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BIOMASS GASIFICATION HOT GAS FILTER TESTING RESULTS

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ABSTRACT

Westinghouse Electric Corporation, under contract to the US Department of Energy's National Renewable Energy Laboratory, has been conducting hot gas cleanup system testing compatible with a pressurized fluidized bed gasifier and the operation of a gas turbine. The testing is in support of the US Department of Energy's Biomass Power Program, and specifically, the Biomass Gasification Facility Demonstration in Paia, Hawaii.

The hot gas cleanup testing was conducted at the Institute of Gas Technology's research facilities in Chicago, Illinois, using the RENUGAS ® 9.1 metric ton (10 ton) per day process development unit. The initial testing began in September 1994 and concluded February 1995. Based on the results of this testing, the hot gas cleanup system's operation is being optimized for longer duration testing to be conducted at the Biomass Gasification Facility in Hawaii.

Initial test results show that hot gas filtration of bagasse flyash/char, as well as tar and oils reduction, at gasifier operating conditions can be successfully accomplished. The results of these initial tests are summarized in this paper.

INTRODUCTION

Westinghouse Electric Corporation, under contract to the US Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), has been conducting hot gas filter testing with the Institute of Gas Technology (IGT) at its process development unit (PDU) test facilities in Chicago, IL. The initial tests were conducted during the September 1994 to February 1995 time period. The objective of the testing is to define the hot gas cleanup technology required to meet emissions requirements, protect the internal components of the gas turbine and generate power utilizing biomass gasification. Initial testing has resulted in important conclusions and recommendations for the next series of longer duration tests to be conducted in a slipstream operation at the Biomass Gasification Facility (BGF) in Paia, Hawaii.

PROCESS AND EQUIPMENT DESCRIPTIONS

The Westinghouse hot gas cleanup (HGCU) system has been integrated with IGT's RENUGAS biomass gasification process as shown in Fig. 1. The RENUGAS process is a pressurized fluidized bed, air or oxygen-blown, biomass gasifier. The development and operation of IGT's 9.1 metric ton (10 ton) per day PDU is thoroughly described by Wiant, et al., (1993) and Lau, et al., (1993). As seen in Fig. 1, the PDU was configured with tar cracker and hot gas filter vessels. It was determined early on in the program that the integration of a tar cracker would be prudent to protect the hot gas filter from the potential coking/plugging of the porous ceramic filters with the tars present in the product gas Wiant, et al., (1994). Lau, et al., (1993) and Westinghouse Electric Corporation (1995a and 1995b) describe the Westinghouse hot gas filter and tar cracker systems in complete detail.

TEST OPERATIONS

The first test was to determine tar cracker performance. It was designed as a single test campaign with a series of short duration test setpoints. This test was conducted without the hot gas filter candles installed in the filter vessel. The information from these tests defined the operational conditions for the filter and assessed the impact of product gas conditions on the life of the filter elements.

Two filter tests were conducted (FP-1 and FP-2). The primary test parameter was filter face velocity. Since the gas flow rate was to be essentially constant throughout the test periods, the face velocity would be altered by changing the number of installed filter elements in the HGCU unit between tests (Westinghouse Electric Corporation, 1995a).

