# Summary, Biomass Gasifier Facility Start-Up Tests — October and December 1995

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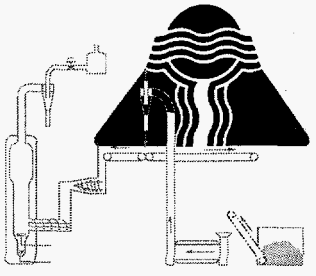



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# Summary, Biomass Gasifier Facility Start-Up Tests — October and December 1995

by

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## Contents

## Executive Summary

Shakedown testing of the biomass gasifier facility, located at the Hawaiian Commercial and Sugar Co. factory in Paia on the island of Maui, utilizing sugarcane bagasse, occurred in October 1995. Input and output streams for the process were sampled during three periods of steady-state operation in an air-blown mode. Additional tests were carried out in early December, 1995. Air and a mixture of air and steam were utilized as the fluidizing agent in the December operations, with two sampling periods occurring during air gasification and a single period under air-steam-blown conditions. This summary reports average values for the October test period, the December air-blown tests and the December air-steam tests (see following table). Details of individual tests are presented in the body of this report.

During the October sampling periods, the average reactor temperature and pressure were 1545°F (840°C) and 43 psi (300 kPa), respectively. Bagasse from the sugar factory entered the dryer at a nominal moisture content of 45% and exited at 26%, wet basis. Wet fuel feed rate to the reactor averaged 1.2 ton $hr^{-1}$ (1.1 tonne $hr^{-1}$). Average gas composition determined over the sample periods was 4% $H_2$, 10% CO, 18% $CO_2$, 3% $CH_4$, 1% $C_2$'s and higher hydrocarbons, and the balance $N_2$. The higher heating value of the gas was 100 Btu $ft^{-3}$ (3.7 MJ $m^{-3}$). Condensable hydrocarbons ($C_6$ and higher) in the output stream averaged 2.3% of dry fuel feed with benzene ($C_6H_6$) and naphthalene ($C_{10}H_8$) being the principal constituents. Carbon conversion efficiency, defined as the percentage of fuel carbon converted into gas or liquids, was estimated to be ~96%.

In December, the reactor was operated in air blown mode with increased wet bagasse feed rate and reactor pressure, 1.9 ton $hr^{-1}$ (1.7 tonne $hr^{-1}$) and 61 psi (420 kPa), respectively. Fuel moisture content was roughly 30%. These conditions resulted in improved gas quality with average composition determined as 5% $H_2$, 12% CO, 19% $CO_2$, 4% $CH_4$, 1% $C_2$'s and higher hydrocarbons, and the balance $N_2$, with a higher heating value of 121 Btu $ft^{-3}$ (4.5 MJ $m^{-3}$). Condensable hydrocarbons were reduced to 1.3% of dry fuel mass. Carbon conversion efficiency improved to 98%, 2% higher than the tests performed in October.

Near the end of the operational period in December, gasification with air and steam was carried out at a reactor temperature and pressure of 1575°F (860°C) and 73 psi (500 kPa). Wet fuel feed rate was 1.7 ton $hr^{-1}$ (1.6 tonne $hr^{-1}$), with a reduced moisture content of 17%. These conditions and the added steam resulted in improved gas quality and increased heating value. Composition was determined as 8% $H_2$, 12% CO, 18% $CO_2$, 7% $CH_4$, 1% $C_2$'s and higher hydrocarbons, and the balance $N_2$, with a higher heating value of 156 Btu $ft^{-3}$ (5.8 MJ $m^{-3}$). Carbon conversion efficiency was similar to the earlier runs.

Summary of BGF Test Results.

| | October (air) | December (air) | December (air/steam) |
|---|---|---|---|
| Temperature (°F) | 1545 | 1535 | 1575 |
| Pressure (psi) | 43 | 61 | 73 |
| Feed-rate (lb/h, wet basis) | 2310 | 3779 | 3441 |
| Feed moisture content (%) | 26 | 31 | 17 |
| Dry gas composition (volume %) | | | |
| $H_2$ | 4.4 | 5 | 8.5 |
| CO | 9.9 | 12 | 12.1 |
| $CO_2$ | 18.3 | 18.8 | 18 |
| $CH_4$ | 3.3 | 4.3 | 6.9 |
| $C_2$'s | 0.5 | 0.8 | 0.7 |
| $C_3$+'s | 0.3 | 0.3 | 0 |
| $O_2$ | 0 | 0 | 0 |
| $N_2$ | 62.5 | 58.6 | 49.2 |
| $H_2S$ | 0 | 0 | 0 |
| Heating value (Btu/$ft^3$, dry) | 100 | 121 | 156 |

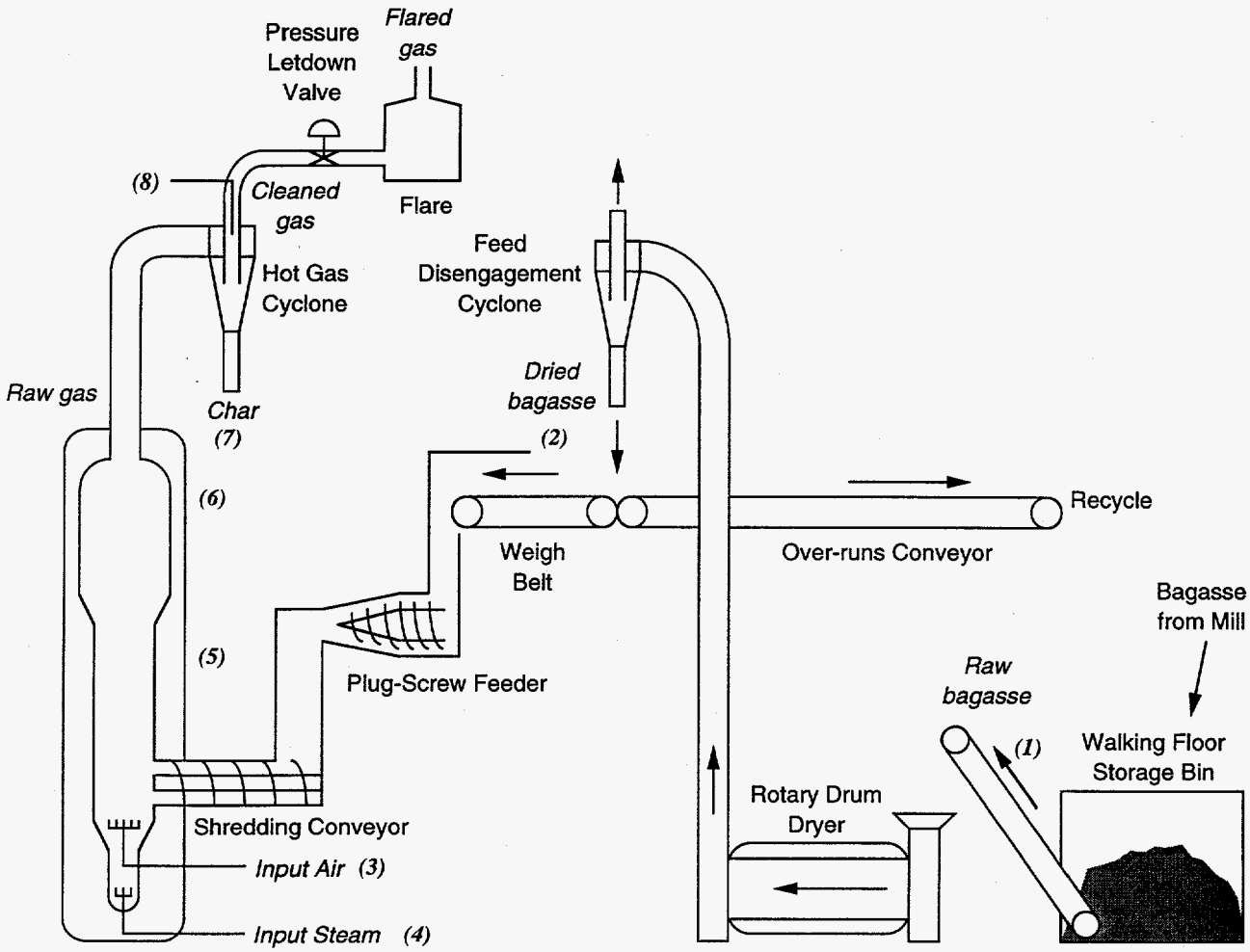
## Introduction

A primary objective of the biomass gasifier facility (BGF) test program is to obtain technical information on a near-commercial scale biomass gasification system that can be used in projecting the performance of commercial systems under actual operating conditions, formulating and assessing control strategies for commercial gasification systems and identifying optimal operating conditions for electric power generation or for methanol production. Mass and energy balances are two of the technical bases by which the performance of thermochemical conversion processes such as gasification is assessed. The data necessary to perform mass and energy balances on a process are obtained by identifying and quantifying individual input and output streams. To obtain this information, input/output sampling was performed at the BGF during three periods of steady state operation during the shake-down test, which took place October 2 to 9, 1995. Follow-on testing occurred on December 4 through 9, 1995, during which time input/output samples were collected in three steady state periods. This report summarizes the measurements and analyses performed for the six sampling periods and the resulting mass and energy balances.

## Methods

The data required to perform mass and energy balances were obtained by measuring input and output streams as shown in Figure 1. Bagasse feedrate into the reactor, steam and air input flowrates and gasifier temperatures and pressure were obtained from the WEStation Data Historian for each of the sample periods. Raw and dried bagasse moisture contents were determined from grab samples taken off the reclaim conveyor and weigh-belt, respectively. In addition, proximate and ultimate analyses and heating values were determined for the samples obtained from the weigh-belt. Ash fusion temperature and inorganic elemental composition were determined for selected weigh-belt samples from the October tests. Char removed from the process stream by the hot gas cyclone was collected and weighed for each sampling period. This char stream was subsampled and subjected to ultimate analysis. A 0.375" diameter probe was installed in the 6" diameter, refractory-lined pipe at the outlet of the hot gas cyclone to extract samples of the process stream. The sample stream was sequentially separated into solid, condensable and gas fractions using the conditioning system shown in Figure 2. Solids were removed in the heated filters. The sample stream was maintained at a temperature of 800 to 900°F prior to this point in order to maintain the condensable species in the vapor phase. After filtration, the sample stream temperature was reduced in two heat exchangers, the first using cold water, the second, cooled to ~32°F using a mechanical refrigeration unit. Resulting condensate was collected in drainpots and removed. The cooled gas passed through a coalescing filter to remove liquid aerosol and then through a pressure reducing valve, resulting in a dry stream at 15 psig. Gas was sampled and analyzed every 28 minutes by an on-line gas chromatograph (GC) utilizing dual thermal conductivity detectors (TCD) and a flame ionization detector (FID). Gas samples were also withdrawn in bombs in the interval between on-line sampling events, allowing for later off-line analyses. A mass flow meter was used to adjust the flow rate through the system, permitting the sample stream to be isokinetically withdrawn at the probe. Finally, the total flow through the sampling system over a given time period was determined by passing the entire flow through a dry test meter.

Although the sampling system was designed to isokinetically extract ~0.4 % of the total product gas flow, isokinetic conditions were never achieved due to restrictive, undersized filters. Sub-isokinetic flow at the probe inlet results in a sample of entrained char and particulate which is not representative of the distribution of particles present in the process stream. Gas and condensate which are separated from the sample stream in the gas conditioning unit are, however, representative of the total product flow.




## Legend

| Location | Stream | Measurements or Samples Collected |
|---|---|---|
| 1 | Raw bagasse | Grab samples for moisture content determination |
| 2 | Dried bagasse | Feed rate; grab samples for bagasse analysis |
| 3 | Input air | Flow rate |
| 4 | Input steam | Flow rate |
| 5 | Raw gas | Averaged temperature, pressure |
| 6 | Raw gas | Temperature for determination of hot-gas efficiency |
| 7 | Char | Discharge rate; representative samples for char analysis |
| 8 | Cleaned gas | Isokinetic sampling for determination of entrained solids, condensables, and gas rates and compositions |

Figure 1. Summary of Process Sampling and Sample Locations for BGF.

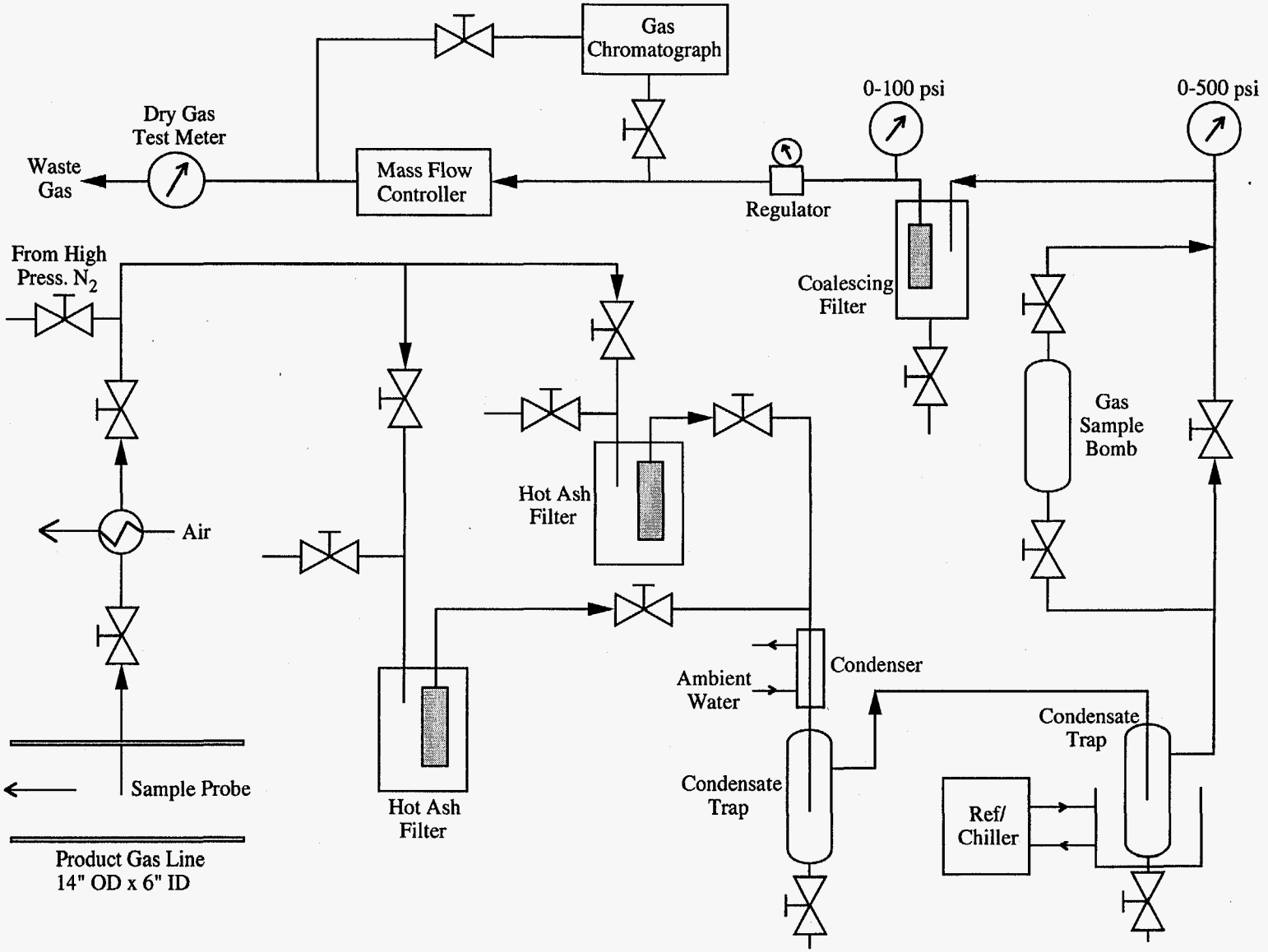



Figure 2. Sample Extraction and Conditioning System.

At the conclusion of a sampling period, filtered solids were removed, weighed and subjected to proximate analysis. The condenser section of the sample system was flushed to remove any remaining liquids. Gross condensate was separated into aqueous and tar/oil components using $CH_2Cl_2$, and each fraction quantified. The aqueous fraction was analyzed for chloride, nitrogen, sulfate, sodium and potassium. Subsamples of the tars and oils dissolved in $CH_2Cl_2$ were quantified by gas chromatography using a flame ionization detector. Utilizing the disparate boiling point of $CH_2Cl_2$ compared to the tars and oils in solution, the remainder of the condensate sample was separated. The resulting concentrated tar and oil sample was analyzed for heating value and the elements C, H, O, N, S and Cl.

## Results

Material and energy balances for the BGF were performed using data collected during six sampling periods, three each from the October and December 1995 tests. Note that condensate and entrained char samples were not collected during the final sampling period of the December tests (SP-3 – 12/7/95) due to plugging of the sample probe. Bagasse feed rate, air and steam flow rates, fuel moisture content, cyclone char quantity, and gas composition were measured during the period and are reported as such. Results of the material and energy balances are discussed in the following sections and are provided in the attached summary tables and appendices.

Measured input and output parameters and calculated quantities are summarized in Table 1 (Raw Data -- Unadjusted). Data obtained from the WEStation Data Historian for the six sample periods were used to compute an average value and coefficient of variation for each of the measured quantities. Values calculated from measured quantities, with the exception of equivalence ratio and carbon conversion efficiency, were determined using a material balance spreadsheet provided by IGT. Carbon conversion efficiency was determined using only bagasse feed rate, cyclone char quantity, and their respective ultimate analyses. Analytical results for the aforementioned process streams, as well as for entrained char, aqueous condensate, tar/oil in $CH_2Cl_2$ and rotovaped tars (tars separated from the $CH_2Cl_2$) are provided in Appendix A.

The coefficients of variation (CV) for the measured quantities are indicative of the degree to which steady state conditions were maintained over the sampling period. The CV's for reactor temperatures and air flow rates were generally less than 4%. Bagasse feed rate and gasifier pressure CV's were higher, ranging between 4 and 10%, with a single sample period, the initial period during the October tests, exhibiting a larger CV for bagasse feed rate of 14%.

A trend of improving gas quality is evident over the course of the successive sampling periods. Higher heating value of the product gas (dry, condensate-free) increases from 85 to 155 Btu $scf^{-1}$ due largely to the increasing $H_2$, CO and $CH_4$, and reduced $N_2$ levels.

Balances for the elements C, H, O, N and S and the inorganic ash fraction of the feedstock are summarized in Table 1. Tables used to compute these values are shown in Appendix B. The ability to balance elemental inputs and outputs is directly affected by the absolute amount of each element in the system at any given time, i.e., an element which comprises 50% of the mass in the system is generally easier to quantify than one present at levels below 0.1%, particularly when some material flows are sampled on a discrete rather than continuous basis. For the sampling periods in Table 1, the total mass in the system at any given time is comprised of 35-55% N, 30-40% O, 10-20% C, 2-4% H, 1-2% ash and less than 0.05% S. Nitrogen balances of 100% for all sample periods are a direct result of using the nitrogen contents of the input air stream (78% by volume) and product gas (determined by GC analysis) to compute the product gas flow rate. In effect, this forces N to balance.

Table 1. Raw Data -- Unadjusted.

| Test Date | 10/6/95 | 10/7/95 | 10/8/95 | 12/6/95 | 12/7/95 | 12/7/95 | |
|---|---|---|---|---|---|---|---|
| Sampling Period | SP-3 | SP-4 | SP-5 | SP-1 | SP-2 | SP-3 | Comments |
| Period Duration, h | 0.65 | 0.70 | 1.18 | 1.20 | 1.12 | 1.00 | |
| Temperature, °F [CV] | 1543 [2%] | 1548 [2%] | 1543 [2%] | 1459 [2%] | 1612 [2%] | 1575 [2%] | 1 |
| Pressure, psi [CV] | 41 [13%] | 41 [7%] | 46 [6%] | 35 [10%] | 86 [12%] | 73 [8%] | 1 |
| Bagasse Feedrate (wet), lb/h [CV] | 2242 [14%] | 2227 [9%] | 2460 [6%] | 3390 [4%] | 4167 [10%] | 3441 [5%] | 1 |
| Moisture Content, % | 25.4 | 19.5 | 33.75 | 31.62 | 31.33 | 16.85 | |
| Bagasse Feedrate (dry), lb/h | 1673 | 1793 | 1630 | 2318 | 2861 | 2861 | |
| Bagasse Composition (dry), wt% | | | | | | | |
| Carbon | 48.27 | 48.09 | 48.21 | 48.75 | 47.81 | 47.66 | |
| Hydrogen | 5.68 | 5.67 | 5.60 | 5.79 | 5.67 | 5.66 | |
| Oxygen | 42.33 | 42.16 | 42.56 | 41.64 | 41.55 | 41.61 | |
| Nitrogen | 0.15 | 0.14 | 0.12 | 0.22 | 0.27 | 0.21 | |
| Sulfur | 0.12 | 0.07 | 0.05 | 0.03 | 0.04 | 0.03 | |
| Ash | 3.46 | 3.89 | 3.47 | 3.57 | 4.66 | 4.83 | |
| Air to Gasifier Port, scfm [CV] | 531 [0%] | 457 [3%] | 486 [0%] | 497 [0%] | 513 [4%] | 394 [8%] | 1 |
| Air to Steam Sparge, scfm [CV] | 330 [2%] | 378 [1%] | 381 [1%] | 200 | 200 | 0 | 1,2 |
| Air to Preheater, scfm | 200 | 105 | 155 | 0 | 0 | 0 | |
| Total Air, scfm | 1061 | 940 | 1022 | 697 | 713 | 394 | |
| Steam to Steam Sparge, scfm | 0 | 0 | 0 | 0 | 0 | 200 | 2 |
| Cyclone Char (dry), lb | 68 | 97 | 139 | 108 | 81 | 108 | |
| Cyclone Char (dry), lb/h | 105 | 139 | 117 | 90 | 73 | 108 | |
| Entrained Char (dry), lb/h | 8.45 | 2.16 | 2.36 | 1.69 | 6.06 | 0 | 3 |
| Aqueous Condensate, lb/h | 1068 | 810 | 1295 | 890 | 826 | 0 | 3 |
| Product Gas (dry), lb/h | 6233 | 5506 | 6443 | 4500 | 4492 | 2721 | |
| Avg. Gas Comp., vol % | | | | | | | |
| $H_2$ | 3.83 | 4.49 | 4.99 | 4.28 | 5.77 | 8.46 | |
| $CO_2$ | 19.35 | 18.29 | 17.30 | 18.25 | 19.29 | 17.99 | |
| $C_2H_4$ | 0.44 | 0.36 | 0.75 | 1.17 | 0.22 | 0.55 | |
| $C_2H_6$ | 0.00 | 0.01 | 0.04 | 0.11 | 0.02 | 0.19 | |
| $O_2$/Ar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| $N_2$ | 65.35 | 64.41 | 57.87 | 58.32 | 58.96 | 49.20 | |
| $CH_4$ | 2.70 | 2.98 | 4.13 | 4.14 | 4.39 | 6.94 | |
| CO | 8.33 | 8.98 | 12.47 | 13.51 | 10.45 | 12.11 | |
| $C_3H_8$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| $C_3H_6$ | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | |
| $C_6H_6$ | 0.29 | 0.29 | 0.30 | 0.24 | 0.30 | 0.00 | |
| $H_2S$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| Total | 100.29 | 99.81 | 97.85 | 100.03 | 99.40 | 95.44 | |
| Equivalence Ratio | 0.51 | 0.43 | 0.51 | 0.24 | 0.19 | 0.11 | |
| Mass Balances, % | | | | | | | |
| Carbon | 112 | 94 | 136 | 69 | 49 | 37 | |
| Hydrogen | 107 | 93 | 119 | 59 | 49 | 20 | |
| Oxygen | 110 | 100 | 116 | 77 | 66 | 35 | |
| Nitrogen | 100 | 100 | 100 | 100 | 100 | 100 | |
| Sulfur | 4.8 | 7.0 | 8.9 | 8.2 | 3.2 | 2.5 | |
| Ash | 129 | 142 | 157 | 74 | 38 | 53 | |
| Gas Heating Value, Btu/scf (dry) | 85.1 | 91.1 | 124.8 | 129 | 112.7 | 155.5 | |
| Gas Yield, scf(dry)/lb feed (dry) | 47.2 | 39.4 | 51.4 | 25.0 | 19.0 | 12.9 | |
| Carbon Conv. to Gas & Liq., % | 108 | 89.5 | 132 | 66.4 | 47.7 | 34.7 | 4 |
| Carbon Conv. Efficiency, % | 96.3 | 95.4 | 96.3 | 97.7 | 98.7 | 97.4 | 5 |

1. Sampling Period Average [Coefficient of Variation]
2. Estimated for December Tests; transmitter at steam sparge ring not operational
3. December SP-3 sample not collected due to plugged sample probe
4. Based on actual measurements
5. Calculated as 100*(Input carbon – Lockhopper carbon)/Input carbon

Carbon, hydrogen, oxygen and ash balances for the October operations generally exceed 100%. The opposite is true for the December sampling periods, where inputs of all elements are consistently in excess of those found in the output. During the December tests, the differential pressure transmitter across the orifice meter in the line to the steam sparge was not functioning. As such, December flow rates for "air to steam sparge" (first two sampling periods) and "steam to steam sparge" (third sampling period) shown in Table 1 were estimated by on-site operations engineers. Another possible explanation for the consistent reversal in the bias of the element balances between the tests in October and those in December is the recalibration of the bagasse weigh belt which occurred during the interim period. The dubious nature of the air or bagasse flow rate measurements in December is supported by equivalence ratio calculations, also shown in the table. The higher bagasse feed rates (compared to October tests), observed reactor temperatures, and corresponding equivalence ratios suggest that the total input air flow rates are too low. It is unlikely that temperatures measured in the gasifier could be attained or maintained at equivalence ratios below 0.25. To investigate potential causes of the poor elemental balances, two adjustment procedures were performed.

