes and low demand for forest products; the project gas is used to fire a drying kiln in a saw mill. The plant was indefinitely shut down in late 1981. SFA feels that the low specific capacity (42 lb wood/hr ft^2 cross section) of the gasifier places it at a competitive disadvantage until this factor is improved; however, the cost may not be completely defined by this factor.

Description of Installations

Expected performance data predicted for the Ainsworth Lumber plant are given in Table 4-2. Figure 4-2 is a sketch of the gasifier, two of which are installed at Ainsworth. The gasification plant consists of the gasifiers, fuel handling, gas cleaning, water and condensate handling, air and steam supply, gas flaring, and instrumentation. A typical cold start-up time is said to be four hours.

The gasifier reactor shown in Figure 4-2 is a double-walled vessel 10 ft OD x 20 ft high. The bottom part is refractory-lined. An inverted conical stainless steel liner and hydraulic ram "archbreakers" are installed to overcome bridging problems. The conical hearth has a rotating upper part and stationary lower part. Steam and air are injected through a single line to a distributor at the bottom. Ash is withdrawn through hydraulic gate valves for manual disposal. Fuel is fed through an airlock into a fuel dispersion cone, and product gas leaves at the top.

A feed conveyor carries feed to the airlock. The product gas is cleaned by cooled condensate in a wet cyclone. A scrubber is provided at Ainsworth but has not been operated yet. Operating problems have included plugging of condensate drains by char and unconverted fuel carried over by the gas.

Reportedly, the atmospheric pressure gasifier was designed for a space velocity of 2.5 h^{-1} of sawmill waste with an expected maximum output capacity of 20 to 30 million Btu/h (20 million given in Table 4-2). The heating value for the feed rate given in Table 4-2 appears to be insufficient to provide 20 million Btu/h output:

$$\left(9000\ \frac{\text{Btu}}{\text{lb}}\ \text{max}\right)\left(\frac{40 \times 2000 \times 0.65}{24}\ \frac{\text{lb}}{\text{hr}}\ \text{dry wood}\right) = 19.5 \times 10^{6}\ \frac{\text{Btu}}{\text{hr}}\ \text{input}$$

Table 4-2

EXPECTED PERFORMANCE OF WESTWOOD POLYGAS GASIFIER[a]

Gas Composition:	N_2	44.5 vol % of dry gas
	CO_2	9.0
	H_2	18.0
	CO	28.0
	Illuminants[b]	0.5
	Total	100.0
Gas calorific value:		150 Btu/scf (5.9 MJ/Nm^3)
Maximum reactor output:		20 x 10^6 Btu/h (21,000 MJ/h)
Fuel requirement (35% moisture chips):		40 tons/d (36 tonnes/d)

Note: Fuel should be sized to 4 in (100 mm) minus, and should have a moisture content of 25 to 50% (wet basis). Particle size and moisture content should be evenly distributed.