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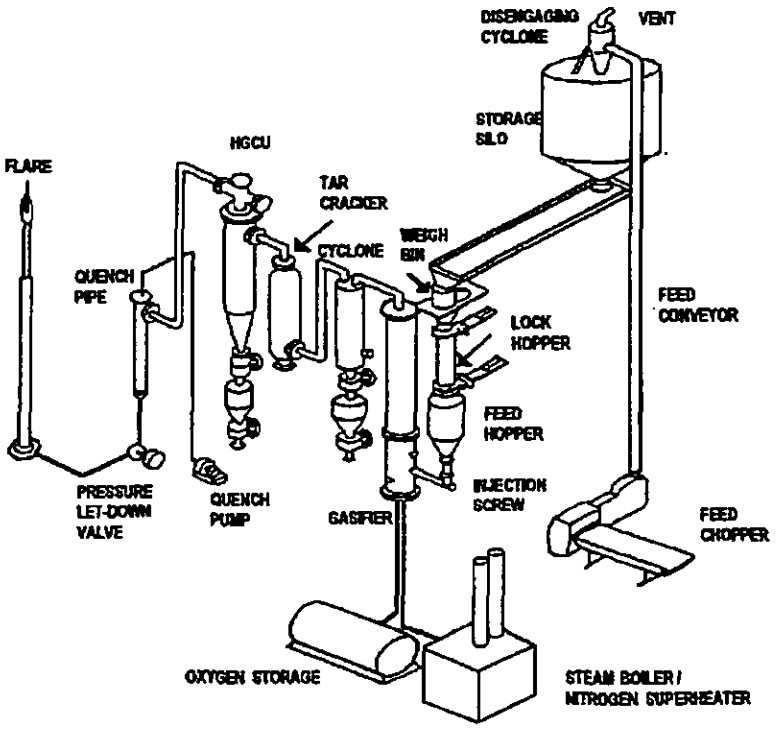


Figure 1. RENUGAS Process Development Unit Test Configuration

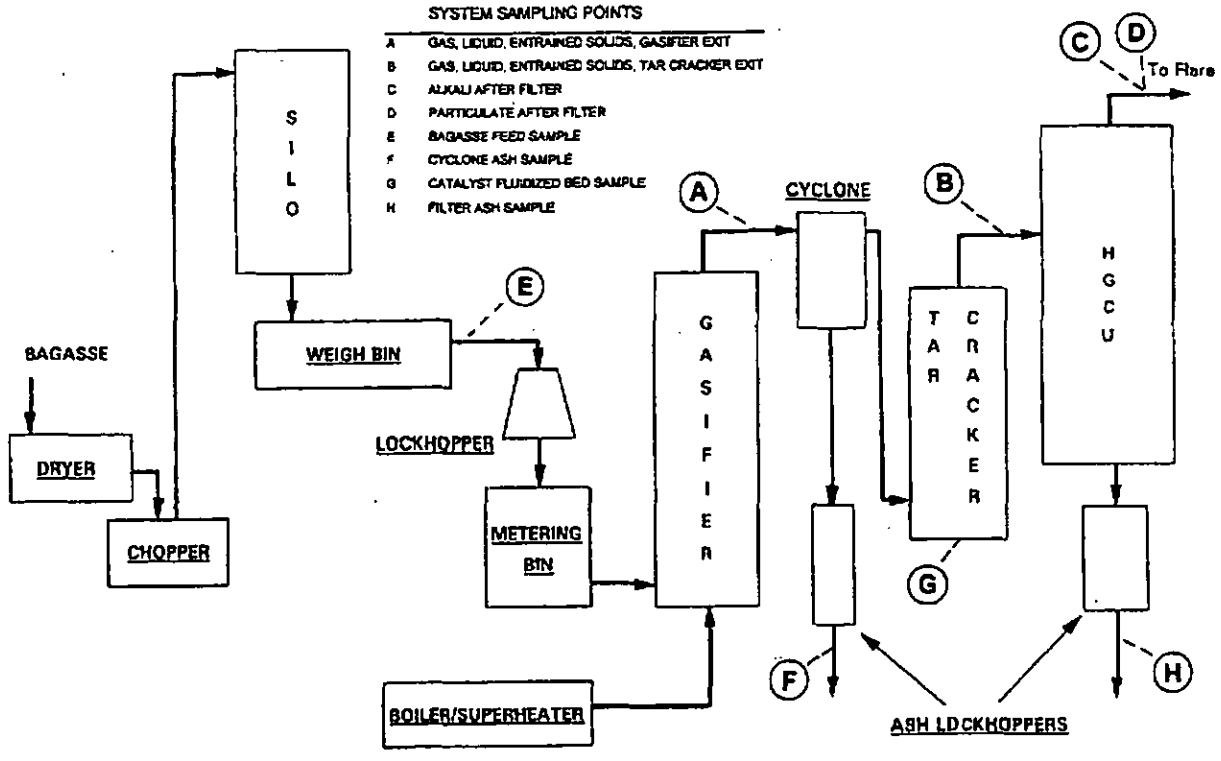


Figure 2. IGT PDU System and Sampling Points

Sampling Procedures

Figure 2 shows a block diagram of the PDU system and sampling points. The product gas was sampled after the gasifier at Station A and after the tar cracker at Station B. At these two stations gas, condensable liquids and entrained solids were collected and separated for off-line analysis. Immediately after the filter vessel, Station C, a Westinghouse developed alkali probe sampled a product gas slipstream for sodium (Na) and potassium (K). From the same product gas line after the filter, Station D, a dust detector probe sampled for particulate.