The first adjustment procedure was a method prescribed by IGT. Quantities affected by the adjustment and their relative differences compared to the raw data are summarized in Table 2 (Adjusted Data -- IGT Adjustment Procedure). Selected pages from IGT's spreadsheet are included in Appendix C (Mass Balance Spreadsheet -- IGT Adjustment). The procedure employs input and output stream adjustment factors to force elemental balances. More specifically, ash was forced to balance by applying a multiplication factor to adjust the amount of cyclone char collected. A carbon balance was induced by employing a multiplication factor to adjust the input air flow. A sulfur balance was forced by using a multiplication factor to compensate for the loss of $H_2S$ in the aqueous condensate. Similarly, nitrogen was balanced by introducing a multiplication factor to compensate for the loss of $NH_3$ in the aqueous condensate. The final step of the IGT procedure was to balance hydrogen by adding water to the condensate in the required amount. No direct adjustment procedure was used to force an oxygen balance.

By the nature of the method, results from the IGT adjustment procedure, shown in Table 2, yielded complete closure of elemental balances with the exception of oxygen. According to the adjusted data, char collected from the cyclone exceeded the amount required for complete ash closure by up to 36% during the October campaign. Also, input air flow may have been inaccurately measured by up to 26%. Percent differences between adjusted and raw quantities for the December tests indicate that both cyclone char and input air flow may have been underestimated. Based on the adjusted data, plausible equivalence ratios (ranging from 0.31 to 0.38) were calculated for the December tests.

In a second effort to reconcile the material balances, a "single number adjustment" was sought based on the perceived uncertainties associated with the measured input and output streams. Input air flow rate was identified as being the measurement instilling the least amount of confidence, particularly during the December tests. Based on bagasse ultimate analysis, product gas analysis and stoichiometry, a single correction factor was calculated for the total input air flow which balanced nitrogen and equated fuel carbon with product gas carbon. Results of this adjustment procedure are summarized in Table 3 (Adjusted Data -- HNEI Adjustment Procedure). Selected pages from the same material balance spreadsheet used for the raw data calculations but utilizing the adjusted input air flow rate are provided in Appendix D (Mass Balance Spreadsheet -- HNEI Adjustment). All other input and output streams were assumed to be measured accurately during the tests.

Table 3 summarizes the changes produced by the single air flow adjustment on affected quantities; entrained char, product gas flow rate and aqueous condensate. Each scales directly with air flow rate via the nitrogen balance, and as a result all are changed by the same percentage. Differences in

Table 2. Adjusted Data -- IGT Adjustment Procedure.

| Date | 10/6/95 | 10/7/95 | 10/8/95 | 12/6/95 | 12/7/95 | 12/7/95 | |
|---|---|---|---|---|---|---|---|
| Sampling Period | SP-3 | SP-4 | SP-5 | SP-1 | SP-2 | SP-3 | Comments |
| Cyclone Char (Raw), lb/h | 105 | 139 | 117 | 90 | 73 | 108 | |
| Cyclone Char (Adj.), lb/h | 81 | 98 | 75 | 121 | 191 | 204 | |
| Adjustment Factor | 0.774 | 0.705 | 0.636 | 1.352 | 2.630 | 1.892 | 6 |
| % Diff. (Adj. vs. Raw), % | -23 | -30 | -36 | 35 | 163 | 89 | |
| Entrained Char (Raw), lb/h | 8.45 | 2.16 | 2.36 | 1.69 | 6.06 | 0 | |
| Entrained Char (Adj.), lb/h | 7.57 | 2.33 | 1.74 | 2.47 | 12.19 | 0 | 7 |
| % Diff. (Adj. vs. Raw), % | -10 | 8 | -26 | 46 | 101 | — | 8 |
| Total Input Air (Raw), scfm | 1061 | 940 | 1022 | 697 | 713 | 394 | |
| Total Input Air (Adj.), scfm | 951 | 1013 | 752 | 1016 | 1433 | 1080 | |
| Adjustment Factor | 0.896 | 1.078 | 0.736 | 1.457 | 2.010 | 2.740 | 9 |
| % Diff. (Adj. vs. Raw), % | -10 | 8 | -26 | 46 | 101 | 174 | |
| Product Gas (Raw), lb/h | 6233 | 5506 | 6443 | 4500 | 4492 | 2721 | |
| Product Gas (Adj.), lb/h | 5584 | 5936 | 4742 | 6556 | 9028 | 7455 | 7 |
| % Diff. (Adj. vs. Raw), % | -10 | 8 | -26 | 46 | 101 | 174 | |
| Aqueous Condensate (Raw), lb/h | 1068 | 810 | 1295 | 890 | 826 | 0 | |
| Aqueous Condensate (Adj.), lb/h | 1078 | 882 | 1342 | 1890 | 1786 | 1895 | |
| Adjustment Factor | 4.60 | 0.32 | 27.20 | 42.00 | 8.10 | 112.30 | 10 |
| % Diff. (Adj. vs. Raw), % | 1 | 9 | 4 | 112 | 116 | — | 8 |
| Equivalence Ratio (Raw) | 0.51 | 0.43 | 0.51 | 0.24 | 0.19 | 0.11 | |
| Equivalence Ratio (Adj.) | 0.46 | 0.46 | 0.38 | 0.35 | 0.38 | 0.31 | |
| % Diff. (Adj. vs. Raw), % | -10 | 7 | -25 | 46 | 100 | 182 | |
| Mass Balances (Raw), % Carbon | 112 | 94 | 136 | 69 | 49 | 37 | |
| Hydrogen | 107 | 93 | 119 | 59 | 49 | 20 | |
| Oxygen | 110 | 100 | 116 | 77 | 66 | 35 | |
| Nitrogen | 100 | 100 | 100 | 100 | 100 | 100 | |
| Sulfur | 4.8 | 7.0 | 8.9 | 8.2 | 3.2 | 2.5 | |
| Ash | 129 | 142 | 157 | 74 | 38 | 53 | |
| Mass Balances (Adj.), % Carbon | 100 | 100 | 100 | 100 | 100 | 100 | |
| Hydrogen | 100 | 100 | 100 | 100 | 100 | 100 | |
| Oxygen | 109 | 104 | 113 | 119 | 109 | 133 | |
| Nitrogen | 100 | 100 | 100 | 100 | 100 | 100 | 11 |
| Sulfur | 100 | 100 | 100 | 100 | 100 | 4.8 | 8,12 |
| Ash | 100 | 100 | 100 | 100 | 100 | 100 | |
| Gas Yield, scf (dry)/lb feed (dry) | 42.3 | 42.4 | 37.8 | 36.4 | 38.1 | 35.5 | |
| Carbon Conv. to Gas & Liq., % | 96.3 | 96.5 | 97.5 | 96.8 | 95.9 | 95.1 | |
| Carbon Conv. Eff. (Raw), % | 96.3 | 95.4 | 96.3 | 97.7 | 98.7 | 97.4 | |
| Carbon Conv. Eff. (Adj.), % | 97.1 | 96.7 | 97.6 | 96.9 | 96.6 | 95.1 | |
| % Diff. (Adj. vs. Raw), % | -0.9 | -1.4 | -1.4 | 0.8 | 2.1 | 2.4 | |

6. Multiplication factor used to adjust Cyclone Char (forces Ash to balance)
7. Affected by Input Air adjustment
8. December SP-3 not adjustable (sample not collected due to plugged sample probe)
9. Multiplication factor used to adjust Input Air (forces Carbon to balance)
10. Additive term adds or subtracts pounds of hydrogen to adjust water in condensate (forces Hydrogen to balance)
11. Nitrogen forced to balance; multiplication factor used to compensate for the loss of ammonia in aqueous condensate
12. Sulfur forced to balance; multiplication factor used to compensate for the loss of H2S in aqueous condensate

Table 3. Adjusted Data -- HNEI Adjustment Procedure.

| Date | 10/6/95 | 10/7/95 | 10/8/95 | 12/6/95 | 12/7/95 | 12/7/95 | |
|---|---|---|---|---|---|---|---|
| Sampling Period | SP-3 | SP-4 | SP-5 | SP-1 | SP-2 | SP-3 | Comments |
| Input Air Adjustment Factor | 1.00 | 1.21 | 0.78 | 1.55 | 2.19 | 2.99 | 17 |
| Entrained Char (Raw), lb/h | 8.45 | 2.16 | 2.36 | 1.69 | 6.06 | 0 | |
| Entrained Char (Adj.), lb/h | 8.45 | 2.62 | 1.87 | 2.63 | 13.28 | 0 | 13 |
| % Diff. (Adj. vs. Raw), % | 0 | 21 | -21 | 56 | 119 | — | 14 |
| Total Input Air (Raw), scfm | 1061 | 940 | 1022 | 697 | 713 | 394 | |
| Total Input Air (Adj.), scfm | 1061 | 1137 | 807 | 1080 | 1561 | 1178 | 15 |
| % Diff. (Adj. vs. Raw), % | 0 | 21 | -21 | 55 | 119 | 199 | |
| Product Gas (Raw), lb/h | 6233 | 5506 | 6443 | 4500 | 4492 | 2721 | |
| Product Gas (Adj.), lb/h | 6233 | 6662 | 5090 | 6975 | 9837 | 8136 | 13 |
| % Diff. (Adj. vs. Raw), % | 0 | 21 | -21 | 55 | 119 | 199 | |
| Aqueous Condensate (Raw), lb/h | 1068 | 810 | 1295 | 890 | 826 | 0 | |
| Aqueous Condensate (Adj.), lb/h | 1068 | 980 | 1023 | 1380 | 1808 | 0 | 13 |
| % Diff. (Adj. vs. Raw), % | 0 | 21 | -21 | 55 | 119 | — | 14 |
| Equivalence Ratio (Raw) | 0.51 | 0.43 | 0.51 | 0.24 | 0.19 | 0.11 | |
| Equivalence Ratio (Adj.) | 0.51 | 0.51 | 0.40 | 0.37 | 0.41 | 0.34 | 16 |
| % Diff. (Adj. vs. Raw), % | 0 | 19 | -22 | 54 | 116 | 209 | |
| Mass Balances (Raw), % | | | | | | | |
| Carbon | 112 | 94 | 136 | 69 | 49 | 37 | |
| Hydrogen | 107 | 93 | 119 | 59 | 49 | 20 | |
| Oxygen | 110 | 100 | 116 | 77 | 66 | 35 | |
| Nitrogen | 100 | 100 | 100 | 100 | 100 | 100 | |
| Sulfur | 4.8 | 7.0 | 8.9 | 8.2 | 3.2 | 2.5 | |
| Ash | 129 | 142 | 157 | 74 | 38 | 53 | |
| Mass Balances (Adj.), % | | | | | | | |
| Carbon | 112 | 113 | 109 | 105 | 107 | 106 | |
| Hydrogen | 107 | 112 | 94 | 92 | 106 | 60 | |
| Oxygen | 110 | 110 | 101 | 104 | 112 | 77 | |
| Nitrogen | 100 | 100 | 100 | 100 | 100 | 100 | |
| Sulfur | 4.8 | 8.1 | 7.3 | 11 | 5.5 | 2.5 | |
| Ash | 129 | 142 | 157 | 74 | 38 | 53 | |
| Gas Yield, scf (dry)/lb feed (dry) | 47.2 | 47.6 | 40.6 | 38.7 | 41.5 | 38.7 | |
| Carbon Conv. to Gas & Liq., % | 96.3 | 108.3 | 104.6 | 103.0 | 104.5 | 103.8 | |

13. Affected by Input Air adjustment
14. December SP-3 not adjustable (sample not collected due to plugged sample probe)
15. Total Input Air adjusted by using adjusted Equivalence Ratio
16. Equivalence Ratio adjustment based on stoichiometry and nitrogen and carbon balances
17. Ratio of Adjusted Equivalence Ratio and Raw Equivalence Ratio; i.e., ER(Adj.)/ER(Raw)

these quantities are less than ~22% for the October tests. Substantially larger differences in these quantities for the December tests suggest that air flow was indeed underestimated. Elemental balances for all sampling periods generally improved with the application of the single adjustment factor, the exception being the second sampling period in the October tests.

Energy balances around the reactor for the six sampling periods were performed to yield cold and hot gas thermal efficiencies. Efficiencies on a $N_2$-free, dry basis are included in Table 4 (Energy Balance Results). Cold gas thermal efficiency is defined as the chemical energy of the product gas divided by the chemical energy of the bagasse. Hot gas thermal efficiency includes the sensible enthalpy component of the product gas, with the temperature of the product stream taken at the exit of the gasifier (Nozzle 21). Although the temperature at the exit of the hot gas cyclone where the product gas was sampled would have been the most appropriate for use in this calculation, the exit of the gasifier was the closest temperature measurement which was recorded on the WEStation Data Historian. Cold and hot gas efficiencies calculated using the raw unadjusted data ranged from 25 to 85%. The IGT adjustment procedure resulted in hot and cold gas efficiencies ranging from 45 to 77%, whereas the HNEI adjustment methodology produced a range from 50 to 85%. Because IGT's method forces closure on all balances except oxygen, efficiencies computed using the resulting inputs and outputs are in keeping with laws of energy conservation.

Limited comparison of the results presented above with those obtained from bagasse fueled tests performed using the RENUGAS® process development unit (PDU) at IGT has been undertaken due to obvious differences in operating conditions. IGT test reports for bagasse are at elevated pressure (~300 psig) and with steam and oxygen input flows preheated in excess of 700°F. Gas composition comparisons are only valid on a dry, $N_2$-free basis due to IGT's individual metering of fluidizing gases. Averaged BGF results and data reported as part of the test program conducted by IGT to provide engineering design information for the BGF are shown in Table 5. The data for the December air/steam sampling period for the BGF compares well with the data from the PDU tests. Major gas components differ by less than 3% (absolute) and higher heating values by ~10% (absolute).

Table 4. Energy Balance Results.

| Date | 10/6/95 | 10/7/95 | 10/8/95 | 12/6/95 | 12/7/95 | 12/7/95 | |
|---|---|---|---|---|---|---|---|
| Sampling Period | **SP-3** | **SP-4** | **SP-5** | **SP-1** | **SP-2** | **SP-3** | Comments |
| **Raw Data** | | | | | | | |
| Cold Gas Thermal Efficiency, % | 50.4 | 43.0 | 76.9 | 40.3 | 27.2 | 25.5 | 18 |
| Hot Gas Thermal Efficiency, % | 58.2 | 49.2 | 85.9 | 44.7 | 30.9 | 28.2 | 18,19 |
| **IGT Adjustment** | | | | | | | |
| Cold Gas Thermal Efficiency, % | 45.1 | 46.3 | 56.6 | 58.7 | 54.7 | 69.9 | 18 |
| % Diff. (Adj. vs. Raw), % | -11 | 8 | -26 | 46 | 101 | 174 | |
| Hot Gas Thermal Efficiency, % | 52.2 | 53.0 | 63.2 | 65.2 | 62.1 | 77.4 | 18,19 |
| % Diff. (Adj. vs. Raw), % | -10 | 8 | -26 | 46 | 101 | 174 | |
| **HNEI Adjustment** | | | | | | | |
| Cold Gas Thermal Efficiency, % | 50.4 | 51.1 | 60.7 | 62.4 | 59.6 | 76.3 | 18 |
| % Diff. (Adj. vs. Raw), % | 0 | 19 | -21 | 55 | 119 | 199 | |
| Hot Gas Thermal Efficiency, % | 58.2 | 58.5 | 67.9 | 69.3 | 67.6 | 84.4 | 18,19 |
| % Diff. (Adj. vs. Raw), % | 0 | 19 | -21 | 55 | 119 | 199 | |

18. N2 free, dry basis
19. Temperature of product gas measured by thermocouple located at gasifier exit (Nozzle 21)

Table 5. Comparison of BGF and PDU Test Results.

| | BGF October (air) | BGF December (air) | BGF December (air/steam) | IGT PDU* 1992March ($O_2$/$N_2$/steam) |
|---|---|---|---|---|
| Temperature (°F) | 1545 | 1535 | 1575 | 1568 |
| Pressure (psig) | 43 | 61 | 73 | 310 |
| Feed-rate (lb/h, wet basis) | 2310 | 3779 | 3441 | 560 |
| Feed moisture content (%) | 26 | 31 | 17 | 18 |
| Gas Composition, dry, $N_2$-free basis (volume %) | | | | |
| $H_2$ | 12.0 | 12.1 | 18.4 | 18.1 |
| CO | 27.0 | 29.1 | 26.2 | 26.1 |
| $CO_2$ | 49.9 | 45.6 | 39.0 | 37.6 |
| $CH_4$ | 9.0 | 10.4 | 14.9 | 17.3 |
| $C_2$'s | 1.4 | 1.9 | 1.5 | 0.5 |
| $C_3$+'s | 0.8 | 0.7 | 0.0 | 0.3 |
| Heating value (Btu/ft$^3$, dry, $N_2$ free) | 267 | 292 | 307 | 338 |

* Source: Carty, R.H., M. Onischak, J. Gissy. 1992. "Biomass gasifier scale-up demonstration facility: Progress Report for the Period 2/28/92 through 5/27/92." pp. 24-25. Work performed for PICHTR by IGT. Contract No. DE-FC02-91CH10407.

## Summary and Conclusions

Testing at the BGF occurred over two periods in October and December of 1995. Complete sampling of the process's input and output streams was conducted for three steady state periods of air-blown operation during the October tests with two additional sampling periods obtained in the December effort. Near the conclusion of the December test, during a period of air-steam gasification, a sixth sampling period was used to collect input/output information on all but the condensate and entrained char streams.

Information concerning input quantities, with the exception of bagasse moisture content, was obtained from the WEStation Data Historian. Gas, condensable species and entrained char samples were extracted from the process flow using an isokinetic sampling system and gas conditioning unit. Char removed by the hot gas cyclone was quantified gravimetrically.

In general, gas quality improved over successive sampling periods -- higher heating values increased from 85 to 155 Btu scf$^{-1}$. Hydrogen, carbon monoxide and methane levels increased and diluent nitrogen levels were reduced. Interpretation of the data beyond the gas analyses is hampered by poor closure of elemental balances for the raw data collected during the sampling periods, particularly those in December which result primarily from inaccurate or unavailable air and steam input flowrates and possibly from erroneous values for bagasse feedrates to the reactor. These deficiencies should be addressed before additional testing is attempted. Furthermore, the isokinetic sampling/sample conditioning system should be modified to permit adequate flowrates to be attained at the sample probe inlet.

Two methods for varying input/output streams to the process were pursued in order to gain better elemental closures. The first, IGT's procedure, utilized five factors to sequentially adjust cyclone char weight, input air flowrate, aqueous condensate $H_2S$ and $NH_3$ levels, and mass of aqueous condensate weight. By design, this method assures closure of all elemental balances except oxygen.

HNEI devised an alternative, single factor adjustment to arrive at a more plausible input air flow rate since the measurement of this quantity was deemed to have the greatest error. The adjustment resulted in elemental closure to within 13% for the major constituents present in the system, C, H, O and N.

# Appendix A
# Sample Analytical Reports

## BGF Sample List — October Tests

| No. | Samp. Per. | Sample | Date | Time | Comments | Analysis | Lab. | I.D. | Date Sent | Total | Sent | Kept |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | — | bagasse | 10/6/95 | 400 | dried | — | — | | — | 69.0 | 0.0 | 69.0 |
| 2 | SP3 | bagasse | 10/6/95 | 2200 | MC=26.3%; tare=9.55 | Ult; Prox; Btu; Fus. temp & comp* | 1 | 2-SP3 | 10/24/95 | 74.6 | 26.4 | 48.2 |
| 3 | SP3 | bagasse | 10/6/95 | 2240 | MC=24.5% | Ult; Prox; Btu | 1 | 3-SP3 | 10/24/95 | 76.2 | 26.9 | 49.3 |
| 4 | SP4 | bagasse | 10/7/95 | 1445 | MC=23% | Ult; Prox; Btu; Fus. temp & comp* | 1 | 4-SP4 | 10/24/95 | 117.6 | 45.6 | 72.0 |
| 5 | SP4 | bagasse | 10/7/95 | 1542 | MC=16% | Ult; Prox; Btu | 1 | 5-SP4 | 10/24/95 | 89.3 | 34.6 | 54.7 |
| 6 | SP5 | bagasse | 10/8/95 | 130 | MC=33%; dried | Ult; Prox; Btu; Fus. temp & comp* | 1 | 6-SP5 | 10/24/95 | 65.2 | 18.9 | 46.3 |
| 7 | SP5 | bagasse | 10/8/95 | 200 | MC=34.5%; dried | Ult; Prox; Btu | 1 | 7-SP5 | 10/24/95 | 66.9 | 26.6 | 40.4 |
| 8 | SP3 | char; ash lockhop. | 10/6/95 | 2215-2254 | 2305; 68 lb dump; SJW | Ultimate analysis | 1 | 8-SP3 | 10/24,13 | 246.3 | 18.0 | 228.2 |
| 9 | SP4 | char; ash lockhop. | 10/7/95 | 1430 | steady state; tare=113.95 | Ultimate analysis | 1 | 9-SP4 | 10/24,13 | 297.1 | 15.1 | 282.0 |
| 10 | SP5 | char; ash lockhop. | 10/8/95 | 0134-0245 | cylone fines | Ultimate analysis | 1 | 10-SP5 | 10/24,13 | 375.4 | 17.8 | 357.7 |
| 11 | SP3 | char; isokin. S.S. | 10/6/95 | 2215-2254 | tare=27.0 | Proximate analysis | 1 | 11-SP3 | 10/24/95 | 2.2 | 2.2 | 0.0 |
| 12 | SP4 | char; isokin. S.S. | 10/7/95 | 1445 | gross=27.6; tare=26.7 | Proximate analysis | 1 | 12-SP4 | 10/24/95 | 0.9 | 0.9 | 0.0 |
| 13 | SP5 | char; isokin. S.S. | 10/8/95 | 0134-0245 | gross=27.5; tare=26.5 | Proximate analysis | 1 | 13-SP5 | 10/24/95 | 1.0 | 1.0 | 0.0 |
| 14 | SP3 | aqueous condensate | 10/6/95 | | tare=26.4 | N, S, Cl, Na, K | 1 | 14-SP3 | 10/24/95 | 35.7 | 20.3 | 15.4 |
| 15 | SP4 | aqueous condensate | 10/7/95 | | tare=26.4 | N, S, Cl, Na, K | 1 | 15-SP4 | 10/24/95 | 35.7 | 21.0 | 14.7 |
| 16 | SP5 | aqueous condensate | 10/8/95 | | | N, S, Cl, Na, K | 1 | 16-SP5 | 10/24/95 | 28.0 | 19.9 | 8.1 |
| 17 | SP3 | tars/oils in MeCl2 | 10/6/95 | | tare=26.0 | Composition (GC/FID) | 2 | 17-SP3 | — | 49.7 | 0.0 | 49.7 |
| 18 | SP4 | tars/oils in MeCl2 | 10/7/95 | | tare=26.0 | Composition (GC/FID) | 2 | 18-SP4 | — | 46.0 | 0.0 | 46.0 |
| 19 | SP5 | tars/oils in MeCl2 | 10/8/95 | | | Composition (GC/FID) | 2 | 19-SP5 | — | 47.3 | 0.0 | 47.3 |
| 20 | SP3 | rotovaped tars/oils | 10/6/95 | | tare=26.3 | Ultimate; Btu; Cl; comp.(GC/FID) | 1,2 | 20-SP3 | 10/24/95 | 14.4 | 7.2 | 7.1 |
| 21 | SP4 | rotovaped tars/oils | 10/7/95 | | tare=26.6 | Ultimate; Btu; Cl; comp.(GC/FID) | 1,2 | 21-SP4 | 10/24/95 | 17.8 | 9.9 | 8.0 |
| 22 | SP5 | rotovaped tars/oils | 10/8/95 | | tare=26.9 | Ultimate; Btu; Cl; comp.(GC/FID) | 1,2 | 22-SP5 | 10/24/95 | 14.2 | 7.5 | 6.7 |
| 26 | All | deposits from flare | 10/10/95 | — | | Elemental analysis of ash | 1 | 26-SPA | 10/24/95 | — | — | — |

