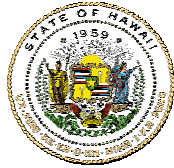


Preliminary Gasification Testing of Eucalyptus Fuels



Prepared for

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by

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Abstract

Biomass from debarked *Eucalyptus grandis* was used as fuel in a gasification test conducted in a benchscale, fluidized-bed gasifier by the Hawaii Natural Energy Institute at the University of Hawaii. The test was conducted at an equivalence ratio of 0.3 and a reactor temperature of 800°C. Reactor pressure varied from 7 to 48 kPa (1 to 7 psi) over the duration of the test and differential bed pressure was constant at 14 kPa (2 psi). Temperature distribution in the reactor, differential pressure across the dense bed, reactor pressure, and the composition of the product gas were monitored.

Using gas chromatography, the concentrations of H₂, CO, CH₄, and C₂H₄, the major combustible species in the product gas, were determined to be 5.9%, 15.2%, 4.3%, and 1.5%, respectively, with a corresponding higher heating value of 5.4 MJ per m³ (146 BTU per ft³) at 1 atm, 273 K. A gas yield of 2.0 m³ of gas (including N₂) per kg of fuel was determined for the process. On a N₂ free basis, the gas yield was 0.84 m³ per kg fuel.

1. Introduction

Biomass is the only renewable resource with the potential to produce power, fuels, and chemicals. Among renewable resources for energy generation, biomass is often a least cost alternative. As a fuel, biomass is highly flexible, as it can be used in direct combustion, combined heat and power (CHP) applications or it can be gasified (thermochemically or biologically) to produce a combustible gas that, after appropriate processing, can be used in gas-fuelled conversion technologies such as fuel cells, combustion turbines, and reciprocating engines. Biorefineries of the future will use biomass as a raw material and produce a suite of products including fuels, chemicals, and power, in much the same way that present day refineries produce an array of products from crude oil.

In a continuing effort to foster the development of biomass-based energy systems, the State of Hawaii, through its participation in the U.S. Department of Energy's, Pacific Regional Biomass Energy Program, has provided support for a the study of biomass fuels available in the State. An earlier report provided analysis of a number of wood materials identified as potential fuel sources on the island of Hawaii. Of these, the non-native *Eucalyptus grandis* has been identified as the tree species that is currently planted in greatest abundance. A potential harvesting strategy for plantation grown *E. grandis* would be to separate the bark, smaller diameter limbs, and leaves, from the trunk of the tree, or bole wood, and leave the bark, limbs, etc. in the forest to serve as ground cover and to return nutrients to the soil. The bole wood would be removed and used for forest products. Processing activities would generate a wood waste stream that could be used for the production of energy, fuels, or chemicals. Gasification is one of the central technologies that can be employed to produce these products. This report presents results of a test conducted in a bench scale fluidized bed gasifier to provide preliminary data on gasification characteristics of debarked *E. grandis*.

2. Materials and Methods

E. grandis fuel samples were obtained from plantation forests managed by Forest Solutions on the Hamakua coast of the island of Hawaii. The canopy portion of the tree comprising small diameter limbs and leaves was removed and the bark was removed from the bole wood. A photo of *E. grandis* and debarked *E. grandis* bolts are shown in Figure 1. The debarked bole wood was chipped and air dried to constant moisture, ~10% wet basis. The chipped material was further reduced in particle size using a hammer mill equipped with a 1/8th inch screen. A sample of the debarked *E. grandis* fuel lot was subjected to ultimate, proximate, heating value, chlorine, elemental ash, and ash deformation temperature analyses.



Figure 1. Bolts of debarked *E. grandis* that were processed for use in gasifier tests are shown at left. *E. grandis* with bark intact is shown at right.