An on-line gas chromatograph (GC) analyzed gas samples from Station B continuously, except for periods of calibration or routine maintenance, during the test periods. The product gas stream was also monitored by an on-line infrared carbon monoxide (CO) analyzer and by an on-line mass spectrometer operated by staff from NREL. During the steady-state operation periods, on-line gas samples were taken alternately from Station A and Station B. Dry gas was analyzed by the on-line GC at nine-minute intervals. The gas flow rate through each station was controlled and monitored to correlate solid and liquid rates to dry product gas rates for material balance computations. Material balance methods and computations are fully explained by Westinghouse Electric Corporation (1995a and 1995b) along with detailed descriptions of the sampling systems and their operations.

Tar Cracker Testing

Table 1 shows the summary of operating conditions for the gasifier and tar cracker during the various test setpoints for the tar cracker performance testing. Test setpoints No. 1, 2, and 3 yielded information to evaluate the oil and tar species conversion with the alumina bead media in the tar cracker and to prepare material balances for the gasifier and tar cracker. Test setpoint No. 1, with bagasse feedstock, produced semi-quantitative information on gas and oil compositions, but, because of a feed interruption and other factors, did not provide the quantitative information necessary to obtain material balances. Test setpoint No. 3 with bagasse feedstock provided the most complete information of the setpoints. Setpoint No. 2 with alfalfa feedstock provided information for the gasifier and tar cracker as a system, because only the sampling system downstream of the tar cracker was operated without plugging during the steady-state operation period. The simulated distillation curves of the tars and product gas after the gasifier and after the tar cracker, along with the accompanying oil loadings for the tar cracker test (setpoint No. 3), as well as the filter tests (FP-1 and 2), is shown in Fig. 3. This data gives an idea of the tar cracker performance with respect to tars/oils destruction.

Approximately 82% of the oil and tar was destroyed in the tar cracker test and the composition of the remaining tars and oils was not altered very much. In both the bagasse and alfalfa feedstock cases, the tar and oil is almost entirely composed of unsubstituted aromatic species which are tertiary, relative-unreactive compounds compared to the highly reactive biomass primary and secondary pyrolysis oil and tar compounds. The NREL on-line mass spectrometer confirmed this character of the oils and tars (Ratcliff, et al., 1995). Considering this test information, it may be possible that the majority of the oil and tar from the RENUGAS gasification process would not crack within the pores of the filter elements to a significant degree, especially, if the filter temperature was maintained below 815°C (1500°F), but above the condensation temperature of the highest boiling-point components, which is approximately 510°C(950°F).

