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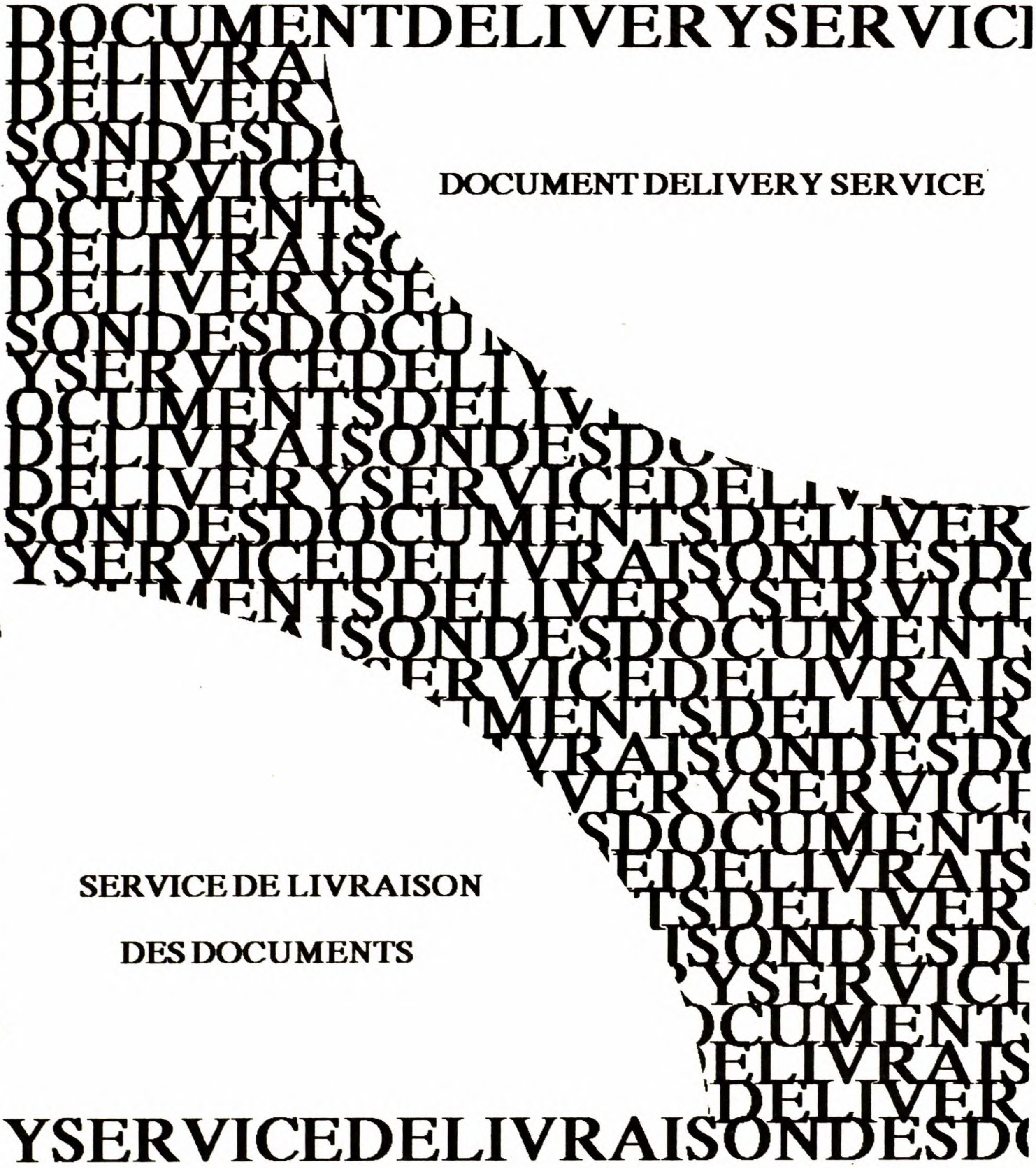

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TECHWEST

DEVELOPMENT OF SAMPLING AND ANALYTICAL PROCEDURES FOR BIOMASS GASIFIERS

ENFOR Project No. C172
DSS Contract No. 41SS.KL229-1-4114

TECHWEST ENTERPRISES LTD.
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INTRODUCTION

Techwest Enterprises Ltd. — established in 1970 — is a majority owned subsidiary of B.C. Research. Our company was founded to promote the development, manufacturing and marketing of products derived mainly from research studies carried on by our affiliate. The modern facilities and extensive technical skills available at B.C. Research are utilized to ensure that our products are quality engineered and rigorously tested to meet our high standards. The wide diversity of our product lines is attributable to the many areas of scientific research where our products have their origins; namely — biology, chemistry, engineering and physics.

DEVELOPMENT OF SAMPLING AND ANALYTICAL PROCEDURES FOR BIOMASS GASIFIERS

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DSS Contract No. 41SS.KL229-1-4114

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EXECUTIVE SUMMARY

Biomass gasifiers produce gas streams which contain aerosols, particulates, condensible organic material, water vapour and noncondensible gases. Calculation of energy and material balances requires an accurate analysis of the gas stream: flow, composition and energy content of solid, liquid and gaseous products.

Conventional sampling trains have proven ineffective in sampling these high temperature gases which are laden with condensible tarry residues.

Therefore, a sampling train was designed and assembled to obtain representative producer gas samples from the various biomass gasifiers. The sampler was designed to allow sampling of gas streams at a wide range of temperatures and tar concentrations and to facilitate the separation of gaseous, particulate, tar and aqueous fractions.

This sampling instrument was extensively tested both in the free-board zone, and external to, the B.C. Research gasifier. The gasifier was operated as a fluidized bed unit but controlled to maximize the production of tars rather than to optimize gas production. After the usual hardware development problems, the sampler performance was shown to be satisfactory in a 700°C raw producer gas environment.

Leakage of noxious gases from the sampling port was precluded by use of a gate valve and spool assembly and a threaded probe cap containing a high temperature compression gasket.

Acetone was found to be the best solvent for sample recovery and cleanup of sampler components.

Due to the low rate of gas production, typical of pilot plant gasifiers, it was found necessary to compute the total flow by performing elemental mass balances around the gasifier.

Conventional laboratory techniques were used to complete the separation of byproducts into discrete fractions and to analyze each fraction. Gas analysis was carried out by dual column gas chromatography. Standard methods were used to analyze the particulate, tar and condensate samples for their elemental composition and calorific value.

Work is in progress on a document entitled "A Workbook for Biomass Gasifier Sampling and Analysis" which covers the step by step methodology and description of the sampling, analysis and calculation of mass and energy balances of biomass gasification processes.

A third document, "Testing The Prototype Sampler on a Downdraft Biomass Gasifier" describes the application of this workbook methodology to the Forintek gasifier. This report is essentially complete.

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STAFF

B.C. Research personnel from the Environment Division and Chemical Technology Division carried out the work under contract to Techwest Enterprises.

The sampling train was designed and assembled by Mr. Gordon Esplin, the project manager, and Mr. Merv Aiken.

The gasifier operation was under the direction of Dr. Rod McElroy. Gasifier operators were Dr. Cedric Briens, Mr. Duncan Morgan and Mr. Rick Labram. Stack sampling was carried out by Mr. Merv Aiken and Mr. Lloyd Phillips.

Chemical analyses were carried out by Mrs. Elizabeth McDonald, Miss Bridie Bennett and Mr. Hans-Pieter Meier.

Assistance in report preparation was given by Miss Diana Kristinsson, Miss Laurie Lucas and Miss Judith Hartley.

1.0 INTRODUCTION

1.1 Objective

To develop a standard procedure for the collection, separation and analysis of "dirty gas" from biomass gasification.

Specifically, to devise procedures for accurate determination of the following:

1) Volume rate of the "dirty gas" which is hot (200-800°C) and contains noncondensible gases, tarry liquid and solid particles.
2) Mass of gas, liquid and solid.
3) Quantity of the liquid fraction with special emphasis on the chemical constituents (qualitative analysis) and energy of the tarry materials.
4) Chemical composition and energy content of the gas, liquid and solid.

1.2 Background

Concerns have been expressed by gasifier operators that a standard method is lacking for systematically collecting, separating and analyzing the "dirty gas" from biomass gasification. Normally, this gas is hot and contains gases (CO, CO_2, H_2, N_2, O_2, CH_4 and other higher hydrocarbons), liquid (water, organic acids and tar) and solid (carbon particles and ash). In the past, conventional methods were used by individual operators for the collection and analysis of this "dirty gas", but there were serious discrepancies in the results among these operators because their methods were not in conformity with one another. Consequently, this has presented problems in the interpretation of the results and in the calculation of the mass balance and energy balance of the gasification process. Hence, there is a need for the development of a standard procedure for the collection, separation and analysis of the "dirty gas" from biomass gasification so that results from various contractors can be compared meaningfully.

Conventional stack sampling trains have proven ineffective in the sampling of high temperature gaseous emissions and tarry residues associated with biomass gasification. A standard particulate sampling train does not have the high probe-temperature capacity required to prevent condensation of tarry residues in the train components located upstream of the filter. Separation of particulates and tars in an orderly fashion is dependent upon individual temperature control of the sampling train components. A standard sampling train has only limited heating capacity. Temperature reduction of the producer gas from the elevated levels found in the gasifier (200-800°C) to a level that will not damage sampling train components is not possible with a conventional sampling train.

In sampling work done on the Saskatchewan Power Corporation's Wood Gasifier at Hudsons Bay, Saskatchewan, 1978-79, a knock-out pot was used to separate moisture, tars and particulates from the producer gas (SPC, 1979). The subsequent separation of the combined sample into water, tars and particulates was more difficult than it would have been if separation of these components occurred in the sampling train.

Biomass gasification products have been analyzed extensively, but there have been relatively few attempts to systematically separate and analyze all of the products (INCO, 1980; SPC, 1979). Usually the analysis has been of a particular product, such as the gas, with little attention paid to the water, tar and particulate fractions.

The methods used to analyze the products have generally been conventional laboratory techniques. For example, gas analysis by gas chromatography has been routinely used and, with the appropriate instrumentation, does not present an analytical problem. The report prepared by INCO Metals Company for ENFOR Project C-12 described analytical procedures for the separation and analysis of each component (INCO 1980). A number of other literature sources provided valuable background information for the analysis of nongaseous products (Duncan, 1981; ESRL, 1980; Fraser, 1972; IERL, 1978; NCASI, 1980).

The development of a standard procedure for the collection, separation and analysis of raw producer gas was undertaken by B.C. Research, for Techwest Enterprises. A sampler was designed, assembled and tested on the biomass fluidized bed gasifier located at B.C. Research, Vancouver, B.C. Analytical procedures were developed and evaluated on the products obtained from the test runs.

2.0 DEVELOPMENT AND TESTING OF SAMPLING APPARATUS

2.1 Design of Sampling Apparatus

The characteristics of raw producer gas from biomass gasification are such that conventional stack sampling equipment and procedures are less than ideal for obtaining representative samples.

The sampler was designed with several unique features that allow accurate sampling of the high temperature gases and tarry residues found in raw producer gas. These features, shown schematically in Figure 1, include:

a) The probe and cyclone are heated to approximately the same temperature as the stack, to prevent condensation of tarry residues and water vapour in the probe.

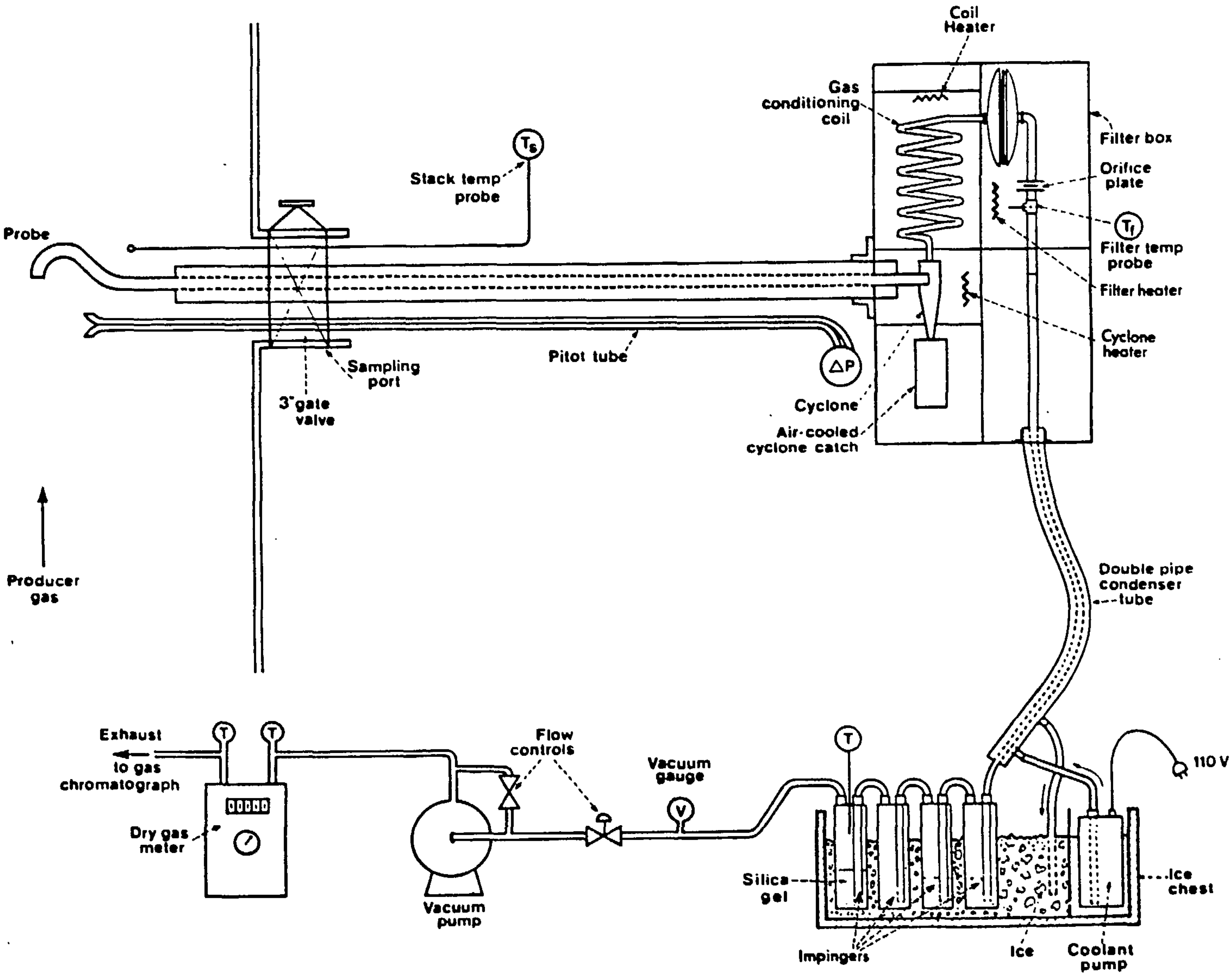
b) The gas sample is passed through a forced convection heat exchanger coil where the temperature is raised or lowered to a standard value of 200°C. Higher temperatures can cause thermal cracking of deposited particulates and tars and breakdown of the fibreglass filter. Lower temperatures can result in tar buildup on the filter, which would rapidly plug the filter and reduce the sampling flow rate.

c) The sampling-rate orifice is placed in the sample box immediately after the filter assembly and thus is kept at the filtering temperature of 200°C. Hence, a knowledge of producer gas composition and moisture content is not required prior to a run and isokinetic sampling can proceed without exploratory tests.

FIGURE 1

GASIFIER SAMPLING TRAIN

(SCHEMATIC)



d) The sample gas leaving the orifice plate assembly at a temperature of 200°C is quenched immediately to approximately 0°C. This is accomplished in a unique counter-current heat exchanger/condenser which also acts as the sample line to the impinger assembly. Rapid heat exchange is accomplished by counter-current ice water circulation in the Teflon double pipe condenser tube. The tar and water condense in the inner Teflon sample tube. The condensate then flows by gravity to the impinger assembly while the noncondensible gases pass through the impinger train containing silica gel to the conventional vacuum pump and control unit.

At the design flow of 30 standard dry litres/min (1 cfm) a conventional ice-cooled impinger train would be unable to remove the sensible and latent heat present in the gas stream.

2.2 Description of Sampling Apparatus

A copy of a photograph of the finished gasifier sampler is shown in Figure 2. Conventional, "off-the-shelf" high volume sampling train components were redesigned to enable sampling of the high temperature gases and tarry residues.

A 300 watt heating tape with heavyduty Fibrox fibre and high temperature ceramic insulation was added to a standard Aerotherm sample probe to enable the probe to withstand temperatures in the 500-800°C range. Figure 3 presents a schematic drawing of this probe.

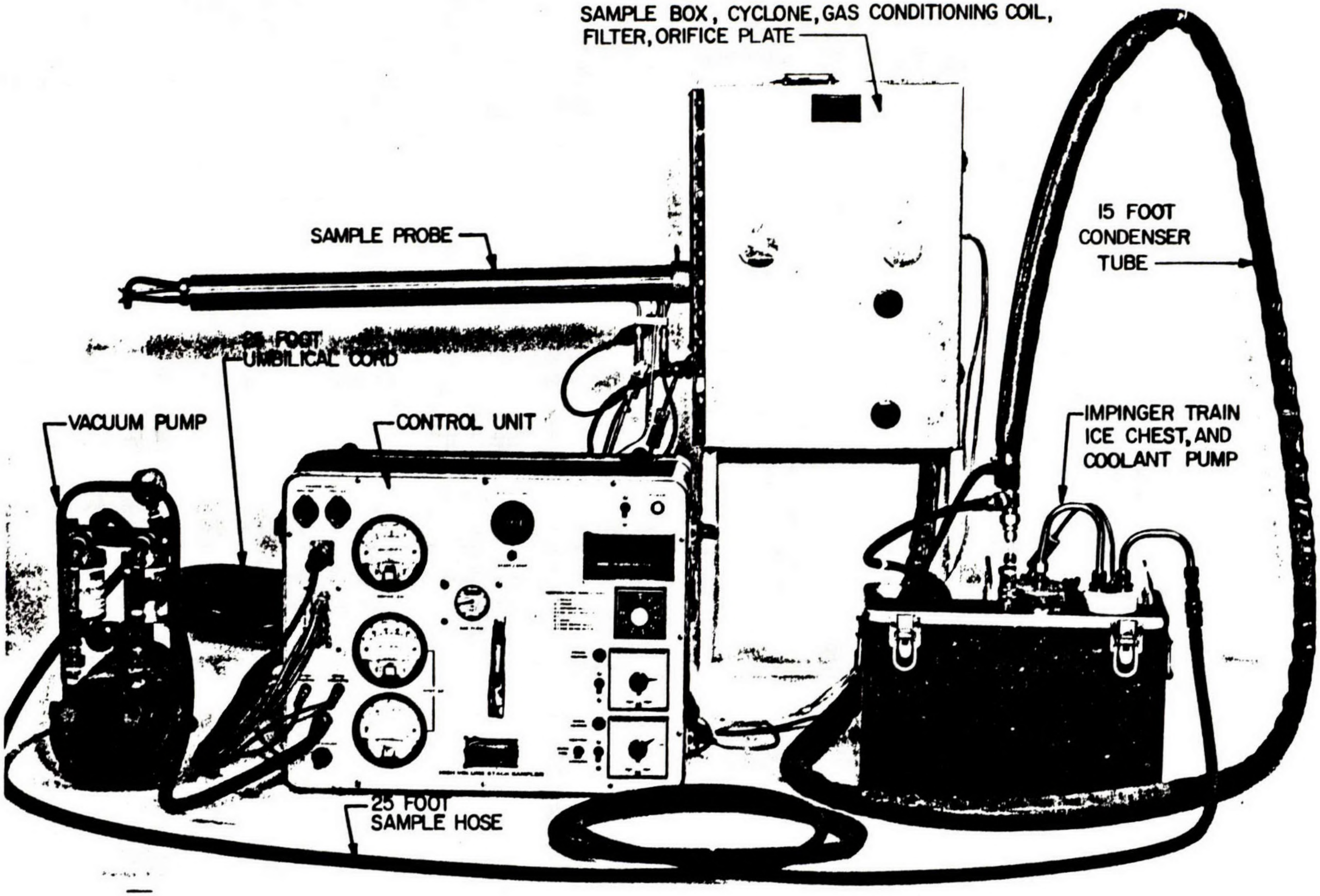
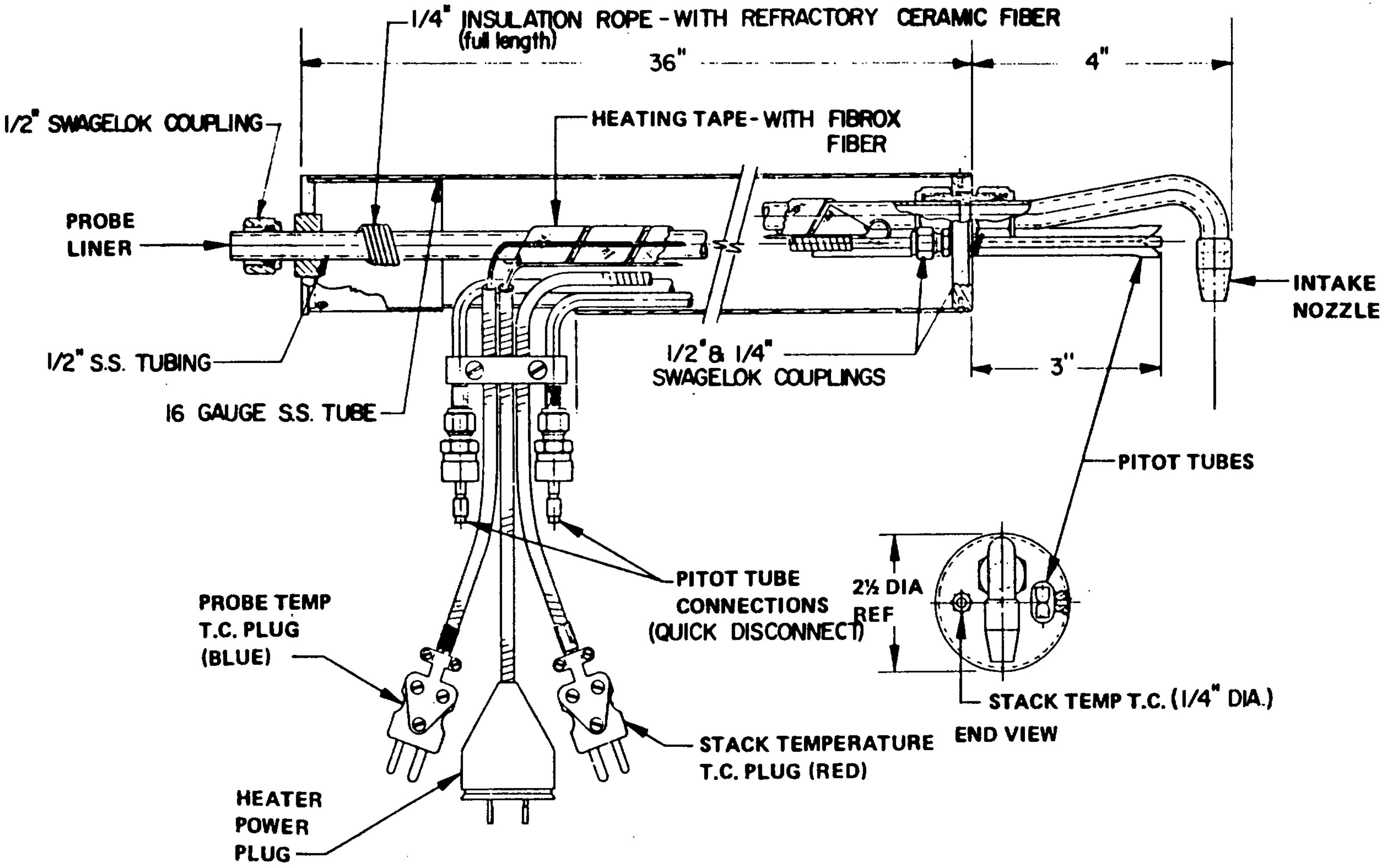


FIGURE 2

GASIFIER SAMPLER

FIGURE 3

SAMPLE PROBE



Adapted from Aerotherm Manual

Figure 4 illustrates the interior of the sample box. Automatic, solid state temperature controllers regulate the temperature of individual ceramic-fibre insulated compartments for the cyclone, the gas conditioning coil, and the filter housing.

The cyclone, Figure 5, removes the larger particulates from the raw producer gas stream. This material is collected in an ambient temperature container to prevent sample loss and/or degradation during a prolonged sampling period. The temperature of the cyclone is maintained at the probe temperature to prevent tar condensation at this location.

The gas conditioning coil is designed to cool the gas from 800°C down to 200°C or, conversely, to heat the gas from ambient temperatures up to the reference temperature of 200°C. A thermistor measures the temperature of the gas at the coil exit and compares this value to a set-point. Power to the coil heater is then controlled by "clipping" the a-c voltage signal. A blower (lower right in Figure 4) constantly passes air, via a flexible duct, over the heating coil and then over the conditioning coil, thereby effecting a counter-current heat exchanger.

Gas filtration occurs on a 5.5" (14 cm) diameter glass fibre filter held in a 6" (15 cm) stainless steel Aerotherm filter housing. The large filter enables prolonged sampling periods without filter plugging occurring. As previously mentioned, the insulated filter compartment is maintained at 200°C via a solid state temperature controller which controls power to a resistive heating element.

FIGURE 4

SAMPLE BOX

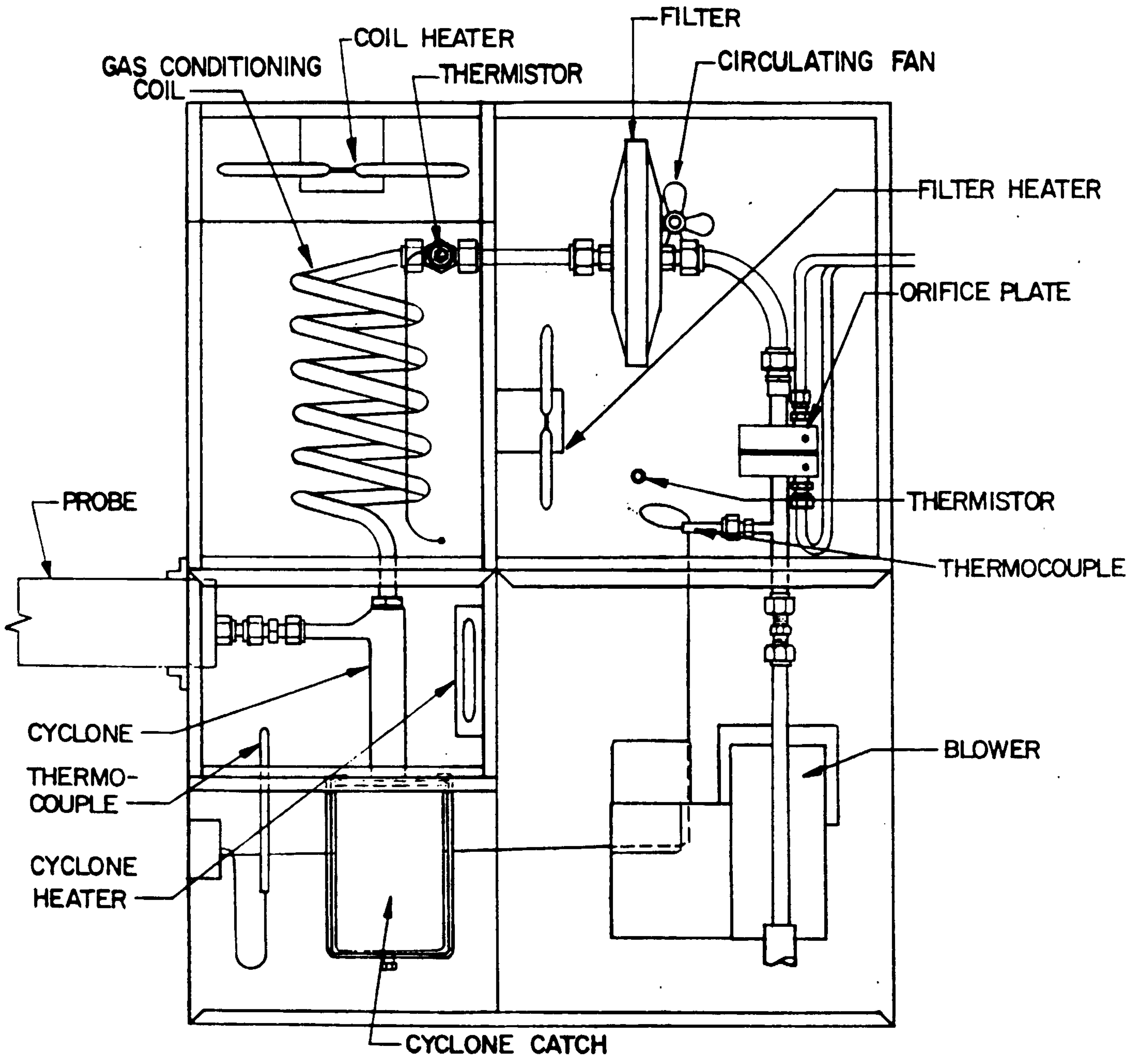
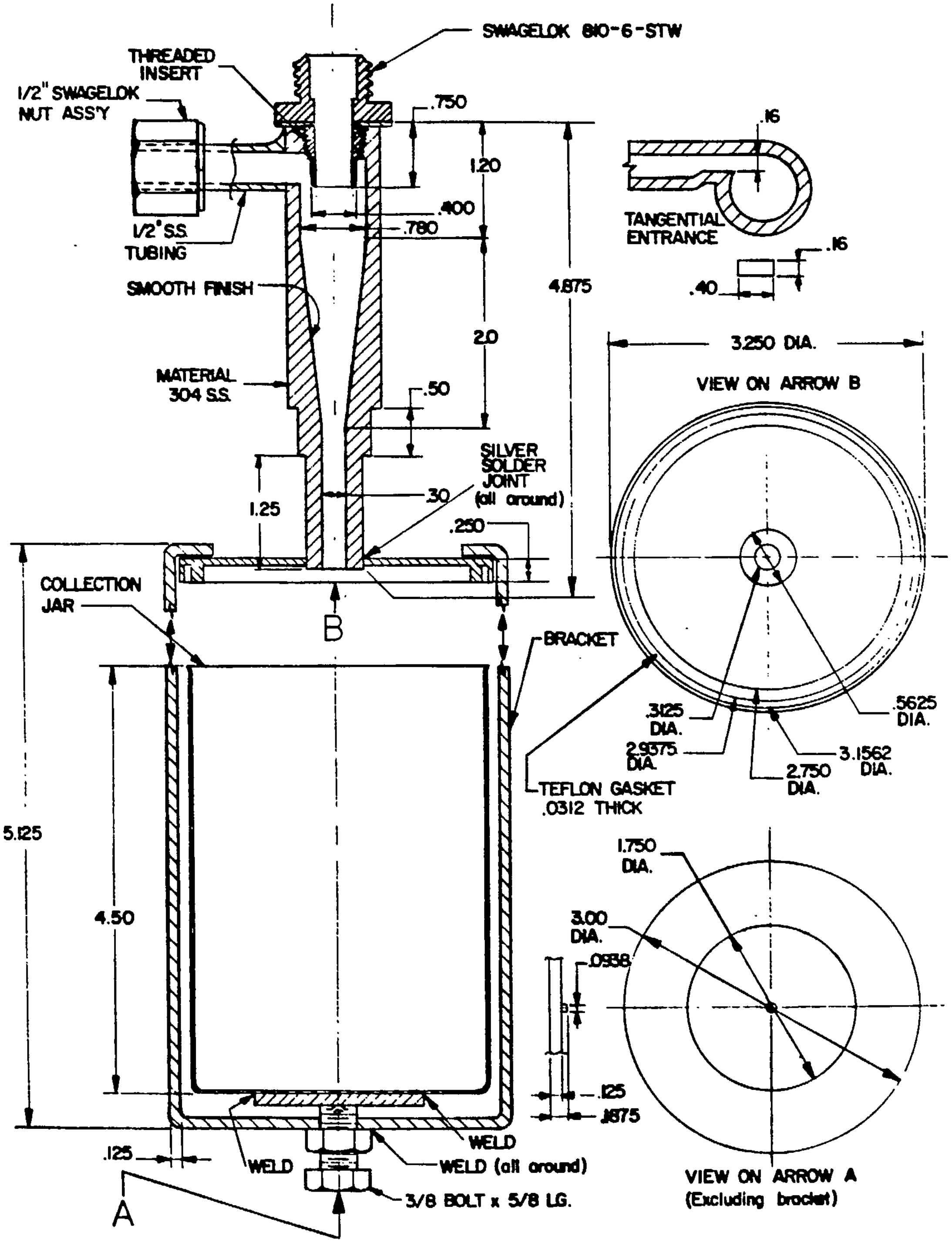


FIGURE 5

CYCLONE



Also located within the filter compartment is the orifice plate assembly, Figure 6. Conventional sampling apparatus has this metering device located as the last component of the sampling apparatus, after the gas stream has been cooled and the condensibles have been removed. Isokinetic sampling is thereby very difficult to effect since the sampling rate at the probe nozzle cannot be ascertained until the run has been completed and the gas moisture content and density computed. By locating the orifice plate in the filter box and maintaining it at 200°C assumptions about gas composition and density are not required for isokinetic sampling.

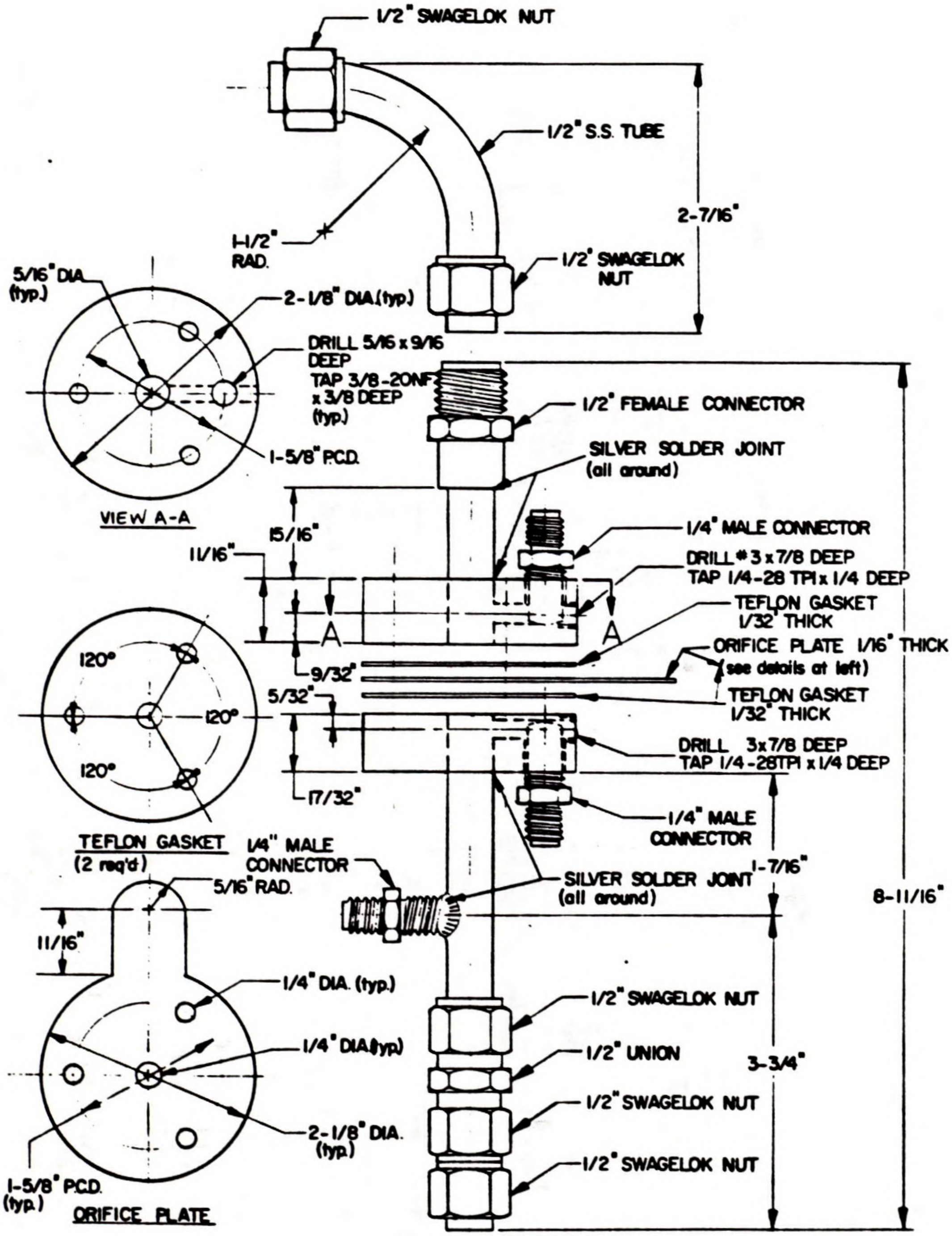
The gas, which has been filtered at 200°C, still contains the majority of the condensible organic matter plus the water vapour. These substances are condensed in an ice cooled, counter-current Teflon heat-exchanger, Figure 7. This 15 ft (4.5 m) condenser tube also physically transports the gases from the sample box to an ice cooled impinger assembly, Figure 8. Here the condensed material is removed from the gas stream and collected. A coolant pump forces ice water up the inner annulus of the condenser, counter-current to the direction of the gas flow, as shown in Figure 7. The water then returns down the outer annulus of the condenser assembly.

The cooled, noncondensible gases then pass through a silica gel drying impinger to remove the last traces of moisture, and then to a conventional hi-volume vacuum pump and control box system as depicted in Figure 1.

A more detailed description of the components of the sampling apparatus will be given in "A Workbook For Biomass Gasifier Sampling and Analysis", currently being written.