[a] Westwood Polygas estimates

[b] Term often used for unsaturated hydrocarbons

Source: Reference 14

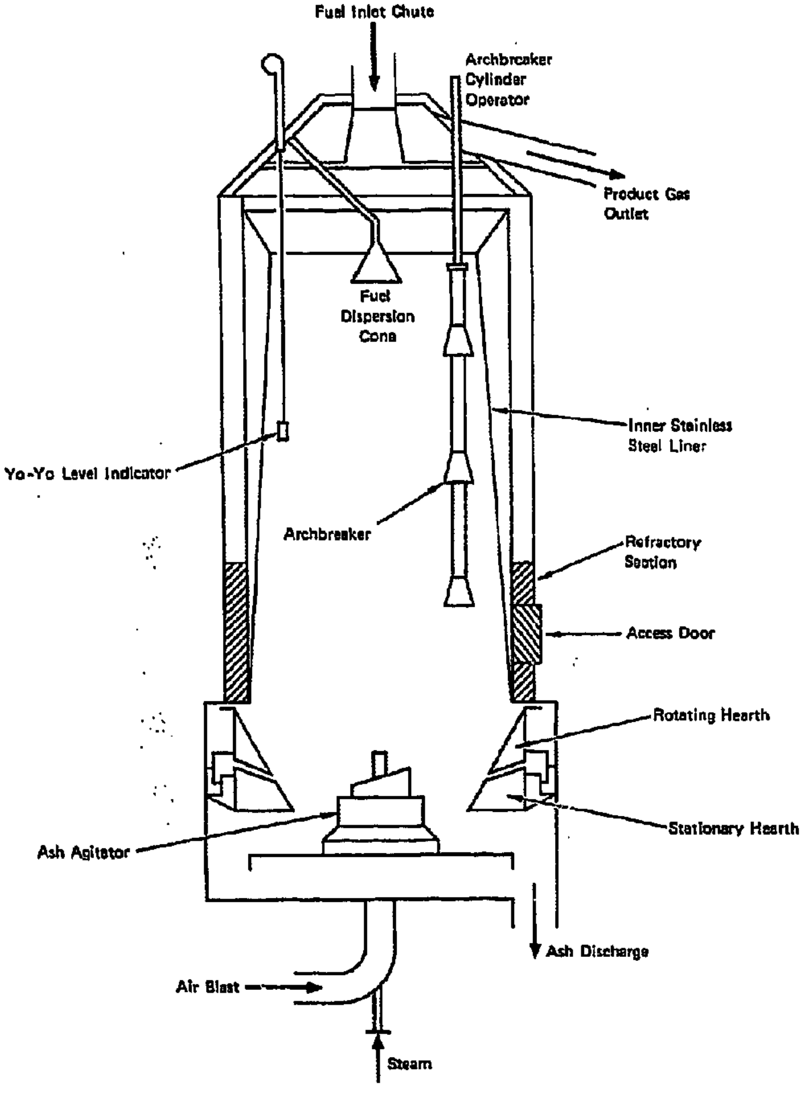


Figure 4-2. Westwood Polygas Gasifier

Source: Reference 14.

Section 5

REFERENCES

1. Technical Information Bulletin for Fuel Gas Production. Omnifuel brochure, 1981.

2. W. E. Ballantyne, et. al. "Energy Recovery from Municipal Solid Waste and Sewage Sludge Using Multisolid Fluidized-Bed Technology," (J. L. Jones and S. B. Radding, ed.) in Thermal Conversion of Solid Wastes and Biomass. Washington: American Chemical Society, 1980, pp. 109-123.

3. M. Pell and B. Johnson. "Conoco-Stone and Webster Solids Circulating Fluidized Bed Combustion," in Coal Technology '82, Volume 5 - Industrial/Utility Applications for Coal. Houston: Coal Technology Management, 1982, pp. 15-28.

4. Omnifuel Gasifier Handed Over to Levesque Plywood Ltd. Omnifuel Newsletter, September 1982.

5. J. W. Black. Private communication, December 1981.

6. International Critical Tables, Vol. 1, p. 393, 1926, through Hougen, Watson, and Ragatz, Chemical Process Principles, Part I, 2nd edition, New York: Wiley, 1954, p. xivv.

7. D. Ball, et. al. Study of Potential Problems and Optimum Opportunities of Retrofitting Industrial Processes to Low and Intermediate Energy Gas From Coal. Research Triangle Park, NC: Environmental Protection Agency, EPA-650/2-74-052, 1974.

8. D. R. Shoffstall and R. T. Waibel. Low-Btu Gas Combustion Research. Palo Alto, CA: Electric Power Research Institute, EPRI FP-848, August 1978.

9. A. Freedberg. "Performance Characteristics of Existing Utility Boilers When Fired With Low-Btu Gas," in Conference Proceedings, "Power Generation - Clean Fuels Today. Palo Alto, CA: Electric Power Research Institute, EPRI-SR-1, 1974, pp. 20-26.

10. L. Winsor. "Technical and Economic Comparison of Replacing Oil With Low or Medium Btu Gas in a Utility Power Plant Boiler," in Coal Technology '80, Volume 5 - Synthetic Fuels from Coal. Houston: Coal Technology Management, 1980, pp. 33-59.

11. E. B. Rogers, Jr. and K. C. Moh. Status of Wood Burning Systems as Sources of Energy (With Emphasis on Wood Gasification). Applied Engineering Company paper, February 1981.

12. J. F. Jackson. Wood Gasification Systems For the Northwest Regional Hospital, Rome, Georgia. Applied Engineering Company paper, July 1981.

13. Georgia Forestry Commission. Wood Gasification, A Unique Method of Extracting Energy from the Forests of Georgia. The Rome, Georgia Demonstration. Ca. 1981.