Hot Gas Filter Testing

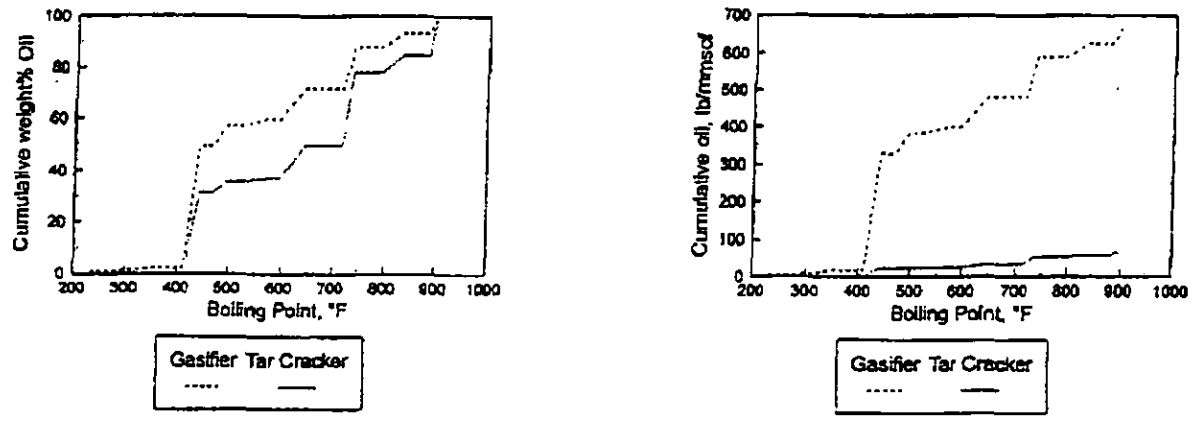
Operation of the gasifier, tar cracker, and filter as a combined system was conducted in two, one-week test campaigns, tests FP-1 and FP-2 respectively. The gasifier-tar cracker system was operated under steady conditions for a total of 45 hours in the two tests to provide a typical dust laden product gas to the filter for performance evaluation. Based on the results and recommendations from the tar cracker tests, cracking of the tars from the gasifier was not deemed necessary for the filter tests. The tar cracker was operated at lower temperatures than in the tar cracker performance tests for the purpose of providing a controlled gas temperature to the filter vessel. At lower temperatures, the tar cracker, as expected, did not reduce the tars significantly.

Test FP-1 was conducted with a total of fourteen candles, seven on each of two plenums as shown in Fig. 4. The upstream cyclone was disabled so as to increase the loading and mean particle size of the particulate material entering the HGCU vessel. The tar cracker was operated, with a result of substantially increasing the temperature of the gas. The nominal conditions are summarized in Table 2. Pulse cleaning

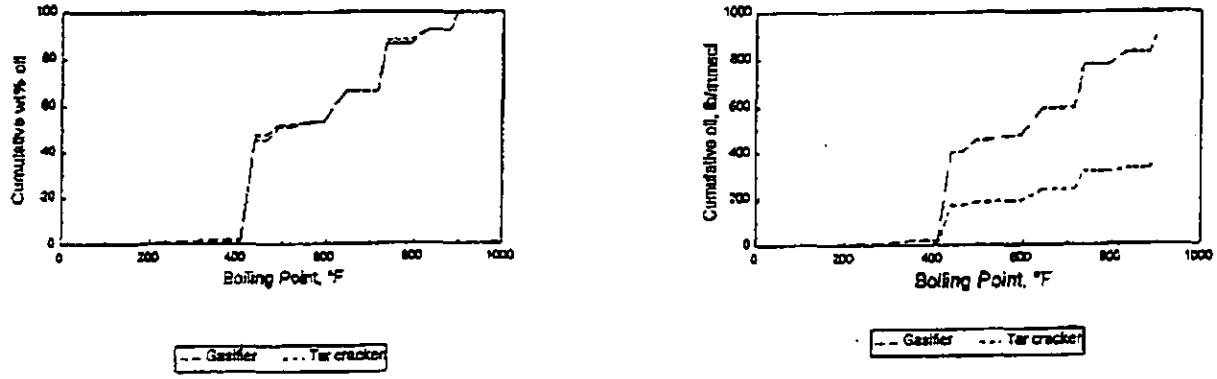
Table 1. Summary Tar Cracker Test Operating Conditions

Test Setpoints	Setpoint No. 1	Setpoint No. 2	Setpoint No. 3
Gasifier			
Temp. °C (°F)	845 (1550)	800 (1470)	845 (1550)
Pressure MPa (psig)	2.1 (300)	2.1 (299)	2.1 (300)
Fd. Rt. kg/hr (lb/hr)	272 (600)	290 (640)	218 (480)
Feedstock	Bagasse	Alfalfa	Bagasse
Tar Cracker			
Temp. °C (°F)	955 (1750)	945 (1740)	980 (1800)
Bed Material	Alumina Beads	Alumina Beads	Alumina Beads