FIGURE 6

ORIFICE PLATE ASSEMBLY



SCALE: 3/4 FULL SIZE

FIGURE 7

CONDENSER TUBE

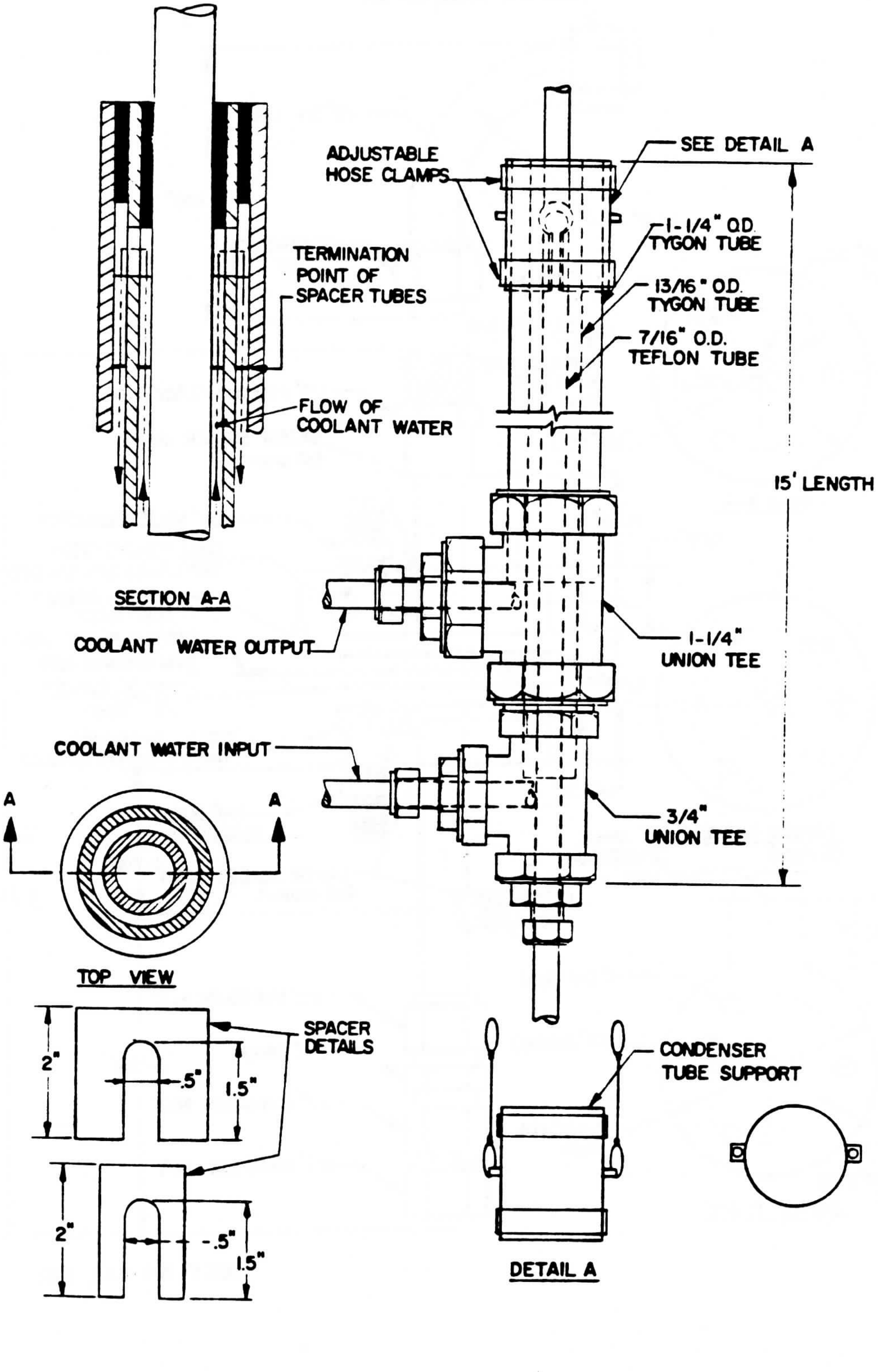
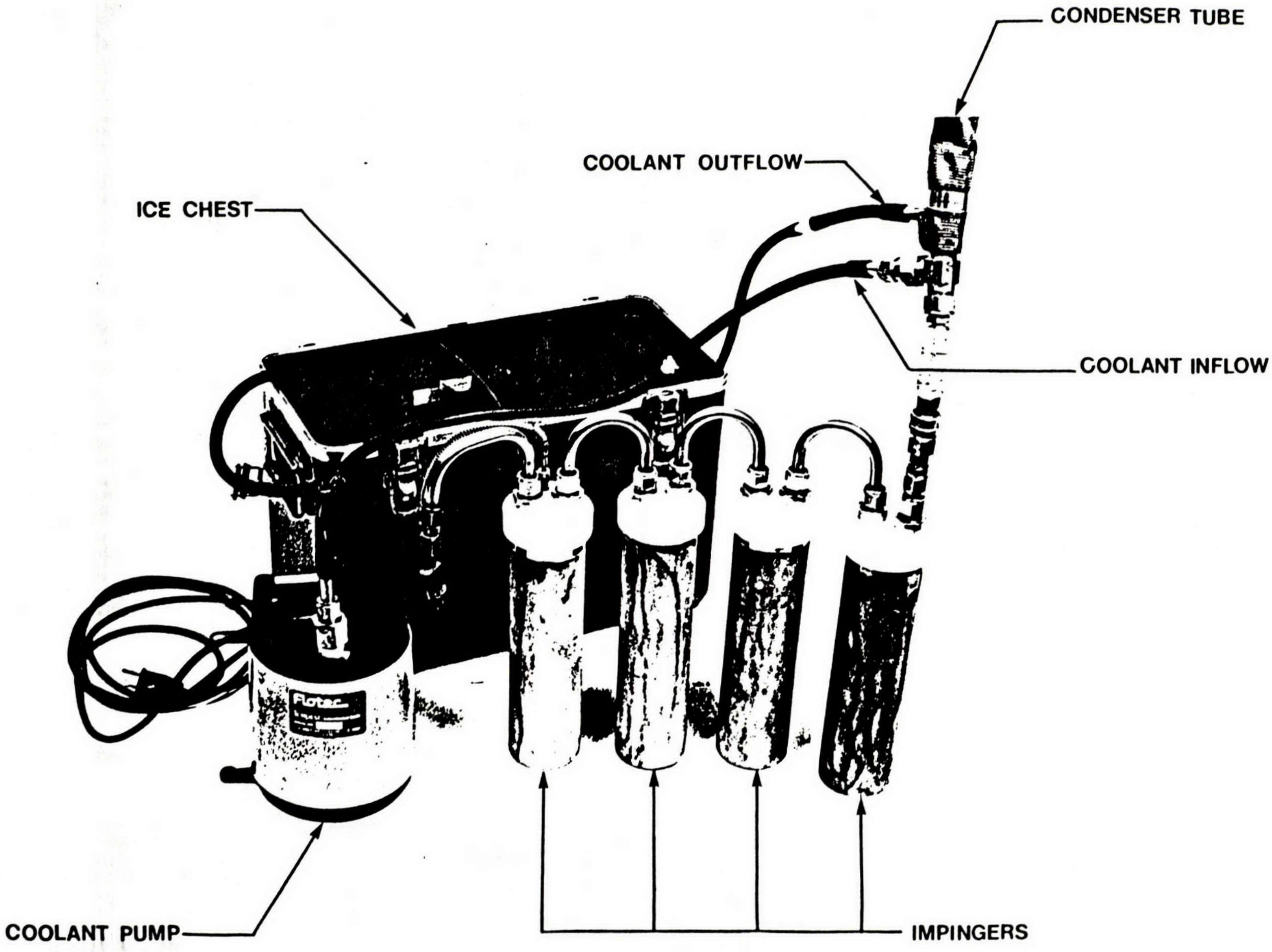


FIGURE 8

COOLANT RECYCLING SYSTEM AND IMPINGER ASSEMBLY



2.3 Gas Sampling Procedure

Sampling methods were similar to those described in EPA CFR 40-60 and EPS 1-AP-74-1 with modifications as dictated by the conditions encountered in the gasifier operation (EPA, 1977; EPS, 1974).

To prevent the escape of poisonous producer gas from the sampling port, the sampling probe was inserted through a high temperature gasketed flange and gate valve assembly, shown in Figure 9.

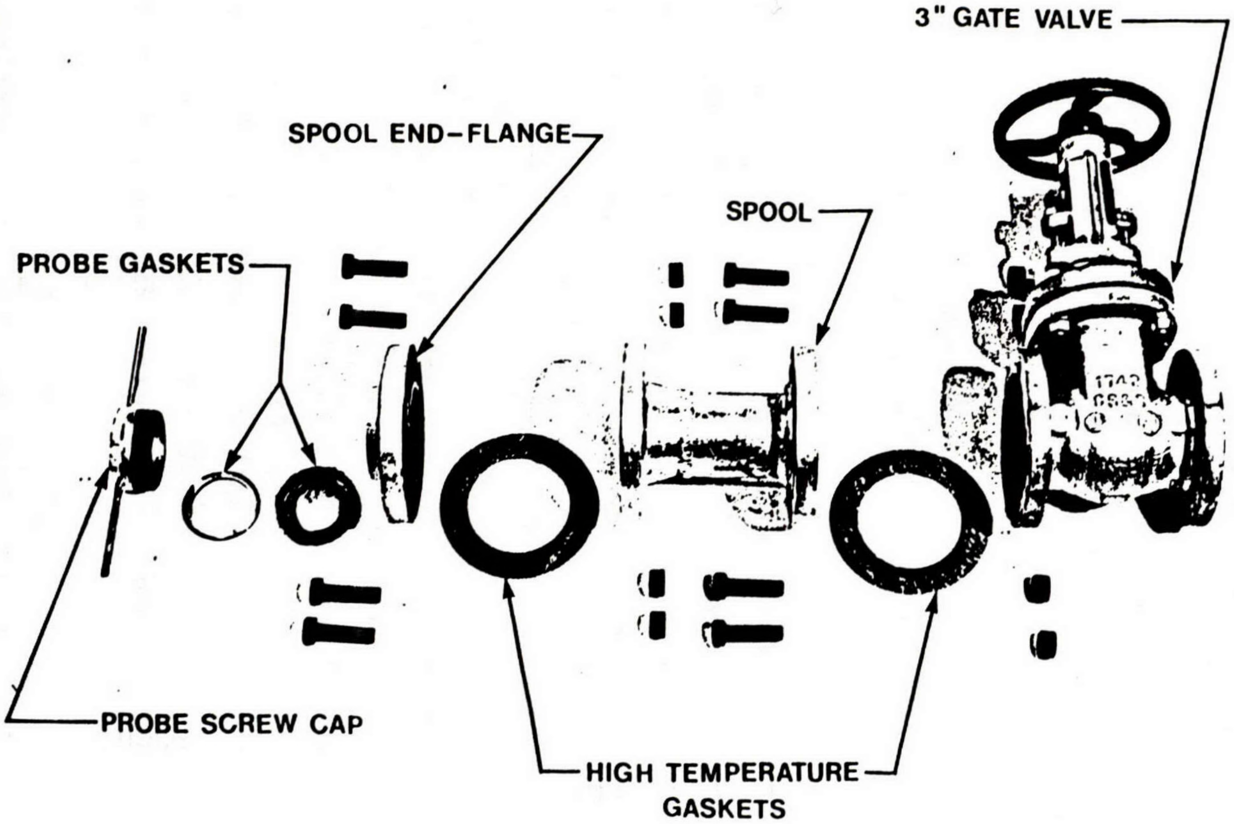
Raw gas was drawn through a nozzle of known diameter and hence through the sampler as previously described. The gas sample flow rate was measured by the orifice plate assembly, and was controlled by the coarse and fine controls on the vacuum pump. The isokinetic sampling rate was computed with the aid of a simple nomograph, from the measured stack velocity and temperature, resulting in a nozzle velocity identical to the stack gas velocity. Total gas volume sampled was measured with a dry gas meter.

Gas samples for chromatographic analysis were collected from the discharge of the gas meter. Integrated samples were obtained by passing a small stream into a Tedlar sampling bag. Grab samples were collected in glass sampling bottles which had a side arm sealed by a septum.

The train components were cleaned with acetone, which readily dissolved the tarry residues found in the nozzle, probe, cyclone, coil, filter, orifice plate, condenser tube and impingers. The coil and condenser tube were flushed using a peristaltic pump to recirculate the acetone. Four acetone

FIGURE 9

GATE VALVE-SPOOL ASSEMBLY



washes of each component were used to remove all the tarry residues. Separate wash samples were collected for the nozzle and probe, the cyclone, the coil and filter, the orifice plate and condenser tube, and the impingers.

2.4 Gas Sampling Tests

Developmental testing of the sampling hardware was carried out using the B.C. Research gasifier operating as a fluidized bed unit (sand media). The gasifier was controlled to produce tars; optimal gas production was not an object of the testing. Details of the experimental conditions used for each run are presented in Appendices A and B.

For the first five sampling runs, gas samples were taken from the gasifier discharge stack, where gas temperatures were in the range 100 to 300°C. For the last three runs, gas samples were taken from within the free-board zone of the gasifier. This location provided a high temperature environment, 540 to 640°C, typical of fluidized bed gasifiers.

A problem of premature tar condensation in the sampling train components upstream of the filter due to inadequate system preheat became apparent during the first three runs when plugging and reduced sampling rates occurred. This problem was compounded by very low sampling rates which were dictated by an extremely low stack gas velocity. In subsequent runs, greater emphasis was therefore made on sampling train preheat and better temperature control of the entire sampling train.

A range of sampling rates was used, from a low of 0.21 cfm in Run 3 to a high of 1.74 cfm in Run 5, to observe if any variances in sampler operation did occur. Sampling flow rates were controlled by use of differently sized orifice plates and sample nozzles. Isokinetic sampling was difficult because the extremely low stack gas velocities encountered, estimated at 2 ft/sec, could not be measured accurately with the probe's conventional S-type pitot tube.

The purpose of Run 1 was the initial testing of the sampling train on producer gas discharged from a gasifier. Problems encountered were: failure of the stack gas thermocouple, carryover of aerosols from the condenser bottle into the silica gel impinger and excessive sample box temperatures in the temperature control compartment. Changes made before Run 2 were: addition of water to the condenser bottle to prevent carryover of aerosols, replacement of the faulty stack thermocouple and addition of a blower to help reduce the temperature in the controller compartment of the sample box.

During Run 2 temperature control of the sample box was inadequate, the Lexan silica gel impinger cracked, and condensation occurred in the pressure lines of the orifice plate assembly. Changes made before Run 3 were: addition of a metal impinger to replace the Lexan model, recalibration of the temperature control system and alteration of the pressure lines from the orifice plate assembly to eliminate deposition of condensible material.

In Run 3 a major air leak developed in the welded surfaces of the orifice plate assembly and a blockage occurred in the cyclone. The blockage was caused by a loss of heat in the sample probe (faulty plug) and resultant condensation of tars in the narrow cyclone opening.

During the pretest leak check for Run 4, the repaired orifice plate assembly again failed and was replaced by a tube bypass. An orifice in the control unit was utilized. During Run 4 problems persisted with obtaining adequate electrical power at the test site.

For Run 5 a third impinger (dry) was added to improve collection of the aerosols. The aerotherm cyclone and oven were used while a new orifice plate assembly was being constructed and the cyclone entrance enlarged.

The only problem encountered in Run 5 was a loose condenser tube connector.

During Run 6 an air leak developed in the cyclone collection cup connection (weld joint). The temperature control system in the sample box was still not able to keep temperatures at the desired levels. Before Run 7 the air leak in the cyclone was repaired, the temperature controller system was recalibrated and a probe port seal was developed. A new shaft seal was installed in the sample pump and the entire train was observed to have a leak rate of less than 0.00057 m^3/min (0.02 ft^3/min).

During Run 7, precise temperature control in the sample box was not evident and carryover of fine tarry aerosols into the silica gel impinger still occurred despite addition of a second impinger containing water. After Run 7 a major overhaul was carried out of the sample box temperature control system. The controllers were moved to the exterior of the sample box and the faulty filter controller replaced. A larger cyclone collection flask was added. The controllers were once again calibrated.

During Run 8 the sampler operated efficiently with no problems encountered. Additional water in the first two impingers and addition of glass wool in the third impinger resulted in almost total collection of condensibles in the impingers. The temperature control system maintained the sample gas at 200°C through the filter and orifice plate. The gasifier sampler was deemed ready for extensive use after Run 8.

3.0 ANALYTICAL PROCEDURES

3.1 Elemental Analysis

Analyses of feed, particulate and tar samples for carbon, hydrogen and, when appropriate, nitrogen, oxygen and sulfur were carried out by Canadian Microanalytical Services Ltd., Vancouver.

3.2 Calorific Value

Calorific values of feed, particulate and tar samples were determined using a Parr Adiabatic Calorimeter, Model 1241, Automatic Type. Ground feed samples were pressed into pellets before analysis. Paraffin oil was added to the particulate and tar samples as a combustion aid.

3.3 Ash

Ash analysis of wood, particulate and tar samples was carried out by igniting the sample in air. The sample was placed in a cold muffle furnace and heated to 750°C, then held for 2 hours at 750°C.

3.4 Thermogravimetric Analysis

Samples of particulates and tar were analyzed for ash, volatile carbon and fixed carbon on a Du Pont 1090 Thermal Analysis/Data System operating with a 951 Thermogravimetric Analyzer. The samples were heated to 900°C in a flow of either, nitrogen with subsequent combustion in oxygen, or air.

3.5 Analysis of Feed

Grab samples of alder sawdust were collected throughout runs seven and eight. The moisture content of the sawdust was determined by drying a sample for 16 hours at 105°C. A portion of the mixed sample from each run was dried at 105°C for 16 hours, then ground to pass through a sieve with a pore size of 0.5 mm. Samples of ground material were analyzed for elements, ash and calorific value. Samples for analysis were selected from the larger samples using the procedure of coning and quartering described in ASTM method C702 (ASTM, 1976).

3.6 Gas Analysis

Gas samples were analyzed using a Hewlett Packard Gas Chromatograph 5700A with a 5880A terminal. Two columns were used in series: 6' x 1/8" (1.8 m x 3 mm) Porapak Q, 80-100 mesh and 10' x 1/8" (3 m x 3 mm) molecular sieve 13X, 60-80 mesh. A thermal conductivity detector was used. The sample was injected through a sample loop of 1 cm^3 capacity. Valve switching was used to separate the gases onto the desired column.

Samples were collected in either glass sampling bottles equipped with a septum or in Tedlar film bags. A 5 cm^3 sample was withdrawn from the glass bottle and injected through the sampling loop with about three cm^3 of sample used to flush the loop. The Tedlar bags were connected directly to the loop.

Three calibration gas mixtures were used to achieve a multi-level calibration. The composition of the gas mixtures is shown in Table 1.

TABLE 1

COMPOSITION OF CALIBRATION GAS MIXTURES

	Gas Composition, % by Volume		
Gas	A	B	C[a]
methane, CH_4	5.92	5.65	2.83
carbon dioxide, CO_2	6.00	13.0	6.50
ethylene, C_2H_4	-	0.933	0.467
ethane, C_2H_6	2.02	1.95	0.98
propane, C_3H_8	-	0.0565	0.028
oxygen, O_2	0.297	1.012	0.506
nitrogen, N_2	1.02	balance (42.6)	21.30
carbon monoxide, CO	1.03	19.1	9.6
hydrogen, H_2	balance (83.71)	15.7	7.9

[a] Gas B diluted by half with helium.

Hydrogen was analyzed as soon as the samples were received. The molecular sieve column was used to separate hydrogen from nitrogen, with argon as the carrier gas. Carbon dioxide was prevented from deactivating the molecular sieve column by closing valve 2 before carbon dioxide could enter the column. A calibration curve for the hydrogen analysis was prepared by successive dilution of hydrogen in argon. Instrumental conditions for hydrogen analysis are given in Appendix E.

Analysis for methane, carbon dioxide, ethylene, ethane, carbon monoxide, nitrogen and oxygen was carried out using both columns in series with helium as the carrier gas. The first four gases were separated on the porapak column, the latter three gases on the molecular sieve column. Each of the calibration gases was injected, in duplicate, to establish the multi-level calibration curve. Samples were injected, in duplicate, and the concentration of each gas calculated from the average of the results. The buildup of heavy hydrocarbons on the porapak column was eliminated by backflushing the column during each run. Instrumental conditions are given in Appendix E.

Propane was analyzed using an oven temperature of 100°C and the porapak column only, the remaining conditions as described in Appendix E.

A second determination of the oxygen and nitrogen content was carried out using a Fisher Hamilton Gas Partitioner. A 1 cm^3 sample was injected directly onto the columns. The two columns were: 2' x 3/16" (0.6 m x 5 mm) chromasorb P 30% DEHS, 60-80 mesh and 2' x 3/16" (0.6 m x 5 mm) molecular sieve 13X, 40-60 mesh. The signal from column 2 only was recorded on a strip chart recorder. Peak heights were used to calculate the concentrations of oxygen and nitrogen. The helium flow rate was 35 cm^3/min and cell current was 250 ma.

3.7 Analysis of Particulates

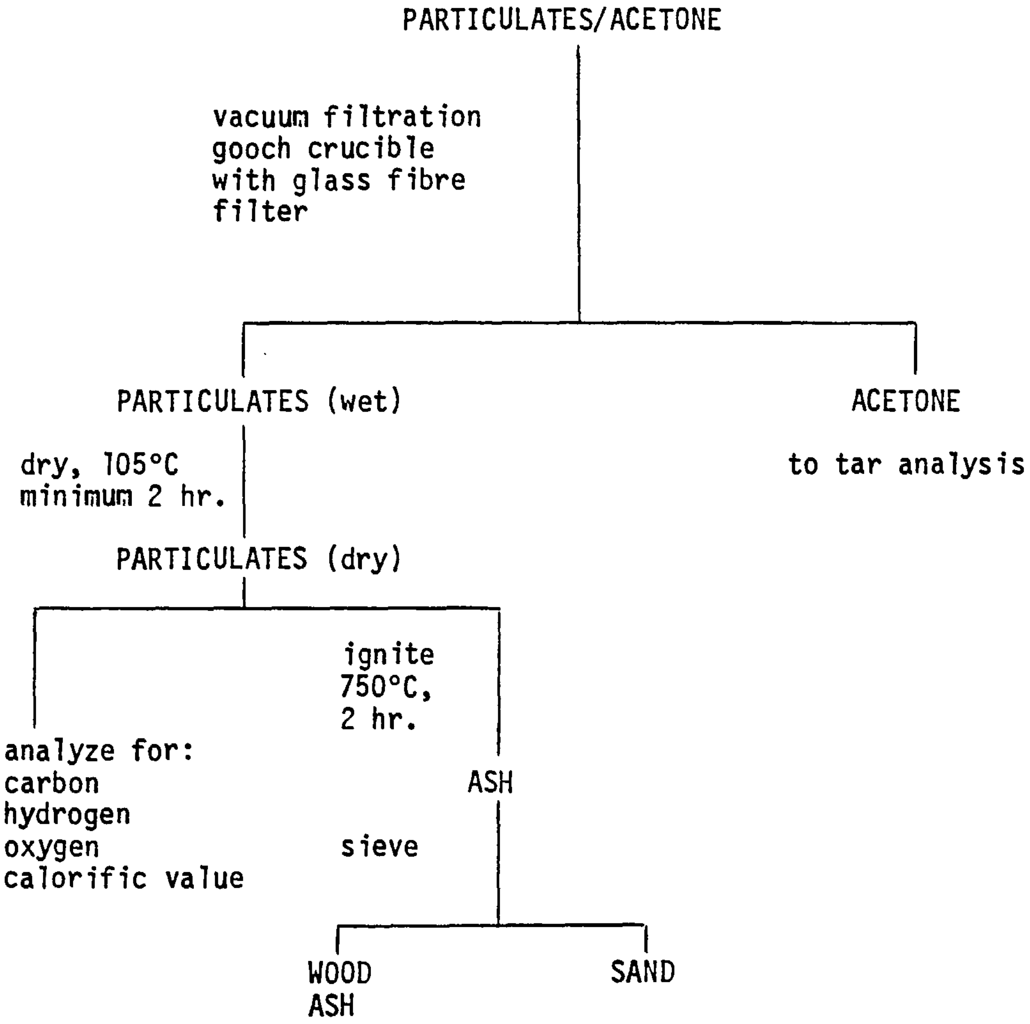
The procedures for analyzing particulates collected on the filter, in the cyclone, in the acetone washes of the sampler components and the condensate are described below. Figure 10 summarizes the analytical procedure.

Adequate mixing of dried particulate samples before removing portions for analysis was necessary to obtain reproducible results. The procedure of coning and quartering was used to obtain representative subsamples, as described in ASTM method C702 (ASTM, 1976).

The filter from the sampling train was placed in a large beaker and washed with acetone until the acetone was colourless. The filter was then removed and dried at 105°C for 2 hours. The increase in weight from the tare weight, measured before the start of the run, gave the weight of particulates remaining on the filter. Particulates removed from the filter by the acetone wash were filtered by vacuum filtration. A glass fibre filter and gooch crucible were heated at 105°C for one hour, cooled in a dessicator and weighed. The increase in weight, after filtering the sample and drying the crucible at 105°C to constant weight, gave the weight of particulates washed off the filter. Usually, 2 to 3 hours was sufficient to dry the samples. The sum of the weight of particulates washed off the filter and the increase in weight of the filter gave the total weight of particulates collected on the filter. The particulates were analyzed for elements, calorific value and ash. The acetone filtrate was saved for further analysis.

FIGURE 10

ANALYSIS OF PARTICULATES



Notes:

a) Filter washed with acetone until acetone colourless. Filter dried 105°C for 2 hr. Particulates washed off the filter were separated from acetone by vacuum filtration.

b) Dry cyclone catch mixed with acetone, then vacuum filtered.

A dry cyclone catch was obtained in some of the runs. The sample was mixed with acetone and filtered under vacuum through a glass fibre filter in a gooch crucible. Acetone washing of the particulates was continued until the acetone was colourless. The particulates were dried to constant weight at 105°C, a minimum of 2 hours. The particulates were analyzed for elements, calorific value and ash. The acetone was saved for further analysis.

Particulates in the acetone washes of the sampler components were separated by vacuum filtration using a glass fibre filter in a gooch crucible. The particulates were rinsed with acetone, then dried at 105°C to constant weight, a minimum of 2 hours drying time. The particulates were analyzed for elements, calorific value and ash. Acetone filtrates were saved for further analysis.

The condensate sample contained particulates and tar. About 1 g of diatomaceous earth (e.g. Celite 535) was added to a tared crucible containing a glass fibre filter. The weight of diatomaceous earth was measured to the nearest 0.1 mg. The vacuum filtration was completed as rapidly as possible and the aqueous filtrate removed for subsequent analysis. Particulates and tar remained on top of the Celite. The crucible was then placed on a second vacuum flask and the diatomaceous earth washed with acetone to dissolve the tar, until the acetone was colourless. The acetone wash was saved for further analysis. The crucible, filter, diatomaceous earth and particulates were dried at 105°C to constant weight. Usually, 2 hours drying time was sufficient.

Ash from particulate samples was sieved on a shaker to determine the amount of sand present. The material which passed a 120 mesh screen was assumed to be wood ash and the material remaining on the screen was assumed to be sand.

3.8 Analysis of Tar

Condensed tars were removed from the sampling train by washing the sampler components with acetone. Particulates were removed as described in Section 3.7. Acetone filtrates collected from washes of dry particulate catches, the filter and the sampler components prior to the filter, were combined. The acetone filtrate from the condenser tube wash was combined with the acetone wash of the diatomaceous earth used for the separation of particulates from the condensate. Therefore, two samples of tar dissolved in acetone were obtained for each run. Figure 11 summarizes the analysis of the tar.

Acetone was evaporated in a rotary evaporator at 30°C. The weight of tar was calculated from the increase in weight of the previously tared flask. Samples of tar were analyzed for elements and calorific value, and the results corrected for the moisture content of the tar.

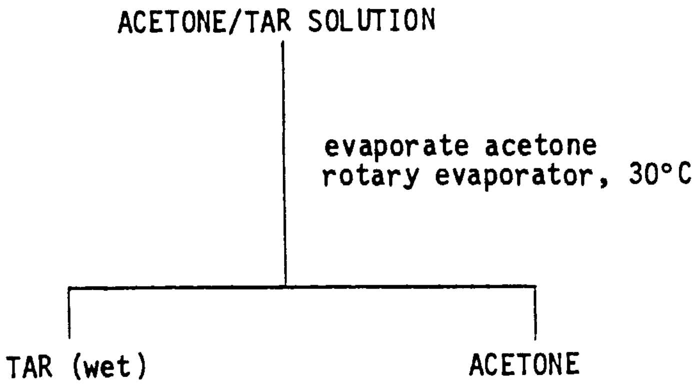
Moisture content of the tar was determined by a Karl Fischer titration as described in ASTM method E203 (ASTM, 1981).

3.9 Analysis of Condensate

The aqueous filtrate separated from the particulates and tar was stored at 4°C under nitrogen and analyzed as soon as possible after collection. The analyses carried out are summarized in Table 2. The NCASI procedure for methanol,

FIGURE 11

ANALYSIS OF TAR



analyze for:

- carbon
- hydrogen
- oxygen
- calorific value
- moisture content by Karl Fischer titration

PREFILTER TAR SAMPLE:

- probe and nozzle wash
- cyclone catch wash
- coil and filter housing wash
- filter wash

POSTFILTER TAR SAMPLE:

- condensate tube, orifice and impinger wash
- acetone wash of diatomaceous earth after removal of tar and particulates from condensate

TABLE 2

PROCEDURES FOR ANALYSIS OF CONDENSATE

ANALYSIS	PROCEDURE	DESCRIPTION
pH	APHA No. 423[a]	
TOC	APHA No. 505	combustion-infrared method
COD	APHA No. 508A	dichromate reflux method
phenols	APHA No. 510C	distillation and direct photometric method
organic acids	APHA No. 504A	chromatographic separation method for organic acids
methanol	NCASI Tech. Bull. #310 April 1978[b]	gas chromatographic alcohol analysis
ethanol	"	
acetone	"	

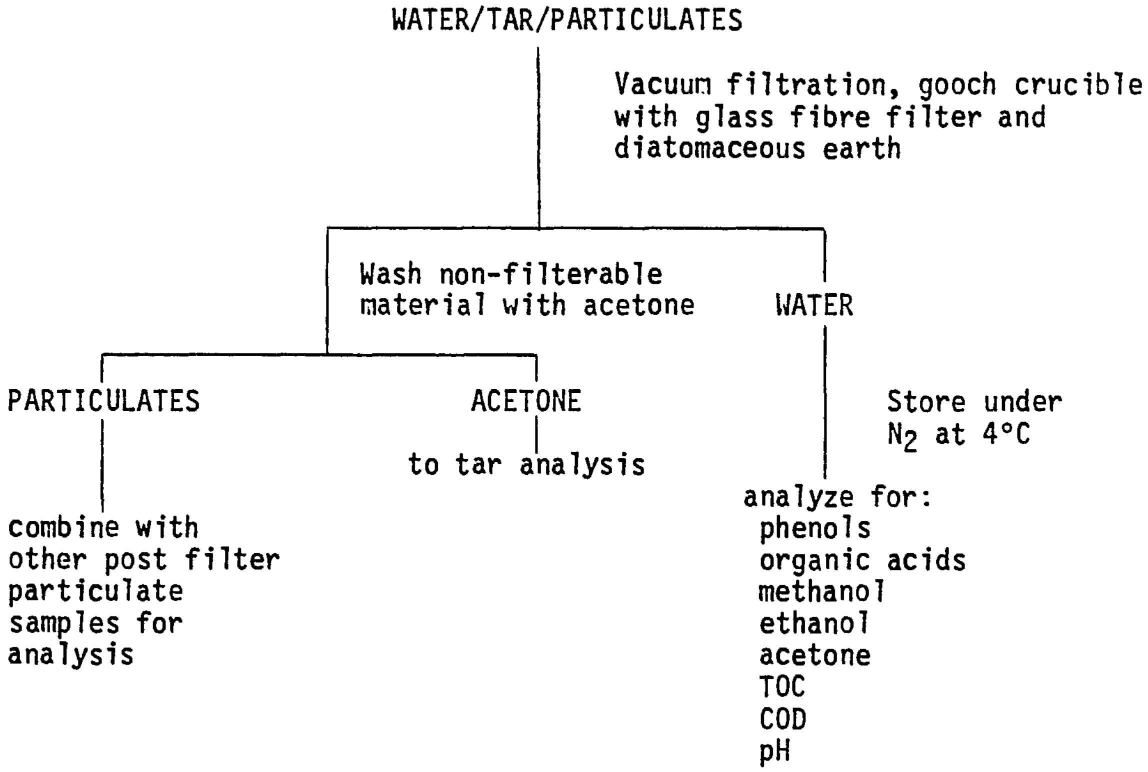
a) APHA Standard Methods for the Examination of Water and Wastewater, 15th Edition. (APHA, 1980)

b) Refer Appendix C.

ethanol and acetone is included as Appendix C. Some changes were made to the procedure to accommodate our equipment. The column used was 15' x 1/8" (4.5 m x 3 mm) SS Poropak Q. The analysis was run isothermally at 120°C, injection temperature 250°C, F.I.D. detector temperature 270°C and helium flow rate of 30 cm^3/min. Figure 12 summarizes the condensate analysis.

FIGURE 12

ANALYSIS OF CONDENSATE



4.0 RESULTS AND DISCUSSION

4.1 Gas Sampling Tests

A summary of the gasifier and sampler operating parameters is given in Table 3, for each of the eight gas sampling tests. Details are included as Appendices A and B.

The sampling apparatus was shown to be functional for collecting a representative sample of the raw producer gas from a biomass gasifier. The sampling probe withstood the high temperatures inside the gasifier with no damage apparent to the probe heater, thermocouple, stack thermocouple or pitot lines. The three heaters in the sample box maintained the desired temperatures of the cyclone, coil and filter-orifice assemblies after some initial difficulty in calibration of the temperature controllers. The cyclone removed the larger particulates from the gas sample. The gas conditioning coil effectively cooled the gas sample from 640°C to the reference temperature of 200°C in the filter-orifice plate assemblies. Placement of the orifice plate in the heated compartment with the filter assembly eliminated the necessity of pretest moisture and gas density determinations required in the calculation of isokinetic sampling rates. The condenser tube successfully reduced the gas sample temperature from 200°C to between 0 and 10°C. The coolant circulating system maintained a steady flow of ice water through the condenser tube with a pump head of about fifteen feet. The impinger train, comprising four impingers, removed all but a small amount of the fine tarry aerosol from the gas sample stream.

Visual observation of the dismantled sampling train components indicated that tar condensed from the gas stream with even a small change in gas temperature and continued to condense in

TABLE 3

SUMMARY OF GAS SAMPLING TESTS

			GASIFIER					SAMPLING			Particulate Emissions	
RUN	DATE 1982	LOCATION	Inflow Volume cfm[a]	Exit Volume cfm[a]	Sampling Location Temp. °C	Bed Temp. °C	Upper Free-Board Temp. °C	Flowrate cfm	Time min.	Volume SCF	gr/SCF	lb/hr
1	5/26	Gasifier Discharge	60	-	estimated 225	714	557	.34	45	14.5	-	-
2	5/28	"	70	-	142	223	454	.34	45	15.9	-	-
3	6/1	"	62.5	-	216	711	542	.21	65	13.3	-	-
4	6/2	"	70	70	277	691	637	.60	45	25.5	4.54	2.7
5	6/3	"	68	69	estimated 285	746	651	1.74	40	68.4	2.91	1.7
6	6/8	Gasifier reactor	73	89	636	723	602	.59	45	23.8	3.75	2.9
7	6/22	"	65	71	538	720	513	.58	72	42.9	7.62	4.6
8	6/29	"	78	75	601	785	602	.90	29	25.3	2.66	1.7

(a) Based on 1 atmosphere and 15°C.

the system until the gas stream left the impinger train. The results of the tar analysis support this observation (Appendix G). For example, in Run 8 the weight of tar condensed in the prefilter components was 9.5 g and the weight of tar condensed in the postfilter components was 7.9 g. However, the sampling train adequately handled this amount of tar deposition prior to the filter, without blockages or reduced sampling rates occurring.

Condensed tar was present in the impingers after each run. Conventional calculation of stack gas moisture, using the difference in the weight of impingers before and after a run, would not be correct if the weight of tar was significant. For these runs, calculations showed that a 10 percent error in the weight of condensate would give an error of 1 percent in the stack gas moisture content. This error would result in a 1 percent error in the calculated volume flow rate of the stack gas and the mass and energy balances. To minimize this source of error the impingers were weighed before and after a run, the condensate and tar decanted, the tar separated by filtration, and the weight of tar subtracted from the increased weight of the impingers.

In cases where extremely low stack gas velocities are encountered and conventional flow determinations cannot be made, sulphur hexafluoride (SF_6) tracer gas could be used in the determination of accurate gas volumes. Nitrogen analysis of gasifier inflow and outflow materials can also be used in gas flow determinations, if care is exercised to obtain reliable values. To ensure accurate mass and energy balances, sampling train leak rates must be taken into account when calculating the volume of the gas sample drawn from the source and in correction of the gas constituent concentrations.

4.2 Analysis of Products

Samples were received from eight runs of the B.C. Research gasifier. Runs 1, 2 and 3 were gasifier and sampler debugging runs. The analytical techniques were evaluated using samples from these runs. Results of the analyses of samples from runs four to eight are presented in this report.

4.2.1 Feed

Results obtained from the analysis of feed samples from runs seven and eight are presented in Appendix D. The techniques used did not present any problems if the finely ground sample was thoroughly mixed to obtain representative subsamples.