* fusion temperature and elemental analysis of ash; I.D.'s are 2-3-SP3, 4-5-SP4, and 6-7-SP5

SP3: 10/6/95 (22:15 to 22:54)
SP4: 10/7/95 (14:50 to 15:32)
SP5: 10/8/95 (1:34 to 2:45)

Lab 1 — Hazen
Lab 2 — HNEI

## Tars/Oils Analysis (GC/FID) — October Tests

| | MeCl2 Wash | | | Rotovaped Tars | | |
|---|---|---|---|---|---|---|
| Sample ID | 17-SP3 | 18-SP4 | 19-SP5 | 20-SP3 | 21-SP4 | 22-SP5 |
| Compound Name | mg/ml | mg/ml | mg/ml | mg/g | mg/g | mg/g |
| Benzene, C6H6 | 0.390 | 0.482 | 0.445 | 127.27 | 28.23 | 8.09 |
| Toluene, C7H8 | 0 | 0 | 0 | 0 | 0 | 0 |
| Styrene, C8H8 | 0 | 0 | 0 | 0 | 0 | 0 |
| Xylene, C8H10 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phenol, C6H6O | 0 | 0 | 0 | 0 | 0 | 0 |
| a-Methylstyrene, C9H10 | 0 | 0 | 0 | 0 | 0 | 0 |
| Benzofuran, C8H6O | 0 | 0 | 0 | 0 | 0 | 0 |
| Indene, C9H8 | 0.063 | 0.284 | 0.227 | 0 | 0 | 0 |
| o-Cresol, C7H8O | 0 | 0 | 0 | 0 | 0 | 0 |
| Naphthalene, C10H8 | 1.016 | 2.466 | 2.182 | 225.81 | 218.93 | 272.96 |
| 1-Methylnaphthalene, C11H10 | 0.011 | 0.029 | 0.022 | 2.34 | 2.37 | 2.68 |
| Internal Standard (2-Ethylnaphthalene | 0.762 | 0.537 | 0.551 | 75.74 | 69.67 | 76.94 |
| Acenaphthylene, C12H8 | 0.288 | 0.738 | 0.542 | 60.32 | 59.43 | 66.58 |
| Acenaphthene, C12H10 | 0.012 | 0.025 | 0.023 | 4.01 | 2.51 | 2.97 |
| Fluorene, C13H10 | 0.057 | 0.150 | 0.109 | 14.24 | 11.17 | 13.59 |
| Phenanthrene, C14H10 | 0.535 | 1.274 | 0.866 | 117.13 | 77.04 | 104.26 |
| Anthracene, C14H10 | 0.087 | 0.215 | 0.146 | 25.33 | 13.13 | 17.59 |
| Fluoranthene, C16H10 | 0.258 | 0.581 | 0.365 | 56.45 | 32.93 | 42.77 |
| Pyrene, C16H10 | 0.255 | 0.561 | 0.348 | 55.57 | 31.86 | 41.40 |
| Chrysene, C18H12 | 0.071 | 0.118 | 0.039 | 18.99 | 9.73 | 11.32 |
| Benzo(k)fluoranthene, C20H12 | 0.039 | 0.082 | 0.003 | 11.88 | 6.74 | 8.40 |
| di-Benzoanthracene, C22H14 | 0.263 | 0.418 | 0.000 | 35.50 | 0 | 35.29 |
| Indenopyrene, C22H12 | 0.000 | 0.024 | 0.000 | 2.80 | 1.39 | 1.62 |

Notes: 1) mg/ml = mg of compound per ml of MeCl2 Wash
2) mg/g = mg of compound per g of rotovaped tar

**Hazen Research, Inc.**
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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-1
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
2-SP3

-

| Reporting Basis > | As Rec'd | | Dry | Air Dry |
|---|---|---|---|---|
| **Proximate (%)** | | | | |
| Moisture | 6.69 | | 0.00 | 3.53 |
| Ash | 3.72 | | 3.99 | 3.85 |
| Volatile | 78.52 | | 84.15 | 81.18 |
| Fixed C | 11.07 | | 11.86 | 11.44 |
| Total | 100.00 | | 100.00 | 100.00 |
| Sulfur | 0.15 | | 0.16 | 0.15 |
| Btu/lb (HHV) | 7381 | | 7911 | 7631 |
| MMF Btu/lb | 7689 | | 8266 | |
| MAF Btu/lb | | | 8240 | |
| Air Dry Loss (%) | | 3.28 | | |
| **Ultimate (%)** | | | | |
| Moisture | 6.69 | | 0.00 | 3.53 |
| Carbon | 44.61 | | 47.81 | 46.12 |
| Hydrogen | 5.27 | | 5.64 | 5.44 |
| Nitrogen | 0.14 | | 0.15 | 0.14 |
| Sulfur | 0.15 | | 0.16 | 0.15 |
| Ash | 3.72 | | 3.99 | 3.85 |
| Oxygen* | 39.42 | | 42.25 | 40.77 |
| Total | 100.00 | | 100.00 | 100.00 |
| Chlorine** | | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.15 | 0.16 |

Water Soluble Alkalies (%)

Na2O
K2O

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 5.04
Lb. SO2/MM Btu= 0.39
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

**Hazen Research, Inc.**
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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-2
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
3-SP3

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 5.69 | 0.00 | 2.80 |
| Ash | 2.77 | 2.93 | 2.85 |
| Volatile | 79.71 | 84.52 | 82.15 |
| Fixed C | 11.83 | 12.55 | 12.20 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | 0.08 | 0.08 | 0.08 |
| Btu/lb (HHV) | 7566 | 8022 | 7797 |
| MMF Btu/lb | 7798 | 8284 | |
| MAF Btu/lb | | 8264 | |
| Air Dry Loss (%) | 2.97 | | |
| **Ultimate (%)** | | | |
| Moisture | 5.69 | 0.00 | 2.80 |
| Carbon | 45.96 | 48.73 | 47.37 |
| Hydrogen | 5.38 | 5.71 | 5.55 |
| Nitrogen | 0.14 | 0.14 | 0.14 |
| Sulfur | 0.08 | 0.08 | 0.08 |
| Ash | 2.77 | 2.93 | 2.85 |
| Oxygen* | 39.98 | 42.41 | 41.21 |
| Total | 100.00 | 100.00 | 100.00 |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.08 | 0.08 |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 3.66
Lb. SO2/MM Btu= 0.21
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerard H. Cunningham
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-3
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
4-SP4

-

| Reporting Basis > | As Rec'd | | Dry | Air Dry |
|---|---|---|---|---|
| **Proximate (%)** | | | | |
| Moisture | 20.10 | | 0.00 | 3.81 |
| Ash | 4.05 | | 5.06 | 4.87 |
| Volatile | 66.40 | | 83.11 | 79.94 |
| Fixed C | 9.45 | | 11.83 | 11.38 |
| Total | 100.00 | | 100.00 | 100.00 |
| Sulfur | 0.05 | | 0.06 | 0.06 |
| Btu/lb (HHV) | 6333 | | 7927 | 7625 |
| MMF Btu/lb | 6622 | | 8385 | |
| MAF Btu/lb | | | 8349 | |
| Air Dry Loss (%) | | 16.94 | | |
| **Ultimate (%)** | | | | |
| Moisture | 20.10 | | 0.00 | 3.81 |
| Carbon | 38.09 | | 47.68 | 45.86 |
| Hydrogen | 4.50 | | 5.64 | 5.42 |
| Nitrogen | 0.12 | | 0.15 | 0.14 |
| Sulfur | 0.05 | | 0.06 | 0.06 |
| Ash | 4.05 | | 5.06 | 4.87 |
| Oxygen* | 33.09 | | 41.41 | 39.84 |
| Total | 100.00 | | 100.00 | 100.00 |
| Chlorine** | | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.05 | 0.06 |

Water Soluble Alkalies (%)

Na2O
K2O

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 6.39
Lb. SO2/MM Btu= 0.16
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-4
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
5-SP4

-

| Reporting Basis > | As Rec'd | | Dry | Air Dry |
|---|---|---|---|---|
| **Proximate (%)** | | | | |
| Moisture | 13.96 | | 0.00 | 3.57 |
| Ash | 2.33 | | 2.71 | 2.61 |
| Volatile | 73.75 | | 85.71 | 82.65 |
| Fixed C | 9.96 | | 11.58 | 11.17 |
| Total | 100.00 | | 100.00 | 100.00 |
| Sulfur | 0.06 | | 0.07 | 0.07 |
| Btu/lb (HHV) | 6936 | | 8061 | 7773 |
| MMF Btu/lb | 7114 | | 8304 | |
| MAF Btu/lb | | | 8285 | |
| Air Dry Loss (%) | | 10.77 | | |
| **Ultimate (%)** | | | | |
| Moisture | 13.96 | | 0.00 | 3.57 |
| Carbon | 41.73 | | 48.50 | 46.77 |
| Hydrogen | 4.90 | | 5.69 | 5.49 |
| Nitrogen | 0.12 | | 0.13 | 0.13 |
| Sulfur | 0.06 | | 0.07 | 0.07 |
| Ash | 2.33 | | 2.71 | 2.61 |
| Oxygen* | 36.90 | | 42.90 | 41.36 |
| Total | 100.00 | | 100.00 | 100.00 |
| Chlorine** | | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.06 | 0.07 |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 3.36
Lb. SO2/MM Btu= 0.18
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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FAX: (303) 278-1528

Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-5
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
6-SP5

-

| Reporting Basis > | As Rec'd | | Dry | Air Dry |
|---|---|---|---|---|
| **Proximate (%)** | | | | |
| Moisture | 6.55 | | 0.00 | 3.27 |
| Ash | 3.37 | | 3.61 | 3.49 |
| Volatile | 79.18 | | 84.73 | 81.96 |
| Fixed C | 10.90 | | 11.66 | 11.28 |
| Total | 100.00 | | 100.00 | 100.00 |
| Sulfur | 0.04 | | 0.04 | 0.04 |
| Btu/lb (HHV) | 7485 | | 8010 | 7748 |
| MMF Btu/lb | 7768 | | 8335 | |
| MAF Btu/lb | | | 8310 | |
| Air Dry Loss (%) | | 3.39 | | |
| **Ultimate (%)** | | | | |
| Moisture | 6.55 | | 0.00 | 3.27 |
| Carbon | 45.12 | | 48.28 | 46.70 |
| Hydrogen | 5.26 | | 5.63 | 5.44 |
| Nitrogen | 0.12 | | 0.12 | 0.12 |
| Sulfur | 0.04 | | 0.04 | 0.04 |
| Ash | 3.37 | | 3.61 | 3.49 |
| Oxygen* | 39.54 | | 42.32 | 40.94 |
| Total | 100.00 | | 100.00 | 100.00 |
| Chlorine** | | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.04 | 0.04 |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 4.50
Lb. SO2/MM Btu= 0.10
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerald H. Cunningham
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

**Hazen Research, Inc.**
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FAX: (303) 278-1528

Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-6
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
7-SP5

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 6.70 | 0.00 | 3.00 |
| Ash | 3.11 | 3.33 | 3.23 |
| Volatile | 79.17 | 84.86 | 82.31 |
| Fixed C | 11.02 | 11.81 | 11.46 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | 0.06 | 0.06 | 0.06 |
| Btu/lb (HHV) | 7512 | 8051 | 7810 |
| MMF Btu/lb | 7772 | 8351 | |
| MAF Btu/lb | | 8328 | |
| Air Dry Loss (%) | 3.81 | | |
| **Ultimate (%)** | | | |
| Moisture | 6.70 | 0.00 | 3.00 |
| Carbon | 44.91 | 48.13 | 46.69 |
| Hydrogen | 5.20 | 5.57 | 5.40 |
| Nitrogen | 0.12 | 0.12 | 0.12 |
| Sulfur | 0.06 | 0.06 | 0.06 |
| Ash | 3.11 | 3.33 | 3.23 |
| Oxygen* | 39.90 | 42.79 | 41.50 |
| Total | 100.00 | 100.00 | 100.00 |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.06 | 0.06 |

Water Soluble Alkalies (%)

Na2O
K2O

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 4.14
Lb. SO2/MM Btu= 0.15
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-7
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
8-SP3

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.73 | 0.00 | 0.73 |
| Ash | 70.56 | 71.08 | 70.56 |
| Volatile | | | |
| Fixed C | | | |
| Total | | | |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | 0.73 | 0.00 | 0.73 |
| Carbon | 28.60 | 28.81 | 28.60 |
| Hydrogen | 0.47 | 0.47 | 0.47 |
| Nitrogen | 0.14 | 0.14 | 0.14 |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Ash | 70.56 | 71.08 | 70.56 |
| Oxygen* | <0.01 | <0.01 | <0.01 |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.02 | 0.02 |

Water Soluble Alkalies (%)

Na2O
K2O

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerald H. Cunningham
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-8
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
9-SP4

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.75 | 0.00 | 0.75 |
| Ash | 70.71 | 71.24 | 70.71 |
| Volatile | | | |
| Fixed C | | | |
| Total | | | |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | 0.75 | 0.00 | 0.75 |
| Carbon | 28.52 | 28.74 | 28.52 |
| Hydrogen | 0.41 | 0.41 | 0.41 |
| Nitrogen | 0.13 | 0.13 | 0.13 |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Ash | 70.71 | 71.24 | 70.71 |
| Oxygen* | <0.01 | <0.01 | <0.01 |
| Chlorine** | | | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

| Forms of Sulfur (as S,%) | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.02 | 0.02 |

Report Prepared By:

Water Soluble Alkalies (%)

Na2O
K2O

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-9
Date Rec'd. 10/21/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
10-SP5

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.66 | 0.00 | 0.66 |
| Ash | 75.13 | 75.63 | 75.13 |
| Volatile | | | |
| Fixed C | | | |
| Total | | | |
| Sulfur | 0.01 | 0.01 | 0.01 |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | 0.66 | 0.00 | 0.66 |
| Carbon | 24.61 | 24.77 | 24.61 |
| Hydrogen | 0.41 | 0.41 | 0.41 |
| Nitrogen | 0.12 | 0.12 | 0.12 |
| Sulfur | 0.01 | 0.01 | 0.01 |
| Ash | 75.13 | 75.63 | 75.13 |
| Oxygen* | <0.01 | <0.01 | <0.01 |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.01 | 0.01 |

Water Soluble Alkalies (%)

Na2O
K2O

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-10
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
11-SP3

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.52 | 0.00 | 0.52 |
| Ash | 3.76 | 3.78 | 3.76 |
| Volatile | 5.38 | 5.41 | 5.38 |
| Fixed C | 90.34 | 90.81 | 90.34 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | | | |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | | | |
| Carbon | | | |
| Hydrogen | | | |
| Nitrogen | | | |
| Sulfur | | | |
| Ash | | | |
| Oxygen* | | | |
| Total | | | |
| Chlorine** | | | |
| **Forms of Sulfur (as S,%)** | | | |
| Sulfate | | | |
| Pyritic | | | |
| Organic | | | |
| Total | | | |
| **Water Soluble Alkalies (%)** | | | |
| Na2O | | | |
| K2O | | | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerard H. Gronhovd
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-11
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
12-SP4

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.82 | 0.00 | 0.82 |
| Ash | 7.12 | 7.18 | 7.12 |
| Volatile | 6.64 | 6.69 | 6.64 |
| Fixed C | 85.42 | 86.13 | 85.42 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | | | |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | | | |
| Carbon | | | |
| Hydrogen | | | |
| Nitrogen | | | |
| Sulfur | | | |
| Ash | | | |
| Oxygen* | | | |
| Total | | | |
| Chlorine** | | | |
| **Forms of Sulfur (as S,%)** | | | |
| Sulfate | | | |
| Pyritic | | | |
| Organic | | | |
| Total | | | |
| **Water Soluble Alkalies (%)** | | | |
| Na2O | | | |
| K2O | | | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-12
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
13-SP5

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.36 | 0.00 | 0.36 |
| Ash | 11.63 | 11.67 | 11.63 |
| Volatile | 13.06 | 13.11 | 13.06 |
| Fixed C | 74.95 | 75.22 | 74.95 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | | | |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | | | |
| Carbon | | | |
| Hydrogen | | | |
| Nitrogen | | | |
| Sulfur | | | |
| Ash | | | |
| Oxygen* | | | |
| Total | | | |
| Chlorine** | | | |
| **Forms of Sulfur (as S,%)** | | | |
| Sulfate | | | |
| Pyritic | | | |
| Organic | | | |
| Total | | | |
| **Water Soluble Alkalies (%)** | | | |
| Na2O | | | |
| K2O | | | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date November 8, 1995
HRI Project 002-1F
HRI Series No. J470/95
Date Rec'd 10/27/95
Cust. P.O. # 8574015

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road, Crawford 315
Honolulu, Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. J470/95-17
SAMPLE IDENTIFICATION: 14-SP3

| | |
|---|---|
| Chloride, mg/l | 300 |
| Nitrogen, mg/l | 1800 |
| Sulfate as SO4, mg/l | 154 |
| Sodium, mg/l | 16.0 |
| Potassium, mg/l | 0.4 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

**Hazen Research, Inc.**
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| | |
|---|---|
| Date | November 8, 1995 |
| HRI Project | 002-1F |
| HRI Series No. | J470/95 |
| Date Rec'd | 10/27/95 |
| Cust. P.O. # | 8574015 |

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road, Crawford 315
Honolulu, Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. J470/95-18
SAMPLE IDENTIFICATION: 15-SP4

| | |
|---|---|
| Chloride, mg/l | 267 |
| Nitrogen, mg/l | 2000 |
| Sulfate as SO4, mg/l | 164 |
| Sodium, mg/l | 11.4 |
| Potassium, mg/l | 0.2 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

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Date November 8, 1995
HRI Project 002-1F
HRI Series No. J470/95
Date Rec'd 10/27/95
Cust. P.O. # 8574015

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road. Crawford 315
Honolulu. Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. J470/95-19
SAMPLE IDENTIFICATION: 16-SP5

| | |
|---|---|
| Chloride, mg/l | 157 |
| Nitrogen. mg/l | 1300 |
| Sulfate as SO4. mg/l | 126 |
| Sodium. mg/l | 11.4 |
| Potassium. mg/l | 0.2 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

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| | |
|---|---|
| Date | November 8, 1995 |
| HRI Project | 002-1F |
| HRI Series No. | J470/95 |
| Date Rec'd | 10/27/95 |
| Cust. P.O. # | 8574015 |

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road, Crawford 315
Honolulu, Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. J470/95-20
SAMPLE IDENTIFICATION: 20-SP3

| | |
|---|---|
| Water, % | 0.60 |
| Ash, % | <0.001 |
| Sulfur, % | 0.037 |
| Carbon, % | 74.36 |
| Hydrogen, % | 4.70 |
| Nitrogen, % | 0.65 |
| Oxygen, %* | 19.65 |
| Calorific Value, BTU/lb (HHV) | 14338 |
| Chlorine, % | 13.70 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

* Oxygen by difference

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| | |
|---|---|
| Date | November 8, 1995 |
| HRI Project | 002-1F |
| HRI Series No. | J470/95 |
| Date Rec'd | 10/27/95 |
| Cust. P.O. # | 8574015 |

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road, Crawford 315
Honolulu, Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. J470/95-21
SAMPLE IDENTIFICATION: 21-SP4

| | |
|---|---|
| Water, % | 0.59 |
| Ash, % | <0.001 |
| Sulfur, % | 0.034 |
| Carbon, % | 79.05 |
| Hydrogen, % | 4.81 |
| Nitrogen, % | 0.16 |
| Oxygen, %* | 15.36 |
| Calorific Value, BTU/lb (HHV) | 14587 |
| Chlorine, % | 10.48 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

* Oxygen by difference

**Hazen Research, Inc.**
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| | |
|---|---|
| Date | November 8, 1995 |
| HRI Project | 002-1F |
| HRI Series No. | J470/95 |
| Date Rec'd | 10/27/95 |
| Cust. P.O. # | 8574015 |

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road. Crawford 315
Honolulu. Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. J470/95-22
SAMPLE IDENTIFICATION: 22-SP5

| | |
|---|---|
| Water. % | 0.37 |
| Ash. % | <0.001 |
| Sulfur. % | 0.019 |
| Carbon. % | 76.16 |
| Hydrogen. % | 4.75 |
| Nitrogen. % | 0.04 |
| Oxygen. %* | 18.66 |
| Calorific Value. BTU/lb (HHV) | 14363 |
| Chlorine. % | 11.44 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

* Oxygen by difference

**Hazen Research, Inc.**
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| | |
|---|---|
| Date | November 7 1995 |
| HRI Project | 002-1F |
| HRI Series No. | J470/95-16 |
| Date Rec'd. | 10/27/95 |
| Cust. P.O.# | 8574015 |

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification:
26-SPA

-

Elemental Analysis of Ash (%)

| | |
|---|---|
| SIO2 | 43.76 |
| AL2O3 | 20.70 |
| TIO2 | 5.03 |
| FE2O3 | 23.93 |
| CAO | 2.76 |
| MGO | 1.29 |
| NA2O | 0.21 |
| K2O | 2.05 |
| P2O5 | 0.99 |
| SO3 | 0.03 |
| CL | |
| CO2 | |
| Total | 100.75 |

Ash Fusion Temperatures (Deg F)

| | Oxidizing Atmosphere | Reducing Atmosphere |
|---|---|---|
| Initial Softening | | |
| Hemispherical | | |
| Fluid | | |

Report Prepared By:

Gerald H. Cunningham
Fuels Laboratory Supervisor

Note: The ash was calcined @ 1110 deg F (600 C) prior to analysis.

**Hazen Research, Inc.**
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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-13
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification:
2-3-SP3

-

Elemental Analysis of Ash (%)

| | |
|---|---|
| SIO2 | 40.37 |
| AL2O3 | 22.26 |
| TIO2 | 4.44 |
| FE2O3 | 21.78 |
| CAO | 3.73 |
| MGO | 1.31 |
| NA2O | 0.24 |
| K2O | 2.53 |
| P2O5 | 1.12 |
| SO3 | 0.63 |
| CL | |
| CO2 | |
| Total | 98.41 |

Ash Fusion Temperatures (Deg F)

| | Oxidizing Atmosphere | Reducing Atmosphere |
|---|---|---|
| Initial | 2341 | 2035 |
| Softening | 2456 | 2062 |
| Hemispherical | 2464 | 2071 |
| Fluid | 2470 | 2085 |

Report Prepared By:

Fuels Laboratory Supervisor

Note: The ash was calcined @ 1110 deg F (600 C) prior to analysis.

**Hazen Research, Inc.**
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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-14
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification:
4-5-SP4

-

Elemental Analysis of Ash (%)

| | |
|---|---|
| SIO2 | 40.31 |
| AL2O3 | 23.31 |
| TIO2 | 4.12 |
| FE2O3 | 22.57 |
| CAO | 3.47 |
| MGO | 1.26 |
| NA2O | 0.25 |
| K2O | 2.12 |
| P2O5 | 1.07 |
| SO3 | 0.52 |
| CL | |
| CO2 | |
| Total | 99.00 |

Ash Fusion Temperatures (Deg F)

| | Oxidizing Atmosphere | Reducing Atmosphere |
|---|---|---|
| Initial | 2405 | 2025 |
| Softening | 2462 | 2045 |
| Hemispherical | 2465 | 2060 |
| Fluid | 2467 | 2095 |

Report Prepared By:

Fuels Laboratory Supervisor

Note: The ash was calcined @ 1110 deg F (600 C) prior to analysis.

**Hazen Research, Inc.**
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Date November 7 1995
HRI Project 002-1F
HRI Series No. J470/95-15
Date Rec'd. 10/27/95
Cust. P.O.# 8574015

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification:
6-7-SP5

-

Elemental Analysis of Ash (%)

| | |
|---|---|
| SIO2 | 44.94 |
| AL2O3 | 21.19 |
| TIO2 | 3.05 |
| FE2O3 | 18.36 |
| CAO | 3.31 |
| MGO | 1.79 |
| NA2O | 0.29 |
| K2O | 3.11 |
| P2O5 | 1.21 |
| SO3 | 1.55 |
| CL | |
| CO2 | |
| Total | 98.80 |

Ash Fusion Temperatures (Deg F)

| | Oxidizing Atmosphere | Reducing Atmosphere |
|---|---|---|
| Initial | 2270 | 2000 |
| Softening | 2418 | 2027 |
| Hemispherical | 2432 | 2050 |
| Fluid | 2465 | 2075 |

Report Prepared By:

Fuels Laboratory Supervisor

Note: The ash was calcined @ 1110 deg F (600 C) prior to analysis.