14. G. Gurnick. Private communication, November 1981.

15. J. W. Black. Private communication, July 1982.

Appendix A

DATA SHEETS* FROM OMNIFUEL GASIFICATIONS SYSTEMS LTD.

(Received January 28, 1982)

---

[*] Questionnaire developed by Synthetic Fuels Associates, Inc. under Phase I of EPRI Research Project 986-10.

Wood Gasifier Heat and Material Balance Data

General

Owner of equipment	Levesque Plywood Ltd.
Vendor or licensor	Omnifuel Gasification Systems Ltd.
Unit tested	Fluidized Bed Gasifier
Date of test	October 29/30

Dimensions: A drawing or sketch is desirable. Requested locations of instruments and sample points may be shown on a drawing (preferably a drawing to scale), showing key distances.

Flow Rates

Feedstock

Type of wood and description	Particle Board Sanderdust		
Meter constant and calibration date			
Times of measurements	19.30	to 20.15	
Meter readings	N/A		
Feed rates	9720 lb./hr.	(dry basis)	
Remarks	Rate is measured by diverting all of the flow for a period of time and weighing. The weights are averaged. The feed system is designed to be volumetric flow.		

Oxidant

Air or oxygen?	Air
Purity of oxygen, vol%	N/A
Meter formula	N/A
Calibration date	N/A
Times of measurements	
Meter readings	--
Feed rates	Proprietary
Remarks	--

Steam (if any)

Meter formula	None
Calibration date	N/A
Times of measurements	N/A
Meter readings	N/A
Feed rates	N/A
Remarks	N/A

Ash (fly ash and/or bottom ash)	Start Time	Finish Time	Pounds Collected	Rate lb/hr
Give Location #1: (Cyclone Ash)		~20.00		134
Give Location #2, if any: ( )				

Ash content of bed material removed: None

Ash (continued)

Remarks

Total Product Gas

Meter formula Not Measured

Date of calibration

Times of measurements ________ ________ ________

Meter readings

Flow rates

Remarks

Product Liquids

Where collected? No liquids collected. All compustible products are combusted in the burners. Gas temperature is maintained above 800°F.

If accumulated during test, give:

Time at start

Time at end

Volume* or weight at start

Volume* or weight at end

Remarks

---

*Report temperature of fluid if volume measurements are used and density at collection temperature in g/cc.

Product Liquids (continued)

If measured continuously, give:
Meter formula

Date of calibration

Time of measurements ________ ________ ________

Meter readings

Flow rates

N/A

Remarks

Inert bed material, if any

Pounds added during test

Added where?

Pounds removed during test

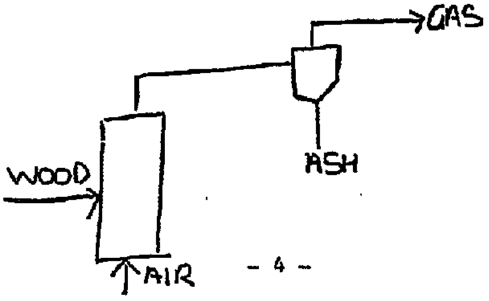
Removed where?

Remarks

Not added during test. Bed weight slowly decreases (less than 100 lbs./day.

Other streams

Give rates of any other streams added or removed during test in similar format.



No other streams are present.

Accumulations

Give changes, if any, in gasifier inventory:

Remarks:	Bed weight lb		Bed volume cu. ft.	
	Start	End	Start	End

Gasifier inventory decreased with time. Estimated at 100 lb./day.

Compositions

Feedstock

Location of sample point: Particle Board Sanderdust

Times of sampling ______ ______ ______

Describe sample preparation procedure:

Analysis by which lab? Forintek, Ottawa

Sample	#1	#2	#3
Composition, wt%:*			
Moisture, wet basis	5%	5%	
Carbon (C), dry basis	46.21	46.80	
Hydrogen (H), dry basis	5.92	6.04	
Oxygen (O), dry basis	42.49	41.74	
Sulfur (S), dry basis	Not detected		
Nitrogen (N), dry basis	4.97	5.00	
Ash, dry basis	0.41	0.42	
Higher heating value by calorimeter, Btu/lb bone dry	8464	8566	

Give ASTM or other test methods used for all above tests.

Remarks High nitrogen due to urea based glues in particle board.

---

*Heating values and compositions should be for same samples.