4.2.2 Gas

Results of the analysis of gas samples from runs four to eight are included as Appendix E. During runs four, five and six, three grab samples were collected from each run. The results from the analysis of the three samples were averaged to give the gas composition for mass and energy balance calculations. The gas compositions used for the calculations of mass and energy balances for runs seven and eight were the compositions of the integrated samples collected in Tedlar bags. During run six an excessive leak rate of 0.11 cfm occurred which resulted in diluted gas samples. The average gas composition for run six was corrected to remove the effect of dilution before calculation of mass and energy balances.

After storage of the gas samples in both Tedlar bags and glass bottles for longer than about 36 hours at 4°C, a significant increase in air concentration was found. Tedlar bags were favoured for the collection of gas samples because of ease of handling at the collection site and in the laboratory.

Gas analysis by gas chromatography is relatively simple if the appropriate instrumentation is available to analyze the required gases. However, the problem we encountered with the analysis for oxygen and nitrogen is typical of problems which can occur in gas analysis. The molecular sieve column installed in our gas chromatograph could not separate oxygen and nitrogen at the levels found in the samples. With the exception of the analyses for run six, regeneration of the column did not improve the resolution enough to give a satisfactory separation. A new column was found to be satisfactory but was not obtained in time. A separate injection of the gas sample to determine oxygen and nitrogen introduced the potential for a large error, as shown in the results for Run 8, where the sum of the gas concentrations was only 93%.

The procedures for calculating the concentrations of oxygen and nitrogen for each sample are shown in Appendix E.

The analysis for hydrogen should be completed on the day of collection because the concentration of hydrogen decreased if the sample was stored overnight in either Tedlar bags or glass sampling bottles.

A separate injection of the gas sample to determine hydrogen is a standard technique because the carrier gas used is argon, not helium as used for the other gases. A separate injection for the analysis of propane and higher hydrocarbons does not lead to a large error because the amounts present in the sample are low.

The use of at least one calibration gas to determine response factors for the individual gases is recommended before the start of each day's analyses. The response factor for each gas was found to change slightly from day to day.

Figure 13 shows a gas chromatogram of the producer gas for the analysis of methane, carbon dioxide, ethylene, ethane, oxygen, nitrogen and carbon monoxide.

4.2.3 Particulates

The analysis of particulates did not present any problems if the samples were thoroughly mixed to obtain representative subsamples. The results of the particulates analysis are shown in Appendix F.

Thermogravimetric analysis of particulate samples were run to investigate their behavior when heated in air and when heated in nitrogen followed by combustion in oxygen. Figure 14 shows the thermogram of a sample in air and Figure 15 shows the same sample heated in nitrogen. The results for ash and volatiles were the same by either procedure. Therefore, the determination of ash in air at 750°C was acceptable for these samples.

In later runs, the dried particulate samples were combined before the analyses for ash, elements and calorific value. If each particulate sample was analyzed, the process was quite long. However, combination of the samples reduced the analysis time considerably and permitted replicate analyses to be carried out.

4.2.4 Tar

No problems occurred during the analysis of the tar for elements and calorific value. The results are included as Appendix G.

FIGURE 13

Gas Chromatogram of Producer Gas

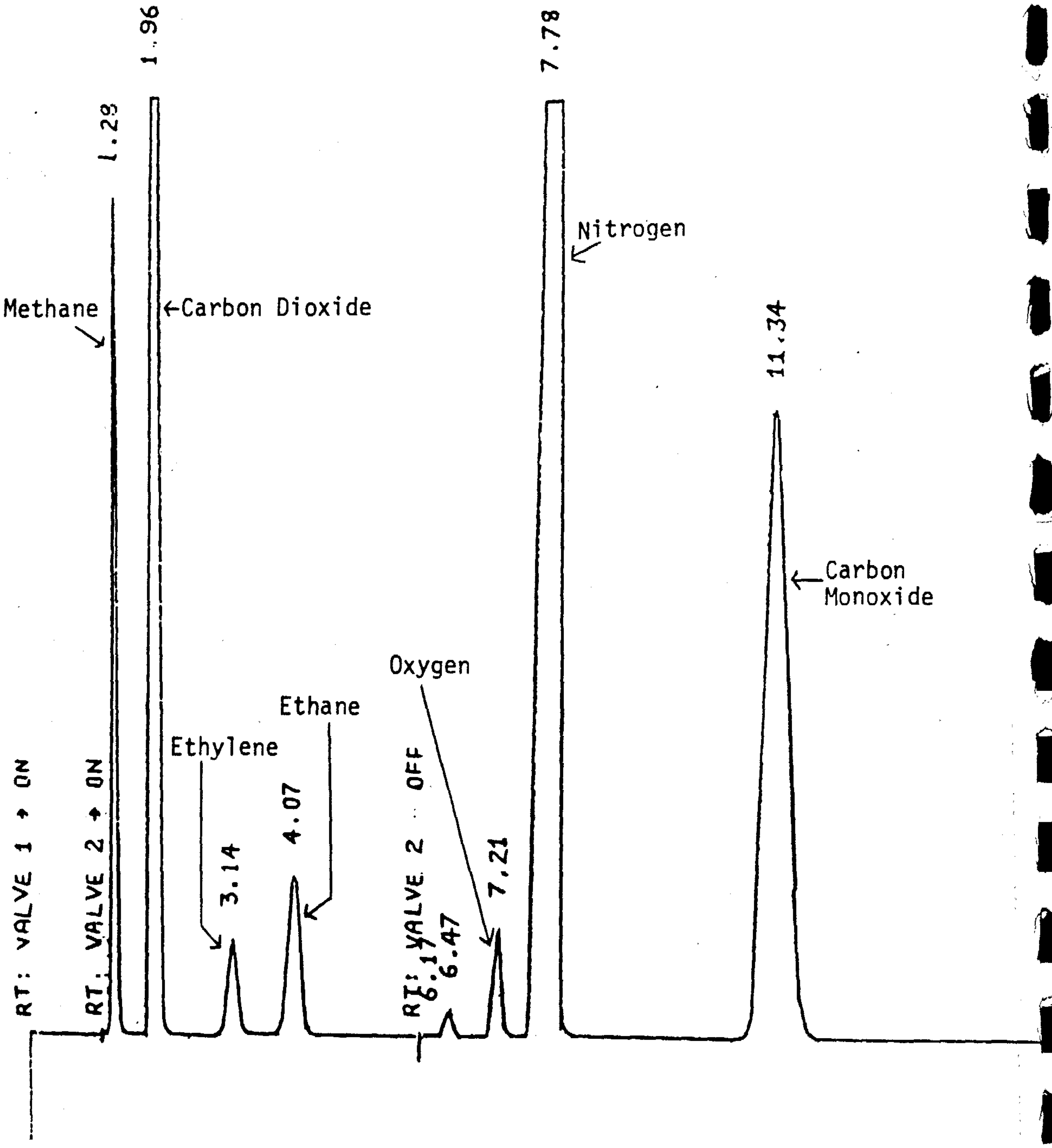


FIGURE 14

Thermogravimetric analysis of particulate sample in air : Run 8

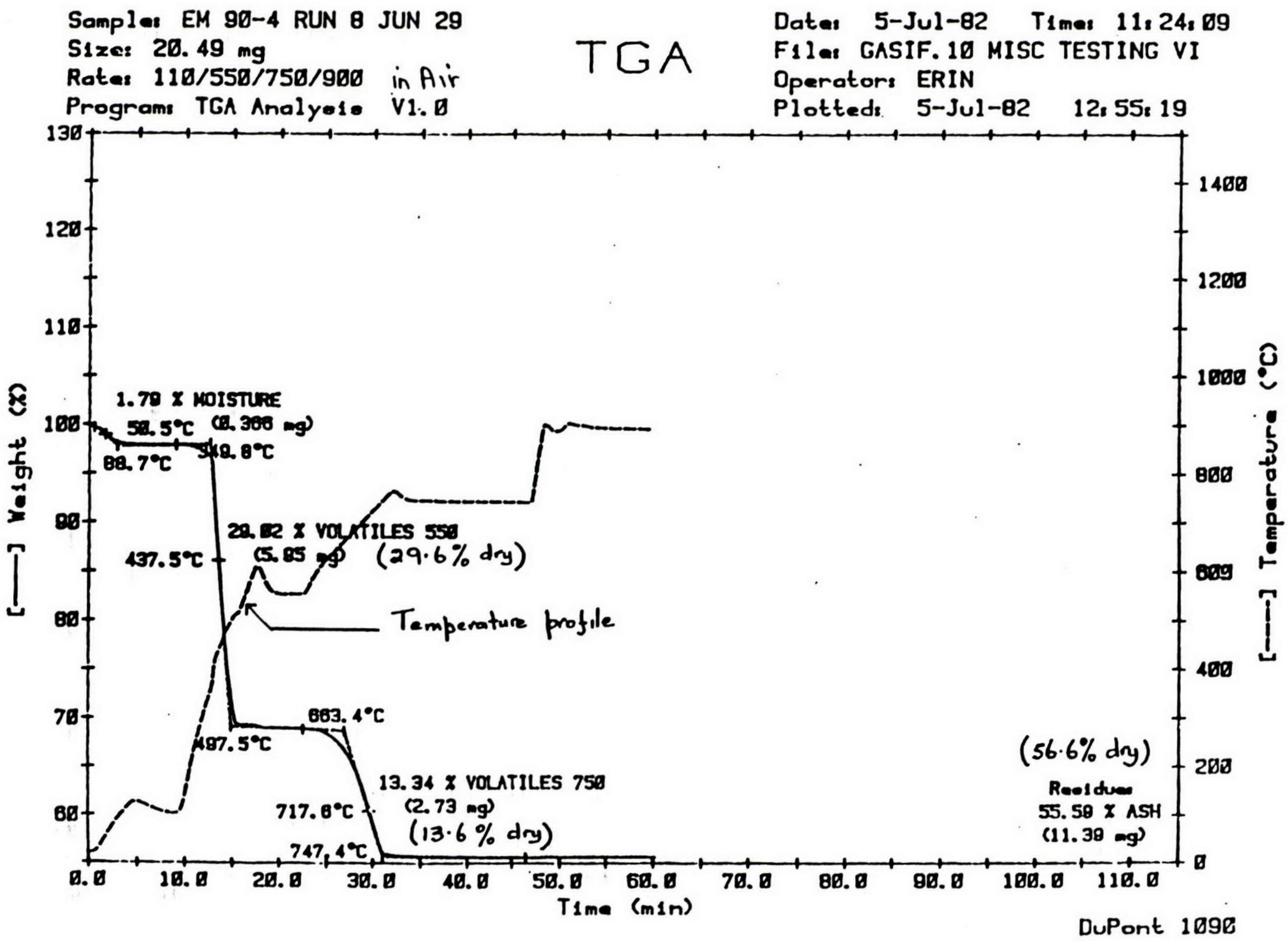
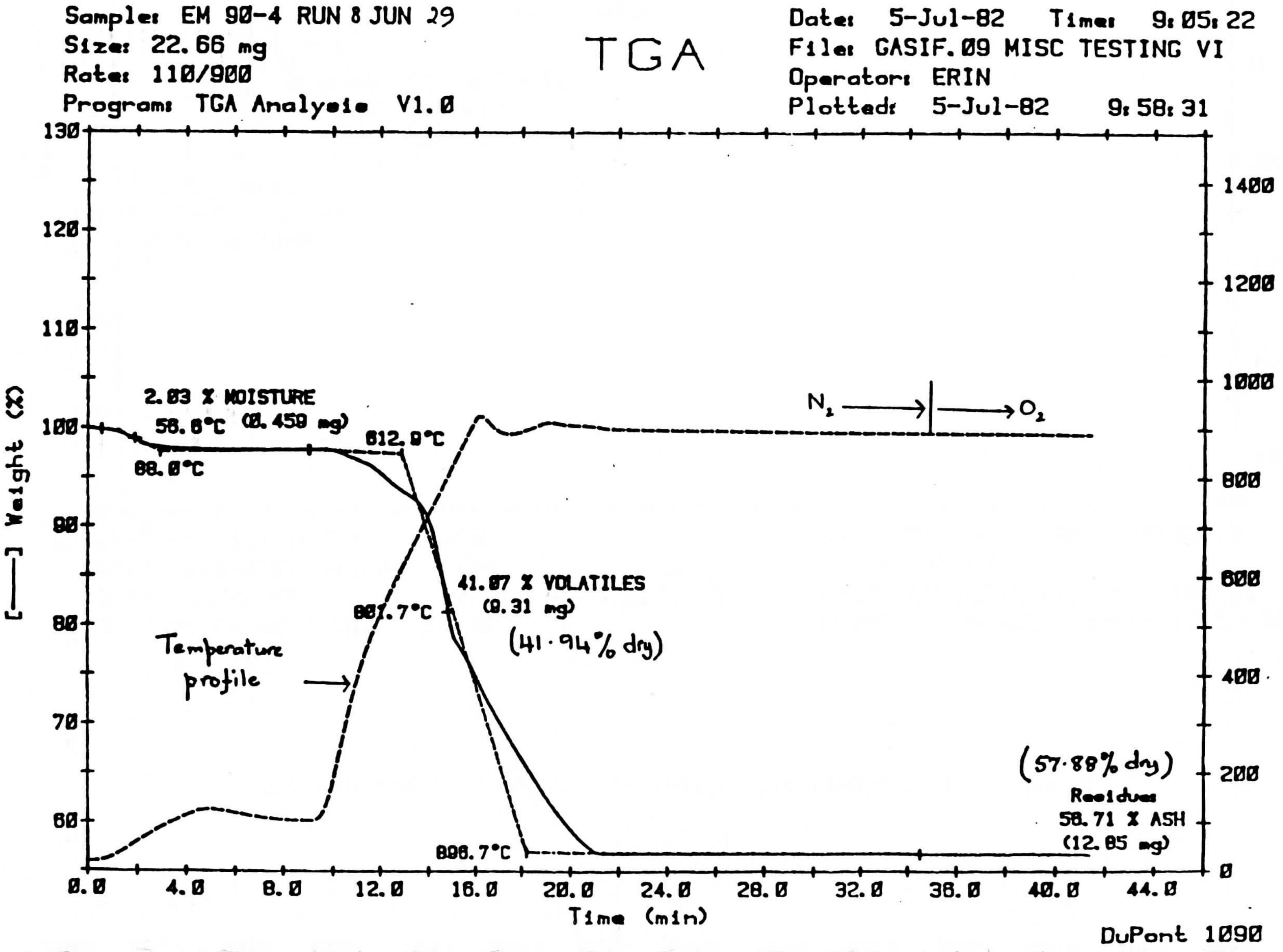


FIGURE 15

Thermogravimetric analysis of particulate samples in nitrogen then oxygen : Run 8



Moisture content of the tar was determined by a Karl Fischer titration, rather than by toluene distillation, for two reasons. First, the titration required about a gram of sample to determine a water content as low as 0.1%, whereas distillation would have required about 100 g of sample. Second, work at the University of Sherbrooke on the analysis of wood oil has shown that the distillation procedure gave higher results than the titration.

Thermogravimetric analysis of a tar sample showed the behaviour of the sample when heated in air. A thermogram of tar from Run 7, Figure 16, shows that if the tar had been dried at 110°C, a moisture content of 13.5% would have been obtained, whereas titration of the sample gave a moisture content of 0.2%.

Analyses of a combined tar sample to determine its chemical composition are in progress.

4.2.5 Condensate

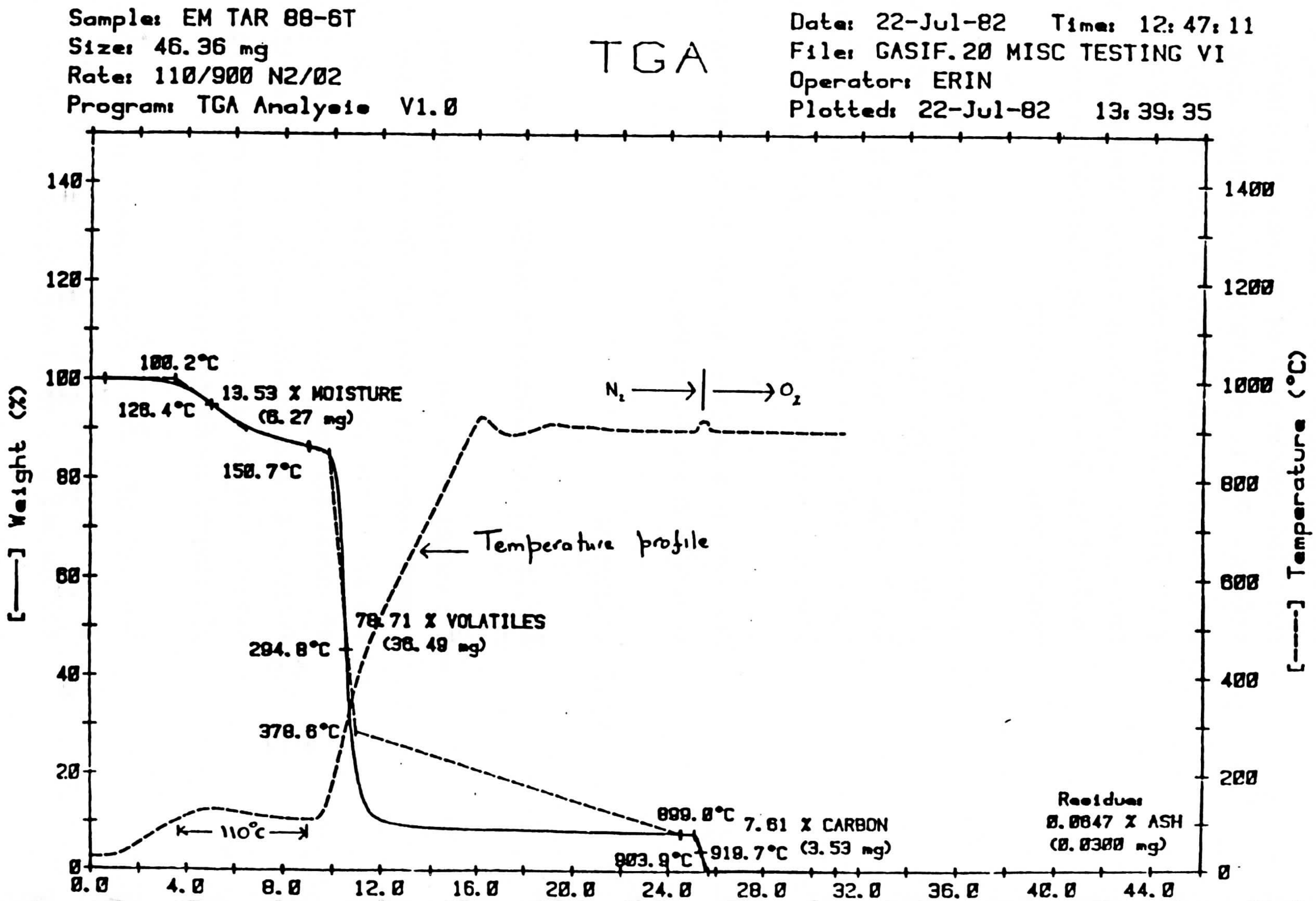
Results of the condensate analysis are included in Appendix H.

The weight of carbon in the condensate measured by total organic carbon analysis was, for all the samples, higher than the sum of the carbon weights calculated from the concentration of individual components. To compensate for the unidentified fraction of a condensate sample, the calculated hydrogen and oxygen contents and calorific value were increased by the ratio of measured carbon to calculated carbon.

The ratio of chemical oxygen demand to total organic carbon was in the range 2.15 to 2.26 for all the samples. Therefore, in the absence of a total organic carbon analyzer, a chemical

FIGURE 16

Thermogravimetric analysis of tar sample : Run 7



oxygen demand analysis could be used to calculate the organic carbon content of the condensate. The ratio of chemical oxygen demand to total organic carbon would have to be established for condensate samples from different gasifiers.

Acetone was found in all the condensate samples and was probably a byproduct from combustion of the wood. The sampling train and sample bottles were rinsed with acetone the day prior to the run and allowed to air-dry overnight. To the best of our knowledge, the condensate samples were not contaminated with acetone from the washing procedure.

The analytical procedures used to identify individual components in the condensate; phenols, organic acids, methanol, ethanol and acetone, were standard techniques and no problems were encountered.

Initially, the condensates were clear yellow solutions. After 4 to 5 days, stored at 4°C under nitrogen, the condensate went cloudy and a brown precipitate started to settle. Analyses of condensate over a four week period showed no change in the values for pH, total organic carbon, organic acids and phenols (volatile).

4.3 Contribution of Inflow and Outflow Streams to Mass, Energy and Element Balances

The percent contributions of the inflow and outflow streams to the mass, energy and element balances for run eight are shown in Table 4. This table shows that some of the sample measurements and analyses are relatively more important than others in achieving accurate balances.

TABLE 4

CONTRIBUTION OF INFLOW AND OUTFLOW STREAMS TO MASS, ENERGY AND ELEMENT BALANCES

Description	Mass Balance %	Energy Balance %	Carbon %	Hydrogen %	Oxygen %	Nitrogen %
INPUT						
dry feed	20.7	99.1	100.0	57.3	28.3	0.1
moisture in feed	7.9	0.1	0	40.0	21.1	0
air	70.8	0	0	0	49.1	99.9
moisture in air	0.6	0	0	2.7	1.5	0
(process energy)		0.8				
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0
OUTPUT						
dry clean gas	82.9	71.0	88.1	29.2	61.1	99.9
moisture in gas	14.8	13.0	0	63.1	37.7	0
particulates	0.4	1.0	1.6	0	0.1	0
tar	1.6	13.5	9.3	6.9	0.9	0
condensate	0.3	1.4	1.0	0.8	0.2	0.1
(process energy)		0.1				
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

The flow rate of process air to the gasifier must be measured accurately. Periodic calibration of the flow measuring device is recommended. Collection of wet feed samples should be carried out so that changes in moisture content do not occur before analysis. A sufficient number of feed samples should be analyzed to allow for inhomogeneity of the feed.

The dry clean gas is the major contributor of the outflow streams, to all but the hydrogen balance. Therefore, all possible precautions should be taken to ensure accurate gas composition analysis. The samples should be analyzed on the day of collection and the gas chromatograph should be calibrated daily with two or more calibration gas mixtures.

Moisture in the producer gas is usually calculated from the increase in weight of the impinger train after a run. Tar collected in the impingers would be included in this weight. For these runs, a 10 percent error in the weight gain of the impinger train was calculated to give about a 1 percent error in each of the mass and energy balances. The weight of the tar should be determined by filtration of the decanted condensate and tar, then the weight of tar subtracted from the increase in weight of the impingers.

The contribution of the particulates to the balances is small. Therefore, combination of all the particulate samples from a sampling run is recommended, with replicate analyses carried out on the combined samples.

Tar contributes a significant part of the energy and carbon balances. The determination of water content of the tar is important in obtaining an accurate calorific value and carbon content. Karl Fischer titration is recommended for water determination. Analysis of a combined sample of all the tars collected from a run would give the required data.

The condensate contributes only a small part of the balances, with the largest contribution being 1.4% of the energy balance. Carbon can be determined by total organic carbon measurement of the sample, but the calorific value can only be calculated after analysis of the condensate for individual components.

The nitrogen balance has one major input stream, process air, and one major output stream, dry clean gas. Assuming that reliable flow and nitrogen content values are obtained, the stack gas flow rate can be calculated. Conversely, if the stack gas flow rate is known the process air input can be determined.

The carbon balance could also be used to calculate the stack gas flow rate. The wet feed is the only source of carbon and reliable carbon values can be obtained if care is exercised in obtaining representative samples. Carbon contents of the output streams can be determined with reliable accuracy because of the separation of the products in the sampling train.

4.4 Mass Balance

The overall mass balance and those for carbon, hydrogen, oxygen and nitrogen were calculated for gasifier runs four through eight. Table 5 summarizes these results.

The mass balances compare the amounts of each species present in each phase of the outflow mass streams to the amounts present in the inflow mass streams. For this gasifier, there

TABLE 5

MASS AND ENERGY BALANCE SUMMARY

	MASS BALANCE Closure %					ENERGY BALANCE		
						Gross Energy Balance Closure %	Energy Conversion Efficiency, %	
RUN	Overall	C	H	O	N		Gross	Net
4	89	96	104	105	76	74	73	46
5	88	93	93	105	75	65	64	42
6	105	90	135	107	104	101	101	47
7	89	95	105	90	85	92	92	51
8	83	103	97	86	76	91	91	52

were two mass inflow streams, the feed and the process air flows; and one mass outflow, the stack exhaust. Four phases were identified in the inflow stream: the dry feed, the moisture in the wet feed, the dry process air, and the humidity in the process air. Five phases were considered in the outflow mass streams: the dry producer gas, the moisture in the gas stream, the particulates, the tars, and the water soluble organic compounds. Other gasifiers may have different numbers of mass streams and phases associated with them, for example, a steam inflow or an ash outflow. Gaseous streams were referenced to 15°C and 1 atmosphere, and a one hour basis was assumed for the balances.

The stack gas velocities were too low to be measured by a pitot tube during these gasifier runs, hence the stack flows used in the mass (and energy) balances were based on the species for which the most complete and consistent mass analyses were available. The flows employed in these balances are the averages of the two calculated by closing the carbon and hydrogen balances. If available, a stack flow obtained from direct measurement, or based on a tie element such as nitrogen, should be used. The stack exhaust was the only stream exiting this gasifier, therefore, the mass balance outflows are directly proportional to the stack flow used in the computation of the balance.

The mass balance for Run 8, as shown in Appendix I, was calculated by hand. Formulae were then derived and these were used to prepare worksheets and to write computer programs, as shown in Appendix K. The mass balances were calculated on an Apple computer in three stages. First, mass concentrations were calculated from the dry producer gas analysis results, as well as higher heat of combustion and heat capacity, as shown in Appendix L. Second, the mass balance input variables were assembled and filed on magnetic disks by the filing routine listed in Appendix K. Third, using the previously written program, the mass balance was calculated as shown in Appendices K and M.

4.5 Energy Balance

Energy balances were calculated for runs four through eight and are summarized in Table 5. Energy transfers were primarily associated with mass flow streams. Other energy flows considered for this gasifier were the process energy consumed during the gasification runs and the heat lost from the reactor surface through convection. All computations were referenced to 15°C and one atmosphere, with the exception of the heats of combustion, which are normally referenced to 25°C and vary little with temperature. Higher heats of combustion were used for both the input and output computations of the balance, because water exists as a liquid at these reference conditions.

The principal energy input to this gasifier was the heat of combustion of the dry feed stream. Enthalpies of the input mass streams were generally small. Sensible and latent heat terms for the input streams could be significant for other gasifiers operating at different conditions. In particular, the enthalpy of the moisture phases in the mass streams could be important if, for example, moist feed below 0°C or steam were introduced into a gasifier.

A secondary contribution to the input side of the energy balance was the electro-mechanical process energy used to operate the gasifier, chiefly the power consumed by the air compressor.

Energy associated with various phases of the outflow mass streams was available as the heats of combustion of the incompletely reacted products, the latent heat of phase changes, and the sensible heat from the exothermic reaction. The heats of combustion were measured from stack gas samples for the dry particulate, tar, and water soluble organic phases. The heat of combustion of the dry producer gas was calculated as a mass-weighted sum of the standard heats of combustion of the component gases. The heating value of this clean, dry producer gas ranged from 2.7-3.7 mJ/m^3 (73-100 Btu/ft^3).

The latent heat of phase changes, significant only for the transition of steam at the sampling conditions to water at the reference conditions, was accounted for by using enthalpy values of water obtained from thermodynamic tables.

The heat capacity of the particulate, tar and water soluble organic phases of the stack flow were not measured, and the sensible heat contributions of these phases to the output side of the energy balance was assumed to be small. The heat capacity of gases under atmospheric pressure depends greatly on temperature, for example, the heat capacity of methane changes by 115% between 15°C and 800°C. Therefore, virial expressions of heat capacities as functions of temperature were used to calculate the sensible heat of the dry producer gas. The heat available from the hot gas was computed by integrating the enthalpy expression, (Equation 1), using a mass-weighted average of the virial expressions for the component gases as the specific heat.

$$\%H = \int_{T_{REF}}^{T_{STACK}} CpdT \qquad \text{. . . Equation 1}$$

$\%H$ = the change in enthalpy of the gas
Cp = the specific heat of the gas
T_{STACK} = the sampling temperature
T_{REF} = the reference temperature

The energy loss from the reactor was calculated from surface temperature measurements taken at the end of run eight. Sections of the gasifier were approximated as vertical and horizontal plates and cylinders. Literature expressions yielded coefficients of heat transfer due to natural convection as functions of surface temperature and dimensions for the various sections. The heat losses were calculated from equation 2 and summed to produce total heat losses to each of the reactor sampling port and the stack sampling port. It was not known whether the heat loss of the batch operations in these runs approached the steady state conditions of a continuous process.

$$\Delta q = hA\Delta T \qquad \text{. . . Equation 2}$$

Δq = heat loss from reactor
h = coefficient of heat loss due to natural convection
A = surface area of section
ΔT = surface temperature - ambient temperature

The energy balances were computed similarly to the mass balances. The hand-worked calculation for run eight in Appendix J was used to derive the energy balance program in Appendix K. The heats of combustion and heat capacities of the producer gas were calculated by the gas analysis program in Appendix K, and these, along with other data, were filed on magnetic disk. The disk files were accessed by the energy balance program for each gasifier run to produce the energy balance program results, shown in Appendix N.

4.6 Energy Conversion Efficiency

Two energy conversion efficiencies were applied to the gasification operations. The first, the gross efficiency, reflects the recoverable energy available to a process adjacent to a gasifier, a boiler or drier, for example. Hence, it includes the sensible and latent heats of the product stream referenced to 15°C. The gross efficiency is defined as the recoverable energy divided by the total energy input, and is expressed as a percentage. For the B.C. Research gasifier, the gross efficiency was characterized by the total energy output from the energy balance less the convective heat loss, divided by the heat of combustion of the feed plus small contributions from process energy and sensible heats of the input mass streams.

The second energy conversion efficiency, the net efficiency, denotes the recoverable energy transferable to a distant process. The net efficiency is defined as the standard higher heat of combustion of the dry producer gas divided by the total energy input, expressed as a percentage.

The energy conversion efficiencies calculated for runs four through eight are shown in Table 5 and included in the energy balances in Appendix N.

5.0 CONCLUSION

A sampling train was designed and assembled to obtain representative producer gas samples from various biomass gasifiers.

The sampler was extensively tested both in the free-board zone, and external to, the B.C. Research gasifier. After typical development problems the sampler performance was shown to be satisfactory in a 700°C raw producer gas environment.

The gasifier flow rate for these low flow stack tests was calculated by balancing carbon and hydrogen mass flows and averaging the results. However, with a measurable flow rate in the stack, the velocity would be measured with the pitot tube installed in the sample probe.

The sampler separated dry, clean gas from the solid, liquid and tarry residues. Partial separation of these residues was effected in the sampler. Subsequent separation of particulates, condensate and tar into discrete fractions was readily achieved using conventional laboratory techniques.

The procedures used for the analysis of the feed, particulates, tar and condensate were found to be satisfactory. The procedure used for analysis of the gas was also satisfactory, but the operation of the gas chromatograph gave a problem with the analysis for oxygen and nitrogen. Analyses for methane, carbon dioxide, ethylene, ethane, propane, carbon monoxide and hydrogen did not present any problems.

Computer programs were written for calculation of mass and energy balances of the gasification process. Mass and energy balances were calculated using gasifier inflow and outflow data and results of the analyses of gas, solid and liquid samples from each stack test.

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APPENDIX A

BIOMASS GASIFICATION SAMPLING SUMMARIES, RUNS 1-8

BIOMASS GASIFICATION SAMPLING SUMMARY

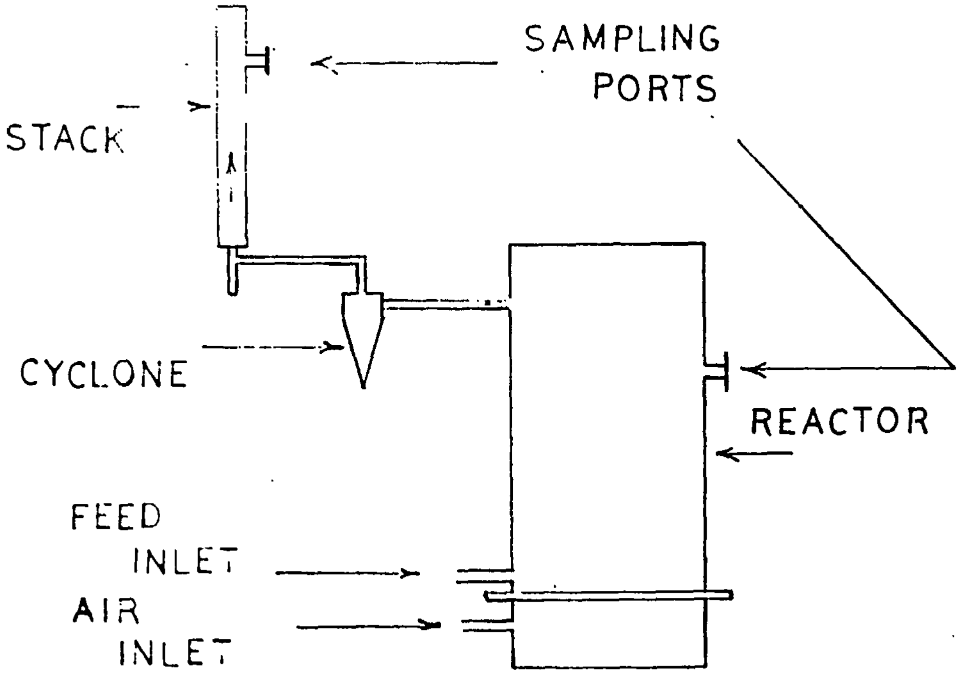
Run Identification

Run Number: 1

Date: May 26, 1982

Location: B.C. Research Fluidized Bed Gasifier

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** May 26, 1982

Purpose of Run: To test sample train under stack conditions.

Gasifier Operating Performance: Fair.

Sampling Problems Encountered: 1. Sample probe stack thermocouple failed. 2. Condensibles carried over to silica gel impinger. 3. Temperature controller compartment temperature too high. Filter compartment temperature too high.

Sampling Train Changes Required: 1. Add water to condenser bottle to catch uncondensed vapours and tars from condenser tube. 2. Replace faulty stack probe thermocouple. Add blower to temperature controller compartment for better cooling.