## BGF Sample List — December Tests

| No. | Samp. Per. | Sample | Date | Time | Comments | Analysis | Lab | I.D. | Date Sent | Quantity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Total | Sent | Kept |
| 1 | SP1 | Bagasse | 12/6/95 | 8:58 | Dried | | — | 1-SP1-2 | — | 209.35 | 52.75 | 156.6 |
| 2 | SP1 | Bagasse | 12/6/95 | 9:25 | Dried | | — | 2-SP1-2 | — | 184.45 | 52.05 | 132.4 |
| 3 | SP1 | Bagasse | 12/6/95 | 10:00 | Dried | | — | 3-SP1-2 | — | 197.65 | 71.35 | 126.3 |
| 4 | SP1 | Bagasse | 12/6/95 | 8:58-10:00 | Combined sample | Ult, Prox, Btu | 1 | 4-SP1-2 | 12/21/95 | 175.8 | 175.8 | 0 |
| 5 | SP2 | Bagasse | 12/7/95 | 11:10 | Dried | | — | 5-SP2-2 | — | 200.75 | 67.95 | 132.8 |
| 6 | SP2 | Bagasse | 12/7/95 | 11:38 | Dried | | — | 6-SP2-2 | — | 214.75 | 62.05 | 152.7 |
| 7 | SP2 | Bagasse | 12/7/95 | 12:00 | Dried; MC=34.59% | | — | 7-SP2-2 | — | 229.15 | 59.55 | 169.6 |
| 8 | SP2 | Bagasse | 12/7/95 | 11:10-12:00 | Combined sample | Ult, Prox, Btu | 1 | 8-SP2-2 | 12/21/95 | 189.2 | 189.2 | 0 |
| 9 | SP3 | Bagasse | 12/7/95 | 19:15-19:24 | Dried | | — | 9-SP3-2 | — | 208.65 | 89.45 | 119.2 |
| 10 | SP3 | Bagasse | 12/7/95 | 19:25-19:30 | Dried | | — | 10-SP3-2 | — | 207.05 | 89.85 | 117.2 |
| 11 | SP3 | Bagasse | 12/7/95 | 19:15-19:30 | Combined sample | Ult, Prox, Btu | 1 | 11-SP3-2 | 12/21/95 | 181.7 | 181.7 | 0 |
| 12 | SP1 | Char; ash lockhop. | 12/6/95 | 9:00-10:12 | | Ultimate | 1 | 12-SP1-2 | 12/21/95 | 746.91 | 314.8 | 432.11 |
| 13 | SP2 | Char; ash lockhop. | 12/7/95 | 11:08-12:15 | | Ultimate | 1 | 13-SP2-2 | 12/21/95 | 423.11 | 204.6 | 218.51 |
| 14 | SP3 | Char; ash lockhop. | 12/7/95 | 18:30-19:30 | | Ultimate | 1 | 14-SP3-2 | 12/21/95 | 455.01 | 202.9 | 252.11 |
| 15 | SP1 | Char; isokin. S.S. | 12/6/95 | 9:00-10:12 | tare=26.4 g | Proximate | 1 | 15-SP1-2 | 12/21/95 | 0.8 | 0.8 | 0 |
| 16 | SP2 | Char; isokin. S.S. | 12/7/95 | 11:08-12:15 | tare=26.8 g | Proximate | 1 | 16-SP2-2 | 12/21/95 | 4.1 | 4.1 | 0 |
| 17 | SP1 | Aqueous cond. | 12/6/95 | | | N, S, Cl, Na, K | 1 | 17-SP1-2 | 12/21/95 | 79.1 | 48.55 | 48.55 |
| 18 | SP2 | Aqueous cond. | 12/7/95 | | | N, S, Cl, Na, K | 1 | 18-SP2-2 | 12/21/95 | 79.8 | 48.55 | 48.55 |
| 19 | SP1 | MeCl2 Wash | 12/6/95 | 9:10-10:12 | tare=26.7 g | Composition | 2 | 19-SP1-2 | — | 49.7 | 0 | 49.7 |
| 20 | SP2 | MeCl2 Wash | 12/7/95 | 11:08-12:15 | tare=26.7 g | Composition | 2 | 20-SP2-2 | — | 47.7 | 0 | 49.7 |
| 21 | SP1 | Rotovaped tars | 12/6/95 | | | Ult, Btu, Cl; comp. | 1, 2 | 21-SP1-2 | 12/21/95 | 8.8 | 4.88 | 3.92 |
| 22 | SP2 | Rotovaped tars | 12/7/95 | | | Ult, Btu, Cl; comp. | 1, 2 | 22-SP2-2 | 12/21/95 | 19.8 | 8.65 | 11.15 |

SP1: 12/6/95 (9:00 to 10:12)
SP2: 12/7/95 (11:08 to 12:15)
SP3: 12/7/95 (18:30 to 19:30)

Lab 1 — Hazen
Lab 2 — HNEI

## Tars/Oils Analysis (GC/FID) — December Tests

| | Rotovaped Tars | | | | MeCl2 Wash | |
|---|---|---|---|---|---|---|
| Sample ID | 21-SP1-2 | | 22-SP2-2 | | 19-SP1-2 | 20-SP2-2 |
| | mg/ml | mg/g | mg/ml | mg/g | mg/ml | mg/ml |
| Benzene, C6H6 | 0 | 0 | 0 | 0 | 0.284 | 0.577 |
| Toluene, C7H8 | 0 | 0 | 0 | 0 | 0.03 | 0.034 |
| Xylene, C8H10 | 0 | 0 | 0 | 0 | 0.009 | 0.006 |
| a-Methylstyr, C9H10 | 0 | 0 | 0 | 0 | 0.263 | 0 |
| Indene, C9H8 | 0.348 | 52.66 | 0 | 0 | 0.389 | 0.14 |
| Naphthalene, C10H8 | 1.769 | 267.9 | 1.803 | 271.9 | 1.675 | 3.679 |
| 1-Methylnaph, C11H10 | 0.046 | 6.905 | 0.013 | 2.028 | 0.041 | 0.032 |
| Internal Standard | 0.63 | 95.38 | 0.549 | 82.74 | 0.644 | 0.817 |
| Acenaphthylene, C12H8 | 0.436 | 66.02 | 0.299 | 45.11 | 0.389 | 0.721 |
| Acenaphthene, C12H10 | 0.013 | 2.013 | 0.026 | 3.849 | 0.013 | 0.059 |
| Fluorene, C13H10 | 0.119 | 17.96 | 0.043 | 6.527 | 0.104 | 0.1 |
| Phenanthrene, C14H10 | 0.366 | 55.49 | 0.594 | 89.52 | 0.335 | 1.348 |
| Anthracene, C14H10 | 0.073 | 11.13 | 0.058 | 8.7 | 0.066 | 0.136 |
| Fluoranthene, C16H10 | 0.108 | 16.28 | 0.405 | 61.03 | 0.091 | 0.928 |
| Pyrene, C16H10 | 0.082 | 12.41 | 0.325 | 49.00 | 0.067 | 0.761 |
| Chrysene, C18H12 | 0.004 | 0.624 | 0.009 | 1.328 | 0 | 0.02 |
| Benzo(k)fluor, C20H12 | 0 | 0 | 0.004 | 0.593 | 0 | 0.124 |
| di-Benzoanthr, C22H14 | 0 | 0 | 0 | 0 | 0 | 1.99 |
| Indenopyrene, C22H12 | 0 | 0 | 0.03 | 4.519 | 0 | 0.078 |

Notes: 1) mg/ml = mg of compound per ml of MeCl2 Wash
2) mg/g = mg of compound per g of rotovaped tar

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-1
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
4-SP1-2

-

| Reporting Basis > | As Rec'd | | Dry | Air Dry |
|---|---|---|---|---|
| **Proximate (%)** | | | | |
| Moisture | 4.20 | | 0.00 | 2.20 |
| Ash | 3.42 | | 3.57 | 3.49 |
| Volatile | 81.79 | | 85.37 | 83.49 |
| Fixed C | 10.59 | | 11.06 | 10.82 |
| Total | 100.00 | | 100.00 | 100.00 |
| Sulfur | 0.03 | | 0.03 | 0.03 |
| Btu/lb (HHV) | 7670 | | 8005 | 7829 |
| MMF Btu/lb | 7963 | | 8326 | |
| MAF Btu/lb | | | 8302 | |
| Air Dry Loss (%) | | 2.04 | | |
| **Ultimate (%)** | | | | |
| Moisture | 4.20 | | 0.00 | 2.20 |
| Carbon | 46.71 | | 48.75 | 47.68 |
| Hydrogen | 5.55 | | 5.79 | 5.66 |
| Nitrogen | 0.22 | | 0.22 | 0.22 |
| Sulfur | 0.03 | | 0.03 | 0.03 |
| Ash | 3.42 | | 3.57 | 3.49 |
| Oxygen* | 39.87 | | 41.64 | 40.72 |
| Total | 100.00 | | 100.00 | 100.00 |
| Chlorine** | | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.03 | 0.03 |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 4.46
Lb. SO2/MM Btu= 0.08
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerald H. Cunningham
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-2
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
8-SP2-2

-

| Reporting Basis > | As Rec'd | | Dry | Air Dry |
|---|---|---|---|---|
| **Proximate (%)** | | | | |
| Moisture | 4.91 | | 0.00 | 2.02 |
| Ash | 4.44 | | 4.66 | 4.57 |
| Volatile | 81.57 | | 85.78 | 84.05 |
| Fixed C | 9.08 | | 9.56 | 9.36 |
| Total | 100.00 | | 100.00 | 100.00 |
| Sulfur | 0.04 | | 0.04 | 0.04 |
| Btu/lb (HHV) | 7474 | | 7860 | 7701 |
| MMF Btu/lb | 7850 | | 8277 | |
| MAF Btu/lb | | | 8244 | |
| Air Dry Loss (%) | | 2.95 | | |
| **Ultimate (%)** | | | | |
| Moisture | 4.91 | | 0.00 | 2.02 |
| Carbon | 45.46 | | 47.81 | 46.84 |
| Hydrogen | 5.39 | | 5.67 | 5.55 |
| Nitrogen | 0.25 | | 0.27 | 0.26 |
| Sulfur | 0.04 | | 0.04 | 0.04 |
| Ash | 4.44 | | 4.66 | 4.57 |
| Oxygen* | 39.51 | | 41.55 | 40.72 |
| Total | 100.00 | | 100.00 | 100.00 |
| Chlorine** | | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.04 | 0.04 |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 5.93
Lb. SO2/MM Btu= 0.10
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-3
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
11-SP3-2

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 3.33 | 0.00 | 1.72 |
| Ash | 4.67 | 4.83 | 4.75 |
| Volatile | 80.50 | 83.27 | 81.84 |
| Fixed C | 11.50 | 11.90 | 11.69 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | 0.03 | 0.03 | 0.03 |
| Btu/lb (HHV) | 7622 | 7885 | 7749 |
| MMF Btu/lb | 8027 | 8319 | |
| MAF Btu/lb | | 8285 | |
| Air Dry Loss (%) | 1.64 | | |
| **Ultimate (%)** | | | |
| Moisture | 3.33 | 0.00 | 1.72 |
| Carbon | 46.07 | 47.66 | 46.84 |
| Hydrogen | 5.48 | 5.66 | 5.57 |
| Nitrogen | 0.21 | 0.21 | 0.21 |
| Sulfur | 0.03 | 0.03 | 0.03 |
| Ash | 4.67 | 4.83 | 4.75 |
| Oxygen* | 40.21 | 41.61 | 40.88 |
| Total | 100.00 | 100.00 | 100.00 |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.03 | 0.03 |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu= 6.13
Lb. SO2/MM Btu= 0.08
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-4
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
12-SP1-2

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.42 | 0.00 | 0.42 |
| Ash | 74.93 | 75.25 | 74.93 |
| Volatile | | | |
| Fixed C | | | |
| Total | | | |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | 0.42 | 0.00 | 0.42 |
| Carbon | 22.21 | 22.30 | 22.21 |
| Hydrogen | 0.36 | 0.36 | 0.36 |
| Nitrogen | 0.26 | 0.26 | 0.26 |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Ash | 74.93 | 75.25 | 74.93 |
| Oxygen* | 1.80 | 1.81 | 1.80 |
| Total | 100.00 | 100.00 | 100.00 |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.02 | 0.02 |

Water Soluble Alkalies (%)

Na2O
K2O

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerald L. Luning
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-5
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
13-SP2-2

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.58 | 0.00 | 0.58 |
| Ash | 74.15 | 74.58 | 74.15 |
| Volatile | | | |
| Fixed C | | | |
| Total | | | |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | 0.58 | 0.00 | 0.58 |
| Carbon | 26.10 | 26.25 | 26.10 |
| Hydrogen | 0.32 | 0.32 | 0.32 |
| Nitrogen | 0.27 | 0.27 | 0.27 |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Ash | 74.15 | 74.58 | 74.15 |
| Oxygen* | <0.01 | <0.01 | <0.01 |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | 0.02 | 0.02 |

Water Soluble Alkalies (%)

Na2O
K2O

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-6
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
14-SP3-2

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | 0.73 | 0.00 | 0.73 |
| Ash | 67.13 | 67.62 | 67.13 |
| Volatile | | | |
| Fixed C | | | |
| Total | | | |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | 0.73 | 0.00 | 0.73 |
| Carbon | 32.39 | 32.63 | 32.39 |
| Hydrogen | 0.40 | 0.40 | 0.40 |
| Nitrogen | 0.35 | 0.35 | 0.35 |
| Sulfur | 0.02 | 0.02 | 0.02 |
| Ash | 67.13 | 67.62 | 67.13 |
| Oxygen* | <0.01 | <0.01 | <0.01 |
| Chlorine** | | | |
| **Forms of Sulfur (as S,%)** | | | |
| Sulfate | | | |
| Pyritic | | | |
| Organic | | | |
| Total | 0.02 | 0.02 | |
| **Water Soluble Alkalies (%)** | | | |
| Na2O | | | |
| K2O | | | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-7
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
15-SP1-2 - Insufficient sample to analyze moisture in this sample. - GHC

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| **Proximate (%)** | | | |
| Moisture | | | |
| Ash | 35.73 | 35.73 | 35.73 |
| Volatile | 13.33 | 13.33 | 13.33 |
| Fixed C | 50.94 | 50.94 | 50.94 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | | | |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| **Ultimate (%)** | | | |
| Moisture | | | |
| Carbon | | | |
| Hydrogen | | | |
| Nitrogen | | | |
| Sulfur | | | |
| Ash | | | |
| Oxygen* | | | |
| Total | | | |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | | |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerald M. Cimbala
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

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Date January 10 1996
HRI Project 002-14G
HRI Series No. L391/95-8
Date Rec'd. 12/27/95
Cust. P.O.# 8574020

REPORT OF ANALYSIS

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Rd, Crawford 315
Honolulu, Hawaii 96822

Sample Identification
16-SP2-2

-

| Reporting Basis > | As Rec'd | Dry | Air Dry |
|---|---|---|---|
| Proximate (%) | | | |
| Moisture | 0.34 | 0.00 | 0.34 |
| Ash | 6.24 | 6.26 | 6.24 |
| Volatile | 4.06 | 4.07 | 4.06 |
| Fixed C | 89.36 | 89.67 | 89.36 |
| Total | 100.00 | 100.00 | 100.00 |
| Sulfur | | | |
| Btu/lb (HHV) | | | |
| MMF Btu/lb | | | |
| MAF Btu/lb | | | |
| Air Dry Loss (%) | | | |
| Ultimate (%) | | | |
| Moisture | | | |
| Carbon | | | |
| Hydrogen | | | |
| Nitrogen | | | |
| Sulfur | | | |
| Ash | | | |
| Oxygen* | | | |
| Total | | | |
| Chlorine** | | | |

Forms of Sulfur (as S,%)

| | | |
|---|---|---|
| Sulfate | | |
| Pyritic | | |
| Organic | | |
| Total | | |

Water Soluble Alkalies (%)

| | |
|---|---|
| Na2O | |
| K2O | |

Lb. Alkali/MM Btu=
Lb. Ash/MM Btu=
Lb. SO2/MM Btu=
HGI= @ % Moisture
As Rec'd. Sp.Gr.=
Free Swelling Index=

Report Prepared By:

Gerald H. Cunningham
Fuels Laboratory Supervisor

* Oxygen by Difference.
** Not usually reported as part of the ultimate analysis.

**Hazen Research, Inc.**
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860
FAX: (303) 278-1528

| | |
|---|---|
| Date | January 21, 1996 |
| HRI Project | 002-14G |
| HRI Series No. | L391/95 |
| Date Rec'd | 12/27/95 |
| Cust. P.O. # | 8574020 |

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road, Crawford 315
Honolulu, Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. L391/95-9
SAMPLE IDENTIFICATION: 17-SP1-2

| | |
|---|---|
| Chloride, mg/l | 26 |
| Nitrogen, mg/l | 1100 |
| Sulfur, mg/l | 50 |
| Sodium, mg/l | 3.5 |
| Potassium, mg/l | <0.2 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

NA = Analysis not available.

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## REPORT OF ANALYSIS

SAMPLE NO. L391/95-10
SAMPLE IDENTIFICATION: 18-SP2-2

| | |
|---|---|
| Chloride, mg/l | 366 |
| Nitrogen, mg/l | 1600 |
| Sulfur, mg/l | 40 |
| Sodium, mg/l | 2.5 |
| Potassium. mg/l | <0.2 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

NA = Analysis not available.

**Hazen Research, Inc.**
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Tel: (303) 279-4501 • Telex 45-860
FAX: (303) 278-1528

| | |
|---|---|
| Date | January 11, 1996 |
| HRI Project | 002-14G |
| HRI Series No. | L391/95 |
| Date Rec'd | 12/27/95 |
| Cust. P.O. # | 8574020 |

Hawaii Natural Energy Institute
Darren Ishimura
2550 Campus Road, Crawford 315
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## REPORT OF ANALYSIS

SAMPLE NO. L391/95-11
SAMPLE IDENTIFICATION: 21-SP1-2

| | |
|---|---|
| Water, % | 0.18 |
| Ash, % | <0.001 |
| Sulfur, % | 0.064 |
| Carbon, % | 81.62 |
| Hydrogen, % | 5.00 |
| Nitrogen, % | 0.52 |
| Oxygen, %* | 12.62 |
| Calorific Value, BTU/lb (HHV) | 14888 |
| Chlorine, % | 12.63 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

* Oxygen by difference

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FAX: (303) 278-1528

Date January 11, 1996
HRI Project 002-14G
HRI Series No. L391/95
Date Rec'd 12/27/95
Cust. P.O. # 8574020

Hawaii Natural Energy Institute
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2550 Campus Road. Crawford 315
Honolulu, Hawaii 96822

## REPORT OF ANALYSIS

SAMPLE NO. L391/95-12
SAMPLE IDENTIFICATION: 22-SP2-2

| | |
|---|---|
| Water, % | 0.63 |
| Ash, % | <0.001 |
| Sulfur, % | 0.039 |
| Carbon, % | 74.51 |
| Hydrogen, % | 4.40 |
| Nitrogen, % | 0.18 |
| Oxygen, %* | 20.24 |
| Calorific Value, BTU/lb (HHV) | 13855 |
| Chlorine, % | 12.89 |

By:
Gerard H. Cunningham
Fuel Laboratory Manager

* Oxygen by difference

# Appendix B
# Mass Balance Spreadsheet -- Raw Data

## Biomass Gasifier Facility

| | | | |
|---|---|---|---|
| PROJECT NUMBER..... | | | |
| TEST NUMBER..... | BGF1/SP3 | | |
| DATE OF TEST..... | 10/6/95 | | |
| Latest file update: | 2/14/96 | 1:51 PM | |
| Reactor I.D., inches.... | 37.00 | | |
| Sampling period..... | 22:15 | to | 22:54 |
| Sampling basis..... | 0.650 | hours | |
| TEST CONDITIONS: | | | |
| Temperature, °F..... | 1543.00 | | |
| Pressure, psig..... | 41.2 | | |
| TEST DESCRIPTION: | | | |

**MATERIAL INPUT DATA:**

| | | Steady-state period | | | |
|---|---|---|---|---|---|
| | lb/h | SCF/h | lb | SCF | Vol% |
| Biomass feed (as rec'd) | 2242.0 | -- | 1457.3 | -- | -- |
| Steam to nozzle..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Steam to ring..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Total steam..... | 0.0 | 0.00 | 0.0 | 0.00 | 0.0% |
| Air to nozzle..... | 2434.5 | 31860.00 | 1582.41 | | |
| Air to ring..... | 1512.9 | 19800.00 | 983.42 | | |
| Air to burner..... | 916.9 | 12000.00 | 596.01 | | |
| Total air..... | 4864.4 | 63660.00 | 1579.4 | 0.00 | 0.0% |
| Oxygen (calc)..... | 1019.1 | 12069.78 | 662.40 | 7845.35 | 19.0% |
| Nitrogen (calc)..... | 3798.1 | 51391.57 | 2468.76 | 33404.52 | 81.0% |
| Argon (calc)..... | 45.4 | 431.02 | 29.53 | 280.16 | 0.7% |
| CO2 (calc)..... | 1.6 | 13.82 | 1.04 | 8.99 | 0.0% |
| Neon, etc. (calc)..... | 0.1 | 1.3 | 0.09 | 0.82 | 0.0% |
| DRY gas input..... | 4864.4 | 63907.45 | 3131.2 | 41249.88 | 100.0% |
| WET gas input..... | 4864.4 | 63907.45 | 7872.4 | 41249.88 | 100.0% |

**MATERIAL OUTPUT DATA:**

| | lb/h | SCF/h | lb | SCF | Vol% |
|---|---|---|---|---|---|
| Char (cyclone discharge).... | 104.6 | -- | 68.0 | -- | -- |
| Char (entrained)..... | 8.4 | -- | 5.5 | -- | -- |
| Total char (filter+cyc) | 113.1 | -- | 73.5 | -- | -- |
| Condensate..... | 1114.9 | -- | 724.7 | -- | -- |
| AQUEOUS phase..... | 1067.9 | 22460.38 | 694.1 | 14599.25 | -- |
| OIL phase..... | 47.0 | -- | 30.5 | -- | -- |
| N2 (as tracer)..... | 3798.1 | 51391.57 | 2468.8 | 33404.52 | 50.7% |
| DRY product gas..... | 6232.7 | 78892.54 | 4051.2 | 51280.15 | 77.8% |
| WET product gas..... | 7300.3 | 101352.93 | 4745.2 | 65879.40 | 100.0% |
| DRY N2-FREE product gas. | 2434.6 | 27500.97 | 1582.5 | 17875.63 | 27.1% |

**SAMPLE SYSTEM DATA:**

| | | Comments |
|---|---|---|
| Gas meter initial reading, cu ft. | 6316.30 | |
| Gas meter final reading, cu ft... | 6353.00 | |
| Gas meter temperature, °F..... | 80.00 | |
| Gas meter pressure, psig..... | 5.00 | |
| Meter correction factor..... | 1.000 | |
| Total DRY gas sampled, SCF..... | 47.36 | |
| % of reactor gas flow..... | 0.09% | |
| | | |
| Char fines collected, g..... | 2.30 | |
| Char carryover, lb/MSCF (wet).... | 0.083 | |
| Condensate collected, g..... | 303.59 | |
| AQUEOUS condensate, g..... | 290.80 | |
| OIL in condensate, g..... | 12.79 | |
| C6H6 in condensate OIL, g..... | 1.35 | |
| Equiv C6H6 volume, SCF..... | 0.014 | |
| Equiv steam volume, SCF..... | 13.48 | |
| Total WET gas sampled, SCF.... | 60.84 | |
| Steam in wet product gas, vol%... | 22.16 | |

**SOLID ANALYSES:**

| | ---------Feed--------- | | | ----Char (cyclone)---- | | | ---Char (entrained)--- | | |
|---|---|---|---|---|---|---|---|---|---|
| PROXIMATE, wt% | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) |
| Moisture..... | 25.40 | 0.00 | 0.00 | 0.73 | 0.00 | 0.00 | 0.52 | -0.85 | -1.22 |
| V. M..... | 62.92 | 84.34 | 87.36 | | 0.00 | 0.00 | 5.38 | 5.42 | 18.74 |
| Ash..... | 2.58 | 3.46 | 0.00 | 70.56 | 71.08 | 0.00 | 3.76 | 3.79 | 1.00 |
| Fixed carbon.. | 9.10 | 12.20 | 12.64 | | | | 90.34 | 91.64 | 81.48 |
| ULTIMATE, wt% | | | | | | | | | |
| C..... | 36.01 | 48.27 | 50.00 | 28.60 | 28.81 | 99.62 | 90.15 | 90.81 | 314.00 |
| H..... | 4.23 | 5.68 | 5.88 | 0.47 | 0.47 | 1.63 | 2.68 | 2.70 | 9.34 |
| N..... | 0.11 | 0.15 | 0.15 | 0.14 | 0.14 | 0.48 | 0.00 | 0.00 | 0.00 |
| S..... | 0.09 | 0.12 | 0.12 | 0.02 | 0.02 | 0.07 | 0.00 | 0.00 | 0.00 |
| O (by diff)... | 31.58 | 42.33 | 43.85 | -0.52 | -0.52 | -1.80 | 2.69 | 2.71 | 9.37 |
| Ash..... | 2.58 | 3.46 | --- | 70.56 | 71.08 | --- | 3.75 | 3.78 | --- |
| HHV, Btu/lb..... | 5942.64 | 7966.00 | 8251.50 | 0.00 | | 0.00 | 0.00 | | 0.00 |
| C/ash ratio..... | 13.95 | | | 0.41 | | | 24.02 | | |
| INPUT, lb..... | 1457.30 | 1087.15 | 1049.55 | --- | --- | --- | | | |
| OUTPUT, lb..... | --- | --- | --- | 73.49 | 72.95 | 21.10 | | | |