Product Gas

Location of sample point	After Secondary Cyclone
Times of sampling	______ ______ ______
Composition, volume %:	
Moisture, wet basis	Approximately 10%
Hydrogen (H_2), dry basis	6.70
Carbon monoxide (CO), dry basis	21.66
Methane (CH_4), dry basis	9.49
Other hydrocarbons, dry basis[*]	2.34
Carbon dioxide (CO_2), dry basis	56.06
Nitrogen (N_2), dry basis	
Hydrogen sulfide (H_2S), dry basis	Not measured
Other (name): Argon	.56
______	
______	
Higher heating value by calorimeter, Btu/lb	Not measured
Gas density, g/cc at 60° F	Not measured
Analysis by which lab?	Process G.C.

Give ASTM or other test methods used for all above tests

Remarks

[*] If other hydrocarbons are greater than 2 vol%, give breakdown.

Product Liquids*

Location of sample point N/A

Times of sampling ________ ________ ________

Water, wt%, wet basis

Composition, wt%, dry basis

Carbon (C)

Hydrogen (H)

Oxygen (O)

Sulfur (S)

Nitrogen (N)

Ash

Higher heating value by calorimeter,
Btu/lb bone dry oil

Liquid density, dry, 60° F, g/cc
Liquid density at sampling temperature

Temperature of sampling, °F

Analysis by which lab?

Give ASTM or other test methods used for above tests:

Remarks:

*If product liquid separates into two phases, report the following data for each phase separately.

Ash

Location of sample points: Ash from Cyclones

#1 (e.g., bottom ash)

#2 (e.g., fly ash)

Times of sampling				
Sample	#1	#2	#1	#2
Carbon content, wt%, dry basis	71			
Ash composition, wt%, dry basis				
SiO_2	29			
Al_2O_3				
Fe_2O_3				
CaO				
MgO				
Na_2O				
K_2O				

Analysis by which lab?

Give ASTM or other test method used for all above tests:

Remarks:

Temperatures, °F	Measurement Point Or Meter Number	Thermocouple Metals	Calibration Date	Temperatures, °F		
Time of test		Typek				
Feedstock temp. to gasifier				50		
Oxidant temp. to gasifier				721°F		
Steam temp. to gasifier				--		
Ash stream #1 (e.g., bottom ash) temp. from gasifier				--		
Ash stream #2 (e.g., fly ash) temp. from gasifier				--		
Product gas temp. from gasifier				1390		
Product liquid temp. at (give location)				--		
Gasifier surface temp. at (give location)						
#1				--		
#2						
#3						
Gasifier inside temp. at (give location)						
#1						
#2						
#3				~1400		

Narrative description of instruments and locations: If not previously defined, give description of measuring instruments and location (e.g., thermometer in wood feed line 3" below angle valve on screw conveyor).

Feedstock
Oxidant
Steam
Ash stream #1
Ash stream #2
Product gas
Product liquid

Remarks:

Pressures, psig	Measurement Point or Meter Number	Type of Instrument	Calibration Date	Pressures		
Time of test						
Gasifier inlet gas pressure, psig				3		
Gasifier outlet gas pressure, psig						
Bed differential pressure, psi						
Atmospheric pressure at site, psia						

Narrative description of locations: If not previously defined, give description of location (e.g., 3' upstream of nozzle at gasifier inlet).

Gasifier inlet
Gasifier outlet
Bed differential pressure

Remarks:

Entrainment

Particulates in product gas may be determined by isokinetic sampling. This data is desirable but not essential. If reported, give method used. Show location of measurement.

Auxiliary Energy Requirements

Time of test ________ ________ ________

Feedstock conveyor power, kW

Forced draft fan power, kW

Induced draft fan power, kW

Feedstock drier duty, million Btu/hr

Oxidant preheater duty, million Btu/hr

Entrainment

Isokinetic sampling - Environment Canada "Standard Reference Methods for Source Testing;" Measurement of Emissions of Particulates from Stationary Sources EPS-1-AP-74-1.

Particulate loading in Oil Heater stack .15 gran/scf at 12% CO_2

Containing 44% carbon

Appendix B

CALCULATIONS AND DESCRIPTIONS OF UNSUCCESSFUL BALANCES

This appendix gives derivation and documentation of the results and discussion of the rejected trials. Gaps existed in the reported experimental data so that analysis was not straightforward. Omnifuel was requested to fill out a data form to the extent possible; the Omnifuel reply is given in Appendix A. The principal gaps in the data include the air rate (considered proprietary), the gas rate (not measured), and the heating value of the gas.