Sampling Train Improvements: -

Observations, Conclusions: The first run using the sample train was satisfactory. The equipment stood up well to the high temperatures encountered. The temperature control system was erratic due to overheaded controllers. Stack gas velocities were not obtained due to the very low gas velocity.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 26, 1982

1. Gasifier

Operators:	Dr. Cedric Briens Duncan Morgan Rick Labram
Start-Up Time:	0730
Shut-Down Time:	1715
Feed Type:	Alderwood Sawdust
Feed Moisture Content, %:	38.3
Total Feed Consumed, lb: (10 bags)	176
Feed Rate, lb/hr: *	120
Bed Material(s):	Gravel, Sand
Bed Depth, Inches:	24
Bed Temperature, °C (T2&T3)	714
Upper Bed " (T4)	719
Over Bed " (T5&T6)	713
Gasif. Top " (T7)	557
Gasif. Exit " (T9)	Out of order
Sampling Location "	Estimated 225
Reactor Static Pressure, Inches H_2O:	Est. +.20
Air Inflow Rate CFM:	60
Producer Gas Characteristics, High Temp/ /Low Tar, Low Temp/ /High Tar :	Low Temp/High Tar
Ambient Weather Conditions,	
Temperature, °C:	15
Pressure, Inches H_g:	29.85
Humidity, %:	63
Wind:	380° @ 14 KTS
Cloud Cover:	7/10
Precipitation:	0

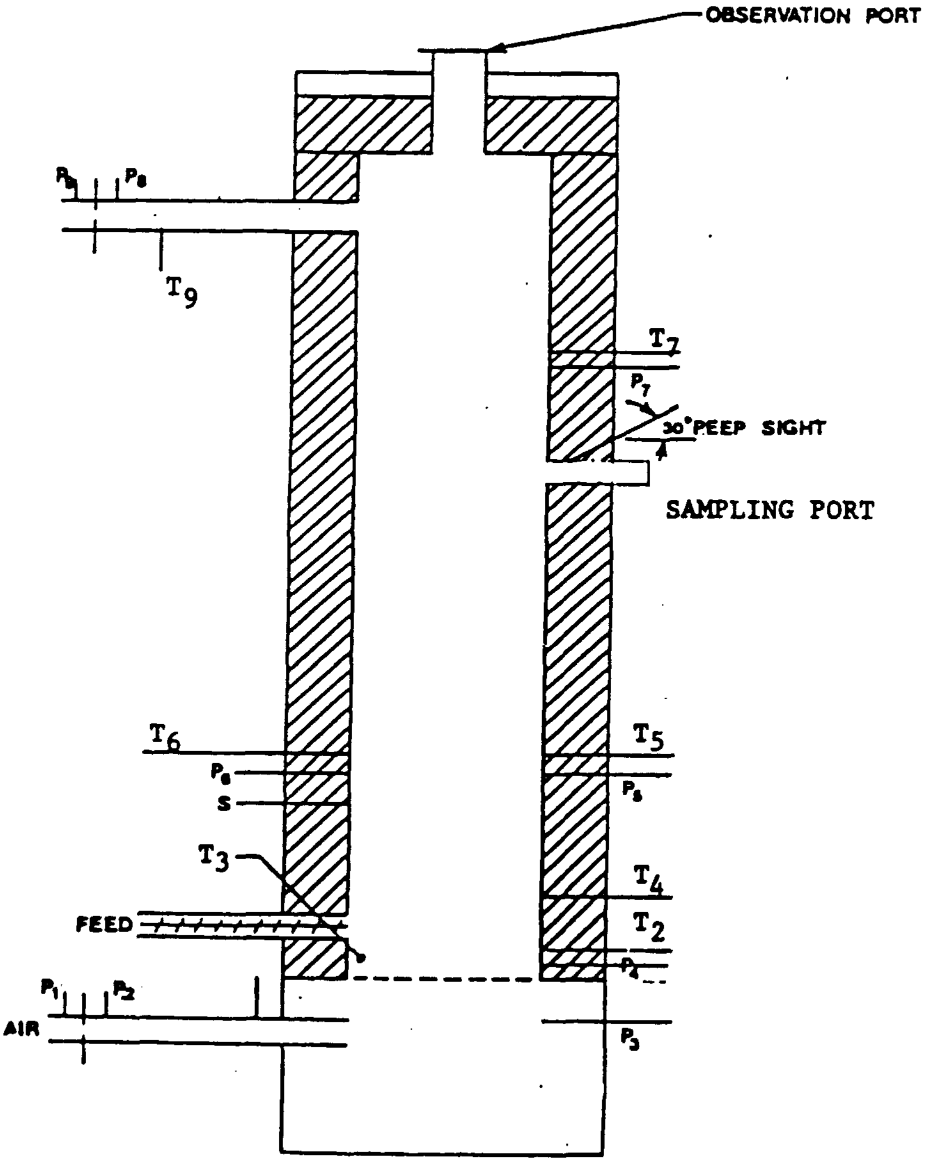
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 26, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail Date: May 26, 1982

(Continued)

2. Sampling

Operators: Merv Aiken
Lloyd Philips

Train Preheat Time, Minutes: 10
Sampling Period, Start: 1435
Sampling Period, Finish: 1520
Total Sampling Time, Min: 45
Average Temperatures, °C
Stack: Estimated 225
Probe: 290
Cyclone: 170
Coil: Estimated 160
Filter: 155
Orifice Plate: 155
Impinger Outlet: 15
Dry Gas Meter Inlet: 29
Dry Gas Meter Outlet: 28
Nozzle Diameter, Inches: .75
Orifice Diameter, Inches: .188
Average Sampling Rate, SCFM .34
Total Sampling Volume, SCF: 14.5
Maximum Pump Vacuum, Inches H_g: 3.8
Average Stack Velocity, Inches H_2O: Estimated .0004
Stack Static Pressure, Inches H_2O: Estimated +.20
Stack Exit Flow Rate, SCFM: Estimated 60
Stack Exit Flow Rate, SCFM: Estimated 60
Flow Rate Determination Method: Estimation from previous data.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail

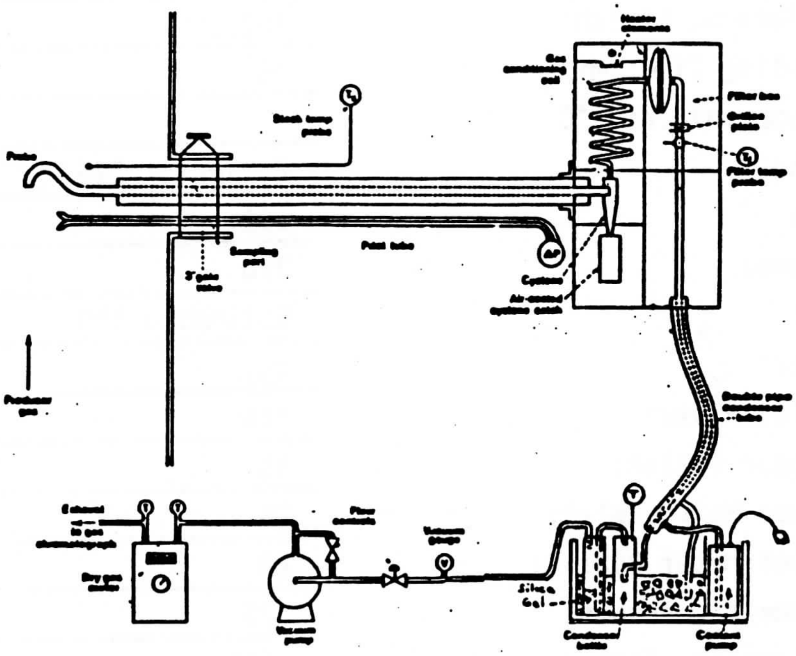
Date: May 26, 1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-cyclone-coil-filter-orifice-condenser tube-condenser bottle-silica gel-pump-control unit.

GASIFIER SAMPLING TRAIN



Observations, Conclusions:

OBSERVATIONS

The temperature in the temperature controller compartment of the sample box exceeded the recommended limit of 60° C.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 26, 1982

(Continued)

3. Sample Recovery

General Procedure: The individual components of the train were flushed with acetone after the filter and condenser catch were removed. The coil and condenser tube were flushed using acetone and a peristaltic circulating pump.

Sample Identification	
#1	Nozzle-probe wash
#2	Cyclone catch and wash
#3	Coil and filter wash
#4	Filter
#6	Cond. tube, orifice and cond. bottle wash
#7	Condensate
Special	
Collected Sample Weights:	
Cyclone, g:	-
Filter, g:	1.470
Impinger #1, g:	76.3
#2, g:	-
#3, g:	-
Silica Gel, 4, g:	12.0
Total Impinger Weight Gain, g:	88.3

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 26, 1982

(Continued)

3. Sample Recovery (con't)

Observations, Conclusions: The condenser bottle without initial distilled water addition did not pick up all of the condensed tars and vapors. The lexan silica gel impinger cracked. Large amounts of fallout were present in the nozzle probe, cyclone and coil, probably due to inadequate system preheat.

4. Analytical

Observations, Conclusions:

BIOMASS GASIFICATION SAMPLING SUMMARY

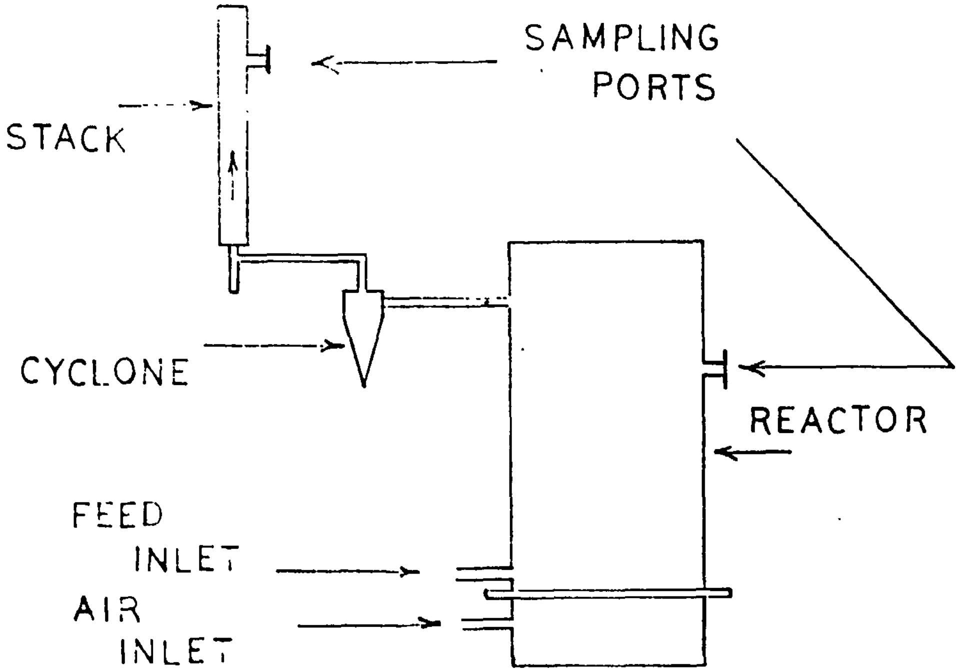
Run Identification

Run Number: 2

Date: May 28, 1982

Location: B.C. Research Fluidized Bed Gasifier

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** May 28, 1982

Purpose of Run: To further test sampling train and to test repairs and alterations.

Gasifier Operating Performance: Poor. Due to the presence of water in the gasifier bed, proper bed temperature could not be attained. Propane was therefore used to maintain combustion.

Sampling Problems Encountered: Lexan silica gel impinger cracked. Filter compartment temperature too low. Water condensed out in orifice lines to the control unit.

Sampling Train Changes Required: Metal impingers needed. Recalibrate temperature controllers. Change orifice ports from a downward 90° bend to an upward 90° bend to eliminate collection of condensed moisture.

Sampling Train Improvements: 250 ml H_2O was used in the condenser bottle to catch condensibles that passed through the condenser tube. New stack thermocouple installed. Blower in temperature controller compartment reduced temperature to 55°C.

Observations, Conclusions: Run 2 sample analysis was not performed because of the faulty samples collected due to poor gasifier operation.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 28, 1982

1. Gasifier

Operators:	Dr. Cedric Briens Duncan Morgan Rick Labram
Start-Up Time:	0710
Shut-Down Time:	1850
Feed Type:	Alderwood Sawdust
Feed Moisture Content, %:	38.3
Total Feed Consumed, lb:	550
Feed Rate, lb/hr: *	120
Bed Material(s):	Gravel, sand
Bed Depth, Inches:	24
Bed Temperature, °C (T2&T3)	223
Upper Bed " T4	381
Over Bed " T5&T6	504
Gasif. Top " T7	454
Gasif. Exit " T9	411
Sampling Location "	142
Reactor Static Pressure, Inches H_2O:	Est. +.20
Air Inflow Rate CFM:	70
Producer Gas Characteristics, High Temp/ /Low Tar, Low Temp/ /High Tar :	Low Temp/High Tar
Ambient Weather Conditions,	
Temperature, °C:	18
Pressure, Inches H_g:	30.11
Humidity, %:	64
Wind:	240 @ 7 KTS
Cloud Cover:	1/10
Precipitation:	0

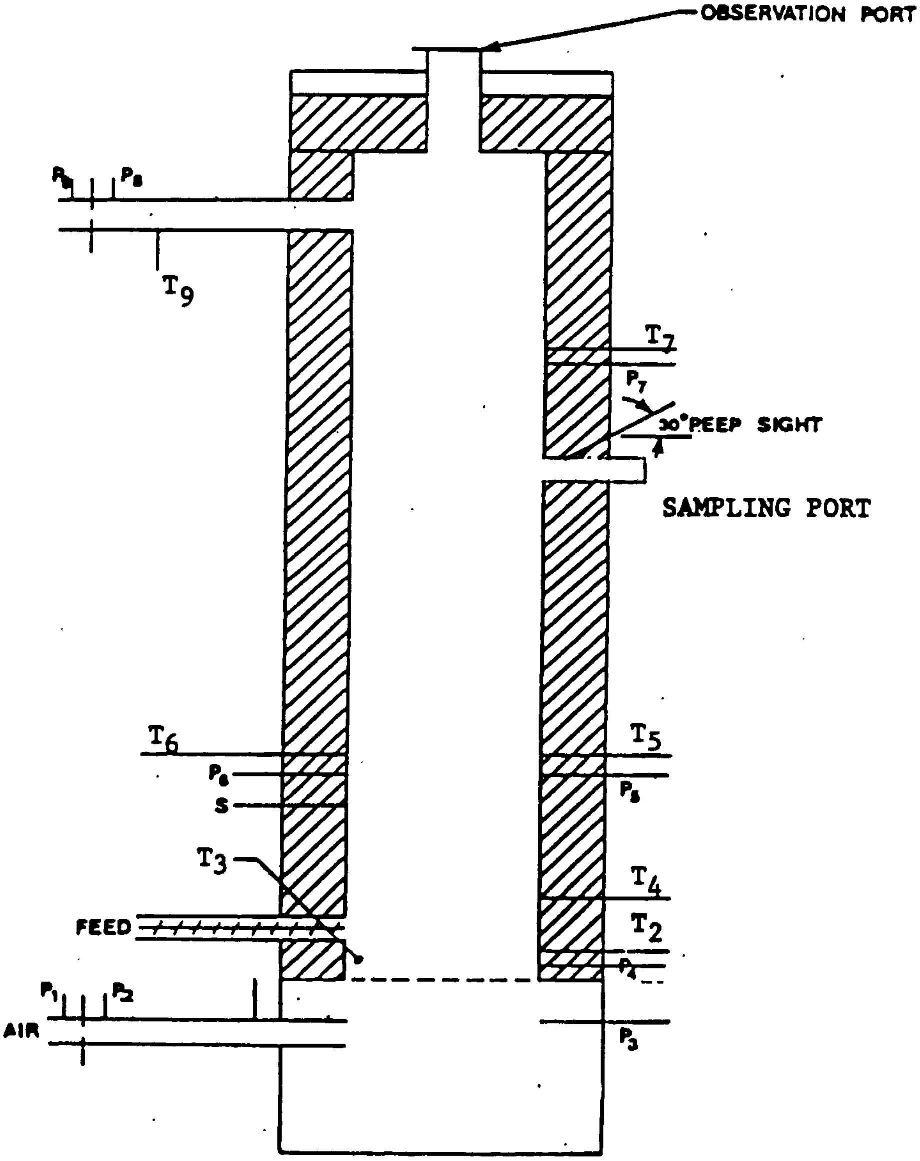
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 28, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail Date: May 28, 1982

(Continued)

2. Sampling

Operators:	Merv Aiken
	Lloyd Philips
Train Preheat Time, Minutes:	15
Sampling Period, Start:	1347
Sampling Period, Finish:	1432
Total Sampling Time, Min:	45
Average Temperatures, °C	
Stack:	142
Probe:	306
Cyclone:	167
Coil:	Estimated 172
Filter:	176
Orifice Plate:	176
Impinger Outlet:	22
Dry Gas Meter Inlet:	34
Dry Gas Meter Outlet:	34
Nozzle Diameter, Inches:	.50
Orifice Diameter, Inches:	.188
Average Sampling Rate, SCFM	.34
Total Sampling Volume, SCF:	15.9
Maximum Pump Vacuum, Inches H_g:	12.0
Average Stack Velocity, Inches H_2O:	Estimated .0004
Stack Static Pressure, Inches H_2O:	Estimated +.20
Stack Exit Flow Rate, SCFM	Estimated 70
Stack Exit Flow Rate, SCFM:	Estimated 70
Flow Rate Determination Method:	Estimation

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail

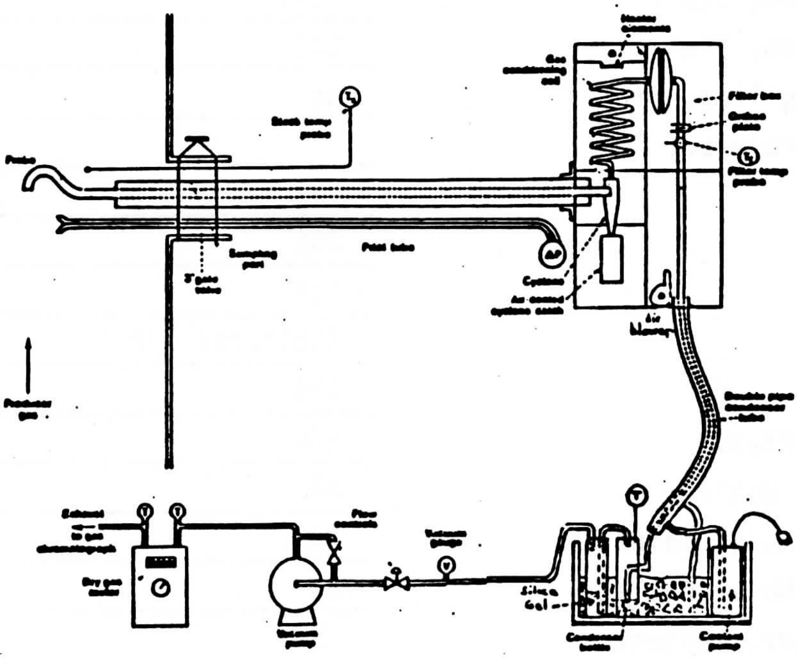
Date: May 28,1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-cyclone-coil-filter-orifice-condenser tube-condenser bottle-silica gel-pump-control unit.

GASIFIER SAMPLING TRAIN



Observations, Conclusions: None

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 28, 1982

(Continued)

3. Sample Recovery

General Procedure: Samples discarded and train components flushed and rinsed with acetone for next run.

Sample Identification	None
#1	
#2	
#3	
#4	
#6	
#7	
Special	
Collected Sample Weights:	
Cyclone, g:	
Filter, g:	
Impinger #1, g:	24.0
#2, g:	
#3, g:	
Silica Gel, 4, g:	17.0
Total Impinger Weight Gain, g:	41.0

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** May 28, 1982

(Continued)

3. Sample Recovery (con't)

Observations, Conclusions: Cyclone catch contained liquid material and particulates. In Run #2, the condenser bottle contained an initial 250 ml of distilled water. The lexan silica gel impinger cracked for the second run in a row.

4. Analytical

Observations, Conclusions:

BIOMASS GASIFICATION SAMPLING SUMMARY

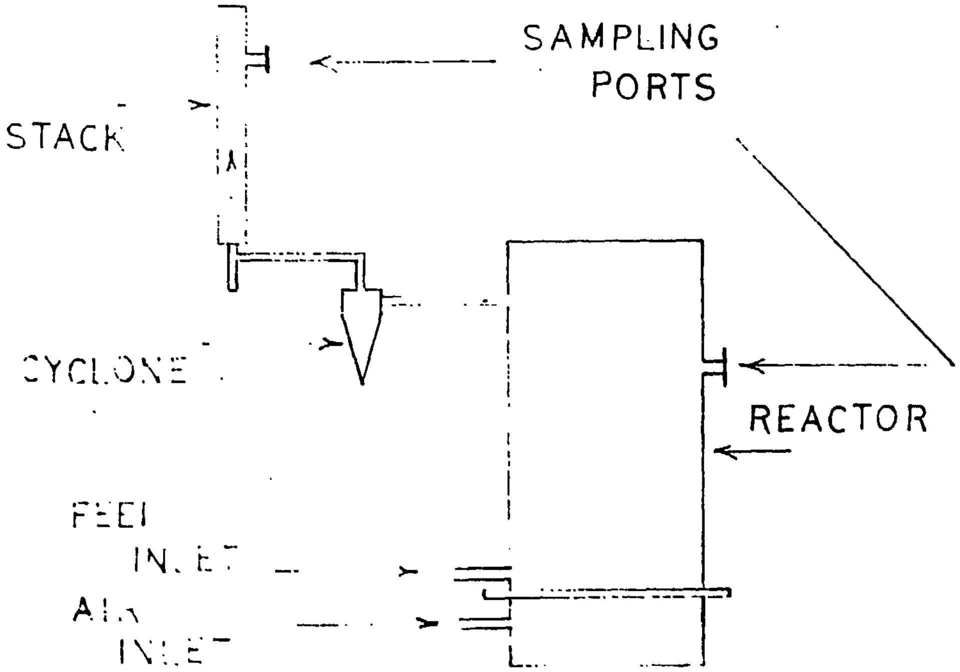
Run Identification

Run Number: 3

Date: June 1, 1982

Location: B.C. Research Fluidized Bed Gasifier

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** June 1, 1982

Purpose of Run: To test altered orifice plate and new impingers.

Gasifier Operating Performance: Good. Gasifier operating temperatures were reached quickly and remained steady.

Sampling Problems Encountered: Cyclone plugged with oversized material and condensed tars. A major leak developed in orifice plate assembly. Sample probe heater thermocouple did not operate due to faulty line plug.

Sampling Train Changes Required: Repair orifice plate air leaks. Check out probe heater thermocouple.

Sampling Train Improvements: New metal impingers (2).

Observations, Conclusions: Plugged cyclone was caused by a combination of loss of the probe heater at the beginning of the run, resulting in condensation of tars in the narrow entrance to the cyclone and presence of large particles. Run 3 sample analysis was not performed because of the faulty samples collected due to the major air-leak in the train and the cyclone plug-up.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 1, 1982

1. Gasifier

Operators: Dr. Cedric Briens
Duncan Morgan

Start-Up Time: 0420

Shut-Down Time: 1350

Feed Type: Alderwood Sawdust

Feed Moisture Content, %: 38.3

Total Feed Consumed, lb: 528

Feed Rate, lb/hr:* 145.2

Bed Material(s): Gravel, sand

Bed Depth, Inches: 24

Bed Temperature, °C (T2&T3) 711

Upper Bed " T4 726

Above Bed " T5&T6 710

Gasif. Top " T7 542

Gasif. Exit " T9 499

Sampling Location " 216

Reactor Static Pressure, Inches H_2O: Est. +.20

Air Inflow Rate CFM: 62.5

Producer Gas Characteristics, High Temp/ /Low Tar, Low Temp/ /High Tar: Low Temp/High Tar

Ambient Weather Conditions,

Temperature, °C: 12

Pressure, Inches H_g: 30.02

Humidity, %: 67

Wind: 130 @ 11 KTS

Cloud Cover: 9/10

Precipitation: 0

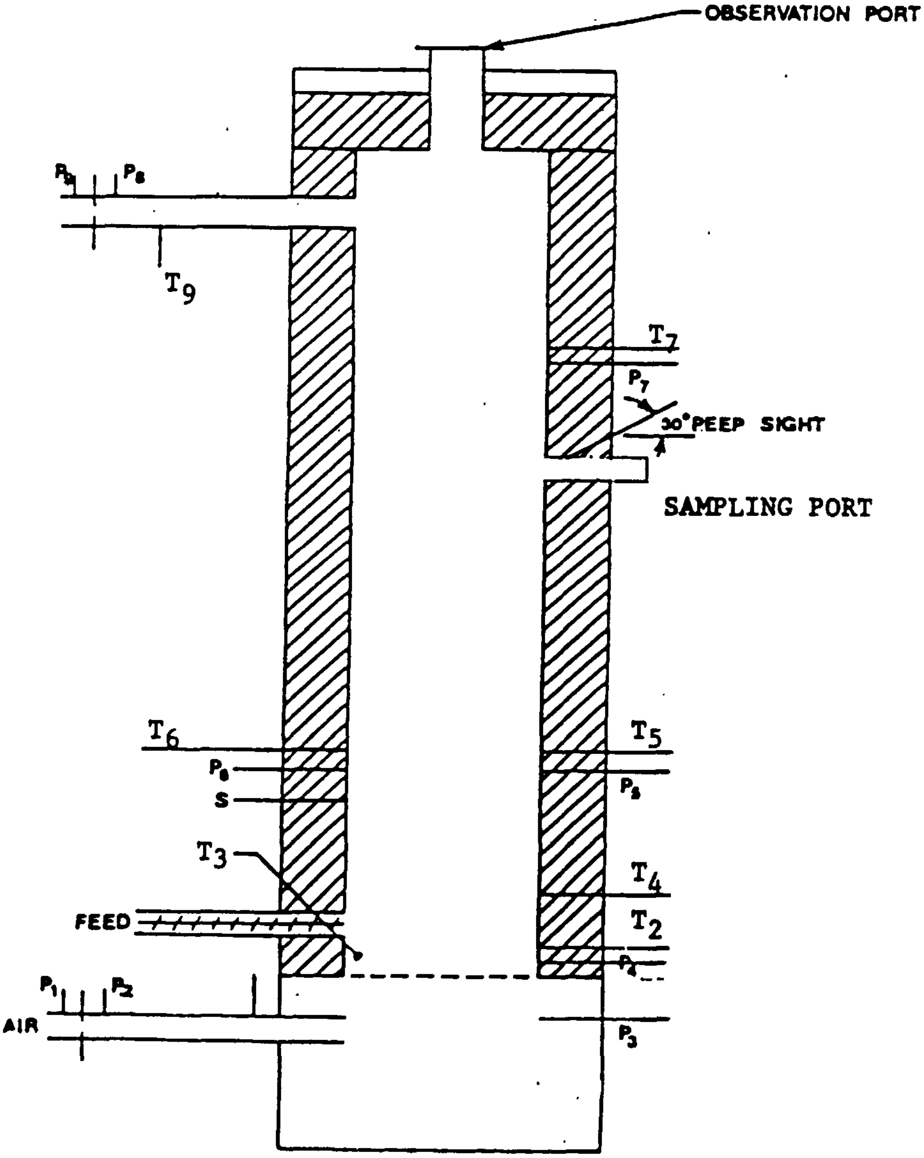
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 1, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail Date: June 1, 1982

(Continued)

2. Sampling

Operators:	Merv Aiken
	Lloyd Philips
Train Preheat Time, Minutes:	15
Sampling Period, Start:	1100
Sampling Period, Finish:	1205
Total Sampling Time, Min:	65
Average Temperatures, °C	
Stack:	216
Probe:*	580
Cyclone:	113
Coil:	Estimated 150
Filter:	158
Orifice Plate:	158
Impinger Outlet:	16
Dry Gas Meter Inlet:	20
Dry Gas Meter Outlet:	18
Nozzle Diameter, Inches:	.50
Orifice Diameter, Inches:	.188
Average Sampling Rate, SCFM	.21
Total Sampling Volume, SCF:	13.3
Maximum Pump Vacuum, Inches H_g:	13.0
Average Stack Velocity, Inches H_2O:	Estimated .00044
Stack Static Pressure, Inches H_2O:	Estimated +.20
Stack Exit Flow Rate, SCFM	Estimated 62.5
Stack Exit Flow Rate, SCFM:	Estimated 62.5
Flow Rate Determination Method:	Estimation

* Heater off at beginning of run due to faulty thermocouple.

BIOMASS GASIFICATION SAMPLING SUMMARY

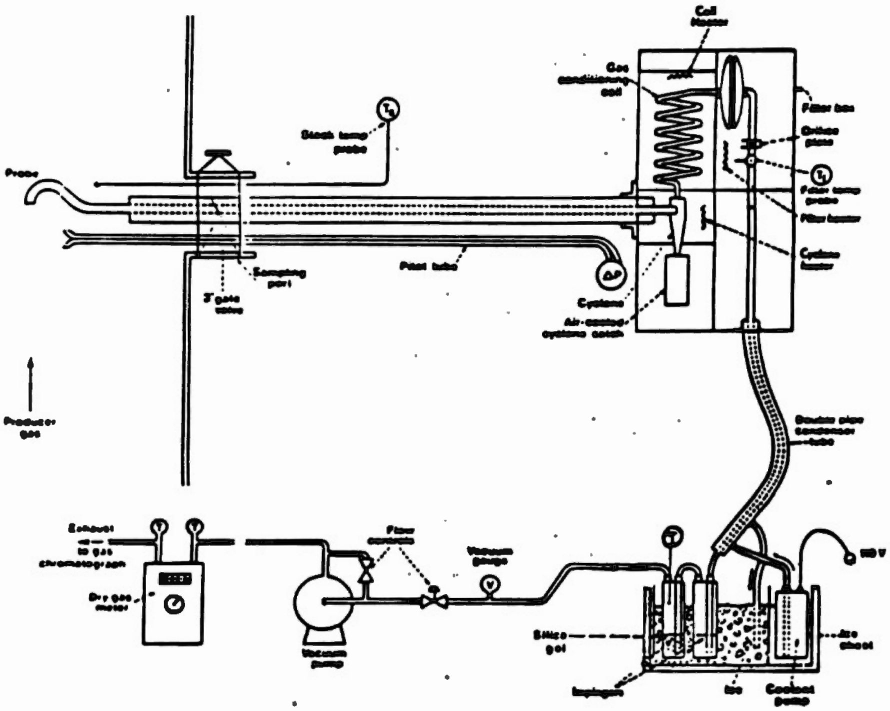
Run Detail **Date:** June 1, 1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-cyclone-coil-filter-orifice plate-condenser tube-condenser bottle-silica gel-pump-control unit.

GASIFIER SAMPLING TRAIN



Observations, Conclusions: Very low sampling rate caused by cyclone plug-up. High leak rate developed in orifice plate assembly during run after cyclone plug-up (the pre-test leak check was good).

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 1, 1982

(Continued)

3. Sample Recovery

General Procedure: Samples discarded and train components flushed and rinsed with acetone for next run.

Sample Identification None

#1

#2

#3

#4

Special

Collected Sample Weights:

Cyclone, g:

Filter, g:

Impinger #1, g: 17.2

#2, g: 5.6

#3, g:

Silica Gel, 4, g: 29.2

Total Impinger Weight Gain, g:

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 1, 1982

(Continued)

3. Sample Recovery (con't)

Observations, Conclusions: None

4. Analytical

Observations, Conclusions:

BIOMASS GASIFICATION SAMPLING SUMMARY

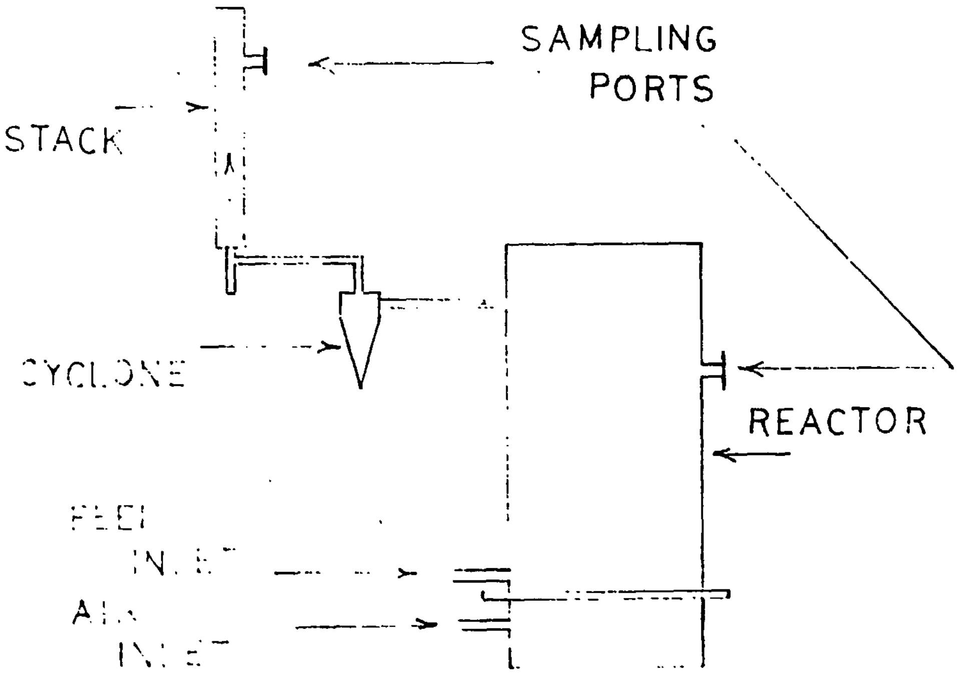
Run Identification

Run Number: 4

Date: June 2, 1982

Location: B.C. Research Fluidized Bed Gasifier

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** June 2, 1982

Purpose of Run: To test complete heater-thermocouple-sensor system and to obtain some decent samples for analysis.

Gasifier Operating Performance: Good

Sampling Problems Encountered: Replaced leaking orifice plate assembly prior to start of run. Filter went off line due to power outage (breaker overload).

Sampling Train Changes Required: More impingers needed to trap condensibles before they reach silica gel.

Sampling Train Improvements:

Observations, Conclusions: Problems persist with obtaining adequate power supply for the heating system.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail Date: June 2, 1982

1. Gasifier

Operators:	Dr. Cedric Briens Duncan Morgan
Start-Up Time:	0445
Shut-Down Time:	1330
Feed Type:	Alderwood Sawdust
Feed Moisture Content, %:	38.3
Total Feed Consumed, lb:	330
Feed Rate, lb/hr:*	145.2
Bed Material(s):	Gravel, sand
Bed Depth, Inches:	24
Bed Temperature, °C (T2&T3)	691
Upper Bed " (T4)	724
Above Bed " (T5&6)	715
Gasif. Top "	637
Gasif. Exit "	583
Sampling Location "	277
Reactor Static Pressure, Inches H_2O:	Estimated +.20
Air Inflow Rate CFM:	70
Producer Gas Characteristics, High Temp/ /Low Tar, Low Temp/ /High Tar :	Low Temp/High Tar
Ambient Weather Conditions,	
Temperature, °C:	11
Pressure, Inches H_g:	30.04
Humidity, %:	37
Wind:	110 @ 5 KTS
Cloud Cover:	10/10 (overcast)
Precipitation:	Raining

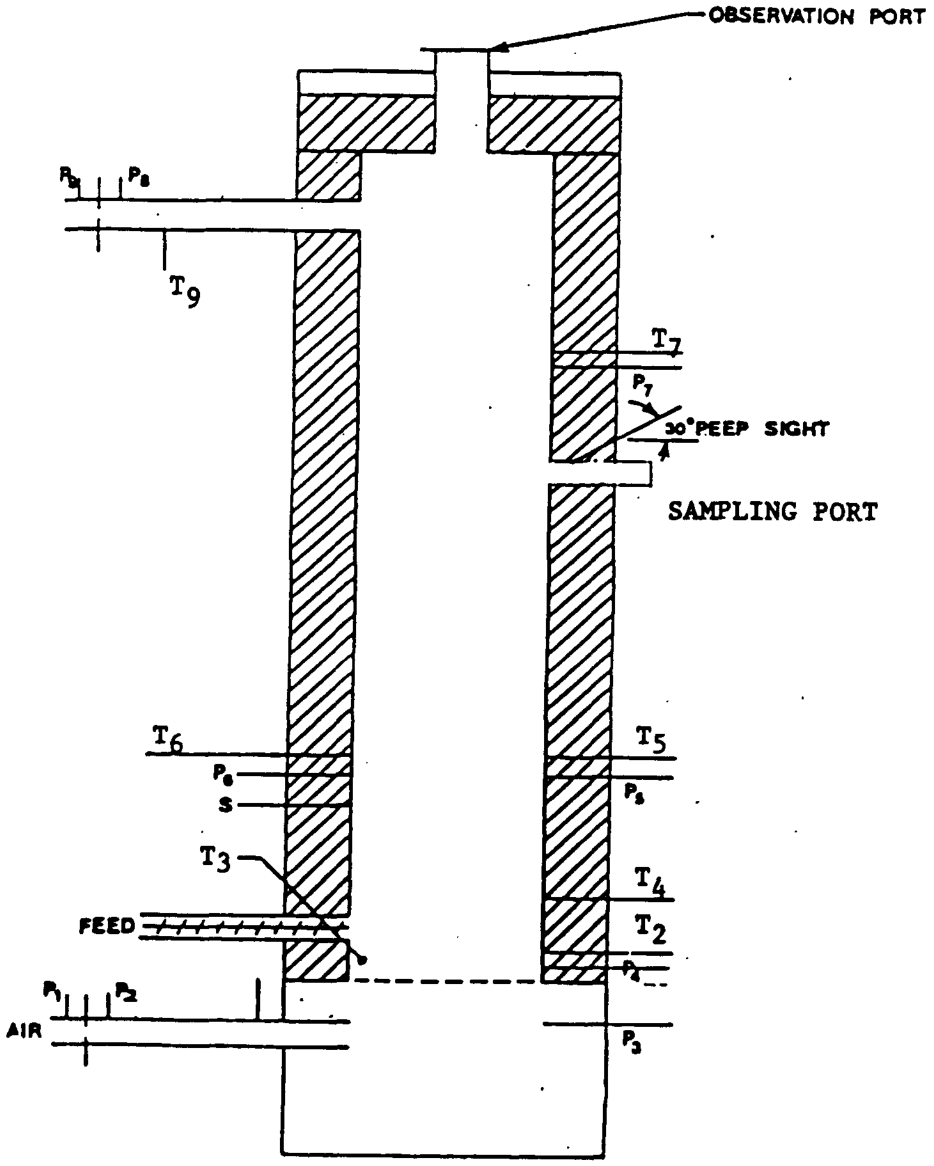
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 2, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail Date: June 2, 1982

(Continued)

2. Sampling

Operators:	Merv Aiken
	Lloyd Philips
Train Preheat Time, Minutes:	15
Sampling Period, Start:	1047
Sampling Period, Finish:	1132
Total Sampling Time, Min:	45
Average Temperatures, °C	
Stack:	277
Probe:	307
Cyclone:	237
Coil:	Estimated 150
Filter:*	181
Orifice Plate: (in control unit)	Estimated 14
Impinger Outlet:	11
Dry Gas Meter Inlet:	14
Dry Gas Meter Outlet:	13
Nozzle Diameter, Inches:	.50
Orifice Diameter, Inches:	.188
Average Sampling Rate, SCFM	.60
Total Sampling Volume, SCF:	25.5
Maximum Pump Vacuum, Inches H_g:	0
Average Stack Velocity, Inches H_2O:	Estimated .00044
Stack Static Pressure, Inches H_2O:	Estimated +.20
Stack Exit Flow Rate, SCFM	Estimated 70
Stack Exit Flow Rate, SCFM:	Estimated 70
Flow Rate Determination Method:	Estimation

* Filter heater went down near end of run.

BIOMASS GASIFICATION SAMPLING SUMMARY

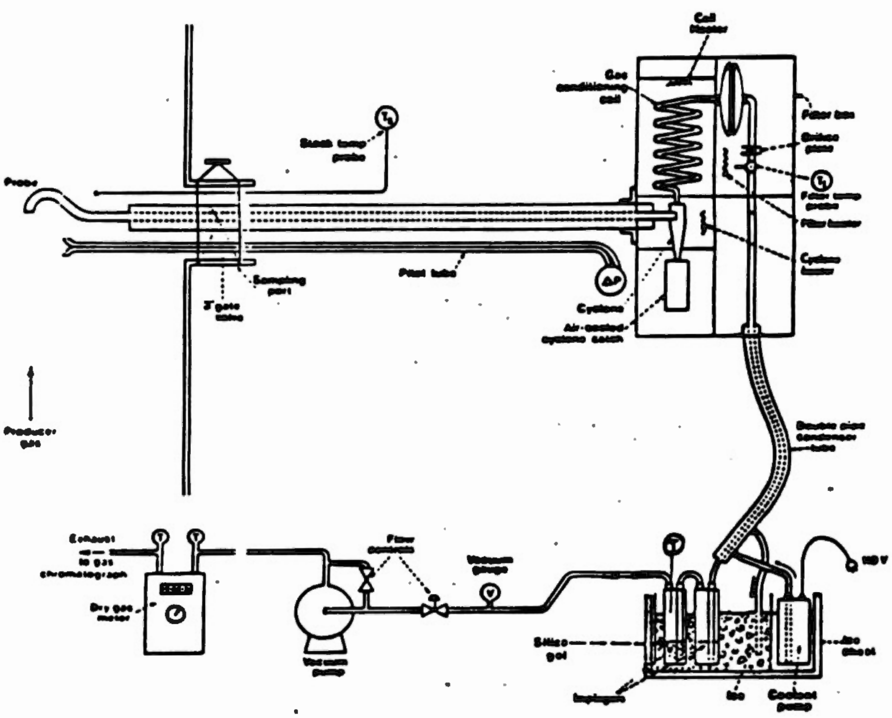
Run Detail **Date:** June 2, 1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-coil-filter-condenser tube-condenser bottles-silica gel-pump-control unit.