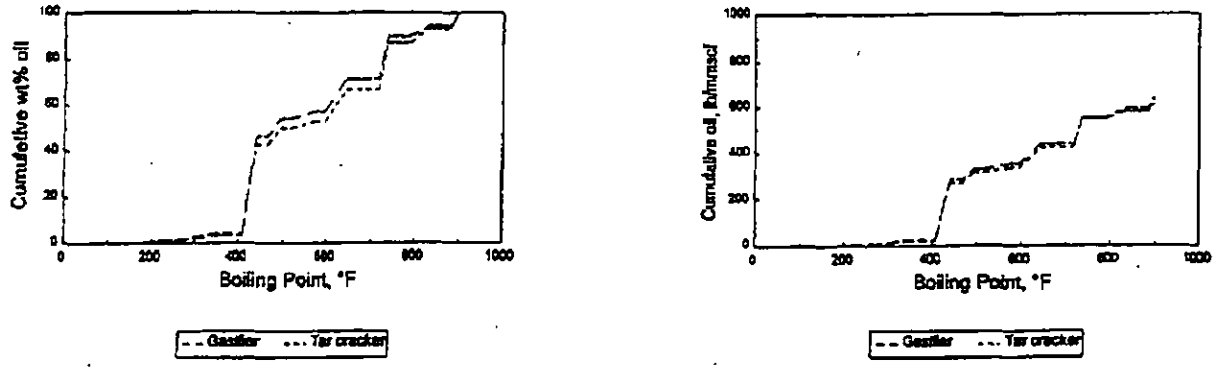
OILS/TARS SIMULATED DISTILLATION **CUMULATIVE OIL LOADING**



SETPOINT NO. 3



TEST FP-1



TEST FP-2

Figure 3. Tars and Oils Cracking Results

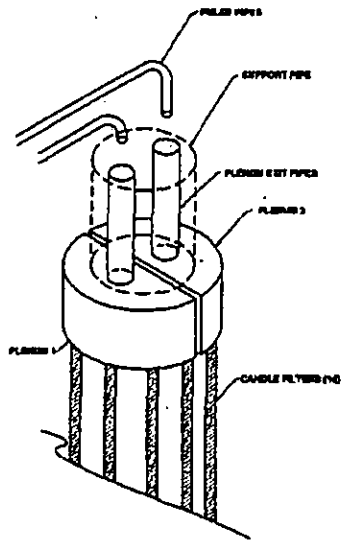


Figure 4. Westinghouse Hot Gas Filter Internals

of the filter was triggered by pressure drop throughout the entire test. Following Segment 2, the system was opened and inspected. There were no candles broken during operation, and no dust was found on top of the tubesheet. Subsequent filter analysis demonstrated a loss of candle strength due to their use at too high a temperature. Recent information supports this re-assessment that the Schumacher Dia Schumalith F40 filters should not be used at temperature levels in excess of 815°C (1500°F). It was therefore decided to run the next test FP-2, at lower temperature. Also during the inspection a hard reddish pottery-like crust was found to coat all the candles. This was apparently a permanent porous coat of iron-rich material deposited during the highest temperature portion of the first test segment. The source of the reddish material was determined to be dirt in the feedstock. It was concluded that except for the high temperature related problems noted, operation was acceptable and that there was therefore a good chance of successful operation at higher face velocities (less candles) if the temperature was moderated in test FP-2.

Test FP-2 was conducted with a total of ten candles, five on each of the two plenums. The upstream cyclone was not disabled, so dust loading and mean particle size of the particulate material entering the HGCU vessel were both smaller than in test FP-1. The tar cracker was operated so as to maintain the gas temperature at a moderate level of about 675°C (1250°F), which would not be expected to result in cracking of tars. Table 3 provides a summary of the operating conditions for the three segments of test FP-2. Upon post-test inspection no candles were damaged and there was no dust on top of the tubesheet. There was a patchy coating of very fine carbon on each candle.