**DRY GAS ANALYSES (excluding condensed C6H6):**

| | Dry GC, vol% |
|---|---|
| H2 | 3.83 |
| CO2 | 19.35 |
| C2H4 | 0.44 |
| C2H6 | 0.00 |
| O2/Ar | 0.00 |
| N2 | 65.35 |
| CH4 | 2.70 |
| CO | 8.33 |
| C3's | 0.00 |
| C4's | 0.00 |
| C6H6 | 0.29 |
| H2S | 0.00 |
| Total (dry).. | 100.29 |

T(gas) 1484.20

Comments T(ref) 60

| | |
|---|---|
| 26.49 | 1.014718 |
| 43.20 | 8.359218 |
| 66.55 | 0.2928 |
| 27.61 | 18.04406 |
| 50.29 | 1.357866 |
| 26.91 | 2.241863 |

JcpdT= 13.27 Btu/scf

**GAS ANALYSES (including condensed C6H6):**

More--> <----More

| | -------Avg vol%------- | | | --Volume, SCF-- | | | HHV, | ----------Mass, lb---------- | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (dry) | (wet) | (dry N2-free) | (SS) | (reac) | MW | Btu/SCF | Total | C | H | N | S | O |
| H2 | 3.82 | 2.97 | 10.95 | 1.81 | 1957.76 | 2.016 | 324.3 | 10.41 | 0.00 | 10.41 | 0.00 | 0.00 | 0.00 |
| CO2 | 19.29 | 15.01 | 55.33 | 9.16 | 9891.01 | 44.01 | 0.00 | 1148.56 | 313.43 | 0.00 | 0.00 | 0.00 | 835.12 |
| C2H4 | 0.44 | 0.34 | 1.26 | 0.21 | 224.91 | 28.05 | 1573.8 | 16.65 | 14.25 | 2.39 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 30.07 | 1769.6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| O2/Ar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 65.14 | 50.71 | | 30.95 | 33404.52 | 28.01 | 0.00 | 2468.76 | 0.00 | 0.00 | 2468.76 | 0.00 | 0.00 |
| CH4 | 2.69 | 2.09 | 7.72 | 1.28 | 1380.14 | 16.04 | 1009.8 | 58.41 | 43.73 | 14.68 | 0.00 | 0.00 | 0.00 |
| CO | 8.30 | 6.46 | 23.82 | 3.95 | 4257.99 | 28.01 | 321.0 | 314.69 | 134.93 | 0.00 | 0.00 | 0.00 | 179.76 |
| C3's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 44.09 | 2450.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C4's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 42.08 | 3300.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C6H6 | 0.32 | 0.25 | 0.92 | 0.15 | 163.82 | 78.11 | 3745.2 | 33.76 | 31.15 | 2.61 | 0.00 | 0.00 | 0.00 |
| H2O | | 22.16 | | 13.48 | 14552.61 | 18.02 | 0.00 | 691.77 | 0.00 | 77.41 | 0.00 | 0.00 | 614.36 |
| H2S | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 | 34.08 | 960.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total (dry) | 100.00 | --- | --- | 47.51 | 51280.15 | 0.00 | 0.00 | 4051.24 | 537.50 | 30.10 | 2468.76 | 0.00 | 1014.88 |
| Total (wet) | --- | 100.00 | --- | 61.00 | 65832.76 | 0.00 | 0.00 | 4743.01 | 537.50 | 107.51 | 2468.76 | 0.00 | 1629.24 |
| Total (dry N2-free).. | --- | --- | 100.00 | | | | | | | | | | |
| Mol wt, lb/lbmol | 29.94 | 27.30 | 33.55 | | | | | | | | | | |
| HHV, Btu/SCF | 85.1 | 66.2 | 244.1 | | | | | | | | | | |

**OIL ANALYSES:**

| ULTIMATE, dry wt% | |
|---|---|
| C | 86.80 |
| H | 5.20 |
| N | 0.78 |
| S | 0.04 |
| O (by diff) | 7.17 |
| Ash | 0.00 |
| HHV, Btu/lb | 15303.82 |
| H/C ratio | 0.714 |

**AQUEOUS CONDENSATE ANALYSES:**

| | | wt% dry feed | Comments |
|---|---|---|---|
| TC, mg/L | | 0.000 | |
| TOC, mg/L | | 0.000 | |
| S, mg/L | 51.00 | 0.003 | |
| N, mg/L | 1800.00 | 0.115 | |
| equiv lb NH3 | 1.52 | 0.140 | |
| Cl, mg/L | 300.00 | 0.019 | |
| equiv lb HCl | 0.21 | 0.020 | |
| CN, mg/L | | 0.000 | |
| equiv lb HCN | 0.00 | 0.000 | |

**MATERIAL BALANCE -- raw data** TEST BGF1/SP3

| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
|---|---|---|---|---|---|---|---|
| Biomass (dry) | 524.77 | 61.70 | 1.58 | 1.305 | 460.19 | 37.62 | 1087.15 |
| Moisture | --- | 41.42 | --- | --- | 328.72 | --- | 370.14 |
| Air | 0.28 | --- | 2468.76 | --- | 692.69 | --- | 3161.74 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 525.05 | 103.12 | 2470.34 | 1.305 | 1481.61 | 37.62 | 4619.03 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 19.59 | 0.32 | 0.10 | 0.014 | -0.35 | 48.33 | 68.00 |
| Moisture | --- | 0.06 | --- | --- | 0.44 | --- | 0.50 |
| Char, entr (dry) | 4.99 | 0.15 | 0.00 | 0.000 | 0.15 | 0.21 | 5.49 |
| Moisture | --- | 0.00 | --- | --- | 0.03 | --- | 0.03 |
| Product gas(dry) | 537.50 | 30.10 | 2468.76 | 0.000 | 1014.88 | --- | 4051.25 |
| Oils/tars | 26.50 | 1.59 | 0.24 | 0.014 | 2.19 | 0.00 | 30.53 |
| Condensate water | 0.00 | 77.75 | 1.25 | 0.035 | 615.30 | --- | 694.34 |
| Total | 588.58 | 109.97 | 2470.35 | 0.063 | 1632.64 | 48.54 | 4850.13 |
| Out/In | 112.1% | 106.6% | 100.0% | 4.8% | 110.2% | 129.0% | 105.0% |

**MATERIAL BALANCE -- adjusted data** TEST BGF1/SP3

| Adjustments: | 1.00000 | 1.00000 | 1.00000 | 1.0000 | 0.00 | |
|---|---|---|---|---|---|---|
| | x cc out | x air in | x aqu S | x aqu N | + lb H | |
| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
| Biomass (dry) | 524.77 | 61.70 | 1.58 | 1.30 | 460.19 | 37.62 | 1087.15 |
| Moisture | --- | 41.42 | --- | --- | 328.72 | --- | 370.14 |
| Air | 0.28 | --- | 2468.76 | --- | 692.69 | --- | 3161.74 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 525.05 | 103.12 | 2470.34 | 1.30 | 1481.61 | 37.62 | 4619.03 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 19.59 | 0.32 | 0.10 | 0.01 | -0.35 | 48.33 | 68.00 |
| Moisture | --- | 0.06 | --- | --- | 0.44 | --- | 0.50 |
| Char, entr (dry) | 4.99 | 0.15 | 0.00 | 0.00 | 0.15 | 0.21 | 5.49 |
| Moisture | --- | 0.00 | --- | --- | 0.03 | --- | 0.03 |
| Product gas(dry) | 537.50 | 30.10 | 2468.76 | 0.00 | 1014.88 | --- | 4051.25 |
| Oils/tars | 26.50 | 1.59 | 0.24 | 0.01 | 2.19 | 0.00 | 30.53 |
| Condensate water | 0.00 | 77.75 | 1.25 | 0.04 | 615.30 | --- | 694.34 |
| Total | 588.58 | 109.97 | 2470.35 | 0.06 | 1632.64 | 48.54 | 4850.13 |
| Out/In | 112.1% | 106.6% | 100.0% | 4.8% | 110.2% | 129.0% | 105.0% |

**ENGINEERING DATA -- unadjusted** TEST BGF1/SP3

| MATERIAL INPUT DATA | |
|---|---|
| Biomass (wet), lb/h..... | 2242.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 1019.08 |
| Nitrogen, lb/h..... | 3798.09 |
| Air, scfm ..... | 1060.97 |
| Oxygen, lb/lb feed (wet)..... | 0.45 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.41 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

| MATERIAL OUTPUT DATA | |
|---|---|
| Cyclone Char (dry), lb/h..... | 104.62 |
| Entrained Char (dry), lb/h ..... | 8.45 |
| Condensate, lb/h..... | 1115.18 |
| Aqueous Phase, lb/h..... | 1068.21 |
| Oil Phase, lb/h..... | 46.97 |
| Dry Product Gas, lb/h..... | 6232.69 |

**ENGINEERING DATA, continued** TEST BGF1/SP3

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 45.2 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 47.2 |
| Gas Heating Value, Btu/SCF (dry)..... | 85.1 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 244.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.504 |
| Carbon Conversion to Gases and Liquids, %..... | 107.5 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 94.2 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.504 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.582 |

**Biomass Gasifier Facility**

| | | | |
|---|---|---|---|
| PROJECT NUMBER..... | | | |
| TEST NUMBER..... | BGF1/SP4 | | |
| DATE OF TEST..... | 10/7/95 | | |
| Latest file update: | 2/14/96 | 2:11 PM | |
| Reactor I.D., inches.... | 37.00 | | |
| Sampling period..... | 14:50:00 | to | 15:32:00 |
| Sampling basis..... | 0.700 | hours | |
| TEST CONDITIONS: | | | |
| Temperature, °F..... | 1548.00 | | |
| Pressure, psig..... | 41.0 | | |
| TEST DESCRIPTION: | | | |

**MATERIAL INPUT DATA:**

| | Steady-state period | | | | |
|---|---|---|---|---|---|
| | lb/h | SCF/h | lb | SCF | Vol% |
| Biomass feed (as rec'd) | 2227.0 | -- | 1558.9 | -- | -- |
| Steam to nozzle..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Steam to ring..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Total steam..... | 0.0 | 0.00 | 0.0 | 0.00 | 0.0% |
| Air to nozzle..... | 2095.2 | 27420.00 | 1466.64 | | |
| Air to ring..... | 1733.0 | 22680.00 | 1213.11 | | |
| Air to burner..... | 481.4 | 6300.00 | 336.98 | | |
| Total air..... | 4309.6 | 56400.00 | 1550.1 | 0.00 | 0.0% |
| Oxygen (calc)..... | 902.9 | 10693.30 | 632.01 | 7485.31 | 19.0% |
| Nitrogen (calc)..... | 3364.9 | 45530.70 | 2355.46 | 31871.49 | 81.0% |
| Argon (calc)..... | 40.3 | 381.86 | 28.18 | 267.30 | 0.7% |
| CO2 (calc)..... | 1.4 | 12.25 | 1.00 | 8.57 | 0.0% |
| Neon, etc. (calc)..... | 0.1 | 1.1 | 0.09 | 0.78 | 0.0% |
| DRY gas input..... | 4309.6 | 56619.23 | 2987.5 | 39356.80 | 100.0% |
| WET gas input..... | 4309.6 | 56619.23 | 7554.3 | 39356.80 | 100.0% |

**MATERIAL OUTPUT DATA:**

| | lb/h | SCF/h | lb | SCF | Vol% |
|---|---|---|---|---|---|
| Char (cyclone discharge).... | 138.6 | -- | 97.0 | -- | -- |
| Char (entrained)..... | 2.2 | -- | 1.5 | -- | -- |
| Total char (filter+cyc) | 140.7 | -- | 98.5 | -- | -- |
| Condensate..... | 850.1 | -- | 595.1 | -- | -- |
| AQUEOUS phase..... | 809.7 | 17030.19 | 566.8 | 11921.13 | -- |
| OIL phase..... | 40.4 | -- | 28.3 | -- | -- |
| N2 (as tracer)..... | 3364.9 | 45530.70 | 2355.5 | 31871.49 | 52.0% |
| DRY product gas..... | 5506.2 | 70570.18 | 3854.3 | 49399.13 | 80.6% |
| WET product gas..... | 6315.7 | 87600.37 | 4421.0 | 61320.26 | 100.0% |
| DRY N2-FREE product gas. | 2141.2 | 25039.48 | 1498.9 | 17527.63 | 28.6% |

**SAMPLE SYSTEM DATA:**

| | | Comments |
|---|---|---|
| Gas meter initial reading, cu ft. | 384.22 | |
| Gas meter final reading, cu ft... | 434.35 | |
| Gas meter temperature, °F..... | 80.00 | |
| Gas meter pressure, psig..... | 5.00 | |
| Meter correction factor..... | 1.000 | |
| Total DRY gas sampled, SCF..... | 64.69 | |
| % of reactor gas flow..... | 0.13% | |
| | | |
| Char fines collected, g..... | 0.90 | |
| Char carryover, lb/MSCF (wet).... | 0.025 | |
| Condensate collected, g..... | 353.49 | |
| AQUEOUS condensate, g..... | 336.70 | |
| OIL in condensate, g..... | 16.79 | |
| C6H6 in condensate OIL, g..... | 1.01 | |
| Equiv C6H6 volume, SCF..... | 0.011 | |
| Equiv steam volume, SCF..... | 15.61 | |
| Total WET gas sampled, SCF.... | 80.30 | |
| Steam in wet product gas, vol%... | 19.44 | |

**SOLID ANALYSES:**

| | ---------Feed--------- | | | ----Char (cyclone)---- | | | ---Char (entrained)--- | | |
|---|---|---|---|---|---|---|---|---|---|
| PROXIMATE, wt% | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) |
| Moisture..... | 19.50 | 0.00 | 0.00 | 0.75 | 0.00 | 0.00 | 0.82 | -0.85 | -1.22 |
| V. M..... | 68.00 | 84.47 | 87.84 | | 0.00 | 0.00 | 6.64 | 6.69 | 23.27 |
| Ash..... | 3.09 | 3.84 | 0.00 | 70.71 | 71.24 | 0.00 | 7.12 | 7.17 | 1.00 |
| Fixed carbon.. | 9.41 | 11.69 | 12.16 | | | | 85.42 | 86.99 | 76.95 |
| ULTIMATE, wt% | | | | | | | | | |
| C..... | 38.71 | 48.09 | 50.04 | 28.52 | 28.74 | 99.93 | 87.67 | 88.33 | 307.13 |
| H..... | 4.56 | 5.67 | 5.90 | 0.41 | 0.41 | 1.43 | 2.18 | 2.20 | 7.65 |
| N..... | 0.11 | 0.14 | 0.15 | 0.13 | 0.13 | 0.45 | 0.00 | 0.00 | 0.00 |
| S..... | 0.06 | 0.07 | 0.07 | 0.02 | 0.02 | 0.07 | 0.00 | 0.00 | 0.00 |
| O (by diff)... | 33.92 | 42.14 | 43.85 | -0.54 | -0.54 | -1.88 | 2.27 | 2.29 | 7.96 |
| Ash..... | 3.13 | 3.89 | --- | 70.71 | 71.24 | --- | 7.13 | 7.18 | --- |
| HHV, Btu/lb..... | 6716.92 | 8344.00 | 8681.72 | 0.00 | | 0.00 | 0.00 | | 0.00 |
| C/ash ratio..... | 12.36 | | | 0.40 | | | 12.30 | | |
| INPUT, lb..... | 1558.90 | 1254.91 | 1206.74 | --- | --- | --- | | | |
| OUTPUT, lb..... | --- | --- | --- | 98.52 | 97.78 | 28.12 | | | |

**DRY GAS ANALYSES (excluding condensed C6H6):**

| | Dry GC, vol% |
|---|---|
| H2 | 4.49 |
| CO2 | 18.29 |
| C2H4 | 0.36 |
| C2H6 | 0.01 |
| O2/Ar | 0.00 |
| N2 | 64.41 |
| CH4 | 2.98 |
| CO | 8.98 |
| C3's | 0.00 |
| C4's | 0.00 |
| C6H6 | 0.29 |
| H2S | 0.00 |
| Total (dry).. | 99.82 |

Comments

| | | |
|---|---|---|
| T(gas) | 1477.70 | |
| T(ref) | 60 | |
| | 26.37 | 1.184974 |
| | 42.97 | 7.861152 |
| | 66.15 | 0.237925 |
| | 27.48 | 17.69752 |
| | 49.99 | 1.487513 |
| | 26.78 | 2.404486 |
| JcpdT= | 13.18 | Btu/scf |

**GAS ANALYSES (including condensed C6H6):**

More--> <----More

| | -------Avg vol%------- | | | --Volume, SCF-- | | | HHV, | ----------Mass, lb---------- | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (dry) | (wet) | dry N2-free) | (SS) | (reac) | MW | Btu/SCF | Total | C | H | N | S | O |
| H2 | 4.50 | 3.63 | 12.69 | 2.91 | 2223.59 | 2.016 | 324.3 | 11.83 | 0.00 | 11.83 | 0.00 | 0.00 | 0.00 |
| CO2 | 18.32 | 14.76 | 51.64 | 11.83 | 9051.60 | 44.01 | 0.00 | 1051.08 | 286.83 | 0.00 | 0.00 | 0.00 | 764.25 |
| C2H4 | 0.36 | 0.29 | 1.02 | 0.23 | 177.98 | 28.05 | 1573.8 | 13.17 | 11.28 | 1.89 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.01 | 0.01 | 0.03 | 0.01 | 5.99 | 30.07 | 1769.6 | 0.48 | 0.38 | 0.10 | 0.00 | 0.00 | 0.00 |
| O2/Ar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 64.52 | 51.98 | | 41.67 | 31871.49 | 28.01 | 0.00 | 2355.46 | 0.00 | 0.00 | 2355.46 | 0.00 | 0.00 |
| CH4 | 2.98 | 2.40 | 8.40 | 1.93 | 1472.53 | 16.04 | 1009.8 | 62.32 | 46.66 | 15.67 | 0.00 | 0.00 | 0.00 |
| CO | 8.99 | 7.24 | 25.34 | 5.81 | 4442.31 | 28.01 | 321.0 | 328.31 | 140.77 | 0.00 | 0.00 | 0.00 | 187.54 |
| C3's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 44.09 | 2450.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C4's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 42.08 | 3300.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C6H6 | 0.31 | 0.25 | 0.88 | 0.20 | 153.64 | 78.11 | 3745.2 | 31.66 | 29.21 | 2.45 | 0.00 | 0.00 | 0.00 |
| H2O | | 19.44 | | 15.61 | 11941.06 | 18.02 | 0.00 | 567.63 | 0.00 | 63.52 | 0.00 | 0.00 | 504.11 |
| H2S | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 | 34.08 | 960.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total (dry) | 100.00 | --- | --- | 64.58 | 49399.13 | 0.00 | 0.00 | 3854.32 | 515.14 | 31.93 | 2355.46 | 0.00 | 951.79 |
| Total (wet) | --- | 100.00 | --- | 80.20 | 61340.19 | 0.00 | 0.00 | 4421.94 | 515.14 | 95.45 | 2355.46 | 0.00 | 1455.90 |
| Total (dry N2-free).. | --- | --- | 100.00 | | | | | | | | | | |
| Mol wt, lb/lbmol | 29.57 | 27.32 | 32.41 | | | | | | | | | | |
| HHV, Btu/SCF | 91.1 | 73.4 | 256.7 | | | | | | | | | | |

**OIL ANALYSES:**

| ULTIMATE, dry wt% | |
|---|---|
| C | 88.97 |
| H | 5.20 |
| N | 0.18 |
| S | 0.04 |
| O (by diff) | 5.61 |
| Ash | 0.00 |
| HHV, Btu/lb | 15695.66 |
| H/C ratio | 0.696 |

**AQUEOUS CONDENSATE ANALYSES:**

| | | wt% dry feed | Comments |
|---|---|---|---|
| TC, mg/L | | 0.000 | |
| TOC, mg/L | | 0.000 | |
| S, mg/L | 55.00 | 0.002 | |
| N, mg/L | 2000.00 | 0.090 | |
| equiv lb NH3 | 1.38 | 0.110 | |
| Cl, mg/L | 267.00 | 0.012 | |
| equiv lb HCl | 0.16 | 0.012 | |
| CN, mg/L | | 0.000 | |
| equiv lb HCN | 0.00 | 0.000 | |

**MATERIAL BALANCE -- raw data** TEST BGF1/SP4

| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
|---|---|---|---|---|---|---|---|
| Biomass (dry) | 603.49 | 71.15 | 1.76 | 0.878 | 528.82 | 48.82 | 1254.91 |
| Moisture | --- | 34.02 | --- | --- | 269.96 | --- | 303.98 |
| Air | 0.27 | --- | 2355.46 | --- | 660.91 | --- | 3016.64 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 603.76 | 105.17 | 2357.22 | 0.878 | 1459.69 | 48.82 | 4575.53 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 27.88 | 0.40 | 0.13 | 0.019 | -0.52 | 69.10 | 97.00 |
| Moisture | --- | 0.08 | --- | --- | 0.65 | --- | 0.73 |
| Char, entr (dry) | 1.34 | 0.03 | 0.00 | 0.000 | 0.03 | 0.11 | 1.52 |
| Moisture | --- | 0.00 | --- | --- | 0.01 | --- | 0.01 |
| Product gas(dry) | 515.14 | 31.93 | 2355.46 | 0.000 | 951.79 | --- | 3854.32 |
| Oils/tars | 25.15 | 1.47 | 0.05 | 0.011 | 1.59 | 0.00 | 28.26 |
| Condensate water | 0.00 | 63.50 | 1.13 | 0.031 | 502.33 | --- | 566.99 |
| Total | 569.50 | 97.41 | 2356.77 | 0.062 | 1455.87 | 69.21 | 4548.83 |
| Out/In | 94.3% | 92.6% | 100.0% | 7.0% | 99.7% | 141.8% | 99.4% |

**MATERIAL BALANCE -- adjusted data** TEST BGF1/SP4

| Adjustments: | 1.00000 | 1.00000 | 1.00000 | 1.0000 | 0.00 | | |
|---|---|---|---|---|---|---|---|
| | x cc out | x air in | x aqu S | x aqu N | + lb H | | |
| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
| Biomass (dry) | 603.49 | 71.15 | 1.76 | 0.88 | 528.82 | 48.82 | 1254.91 |
| Moisture | --- | 34.02 | --- | --- | 269.96 | --- | 303.98 |
| Air | 0.27 | --- | 2355.46 | --- | 660.91 | --- | 3016.64 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 603.76 | 105.17 | 2357.22 | 0.88 | 1459.69 | 48.82 | 4575.53 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 27.88 | 0.40 | 0.13 | 0.02 | -0.52 | 69.10 | 97.00 |
| Moisture | --- | 0.08 | --- | --- | 0.65 | --- | 0.73 |
| Char, entr (dry) | 1.34 | 0.03 | 0.00 | 0.00 | 0.03 | 0.11 | 1.52 |
| Moisture | --- | 0.00 | --- | --- | 0.01 | --- | 0.01 |
| Product gas(dry) | 515.14 | 31.93 | 2355.46 | 0.00 | 951.79 | --- | 3854.32 |
| Oils/tars | 25.15 | 1.47 | 0.05 | 0.01 | 1.59 | 0.00 | 28.26 |
| Condensate water | 0.00 | 63.50 | 1.13 | 0.03 | 502.33 | --- | 566.99 |
| Total | 569.50 | 97.41 | 2356.77 | 0.06 | 1455.87 | 69.21 | 4548.83 |
| Out/In | 94.3% | 92.6% | 100.0% | 7.0% | 99.7% | 141.8% | 99.4% |

**ENGINEERING DATA -- unadjusted** TEST BGF1/SP4

| MATERIAL INPUT DATA | |
|---|---|
| Biomass (wet), lb/h..... | 2227.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 902.86 |
| Nitrogen, lb/h..... | 3364.95 |
| Air, scfm ..... | 939.97 |
| Oxygen, lb/lb feed (wet)..... | 0.41 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.15 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

| MATERIAL OUTPUT DATA | |
|---|---|
| Cyclone Char (dry), lb/h..... | 138.57 |
| Entrained Char (dry), lb/h ..... | 2.16 |
| Condensate, lb/h..... | 850.36 |
| Aqueous Phase, lb/h..... | 809.98 |
| Oil Phase, lb/h..... | 40.38 |
| Dry Product Gas, lb/h..... | 5506.18 |