GASIFIER SAMPLING TRAIN



Observations, Conclusions: Acceptable leak rate of .05 cfm was attained. Removing the cyclone from the train resulted in an unrestricted sample flow. The filter retained the oversized particulates along with the fine particulates.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 2, 1982

(Continued)

3. Sample Recovery

General Procedure: The sample train components were flushed and rinsed with acetone as in Run 1.

Sample Identification

#1	Nozzle-probe wash
#2	None
#3	Coil-filter wash
#4	Filter
#6	Condenser tube-bottles wash
#7	Condensate

Special

Collected Sample Weights:

Cyclone, g:	-
Filter, g:	1.927
Impinger #1, g:	214.4
#2, g:	-
#3, g:	-
Silica Gel, 4, g:	21.4
Total Impinger Weight Gain, g:	245.8

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 2, 1982

(Continued)

3. Sample Recovery (con't)

Observations, Conclusions: Despite use of a condenser tube and a circulated cooling bath assembly including a condenser bottle containing 100 cc water, tars are still being deposited in the silica gel impinger.

4. Analytical

Observations, Conclusions:

BIOMASS GASIFICATION SAMPLING SUMMARY

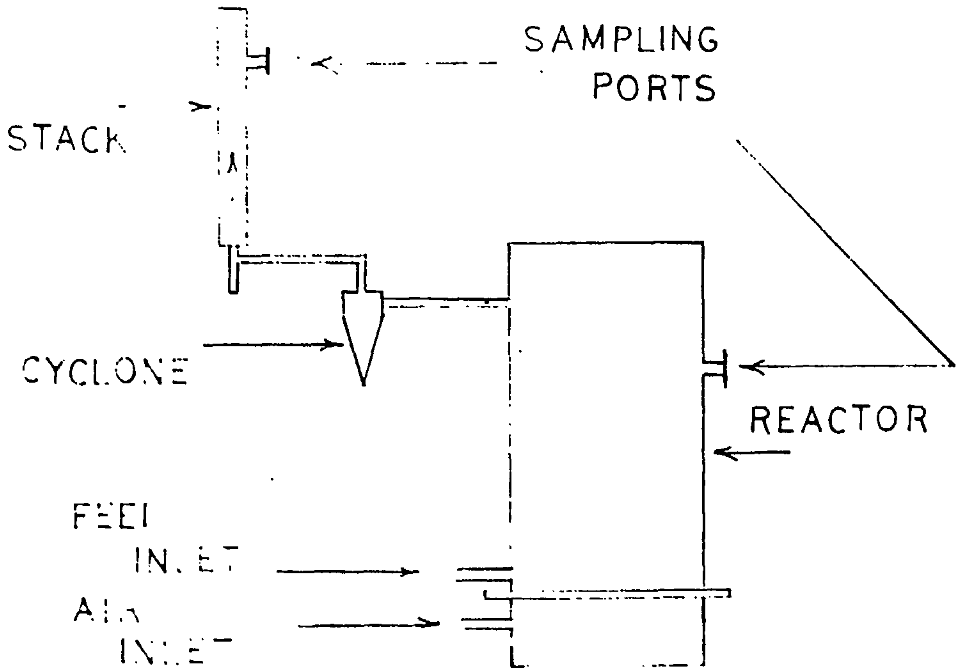
Run Identification

Run Number: 5

Date: June 3, 1982

Location: B.C. Research Fluidized Bed Gasifier Discharge Stack

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** June 3, 1982

Purpose of Run: To obtain a large cyclone sample and to operate sampling train at a higher sampling rate than in previous four runs. To collect additional samples for chemical methodology.

Gasifier Operating Performance: Good.

Sampling Problems Encountered: Faulty stack temperature thermocouple and condenser tube-filter connection.

Sampling Train Changes Required: Replace the polypropylene condenser tube - Insert with a stainless steel tube and swagelok assembly. Replace the old orifice plate (multiple weld leaks).

Sampling Train Improvements: Addition of third impinger to prevent tar carryover to silica gel impinger.

Observations, Conclusions: The sampling train can be operated effectively at high sampling rates.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 3, 1982

1. Gasifier

Operators:	Dr. Cedric Briens
	Duncan Morgan
Start-Up Time:	0440
Shut-Down Time:	1350
Feed Type:	Alderwood Sawdust
Feed Moisture Content, %:	38.3
Total Feed Consumed, lb:	660
Feed Rate, lb/hr:*	145.2
Bed Material(s):	Gravel, sand
Bed Depth, Inches:	24
Bed Temperature, °C	746
Upper Bed "	760
Above Bed "	746
Gasif. Top "	651
Gasif. Exit "	570
Sampling Location "	Est. 285
Reactor Static Pressure, Inches H_2O:	Estimated +.20
Air Inflow Rate CFM:	68
Producer Gas Characteristics, High Temp/ /Low Tar, Low Temp/ /High Tar:	Low Temp/High Tar
Ambient Weather Conditions,	
Temperature, °C:	16
Pressure, Inches H_g:	30.04
Humidity, %:	63
Wind:	220 @ 11 KTS
Cloud Cover:	5/10
Precipitation:	0

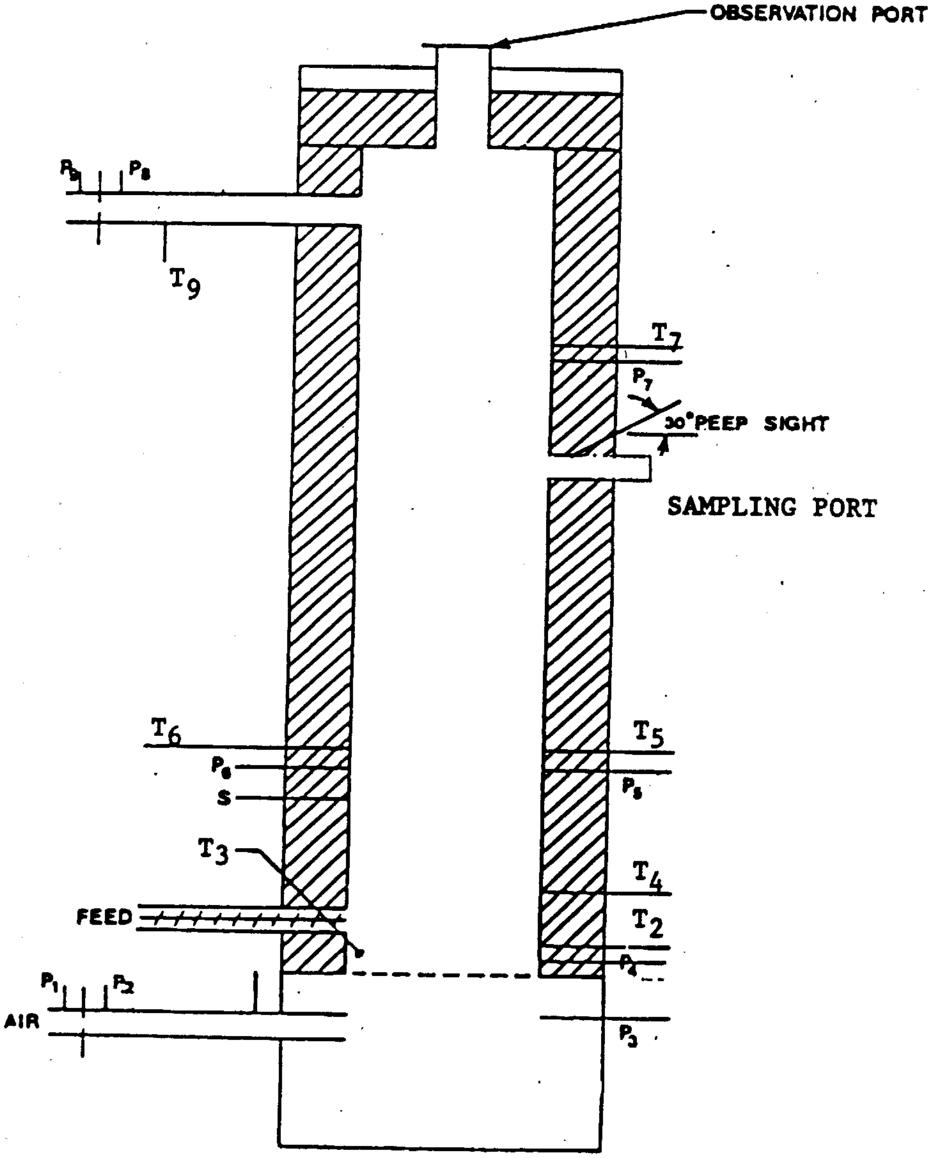
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 3, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 3, 1982

(Continued)

2. Sampling

Operators:	Merv Aiken Lloyd Philips
Train Preheat Time, Minutes:	15
Sampling Period, Start:	1005
Sampling Period, Finish:	1045
Total Sampling Time, Min:	40
Average Temperatures, °C	
Stack:	Est. 285
Probe:	303
Cyclone: (aerotherm)	246
Coil:	Not in use
Filter:	246
Orifice Plate: (aerotherm)	16
Impinger Outlet:	16
Dry Gas Meter Inlet:	23
Dry Gas Meter Outlet:	19
Nozzle Diameter, Inches:	.50
Orifice Diameter, Inches:	.281
Average Sampling Rate, SCFM	1.74
Total Sampling Volume, SCF:	68.4
Maximum Pump Vacuum, Inches H_g:	8.0
Average Stack Velocity, Inches H_2O:	Estimated .0004
Stack Static Pressure, Inches H_2O:	Estimated +.20
Stack Exit Flow Rate, SCFM:	Estimated 68
Stack Exit Flow Rate, SCFM:	Estimated 69
Flow Rate Determination Method:	Estimation

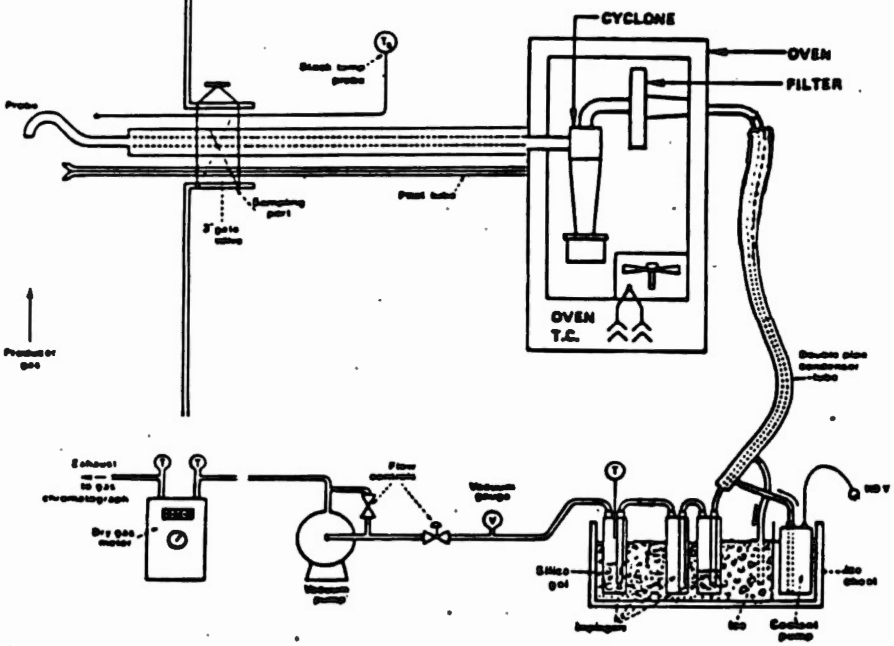
BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 3, 1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-cyclone (aerotherm)-filter-condenser tube-impingers-silica gel-pump-orifice plate-control unit. The aerotherm cyclone and oven were substituted in Run 5 while a new orifice plate assembly was being assembled and the cyclone entrance was being enlarged.



Observations, Conclusions: The teflon sample line separated from the filter at the end of the run. This resulted in cancellation of the post test leak check. The stack temperature thermocouple did not operate for the second time (short in plug wires).

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 3, 1982

(Continued)

3. Sample Recovery

General Procedure: Standard clean-up of the train with acetone was performed. A separate cyclone sample was taken for separate analysis.

Sample Identification	
#1	Probe-nozzle wash
#2	Cyclone wash
#3	Filter wash
#4	Filter
#6	Condenser tube-impingers wash
#7	Condensate
Special	Cyclone catch
Collected Sample Weights:	
Cyclone, g:	11.9
Filter, g:	.593
Impinger #1, g:	518.2
#2, g:	27.0
#3, g:	-
Silica Gel, 4, g:	40.2
Total Impinger Weight Gain, g:	585.4

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 3, 1982

(Continued)

3. Sample Recovery (con't)

Observations, Conclusions: Still getting tar carryover to silica gel impinger despite additional empty impinger. In Run #5, the first impinger contained an initial 100 ml of distilled water.

4. Analytical

Observations, Conclusions:

BIOMASS GASIFICATION SAMPLING SUMMARY

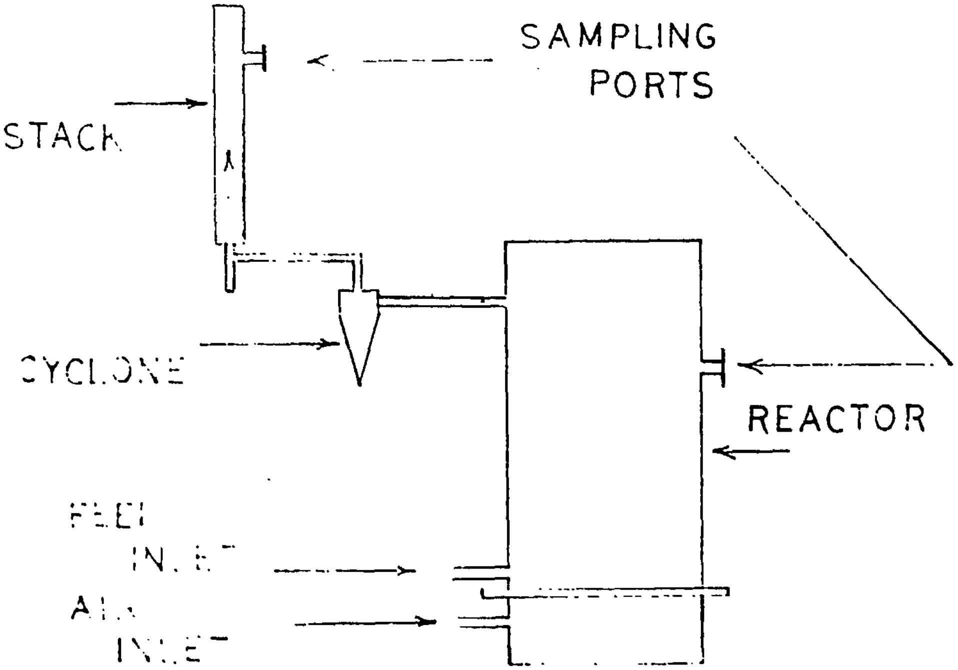
Run Identification

Run Number: 6

Date: June 8, 1982

Location: B.C. Research Fluidized Bed Gasifier Reactor

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** June 8, 1982

Purpose of Run: To test sampler at the elevated temperature conditions found inside the gasifier reactor. To test gate-valve-spool sampling port.

Gasifier Operating Performance: Fair. It took several additional hours to achieve consistant bed temperatures.

Sampling Problems Encountered: Sampler stand height had to be adjusted to gain entry to the gasifier. Air leak developed in cyclone collection cup connection (weld-joint). Temperature controllers still not adjusted correctly.

Sampling Train Changes Required: Add thermocouple port in new orifice plate. Repair cyclone air leak and leak check entire system. Calibrate temperature controllers. Construct probe port seal.

Sampling Train Improvements: New orifice plate assembly.

Observations, Conclusions: The sampling probe and complete train functioned effectively in the high temperature atmosphere of the gasifier reactor.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 8, 1982

1. Gasifier

Operators: Dr. Cedric Briens
Duncan Morgan

Start-Up Time: 0455
Shut-Down Time: 1300
Feed Type: Alderwood Sawdust
Feed Moisture Content, %: 38.3
Total Feed Consumed, lb: 968
Feed Rate, lb/hr:* 145.2
Bed Material(s): Gravel, sand
Bed Depth, Inches: 24
Bed Temperature, °C 723
Upper Bed " 740
Above Bed " 721
Gasif. Top " 602
Gasif. Exit " 569
Sampling Location " 636
Reactor Static Pressure, Inches H_2O: Estimated +.10
Air Inflow Rate CFM: 73
Producer Gas Characteristics, High Temp//Low Tar, Low Temp//High Tar: High Temp/Low Tar

Ambient Weather Conditions,
Temperature, °C: 15
Pressure, Inches H_g: 30.26
Humidity, %: 72
Wind: 140 @ 8 KTS
Cloud Cover: 10/10 (overcast)
Precipitation: 0

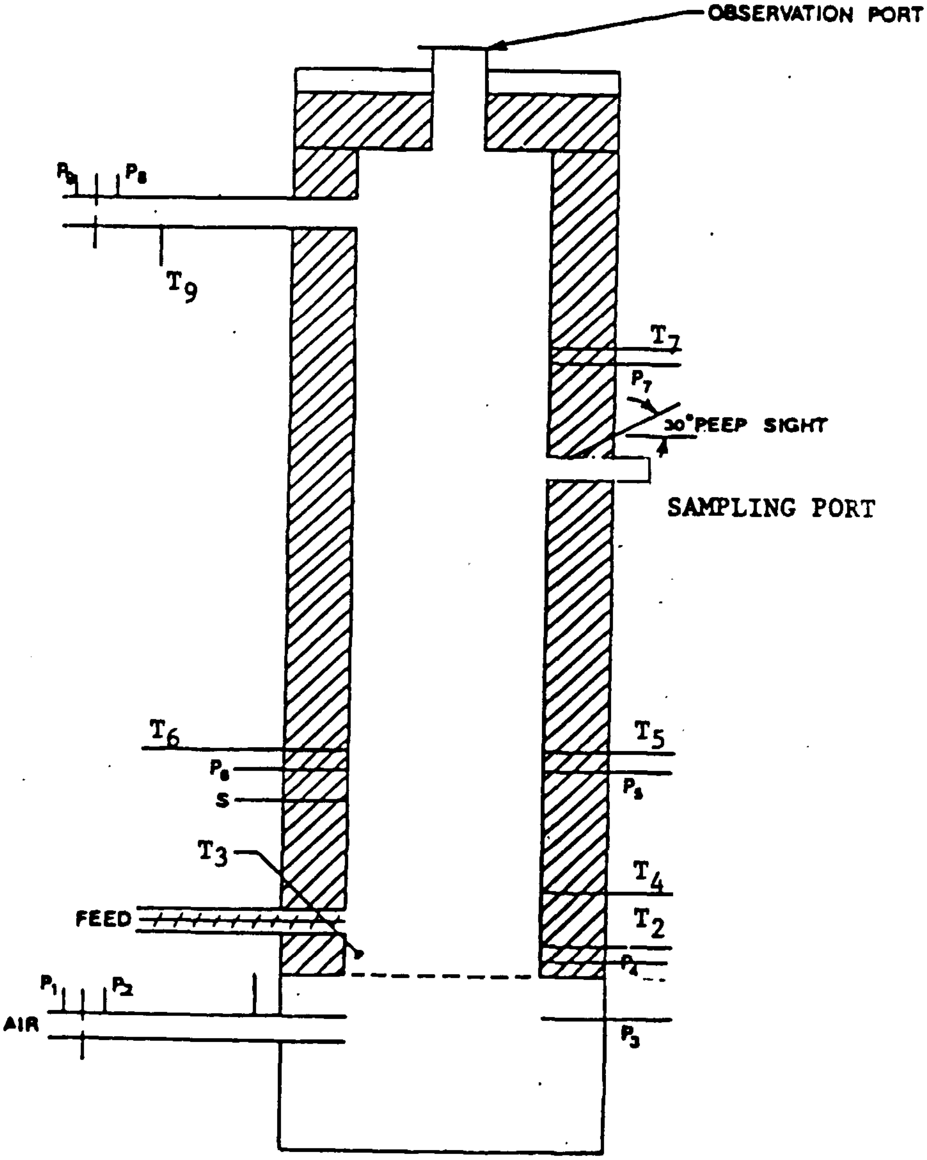
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 8, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail Date: June 8, 1982

(Continued)

2. Sampling

Operators:	Merv Aiken Lloyd Philips
Train Preheat Time, Minutes:	15
Sampling Period, Start:	1205
Sampling Period, Finish:	1250
Total Sampling Time, Min:	45
Average Temperatures, °C	
Stack:	636
Probe:	408
Cyclone:	182
Coil:	Estimated +200
Filter:	245
Orifice Plate:	Estimated 245
Impinger Outlet:	5
Dry Gas Meter Inlet:	23
Dry Gas Meter Outlet:	23
Nozzle Diameter, Inches:	.50
Orifice Diameter, Inches:	.281
Average Sampling Rate, SCFM	.59
Total Sampling Volume, SCF:	28.2
Maximum Pump Vacuum, Inches H_g:	12.0
Average Stack Velocity, Inches H_2O:	Estimated .0004
Stack Static Pressure, Inches H_2O:	Estimated +.10
Stack Exit Flow Rate, SCFM	Estimated 68
Stack Exit Flow Rate, SCFM:	Estimated 69
Flow Rate Determination Method:	Estimation

BIOMASS GASIFICATION SAMPLING SUMMARY

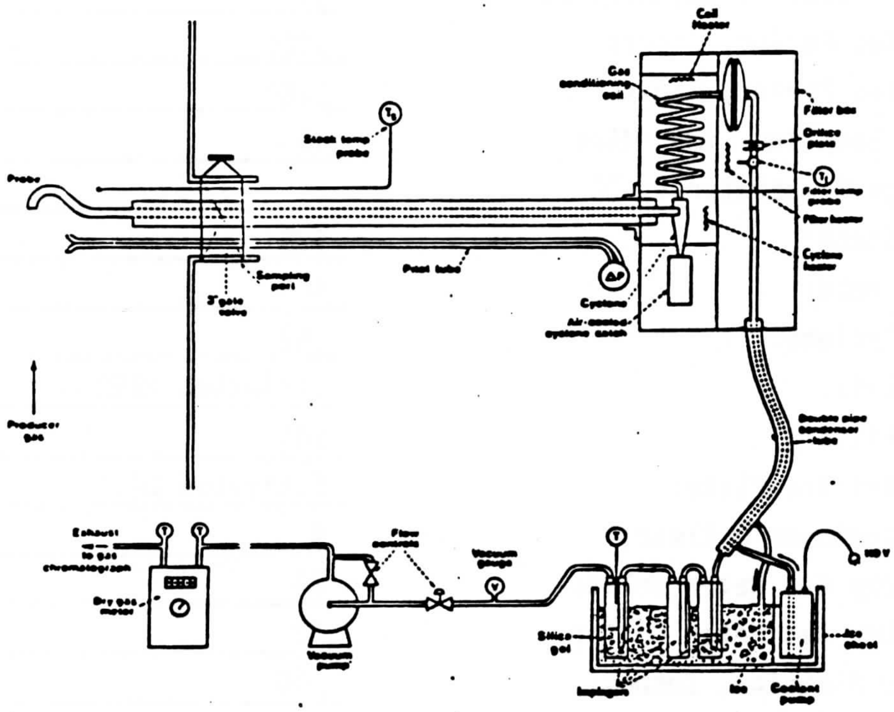
Run Detail **Date:** June 8, 1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-cyclone-coil-filter-orifice plate-condenser tube-impingers-silica gel-pump-control unit.

GASIFIER SAMPLING TRAIN



Observations, Conclusions: Gas temperatures in the filter and orifice are still not close to 200°C. The last major problem is consistant temperature calibration.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 8, 1982

(Continued)

3. Sample Recovery

General Procedure: The individual train components were flushed and rinsed with acetone after the filter and condensate samples were removed. The coil and condenser tube were flushed using acetone and a peristaltic circulating pump.

Sample Identification

#1	Nozzle-probe wash
#2	Cyclone wash
#3	Coil-filter wash
#4	Filter
#6	Cond. tube-impinger-orifice wash
#7	Condensate

Special

Collected Sample Weights:	
Cyclone, g:	-
Filter, g:	.366
Impinger #1, g:	176.9
#2, g:	1.5
#3, g:	-
Silica Gel, 4, g:	15.3
Total Impinger Weight Gain, g:	193.7

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 8, 1982

(Continued)

3. Sample Recovery (con't)

Observations, Conclusions: In Run #6, the first impinger contained an initial 100 ml of distilled water.

4. Analytical

Observations, Conclusions:

BIOMASS GASIFICATION SAMPLING SUMMARY

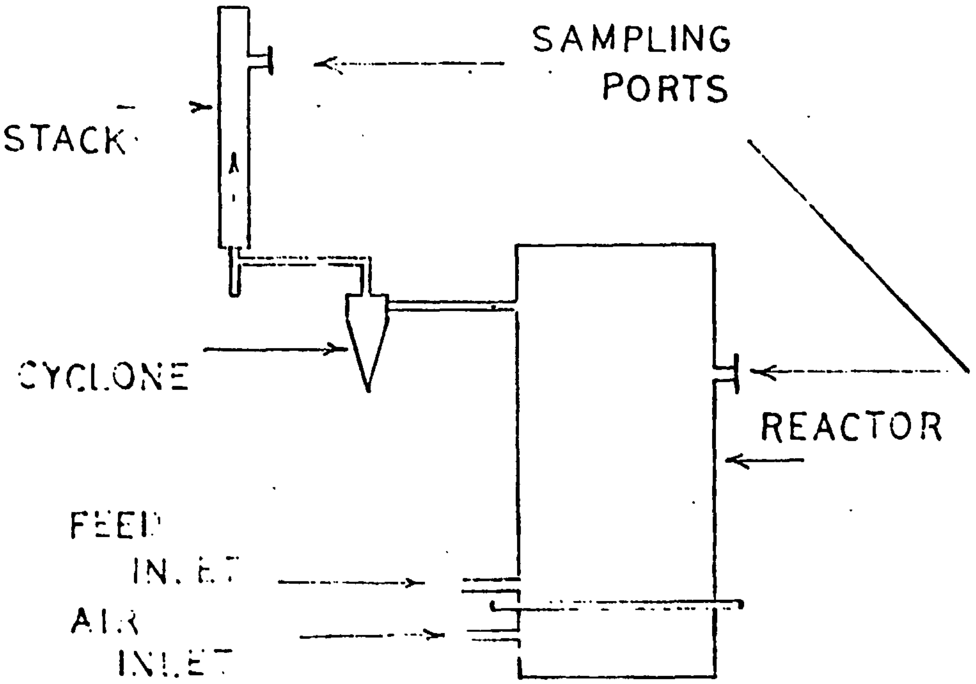
Run Identification

Run Number: 7

Date: June 22, 1982

Location: B.C. Research Fluidized Bed Gasifier Reactor

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** June 22, 1982

Purpose of Run: To test train repairs and probe-port seal.

Gasifier Operating Performance: Good.

Sampling Problems Encountered: Temperature controllers did not operate correctly. Insufficient system preheat (cyclone, coil) due to loss of power resulted in premature fallout of tars. Traces of tar still carried over to silica gel impinger despite addition of second water impinger.

Sampling Train Changes Required: Add a larger cyclone catch to the cyclone. Remove temperature controllers from sample box interior to exterior. Replace faulty controller component (filter heater) and recalibrate.

Sampling Train Improvements: Addition of a shaft seal to the new sampling pump reduced the pump leak from .06 to <.02 cfm.

Observations, Conclusions: The necessity of sufficient system preheat to prevent premature condensation of tars was emphasized by the large amounts of material found in the components located ahead of the filter.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 22, 1982

1. Gasifier

Operators: Duncan Morgan

Start-Up Time: 0740

Shut-Down Time: 1130

Feed Type: Alderwood Sawdust

Feed Moisture Content, %: 38.3

Total Feed Consumed, lb: 330

Feed Rate, lb/hr:* 145.2

Bed Material(s): Gravel, sand

Bed Depth, Inches: 24

Bed Temperature, °C 720

Upper Bed " 723

Above Bed " 688

Gasif. Top " 513

Gasif. Exit " 468

Sampling Location " 538

Reactor Static Pressure, Inches H_2O: Estimated +.10

Air Inflow Rate CFM: 65

Producer Gas Characteristics, High Temp//Low Tar, Low Temp//High Tar: High Temp/Low Tar

Ambient Weather Conditions,

Temperature, °C: 18

Pressure, Inches H_g: 30.05

Humidity, %: 68

Wind: 80 @ 7 KTS

Cloud Cover: 2/10

Precipitation: 0

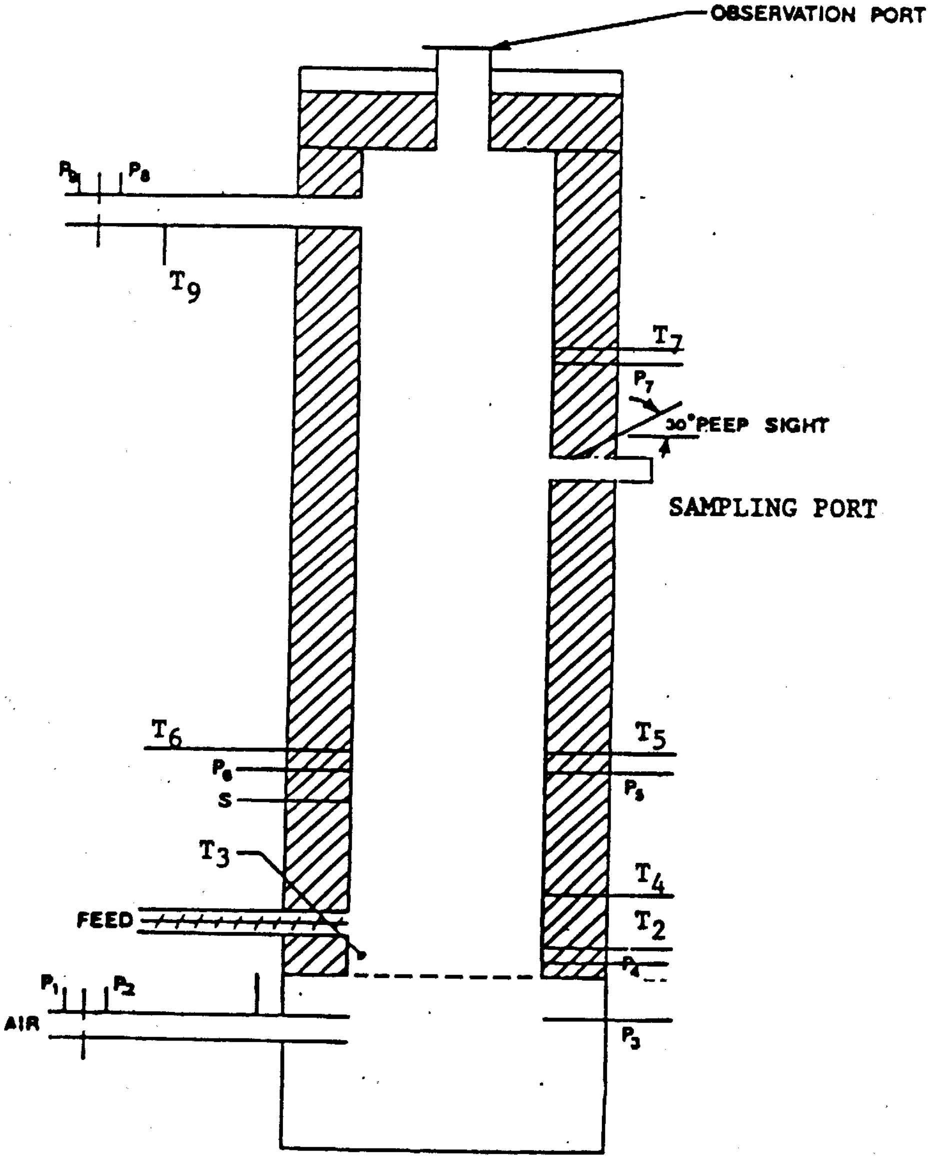
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 22, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail

Date: June 22, 1982

(Continued)

2. Sampling

Operators: Merv Aiken
Lloyd Philips

Train Preheat Time, Minutes: 5
Sampling Period, Start: 1000
Sampling Period, Finish: 1112
Total Sampling Time, Min: 72
Average Temperatures, °C
Stack: 538
Probe: 401
Cyclone: Estimated 160
Coil: Estimated 200
Filter: 137
Orifice Plate: 137
Impinger Outlet: 9
Dry Gas Meter Inlet: 22
Dry Gas Meter Outlet: 22
Nozzle Diameter, Inches: .50
Orifice Diameter, Inches: .281
Average Sampling Rate, SCFM .58
Total Sampling Volume, SCF: 42.9
Maximum Pump Vacuum, Inches H_g: 9.0
Average Stack Velocity, Inches H_2O: Estimated .0004
Stack Static Pressure, Inches H_2O: Estimated +.10
Stack Exit Flow Rate, SCFM: Estimated 65
Stack Exit Flow Rate, SCFM: Estimated 71
Flow Rate Determination Method: Estimation

BIOMASS GASIFICATION SAMPLING SUMMARY

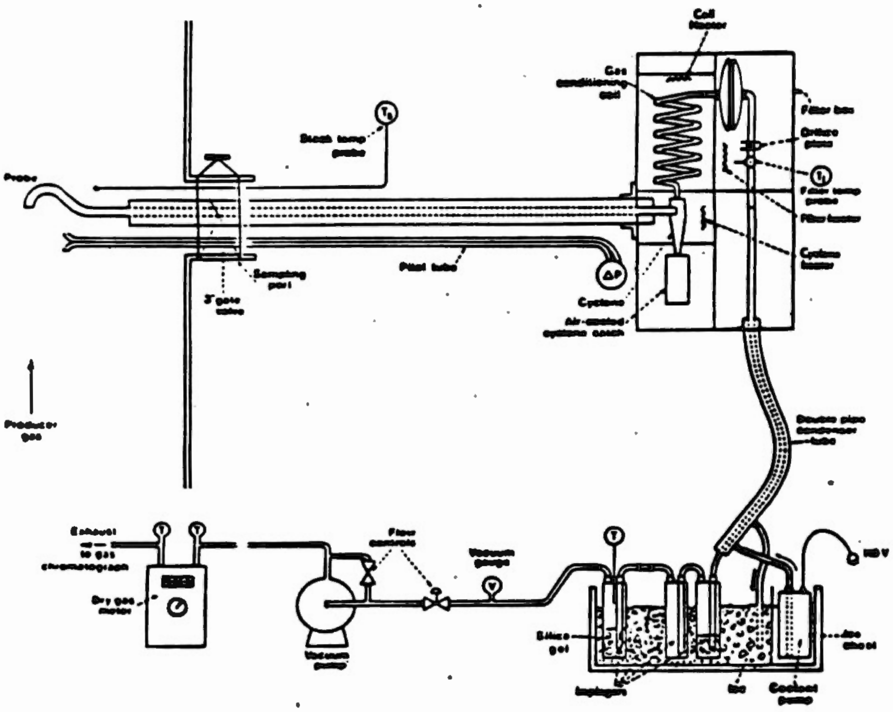
Run Detail **Date:** June 22, 1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-cyclone-coil-filter-cond. tube-impingers-silica gel pump-control unit.

GASIFIER SAMPLING TRAIN



Observations, Conclusions: The cyclone heater was initially inoperative due to a faulty plug connection. The coil heater was initially inoperative due to a disconnected electrical cord. A blown triac in the filter heater temperature controller resulted in the heater remaining on throughout the latter period of the run.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 22, 1982

(Continued)

3. Sample Recovery

General Procedure: The same procedure used in Run 6 was used.

Sample Identification	
#1	Nozzle-probe wash
#2	Cyclone wash
#3	Coil-filter wash
#4	Filter
#6	Cond. tube-impinger-orifice wash
#7	Condensate
Special	Cyclone catch
Collected Sample Weights:	
Cyclone, g:	7.3
Filter, g:	6.341
Impinger #1, g:	324.3
#2, g:	2.2
#3, g:	-
Silica Gel, 4, g:	35.9
Total Impinger Weight Gain, g:	302.4

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 22, 1982

(Continued)

3. Sample Recovery (con't)

Observations, Conclusions: 200 ml of distilled water was added to the first two impingers of the impinger assembly.