Pressure drop performance assessment for the two tests was done by comparing the test results with historical laboratory data. For test FP-1, the filter and cake pressure drops were not abnormal. The filter wall pressure drop was a little high, apparently representing the hard crust of porous material found on each candle. The cake resistance was high, such as can be found with fine gasification-derived powders, but not unmanageable. For test FP-2, however, both the apparent filter pressure drop and the cake pressure drop were quite high towards the end of the test. Not only was the baseline pressure drop rising, but the backpulse cycle length was shorter than expected. It is believed that a buildup of submicron fines was occurring. Such particles are known to result in high cake pressure drop. They will adhere to the filter wall, causing a tenacious residual cake and, therefore, a high apparent pressure drop, although in reality no damage may have been done to the filter's internal permeability. Fine particles also settle slowly when they are blown off by a pulse, with prompt re-entrainment and, therefore, a short cycle time. This analysis was consistent with the particle analysis that was performed. Smaller particles were present for the second test, in which the upstream cyclone was functioning. This led to the suggestion that it may be undesirable to use such a cyclone ahead of the filter in the BGF (Westinghouse Electric Corporation, 1995b).

Table 2. Filter Test FP-1 Summary Operating Conditions

Test FP-1	Segment 1	Segmeot 2
Filter		
Duration, hours	8.5	12.5
Pressure, MPa (psig)	1.8 (265)	1.8 (260)
Face Velocity, m/min (ft/min)	0.85 (2.8)	0.85 (2.8)
Temperature, °C (°F)	900 (1650)	860 (1580)
Inlet Dust Loading, ppm	Not Known	2900
Key Results	• Candle Weakening Due To High Temperature • Increase Baseline ΔP Due To Crust Formation	• Stable Baseline ΔP

Table 3. Filter Test FP-2 Summary Operating Conditions

Test FP-2	Segment 1	Segment 2	Segment 3
Filter			
Duration, hours	1.9	9.7	18.7
Pressure, MPa (psig)	1.3 to 1.7 (195 to 245)	1.4 (200)	1.7 (240)
Face Velocity, m/min (ft/min)	0.37 to 0.64 (1.2 to 2.1)	0.76 to 1.28 (2.5 to 4.2)	1.04 (3.4)
Temperature, °C (°F)	540 to 635 (1000 to 1175)	650 (1200)	665 (1230)
Inlet Dust Loading, ppm	2500	980	1660
Key Results		• Stable Baseline ΔP	• Stable Baseline ΔP, 12 hrs • Rising Baseline ΔP, 6 hrs

Particle analysis conducted on the test FP-1 ash revealed bulk density ratios typical of well behaved material (contrarily, test FP-2 ash was highly adhesive and possibly re-entrainable as well), high flow resistances, mean particle sizes of 10.8 and 3.8 microns for FP-1 and FP-2, respectively (the difference being directly attributable to the use of the primary cyclone in test FP-2), and chemical compositions typical of poor behavior. In summary, indicators reveal bagasse ash with difficult behavior, especially if an upstream cyclone is used to reduce particle size (Westinghouse Electric Corporation, 1995b).

Alkali Sampling Results

The alkali probe was used to measure alkali vapor content of the gas after the filter twice during test FP-2. The results of the measurements are shown in Table 4, along with the total supply of soluble K and Na in the bagasse, and represents the fuel gas concentrations expected if all the feedstock soluble alkali is vaporized. In reality, equilibrium vapor pressures of the soluble species represent limits to the alkali vapor concentrations that could really exist, and are shown in the next to last column of Table 4. Equilibrium substantially limits possible vapor concentrations for both species, as seen in test FP-2, at a temperature of 675°C (1250°F). The solids are the water soluble alkali concentrations measured in the particulate collected from the filter. A sodium level of 1 ppm and negligible potassium were found, reversing the trends identified based on bagasse analysis. This trend and the amount of sodium, potentially at turbine-damaging levels, needs to be confirmed during the longer duration tests with the BGF slipstream (Westinghouse Electric Corporation, 1995b).

Clean Gas Solids Sampling

One solids sample was collected downstream of the HGCU filter vessel during test FP-2. The gas sampling probe of Station D was operated for only 1.5 hours with 0.10 gram (1.54 grains) of dust being collected from 3.77 scm (133 scf) of dry product gas. This limited amount of solids collected was too small to obtain a chemical analysis, particle size distribution or accurate assessment of the particulate not trapped by the ceramic candles in the filter. Sampling for product gas particulate loading downstream of the filter will be accomplished in the longer slipstream tests to be performed at the BGF.