The Hawaii Natural Energy Institute maintains a bench scale fluidized-bed gasifier facility to conduct gasification research, a schematic is shown in Figure 2. The fluidized bed gasifier has an internal diameter of 3.5". Typical fuel feed rates are in the range of 1 to 5 kg/hr. The gasifier and the high temperature SiC filter are initially heated to operating temperatures of 800°C and 725°C, respectively, using external electric heaters. When operating temperatures have been reached, fuel is metered to the gasifier from the sealed feed hopper using a calibrated metering screw. Air and/or steam are metered to the gasifier to maintain desired oxidizer to fuel ratios. As the fuel particles react and are reduced in size, some may escape the bed and are carried out of the reactor in the product gas stream. These are removed from the gas flow by a SiC candle filter with a 0.5 μm pore size, located downstream. The solids-free gas flows to a condenser where it is cooled and the resulting gas/liquid stream flows into a series of separator devices to remove condensate and aerosol. Gas exiting the separator section is directed to on-line infrared (CO, CO₂, and CH₄) and thermal conductivity (H₂) analyzers and grab samples are also collected for off-line analysis using gas chromatography. The product gas stream exiting the sampling system is combusted in a flare for final disposal.

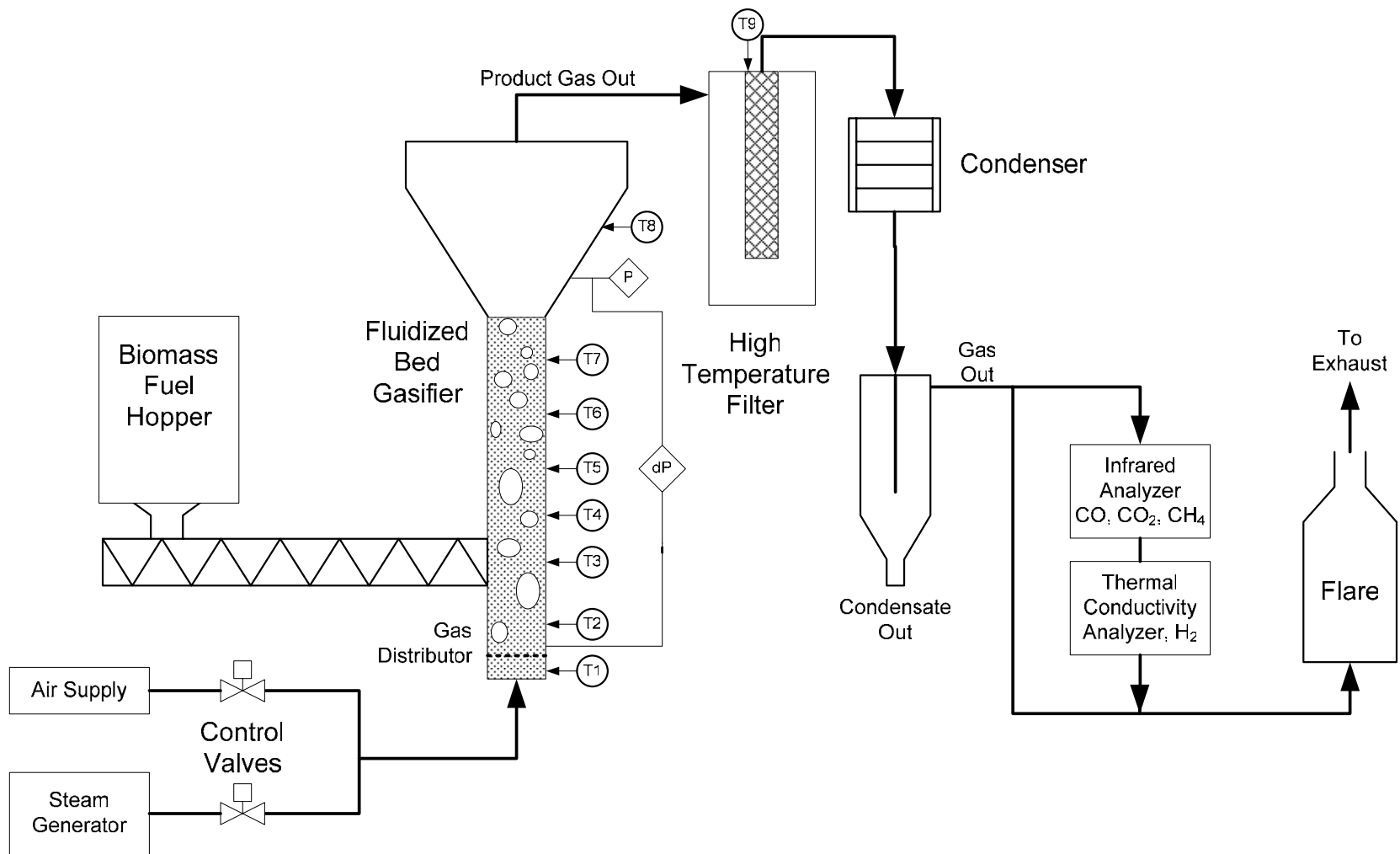


Figure 2. Schematic diagram of the gasifier facility at the University of Hawaii.

3. Results and Discussion

3.1 Fuel