4. Analytical

Observations, Conclusions:

BIOMASS GASIFICATION SAMPLING SUMMARY

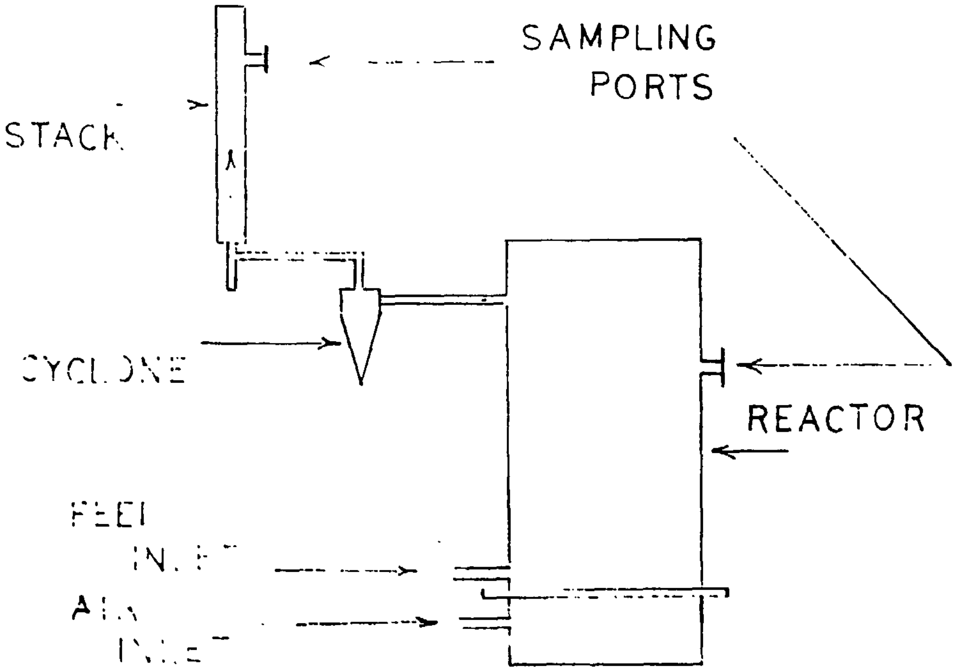
Run Identification

Run Number: 8

Date: June 29, 1982

Location: B.C. Research Fluidized Bed Gasifier Reactor

Sampling Site Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Summary **Date:** June 29, 1982

Purpose of Run: Final sampling run to test temperature controller system and to evaluate entire train.

Gasifier Operating Performance: Good after initial ignition problems.

Sampling Problems Encountered: Slight tar carryover to silica gel impinger despite addition of glass wool to 3rd impinger.

Sampling Train Changes Required: Addition of granular activated charcoal and glass wool to impinger #3 to pick up traces of carryover tar from condenser tube and first 2 impingers.

Sampling Train Improvements: Temperature controllers heat sink.

Observations, Conclusions: The entire sampling train is now ready for extensive use.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 29, 1982

1. Gasifier

Operators:	Duncan Morgan
Start-Up Time:	0720
Shut-Down Time:	1105
Feed Type:	Alderwood Sawdust
Feed Moisture Content, %:	38.3
Total Feed Consumed, lb:	352
Feed Rate, lb/hr: *	145.2
Bed Material(s):	Gravel, sand
Bed Depth, Inches:	24
Bed Temperature, °C (T2&T3)	785
Upper Bed " (T4)	803
Above Bed " (T5&T6)	756
Gasif. Top " (T7)	602
Gasif. Exit "	564
Sampling Location "	601
Reactor Static Pressure, Inches H_2O:	Estimated +.10
Air Inflow Rate CFM:	78
Producer Gas Characteristics, High Temp/ /Low Tar, Low Temp/ /High Tar :	High Temp/Low Tar
Ambient Weather Conditions,	
Temperature, °C:	21
Pressure, Inches H_g:	29.78
Humidity, %:	64
Wind:	150 @ 2 KTS
Cloud Cover:	5/10
Precipitation:	0

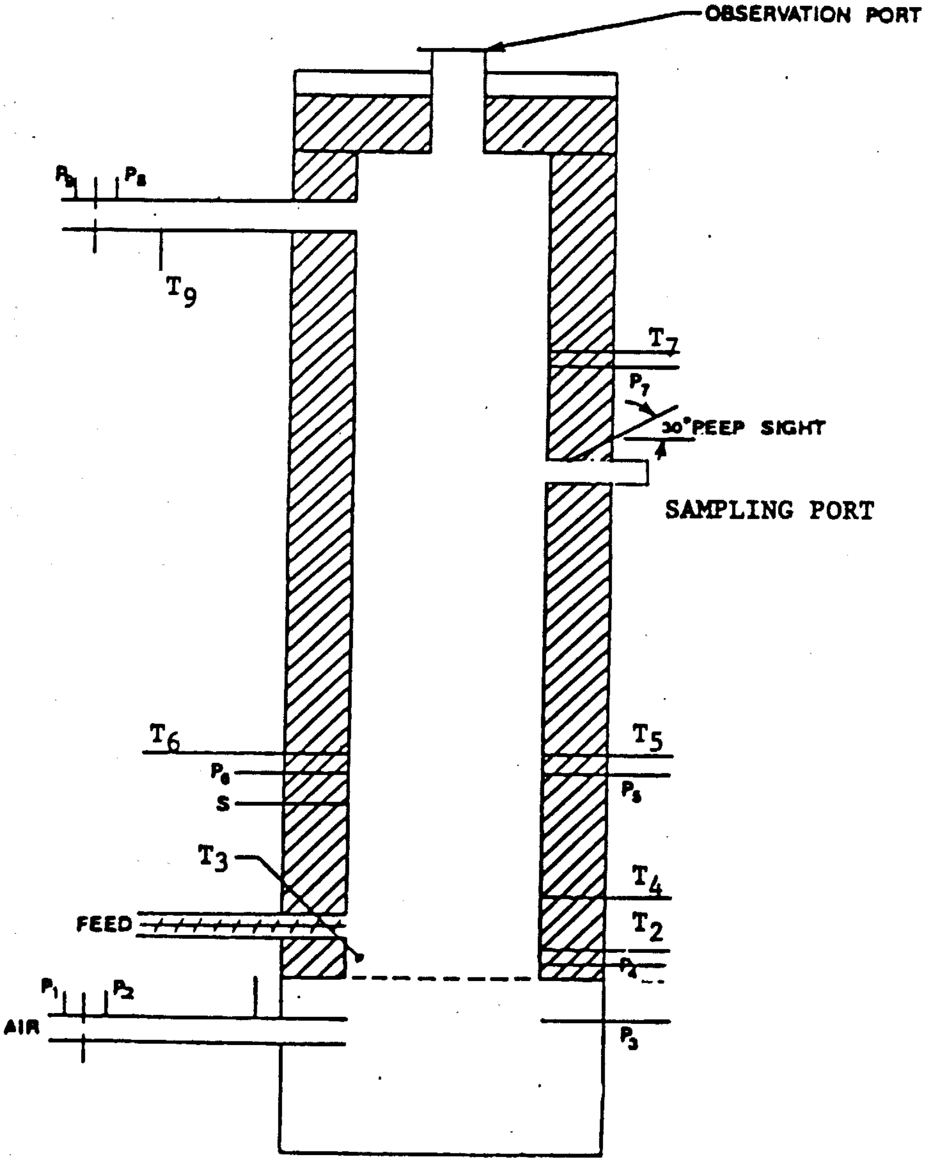
* During sampling period.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 29, 1982

(Continued)

Gasifier Sketch:



BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 29, 1982

(Continued)

2. Sampling

Operators:	Merv Aiken
	Lloyd Philips
Train Preheat Time, Minutes:	20
Sampling Period, Start:	1035
Sampling Period, Finish:	1104
Total Sampling Time, Min:	29
Average Temperatures, °C	
Stack:	601
Probe:	371
Cyclone:	215
Coil:	200
Filter:	203
Orifice Plate:	203
Impinger Outlet:	8
Dry Gas Meter Inlet:	25
Dry Gas Meter Outlet:	24
Nozzle Diameter, Inches:	.50
Orifice Diameter, Inches:	.281
Average Sampling Rate, SCFM	.90
Total Sampling Volume, SCF:	25.3
Maximum Pump Vacuum, Inches H_g:	12.0
Average Stack Velocity, Inches H_2O:	Estimated .0004
Stack Static Pressure, Inches H_2O:	Estimated +.10
Stack Exit Flow Rate, SCFM:	Estimated 78
Stack Exit Flow Rate, SCFM:	Estimated 75
Flow Rate Determination Method:	Estimation

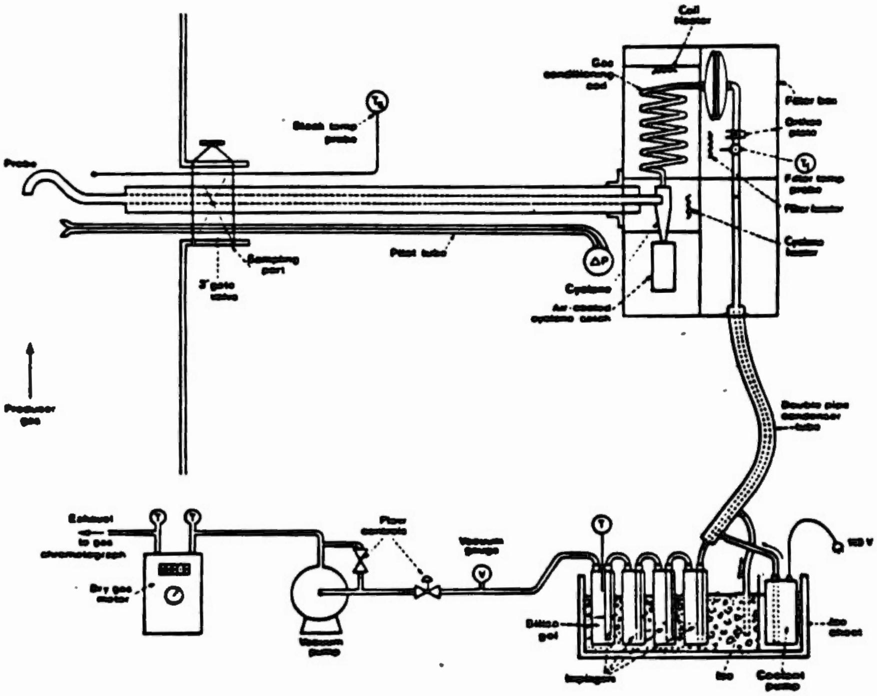
BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 29, 1982

(Continued)

2. Sampling (con't)

Train Configuration: Nozzle-probe-cyclone-coil-filter-orifice-condenser tube-impinger train-pump-control unit.



Observations, Conclusions: The leak rate for the entire train was .03 cfm (.1%). With adequate train preheat, little fallout of tars was noticed in the cyclone, coil and on the filter. A sudden pump vacuum build-up near the end of the run was apparently caused by either build-up of dry material in the probe or tar build-up on the filter.

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 29, 1982

(Continued)

3. Sample Recovery

General Procedure: The same cleanup procedure used in Run 6 and 7 was used.

Sample Identification	
#1	Nozzle-probe wash
#2	Cyclone wash
#3	Coil-filter wash
#4	Filter
#6	Cond. tube-impinger-orifice wash
#7	Condensate
Special	
Collected Sample Weights:	
Cyclone, g:	3.2
Filter, g:	.274
Impinger #1, g:	105.7
#2, g:	1.4
#3, g:	.2
Silica Gel, 4, g:	14.1
Total Impinger Weight Gain, g:	131.4

BIOMASS GASIFICATION SAMPLING SUMMARY

Run Detail **Date:** June 29, 1982

(Continued)

3. Sample Recovery (con't)

Observations, ~~Conclusions~~: The glass wool in impinger #3 collected tars that passed through the first two impingers. The filter contained a thin layer of heavy tarry residue.

4. Analytical

Observations, Conclusions:

APPENDIX B

DAILY SAMPLING LOG SHEETS

STACK TESTING LOG SHEET

DATE: 5/26/82
PROCESS: B.C. Research Gasifier
PORT LOCATION: Disch. Stack
OPERATORS: M. Aiken, L. Philips
RUN NO.: 1
ORIFICE: .187 "DIA., ΔH @ 1.88
NOZZLE: .75 "DIA., .00307 FT^2 AREA
FILTER WT. AFTER ______ g
PF51 **BEFORE** 1.1366 g
RESIDUE WEIGHT ______ g
BAROMETRIC PRESSURE (P_B) 29.85 "Hg
STATIC PRESSURE (Ps) Est.+.20 "H_2O +.01 "Hg

STACK DIAMETER 1.0 FT, .785 FT^2 AREA

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	______ g	______ g	______ g
#1 IMPINGER (0 H_2O)	1718.6 g	1642.3 g	76.3 g
#2 IMPINGER	______ g	______ g	______ g
#3 IMPINGER	______ g	______ g	______ g
SILICA GEL IMPINGER	1073.3 g	1061.3 g	12.0 g

TOTAL IMPINGER GAIN 88.3 g

LEAK TEST PRE-TEST ______ FT^3
0.K. FT^3
______ FT^3

POST-TEST 863.180 FT^3
863.100 FT^3
0.080 FT^3

TEST DATA SECTION

POINT		CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER		COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H_2O	ORIFICE ΔH "H_2O	DRY GAS METER READING FT^3	PUMP VACUUM "Hg
NO.	DIST. "							INLET °F	OUTLET °F								
-	-	1435	--	--	--	--	--	--	--					----	----	847.810	----
1	MID	1440	N.O.	557	61	194	294	84	81	✓	✓	✓	✓	est.0004	.50	-	0
2		45		553	60	261	321	83	82							-	
3		50		552	63	282	332	83	82							-	
4		55		551	65	315	343	84	82							-	
5		1500		-	-	-	-	-	-							-	
6		05		-	-	-	-	-	-							-	
7		10		557	61	289	316	85	83							-	
8		15		-	-	-	-	-	-							-	↓
9	↓	1520	↓	553	64	314	295	82	83						↓	862.940	3.8
10																	
11																	
12																	
13																	
14		No gas samples taken.															
15		Repair T5 thermo.															
16		Need another blower.															
17																	
18																	
		45	°F	--	62.3°F	276°F	317°F	83.5°F	82.2°F	----	----	----	----	----	.50	15.130	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT^3	----
		---	°R	--	---	---	---	AVERAGE	82.8 °F	----	----	----	----	----	---	---	----
		---	°C	--	---	136°C	159°C		543 °R	----	----	----	----	----	---	---	----

STACK TESTING LOG SHEET

DATE: 5/28/82
PROCESS: B.C. Research Gasifier
PORT LOCATION: Disch Stack
OPERATORS: Aiken, Philips
RUN NO.: 2
ORIFICE: .187 "DIA., ΔH @ 1.88
NOZZLE: .50 "DIA., .00136 FT^2 AREA
FILTER WT. AFTER ______ g
PF 52 **BEFORE** 1.1353 g
RESIDUE WEIGHT ______ g
BAROMETRIC PRESSURE (P_B) 30.11 "Hg
STATIC PRESSURE (Ps) est +.20 "H_2O +.01 "Hg

STACK DIAMETER 1.0 FT, .785 FT^2 AREA

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	______ g	______ g	______ g
#1 IMPINGER (250 cc H_2O)	1184.6 g	1160.6 g	24.0 g
#2 IMPINGER	______ g	______ g	______ g
#3 IMPINGER	______ g	______ g	______ g
SILICA GEL IMPINGER	1161.1 g	1144.1 g	17.0 g

TOTAL IMPINGER GAIN 41.0 g

LEAK TEST PRE-TEST ______ FT^3
0.K. FT^3
______ FT^3

POST-TEST 880.881 FT^3
880.825 FT^3
.056 FT^3

TEST DATA SECTION

POINT		CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER		COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H_2O	ORIFICE ΔH "H_2O	DRY GAS METER READING FT^3	PUMP VACUUM "Hg
NO.	DIST. "							INLET °F	OUTLET °F								
-	-	1342	--	--	--	--	--	--	--					----	----	863.802	----
1	MID	1347	290	588	72	289	315	94	91	✓	✓	✓	✓	est.0004	1.00	865.4	0
2		52	287	581	79	311	320	94	92							866.9	0
3		57	283	580	76	330	327	94	92							868.9	0
4		1402	278	584	74	349	334	94	92							870.4	.5
5		07	289	582	75	357	338	94	93							872.3	3.5
6		12	278	581	73	362	337	94	93							874.4	6.5
7		17	283	583	61	365	340	94	93							875.2	7.0
8		22	276	580	65	368	337	94	94							877.5	9.5
9		27	298	580	66	371	336	95	94							879.1	12.0
10	↓	1432	301	582	70	373	341	95	94						↓	880.725	12.0
11																	
12	Gas	samples															
13	#1	1401															
14	#2	1411															
15	#3	1421															
16	#4	1431															
17	Propane burner on																
18																	
		50.0	286 °F	--	71°F	347.5°F	333°F	94 °F	93 °F	----	----	----	----	----	1.00	16.923	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT^3	----
		---	746 °R	--	---	---	---	AVERAGE	93.5 °F	----	----	----	----	----	---	---	----
		---	141 °C	--	22°C	175°C	167°C		554 °R	----	----	----	----	----	---	---	----

STACK TESTING LOG SHEET

DATE: 6/1/82
PROCESS: B.C. Research Gasifier
PORT LOCATION: Disch. Stack
OPERATORS: Aiken, Philips
RUN NO.: 3
ORIFICE: .187 "DIA., ΔH @ 1.88
NOZZLE: .50 "DIA., .00136 FT² AREA
FILTER WT. AFTER ______ g
PF 53 BEFORE 1.1300 g
RESIDUE WEIGHT ______ g
BAROMETRIC PRESSURE (P_B) 30.02 "Hg
STATIC PRESSURE (Ps) est.+.20 "H_2O +.01 "Hg

STACK DIAMETER 1.0 FT, .785 FT² AREA

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	516.9 g	499.7 g	17.2 g
#1 IMPINGER (100 cc H_2O)	1659.9 g	1654.3 g	5.6 g
#2 IMPINGER	______ g	______ g	______ g
#3 IMPINGER	______ g	______ g	______ g
SILICA GEL IMPINGER	2025.4 g	1996.2 g	29.2 g

TOTAL IMPINGER GAIN 34.8 g

LEAK TEST PRE-TEST ______ FT³
O.K. FT³
______ FT³

POST-TEST 895.430 FT³
895.250 FT³
.180 FT³

TEST DATA SECTION

POINT NO.	POINT DIST. "	CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER INLET °F	DRY GAS METER OUTLET °F	COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H_2O	ORIFICE ΔH "H_2O	DRY GAS METER READING FT³	PUMP VACUUM "Hg
-	-	1100	--	--	--	--	--	--	--					----	----	881.162	----
1	MID															-	
2		1105	-	-	-	-	-	-	-	✓	✓	✓	✓	est.0004	1.0	-	13.5
3		10	382	151	53	292	287	61	58							884.2	
4		15	398	151	60	316	261	63	60							885.3	
5		20	-	-	-	-	-	-	-	-	-	-	-				
6		25	413	144	57	302	241	66	62							886.7	0
7		30	412	151	57	313	229	67	64							887.7	9.5
8		35	425	159	60	320	218	68	65							889.6	9.5
9		40	-	-	-	-	-	-	-	-	-	-	-			-	-
10		45	422	490	61	326	227	69	66							890.6	12.0
11		50	427	574	61	327	222	70	67							891.8	12.0
12		55	434	578	63	326	222	71	68							892.8	13.0
13		1200	444	581	64	326	225	72	69							893.8	13.0
14	↓	05	444	580	60	326	228	74	70					↓	↓	894.600	13.0
15	Gas samples																
16	#1	1125															
17	#2	1142															
18	#3	1200															
		65.0	420 °F	--	59.5°F	317°F	235°F	68.1 °F	64.9 °F	----	----	----	----	----		13.432	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT³	----
		---	880 °R	--	---	---	---	AVERAGE	66.5 °F	----	----	----	----	----	---	---	----
		---	216 °c	--	15°C	158°C	113°C		527 °R	----	----	----	----	----	---	---	----

Unsteady ΔH, cycle plug-up.

STACK TESTING LOG SHEET

DATE: 6/2/82
PROCESS: B.C. Research Gasifier
PORT LOCATION: Disch. Stack
OPERATORS: Aiken, Philips
RUN NO.: 4
ORIFICE: .187 "DIA., ΔH @ 1.88
NOZZLE: .50 "DIA., .00136 FT² AREA
FILTER WT. AFTER 3.0546 g
PF 54 BEFORE 1.1276 g
RESIDUE WEIGHT 1.9270 g
BAROMETRIC PRESSURE (P_B) 30.04 "Hg
STATIC PRESSURE (Ps) est.+.20"H_2O +.01 "Hg

STACK DIAMETER 1.0 FT, .785 FT² AREA

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	g	g	g
#1 IMPINGER (100 cc H_2O)	1868.0 g	1653.6 g	214.4 g
#2 IMPINGER	g	g	g
#3 IMPINGER	g	g	g
SILICA GEL IMPINGER	1946.5 g	1925.1 g	21.4 g

TOTAL IMPINGER GAIN 235.8 g

LEAK TEST PRE-TEST FT³
0.K. FT³
FT³
POST-TEST 922.403 FT³
922.360 FT³
0.043 FT³

TEST DATA SECTION

POINT		CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	(aero) ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER		COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H_2O	ORIFICE ΔH "H_2O	DRY GAS METER READING FT³	PUMP VACUUM "Hg
NO.	DIST. "							INLET °F	OUTLET °F								
-	-	1047	--	--	--	--	--	--	--					----	----	896.968	----
1	MID	1052	470	588	49	332	429	55	54	✓	✓	✓	✓	est.0004	1.0	899.5	0
2	↓	1057	494	580	49	353	426	55	54					↓	↓	902.5	↓
3		1102	-	-	-	-	-	-	-	-	-	-	-			-	
4		1107	531	583	52	382	447	57	56							908.1	
5		1112	541	578	52	387	485	58	56							911.0	
6		1117	543	577	52	388	493	58	57							913.7	
7		1122	550	577	52	304	470	58	57							916.5	
8		1127	561	580	53	260	463	59	58							919.4	
9		1132	559	587	54	240	458	60	59							922.235	
10																	
11																	
12																	
13	Gas Samples																
14	#1	1057															
15	#2	1112															
16	#3	1127															
17	Replaced orif. with pipe bypass (leak).																
18																	
		45	531 °F	--	51.6°F	331	459°F	57.5 °F	56.4 °F	----	----	----	----	----		25.267	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT³	----
		---	991 °R	--	---	---	---	AVERAGE	56.9 °F	----	----	----	----	----	---	---	----
		---	277 °C	307°C	11°C	166°C	237°C		517 °R	----	----	----	----	----	---	---	----

STACK TESTING LOG SHEET

DATE: 6/3/82
PROCESS: B.C.R. Gasifier
PORT LOCATION: Disch. Stk.
OPERATORS: Aiken, Philips
RUN NO.: 5
ORIFICE: .281 "DIA., ΔH @ .260
NOZZLE: .50 "DIA., .00136 FT^2 AREA
FILTER WT. AFTER 1.7213 g
PF55. BEFORE 1.1283 g
RESIDUE WEIGHT .5930 g
BAROMETRIC PRESSURE (P_B) 30.04 "Hg
STATIC PRESSURE (Ps) est.+.20 "H_2O +.01 "Hg

STACK DIAMETER 1.0 FT, .785 FT^2 AREA

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	1072.9 g	1061.0 g	11.9 g
#1 IMPINGER (100 cc H_2O)	2171.5 g	1653.3 g	518.2 g
#2 IMPINGER	1124.2 g	1097.2 g	27.0 g
#3 IMPINGER	g	g	g
SILICA GEL IMPINGER	2021.0 g	1980.8 g	40.2 g

TOTAL IMPINGER GAIN 585.4 g

LEAK TEST PRE-TEST ____ FT^3
0.K. FT^3
____ FT^3
POST-TEST ____ FT^3
NONE FT^3
____ FT^3

TEST DATA SECTION

POINT		CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER		COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H_2O	ORIFICE ΔH "H_2O	DRY GAS METER READING FT^3	PUMP VACUUM "Hg
NO.	DIST. "							INLET °F	OUTLET °F								
-	-	1005	--	--	--	--	--	--	--					----	----	922.697	----
1	MID	1010	N.O.	578	52	445	N.O.	67	62	(AERO. OVEN)			✓	est.0004	1.50	931.5	5.0
2		15		574	56	479		68	63							940.3	5.0
3		20		577	55	480		70	64							948.9	6.0
4		25		--	--	--		--	--	--	--					--	--
5		30		576	65	482		78	67							966.3	6.5
6		35		--	--	--		--	--	--	--					--	--
7		40		578	72	481		81	72							983.6	7.5
8	↓	45		577	69	482	↓	81	72						↓	992.180	8.0
9																	
10																	
11	Gas samples																
12	#1	1018															
13	2	1027															
14	3	1040															
15																	
16	Sample line break at end of run.																
17																	
18																	
		40.0	°F	--	61.5°F	475°F	475°F	74.2 °F	66.3 °F	----	----	----	----	----	1.50	69.483	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT^3	----
		---	°R	--	---	---	---	AVERAGE	70.3 °F	----	----	----	----	----	---	---	----
		---	°C	--	16°C	246°C	246°C		530 °R	----	----	----	----	----	---	---	----

STACK TESTING LOG SHEET

DATE: 6/8/82
PROCESS: B.C.R. Gasifier
PORT LOCATION: Reactor
OPERATORS: Aiken, Philips
RUN NO.: 6.
ORIFICE: .281 "DIA., ΔH @ .260
NOZZLE: .50 "DIA., .00136 FT^2 AREA
FILTER WT. AFTER 1.5015 g
BEFORE 1.1355 g
RESIDUE WEIGHT .3660 g
BAROMETRIC PRESSURE (P_B) 30.26 "Hg
STATIC PRESSURE (Ps) est.+.10 "H$_2$O +.01 "Hg

STACK DIAMETER 1.0 **FT,** .785 **FT^2 AREA**

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	- g	- g	- g
#1 IMPINGER	1831.2 g	1654.3 g	176.9 g
#2 IMPINGER	1098.7 g	1097.2 g	1.5 g
#3 IMPINGER	g	g	g
SILICA GEL IMPINGER	1471.0 g	1455.7 g	15.3 g

TOTAL IMPINGER GAIN 1937 g

LEAK TEST PRE-TEST FT^3
O.K. FT^3
FT^3

POST-TEST 23.132 FT^3
23.022 FT^3
.110 FT^3

TEST DATA SECTION

POINT		CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER		COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H$_2$O	ORIFICE ΔH "H$_2$O	DRY GAS METER READING FT^3	PUMP VACUUM "Hg
NO.	DIST. "							INLET °F	OUTLET °F								
-	-	1205	--	--	--	--	--	--	--					----	----	993.902	----
1	8.	1210	1129	762	44	N.O.	302	73	72	✓	✓	✓	✓	est.0004	.85	997.1	7.5
2		15	1148	761	42	--	332	73	72						1.15	1000.3	6.5
3		20	1161	760	41	--	354	73	72						1.15	1003.5	6.5
4		25	1171	763	40	(THERMO)	360	73	72						1.00	6.5	8.5
5		30	1181	769	40	(IN OVEN)	365	73	72							9.3	8.5
6		35	1185	768	40	465	369	74	73							---	---
7		40	1190	766	40	470	375	74	73							14.9	8.0
8		45	1194	772	41	473	377	75	74							17.6	10.0
9		50	1201	770	42	477	376	75	74							20.1	12.0
10	↓	55	1207	767	43	477	377	76	74					↓	↓	1022.802	8.0
11																	
12	Gas samples					oven over 200°C											
13	#1	12.22															
14	2	12.32															
15	3	12.42															
16																	
17	Reactor air shut off to put probe in.																
18																	
		50.0	1177 °F	--	41.3°F	472°F	359	73.9 °F	72.8°F	----	----	----	----	----	1.02	28.900	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT^3	----
		---	636 °R	--	---	---	---	AVERAGE	73.4 °F	----	----	----	----	----	---	---	----
		---	636 °C	--	5°C	245°C	182°C		534 °R	----	----	----	----	----	---	---	----

STACK TESTING LOG SHEET

DATE: 6/22/82
PROCESS: B.C.R. Gasifier
PORT LOCATION: Reactor
OPERATORS: Aiken, Philips
RUN NO.: 7
ORIFICE: .281 "DIA., ΔH @ .260
NOZZLE: .50 "DIA., .00136 FT^2 AREA
FILTER WT. AFTER ______ g
PF 58 BEFORE ______ g
RESIDUE WEIGHT 6.341 g
BAROMETRIC PRESSURE (P_B) 30.05 "Hg
STATIC PRESSURE (Ps) est.+.10 "H_2O +.01 "Hg

STACK DIAMETER 1.0 FT, .785 FT^2 AREA

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	776.5 g	769.2 g	7.3 g
#1 IMPINGER (100 cc H_2O)	1977.3 g	1653.0 g	(FULL) 324.3 g
#2 IMPINGER (100 cc H_2O)	1197.4 g	1195.2 g	2.2 g
#3 IMPINGER	______ g	______ g	______ g
SILICA GEL IMPINGER	1511.8 g	1475.9 g	35.9 g

TOTAL IMPINGER GAIN 362.4 g

LEAK TEST PRE-TEST ______ FT^3
0.K. FT^3
______ FT^3

POST-TEST 236.020 FT^3
236.000 FT^3
0.020 FT^3

TEST DATA SECTION

POINT NO.	POINT DIST. "	CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER INLET °F	DRY GAS METER OUTLET °F	COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H_2O	ORIFICE ΔH "H_2O	DRY GAS METER READING FT^3	PUMP VACUUM "Hg
-	-	1000	--	--	--	--	--	--	--					----	----	190.632	----
1		1005	921	748	41	168	est 200	72	72	✓	✓	✓	✓	est.0004	1.50	194.2	0
2		10	962	750	40	190		71	72							197.4	5.0
3		15	986	750	40	201		71	72							200.4	7.0
4		20	997	750	40	206		71	72							203.3	8.0
5		25	994	760	41	208	↓	71	71							206.2	8.0
6		30	1002	751	43	210	285	71	71							209.3	8.5
7		35	993	757	44	213	365	71	71							212.1	8.5
8		40	1008	753	46	207	363	71	72							215.2	9.0
9		45	POWER-OFF				--	--	--	--	--	--				--	--
10		50	1006	753	51	318	391	71	71							220.0	6.0
11		55	1013	752	56	379	429	71	71							223.2	3.0
12		1100	1020	760	58	399	365	71	71							226.4	2.0
13		05	1020	755	59	365	353	71	71							229.2	2.0
14		10	1037	755	62	426	443	71	71							231.8	1.0
15		1112	1033	751	65	400	459	72	71						↓	234.238	1.0
16																	
17	Power problems, controller breakdown (filter).																
18																	
		72	1000°F	--	49°F	278°F	318°F	71 °F	71 °F	----	----	----	----	----	1.50	43.606	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT^3	----
		---	1460°R	--		---	---	AVERAGE	71 °F	----	----	----	----	----	---	---	----
		---	538°C	--	9°C	137°C	161°C		531 °R	----	----	----	----	----	---	---	----

STACK TESTING LOG SHEET

DATE: 6/29/82

PROCESS: B.C. Research Gasifier

PORT LOCATION: Reactor

OPERATORS: Aiken, Philips

RUN NO.: 8

ORIFICE: .281 "DIA., ΔH @ .260

NOZZLE: .50 "DIA., .00136 FT^2 AREA

FILTER WT. AFTER 1.3912 g

PF 59 BEFORE 1.1172 g

RESIDUE WEIGHT .2740 g

BAROMETRIC PRESSURE (P_B) 29.78 "Hg

STATIC PRESSURE (Ps) est.+.10 "H_2O +.01 "Hg

STACK DIAMETER 1.0 FT, .785 FT^2 AREA

	FINAL WEIGHT	INITIAL WEIGHT	NET WEIGHT
CYCLONE	770.0 g	766.8 g	3.2 g
#1 IMPINGER (200 cc H_2O)	1918.5 g	1752.8 g	165.7 g
#2 IMPINGER (200 cc H_2O)	1298.1 g	1296.7 g	1.4 g
#3 IMPINGER (Glass wool)	1109.6 g	1109.4 g	.2 g
SILICA GEL IMPINGER	1551.7 g	1537.6 g	14.1 g

TOTAL IMPINGER GAIN 181.4 g

LEAK TEST PRE-TEST ____ FT^3

0.K. FT^3

____ FT^3

POST-TEST 262.111 FT^3

262.077 FT^3

0.034 FT^3

TEST DATA SECTION

POINT		CLOCK TIME (24 HRS)	STACK GAS TEMP. °F	PROBE TEMP. °F	IMP. OUTL. TEMP. °F	ORIFICE TEMP. °F	CYCLONE TEMP. °F	DRY GAS METER		COIL HEATER ON/OFF	FILTER HEATER ON/OFF	BLOWER ON/OFF	COOLANT PUMP ON/OFF	STACK VELOCITY HEAD ΔP "H_2O	ORIFICE ΔH "H_2O	DRY GAS METER READING FT^3	PUMP VACUUM "Hg
NO.	DIST. "							INLET °F	OUTLET °F								
-	-	1035	--	--	--	--	--	--	--					----	----	235.901	----
1		1040	1042	696	52	349	409	77	77	✓	✓	✓	✓	est.0004	1.00	240.9	2.5
2		5	1107	697	48	382	416	76	76							246.0	2.5
3		50	1124	704	48	402	418	77	76							250.9	2.0
4		55	1126	697	45	412	420	77	76							255.4	3.0
5		1100	1134	701	44	419	423	77	76							259.3	7.0
6		1104	1147	700	45	422	425	77	76						↓	261.910	12.0
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14	Vac. bukld-up at end of run.																
15																	
16																	
17																	
18																	
		29	1113°F	699°F		398°F	419°F	77 °F	76 °F	----	----	----	----	----		26.009	----
		MINUTES	AVERAGE	--	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	----	----	----	----	----	AVERAGE	TOTAL FT^3	----
		---	1573°R	--	---	---	---	AVERAGE	77 °F	----	----	----	----	----	---	---	----
		---	601 °C	371°C	8°C	203°C	215°C		537 °R	----	----	----	----	----	---	---	----

APPENDIX C

GAS CHROMATOGRAPHIC ALCOHOL ANALYSIS

APPENDIX

Gas Chromatographic Alcohol Analysis Procedure Used In the Kraft Pulping Process Condensate Study

Method:

Direct injection of condensate sample on a gas chromatographic column for determination of the concentration of alcoholic constituents.

Laboratory Equipment and Materials:

Gas chromatograph equipped with FID, temperature programming and dual column capability
Related chromatographic supplies
Appropriate glassware
Prepurified hydrogen, helium, and medical grade air
Redistilled methanol (standard)
Absolute or 95% ethanol (standard)

Procedure:

1. Prepare dual 0.2 mm I.D. x 1 m 6% FFAP on Porapak T (100-120 mesh) (column packing obtained from Analab) Preferably of pyrex glass construction
2. Condition the columns overnight at 170°C reached by temperature programming from ambient at 4°C per minute
3. Prepare methanol and ethanol (CH_3OH, F.W. = 32.04; C_2H_5OH, F.W. = 46.07) standards at appropriate concentrations (generally 1-2000 ppm). This was performed by adding 1 ml of the pure standard solution, by pipette, into a 1 liter volumetric flask partially filled with water and then bringing the total volume to 1 liter. The concentrations of the solutions were then determined by calculations (sp. gr. $CH_3OH = 0.792\ {}^{20}_{4}$; sp. gr. absolute $C_2H_5OH = 0.789\ {}^{20}_{4}$). This would be equivalent to standard methanol and ethanol stock solutions of 792 mg/l and 789 mg/l respectively, at 20°C. The pipette is held below the surface of the water solution when introducing the pure alcohol to prevent evaporation. Subsequent concentrations are obtained by dilution of these stock solutions.
4. The gas chromatograph operational parameters were set as follows:
   He (carrier) at 20 ml/min
   H_2 at 20 ml/min
   Air at 300 ml/min
   Injector and detector temperatures at 160°C
   Temperature program from 80°C for 5 minutes to 140°C at 4°C per minute
5. Inject the standards (at least 3 concentrations in duplicate) of the proper concentration to establish the calibration curves, plotting concentration vs. response.
6. Inject appropriate quantities of sample (such that the quantity of alcohol present can be adequately determined, yet such that the flame in the detector is not extinguished by too much water) and determine the alcohol concentration from the curves previously generated. Note: CH_3OH elutes in approximately 10 minutes, C_2H_5OH in approximately 16.5 minutes. Other peaks from condensate samples have been observed at about 13, 14.5, and 18 minutes.

Additional Information:

Repeated use of the column allowed buildup of terpenes and other materials, eventually inducing column bleed. This can be minimized by running the columns at high temperatures (about 170°C) overnight, driving these terpenes and other compounds off the column.

The carrier gas was helium rather than nitrogen to minimize the amount of oxygen present. Oxygen at high temperatures in this column will produce acetaldehyde which subsequently condenses and absorbs on the column when trace quantities of amines are present.

The 6% FFAP column coating is a Carbowax 20M treated with 2-nitroterephthalic acid. The Porapak T column support demonstrates the highest polarity and therefore the greatest water retention in the Porapak series of column supports.

Method Precision and Accuracy:

To determine the precision and accuracy of this method in determining alcohol concentrations, two methanol standards of 792 mg/l were prepared (A,B). These solutions were sequentially diluted to yield, in addition to the original 792 mg/l, solutions of 79.2 and 7.92 mg/l (A1, A2, A3 and B1, B2, B3 successively). Finally two vials, designated a and b, from each solution were taken for two 2 μl injections each by an automatic injector. Therefore the identification symbol for each container or vial would be A1a, A1b, A2a, A2b, A3a, A3b, B1a, B1b, B2a, B2b, B3a, and B3b. Thus A2b would indicate from standard solution A at 79.2 mg/l, the second vial.

Results:

The results of these investigations, as presented in Table I indicated that no group of averaged samples had an average percent deviation greater than 2 percent, in fact the largest single point deviation was only 3.57 percent. The final column, the average data from all vials, indicates that when preparing duplicate standards and comparing the results of 4 injections each, the average percent deviation was 1.6 percent. On a two injection each basis, the maximum average percent deviation between two standards was 3.25 percent. Finally, the maximum deviation of any two points was less than 7.0 percent.