**ENGINEERING DATA, continued** TEST BGF1/SP4

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 39.3 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 39.4 |
| Gas Heating Value, Btu/SCF (dry)..... | 91.1 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 256.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.430 |
| Carbon Conversion to Gases and Liquids, %..... | 89.5 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 100.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.430 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.492 |

**Biomass Gasifier Facility**

| | | | |
|---|---|---|---|
| PROJECT NUMBER..... | | | |
| TEST NUMBER..... | BGF1/SP5 | | |
| DATE OF TEST..... | 10/8/95 | | |
| Latest file update: | 2/12/96 | 12:11 PM | |
| Reactor I.D., inches.... | 37.00 | | |
| Sampling period..... | 1:34:00 | to | 2:45:00 |
| Sampling basis..... | 1.183 | hours | |
| TEST CONDITIONS: | | | |
| Temperature, °F..... | 1543.00 | | |
| Pressure, psig..... | 46.0 | | |
| TEST DESCRIPTION: | | | |

**MATERIAL INPUT DATA:**

| | Steady-state period | | | | |
|---|---|---|---|---|---|
| | lb/h | SCF/h | lb | SCF | Vol% |
| Biomass feed (as rec'd) | 2460.0 | -- | 2911.0 | -- | -- |
| Steam to nozzle..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Steam to ring..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Total steam..... | 0.0 | 0.00 | 0.0 | 0.00 | 0.0% |
| Air to nozzle..... | 2228.2 | 29160.00 | 2636.66 | | |
| Air to ring..... | 1746.8 | 22860.00 | 2067.01 | | |
| Air to burner..... | 710.6 | 9300.00 | 840.91 | | |
| Total air..... | 4685.6 | 61320.00 | 2907.9 | 0.00 | 0.0% |
| Oxygen (calc)..... | 981.6 | 11626.12 | 1161.59 | 13757.57 | 19.0% |
| Nitrogen (calc)..... | 3658.5 | 49502.53 | 4329.21 | 58577.99 | 81.0% |
| Argon (calc)..... | 43.8 | 415.17 | 51.79 | 491.29 | 0.7% |
| CO2 (calc)..... | 1.5 | 13.32 | 1.83 | 15.76 | 0.0% |
| Neon, etc. (calc)..... | 0.1 | 1.2 | 0.17 | 1.43 | 0.0% |
| DRY gas input..... | 4685.6 | 61558.35 | 5490.8 | 72335.57 | 100.0% |
| WET gas input..... | 4685.6 | 61558.35 | 13943.3 | 72335.57 | 100.0% |

**MATERIAL OUTPUT DATA:**

| | lb/h | SCF/h | lb | SCF | Vol% |
|---|---|---|---|---|---|
| Char (cyclone discharge).... | 117.5 | -- | 139.0 | -- | -- |
| Char (entrained)..... | 2.4 | -- | 2.8 | -- | -- |
| Total char (filter+cyc) | 119.8 | -- | 141.8 | -- | -- |
| Condensate..... | 1326.9 | -- | 1570.2 | -- | -- |
| AQUEOUS phase..... | 1294.7 | 27230.59 | 1532.1 | 32222.87 | -- |
| OIL phase..... | 32.2 | -- | 38.1 | -- | -- |
| N2 (as tracer)..... | 3658.5 | 49502.53 | 4329.2 | 58577.99 | 44.6% |
| DRY product gas..... | 6442.9 | 83713.27 | 7624.1 | 99060.70 | 75.5% |
| WET product gas..... | 7737.4 | 110943.86 | 9155.9 | 131283.57 | 100.0% |
| DRY N2-FREE product gas. | 2784.4 | 34210.74 | 3294.9 | 40482.71 | 30.8% |

**SAMPLE SYSTEM DATA:**

| | | Comments |
|---|---|---|
| Gas meter initial reading, cu ft. | 434.35 | |
| Gas meter final reading, cu ft... | 494.88 | |
| Gas meter temperature, °F..... | 80.00 | |
| Gas meter pressure, psig..... | 5.00 | |
| Meter correction factor..... | 1.000 | |
| Total DRY gas sampled, SCF..... | 78.11 | |
| % of reactor gas flow..... | 0.08% | |
| | | |
| Char fines collected, g..... | 1.00 | |
| Char carryover, lb/MSCF (wet).... | 0.021 | |
| Condensate collected, g..... | 561.64 | |
| AQUEOUS condensate, g..... | 548.00 | |
| OIL in condensate, g..... | 13.64 | |
| C6H6 in condensate OIL, g..... | 0.98 | |
| Equiv C6H6 volume, SCF..... | 0.010 | |
| Equiv steam volume, SCF..... | 25.41 | |
| Total WET gas sampled, SCF.... | 103.52 | |
| Steam in wet product gas, vol%... | 24.54 | |

**SOLID ANALYSES:**

| | ---------Feed--------- | | | ----Char (cyclone)---- | | | ---Char (entrained)--- | | |
|---|---|---|---|---|---|---|---|---|---|
| PROXIMATE, wt% | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) |
| Moisture..... | 33.75 | 0.00 | 0.00 | 0.73 | 0.00 | 0.00 | 0.36 | -0.85 | -1.22 |
| V. M..... | 56.18 | 84.80 | 87.85 | | 0.00 | 0.00 | 13.06 | 13.16 | 45.49 |
| Ash..... | 2.30 | 3.47 | 0.00 | 70.56 | 71.08 | 0.00 | 11.63 | 11.72 | 1.00 |
| Fixed carbon.. | 7.77 | 11.73 | 12.15 | | | | 74.95 | 75.98 | 54.73 |
| ULTIMATE, wt% | | | | | | | | | |
| C..... | 31.94 | 48.21 | 49.94 | 24.59 | 24.77 | 101.64 | 74.40 | 74.95 | 307.55 |
| H..... | 3.71 | 5.60 | 5.80 | 0.41 | 0.41 | 1.68 | 0.00 | 0.00 | 0.00 |
| N..... | 0.08 | 0.12 | 0.12 | 0.12 | 0.12 | 0.49 | 0.00 | 0.00 | 0.00 |
| S..... | 0.03 | 0.05 | 0.05 | 0.01 | 0.01 | 0.04 | 0.00 | 0.00 | 0.00 |
| O (by diff)... | 28.19 | 42.55 | 44.08 | -0.93 | -0.94 | -3.86 | 21.11 | 21.27 | 87.28 |
| Ash..... | 2.30 | 3.47 | --- | 75.08 | 75.63 | --- | 3.75 | 3.78 | --- |
| HHV, Btu/lb..... | 5527.24 | 8343.00 | 8642.91 | 0.00 | | 0.00 | 0.00 | | 0.00 |
| C/ash ratio..... | 13.89 | | | 0.33 | | | 19.83 | | |
| INPUT, lb..... | 2911.00 | 1928.54 | 1861.58 | --- | --- | --- | | | |
| OUTPUT, lb..... | --- | --- | --- | 141.80 | 140.76 | 40.71 | | | |

**DRY GAS ANALYSES (excluding condensed C6H6):**

| | Dry GC, vol% |
|---|---|
| H2 | 4.99 |
| CO2 | 17.30 |
| C2H4 | 0.75 |
| C2H6 | 0.04 |
| O2/Ar | 0.00 |
| N2 | 57.87 |
| CH4 | 4.13 |
| CO | 12.47 |
| C3's | 0.00 |
| C4's | 0.00 |
| C6H6 | 0.30 |
| H2S | 0.00 |
| Total (dry).. | 97.85 |

Comments

| | | |
|---|---|---|
| T(gas) | | 1484.90 |
| T(ref) | | 60 |
| | 26.51 | 1.322717 |
| | 43.22 | 7.47783 |
| | 66.59 | 0.499413 |
| | 27.63 | 15.98716 |
| | 50.32 | 2.078396 |
| | 26.93 | 3.357814 |
| ∫cpdT= | | 14.74 Btu/scf |

**GAS ANALYSES (including condensed C6H6):**

More--> <----More

| | Avg vol% (dry) | Avg vol% (wet) | Avg vol% dry N2-free | Volume, SCF (SS) | Volume, SCF (reac) | MW | HHV, Btu/SCF | Mass, lb Total | Mass, lb C | Mass, lb H | Mass, lb N | Mass, lb S | Mass, lb O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H2 | 5.10 | 3.85 | 12.48 | 3.90 | 5051.05 | 2.016 | 324.3 | 26.87 | 0.00 | 26.87 | 0.00 | 0.00 | 0.00 |
| CO2 | 17.68 | 13.34 | 43.26 | 13.51 | 17511.65 | 44.01 | 0.00 | 2033.48 | 554.92 | 0.00 | 0.00 | 0.00 | 1478.56 |
| C2H4 | 0.77 | 0.58 | 1.88 | 0.59 | 759.18 | 28.05 | 1573.8 | 56.19 | 48.11 | 8.08 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.04 | 0.03 | 0.10 | 0.03 | 40.49 | 30.07 | 1769.6 | 3.21 | 2.57 | 0.65 | 0.00 | 0.00 | 0.00 |
| O2/Ar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 59.13 | 44.62 | | 45.20 | 58577.99 | 28.01 | 0.00 | 4329.21 | 0.00 | 0.00 | 4329.21 | 0.00 | 0.00 |
| CH4 | 4.22 | 3.18 | 10.33 | 3.23 | 4180.53 | 16.04 | 1009.8 | 176.93 | 132.48 | 44.47 | 0.00 | 0.00 | 0.00 |
| CO | 12.74 | 9.61 | 31.18 | 9.74 | 12622.56 | 28.01 | 321.0 | 932.87 | 399.99 | 0.00 | 0.00 | 0.00 | 532.88 |
| C3's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 44.09 | 2450.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C4's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 42.08 | 3300.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C6H6 | 0.32 | 0.24 | 0.78 | 0.24 | 317.25 | 78.11 | 3745.2 | 65.38 | 60.32 | 5.06 | 0.00 | 0.00 | 0.00 |
| H2O | | 24.54 | | 25.41 | 32926.37 | 18.02 | 0.00 | 1565.18 | 0.00 | 175.14 | 0.00 | 0.00 | 1390.03 |
| H2S | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 | 34.08 | 960.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total (dry) | 100.00 | --- | --- | 76.45 | 99060.70 | 0.00 | 0.00 | 7624.13 | 1198.39 | 85.13 | 4329.21 | 0.00 | 2011.43 |
| Total (wet) | --- | 100.00 | --- | 101.85 | 131987.07 | 0.00 | 0.00 | 9189.31 | 1198.39 | 260.27 | 4329.21 | 0.00 | 3401.47 |
| Total (dry N2-free).. | --- | --- | 100.00 | | | | | | | | | | |
| Mol wt, lb/lbmol | 29.17 | 26.43 | 30.85 | | | | | | | | | | |
| HHV, Btu/SCF | 124.8 | 94.2 | 305.5 | | | | | | | | | | |

**OIL ANALYSES:**

| ULTIMATE, dry wt% | |
|---|---|
| C..... | 86.34 |
| H..... | 5.15 |
| N..... | 0.05 |
| S..... | 0.02 |
| O (by diff)..... | 8.44 |
| Ash..... | 0.00 |
| HHV, Btu/lb..... | 15153.01 |
| H/C ratio..... | 0.711 |

**AQUEOUS CONDENSATE ANALYSES:**

| | | wt% dry feed | Comments |
|---|---|---|---|
| TC, mg/L..... | | 0.000 | |
| TOC, mg/L..... | | 0.000 | |
| S, mg/L..... | 42.00 | 0.003 | |
| N, mg/L..... | 1300.00 | 0.106 | |
| equiv lb NH3..... | 2.42 | 0.126 | |
| Cl, mg/L..... | 157.00 | 0.013 | |
| equiv lb HCl..... | 0.25 | 0.013 | |
| CN, mg/L..... | | 0.000 | |
| equiv lb HCN..... | 0.00 | 0.000 | |

**MATERIAL BALANCE -- raw data** TEST BGF1/SP5

| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
|---|---|---|---|---|---|---|---|
| Biomass (dry) | 929.75 | 108.00 | 2.31 | 0.964 | 820.59 | 66.92 | 1928.54 |
| Moisture | --- | 109.94 | --- | --- | 872.50 | --- | 982.43 |
| Air | 0.50 | --- | 4329.21 | --- | 1214.71 | --- | 5544.41 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 930.25 | 217.93 | 4331.52 | 0.964 | 2907.80 | 66.92 | 8455.38 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 34.43 | 0.57 | 0.17 | 0.014 | -1.31 | 105.13 | 139.00 |
| Moisture | --- | 0.11 | --- | --- | 0.90 | --- | 1.01 |
| Char, entr (dry) | 2.10 | 0.00 | 0.00 | 0.000 | 0.59 | 0.11 | 2.80 |
| Moisture | --- | 0.00 | --- | --- | 0.01 | --- | 0.01 |
| Product gas(dry) | 1198.39 | 85.13 | 4329.21 | 0.000 | 2011.43 | --- | 7624.16 |
| Oils/tars | 32.92 | 1.96 | 0.02 | 0.008 | 3.22 | 0.00 | 38.13 |
| Condensate water | 0.00 | 171.56 | 1.99 | 0.064 | 1358.77 | --- | 1532.38 |
| Total | 1267.84 | 259.34 | 4331.39 | 0.086 | 3373.62 | 105.23 | 9337.50 |
| Out/In | 136.3% | 119.0% | 100.0% | 8.9% | 116.0% | 157.2% | 110.4% |

**MATERIAL BALANCE -- adjusted data** TEST BGF1/SP5

| Adjustments: | 1.00000 | 1.00000 | 1.00000 | 1.0000 | 0.00 | | |
|---|---|---|---|---|---|---|---|
| | x cc out | x air in | x aqu S | x aqu N | + lb H | | |
| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
| Biomass (dry) | 929.75 | 108.00 | 2.31 | 0.96 | 820.59 | 66.92 | 1928.54 |
| Moisture | --- | 109.94 | --- | --- | 872.50 | --- | 982.43 |
| Air | 0.50 | --- | 4329.21 | --- | 1214.71 | --- | 5544.41 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 930.25 | 217.93 | 4331.52 | 0.96 | 2907.80 | 66.92 | 8455.38 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 34.43 | 0.57 | 0.17 | 0.01 | -1.31 | 105.13 | 139.00 |
| Moisture | --- | 0.11 | --- | --- | 0.90 | --- | 1.01 |
| Char, entr (dry) | 2.10 | 0.00 | 0.00 | 0.00 | 0.59 | 0.11 | 2.80 |
| Moisture | --- | 0.00 | --- | --- | 0.01 | --- | 0.01 |
| Product gas(dry) | 1198.39 | 85.13 | 4329.21 | 0.00 | 2011.43 | --- | 7624.16 |
| Oils/tars | 32.92 | 1.96 | 0.02 | 0.01 | 3.22 | 0.00 | 38.13 |
| Condensate water | 0.00 | 171.56 | 1.99 | 0.06 | 1358.77 | --- | 1532.38 |
| Total | 1267.84 | 259.34 | 4331.39 | 0.09 | 3373.62 | 105.23 | 9337.50 |
| Out/In | 136.3% | 119.0% | 100.0% | 8.9% | 116.0% | 157.2% | 110.4% |

**ENGINEERING DATA -- unadjusted** TEST BGF1/SP5

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 2460.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 981.62 |
| Nitrogen, lb/h..... | 3658.49 |
| Air, scfm ..... | 1021.97 |
| Oxygen, lb/lb feed (wet)..... | 0.40 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.14 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 117.46 |
| Entrained Char (dry), lb/h ..... | 2.36 |
| Condensate, lb/h..... | 1327.20 |
| Aqueous Phase, lb/h..... | 1294.97 |
| Oil Phase, lb/h..... | 32.23 |
| Dry Product Gas, lb/h..... | 6442.95 |

**ENGINEERING DATA, continued** TEST BGF1/SP5

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 45.1 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 51.4 |
| Gas Heating Value, Btu/SCF (dry)..... | 124.8 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 305.5 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.769 |
| Carbon Conversion to Gases and Liquids, %..... | 132.4 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 130.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.769 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.859 |

**Biomass Gasifier Facility**

| | | | |
|---|---|---|---|
| PROJECT NUMBER..... | | | |
| TEST NUMBER..... | BGF2/SP1 | | |
| DATE OF TEST..... | 12/6/95 | | |
| Latest file update: | 2/14/96 | 3:09 PM | |
| Reactor I.D., inches.... | 37.00 | | |
| Sampling period..... | 9:00:00 | to | 10:12:00 |
| Sampling basis..... | 1.200 | hours | |
| TEST CONDITIONS: | | | |
| Temperature, °F..... | 1459.00 | | |
| Pressure, psig..... | 35.0 | | |
| TEST DESCRIPTION: | | | |

**MATERIAL INPUT DATA:**

| | | Steady-state period | | | |
|---|---|---|---|---|---|
| | lb/h | SCF/h | lb | SCF | Vol% |
| Biomass feed (as rec'd) | 3390.0 | -- | 4068.0 | -- | -- |
| Steam to nozzle..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Steam to ring..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Total steam..... | 0.0 | 0.00 | 0.0 | 0.00 | 0.0% |
| Air to nozzle..... | 2278.6 | 29820.00 | 2734.31 | | |
| Air to ring..... | 916.9 | 12000.00 | 1100.33 | | |
| Air to burner..... | 0.0 | 0.00 | 0.00 | | |
| Total air..... | 3195.5 | 41820.00 | 1100.3 | 0.00 | 0.0% |
| Oxygen (calc)..... | 669.5 | 7928.97 | 803.36 | 9514.76 | 19.0% |
| Nitrogen (calc)..... | 2495.1 | 33760.53 | 2994.09 | 40512.64 | 81.0% |
| Argon (calc)..... | 29.8 | 283.15 | 35.82 | 339.78 | 0.7% |
| CO2 (calc)..... | 1.1 | 9.08 | 1.27 | 10.90 | 0.0% |
| Neon, etc. (calc)..... | 0.1 | 0.8 | 0.12 | 0.99 | 0.0% |
| DRY gas input..... | 3195.5 | 41982.55 | 3797.4 | 50027.40 | 100.0% |
| WET gas input..... | 3195.5 | 41982.55 | 8732.4 | 50027.40 | 100.0% |

**MATERIAL OUTPUT DATA:**

| | lb/h | SCF/h | lb | SCF | Vol% |
|---|---|---|---|---|---|
| Char (cyclone discharge).... | 89.7 | -- | 107.6 | -- | -- |
| Char (entrained)..... | 1.7 | -- | 2.0 | -- | -- |
| Total char (filter+cyc) | 91.3 | -- | 109.6 | -- | -- |
| Condensate..... | 908.5 | -- | 1090.2 | -- | -- |
| AQUEOUS phase..... | 890.0 | 18718.39 | 1068.0 | 22462.07 | -- |
| OIL phase..... | 18.5 | -- | 22.2 | -- | -- |
| N2 (as tracer)..... | 2495.1 | 33760.53 | 2994.1 | 40512.64 | 44.1% |
| DRY product gas..... | 4499.9 | 57910.73 | 5399.9 | 69492.87 | 75.6% |
| WET product gas..... | 5389.7 | 76629.11 | 6467.7 | 91954.94 | 100.0% |
| DRY N2-FREE product gas. | 2004.8 | 24150.19 | 2405.8 | 28980.23 | 31.5% |

**SAMPLE SYSTEM DATA:**

| | | Comments |
|---|---|---|
| Gas meter initial reading, cu ft. | 495.14 | |
| Gas meter final reading, cu ft... | 541.86 | |
| Gas meter temperature, °F..... | 80.00 | |
| Gas meter pressure, psig..... | 5.00 | |
| Meter correction factor..... | 1.000 | |
| Total DRY gas sampled, SCF..... | 60.29 | |
| % of reactor gas flow..... | 0.09% | |
| | | |
| Char fines collected, g..... | 0.80 | |
| Char carryover, lb/MSCF (wet).... | 0.022 | |
| Condensate collected, g..... | 429.04 | |
| AQUEOUS condensate, g..... | 420.30 | |
| OIL in condensate, g..... | 8.74 | |
| C6H6 in condensate OIL, g..... | 0.48 | |
| Equiv C6H6 volume, SCF..... | 0.005 | |
| Equiv steam volume, SCF..... | 19.49 | |
| Total WET gas sampled, SCF.... | 79.78 | |
| Steam in wet product gas, vol%... | 24.43 | |

**SOLID ANALYSES:**

| | ---------Feed--------- | | | ----Char (cyclone)---- | | | ---Char (entrained)--- | | |
|---|---|---|---|---|---|---|---|---|---|
| PROXIMATE, wt% | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) |
| Moisture..... | 31.62 | 0.00 | 0.00 | 0.42 | 0.00 | 0.00 | 0.00 | -0.85 | -1.22 |
| V. M..... | 58.38 | 85.38 | 88.54 | | 0.00 | 0.00 | 13.33 | 13.39 | 41.27 |
| Ash..... | 2.44 | 3.57 | 0.00 | 67.28 | 67.56 | 0.00 | 35.73 | 35.88 | 1.00 |
| Fixed carbon.. | 7.56 | 11.06 | 11.46 | | | | 50.94 | 51.58 | 58.95 |
| ULTIMATE, wt% | | | | | | | | | |
| C..... | 33.34 | 48.75 | 50.55 | 29.11 | 29.23 | 90.10 | 55.15 | 55.38 | 170.72 |
| H..... | 3.96 | 5.79 | 6.00 | 0.47 | 0.47 | 1.45 | 4.42 | 4.44 | 13.69 |
| N..... | 0.15 | 0.22 | 0.23 | 0.34 | 0.34 | 1.05 | 0.00 | 0.00 | 0.00 |
| S..... | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.09 | 0.00 | 0.00 | 0.00 |
| O (by diff)... | 28.47 | 41.64 | 43.18 | 2.36 | 2.37 | 7.31 | 4.43 | 4.45 | 13.72 |
| Ash..... | 2.44 | 3.57 | --- | 67.28 | 67.56 | --- | 35.58 | 35.73 | --- |
| HHV, Btu/lb..... | 5473.82 | 8005.00 | 8301.36 | 0.00 | | 0.00 | 0.00 | | 0.00 |
| C/ash ratio..... | 13.66 | | | 0.43 | | | 1.55 | | |
| INPUT, lb..... | 4068.00 | 2781.70 | 2682.44 | --- | --- | --- | | | |
| OUTPUT, lb..... | --- | --- | --- | 109.61 | 109.15 | 35.40 | | | |

**DRY GAS ANALYSES (excluding condensed C6H6):**

| | Dry GC, vol% |
|---|---|
| H2 | 4.28 |
| CO2 | 18.25 |
| C2H4 | 1.17 |
| C2H6 | 0.11 |
| O2/Ar | 0.00 |
| N2 | 58.32 |
| CH4 | 4.14 |
| CO | 13.51 |
| C3's | 0.00 |
| C4's | 0.01 |
| C6H6 | 0.24 |
| H2S | 0.00 |
| Total (dry).. | 100.03 |

| | | |
|---|---|---|
| T(gas) | 1385.81 | |
| Comments T(ref) | 60 | |
| | 24.61 | 1.053402 |
| | 39.80 | 7.262945 |
| | 60.58 | 0.708755 |
| | 25.57 | 14.91212 |
| | 45.72 | 1.892693 |
| | 24.95 | 3.370332 |
| ∫cpdT= | 14.29 | Btu/scf |