The principal uncertainties in reported data are that the dry gas percentage compositions add up to 96.81 vol% rather than 100% (indicating that 3.19 vol% of the gas is missing) and that the water vapor content is uncertain because of experimental difficulties in its measurement. Furthermore, the sampling valve to the gas chromatograph reportedly leaked during the analysis because of corrosion. The corrosion was caused by a small amount of condensable matter, estimated as 0.1% by weight of the gas but not reported.

The data reported permit calculating heat and material balances, provided assumptions are made concerning the inconsistent and uncertain compositions. A valid material balance must close with respect to both total mass and the mass of each element. The element argon can be used to relate dry gas rate to air rate, since argon comes only from air. An assumption on the water vapor concentration and balances using carbon or nitrogen can then be used to establish the rates of all the streams. This method is the most direct, but the small concentrations of argon in air and in the product gas may result in large percentage errors.

Complete nitrogen analyses are available for feed, air, and dry gas, so these data and an assumption on the uncertain water vapor concentration also permit calculation of the unknown flow rates. (Originally nitrogen and carbon dioxide were reported aggregated, but a breakdown was obtained by telephone.)

The assumption used to force the dry gas composition to add up to 100% is quite important in making the elemental balances close along with total mass balances. In early trials the composition was normalized, and several water vapor concentrations were tried. Then the missing 3.19% was assumed to be nitrogen. All these trials gave poor elemental balances and probably optimistic thermal efficiencies. The seventh trial gave good elemental closures through a nitrogen balance. This trial assumed that the missing 3.19% was carbon dioxide, and that the water vapor concentration was that reported by Omnifuel. In addition, the calculated thermal efficiency was reasonable, but probably low, as previously discussed.

The following tables show the development of the final results. Table B-1 gives the data that were measured or could be calculated directly from Omnifuel measurements. Only the wood waste and ash had both flow rates and compositions measured. Two analyses were available for wood waste; these were averaged.

The first trial entailed several steps. Table B-1 shows that Omnifuel personnel gave only an estimate of the moisture content of the gas because their analyzer was giving trouble. Therefore, adjustment of water vapor concentration was allowable if necessary to close balances. Furthermore, the dry gas composition did not add up to 100%. To gain an initial estimate of the fuel gas composition, the dry gas composition was normalized, and moisture was taken as the value estimated by Omnifuel. A literature value was used for dry air composition (6) and 0.04 lb H_2O/lb dry air was assumed consistent with the cool temperatures at the plant location. Then three weight ratios were calculated from the compositions, namely, the ratio of dry wood to carbon, the ratio of dry air to argon, and the ratio of carbon to argon in the fuel gas. Combining these ratios gave the weight ratio of air to wood, which was multiplied by the wood rate to get the air rate.

The particulate loading in the fuel gas was found by estimating the total flow of flue gas after complete combustion and applying the measured figure of 0.15 grain/scf to it. The carbon on ash was lower at this point than in the fuel gas, so the mineral ash flow rate was calculated in the flue gas and assumed to be the same in the fuel gas. Carbon on particulate in the fuel gas was calculated from the ash analysis. The particulate flow amounts to a small correction, and these estimates were used for all the trials, except that the refinement of assuming carbon on particulate was 5% hydrogen was made in later trials.

Table B-1
REPORTED AND DIRECTLY CALCULATED DATA FROM OMNIFUEL

Component	Wood				Ash		Gas	
	Sample No. 1 wt %	Sample No. 2 wt %	Average wt %	Rate, lb/h	Analysis wt %	Rate, lb/h	Component	Analysis vol %
							H_2O[a]	Ca. 10
Moisture	5.00[a]	5.00[a]	5.00[a]	[b]			H_2	6.70
C	46.21	46.80	46.50	4,520	71	95	CO	21.66
H	5.92	6.04	5.98	638			CH_4	9.49
O	42.49	41.74	42.12	4,549			Other hydrocarbons	2.34
N	4.97	5.00	4.98	484			$CO_2 + N_2$	56.06
Ash	0.41	0.42	0.42	41	29	39	Ar	0.56
Total				10,232		134		
Higher heating value, Btu/lb bone dry	8,464	8,566						

[a] Wet basis. All other concentrations are on dry basis

[b] Moisture allocated to hydrogen and oxygen

Note: Particulate loading in oil heater stack 0.15 grain/scf at 12% CO_2, containing 44% carbon.