Various other methods of determining peak area were evaluated including the integrator readout, the calculated area utilizing either a flat or trapezoidal baseline (measured by triangulation, $A = \frac{1}{2} bh$), and the peak height again utilizing either a flat or trapezoidal baseline. The results of these measurements are presented in Table II.

Table II. Comparison of Peak Area/Height Measurements by Various Methods

Concentration mg/l	Method	$\bar{x}^1$	s.d.[2]	Percent[3] s.d.
7.9	Calc. area (flat b.l.[4])	42.91	5.37	12.53
	Calc. area (trap b.l.[5])	25.68	2.01	8.12
	Height (flat b.l.[4])	0.738	0.029	3.90
	Height (trap b.l.[5])	0.546	0.016	2.93
	Integrated Area	4458	110.6	2.48
79.2	Calc. area (flat b.l.[4])	268.1	15.75	5.87
	Height (flat b.l.[4])	4.96	0.171	3.46
	Integrated area	31489	568	1.80
792	Calc. area (flat b.l.[4])	2577	137.5	5.34
	Height (flat b.l.[4])	51.15	2.070	4.05
	Integrated area	314936	7633	2.42

1. $\bar{x}$ denotes average
2. s.d. denotes standard deviation
3. Percent s.d. denotes percent standard deviation
4. Flat b.l. denotes flat baseline
5. Trap b.l. denotes trapezoidal baseline

The data in the table indicates that throughout the range investigated, the integrator area determination yielded results with the most precision while the peak height, utilizing a trapezoidal baseline when necessary, also yielded consistent results.

Figures 1, 2 and 3 further delineate this data for calculated peak area, measured peak height, and integrator peak area respectively vs. concentration. These graphs indicate that the peak height determination method is the most accurate in determining concentration as the curve developed (Figure 2) most closely passes through the origin. The calculated peak area determination is second and the integrator area is also close to passing through (0,0). It appears as if there may be some difficulty in separating the water and methanol peaks when using the integrator and determining methanol concentrations of about 10 mg/l or less.

Finally, two ethanol peaks were analyzed for peak area by manual means and compared to ethanol peaks injected both before and after the ethanol injection. A comparison of the two compounds' peak area indicated that on a mass basis the detector response factor of ethanol when compared to methanol was 1.47 whereas on a molar basis the factor was 1.02.

In summary, these results indicate that the use of these chromatographic techniques, utilizing a 0.02 mm I.D. x 1 m 6% FFAP on Porapak T (100-120 mesh) column is more than adequate for analyzing condensate samples from the multiple-effect evaporators. Above 10 mg/l methanol concentrations the errors in the analysis were less than 10 percent when comparing two values if the values are the average of two injections by an automatic injector.

APPENDIX D

RESULTS OF WOOD ANALYSIS:

% Moisture

% O.D. Wood

% Ash

% Carbon

% Hydrogen

% Nitrogen

% Oxygen

Calorific Value

: Runs 7 and 8

TABLE D-1

RESULTS OF WOOD ANALYSIS

	Moisture	Ovendry Wood	Ash	Carbon	Hydrogen	Nitrogen	Oxygen	Calorific Value
	%	%	%	%	%	%	%	kJ/kg
Run 7	26.50	73.50	0.80	47.91	6.08	0.32	45.69	17970
Run 8	27.67	72.33	0.78	47.34	6.09	0.31	46.26	17850

Ash, elements and calorific value results on dry wood basis.

APPENDIX E

RESULTS OF GAS ANALYSIS AND INSTRUMENT CONDITIONS

Gas Composition: Runs 4 to 8

Instrument conditions for analysis of gases other than hydrogen:

sample volume 1 cm^3
helium flow rate 25 cc/min
injection temperature 100°C
detector temperature 150°C
oven temperature 60°C
detector current 150 ma
polarity B
threshold 4
peak width 0.04
attenuation 2^6
signal C.

Run table:

RT	0.01	Valve 1 ON
RT	1.19	Valve 2 ON
RT	6.20	Valve 1 OFF
RT	11.40	Valve 2 OFF
RT	15.00	Stop.

The run table shows that, at 0.01 minutes after injection, valve 1 was opened, allowing the sample to flow through both columns. At 1.19 minutes, valve 2 was closed, trapping carbon monoxide, oxygen and nitrogen at the start of the molecular sieve column. From 1.19 to 6.20 minutes, methane, carbon dioxide, ethylene and ethane were eluted from the porapak column. At 6.20 minutes, valve 1 was closed and the porapak column backflushed for 5.20 minutes. At 11.40 minutes, valve 2 was opened and oxygen, nitrogen and carbon monoxide were eluted from the molecular sieve column.

Instrument conditions for hydrogen analysis:

sample volume 1 cm^3
argon flow rate 20 cm^3/min
injection temperature 100°C
detector temperature 150°C
oven temperature 60°C
detector current 150 ma
polarity A
threshold 4
peak width .04
attenuation 2^8
signal C.

The run table for valve switching was set up as follows:

Run Time (RT)	0.01	Valve 1 ON
RT	1.65	Valve 2 ON
RT	5.0	Valve 2 OFF
RT	6.5	Stop.

TABLE E-1

RUN 4: GAS COMPOSITION

Sample Collection: Grab Samples in Glass Sampling Bottles

Gas	Composition, % by Volume		
	Sample 1	Sample 2	Sample 3
CH_4	3.07	2.72	2.84
CO_2	17.94	17.05	18.19
C_2H_4	0.92	0.83	0.86
C_2H_6	0.49	0.44	0.43
O_2 [a]	5.69	5.91	5.76
N_2 [b]	59.46	61.71	60.11
CO	9.97	8.89	9.13
H_2	2.45	2.45	2.68
C_3H_8	NIL	NIL	NIL
TOTAL	100	100	100

[a] Estimated value (100-T) x .0874 = oxygen

[b] Estimated value [100-(T+O_2)] = nitrogen

- T = sum of gases excluding O_2 & N_2

- Oxygen calculated to be 8.74% of combined peak (O_2 + N_2). Percentage derived from analysis of gas samples on Fisher Hamilton gas partitioner.

TABLE E-2

RUN 5: GAS COMPOSITION

Sample Collection: Grab Samples in Glass Sampling Bottles

Gas	Composition, % by Volume		
	Sample 1	Sample 2	Sample 3
CH_4	2.93	2.91	2.52
CO_2	19.53	19.45	19.92
C_2H_4	0.96	0.94	0.83
C_2H_6	0.15	0.15	0.12
O_2 [a]	5.58	5.59	5.74
N_2 [b]	58.28	58.45	59.98
CO	9.69	9.51	8.29
H_2	2.90	3.0	2.60
C_3H_8	NIL	NIL	NIL
TOTAL	100	100	100

[a] Estimated value (100-T) x .0874 = oxygen

[b] Estimated value [100-(T+O_2)] = nitrogen

- T = sum of gases excluding O_2 & N_2

- Oxygen calculated to be 8.74% of combined peak (O_2 + N_2). Percentage derived from analysis of gas samples on Fisher Hamilton gas partitioner.

TABLE E-3

RUN 6: GAS COMPOSITION

Sample Collection: Grab Samples in Glass Sampling Bottles

Gas	Composition, % by Volume		
	Sample 1	Sample 2	Sample 3
CH_4	1.91	2.31	1.84
CO_2	12.01	14.20	12.32
C_2H_4	.66	.85	.72
C_2H_6	.11	.13	.09
O_2 [a]	4.73	1.75	4.34
N_2 [a]	68.28	65.26	68.57
CO	5.98	7.38	5.72
H_2	5.85	6.08	4.81
C_3H_8	0	0	0
TOTAL	99.43	98.15	98.41

[a] calculated from partially resolved peaks of chromatogram from Hewlett Packard gas chromatograph

TABLE E-4

RUN 7, 8: GAS COMPOSITION

Sample Collection: Sample 1 - Grab Samples in Glass Sampling Bottles
Sample 2 - Integrated Sample in Tedlar Bags

	Composition, % by Volume			
	Run #7		Run #8	
Gas	Sample 1	Sample 2	Sample 1	Sample 2
CH_4	2.38	2.89	2.40	2.82
CO_2	15.03	15.44	15.26	17.18
C_2H_4	0.65	0.76	0.92	1.10
C_2H_6	0.17	0.20	0.08	0.09
O_2	7.65[a]	1.96[b]	4.30[a]	1.77[a]
N_2	57.52[a]	62.06[c]	57.04[a]	55.97[a]
CO	8.12	9.59	7.79	9.16
H_2	7.63	7.06	4.89	5.02
C_3H_8	0.04	0.04	0.04	0.04
TOTAL	99.19	100	92.72	93.15

[a] measured on gas partitioner

[b] estimated value (100-T) x .0307 = oxygen

[c] estimated value [100-(T+O_2)] = nitrogen

- T = sum of gases excluding O_2 & N_2
- Oxygen calculated to be 3.07% of combined peak (O_2 + N_2). Percentage derived from analysis of gas samples on Fisher Hamilton gas partitioner.

APPENDIX F

RESULTS OF PARTICULATE ANALYSIS

% Ash

Wt of Ash at 750°C

% Carbon

Wt of Carbon

% Hydrogen

Wt of Hydrogen

% Nitrogen

% Oxygen

Calorific Value

: Runs 4 to 8

TABLE F-1

RESULTS OF PARTICULATE ANALYSIS

Gasifier Run. No: 4

Description	Dry Weight	Ash		Carbon		Hydrogen		Calorific Value	
	g	%	g	%	g	%	mg	kJ/kg	kJ
probe and nozzle wash (acetone)	2.668	65.29	1.742	54.66	1.458	0.80	0.021	8143	21.73
cyclone wash (acetone)	no sample	-	-	-	-	-	-	-	-
cyclone catch (dry)	no sample	-	-	-	-	-	-	-	-
coil and filter wash (acetone)	2.897	27.30	0.791	61.85	1.792	1.08	0.031	16239	47.04
filter[a] (dry)	1.927	42.54	0.820	67.24	1.296	1.47	0.028	14845	28.61
condenser tube and bottle wash (acetone)	nil	-	-	-	-	-	-	-	-
condenser bottle (water)	0.012	-	-	-	-	-	-	-	-
TOTAL	7.504		3.353		4.546		0.080		97.38
Average Value		44.68		60.58		1.07		12997	

a) N = 0.74%, determined on sample from filter.

TABLE F-2

RESULTS OF PARTICULATE ANALYSIS

Gasifier Run. No: 5

Description	Dry Weight	Ash		Carbon		Hydrogen		Calorific Value	
	g	%	g	%	g	%	mg	kJ/kg	kJ
probe and nozzle wash (acetone)	0.426	54.11	0.231	30.30	0.129	0.19	0.001	13669	5.82
cyclone wash (acetone)	(0.031) combined with dry catch	-	-	-	-	-	-	-	-
cyclone catch[a] (dry)	11.835	46.18	5.465	52.45	6.207	0.77	0.091	13669	161.77
coil and filter wash (acetone)	Nil	-	-	-	-	-	-	-	-
filter[b] (dry)	0.593	39.95	0.237	48.89	0.290	0.80	0.005	15598	9.25
condenser tube and bottle wash (acetone)	0.041	39.95	0.016	48.89	0.020	0.80	0.000	15598	.65
condenser bottle (water)	0.001	-	-	-	-	-	-	-	-
TOTAL	12.895		5.949		6.646		0.097		177.48
Average Value		46.13		51.53		0.75		13762	

a) N = 0.55%, determined on sample from cyclone catch.
b) N = 0.61%, determined on sample from filter.

TABLE F-3

RESULTS OF PARTICULATE ANALYSIS

Gasifier Run. No: 6
June 8, 1982

Description	Dry Weight	Ash		Carbon		Hydrogen		Calorific Value	
	g	%	g	%	g	%	mg	kJ/kg	kJ
probe and nozzle wash (acetone)	1.616	62.70	1.013	45.55	0.736	0.55	8.89	8050	13.01
cyclone wash (acetone)	1.056	72.81	0.769	21.82	0.230	<0.1	1.06	17930	18.93
cyclone catch (dry)	no sample	-	-	-	-	-	-	-	-
coil and filter wash (acetone)	2.721	38.45	1.046	55.18	1.501	0.66	17.96	17932	48.79
filter (dry)	0.366	40.41	0.148	"	0.202	"	2.42	"	6.56
condenser tube and bottle wash (acetone)	0.010	58.10	0.006	"	0.005	"	0.07	"	0.18
condenser bottle (water)	0.002	62.38	0.001	"	0.001	"	0.01	"	0.04
TOTAL	5.771		2.983		2.675		0.0304		87.51
Average Value		51.69		46.35		0.53		15160	

TABLE F-4

RESULTS OF PARTICULATE ANALYSIS

Gasifier Run. No: 7

Description	Dry Weight	Ash		Carbon		Hydrogen		Calorific Value	
	g	%	g	%	g	%	mg	kJ/kg	kJ
probe and nozzle wash (acetone)	4.265	43.80	1.868	41.76	1.781	0.45	0.019	16682	71.15
cyclone wash (acetone)	0.736	43.80	0.322	70.97	0.522	0.89	0.007	21880	16.10
cyclone catch (dry)	8.554	26.54 sand= 38.6%	2.270 sand= 0.876 inorg= 1.394	70.97	6.071	0.89	0.076	21880	187.16
coil and filter wash (acetone)	1.108	18.36	0.203	73.22	0.811	1.25	0.014	25121	27.83
filter (dry)	6.341	17.61 sand= 8.3%	1.117 sand= 0.093 inorg= 1.024	73.22	4.643	1.25	0.079	21596	136.94
condenser tube and bottle wash (acetone)	0.043	17.61	0.008	"	0.031	"	0.002	21600	0.93
condenser bottle (water)	0.134	17.61	0.024	"	0.098	"	0.002	21600	2.89
TOTAL	21.181		5.812		13.957		0.199		443.00
Average Value		27.44		65.89		0.94		20915	

TABLE F-5

RESULTS OF PARTICULATE ANALYSIS

Gasifier Run. No: 8
June 29, 1982

Description	Dry Weight	Ash[a]		Carbon		Hydrogen		Calorific Value	
	g	%	g	%	g	%	mg	kJ/kg	kJ
probe and nozzle wash (acetone)	0.907	55.93	0.507						
cyclone wash (acetone)	0.327	55.93	0.183						
cyclone catch[b] (dry)	2.773	55.93 sand= 42.18	1.551	46.38		0.59		10395	
coil and filter wash (acetone)	0.050	"	0.028						
filter (dry)	0.274	"	0.153						
condenser tube and bottle wash (acetone)	0.023	"	0.013						
condenser bottle (water)	0.006	"	0.003						
TOTAL	4.360	55.93	2.438 sand= 1.028 inorg= 1.410	46.38	2.022	0.59	0.026	10395	45.32

a) samples combined for ash determination.
b) N = 0.46%, O = 12.94%, S = 0.87%, determined on sample from cyclone catch.

APPENDIX G

RESULTS OF TAR ANALYSIS

% Moisture

% Carbon Dry Wt

Wt of Carbon Dry Basis

% Hydrogen Dry Wt

Wt of Hydrogen Dry Basis

% Oxygen

Wt of Oxygen Dry Basis

% Nitrogen Dry Wt

Wt of Nitrogen Dry Basis

Calorific Value

: Runs 4 to 8

TABLE G-1

RESULTS OF TAR ANALYSIS

Run Nos. 4, 5, 6

Sample No. 1: Acetone washes before and inclusive of filter.
Sample No. 2: Acetone washes after filter.

					CARBON		HYDROGEN		OXYGEN[a]		NITROGEN[a]		CALORIFIC VALUE	
		Wet Wt	H_2O	Dry Wt	Dry Basis		Dry Basis		Dry Basis		Dry Basis		Dry Basis	
Run No.	Spl No.	g	%	g	%	g	%	g	%	g	%	g	kJ/kg	kJ
4	1	3.103	0.308	3.093	70.17	2.171	10.18	0.315	17.51	0.542	0.30	0.009	34220	105.8
	2	5.814	1.38	5.734	77.32	4.433	8.23	0.472	17.51	1.004	0.30	0.017	33985	194.9
TOTAL				8.827		6.604		0.787		1.546		0.026		300.7
5	1	0.851	0.289	0.849	76.82	0.652	8.24	0.070	17.51	0.149	0.30	0.003	34253	29.1
	2	10.879	0.315	10.845	67.36	7.305	11.51	1.248	17.51	1.899	0.30	0.033	35036	380.0
TOTAL				11.694		7.957		1.318		2.048		0.036		409.1
6	1	8.299	0.268	8.277	69.32	5.737	10.69	0.885	17.51	1.449	0.30	0.025	33805	279.8
	2	4.987	4.80	4.748	71.59	3.399	10.70	0.508	17.51	0.831	0.30	0.014	34883	165.6
TOTAL				13.025		9.136		1.393		2.280		0.039		445.4

[a] based on analysis in Run 8 after filter.

TABLE G-2

RESULTS OF TAR ANALYSIS

Run Nos. 7, 8

Sample No. 1: Acetone washes before and inclusive of filter.
Sample No. 2: Acetone washes after filter.

Run No.	Spl No.	Wet Wt	H_2O	Dry Wt	CARBON Dry Basis		HYDROGEN Dry Basis		OXYGEN[a] Dry Basis		NITROGEN[a] Dry Basis		CALORIFIC VALUE Dry Basis	
		g	%	g	%	g	%	g	%	g	%	g	kJ/kg	kJ
7	1	9.637	0.302	9.608	66.70	6.409	10.99	1.056	17.51[a]	1.682	0.30[a]	0.029[a]	33405	821.0
	2	14.025	0.198	13.997	74.86	10.478	8.49	1.188	17.51[a]	2.451	0.30[a]	0.042[a]	34022	476.2
TOTAL				23.605		16.887		2.244		4.133		0.071		797.2
8	1	9.500	0.279	9.473	66.62	6.311	11.55	1.094	17.51[a]	1.659	0.30[a]	0.028[a]	33375	316.2
	2	7.895	0.275	7.873	72.86	5.737	9.87	0.777	17.51	1.378	0.30	0.024	34657	272.9
TOTAL				17.346		12.048		1.871		3.037		0.052		589.1

[a] based on analysis in Run 8 after filter.

APPENDIX H

RESULTS OF CONDENSATE ANALYSIS

Phenols mg/l

Organic Acids mg/l

Methanol mg/l

Ethanol mg/l

Acetone mg/l

COD mg/l

TOC mg/l

pH

: Runs 4 to 8

TABLE H-1

RESULTS OF CONDENSATE ANALYSIS

RUN NO: 4

Volume Collected: 216 ml

COMPOUND	ELEMENTAL ANALYSIS					
	Concentration	Weight	Carbon	Hydrogen	Oxygen	Calorific Value
	mg/l	mg	mg	mg	mg	kJ
Phenols (phenol)	3774	815.2	624.2	52.4	138.6	26.47
Org. Acids (acetic acid)	2955	638.3	255.3	42.8	340.2	9.30
Methanol	5837	1261	472.6	158.6	629.6	28.61
Ethanol	313	67.6	35.2	8.9	23.5	2.01
Acetone	2458	530.9	329.4	55.3	146.3	16.38
Sub-Total			1717	318.0	1278	82.77
TOC	14081		3041			
TOTAL[a]			3041	563	2264	146.6

[a] Sub-totals x $\frac{3041}{1717}$

TABLE H-2

RESULTS OF CONDENSATE ANALYSIS

RUN NO: 5

Volume Collected: 530 ml

COMPOUND	Concentration	Weight	ELEMENTAL ANALYSIS Carbon	Hydrogen	Oxygen	Calorific Value
	mg/l	mg	mg	mg	mg	kJ
Phenols (phenol)	3566	1890	1447	121.5	321.3	61.37
Org. Acids (acetic acid)	674	357	142.8	24.0	190.2	5.20
Methanol	2865	1518	568.9	191.0	757.9	34.44
Ethanol	99.8	52.9	27.6	6.9	18.4	1.57
Acetone	2140	1134	703.5	118.0	312.4	34.98
Sub-Total			2890	461.4	1600	137.56
TOC	10550		5592			
TOTAL[a]			5592	892.8	3096	266.2

[a] Sub-total x $\frac{5592}{2890}$

TABLE H-3

RESULTS OF CONDENSATE ANALYSIS

RUN NO: 6

Volume Collected: 169 ml

COMPOUND	ELEMENTAL ANALYSIS					
	Concentration	Weight	Carbon	Hydrogen	Oxygen	Calorific Value
	mg/l	mg	mg	mg	mg	kJ
Phenols (phenol)	3661	618.7	473.7	39.8	105.2	20.09
Org. Acids (acetic acid)	557	94.1	37.6	6.3	50.1	1.37
Methanol	3247	548.7	205.7	69.0	274.0	12.45
Ethanol	111	18.8	9.8	2.5	6.5	0.56
Acetone	6144	1038	644.0	108.1	286.0	32.02
Sub-Total			1371	225.7	721.8	66.49
TOC	10808		1827			
TOTAL[a]			1827	300.8	961.9	88.60

[a] Sub-total x $\frac{1827}{1371}$

TABLE H-4

RESULTS OF CONDENSATE ANALYSIS

RUN NO: 7

Volume Collected: 320 ml

COMPOUND	Concentration	Weight	ELEMENTAL ANALYSIS Carbon	Hydrogen	Oxygen	Calorific Value
	mg/l	mg	mg	mg	mg	kJ
Phenols (phenol)	196.6	62.91	48.17	4.045	10.69	2.043
Org. Acids (acetic acid)	4859	1555	622.0	104.3	828.7	22.66
Methanol	6841	2189	820.4	275.4	1093	49.67
Ethanol	373.8	119.6	62.36	15.70	41.55	3.55
Acetone	6159	1971	1223	205.2	543.0	60.81
Sub-Total			2776	604.6	2516.9	138.73
TOC	25188		8060			
TOTAL[a]			8060	1756	7308	402.8

a. Sub-total x $\frac{8060}{2776}$

TABLE H-5

RESULTS OF CONDENSATE ANALYSIS

RUN NO: 8

Volume Collected: 159 ml

	ELEMENTAL ANALYSIS					
COMPOUND	Concentration	Weight	Carbon	Hydrogen	Oxygen	Calorific Value
	mg/l	mg	mg	mg	mg	kJ
Phenols (phenol)	3375	536.6	410.9	34.50	91.22	17.42
Org. Acids (acetic acid)	256.6	40.81	16.32	2.738	21.75	0.70
Methanol	2141	340.4	127.6	42.83	170.0	7.72
Ethanol	nd	-	-	-	-	-
Acetone	1628	258.8	160.6	26.94	71.30	7.98
Sub-total			715.4	107.0	354.3	33.82
TOC_	8086		1286			
TOTAL[a]			1286	192.3	636.9	60.79

a. Sub-total x $\frac{1286}{715.4}$

TABLE H-6

RESULTS OF CONDENSATE ANALYSIS

RUN NO.	COD mg/l	TOC mg/l	COD/TOC Ratio	pH
4	30576	14081	2.17	7.10
5	22644	10550	2.15	7.83
6	24146	10808	2.23	7.90
7	56875	25188	2.26	6.08
8	17930	8086	2.22	7.85

APPENDIX I
HAND CALCULATED MASS BALANCE
RUN 8

MASS BALANCE
HAND CALCULATED EXAMPLE
RUN 8

PHASES

In

i = 1) Dry feed
2) Feed moisture
3) Dry air
4) Air humidity

Out

$$\left.\begin{array}{ll} i = 1) & \text{Dry gas} \\ 2) & \text{Particulates} \\ 3) & \text{Tars} \\ 4) & \text{Water soluble organics} \\ 5) & H_2O \end{array}\right\} \text{Stack Gas}$$

OVERALL

In

where $OV_{in}(n)$ = overall input for "n" phase

1) Dry feed

$$OV_{in}(1) = F_{DRY}$$
$$= 47.64 \text{ kg/hr}$$

F_{DRY} = mass flow rate dry feed, kg/hr

2) Feed water

$$\begin{aligned} OV_{in}(2) &= (F_{WET})(WF) \\ &= (65.86)(.2767) \\ &= 18.22 \text{ kg/hr} \end{aligned}$$

F_{WET} = mass flow rate wet feed, kg/hr

WF = mass fraction H_2O in wet feed, $\frac{\text{kg } H_2O}{\text{kg feed}}$

3) Dry air

$$\begin{aligned} OV_{in}(3) &= A_{DRY} \\ &= 162.6 \text{ kg/hr} \end{aligned}$$

A_{DRY} = mass flow rate dry air, kg/hr

4) Humidity in air

$$\begin{aligned} OV_{in}(4) &= (A_{DRY})(H) \\ &= (162.6)(.00771) \\ &= 1.25 \text{ kg/hr} \end{aligned}$$

H = mass fraction water vapour in air, $\frac{\text{kg } H_2O}{\text{kg dry air}}$

Out

where $OV_{out}(n)$ = overall output for "n" phase.

1) Dry gas

$$\begin{aligned} OV_{out} &= (G_{DRY})(D) \\ &= (127)(1.24) \\ &= 157.48 \text{ kg/hr} \end{aligned}$$

G_{DRY} = volume flow rate, m^3/hr

D = density of dry gas, kg/m^3

2) Particulates

$$OV_{OUT}(2) = (G_{DRY})(PC)$$
$$= (127)\left(\frac{.90436}{.708}\right)$$
$$= .78 \text{ kg/hr}$$

PC = mass concentration of particulates in sample, kg/m^3

3) Tars

$$OV_{OUT}(3) = (G_{DRY})(TC)$$
$$= (127)\left(\frac{.0173}{.708}\right)$$
$$= 3.10 \text{ kg/hr}$$

TC = mass concentration of tar, kg/m^3

4) Water soluble organics

$$OV_{OUT}(4) = (G_{DRY})(SC)$$
$$= (127)\left(\frac{.0026}{.708}\right)$$
$$= .47 \text{ kg/hr}$$

SC = mass concentration of water soluble organics, kg/m^3

5) Water

$$OV_{OUT}(5) = (G_{DRY})(WC)$$
$$= (127)\left(\frac{.1564}{.708}\right)$$
$$= 28.05 \text{ kg/hr}$$

WC = mass concentration of water, kg/m^3

CARBON

In

where $C_{in}(n)$ = carbon input for "n" phase

1) Dry feed

$$C_{in}(1) = (F_{DRY})(CF)$$
$$= (47.64)(.4734)$$
$$= 22.55 \text{ kg/hr}$$

F_{DRY} = mass flow rate dry feed, kg/hr

CF = mass fraction carbon in feed

Out

where $C_{OUT}(n)$ = carbon output for "n" phase

1) Dry gas

$$C_{OUT}(1) = (G_{DRY})(CC)$$
$$= (127)(.1608)$$
$$= 20.42 \text{ kg/hr}$$

G_{DRY} = volume flow rate, m^3/hr

CC = mass concentration carbon in dry gas, kg/m^3

2) Particulates

$$C_{OUT}(2) = (G_{DRY})(PC)(CP)$$
$$= (127)\left(\frac{.00436}{.708}\right)(.4632)$$
$$= .36 \text{ kg/hr}$$

G_{DRY} = volume flow rate dry gas, m^3/hr

PC = particulate concentration, kg/m^3

CP = mass fraction carbon in particulates

3) Tars

$$C_{OUT}(3) = (G_{DRY})(TC)(CT)$$
$$= (127)\left(\frac{.0173}{.708}\right)(.6936)$$
$$= 2.15 \text{ kg/hr}$$

TC = tar concentration, kg/m^3

CT = mass fraction C in tar

4) Water soluble organics

$$C_{OUT}(4) = (G_{DRY})(SC)(CS)$$
$$= (127)\left(\frac{.0026}{.708}\right)(.4846)$$
$$= .23 \text{ kg/hr}$$

SC = water soluble organics concentration, kg/m^3

CS = mass fraction C in water soluble organics

HYDROGEN

where $H_{in}(n)$ = hydrogen input for "n" phase

In

1) Dry feed

$$H_{in}(1) = (F_{DRY})(HF)$$
$$= (47.64)(.0609)$$
$$= 2.9 \text{ kg/hr}$$

$F(_{DRY})$ = mass flow rate dry feed, kg/hr

HF = mass fraction hydrogen feed

2) Feed moisture

$$H_{in}(1) = (F_{WET})(WF)(2/18)$$
$$= (65.86)(.2767)(2/18)$$
$$= 2.02 \text{ kg/hr}$$

F_{WET} = mass flow rate wet feed, kg/hr
WF = mass fraction H_2O in wet feed
2/18 = mass fraction H_{in} H_2O

3) Humidity in air

$$H_{in}(4) = (A_{DRY})(H)(2/18)$$
$$= (162.6)(.00771)(2/18)$$
$$= .14 \text{ kg/hr}$$

A_{DRY} = mass flow rate dry air, kg/hr
H = mass fraction water vapor in air, $\frac{\text{kg } H_2O}{\text{kg dry air}}$
2/18 = mass fraction hydrogen in H_2O

Out

1) Dry gas

$$H_{OUT}(1) = (G_{DRY})(HC)$$
$$= (127)(.0113)$$
$$= 1.44 \text{ kg/hr}$$

G_{DRY} = volume flow rate dry gas, m^3/hr
HC = hydrogen mass concentration in dry gas, kg/m^3

2) Particulates

$$H_{OUT}(2) = (G_{DRY})(PC)(HP)$$
$$= (127)\left(\frac{.00436}{.708}\right)(.006)$$
$$= .0047 \text{ kg/hr}$$

PC = particulate concentration, kg/m^3

HP = mass fraction H in parts

3) Tars

$$H_{OUT}(3) = (G_{DRY})(TC)(HT)$$
$$= (127)\left(\frac{.0173}{.708}\right)(.1081)$$
$$= .34 \text{ kg/hr}$$

TC = tar concentration, kg/m^3

HT = mass fraction H in tars

4) Water soluble organics

$$H_{OUT}(4) = (G_{DRY})(SC)(HS)$$
$$= (127)\left(\frac{.0026}{.708}\right)(.0738)$$
$$= .034 \text{ kg/hr}$$

SC = water soluble organics cone, kg/m^3

HS = mass fraction H in water soluble organics

5) H_2O in process flow

$$H_{OUT}(5) = (G_{DRY})(WC)(2/18)$$
$$= (127)\left(\frac{.1564}{.708}\right)(2/18)$$

3.12 kg/hr

G_{DRY} = volume flow rate dry gas, m^3/hr

WC = mass concentration of water in dry gas flow, kg/m^3

2/18 = mass fraction H in H_2O

OXYGEN

In

1) Dry feed

$O_{in}(1) = (F_{DRY})(OF)$
$= (47.64)(.4569)$
$= 21.77$ kg/hr

F_{DRY} = mass flow rate dry feed, kg/hr
OF = mass fraction oxygen in feed

2) Feed moisture

$O_{in}(2) = (F_{WET})(WF)(16/18)$
$= (65.86)(.2767)(16/18)$
$= 16.2$ kg/hr

F_{WET} = mass flow rate wet feed, kg/hr
WF = mass fraction H_2O in feed
16/18 = mass fraction O in H_2O

3) Dry air

$O_{in}(3) = (A_{DRY})(0.232)$
$= (162.6)(.232)$
$= 37.72$ kg/hr

A_{DRY} = mass flow rate dry air, kg/hr
0.232 = mass fraction oxygen in dry air

4) Humidity in air

$O_{in}(4) = (A_{DRY})(H)(16/18)$
$= (162.6)(.00771)(16/18)$
$= 1.11$ kg/hr

A_{DRY} = mass flow rate dry air, kg/hr

H = mass fraction water vapour in air, $\frac{\text{kg } H_2O}{\text{kg dry air}}$

Out

1) Dry gas

$$\begin{aligned} O_{OUT}(1) &= (G_{DRY})(OC) \\ &= (127)(.3185) \\ &= 40.45 \text{ kg/hr} \end{aligned}$$

G_{DRY} = volume flow rate dry gas, m^3/hr

OC = oxygen mass concentration in dry gas, kg/m^3

2) Particulates

$$\begin{aligned} O_{OUT}(2) &= (G_{DRY})(PC)(OP) \\ &= (127)\left(\frac{.00436}{.708}\right)(.1294) \\ &= 0.10 \text{ kg/hr} \end{aligned}$$

PC = particulates mass concentration, kg/m^3

OP = mass fraction oxygen in particulates

3) Tars

$$\begin{aligned} O_{OUT}(3) &= (G_{DRY})(TC)(OT) \\ &= (127)\left(\frac{.0173}{.708}\right)(.1757) \\ &= .545 \text{ kg/hr} \end{aligned}$$

TC = tar mass concentration, kg/m^3

OT = mass fraction oxygen in tars

4) Water soluble organics

$$O_{OUT}(4) = (G_{DRY})(SC)(OS)$$
$$= (127)\left(\frac{.0026}{.708}\right)(.245)$$
$$= .114 \text{ kg/hr}$$

SC = water soluble organics concentration, kg/m^3

OS = mass fraction oxygen in water soluble organics

5) H_2O in process flow

$$O_{OUT}(5) = (G_{DRY})(WC)(16/18)$$
$$= (127)\left(\frac{.1564}{.708}\right)(16/18)$$
$$= 24.94 \text{ kg/hr}$$

G_{DRY} = volume flow rate dry gas, m^3/hr

WC = mass concentration water in dry gas flow, kg/m^3

16/18 = mass fraction oxygen in H_2O

NITROGEN

In

1) Dry feed

$$N_{in}(1) = (F_{DRY})(NF)$$
$$= (47.64)(.0031)$$
$$= .148 \text{ kg/hr}$$

F_{DRY} = mass flow rate dry feed, kg/hr

NF = mass fraction N in feed

2) Dry air

$$
\begin{aligned}
N_{in}(3) &= (A_{DRY})(0.768) \\
&= (162.6)(.768) \\
&= 124.9 \text{ kg/hr}
\end{aligned}
$$

A_{DRY} = mass flow rate dry air, kg/hr

0.768 = mass fraction atmospheric nitrogen in dry air

Out

1) Dry gas

$$
\begin{aligned}
N_{OUT}(1) &= (G_{DRY})(NC) \\
&= (127)(.749) \\
&= 95.12 \text{ kg/hr}
\end{aligned}
$$

G_{DRY} = volume flow rate dry producer gas, m^3/hr

NC = nitrogen mass concentration in dry gas, kg/m^3

2) Particulates

$$
\begin{aligned}
N_{OUT}(2) &= (G_{DRY})(PC)(NP) \\
&= (127)\left(\frac{.00436}{.708}\right)(.0046) \\
&= .004 \text{ kg/hr}
\end{aligned}
$$

PC = particulate mass concentration in dry producer gas, kg/m^3

NP = mass fraction nitrogen in particulates

3) Tars

$$
\begin{aligned}
N_{OUT}(3) &= (G_{DRY})(TC)(NT) \\
&= (127)\left(\frac{.0173}{.708}\right)(.003) \\
&= .009 \text{ kg/hr}
\end{aligned}
$$

TC = tar mass concentration in dry gas, kg/m^3

NT = mass fraction N in tars

4) Water soluble organics

$$N_{OUT}(4) = (G_{DRY})(SC)(NS)$$
$$= (127)\left(\frac{.0026}{.708}\right)(.1865)$$
$$= .087 \text{ kg/hr}$$

SC = water soluble organics concentration in gas, kg/m^3

NS = mass fraction N in water soluble organics

TOTALS

1) Overall

$$\Sigma_{in} = 47.64 + 18.22 + 162.6 + 1.25 \qquad = \quad 229.7 \text{ kg/hr}$$
$$\Sigma_{out} = 157.48 + .78 + 3.10 + .47 + 28.05 \qquad = \quad 189.9$$

2) Carbon

$$\Sigma_{in} = 22.55 \qquad = \quad 22.55$$
$$\Sigma_{out} = 20.42 + .36 + 2.15 + .23 \qquad = \quad 23.16$$

3) Hydrogen

$$\Sigma_{in} = 2.9 + 2.02 + .14 \qquad = \quad 5.06$$
$$\Sigma_{out} = 1.44 + .0047 + .34 + .034 + 3.12 \qquad = \quad 4.939$$

4) Oxygen

$$\Sigma_{in} = 21.77 + 16.2 + 37.72 + 1.11 \qquad = \quad 76.80$$
$$\Sigma_{out} = 40.45 + 0.1 + 0.545 + 0.114 + 24.94 \qquad = \quad 66.1$$

5) Nitrogen

$$\Sigma_{in} = .148 + 124.9 \qquad = \quad 125.1$$
$$\Sigma_{out} = 95.12 + .004 + .009 + 0.87 \qquad = \quad 95.2$$

% CLOSURES

1) Overall

$$PC(1) = \frac{\Sigma\, OV_{out}}{\Sigma\, OV_{in}} (100) = \frac{189.9}{229.7} (100) \quad = 82.7\%$$

where PC(n) = percent closure of "n" phase

$\frac{\Sigma\, OV_{out}}{\Sigma\, OV_{in}}$ = summation of overall output phases divided by summation of overall input phases.