**GAS ANALYSES (including condensed C6H6):**

More--> <----More

| | -------Avg vol%------- | | | --Volume, SCF-- | | | HHV, | ----------Mass, lb---------- | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (dry) | (wet) | ry N2-free) | (SS) | (reac) | MW | Btu/SCF | Total | C | H | N | S | O |
| H2 | 4.28 | 3.23 | 10.26 | 2.58 | 2973.15 | 2.016 | 324.3 | 15.81 | 0.00 | 15.81 | 0.00 | 0.00 | 0.00 |
| CO2 | 18.24 | 13.79 | 43.75 | 11.00 | 12677.57 | 44.01 | 0.00 | 1472.14 | 401.74 | 0.00 | 0.00 | 0.00 | 1070.40 |
| C2H4 | 1.17 | 0.88 | 2.80 | 0.71 | 812.75 | 28.05 | 1573.8 | 60.15 | 51.51 | 8.65 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.11 | 0.08 | 0.26 | 0.07 | 76.41 | 30.07 | 1769.6 | 6.06 | 4.84 | 1.22 | 0.00 | 0.00 | 0.00 |
| O2/Ar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 58.30 | 44.06 | | 35.16 | 40512.64 | 28.01 | 0.00 | 2994.09 | 0.00 | 0.00 | 2994.09 | 0.00 | 0.00 |
| CH4 | 4.14 | 3.13 | 9.92 | 2.50 | 2875.90 | 16.04 | 1009.8 | 121.71 | 91.13 | 30.60 | 0.00 | 0.00 | 0.00 |
| CO | 13.50 | 10.21 | 32.38 | 8.15 | 9384.87 | 28.01 | 321.0 | 693.59 | 297.39 | 0.00 | 0.00 | 0.00 | 396.20 |
| C3's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 44.09 | 2450.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C4's | 0.01 | 0.008 | 0.02 | 0.01 | 6.9 | 42.08 | 3300.0 | 0.77 | 0.66 | 0.11 | 0.00 | 0.00 | 0.00 |
| C6H6 | 0.25 | 0.19 | 0.60 | 0.15 | 172.63 | 78.11 | 3745.2 | 35.58 | 32.82 | 2.75 | 0.00 | 0.00 | 0.00 |
| H2O | | 24.43 | | 19.49 | 22453.42 | 18.02 | 0.00 | 1067.34 | 0.00 | 119.44 | 0.00 | 0.00 | 947.90 |
| H2S | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 | 34.08 | 960.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total (dry) | 100.00 | --- | --- | 60.32 | 69492.87 | 0.00 | 0.00 | 5399.91 | 880.10 | 59.14 | 2994.09 | 0.00 | 1466.60 |
| Total (wet) | --- | 100.00 | --- | 79.80 | 91946.29 | 0.00 | 0.00 | 6467.24 | 880.10 | 178.58 | 2994.09 | 0.00 | 2414.50 |
| Total (dry N2-free).. | --- | --- | 100.00 | | | | | | | | | | |
| Mol wt, lb/lbmol | 29.45 | 26.66 | 31.46 | | | | | | | | | | |
| HHV, Btu/SCF | 129.0 | 97.5 | 309.3 | | | | | | | | | | |

**OIL ANALYSES:**

| ULTIMATE, dry wt% | |
|---|---|
| C | 93.83 |
| H | 5.48 |
| N | 0.61 |
| S | 0.08 |
| O (by diff) | 0.00 |
| Ash | 0.00 |
| HHV, Btu/lb | 16813.52 |
| H/C ratio | 0.696 |

**AQUEOUS CONDENSATE ANALYSES:**

| | | wt% dry feed | Comments |
|---|---|---|---|
| TC, mg/L | | 0.000 | |
| TOC, mg/L | | 0.000 | |
| S, mg/L | 17.00 | 0.001 | |
| N, mg/L | 1100.00 | 0.042 | |
| equiv lb NH3 | 1.43 | 0.051 | |
| Cl, mg/L | 26.00 | 0.001 | |
| equiv lb HCl | 0.03 | 0.001 | |
| CN, mg/L | | 0.000 | |
| equiv lb HCN | 0.00 | 0.000 | |

**MATERIAL BALANCE -- raw data** TEST BGF2/SP1

| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
|---|---|---|---|---|---|---|---|
| Biomass (dry) | 1356.08 | 161.06 | 6.12 | 0.835 | 1158.30 | 99.31 | 2781.70 |
| Moisture | --- | 143.93 | --- | --- | 1142.33 | --- | 1286.26 |
| Air | 0.35 | --- | 2994.09 | --- | 840.09 | --- | 3834.53 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 1356.42 | 304.99 | 3000.21 | 0.835 | 3140.72 | 99.31 | 7902.49 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 31.45 | 0.51 | 0.37 | 0.032 | 2.55 | 72.68 | 107.58 |
| Moisture | --- | 0.05 | --- | --- | 0.40 | --- | 0.45 |
| Char, entr (dry) | 1.13 | 0.09 | 0.00 | 0.000 | 0.09 | 0.73 | 2.03 |
| Moisture | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Product gas(dry) | 880.10 | 59.14 | 2994.09 | 0.000 | 1466.60 | --- | 5399.92 |
| Oils/tars | 20.84 | 1.22 | 0.14 | 0.018 | 0.00 | 0.00 | 22.21 |
| Condensate water | 0.00 | 119.58 | 1.17 | 0.018 | 947.39 | --- | 1068.16 |
| Total | 933.51 | 180.59 | 2995.76 | 0.068 | 2417.03 | 73.41 | 6600.36 |
| Out/In | 68.8% | 59.2% | 99.9% | 8.2% | 77.0% | 73.9% | 83.5% |

**MATERIAL BALANCE -- adjusted data** TEST BGF2/SP1

| Adjustments: | 1.00000 | 1.00000 | 1.00000 | 1.0000 | 0.00 | | |
|---|---|---|---|---|---|---|---|
| | x cc out | x air in | x aqu S | x aqu N | + lb H | | |
| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
| Biomass (dry) | 1356.08 | 161.06 | 6.12 | 0.83 | 1158.30 | 99.31 | 2781.70 |
| Moisture | --- | 143.93 | --- | --- | 1142.33 | --- | 1286.26 |
| Air | 0.35 | --- | 2994.09 | --- | 840.09 | --- | 3834.53 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 1356.42 | 304.99 | 3000.21 | 0.83 | 3140.72 | 99.31 | 7902.49 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 31.45 | 0.51 | 0.37 | 0.03 | 2.55 | 72.68 | 107.58 |
| Moisture | --- | 0.05 | --- | --- | 0.40 | --- | 0.45 |
| Char, entr (dry) | 1.13 | 0.09 | 0.00 | 0.00 | 0.09 | 0.73 | 2.03 |
| Moisture | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Product gas(dry) | 880.10 | 59.14 | 2994.09 | 0.00 | 1466.60 | --- | 5399.92 |
| Oils/tars | 20.84 | 1.22 | 0.14 | 0.02 | 0.00 | 0.00 | 22.21 |
| Condensate water | 0.00 | 119.58 | 1.17 | 0.02 | 947.39 | --- | 1068.16 |
| Total | 933.51 | 180.59 | 2995.76 | 0.07 | 2417.03 | 73.41 | 6600.36 |
| Out/In | 68.8% | 59.2% | 99.9% | 8.2% | 77.0% | 73.9% | 83.5% |

**ENGINEERING DATA -- unadjusted** TEST BGF2/SP1

| MATERIAL INPUT DATA | |
|---|---|
| Biomass (wet), lb/h..... | 3390.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 669.46 |
| Nitrogen, lb/h..... | 2495.07 |
| Air, scfm ..... | 696.98 |
| Oxygen, lb/lb feed (wet)..... | 0.20 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 1.70 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

| MATERIAL OUTPUT DATA | |
|---|---|
| Cyclone Char (dry), lb/h..... | 89.65 |
| Entrained Char (dry), lb/h ..... | 1.69 |
| Condensate, lb/h..... | 908.64 |
| Aqueous Phase, lb/h..... | 890.13 |
| Oil Phase, lb/h..... | 18.51 |
| Dry Product Gas, lb/h..... | 4499.94 |

**ENGINEERING DATA, continued** TEST BGF2/SP1

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 22.6 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 25.0 |
| Gas Heating Value, Btu/SCF (dry)..... | 129.0 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 309.3 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.403 |
| Carbon Conversion to Gases and Liquids, %..... | 66.4 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 134.4 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.403 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.447 |

**Biomass Gasifier Facility**

| | | | |
|---|---|---|---|
| PROJECT NUMBER..... | | | |
| TEST NUMBER..... | BGF2/SP2 | | |
| DATE OF TEST..... | 12/7/95 | | |
| Latest file update: | 2/12/96 | 12:28 PM | |
| Reactor I.D., inches.... | 37.00 | | |
| Sampling period..... | 11:08:00 | to | 12:15:00 |
| Sampling basis..... | 1.117 | hours | |
| TEST CONDITIONS: | | | |
| Temperature, °F..... | 1612.00 | | |
| Pressure, psig..... | 86.0 | | |
| TEST DESCRIPTION: | | | |

**MATERIAL INPUT DATA:**

| | Steady-state period | | | | |
|---|---|---|---|---|---|
| | lb/h | SCF/h | lb | SCF | Vol% |
| Biomass feed (as rec'd) | 4167.0 | -- | 4653.2 | -- | -- |
| Steam to nozzle..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Steam to ring..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Total steam..... | 0.0 | 0.00 | 0.0 | 0.00 | 0.0% |
| Air to nozzle..... | 2351.9 | 30780.00 | 2626.34 | | |
| Air to ring..... | 916.9 | 12000.00 | 1023.92 | | |
| Air to burner..... | 0.0 | 0.00 | 0.00 | | |
| Total air..... | 3268.9 | 42780.00 | 1023.9 | 0.00 | 0.0% |
| Oxygen (calc)..... | 684.8 | 8110.98 | 764.73 | 9057.26 | 19.0% |
| Nitrogen (calc)..... | 2552.3 | 34535.52 | 2850.12 | 38564.67 | 81.0% |
| Argon (calc)..... | 30.5 | 289.65 | 34.09 | 323.44 | 0.7% |
| CO2 (calc)..... | 1.1 | 9.29 | 1.20 | 10.37 | 0.0% |
| Neon, etc. (calc)..... | 0.1 | 0.8 | 0.11 | 0.94 | 0.0% |
| DRY gas input..... | 3268.9 | 42946.29 | 3614.9 | 47621.93 | 100.0% |
| WET gas input..... | 3268.9 | 42946.29 | 8289.0 | 47621.93 | 100.0% |

**MATERIAL OUTPUT DATA:**

| | lb/h | SCF/h | lb | SCF | Vol% |
|---|---|---|---|---|---|
| Char (cyclone discharge).... | 72.5 | -- | 81.0 | -- | -- |
| Char (entrained)..... | 6.1 | -- | 6.8 | -- | -- |
| Total char (filter+cyc) | 78.6 | -- | 87.8 | -- | -- |
| Condensate..... | 852.7 | -- | 952.2 | -- | -- |
| AQUEOUS phase..... | 825.6 | 17363.27 | 921.9 | 19388.98 | -- |
| OIL phase..... | 27.1 | -- | 30.3 | -- | -- |
| N2 (as tracer)..... | 2552.3 | 34535.52 | 2850.1 | 38564.67 | 45.7% |
| DRY product gas..... | 4491.7 | 58229.83 | 5015.7 | 65023.31 | 77.0% |
| WET product gas..... | 5317.0 | 75593.10 | 5937.4 | 84412.30 | 100.0% |
| DRY N2-FREE product gas. | 1939.3 | 23694.31 | 2165.6 | 26458.65 | 31.3% |

**SAMPLE SYSTEM DATA:**

| | | Comments |
|---|---|---|
| Gas meter initial reading, cu ft. | 541.91 | |
| Gas meter final reading, cu ft... | 609.17 | |
| Gas meter temperature, °F..... | 80.00 | |
| Gas meter pressure, psig..... | 5.00 | |
| Meter correction factor..... | 1.000 | |
| Total DRY gas sampled, SCF..... | 86.80 | |
| % of reactor gas flow..... | 0.13% | |
| | | |
| Char fines collected, g..... | 4.10 | |
| Char carryover, lb/MSCF (wet).... | 0.080 | |
| Condensate collected, g..... | 576.55 | |
| AQUEOUS condensate, g..... | 558.20 | |
| OIL in condensate, g..... | 18.35 | |
| C6H6 in condensate OIL, g..... | 0.94 | |
| Equiv C6H6 volume, SCF..... | 0.010 | |
| Equiv steam volume, SCF..... | 25.88 | |
| Total WET gas sampled, SCF.... | 112.68 | |
| Steam in wet product gas, vol%... | 22.97 | |

**SOLID ANALYSES:**

| | ---------Feed--------- | | | ----Char (cyclone)---- | | | ---Char (entrained)--- | | |
|---|---|---|---|---|---|---|---|---|---|
| PROXIMATE, wt% | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) |
| Moisture..... | 26.30 | 0.00 | 0.00 | 0.42 | 0.00 | 0.00 | 0.34 | -0.85 | -1.22 |
| V. M..... | 63.22 | 85.78 | 89.97 | | 0.00 | 0.00 | 4.06 | 4.08 | 16.04 |
| Ash..... | 3.43 | 4.65 | 0.00 | 74.27 | 74.58 | 0.00 | 6.24 | 6.27 | 1.00 |
| Fixed carbon.. | 7.05 | 9.57 | 10.03 | | | | 89.36 | 90.51 | 84.18 |
| ULTIMATE, wt% | | | | | | | | | |
| C..... | 35.24 | 47.81 | 50.15 | 26.14 | 26.25 | 103.27 | 90.64 | 91.02 | 358.06 |
| H..... | 4.18 | 5.67 | 5.95 | 0.32 | 0.32 | 1.26 | 1.34 | 1.35 | 5.31 |
| N..... | 0.20 | 0.27 | 0.28 | 0.27 | 0.27 | 1.06 | 0.00 | 0.00 | 0.00 |
| S..... | 0.03 | 0.04 | 0.04 | 0.02 | 0.02 | 0.08 | 0.00 | 0.00 | 0.00 |
| O (by diff)... | 30.62 | 41.55 | 43.58 | -1.43 | -1.44 | -5.66 | 1.36 | 1.37 | 5.39 |
| Ash..... | 3.43 | 4.66 | --- | 74.27 | 74.58 | --- | 6.23 | 6.26 | --- |
| HHV, Btu/lb..... | 5792.82 | 7860.00 | 8244.18 | 0.00 | | 0.00 | 0.00 | | 0.00 |
| C/ash ratio..... | 10.26 | | | 0.35 | | | 14.54 | | |
| INPUT, lb..... | 4653.15 | 3429.37 | 3269.77 | --- | --- | --- | | | |
| OUTPUT, lb..... | --- | --- | --- | 87.77 | 87.40 | 22.21 | | | |

**DRY GAS ANALYSES (excluding condensed C6H6):**

| | Dry GC, vol% |
|---|---|
| H2 | 5.77 |
| CO2 | 19.29 |
| C2H4 | 0.22 |
| C2H6 | 0.02 |
| O2/Ar | 0.00 |
| N2 | 58.96 |
| CH4 | 4.39 |
| CO | 10.45 |
| C3's | 0.00 |
| C4's | 0.00 |
| C6H6 | 0.30 |
| H2S | 0.00 |
| Total (dry).. | 99.40 |

Comments

| | | |
|---|---|---|
| T(gas) | 1505.15 | |
| T(ref) | 60 | |
| 26.90 | 1.55189 | |
| 43.93 | 8.474109 | |
| 67.84 | 0.149241 | |
| 28.05 | 16.53712 | |
| 51.28 | 2.251285 | |
| 27.33 | 2.856286 | |
| JcpdT= | 15.28 | Btu/scf |

**GAS ANALYSES (including condensed C6H6):**

More--> <----More

| | Avg vol% (dry) | Avg vol% (wet) | Avg vol% (dry N2-free) | Volume, SCF (SS) | Volume, SCF (reac) | MW | HHV, Btu/SCF | Mass, lb Total | Mass, lb C | Mass, lb H | Mass, lb N | Mass, lb S | Mass, lb O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H2 | 5.80 | 4.47 | 14.26 | 5.01 | 3774.05 | 2.016 | 324.3 | 20.08 | 0.00 | 20.08 | 0.00 | 0.00 | 0.00 |
| CO2 | 19.40 | 14.95 | 47.69 | 16.74 | 12617.24 | 44.01 | 0.00 | 1465.13 | 399.82 | 0.00 | 0.00 | 0.00 | 1065.31 |
| C2H4 | 0.22 | 0.17 | 0.54 | 0.19 | 143.90 | 28.05 | 1573.8 | 10.65 | 9.12 | 1.53 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.02 | 0.02 | 0.05 | 0.02 | 13.08 | 30.07 | 1769.6 | 1.04 | 0.83 | 0.21 | 0.00 | 0.00 | 0.00 |
| O2/Ar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 59.31 | 45.69 | | 51.18 | 38564.67 | 28.01 | 0.00 | 2850.12 | 0.00 | 0.00 | 2850.12 | 0.00 | 0.00 |
| CH4 | 4.42 | 3.40 | 10.85 | 3.81 | 2871.42 | 16.04 | 1009.8 | 121.52 | 90.99 | 30.55 | 0.00 | 0.00 | 0.00 |
| CO | 10.51 | 8.10 | 25.83 | 9.07 | 6835.16 | 28.01 | 321.0 | 505.15 | 216.60 | 0.00 | 0.00 | 0.00 | 288.56 |
| C3's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 44.09 | 2450.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C4's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 42.08 | 3300.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C6H6 | 0.31 | 0.24 | 0.77 | 0.27 | 203.80 | 78.11 | 3745.2 | 42.00 | 38.75 | 3.25 | 0.00 | 0.00 | 0.00 |
| H2O | | 22.97 | | 25.88 | 19503.74 | 18.02 | 0.00 | 927.12 | 0.00 | 103.75 | 0.00 | 0.00 | 823.38 |
| H2S | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 | 34.08 | 960.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total (dry) | 100.00 | --- | --- | 86.29 | 65023.31 | 0.00 | 0.00 | 5015.70 | 756.11 | 55.61 | 2850.12 | 0.00 | 1353.86 |
| Total (wet) | --- | 100.00 | --- | 112.17 | 84527.06 | 0.00 | 0.00 | 5942.82 | 756.11 | 159.36 | 2850.12 | 0.00 | 2177.24 |
| Total (dry N2-free).. | --- | --- | 100.00 | | | | | | | | | | |
| Mol wt, lb/lbmol | 29.23 | 26.66 | 31.02 | | | | | | | | | | |
| HHV, Btu/SCF | 112.7 | 86.8 | 277.1 | | | | | | | | | | |

**OIL ANALYSES:**

| ULTIMATE, dry wt% | |
|---|---|
| C..... | 86.16 |
| H..... | 4.81 |
| N..... | 0.21 |
| S..... | 0.05 |
| O (by diff)..... | 8.77 |
| Ash..... | 0.00 |
| HHV, Btu/lb..... | 14933.64 |
| H/C ratio..... | 0.665 |

**AQUEOUS CONDENSATE ANALYSES:**

| | | wt% dry feed | Comments |
|---|---|---|---|
| TC, mg/L..... | | 0.000 | |
| TOC, mg/L..... | | 0.000 | |
| S, mg/L..... | 13.00 | 0.000 | |
| N, mg/L..... | 1600.00 | 0.043 | |
| equiv lb NH3..... | 1.79 | 0.052 | |
| Cl, mg/L..... | 366.00 | 0.010 | |
| equiv lb HCl..... | 0.35 | 0.010 | |
| CN, mg/L..... | | 0.000 | |
| equiv lb HCN..... | 0.00 | 0.000 | |

**MATERIAL BALANCE -- raw data** TEST BGF2/SP2

| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
|---|---|---|---|---|---|---|---|
| Biomass (dry) | 1639.58 | 194.45 | 9.26 | 1.372 | 1424.90 | 159.81 | 3429.37 |
| Moisture | --- | 136.94 | --- | --- | 1086.80 | --- | 1223.74 |
| Air | 0.33 | --- | 2850.12 | --- | 799.70 | --- | 3650.15 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 1639.91 | 331.38 | 2859.38 | 1.372 | 3311.41 | 159.81 | 8303.26 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 21.26 | 0.26 | 0.22 | 0.016 | -1.17 | 60.41 | 81.00 |
| Moisture | --- | 0.04 | --- | --- | 0.30 | --- | 0.34 |
| Char, entr (dry) | 6.16 | 0.09 | 0.00 | 0.000 | 0.09 | 0.42 | 6.77 |
| Moisture | --- | 0.00 | --- | --- | 0.02 | --- | 0.02 |
| Product gas(dry) | 756.11 | 55.61 | 2850.12 | 0.000 | 1353.86 | --- | 5015.71 |
| Oils/tars | 26.11 | 1.46 | 0.06 | 0.015 | 2.66 | 0.00 | 30.31 |
| Condensate water | 0.00 | 103.25 | 1.47 | 0.012 | 817.37 | --- | 922.11 |
| Total | 809.65 | 160.71 | 2851.88 | 0.043 | 2173.14 | 60.83 | 6056.26 |
| Out/In | 49.4% | 48.5% | 99.7% | 3.2% | 65.6% | 38.1% | 72.9% |

**MATERIAL BALANCE -- adjusted data** TEST BGF2/SP2

| Adjustments: | 1.00000 | 1.00000 | 1.00000 | 1.0000 | 0.00 | |
|---|---|---|---|---|---|---|
| | x cc out | x air in | x aqu S | x aqu N | + lb H | |
| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
| Biomass (dry) | 1639.58 | 194.45 | 9.26 | 1.37 | 1424.90 | 159.81 | 3429.37 |
| Moisture | --- | 136.94 | --- | --- | 1086.80 | --- | 1223.74 |
| Air | 0.33 | --- | 2850.12 | --- | 799.70 | --- | 3650.15 |
| Steam | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Total | 1639.91 | 331.38 | 2859.38 | 1.37 | 3311.41 | 159.81 | 8303.26 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 21.26 | 0.26 | 0.22 | 0.02 | -1.17 | 60.41 | 81.00 |
| Moisture | --- | 0.04 | --- | --- | 0.30 | --- | 0.34 |
| Char, entr (dry) | 6.16 | 0.09 | 0.00 | 0.00 | 0.09 | 0.42 | 6.77 |
| Moisture | --- | 0.00 | --- | --- | 0.02 | --- | 0.02 |
| Product gas(dry) | 756.11 | 55.61 | 2850.12 | 0.00 | 1353.86 | --- | 5015.71 |
| Oils/tars | 26.11 | 1.46 | 0.06 | 0.02 | 2.66 | 0.00 | 30.31 |
| Condensate water | 0.00 | 103.25 | 1.47 | 0.01 | 817.37 | --- | 922.11 |
| Total | 809.65 | 160.71 | 2851.88 | 0.04 | 2173.14 | 60.83 | 6056.26 |
| Out/In | 49.4% | 48.5% | 99.7% | 3.2% | 65.6% | 38.1% | 72.9% |

**ENGINEERING DATA -- unadjusted** TEST BGF2/SP2

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 4167.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 684.83 |
| Nitrogen, lb/h..... | 2552.35 |
| Air, scfm ..... | 712.98 |
| Oxygen, lb/lb feed (wet)..... | 0.16 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 0.93 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 72.54 |
| Entrained Char (dry), lb/h ..... | 6.06 |
| Condensate, lb/h..... | 852.91 |
| Aqueous Phase, lb/h..... | 825.77 |
| Oil Phase, lb/h..... | 27.14 |
| Dry Product Gas, lb/h..... | 4491.68 |

**ENGINEERING DATA, continued** TEST BGF2/SP2

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 18.1 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 19.0 |
| Gas Heating Value, Btu/SCF (dry)..... | 112.7 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 277.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.272 |
| Carbon Conversion to Gases and Liquids, %..... | 47.7 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 119.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.272 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.309 |

**Biomass Gasifier Facility**

| | | | |
|---|---|---|---|
| PROJECT NUMBER..... | | | |
| TEST NUMBER..... | BGF2/SP3 | | |
| DATE OF TEST..... | 12/7/95 | | |
| Latest file update: | 2/14/96 | 3:28 PM | |
| Reactor I.D., inches.... | 37.00 | | |
| Sampling period..... | 18:30:00 | to | 19:30:00 |
| Sampling basis..... | 1.000 | hours | |
| TEST CONDITIONS: | | | |
| Temperature, °F..... | 1575.00 | | |
| Pressure, psig..... | 73.0 | | |
| TEST DESCRIPTION: | | | |

**MATERIAL INPUT DATA:**

| | | Steady-state period | | | |
|---|---|---|---|---|---|
| | lb/h | SCF/h | lb | SCF | Vol% |
| Biomass feed (as rec'd) | 3441.0 | -- | 3441.0 | -- | -- |
| Steam to nozzle..... | 0.0 | 0.00 | 0.00 | 0.00 | -- |
| Steam to ring..... | 200.0 | 4206.44 | 200.00 | 4206.44 | -- |
| Total steam..... | 200.0 | 4206.44 | 200.0 | 4206.44 | 15.1% |
| Air to nozzle..... | 1806.4 | 23640.00 | 1806.37 | | |
| Air to ring..... | 0.0 | 0.00 | 0.00 | | |
| Air to burner..... | 0.0 | 0.00 | 0.00 | | |
| Total air..... | 1806.4 | 23640.00 | 0.0 | 0.00 | 0.0% |
| Oxygen (calc)..... | 378.4 | 4482.08 | 378.43 | 4482.08 | 16.1% |
| Nitrogen (calc)..... | 1410.4 | 19084.15 | 1410.41 | 19084.15 | 68.7% |
| Argon (calc)..... | 16.9 | 160.06 | 16.87 | 160.06 | 0.6% |
| CO2 (calc)..... | 0.6 | 5.13 | 0.60 | 5.13 | 0.0% |
| Neon, etc. (calc)..... | 0.1 | 0.5 | 0.05 | 0.47 | 0.0% |
| DRY gas input..... | 1806.4 | 23731.89 | 1788.8 | 23566.23 | 84.9% |
| WET gas input..... | 2006.4 | 27938.33 | 3795.2 | 27772.67 | 100.0% |