Candle Filter Characterization

Extensive candle filter characterization analysis was performed on the filters from tests FP-1 and FP-2. These analyses indicate that significant changes occur in the Schumacher clay-bonded silicon carbide matrix at elevated temperatures. There is evidence that these changes are initiated even at relatively modest temperatures. Such changes are likely to limit the service life of the candles. If temperatures are controlled to less than about 705°C (1300°F), then it is possible that matrix changes may stop at a point with acceptable retained strength (Westinghouse Electric Corporation, 1995b).

Table 4. Water Soluble Alkali Analysis

	Vapor Probe	Solids	Equilibrium	Supply
FP-1, 870°C (1600°F)				
K, ppmv	Not Measured	0.10	103	140
Na, ppmv	Not Measured	0.11	88	15
FP-2, 675°C (1250°F)				
K, ppmv	0.05, <0.04	0.05	4.0	140
Na, ppmv	0.77, 1.00	0.03	1.4	15

CONCLUSIONS

The following conclusions were drawn as a result of the initial short duration filter tests performed:

- Stable operation of a filter system in conjunction with a biomass gasifier of the IGT RENUGAS type appears practical at a face velocity in the vicinity of 0.914 to 1.067 meters/min. (3.0 to 3.5 ft./min.).
- The use of a cyclone upstream of the filter vessel causes a reduction in mean particle size which appears to cause the formation of a difficult to clean dust cake and, therefore, to limit HGCU system stable operation.
- The full-scale BGF demonstration plant design, with roughly 100 filter candles, is well within the current experience base. Design tuning based on the presently reported PDU filter tests and the upcoming longer term BGF demonstration plant slipstream tests, will provide excellent prospects for successful BGF plant operation with a gas turbine.
- Although the Schumacher Dia Schumalith F40 candle filters which were used in the ~21-30 hour biomass gasification tests functioned well, a reduction in the bulk strength of the clay bonded silicon carbide matrix was observed. In the reducing gas environment, the clay bonded Schumacher Dia Schumalith F40 filters are, however, not recommended for extended service life at temperatures >600°C (1110°F). Alternate advanced candle filters are potentially available for use in the higher operating temperature gasification system.
- Relatively high levels of sodium vapors (presumably as NaCl) were found. If these are validated in the BGF demonstration plant slipstream tests, an alkali vapor gettering step may be needed for turbine protection.
- Tars did not have any detectable effect on filter operation, even without the use of a tar cracker. The use of a thermal cracker is detrimental to the use of the silicon carbide filters because of the consequent much higher temperature of the gas delivered to the filter vessel..

RECOMMENDATIONS

The following recommendations apply to the BGF demonstration plant slipstream testing of the HGCU system, and if verified there, to the full stream BGF plant operation with a gas turbine. The proposed BGF slipstream configuration, as shown in Fig. 5, is based on the following recommendations.

- Do not use a cyclone ahead of the filter vessel.
- Install a variety of candles of different materials from different vendors in the HGCU vessel for the next 500 hours of testing. Then, after examination and analysis, select one of the candles for use during subsequent slipstream operation, estimated as lasting for an additional 1500 hours.
- Verify alkali vapor levels, and allow space in the design for addition of an alkali getter vessel.
- Operate the BGF slipstream without tar cracking.