Results of the fuel analysis are presented in Table 1. Proximate analysis shows the fuel contains 87% volatile material, 12% fixed carbon, and 0.4% ash on a dry weight basis. The heating value is 19.2 MJ/kg (8,237 BTU/lb), typical of clean, low-ash content biomass fuels. The elemental fuel analysis indicates that the fuel is low in sulfur (0.02%) and chlorine (0.01%) and contains 0.3% nitrogen on a dry weight basis. Fuel bound sulfur and nitrogen are potential contributors to emissions of criteria pollutants and chlorine can be a corrosive agent in high temperature energy conversion devices. The analysis of ash shows that the largest single constituent is CaO at 23.3%, followed by P₂O₅ and K₂O at 19.8 and 14.5%, respectively. The remaining ash components are present at concentrations of less than 10%.

Table 1. Results of fuel analyses performed on samples of *E. grandis*.

Proximate Analysis (% dry basis)		Elemental Analysis of Ash (% dry basis)	
Ash	0.42	SiO ₂	3.25
Volatile	87.34	Al ₂ O ₃	1.89
Fixed C	12.24	TiO ₂	0.16
		Fe ₂ O ₃	1.07
Heating Value		CaO	23.3
BTU/lb	8,237	MgO	4.85
MJ/kg	19.2	Na ₂ O	11
		K ₂ O	14.5
Ultimate Analysis (% dry basis)		P ₂ O ₅	19.79
C	51.12	SO ₃	2.67
H	5.72	Cl	0.88
N	0.33	CO ₂	9.98
S	0.02	Undetermined	6.66
Ash	0.42		
O (by diff)	42.38		
Cl	0.01		

3.2 Gasifier Tests

Tests were conducted in the HNEI gasifier using the debarked *E. grandis* fuel. Salient test parameters are summarized in Table 2. Graphs of reactor and filter temperatures and gas concentration over the course of the day when the test was conducted are shown in Figures 2 and 3. Temperatures, identified as T1 through T9 in the graphs, correspond to locations indicated in the facility schematic shown in Figure 1. The graphs show the initial fluidization of the bed, leak check, and instrument calibration periods from 08:00 to shortly after 10:00, followed by a reactor heat up period lasting until 12:41 when fuel feeding commenced. Fuel was fed to the gasifier for just over 2.5 hours, ending at 15:21. The system was purged with nitrogen and shut down shortly thereafter.