**MATERIAL OUTPUT DATA:**

| | lb/h | SCF/h | lb | SCF | Vol% |
|---|---|---|---|---|---|
| Char (cyclone discharge).... | 108.0 | -- | 108.0 | -- | -- |
| Char (entrained)..... | 0.0 | -- | 0.0 | -- | -- |
| Total char (filter+cyc) | 108.0 | -- | 108.0 | -- | -- |
| Condensate..... | 0.0 | -- | 0.0 | -- | -- |
| AQUEOUS phase..... | 0.0 | 0.00 | 0.0 | 0.00 | -- |
| OIL phase..... | 0.0 | -- | 0.0 | -- | -- |
| N2 (as tracer)..... | 1410.4 | 19084.15 | 1410.4 | 19084.15 | 51.6% |
| DRY product gas..... | 2720.9 | 37020.14 | 2720.9 | 37020.14 | 100.0% |
| WET product gas..... | 2720.9 | 37020.14 | 2720.9 | 37020.14 | 100.0% |
| DRY N2-FREE product gas. | 1310.5 | 17935.99 | 1310.5 | 17935.99 | 48.4% |

**SAMPLE SYSTEM DATA:**

| | | Comments |
|---|---|---|
| Gas meter initial reading, cu ft. | 0.00 | |
| Gas meter final reading, cu ft... | 1.00 | |
| Gas meter temperature, °F..... | 80.00 | |
| Gas meter pressure, psig..... | 5.00 | |
| Meter correction factor..... | 1.000 | |
| Total DRY gas sampled, SCF..... | 1.29 | |
| % of reactor gas flow..... | 0.00% | |
| | | |
| Char fines collected, g..... | 0.00 | |
| Char carryover, lb/MSCF (wet).... | 0.000 | |
| Condensate collected, g..... | 0.00 | |
| AQUEOUS condensate, g..... | 0.00 | |
| OIL in condensate, g..... | 0.00 | |
| C6H6 in condensate OIL, g..... | 0.00 | |
| Equiv C6H6 volume, SCF..... | 0.000 | |
| Equiv steam volume, SCF..... | 0.00 | |
| Total WET gas sampled, SCF.... | 1.29 | |
| Steam in wet product gas, vol%... | 0.00 | |

**SOLID ANALYSES:**

| | ---------Feed--------- | | | ----Char (cyclone)---- | | | ---Char (entrained)--- | | |
|---|---|---|---|---|---|---|---|---|---|
| PROXIMATE, wt% | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) | (rec'd) | (dry) | (maf) |
| Moisture..... | 16.85 | 0.00 | 0.00 | 0.73 | 0.00 | 0.00 | 0.34 | -0.85 | -1.22 |
| V. M..... | 69.24 | 83.27 | 87.50 | 0.77 | 0.78 | 2.43 | 4.06 | 4.09 | 12.83 |
| Ash..... | 4.02 | 4.83 | 0.00 | 67.62 | 68.12 | 0.00 | 6.24 | 6.29 | 1.00 |
| Fixed carbon.. | 9.89 | 11.89 | 12.50 | 30.88 | 31.11 | 97.57 | 89.36 | 90.48 | 87.39 |
| ULTIMATE, wt% | | | | | | | | | |
| C..... | 39.63 | 47.66 | 50.08 | 32.39 | 32.63 | 100.77 | 90.36 | 91.02 | 281.10 |
| H..... | 4.71 | 5.66 | 5.95 | 0.40 | 0.40 | 1.24 | 1.34 | 1.35 | 4.17 |
| N..... | 0.17 | 0.21 | 0.22 | 0.35 | 0.35 | 1.08 | 0.00 | 0.00 | 0.00 |
| S..... | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.06 | 0.00 | 0.00 | 0.00 |
| O (by diff)... | 34.60 | 41.61 | 43.72 | -1.01 | -1.02 | -3.15 | 1.36 | 1.37 | 4.23 |
| Ash..... | 4.02 | 4.83 | --- | 67.13 | 67.62 | --- | 6.21 | 6.26 | --- |
| HHV, Btu/lb..... | 6556.38 | 7885.00 | 8285.17 | 0.00 | | 0.00 | 0.00 | | 0.00 |
| C/ash ratio..... | 9.87 | | | 0.48 | | | 14.54 | | |
| INPUT, lb..... | 3441.00 | 2861.19 | 2722.86 | --- | --- | --- | | | |
| OUTPUT, lb..... | --- | --- | --- | 108.00 | 107.21 | 34.18 | | | |

**DRY GAS ANALYSES (excluding condensed C6H6):**

| | Dry GC, vol% |
|---|---|
| H2 | 8.46 |
| CO2 | 17.99 |
| C2H4 | 0.55 |
| C2H6 | 0.19 |
| O2/Ar | 0.00 |
| N2 | 49.20 |
| CH4 | 6.94 |
| CO | 12.11 |
| C3's | 0.00 |
| C4's | 0.00 |
| C6H6 | 0.00 |
| H2S | 0.00 |
| Total (dry).. | 95.44 |

T(gas) 1446.59

Comments T(ref) 60

| | | |
|---|---|---|
| 25.77 | 2.180436 | |
| 41.89 | 7.536789 | |
| 64.25 | 0.353349 | |
| | | |
| | | |
| 26.83 | 13.19992 | |
| 48.53 | 3.367805 | |
| 26.16 | 3.16803 | |
| JcpdT= | 16.61 | Btu/scf |

**GAS ANALYSES (including condensed C6H6):**

More--> <----More

| | -------Avg vol%------- | | | --Volume, SCF-- | | | HHV, | ----------Mass, lb---------- | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (dry) | (wet) | ry N2-free) | (SS) | (reac) | MW | Btu/SCF | Total | C | H | N | S | O |
| H2 | 8.86 | 8.86 | 18.30 | 0.11 | 3281.54 | 2.016 | 324.3 | 17.46 | 0.00 | 17.46 | 0.00 | 0.00 | 0.00 |
| CO2 | 18.85 | 18.85 | 38.91 | 0.23 | 6978.13 | 44.01 | 0.00 | 810.31 | 221.13 | 0.00 | 0.00 | 0.00 | 589.18 |
| C2H4 | 0.58 | 0.58 | 1.19 | 0.01 | 213.34 | 28.05 | 1573.8 | 15.79 | 13.52 | 2.27 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.20 | 0.20 | 0.41 | 0.00 | 73.70 | 30.07 | 1769.6 | 5.85 | 4.67 | 1.18 | 0.00 | 0.00 | 0.00 |
| O2/Ar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 51.55 | 51.55 | | 0.63 | 19084.15 | 28.01 | 0.00 | 1410.41 | 0.00 | 0.00 | 1410.41 | 0.00 | 0.00 |
| CH4 | 7.27 | 7.27 | 15.01 | 0.09 | 2691.95 | 16.04 | 1009.8 | 113.93 | 85.30 | 28.64 | 0.00 | 0.00 | 0.00 |
| CO | 12.69 | 12.69 | 26.19 | 0.16 | 4697.34 | 28.01 | 321.0 | 347.16 | 148.85 | 0.00 | 0.00 | 0.00 | 198.30 |
| C3's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 44.09 | 2450.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C4's | 0.00 | 0.000 | 0.00 | 0.00 | 0.0 | 42.08 | 3300.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C6H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 78.11 | 3745.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H2O | | 0.00 | | 0.00 | 0.00 | 18.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H2S | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 | 34.08 | 960.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total (dry) | 100.00 | --- | --- | 1.23 | 37020.14 | 0.00 | 0.00 | 2720.90 | 473.48 | 49.54 | 1410.41 | 0.00 | 787.49 |
| Total (wet) | --- | 100.00 | --- | 1.23 | 37020.14 | 0.00 | 0.00 | 2720.90 | 473.48 | 49.54 | 1410.41 | 0.00 | 787.49 |
| Total (dry N2-free).. | --- | --- | 100.00 | | | | | | | | | | |
| Mol wt, lb/lbmol | 27.86 | 27.86 | 27.69 | | | | | | | | | | |
| HHV, Btu/SCF | 155.5 | 155.5 | 320.9 | | | | | | | | | | |

**OIL ANALYSES:**

| | |
|---|---|
| ULTIMATE, dry wt% | |
| C..... | 0.00 |
| H..... | 0.00 |
| N..... | 0.00 |
| S..... | 0.00 |
| O (by diff)..... | 100.00 |
| Ash..... | 0.00 |
| HHV, Btu/lb..... | -4438.50 |
| H/C ratio..... | #DIV/0! |

**AQUEOUS CONDENSATE ANALYSES:**

| | | wt% dry feed | Comments |
|---|---|---|---|
| TC, mg/L..... | | 0.000 | |
| TOC, mg/L..... | | 0.000 | |
| S, mg/L..... | 0.00 | 0.000 | |
| N, mg/L..... | 0.00 | 0.000 | |
| equiv lb NH3..... | 0.00 | 0.000 | |
| Cl, mg/L..... | | #VALUE! | |
| equiv lb HCl..... | #VALUE! | #VALUE! | |
| CN, mg/L..... | | 0.000 | |
| equiv lb HCN..... | 0.00 | 0.000 | |

**MATERIAL BALANCE -- raw data** TEST BGF2/SP3

| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
|---|---|---|---|---|---|---|---|
| Biomass (dry) | 1363.64 | 161.94 | 6.01 | 0.858 | 1190.54 | 138.20 | 2861.19 |
| Moisture | --- | 64.88 | --- | --- | 514.91 | --- | 579.79 |
| Air | 0.16 | --- | 1410.41 | --- | 395.74 | --- | 1806.32 |
| Steam | --- | 22.38 | --- | --- | 177.61 | --- | 199.99 |
| Total | 1363.81 | 249.20 | 1416.42 | 0.858 | 2278.81 | 138.20 | 5447.29 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 35.24 | 0.43 | 0.38 | 0.022 | -1.10 | 73.03 | 108.00 |
| Moisture | --- | 0.09 | --- | --- | 0.70 | --- | 0.79 |
| Char, entr (dry) | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.00 |
| Moisture | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Product gas(dry) | 473.48 | 49.54 | 1410.41 | 0.000 | 787.49 | --- | 2720.92 |
| Oils/tars | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0.00 |
| Condensate water | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | --- | 0.00 |
| Total | 508.72 | 50.06 | 1410.79 | 0.022 | 787.09 | 73.03 | 2829.70 |
| Out/In | 37.3% | 20.1% | 99.6% | 2.5% | 34.5% | 52.8% | 51.9% |

**MATERIAL BALANCE -- adjusted data** TEST BGF2/SP3

| Adjustments: | 1.00000 | 1.00000 | 1.00000 | 1.0000 | 0.00 | | |
|---|---|---|---|---|---|---|---|
| | x cc out | x air in | x aqu S | x aqu N | + lb H | | |
| INPUT, lb | C | H | N | S | O+Ar | Ash | Total |
| Biomass (dry) | 1363.64 | 161.94 | 6.01 | 0.86 | 1190.54 | 138.20 | 2861.19 |
| Moisture | --- | 64.88 | --- | --- | 514.91 | --- | 579.79 |
| Air | 0.16 | --- | 1410.41 | --- | 395.74 | --- | 1806.32 |
| Steam | --- | 22.38 | --- | --- | 177.61 | --- | 199.99 |
| Total | 1363.81 | 249.20 | 1416.42 | 0.86 | 2278.81 | 138.20 | 5447.29 |
| OUTPUT, lb | | | | | | | |
| Char, cyc (dry) | 35.24 | 0.43 | 0.38 | 0.02 | -1.10 | 73.03 | 108.00 |
| Moisture | --- | 0.09 | --- | --- | 0.70 | --- | 0.79 |
| Char, entr (dry) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moisture | --- | 0.00 | --- | --- | 0.00 | --- | 0.00 |
| Product gas(dry) | 473.48 | 49.54 | 1410.41 | 0.00 | 787.49 | --- | 2720.92 |
| Oils/tars | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Condensate water | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | --- | 0.00 |
| Total | 508.72 | 50.06 | 1410.79 | 0.02 | 787.09 | 73.03 | 2829.70 |
| Out/In | 37.3% | 20.1% | 99.6% | 2.5% | 34.5% | 52.8% | 51.9% |

**ENGINEERING DATA -- unadjusted** TEST BGF2/SP3

| MATERIAL INPUT DATA | |
|---|---|
| Biomass (wet), lb/h..... | 3441.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 200.00 |
| Oxygen, lb/h..... | 378.43 |
| Nitrogen, lb/h..... | 1410.41 |
| Air, scfm ..... | 393.99 |
| Oxygen, lb/lb feed (wet)..... | 0.11 |
| Steam, lb/lb feed (wet)..... | 0.06 |
| Superficial Gas Velocity, ft/s... | 0.68 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

| MATERIAL OUTPUT DATA | |
|---|---|
| Cyclone Char (dry), lb/h..... | 108.00 |
| Entrained Char (dry), lb/h ..... | 0.00 |
| Condensate, lb/h..... | 0.00 |
| Aqueous Phase, lb/h..... | 0.00 |
| Oil Phase, lb/h..... | 0.00 |
| Dry Product Gas, lb/h..... | 2720.92 |

**ENGINEERING DATA, continued** TEST BGF2/SP3

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 10.8 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 12.9 |
| Gas Heating Value, Btu/SCF (dry)..... | 155.5 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 320.9 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.255 |
| Carbon Conversion to Gases and Liquids, %..... | 34.7 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 155.5 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.255 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.282 |

# Appendix C
# Mass Balance Spreadsheet -- IGT Adjustment

**ENGINEERING DATA -- adjusted** TEST BGF1/SP3

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 2242.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 913.10 |
| Nitrogen, lb/h..... | 3403.09 |
| Air, scfm ..... | 950.63 |
| Oxygen, lb/lb feed (wet)..... | 0.41 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.41 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 80.97 |
| Entrained Char (dry), lb/h ..... | 7.57 |
| Condensate, lb/h..... | 1120.54 |
| Aqueous Phase, lb/h..... | 1078.45 |
| Oil Phase, lb/h..... | 42.08 |
| Dry Product Gas, lb/h..... | 5584.49 |

**ENGINEERING DATA, continued** TEST BGF1/SP3

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 41.3 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 42.3 |
| Gas Heating Value, Btu/SCF (dry)..... | 85.1 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 244.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.451 |
| Carbon Conversion to Gases and Liquids, %..... | 96.3 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 94.2 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.451 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.522 |

**ENGINEERING DATA -- adjusted** TEST BGF1/SP4

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 2227.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 973.29 |
| Nitrogen, lb/h..... | 3627.41 |
| Air, scfm ..... | 1013.29 |
| Oxygen, lb/lb feed (wet)..... | 0.44 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.15 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 97.69 |
| Entrained Char (dry), lb/h ..... | 2.33 |
| Condensate, lb/h..... | 925.57 |
| Aqueous Phase, lb/h..... | 882.05 |
| Oil Phase, lb/h..... | 43.53 |
| Dry Product Gas, lb/h..... | 5935.66 |

**ENGINEERING DATA, continued** TEST BGF1/SP4

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 42.5 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 42.4 |
| Gas Heating Value, Btu/SCF (dry)..... | 91.1 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 256.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.463 |
| Carbon Conversion to Gases and Liquids, %..... | 96.5 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 100.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.463 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.530 |

**ENGINEERING DATA -- adjusted** TEST BGF1/SP5

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 2460.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 722.48 |
| Nitrogen, lb/h..... | 2692.65 |
| Air, scfm ..... | 752.17 |
| Oxygen, lb/lb feed (wet)..... | 0.29 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.14 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 74.71 |
| Entrained Char (dry), lb/h ..... | 1.74 |
| Condensate, lb/h..... | 1365.42 |
| Aqueous Phase, lb/h..... | 1341.70 |
| Oil Phase, lb/h..... | 23.72 |
| Dry Product Gas, lb/h..... | 4742.01 |

**ENGINEERING DATA, continued** TEST BGF1/SP5

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 35.5 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 37.8 |
| Gas Heating Value, Btu/SCF (dry)..... | 124.8 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 305.5 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.566 |
| Carbon Conversion to Gases and Liquids, %..... | 97.5 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 130.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.566 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.632 |

**ENGINEERING DATA -- adjusted** TEST BGF2/SP1

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 3390.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 975.41 |
| Nitrogen, lb/h..... | 3635.32 |
| Air, scfm ..... | 1015.50 |
| Oxygen, lb/lb feed (wet)..... | 0.29 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 1.70 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 121.21 |
| Entrained Char (dry), lb/h ..... | 2.47 |
| Condensate, lb/h..... | 1916.77 |
| Aqueous Phase, lb/h..... | 1889.81 |
| Oil Phase, lb/h..... | 26.96 |
| Dry Product Gas, lb/h..... | 6556.41 |

**ENGINEERING DATA, continued** TEST BGF2/SP1

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 35.4 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 36.4 |
| Gas Heating Value, Btu/SCF (dry)..... | 129.0 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 309.3 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.587 |
| Carbon Conversion to Gases and Liquids, %..... | 96.8 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 134.4 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.587 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.652 |

**ENGINEERING DATA -- adjusted** TEST BGF2/SP2

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 4167.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 1376.51 |
| Nitrogen, lb/h..... | 5130.22 |
| Air, scfm ..... | 1433.09 |
| Oxygen, lb/lb feed (wet)..... | 0.33 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 0.93 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 190.77 |
| Entrained Char (dry), lb/h ..... | 12.19 |
| Condensate, lb/h..... | 1840.79 |
| Aqueous Phase, lb/h..... | 1786.25 |
| Oil Phase, lb/h..... | 54.55 |
| Dry Product Gas, lb/h..... | 9028.28 |

**ENGINEERING DATA, continued** TEST BGF2/SP2

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 36.9 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 38.1 |
| Gas Heating Value, Btu/SCF (dry)..... | 112.7 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 277.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.547 |
| Carbon Conversion to Gases and Liquids, %..... | 95.9 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 119.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.547 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.621 |

**ENGINEERING DATA -- adjusted** TEST BGF2/SP3

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 3441.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 200.00 |
| Oxygen, lb/h..... | 1036.91 |
| Nitrogen, lb/h..... | 3864.53 |
| Air, scfm ..... | 1079.53 |
| Oxygen, lb/lb feed (wet)..... | 0.30 |
| Steam, lb/lb feed (wet)..... | 0.06 |
| Superficial Gas Velocity, ft/s... | 0.68 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 204.34 |
| Entrained Char (dry), lb/h ..... | 0.00 |
| Condensate, lb/h..... | 1894.84 |
| Aqueous Phase, lb/h..... | 1894.84 |
| Oil Phase, lb/h..... | 0.00 |
| Dry Product Gas, lb/h..... | 7455.31 |

**ENGINEERING DATA, continued** TEST BGF2/SP3

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 37.0 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 35.5 |
| Gas Heating Value, Btu/SCF (dry)..... | 155.5 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 320.9 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.699 |
| Carbon Conversion to Gases and Liquids, %..... | 95.1 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 155.5 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.699 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.774 |

# Appendix D
# Mass Balance Spreadsheet -- HNEI Adjustment

**ENGINEERING DATA -- adjusted** TEST BGF1/SP4

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 2227.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 1092.47 |
| Nitrogen, lb/h..... | 4071.59 |
| Air, scfm ..... | 1137.37 |
| Oxygen, lb/lb feed (wet)..... | 0.49 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.60 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 138.57 |
| Entrained Char (dry), lb/h ..... | 2.62 |
| Condensate, lb/h..... | 1028.94 |
| Aqueous Phase, lb/h..... | 980.08 |
| Oil Phase, lb/h..... | 48.86 |
| Dry Product Gas, lb/h..... | 6662.47 |

**ENGINEERING DATA, continued** TEST BGF1/SP4

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 47.6 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 47.6 |
| Gas Heating Value, Btu/SCF (dry)..... | 91.1 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 256.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.520 |
| Carbon Conversion to Gases and Liquids, %..... | 108.3 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 100.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.520 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.595 |

**ENGINEERING DATA -- adjusted** TEST BGF1/SP5

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 2460.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 775.48 |
| Nitrogen, lb/h..... | 2890.20 |
| Air, scfm ..... | 807.36 |
| Oxygen, lb/lb feed (wet)..... | 0.32 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 1.69 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 117.46 |
| Entrained Char (dry), lb/h ..... | 1.87 |
| Condensate, lb/h..... | 1048.49 |
| Aqueous Phase, lb/h..... | 1023.03 |
| Oil Phase, lb/h..... | 25.46 |
| Dry Product Gas, lb/h..... | 5089.93 |

**ENGINEERING DATA, continued** TEST BGF1/SP5

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 35.6 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 40.6 |
| Gas Heating Value, Btu/SCF (dry)..... | 124.8 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 305.5 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.607 |
| Carbon Conversion to Gases and Liquids, %..... | 104.6 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 130.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.607 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.679 |

**ENGINEERING DATA -- adjusted** TEST BGF2/SP1

MATERIAL INPUT DATA

| | |
|---|---|
| Biomass (wet), lb/h..... | 3390.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 1037.67 |
| Nitrogen, lb/h..... | 3867.36 |
| Air, scfm ..... | 1080.32 |
| Oxygen, lb/lb feed (wet)..... | 0.31 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.64 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

MATERIAL OUTPUT DATA

| | |
|---|---|
| Cyclone Char (dry), lb/h..... | 89.65 |
| Entrained Char (dry), lb/h ..... | 2.63 |
| Condensate, lb/h..... | 1408.40 |
| Aqueous Phase, lb/h..... | 1379.71 |
| Oil Phase, lb/h..... | 28.69 |
| Dry Product Gas, lb/h..... | 6974.90 |

**ENGINEERING DATA, continued** TEST BGF2/SP1

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 35.0 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 38.7 |
| Gas Heating Value, Btu/SCF (dry)..... | 129.0 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 309.3 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.624 |
| Carbon Conversion to Gases and Liquids, %..... | 103.0 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 134.4 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.624 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.693 |

**ENGINEERING DATA -- adjusted** TEST BGF2/SP2

| MATERIAL INPUT DATA | |
|---|---|
| Biomass (wet), lb/h..... | 4167.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 0.00 |
| Oxygen, lb/h..... | 1499.78 |
| Nitrogen, lb/h..... | 5589.64 |
| Air, scfm ..... | 1561.42 |
| Oxygen, lb/lb feed (wet)..... | 0.36 |
| Steam, lb/lb feed (wet)..... | 0.00 |
| Superficial Gas Velocity, ft/s... | 2.04 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

| MATERIAL OUTPUT DATA | |
|---|---|
| Cyclone Char (dry), lb/h..... | 72.54 |
| Entrained Char (dry), lb/h ..... | 13.28 |
| Condensate, lb/h..... | 1867.86 |
| Aqueous Phase, lb/h..... | 1808.43 |
| Oil Phase, lb/h..... | 59.43 |
| Dry Product Gas, lb/h..... | 9836.78 |

**ENGINEERING DATA, continued** TEST BGF2/SP2

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 39.7 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 41.5 |
| Gas Heating Value, Btu/SCF (dry)..... | 112.7 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 277.1 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.596 |
| Carbon Conversion to Gases and Liquids, %..... | 104.5 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 119.7 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.596 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.676 |

**ENGINEERING DATA -- adjusted** TEST BGF2/SP3

| MATERIAL INPUT DATA | |
|---|---|
| Biomass (wet), lb/h..... | 3441.00 |
| Steam to Nozzle, lb/h..... | 0.00 |
| Steam to Ring, lb/h..... | 200.00 |
| Oxygen, lb/h..... | 1131.52 |
| Nitrogen, lb/h..... | 4217.14 |
| Air, scfm ..... | 1178.02 |
| Oxygen, lb/lb feed (wet)..... | 0.33 |
| Steam, lb/lb feed (wet)..... | 0.06 |
| Superficial Gas Velocity, ft/s... | 1.83 |
| Fluidized Bed Height, ft..... | |
| Fluidized Bed Density, lb/ft3.... | |

| MATERIAL OUTPUT DATA | |
|---|---|
| Cyclone Char (dry), lb/h..... | 108.00 |
| Entrained Char (dry), lb/h ..... | 0.00 |
| Condensate, lb/h..... | 0.00 |
| Aqueous Phase, lb/h..... | 0.00 |
| Oil Phase, lb/h..... | 0.00 |
| Dry Product Gas, lb/h..... | 8135.54 |

**ENGINEERING DATA, continued** TEST BGF2/SP3

| | |
|---|---|
| Gas Yield, SCF (wet)/lb feed (wet)..... | 32.2 |
| Gas Yield, SCF (dry)/lb feed (dry)..... | 38.7 |
| Gas Heating Value, Btu/SCF (dry)..... | 155.5 |
| Gas Heating Value, Btu/scf (dry N2-free)..... | 320.9 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.763 |
| Carbon Conversion to Gases and Liquids, %..... | 103.8 |
| Gas Heating Value, Btu/scf (dry incl oil)..... | 155.5 |
| Cold Gas Thermal Efficiency (dry N2-free)..... | 0.763 |
| Hot Gas Thermal Efficiency (dry N2-free)..... | 0.844 |