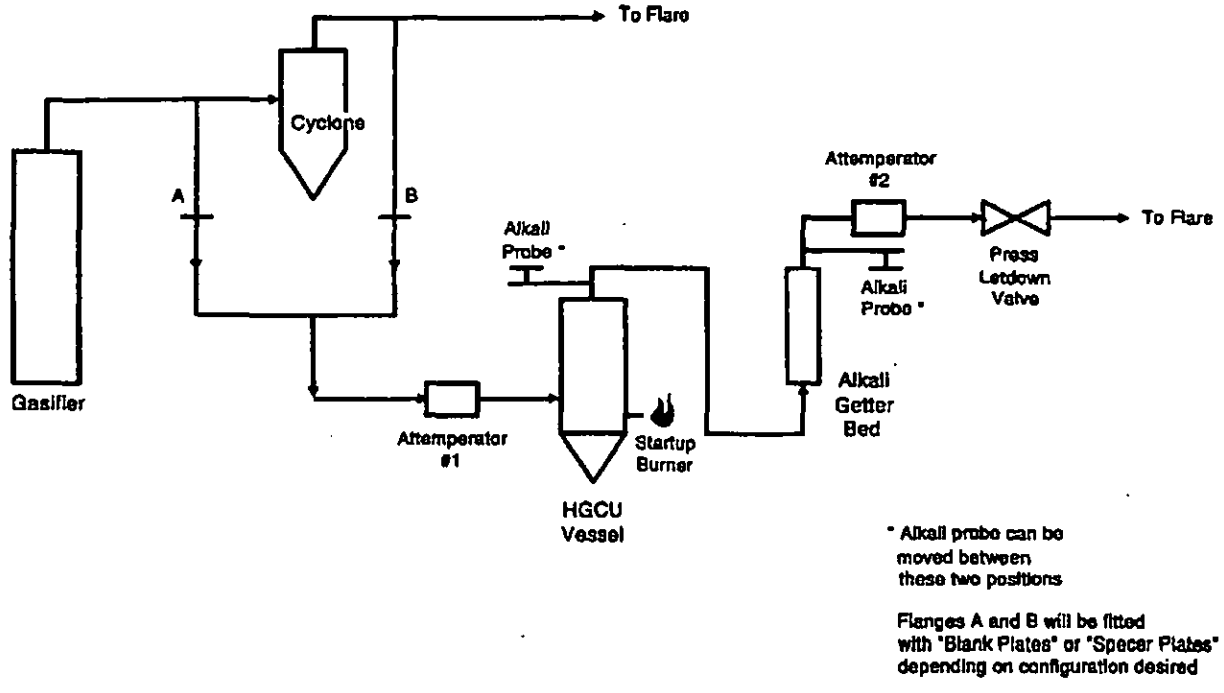


Figure 5. Recommended Slipstream Configuration

SUMMARY

Important insight was gained from the short duration tests about the behavior of the bagasse flyash and the ability to filter it from the gasification product gas stream. Even with the limited amount of actual steady-state operation with the PDU gasifier, operational data that has been obtained from lengthy coal gasification hot gas filtration testing was verified with the biomass filter testing. The longer-term testing to be conducted with the slipstream at the Hawaiian BGF will not only corroborate the data obtained during the short-tests, but will provide important operational and design data needed for the full-scale HGCU system.

ACKNOWLEDGMENTS

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REFERENCES

Wiant, B. C., et al., 1993. "Biomass Gasification Hot Gas Cleanup for Power Generation." In Proceedings of First Biomass Conference of the Americas, Burlington, VT.

Lau, F. S., et al., 1993. "Development of the IGT RENUGAS® Process." In Proceedings of Strategic Benefits of Biomass and Waste Fuels Conference, Washington, DC: Electric Power Research Institute.

Wiant, B. C., et al., 1994. "Biomass Gasification Hot Gas Cleanup Demonstration Program Status." In Proceedings of Sixth National Bioenergy Conference, Reno, NV.

Westinghouse Electric Corporation, 1995. "Hot Gas Cleanup for Operation of a Gas Turbine with a Fluidized Bed Air Blown Gasifier, Tar Cracker Testing Report." Report to National Renewable Energy Laboratory (XAZ-3-12092-01-106794).

Westinghouse Electric Corporation, 1995. "Hot Gas Cleanup for Operation of a Gas Turbine with a Fluidized Bed Air Blown Gasifier, Filter Performance Short Duration Tests." Report to National Renewable Energy Laboratory (XAZ-3-12092-01-106794).

Ratcliff, M.A., et al., 1995. "Product Analysis from the Operation of a 10 Ton/Day Direct Fluidized Bed Biomass Gasifer and HGCU System." In Proceedings of 210th National Meeting of the American Chemical Society, Chicago, IL.