A total of 3.62 kg of fuel at 8.2% moisture content were metered to the reactor over the course of 2.6 hours. Reactor pressure varied from 7 to 48 kPa (1 to 7 psi) over the duration of the test and differential bed pressure was constant at 14 kPa (2 psi). Average gas composition for this period was determined from the data shown in Figure 3. H₂, CH₄, CO, and CO₂ concentrations were 5.1±0.3%, 4.7±0.2%, 14.7±0.7%, and 15.2±0.2%, respectively. Results from validating analyses using gas chromatography (GC) are presented in Table 3. In general, the GC results for H₂, CH₄, CO, and CO₂, are very similar to those from the on-line analyzers, but exhibit greater variation due to the limited number of samples. The GC analysis also identified trace amounts of the higher hydrocarbons ethane (C₂H₆), ethylene (C₂H₄), and acetylene (C₂H₂), with ethylene present in greatest concentration at 1.5%. Based on the GC results, the higher heating value of the gas was determined to be 5.4 MJ per m³ (146 BTU per ft³) at 1 atm, 273 K.

Gas yield was computed by two methods; the first relied on the known flow rate of N₂ into the system based on the air flow rate, the N₂ concentration in the dry product gas, the fuel feed rate as determined by the fuel mass in the feed hopper at the beginning and the end of the test, and the time period that fuel was fed to the reactor. The second method relied on measurements of dry product gas volume obtained from gas meters placed in the gas piping just prior to the flare shown in Figure 2 and the same measurements of fuel usage described above. Gas yields using the N₂ and gas meter measurement methods were calculated to be 2.06 and 1.97 m³ per kg of fuel, respectively. From these values, an inert free gas yield of 0.84 m³ per kg dry fuel can be computed.

Table 2. Summary of operating parameters for fluidized bed gasifier test.

Parameter	Value
Feedstock	Debarked <i>E. grandis</i>
Bed material in (kg)	10
Bed material out (kg)	9.8
Feedstock in (wet kg)	13.872
Feedstock out (wet kg)	10.25
Feedstock to reactor (wet kg)	3.622
Total run time (hr)	2.6
Feedrate (wet kg/hr)	1.39
Moisture content (% wet basis)	8.2
Feedrate (dry kg/hr)	1.279
Fuel ash content (% dry basis)	0.42
Fuel C content (% dry basis)	51.12
Fuel H content (% dry basis)	5.72
Fuel O content (% dry basis)	42.38
Fuel N content (% dry basis)	0.33
Air flow to reactor (lpm)	31.4
Oxygen flow to reactor (lpm)	6.6
Nitrogen flow to reactor (lpm)	24.8
Equivalence ratio	0.3
Average gasifier temperature (°C)	800±11
Average SiC filter temperature (°C)	680±5