Since the moisture in the fuel gas was considered a preliminary estimate, it was adjusted by nitrogen balance for Trial No. 1. The nitrogen flows from wood and from air were added, and the sum was divided by the fraction of nitrogen in dry gas to give the total dry gas flow rate. The moisture in the fuel gas was then found by difference, giving a value of 7.10%.

The final results for Trial No. 1 are given in Table B-2. The percentage errors based on this nitrogen balance are large, especially for carbon and oxygen among the important elements.

In Trial No. 2, the same input rates were assumed as in Trial No. 1. The dry gas output was determined by dividing the argon rate in the input by the normalized concentration of argon in the dry output gas, and the moisture in the output was found by difference of total flows. This approach gave a very high water vapor concentration in the output gas (18 vol %) and poor balances, as shown in Table B-3. At this point, the hydrocarbons were being assumed as C_2H_6, but no adjustment of this composition would have made the balances acceptable.

Trial No. 3 was based on the observation that the first two trials seemed to have too little or too much water vapor in the fuel gas, and perhaps 12.5 vol % would give a good balance. Using this value and normalized dry gas composition, the required air rate and fuel gas rate to give this composition were calculated through a nitrogen balance:

$$(\text{N in wood})\ (\text{wood rate}) + (\text{N in air})\ (\text{air rate}) = (\text{N in gas})\ (\text{gas rate})$$

This approach eliminated dependence on the small argon concentration. The balances given in Table B-4 were improved, but the surplus of hydrogen and carbon and deficiency of oxygen in the output made the rather high calculated cold gas efficiency of about 81% seem unlikely. Also, the gas composition was very far from CO shift equilibrium. This and subsequent balances assume hydrocarbons in the gas are C_2H_4.

Table B-2
TRIAL NO. 1 ELEMENTAL BALANCES
Steam Rates in lb/h

Element	1 Wood	2 Air	Total In	3 Ash	4 Gas	Total Out	% Error $\left(\frac{\text{Out-In}}{\text{Out}}\right)$
C	4,520	0	4,520	95	4,977	5,072	+10.9
H	638	6	644		658	658	+2.1
O	4,549	3,253	7,808		7,220	7,220	-8.1
N	484	10,429	10,913		10,913	10,913	Basis
Ar	0	179	179		196	196	+8.7
Ash	41	0	41	39	11	500	+18.0
Total	10,232	13,867	24,099	134	23,975	24,109	0.0

Table B-3
TRIAL NO. 2 ELEMENTAL BALANCES
Stream Rates in lb/h

Element	1 Wood	2 Air	Total In	3 Ash	4 Gas	Total Out	% Error $\left(\frac{\text{Out-In}}{\text{Out}}\right)$
C	4,520	0	4,520	95	4,545	4,640	+2.6
H	638	6	644		861	861	+25.2
O	4,549	3,253	7,808		8,380	8,380	+6.8
N	484	10,429	10,913		9,989	9,989	-9.3
Ar	0	179	179		179	179	Basis
Ash	41	0	41	39	11	50	+18.0
Total	10,232	13,868	24,099	134	23,964	24,099	0.0

Table B-4
TRIAL NO. 3 ELEMENTAL BALANCES
Stream Rates in lb/h

Element	1 Wood	2 Air	Total In	3 Ash	4 Gas	Total Out	% Error $\left(\frac{\text{Out-In}}{\text{Out}}\right)$
C	4,520	0	4,520	95	4,483	4,578	+1.3
H	638	5	643		696	696	+7.6
O	4,549	2,929	7,478		7,328	7,328	-2.0
N	484	9,387	9,871		9,871	9,871	Basis
Ar	0	161	161		177	177	+9.0
Ash	41	0	41	39	11	50	+18.0
Total	10,232	12,482	22,714	134	22,566	22,700	-0.1

At this point, a new approach was tried. In Trial No. 4 the attempt was made to more closely approach shift equilibrium by reducing the H_2O in the product gas to 4 vol % while adjusting dry gas composition assuming the missing 3.19% was H_2 instead of normalizing the composition. Rates were calculated by nitrogen balance, as in Trial No. 3. In Trial No. 4 and subsequent trials, "carbon" on ash was assumed to be 5% hydrogen. Trial No. 4 gave very poor closure, as shown in Table B-5. Trial No. 5 paralleled Trial No. 4 except that the H_2O in product gas was assumed to be 8.6 vol % in an attempt to improve the balances. Although elemental balances were improved, this trial made it apparent that not all elements could be simultaneously balanced by assuming the missing 3.19% of dry gas was H_2. Trial No. 5 is shown in Table B-6.