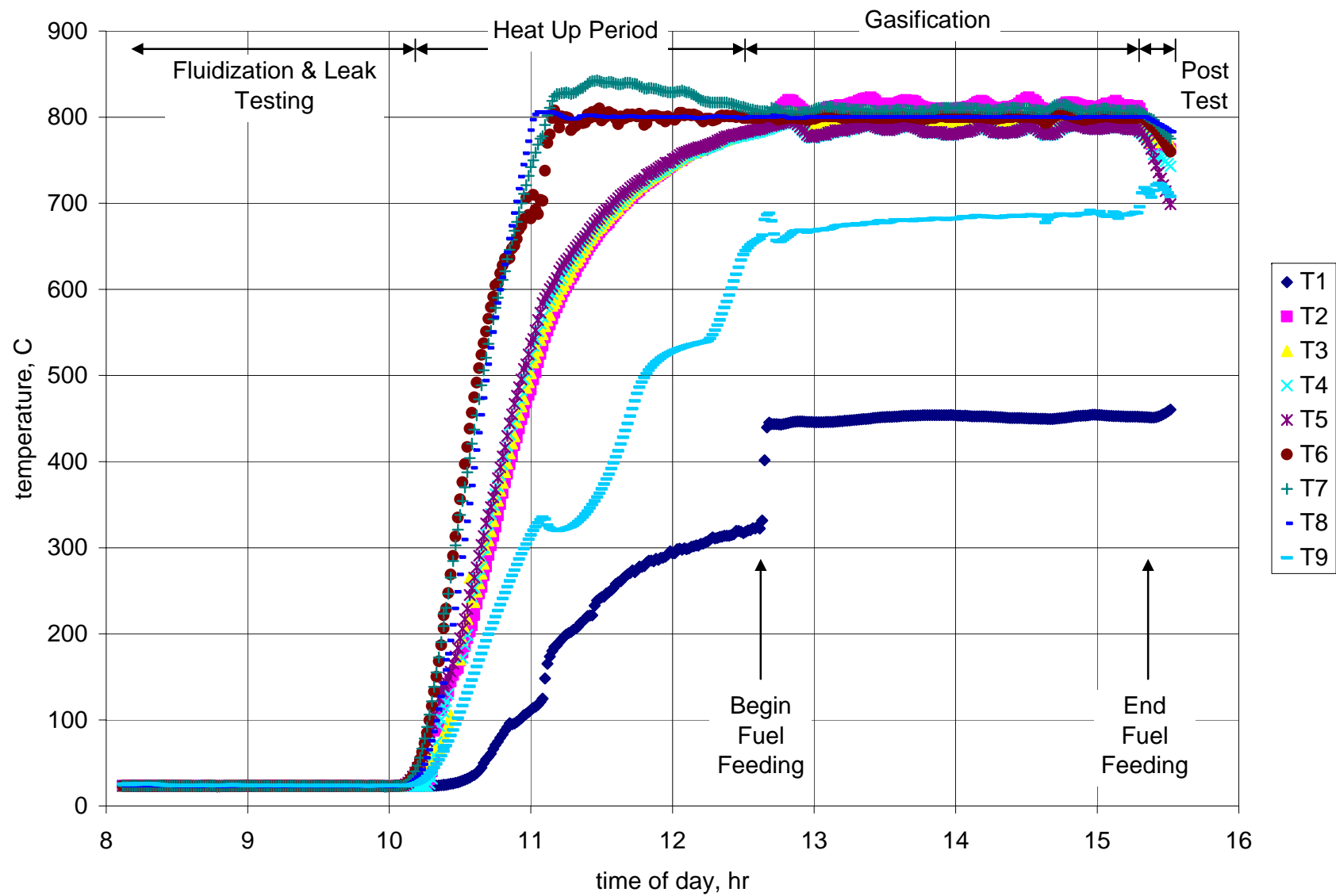


Figure 3. Temperature measurements at various points in the gasifier facility during the test period. Locations shown in Figure 2.