Trial No. 6 assumed the missing 3.19% of dry gas was N_2, and H_2O was 10 vol % of fuel gas. The results, given in Table B-7, again were high in carbon and hydrogen and low in oxygen. This suggested that the only way to balance all the elements was to assume all or part of the missing 3.19% of dry gas was CO_2. This led to the successful trial, Trial No. 7, discussed earlier. Fortuitously, the H_2O in fuel gas was the same as originally estimated by Omnifuel.

Table B-5
TRIAL NO. 4 ELEMENTAL BALANCES
Stream Rates in lb/h

Element	1 Wood	2 Air	Total In	3 Ash	4 Gas	Total Out	% Error $\left(\frac{\text{Out-In}}{\text{Out}}\right)$
C	4,520	0	4,520	90	5,196	5,286	+14.5
H	638	6	644	5	547	552	-16.7
O	4,549	3,415	7,964		7,115	7,115	-11.9
N	484	10,946	11,430		11,430	11,430	Basis
Ar	0	188	188		204	204	+7.8
Ash	41	0	41	39	11	50	+18.0
Total	10,232	14,555	24,787	134	24,503	24,637	-0.6

Table B-6
TRIAL NO. 5 ELEMENTAL BALANCES
Stream Rates in lb/h

Element	1 Wood	2 Air	Total In	3 Ash	4 Gas	Total Out	% Error $\left(\frac{\text{Out-In}}{\text{Out}}\right)$
C	4,520	0	4,520	90	4,749	4,839	+7.1
H	635	5	643	5	652	657	+2.2
O	4,549	3,124	7,673		7,307	7,307	-4.8
N	484	10,015	10,499		10,479	10,479	Basis
Ar	0	172	172		188	188	+9.3
Ash	41	0	41	39	11	50	+22.0
Total	10,232	13,313	23,545	134	23,406	23,540	0.0

Table B-7
TRIAL NO. 6 ELEMENTAL BALANCES
Stream Rates in lb/h

Element	1 Wood	2 Air	Total In	3 Ash	4 Gas	Total Out	% Error $\left(\frac{\text{Out-In}}{\text{Out}}\right)$
C	4,520	0	4,540	90	4,799	4,799	+5.8
H	638	6	644	5	699	704	+8.5
O	4,549	3,373	7,922		7,482	7,482	-5.9
N	484	10,815	11,299		11,299	11,299	Basis
Ar	0	186	186		189	189	+1.6
Ash	41	0	41	39	11	50	+18.
Total	10,232	14,380	24,612	134	24,479	24,612	0.0

An objective measure of the "goodness of fit" of elemental material balance closures is the root mean square (RMS) of the percentage errors in the gaseous elements not used as the calculation basis. The tabulation below shows that Trial No. 7 gives the minimum error and the best fit:

Trial	RMS Error %
1	8.1
2	13.9
3	6.0
4	13.1
5	6.4
6	6.0
7	5.2

Appendix C

OMNIFUEL COMMENTS REGARDING EPRI/SYNTHETIC FUELS ASSOCIATES STUDY OF THE OMNIFUEL WOOD GASIFIER

We have reviewed the draft report on the Omnifuel gasifier by Synthetic Fuels Associates and we consider the information supplied by Omnifuel to have been presented in a very objective manner.

There is a suggestion in the report that the energy efficiencies appear to be low. We concur with this comment. Based on some additional data which we possess, we believe the hot gas flow to be low by about 7 percent. When this is converted to energy available in the gas, the HHV heat out becomes 66.63 MMBtu/hr instead of 62.27 MMBtu/hr with corresponding increases in sensible and latent heat. As a result the cold gas efficiency increases from 75.2 percent to 80.5 percent and the hot gas efficiency from 86.6 percent to 92.6 percent.

We also wish to acknowledge the fact that much of the information provided by Omnifuel resulted from a grant by the Ministry of Energy, Ontario.

John Black
Omnifuel