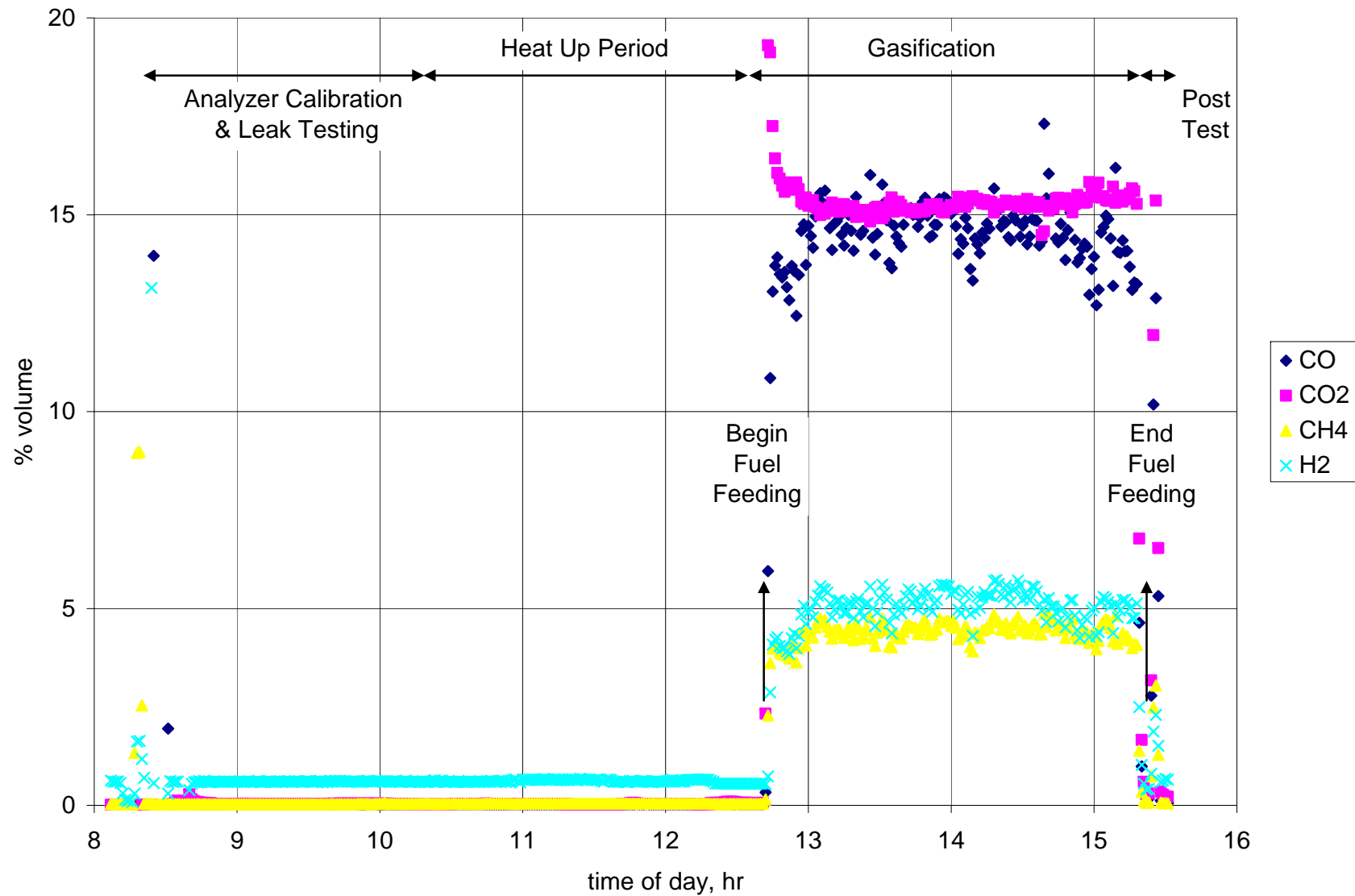


Figure 4. CO, CO₂, CH₄, and H₂ concentrations in the dry product gas from the gasification of *E. grandis* during the test period.

Table 3. Summary of off-line analysis of producer gas using gas chromatography.

Sample No.	1	2	3	4	Average±Standard Deviation
H ₂	6.5	4.5	5.8	6.9	5.9±1.0
N ₂	56.7	60.7	57.3	55.6	57.6±2.2
CO	15.6	13.5	15.1	16.4	15.2±1.2
CH ₄	4.4	3.8	4.2	4.7	4.3±0.4
CO ₂	15.1	15.8	15.7	14.8	15.4±0.5
C ₂ H ₂	0.1	0.1	0.1	0.1	0.1±0.0
C ₂ H ₄	1.4	1.5	1.6	1.4	1.5±0.1
C ₂ H ₆	0.1	0.1	0.2	0.1	0.1±0.1
Total	100.0	100.0	100.0	100.0	100.0

Conclusions

Biomass from debarked *Eucalyptus grandis* was used as fuel in a gasification test conducted in a benchscale, fluidized-bed gasifier by the Hawaii Natural Energy Institute at the University of Hawaii. The test was conducted at an equivalence ratio of 0.3 and a reactor temperature of 800°C. Reactor pressure varied from 7 to 48 kPa (1 to 7 psi) over the duration of the test and differential bed pressure was constant at 14 kPa (2 psi). Temperature distribution in the reactor, differential pressure across the dense bed, reactor pressure, and the composition of the product gas were monitored.

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