2) Carbon

$$PC(2) = \frac{\Sigma C_{out}}{\Sigma C_{in}} (100) = \frac{23.16}{22.55} (100) = 102.7\%$$

3) Hydrogen

$$PC(3) = \frac{\Sigma H_{out}}{\Sigma H_{in}} (100) = \frac{4.939}{5.06} (100) = 97.6\%$$

4) Oxygen

$$PC(4) = \frac{\Sigma O_{out}}{\Sigma O_{in}} (100) = \frac{66.1}{76.80} (100) = 86.1\%$$

5) Nitrogen

$$PC(5) = \frac{\sum N_{out}}{\sum N_{in}} (100) = \frac{95.2}{125.1} (100) = 76.1\%$$

APPENDIX J

HAND CALCULATED ENERGY BALANCE

RUN 8

ENERGY IN

where $E_{in}(n)$ = energy input for "n" phase

1) Heat of combustion of dry feed

$$E_{in}(1) = (F_{DRY})(HF_{DRY})$$
$$= (47.64)(17850000\ J/kg)$$
$$= 850.4 \times 10^6\ J/hr$$

F_{DRY} = mass flow rate of dry feed, kg/hr

HF_{DRY} = std higher heat of combustion (25°C, 1 atm.) of dry feed, J/kg

2) Process (electro-mechanical) energy input

$$E_{in}(2) = E_1 + E_2 + \ldots$$
$$E_1 = (2.5\ HP)(746\ w/HP)(3600\ s/hr)$$
$$= 6.7 \times 10^6\ J/hr$$

E_2 = negligible

E_1 = blower power, J/hr

E_2 = screw feed power, J/hr

3) Enthalpy of humid process air

$$E_{in}(3) = (AD)(ACp)(T_{AIRIN}-T_{REF}) + (AD)(H)(H_{AIR}-H_{REF})$$
$$= \text{negligible} + (162.6\ kg/hr)(.00771)(89000-64000)\ J/kg$$
$$= 31 \times 10^3\ J/hr$$

AD = mass flow rate dry air, kg/hr

ACp = specific heat @ cst press of feed air, J/kg °C

T_{AIRIN} = temp. feed air, °C

H = mass fraction water vapour in air, kg H_2O/kg dry air

H_{AIR} = enthalpy of H_2O @ air feed T, J/kg

H_{REF} = enthalpy of H_2O @ 15°C, J/kg

4) Enthalpy of moisture in feed

$$\begin{aligned} E_{in}(4) &= (G_{DRY})(WC)(H_{FEED}-H_{REF}) \\ &= (127 \text{ m}^3/\text{hr})(.221)(89000-64000) \\ &= 702 \times 10^3 \text{ J/hr} \end{aligned}$$

F_{DRY} = mass flow rate of dry feed, kg/hr
CpF_{DRY} = average specific heat of dry fuel, J/kg°C
T_{FEED} = temperature of feed, °C
T_{REF} = 15°C
G_{DRY} = volume flow rate dry producer gas, m^3/hr
WC = mass concentration water in dry gas flow, kg/m^3
H_{FEED} = enthalpy of H_2O at feed T, P J/kg
H_{REF} = enthalpy of water at 15°C, 1 atm. J/kg

5) Sensible heat of dry feed

$$\begin{aligned} E_{in}(5) &= (F_{DRY})(CpF_{DRY})(T_{FEED}-T_{REF}) \\ &= \text{negligible} \end{aligned}$$

ENERGY OUT

1) Heat of combustion of dry producer gas

$$\begin{aligned} E_{out}(1) &= (G_{DRY})(G_{H \text{ of } C}) \\ &= (127 \text{ m}^3/\text{hr})(3524000 \text{ J/m}^3) \\ &= 447.5 \times 10^6 \text{ J/hr} \end{aligned}$$

G_{DRY} = volume flow rate of dry gas, m^3/hr
$G_{H \text{ of } C}$ = std. higher heat of combustion of dry producer gas, J/m^3

2) Sensible heat of dry producer gas

$$\begin{aligned} E_{out}(2) &= (G_{DRY})(D)(Cp_{DRY})(T_{STACK}-T_{REF}) \\ &= (127\ m^3/hr)(1.24\ kg/m^3)(1178\ J/kg°C)(601-15)°C \\ &= 108.7 \times 10^6\ J/hr \end{aligned}$$

G_{DRY} = volume flow rate of dry gas, m^3/hr

D = density of dry gas, kg/m^3

Cp_{DRY} = average specific heat of dry gas @ cst press, J/kg°C

T_{STACK} = process sampling temperature °C

T_{REF} = 15°C

3) Enthalpy of water in producer gas flow

$$\begin{aligned} E_{out}(3) &= (G_{DRY})(WC)(H_{STACK}-H_{REF}) \\ &= (127\ m^3/hr)(0.221\ kg/m^3)(3700000-64000) J/kg \\ &= 102.1 \times 10^6\ J/hr \end{aligned}$$

G_{DRY} = volume flow rate of dry gas, m^3/hr

WC = mass concentration of water in the dry producer gas flow, kg/m^3

H_{STACK} = enthalpy of steam @ sampling T, P J/kg

H_{REF} = enthalpy of water @ 15°C, 1 atm J/kg

4) Heat of combustion of particulates

$$\begin{aligned} E_{out}(4) &= (G_{DRY})(PC)(P_{H\ of\ C}) \\ &= (127\ m^3/hr)(.00616\ kg/m^3)(10400000\ J/kg) \\ &= 8.14 \times 10^6\ J/hr \end{aligned}$$

G_{DRY} = volume flow rate of dry gas, m^3/hr

PC = mass concentration of particulates in the dry gas flow, kg/m^3

$P_{H\ of\ C}$ = heat of combustion (HHV) of particulates, J/kg

5) Heat of combustion of tars

$$E_{out}(5) = (G_{DRY})(TC)(T_{H\ of\ C})$$
$$= (127\ m^3/hr)(.0244\ kg/m^3)(34000000\ J/kg)$$
$$= 106 \times 10^6\ J/hr$$

TC = tar concentration, kg/m^3

$T_{H\ of\ C}$ = heat of combustion of tar, J/kg

6) Heat of combustion of water soluble organics

$$E_{out}(6) = (G_{DRY})(SC)(S_{H\ of\ C})$$
$$= (127\ m^3/hr)(.00367\ kg/m^3)(23400000\ J/kg)$$
$$= 10.9 \times 10^6\ J/hr$$

SC = water soluble organics mass concentration, kg/m^3

$S_{H\ of\ C}$ = heat of combustion of water soluble organics, J/kg

7) Sensible heat of tars, particulates, water soluble organics

$$E_{out}(7) = [(PCp)(PC) + (TCp)(TC) + (SCp)(SC)](G_{DRY}(T_{STACK} - T_{REF})$$
$$= \text{negligible}$$

PCp = average specific heat of tars, J/Kg°C

TC = mass concentration of tars, kg/hr

TCp = average specific heat of particulates, J/kg°C

PC = mass concentration of particulate, kg/hr

T_{STACK} = process sampling temperature, °C

T_{REF} = 15°C

G_{DRY} = volume flow rate dry gas, m^3/hr

8) Heat loss from process

$$E_{out}(8) = (HL)$$
$$= 1.06 \times 10^6\ J/hr$$

HL = estimated value of heat loss from process, to point of sampling, J/hr

ANALYSIS

1) % Closure

$$C = \frac{\sum E_{out}}{\sum E_{in}} (100) = \frac{(447.5+108.7+102.1+8.14+106+10.9+1.06)\times 10^6}{(850.4+6.71+.03+.07)\times 10^6 \text{ J/hr}} (100)$$

$$= \frac{784.4 \times 10^6}{857.2 \times 10^6} (100)$$

$$= 91.5\%$$

2) Gross efficiency

$$GE = \frac{\text{all heat out except that lost from process}}{\text{total energy in}}$$

$$= \frac{\sum E_{out} - E_{out}(8)}{\sum E_{in}} (100)$$

$$= \frac{(784.4 - 1.06) \times 10^6}{857.2 \times 10^6} (100) = \underline{91.4\%}$$

$E_{out}(8)$ = heat loss from process, J/hr

3) Net efficiency

$$NE = \frac{\text{heating value of gas}}{\text{total energy in}} = \frac{E_{out}(1)}{\sum E_{in}} (100)$$

$$= \frac{447.5}{857.2} (100) = 52.2\%$$

APPENDIX K

COMPUTER PROGRAMS

1. Product Gas Analysis
2. Quickie Sequential Filer
3. Gasifier Mass Balance
4. Gasifier Energy Balance

```
0  GOTO 1000: REM SKIP SUBROUTINE SPACE
10  REM ************************
15  REM *                      *
20  REM *     PRODUCER GAS     *
25  REM *       ANALYSIS       *
30  REM *                      *
35  REM * PREPARED FOR APPLE II *
40  REM * WITH EPSON DOT MATRIX *
45  REM * PRINTER, PKASO BOARD, *
50  REM *    AND DISK DRIVE    *
55  REM *       AUG 1982       *
60  REM *      L PHILLIPS      *
65  REM ************************
1000  REM
                      INITIALIZE

1010  HOME : INVERSE : HTAB 10: PRINT " CHONS GAS ANALYSIS ": NORMAL : POKE 34,2: REM POKE SETS TEXT WINDOW
1100 D$ =  CHR$ (4):I$ =  CHR$ (9)
1150 ABIT = 1E - 20: REM USED TO PREVENT DIVIDE BY 0 ERRS
1300  REM -----SET DEFAULTS FOR PROG PARAMS
1310 UNITS = 1:K1 = 1:K2 = 1:K3 = 1: REM METRIC UNITS
1320 T = 288:P = 101300: REM T,P BASIS
1500  REM -----READ GAS DATA @ LINE 20000
1510  READ NGAS
1520  FOR I = 1 TO NGAS: READ NM$(I),FRM$(I),MW(I),HHV(I),LHV(I),R(I),C(I),H(I),O(I),N(I),S(I),VA(I),VB(I),VC(I),VD(I): NEXT

2000  REM

                      ** MENU ** (ALL ROUTINES RETURN HERE)


2100  HOME : HTAB 10: PRINT "CHOOSE:": PRINT
2110  PRINT "1) SELECT OPTIONS": PRINT
2120  PRINT "2) ENTER CONCENTRATIONS": PRINT
2130  PRINT "3) CALCULATE & PRINT REPORT": PRINT
2140  PRINT "4) PRINT GAS DATA": PRINT
2150  PRINT "5) "
2160  PRINT "6) "
2170  PRINT "7) COMPUTE INTEGRAL AVG CP"
2180  PRINT "8) ": PRINT
2190  PRINT "9) QUIT": PRINT
2200  HTAB 20: INPUT "WHICH? ";CHOICE$:CHOICE =  VAL (CHOICE$)
2210  IF CHOICE > 255 OR CHOICE < 0 THEN 2000
2220  ON CHOICE GOTO 3000,4000,8000,7000,4500,4500,6000,4500,10000: GOTO 2000
3000  REM
                      SET PROGRAM PARAMETERS

3100  REM -----SELECT UNITS
3110  HOME : PRINT "CHOOSE:  1) METRIC UNITS": INPUT "         2) ENGINEERING UNITS ";UNITS
3120  IF UNITS <  > 1 AND UNITS <  > 2 THEN 3110: REM INVALID RESPONSE
3130  IF UNITS = 1 THEN K1 = 1:K2 = 1:K3 = 1: GOTO 3200: REM METRIC SELECTED, CONTINUE
3140  IF UNITS = 2 THEN K1 = 6.2426E - 2:K2 = 2.6856E - 5:K3 = 7.7438E - 4: REM ENG SEL'D: K1=KG/M3->LB/FT3, K2=J/M3->BTU/FT3
    , K3=J/KGK->BTU/LBF
3200  REM -----SELECT T,P BASIS
3210  HOME : PRINT "BASIS IS ";T;" K, ";P;" PASCALS": PRINT "(101300 PA = 1 ATM)": PRINT
3220  INPUT "OK? (Y/N) ";A$: IF  LEFT$ (A$,1) = "Y" THEN 3999: REM CONTINUE
3230  INPUT "NEW TEMP? (KELVIN) ";T
3240  INPUT "NEW PRESS? (PASCALS) ";P
3999  GOTO 2000: REM MENU
4000  REM
                      INPUT GAS CONC'S

4005 AA = 0:BB = 0:CC = 0:DD = 0: REM FOR INT AV CP ROUTINE
```

```
4010  HOME : PRINT "USING 'RETURN' WILL OMIT GAS FROM REPORT": PRINT : PRINT
4100  FOR I = I TO NGAS
4150  PRINT NM$(I);"  ";FRM$(I)
4160  INPUT "VOLUME % CONC'N? ";PCT$:PCT(I) =  VAL (PCT$): PRINT
4170 OK(I) = (PCT$ <  > ""): REM OK=1 FOR EA GAS FOR WHICH REPORT DESIRED
4200  NEXT I
4250  HOME : INPUT "SAMPLE NAME? ";SAM$
4499  GOTO 2000: REM MENU
4500  REM (SPARE ROUTINE SPACE)
4501  GOTO 2000: REM MENU
6000  REM
                    INTEGRAL AVG CP

6050  IF  NOT (VA + VB + VC + VD) THEN  PRINT "DO CALCULATIONS FIRST...";: GET A$: PRINT A$: GOTO 2000: REM ABORT IF NO CALCS

6100  HOME : INPUT "T1? (K) ";TI: INPUT "T2? (K) ";T2
6120  DEF  FN CP(T) = (VA * T + VB / 2 * T * T + VC / 3 * T * T * T + VD / 4 * T ^ 4)
6130 AVG = ( FN CP(T2) -  FN CP(T1)) / (T2 - TI + ABIT)
6150  PRINT D$"PR#1": PRINT : PRINT : REM PRINTER ON
6160  PRINT "INTEGRAL AVG CP BETWEEN "T1" & "T2" = ";AVG;"  J/KG K"
6200  PRINT : PRINT : PRINT D$"PR#0": REM PRINTER OFF
6250  GOTO 2000: REM MENU
7000  REM
                    PRINT GAS DATA

7050  PRINT D$"PR#1": PRINT  CHR$ (15): PRINT I$"I32N": PRINT  CHR$ (12): REM  PRINTER ON, 132 CONDENSED CHARS, FORM-FEED
7080  PRINT  SPC( 24);"MOLAR     HIGHER    LOWER     GAS       MASS      MASS      MASS      MASS      MASS"
7090  PRINT  SPC( 24);"MASS      HEATING   HEATING   CONSTANT  FRACTION  FRACTION  FRACTION  FRACTION  FRACTION"
7100  PRINT  SPC( 24);"          VALUE     VALUE     R         CARBON    HYDROGEN  OXYGEN    NITROGEN  SULFUR"
7105  PRINT
7110  PRINT  SPC( 25);"KG/MOLE   J/KG      J/KG      J/KG K": PRINT
7130  FOR I = I TO NGAS
7140  PRINT NM$(I);I$"16T"FRM$(I);I$"24T"MW(I);I$"34T"HHV(I);I$"44T"LHV(I);
7150  PRINT I$"54T"R(I);I$"64T"C(I);I$"74T"H(I);I$"84T"O(I);I$"94T"N(I);I$"104T"S(I)
7170  NEXT I
7200  PRINT : PRINT : PRINT "VIRIAL COEFICIENTS FOR CP =  A + BT + CT^2 + DT^3  (JOULES/KG K, T IN KELVIN)": PRINT
7210  PRINT  SPC( 25);"A";I$"40TB *10^2";I$;"55TC *10^5";I$;"70TD *10^9": PRINT
7230  FOR I = 1 TO NGAS
7240  PRINT NM$(I);I$"16T";FRM$(I);I$;"25T";VA(I);I$"40T";VB(I);I$"55T";VC(I);I$"70T";VD(I)
7250  NEXT I
7390  PRINT D$"PR#0": REM PRINTER OFF
7400  GOTO 2000: REM MENU
8000  REM
                    CALCULATIONS

8020  REM -----CALC MASS OF EACH GAS & ITS ELEMENTS
8030  FOR I = I TO NGAS
8035 MASS = PCT(I) / I00 / R(I) * P / T * KI
8040 CCNC(I) = MASS * C(I)
8060 HCNC(I) = MASS * H(I)
8080 OCNC(I) = MASS * O(I)
8100 NCNC(I) = MASS * N(I)
8120 SCNC(I) = MASS * S(I)
8140 TCNC(I) = MASS
8180  NEXT I
8200  REM -----SUM THE % & ELEMENTAL CONTRIBUTION (IE, SUM DOWN THE COLUMNS)
8210 PCT = ZERO:TC = ZE:TH = ZE:TO = ZE:TN = ZE:TS = ZE:CNC = ZE
8220  FOR I = I TO NGAS
8240 PCT = PCT + PCT(I):TC = TC + CCNC(I):TH = TH + HCNC(I):TO = TO + OCNC(I):TN = TN + NCNC(I):TS = TS + SCNC(I):CNC = CNC +
     TCNC(I)
8260  NEXT I
8280  REM -----CALC OVERALL SP HT VIRIAL CSTS
8290 VA = ZE:VB = ZE:VC = ZE:VD = ZE
8300  FOR I = I TO NGAS
8310 VA = VA + VA(I) * TCNC(I):VB = VB + VB(I) * TCNC(I):VC = VC + VC(I) * TCNC(I):VD = VD + VD(I) * TCNC(I)
8320  NEXT I
```

```
8330 VA = VA / (CNC + ABIT):VB = VB * 1E - 2 / (CNC + ABIT):VC = VC * 1E - 5 / (CNC + ABIT):VD = VD * 1E - 9 / (CNC + ABIT)
8500  REM -----CALC HEAT OF COMBUSTION FOR EACH GAS
8520  FOR I = 1 TO NGAS:COMB(I) = TCNC(I) * HHV(I): NEXT
8550  REM SUM THE OVERALL H OF C
8560 COMB = ZE: REM ZERO SUM
8570  FOR I = 1 TO NGAS:COMB = COMB + COMB(I): NEXT
8800  REM -----CONSTRUCT A MASS PERCENTAGE TABLE
8810  DEF  FN PC(XX) = XX / (CNC + ABIT) * 100: REM CALCS %-AGE OF OVERALL FOR EACH SPECIES
8820  FOR I = 1 TO NGAS
8830 TABLE(I,1) = PCT(I): REM VOL %
8840 TABLE(I,2) =  FN PC(CCNC(I)):TABLE(I,3) =  FN PC(HCNC(I)):TABLE(I,4) =  FN PC(OCNC(I))
8850 TABLE(I,5) =  FN PC(NCNC(I)):TABLE(I,6) =  FN PC(SCNC(I)):TABLE(I,7) =  FN PC(TCNC(I))
8860  NEXT I
8670 TABLE(I,I) = PCT:TABLE(I,2) =  FN PC(TC):TABLE(I,3) =  FN PC(TH):TABLE(I,4) =  FN PC(TO):TABLE(I,5) =  FN PC(TN):TABLE(I
     ,6) =  FN PC(TS):TABLE(I,7) =  FN PC(CNC)
9000  REM
                       NOW, PRINT REPORT

9050  PRINT D$"PR#1": PRINT  CHR$ (15): PRINT I$"132N": PRINT  CHR$ (12): REM PRINTER ON, 132 CONDENSED CHARS, FORM-FEED
9075  PRINT SAM$: PRINT
9080  PRINT "BASIS = ";T;" K & ";P;" PASCALS": PRINT
9120  PRINT I$"50T";"MASS CONCENTRATION  ";: IF UNITS = 1 THEN  PRINT "(KG/CU M)": PRINT
9125  IF UNITS = 2 THEN  PRINT "(LB/CU FT)": PRINT
9130  PRINT I$;"25T";"VOL %          C              H              O              N              S              TOTAL": PRINT

9140  FOR I = 1 TO NGAS
9150  IF OK(I) THEN  PRINT NM$(I);I$;"16T";FRM$(I);I$;"25T";PCT(I);I$;"40T";CCNC(I) * K1;;I$;"55T";HCNC(I) * K1;
9160  IF OK(I) THEN  PRINT I$;"70T";OCNC(I) * K1;I$;"85T";NCNC(I) * K1;I$;"100T";SCNC(I) * K1;I$"115T";TCNC(I) * K1
9170  NEXT I
9175  PRINT
9180  PRINT "TOTAL";I$;"16T";FRM$(I);I$;"25T";PCT;I$;"40T";TC;I$;"55T";TH;I$;"70T";TO;I$;"85T";TN;I$;"100T";TS;I$"115T";CNC
9200  PRINT : PRINT : PRINT : PRINT I$;"50T";"MASS CONCENTRATION %": PRINT
9210  PRINT I$;"25T";"VOL %          C              H              O              N              S              TOTAL": PRINT

9215  DEF  FN RD(XX) =  INT (XX * 100 + .5) / 100: REM ROUNDS TO 2 DEC PTS
9217  FOR I = 1 TO NGAS
9220  IF OK(I) THEN  PRINT NM$(I);I$"16T";FRM$(I);: FOR J = 1 TO 7: POKE 36,15 * J + 10: PRINT  FN RD(TABLE(I,J));: NEXT J: PRINT
     : REM POKE WORKS LIKE A TAB
9225  REM POKE WORKS LIKE A TAB
9250  NEXT I
9270  PRINT : PRINT "TOTAL";: FOR J = 1 TO 7: POKE 36,15 * J + 10: PRINT  FN RD(TABLE(I,J));: NEXT J: PRINT
9310  PRINT : PRINT : PRINT : PRINT "STD HIGHER HEAT OF COMBUSTION  ";: IF UNITS = 1 THEN  PRINT "(J/CU M)"
9315  IF UNITS = 2 THEN  PRINT "(BTU/CU FT)"
9317  PRINT
9320  FOR I = 1 TO NGAS
9340  IF OK(I) THEN  PRINT FRM$(I)I$"16T"COMB(I) * K2
9360  NEXT I
9380  PRINT : PRINT "TOTAL"I$"16T";COMB * K2: PRINT : PRINT : PRINT
9400  PRINT "HEAT CAPACITY (CP) = ";VA * K3;" + ";VB * K3;" T + ";VC * K3;" T^2 + ";VD * K3;" T^3  ";: IF UNITS = 1 THEN  PRINT
     "(J/KG K)"
9410  IF UNITS = 2 THEN  PRINT "(BTU/LB DEG RANKIN  OR  BTU/LB DEG F)"
9420  PRINT I$"40T(TEMPERATURE IN KELVIN)"
9950  PRINT D$"PR#0": REM PRINTER OFF
9960  GOTO 2000: REM MENU
10000  REM
                         EXIT ROUTINE...

10010  POKE 34,0: REM  RESET TEXT WINDOW
10020  HOME : PRINT "END OF PROGRAM": END
20000  REM
                        GAS DATA

20005  DATA  9: REM # OF GASES IN LIST, MUST BE KEPT UP TO DATE
20010  DATA METHANE,CH4,.016,55500000,50010000,520,.75,.25,0,0,0,1238,312.8.78.98, - 685.5
20020  DATA CARBON DIOXIDE,CO2,.044,0,0,189,.2727,0,.7273,0,0,607.3,95.95,-32.35,0
20030  DATA ETHENE(-YLENE),C2H4,.028,50464000,1E33,294.5,.8571,.1429,0,0,0,140.7,556.7,-297.1,629
```

```
20040  DATA ETHANE,C2H6,.030,51870000,47470000,277,.8,.2,0,0,0,229.3,573.4,-213.15,241.9
20050  DATA OXYGEN,O2,.032,0,0,260,0,0,1,0,0,879.6,19.66,-2.340,0
20060  DATA NITROGEN,N2,.028,0,0,295,0,0,0,1,0,974.2,22.2,-3.389,0
20070  DATA CARBON MONOXIDE,CO,.028,10100000,10100000,297,.4286,0,.5714,0,0,967.3,23.38,-3.563,0
20080  DATA HYDROGEN,H2,.02016,142000000,120000000,4120,0,1,0,0,0,13323,215.5,-16.18,0
20090  DATA PROPANE,C3H8,.044,50360000,46360000,183.7,.8182,.1818,0,0,0,-91.65,690.3,-356.1,718.8
```

		MOLAR MASS	HIGHER HEATING VALUE	LOWER HEATING VALUE	GAS CONSTANT R	MASS FRACTION CARBON	MASS FRACTION HYDROGEN	MASS FRACTION OXYGEN	MASS FRACTION NITROGEN	MASS FRACTION SULFUR
		KG/MOLE	J/KG	J/KG	J/KG K					
METHANE	CH4	.016	55500000	50010000	520	.75	.25	0	0	0
CARBON DIOXIDE	CO2	.044	0	0	189	.2727	0	.7273	0	0
ETHENE(-YLENE)	C2H4	.028	50464000	1E+33	294.5	.8571	.1429	0	0	0
ETHANE	C2H6	.03	51870000	47470000	277	.8	.2	0	0	0
OXYGEN	O2	.032	0	0	260	0	0	1	0	0
NITROGEN	N2	.028	0	0	295	0	0	0	1	0
CARBON MONOXIDE	CO	.028	10100000	10100000	297	.4286	0	.5714	0	0
HYDROGEN	H2	.02016	142000000	120000000	4120	0	1	0	0	0
PROPANE	C3H8	.044	50360000	46360000	183.7	.8182	.1818	0	0	0

VIRIAL COEFICIENTS FOR CP = A + BT + CT^2 + DT^3 (JOULES/KG K, T IN KELVIN)

		A	B *10^2	C *10^5	D *10^9
METHANE	CH4	1238	312.8	78.98	-685.5
CARBON DIOXIDE	CO2	607.3	95.95	-32.35	0
ETHENE(-YLENE)	C2H4	140.7	556.7	-297.1	629
ETHANE	C2H6	229.3	573.4	-213.15	241.9
OXYGEN	O2	879.6	19.66	-2.34	0
NITROGEN	N2	974.2	22.2	-3.389	0
CARBON MONOXIDE	CO	967.3	23.38	-3.563	0
HYDROGEN	H2	13323	215.5	-16.18	0
PROPANE	C3H8	-91.65	690.3	-356.1	718.8

```
10  REM **************************
15  REM *                        *
20  REM *        QUICKIE         *
25  REM *    SEQUENTIAL FILER    *
30  REM *                        *
35  REM * PREPARED FOR APPLE II  *
40  REM * WITH EPSON DOT MATRIX  *
45  REM * PRINTER, PKASO BOARD,  *
50  REM *    AND DISK DRIVE      *
55  REM *       AUG 1982         *
60  REM *      L PHILLIPS        *
65  REM **************************
100  REM            QUICKIE SEQUENTIAL FILER

140  DIM DTA(100),DTA$(100)
150 D$ =  CHR$ (4):I$ =  CHR$ (9)
199  REM -----READ PROMPTS
200  READ NDTA
210  FOR I = 1 TO NDTA: READ DTA$(I): NEXT I
500  HOME : PRINT "1) CREATE A FILE": PRINT
510  PRINT "2) READ & EDIT A FILE": PRINT
520  PRINT "3) DUMP A FILE": PRINT : PRINT
530  INPUT "WHICH? ";CHOICE: IF (CH < 1) + (CH > 3) THEN 500
540  ON CHOICE GOTO 2000,1500,3000
1500  REM -----READ A FILE
1510  GOSUB 5000: REM READ FILE
2000  REM -----INPUT DATA
2110  HOME : PRINT "USE 'RTN' FOR NO CHANGE"
2115  INVERSE : PRINT : INPUT "CHANGE # OF ITEMS? ";A$: NORMAL : IF A$ <  > "" THEN NDTA =  VAL (A$)
2120  FOR I = 1 TO NDTA
2125  PRINT : PRINT I") ";: PRINT DTA$(I);" = ";DTA(I)
2130  PRINT "NEW ";DTA$(I);: INPUT "? ";A$
2140  IF A$ <  > "" THEN DTA(I) =  VAL (A$)
2150  NEXT I
2200  REM -----WRITE FILE
2250  HOME : INPUT "WRITE DATA TO? ";F$: IF F$ = "" THEN 2250
2260  PRINT D$"OPEN"F$: PRINT D$"DELETE"F$: PRINT D$"OPEN"F$: PRINT D$"WRITE"F$
2265  PRINT NDTA
2270  FOR I = 1 TO NDTA: PRINT DTA(I): NEXT I
2280  PRINT D$"CLOSE"F$
2290  PRINT "DONE": END
3000  REM -----READ A FILE & DUMP TO PRINTER
3110  GOSUB 5000: REM READ FILE
3120  PRINT D$"PR#1": PRINT I$"80N"
3130  PRINT  CHR$ (12): PRINT F$: PRINT : PRINT
3150  FOR I = 1 TO NDTA
3160  PRINT I;")";I$"4T";DTA$(I);I$"45T";DTA(I)
3170  NEXT I
3180  PRINT D$"PR#0"
3190  END
5000  REM *****READ FILE SUBROUTINE
5110  HOME : INPUT "READ FILENAME? ";F$: IF F$ = "" THEN 5110
5120  PRINT D$"OPEN"F$: PRINT D$"READ"F$
5125  INPUT NDTA
5130  FOR I = 1 TO NDTA: INPUT DTA(I): NEXT
5140  PRINT D$"CLOSE"F$
5150  RETURN
10100  DATA  53: REM # OF ITEMS
10110  DATA WET FUEL KG/HR,DRY AIR KG/ HR,HUMIDITY,STACK FLOW M3/HR
10120  DATA H2O IN FUEL,C,H,O,N
10130  DATA GAS DENSITY KG/M3,H2O CONC KG/M3,C CONC KG/M3,H CONC KG/M3,O CONC KG/M3,N CONC KG/M3
10140  DATA PARTICULATE CONC KG/M3,TAR CON KG/M3,WATER SOL ORGANICS KG/M3
10150  DATA  C MASS FRACT IN PARTICULATE,H,O,N
10160  DATA  C MASS FRACT IN TAR,H,O,N
10170  DATA  C MASS FRACT IN WAT SOL ORG,H,O,N
10200  DATA SAMPLE T C, FEED T C,AIR FEED T C, REF T C
10210  DATA  ENTHALPY OF H2O @ SAMPLE T J/KG,@ FEED T, @ AIR FEED T, @ REF T
10220  DATA  AVG SPECIFIC HEAT OF DRY GAS  J/KG C,OF DRY FEED , OF AIR FEED, OF PARTICULATE,OF TAR,OF WAT SOL ORGANICS
10230  DATA  HEAT OF COMBUSTION OF DRY GAS J/KG,OF DRY FEED,OF PARTICULATE,OF TAR, OF WAT SOL ORGANICS
10240  DATA  PROCESS ENERGY INPUT,PROCESS ENERGY INPUT,PROCESS ENERGY INPUT,PROCESS HEAT LOSS
```

```
10  REM *************************
15  REM *                       *
20  REM *    GASIFIER MASS      *
25  REM *       BALANCE         *
30  REM *                       *
35  REM * PREPARED FOR APPLE II *
40  REM * WITH EPSON DOT MATRIX *
45  REM * PRINTER, PKASO BOARD, *
50  REM *    AND DISK DRIVE     *
55  REM *       AUG 1982        *
60  REM *      L PHILLIPS       *
65  REM *************************
100 D$ =  CHR$ (4):I$ =  CHR$ (9): REM CTRL-D FOR DOS CMDS, CTRL-I FOR PRINTER CMDS
1000  REM
                    READ DATA FILE

1110  HOME : INPUT "READ FILENAME? ";F$: IF F$ = "" THEN 1110
1140  PRINT D$"OPEN"F$: PRINT D$"READ"F$
1160  INFUT DUMMY: REM DON'T NEED NDTA (# OF ITEMS IN FILE)
1165  REM READ MASS BAL I/P VARS
1170  INPUT FW,AD,H,GD,WF,CF,HF,OF,NF,D,WC,CC,HC,OC,NC,PC,TC,SC,CP,HP,OP,NP,CT,HT,OT,NT,CS,HS,OS,NS
1175  REM DON'T NEED ENERGY BAL VARS
1200  PRINT D$"CLOSE"F$
2000  REM
                 CALCULATIONS

2150 FD = (1 - WF) * FW: REM DRY FEED MASS FLOW
2160  REM --OVERALL IN
2165 AI(1) = FD
2170 AI(2) = FW * WF
2180 AI(3) = AD
2190 AI(4) = AD * H
2200  REM --OVERALL OUT
2210 AO(1) = GD * D
2220 AO(2) = GD * PC
2230 AO(3) = GD * TC
2240 AO(4) = GD * SC
2250 AO(5) = GD * WC
2300  REM --C IN
2310 CI(1) = FD * CF
2350  REM --C OUT
2360 CO(1) = GD * CC
2370 CO(2) = GD * PC * CP
2380 CO(3) = GD * TC * CT
2390 CO(4) = GD * SC * CS
2400  REM --H IN
2410 HI(1) = FD * HF
2420 HI(2) = FW * WF * 2 / 18
2430 HI(4) = AD * N * 2 / 18
2450  REM --H OUT
2460 HO(1) = GD * HC
2470 HO(2) = GD * PC * HP
2480 HO(3) = GD * TC * HT
2490 HO(4) = GD * SC * HS
2500 HO(5) = GD * WC * 2 / 18
2510  REM --O IN
2520 OI(1) = FD * OF
2530 OI(2) = FW * WF * 16 / 18
2540 OI(3) = AD * .232
2550 OI(4) = AD * H * 16 / 18
2560  REM --O OUT
2570 OO(1) = GD * OC
2580 OO(2) = GD * PC * OP
```

```
2590 OO(3) = GD * TC * OT
2600 OO(4) = GD * SC * OS
2610 OO(5) = GD * WC * 16 / 18
2700  REM --N IN
2710 NI(1) = FD * NF
2720 NI(3) = AD * .768
2750  REM --N OUT
2760 NO(1) = GD * NC
2770 NO(2) = GD * PC * NP
2780 NO(3) = GD * TC * NT
2790 NO(4) = GD * SC * NS
3000  REM -----TOTAL THE INS & OUTS
3110  FOR I = 1 TO 5
3120 AI = AI + AI(I):AO = AO + AO(I)
3130 CI = CI + CI(I):CO = CO + CO(I)
3140 HI = HI + HI(I):HO = HO + HO(I)
3150 OI = OI + OI(I):OO = OO + OO(I)
3160 NI = NI + NI(I):NO = NO + NO(I)
3190  NEXT I
3200  REM -----PERCENT CLOSURES
3210 PC(1) = AO / AI * 100
3220 PC(2) = CO / CI * 100
3230 PC(3) = HO / HI * 100
3240 PC(4) = OO / OI * 100
3250 PC(5) = NO / NI * 100
5000  REM
                        PRINT REPORT

5050  PRINT D$"PR#1": PRINT  CHR$ (15): PRINT I$"132N": REM PRINTER ON, CONDENSED CHARS, 132 PER LINE
5080  PRINT F$: PRINT : PRINT
5100  DEF  FN RD(N) =  INT (N * 1000 + .5) / 1000: REM ROUNDS TO 3 DEC PTS
5110  DEF  FN PIN(N) =  INT ((N / AI * 100) * 100 + .5) / 100: REM % IN'S ROUNDED TO 2 PTS
5115  DEF  FN POUT(N) =  INT ((N / AO * 100) * 100 + .5) / 100: REM % OUT'S ROUNDEL TO 2 PTS
6000  REM -----PRINT TABLE OF PHASES IN/OUT
6030 T1$ = I$ + "23T":T2$ = I$ + "33T":T3$ = I$ + "45T":T4$ = I$ + "55T":T5$ = I$ + "67T":T6$ = I$ + "77T":T7$ = I$ + "89T":T8$ = I$
 + "99T":T9$ = I$ + "111T":T0$ = I$ + "121T": REM TABS
6050 A$(1) = "DRY FEED":A$(2) = "FEED MOISTURE":A$(3) = "DRY AIR":A$(4) = "AIR HUMIDITY"
6070  PRINT I$"23TOVERALL   (%)          CARBON    (%)          HYDROGEN  (%)          OXYGEN    (%)          NITROGEN  (%)"
6080  PRINT "IN - KG/HR": PRINT
6090  FOR I = 1 TO 4
7000  PRINT I;") ";A$(I);T1$; FN RD(AI(I));T2$; FN PI(AI(1));T3$; FN RD(CI(I));T4$; FN PI(CI(I));T5$; FN RD(HI(I));T6$; FN PI(HI(I))
;T7$; FN RD(OI(1)1;T8$; FN PI(OI(I));T9$; FN RD(NI(I));T0$; FN PI(NI(I))
7040  NEXT I
7045  PRINT "TOTAL";T1$; FN RD(AI);T2$; FN PI(AI);T3$; FN RD(CI);T4$; FN PI(CI);T5$; FN RD(HI);T6$; FN PI(HI);T7$; FN RD(OI);T8$; FN
 PI(OI);T9$; FN RD(NI);T0$; FN PI(NI)
7050  PRINT : PRINT "OUT - KG/HR": PRINT
7060 A$(1) = "DRY GAS":A$(2) = "PARTICULATES":A$(3) = "TARS":A$(4) = "WATER SOL ORGANICS":A$(5) = "WATER"
7070  FOR I = 1 TO 5
7080  PRINT I;") ";A$(I);T1$; FN RD(AO(I));T2$; FN PO(AO(I));T3$; FN RD(CO(I));T4$; FN PO(CO(I));T5$; FN RD(HO(I));T6$; FN PO(HO(I))
;T7$; FN RD(OO(I));T8$; FN PO(OO(I)1;T9$; FN RD(NO(I));T0$; FN PO(NO(I))
7090  NEXT I
7095  PRINT "TOTAL";T1$; FN RD(AO);T2$; FN PO(AO);T3$; FN RD(CO);T4$; FN PO(CO);T5$; FN RD(HO);T6$; FN PO(HO);T7$; FN RD(OO);T8$; FN
 PO(OO);T9$; FN RD(NO);T0$; FN PO(NO)
7400  DEF  FN RD(N) =  INT (N * 100 + .5) / 100: REM ROUNDS TO 2 DEC PTS
7500  REM ASSEMBLE 5X5 MATRIX, DP(I,J), TO OUTPUT SUMMARY TABLE
7610 DP(1,1) = AI(1) + AI(2):DP(1,2) = AI(3) + AI(4):DP(1,3) = AO(1):DP(1,4) = AO - AO(1)
7620 DP(2,1) = CI(1) + CI(2):DP(2,2) = CI(3) + CI(4):DP(2,3) = CO(1):DP(2,4) = CO - CO(1)
7630 DP(3,1) = HI(1) + HI(2):DP(3,2) = HI(3) + HI(4):DP(3,3) = HO(1):DP(3,4) = HO - HO(1)
7640 DP(4,1) = OI(1) + OI(2):DP(4,2) = OI(3) + OI(4):DP(4,3) = OO(1):DP(4,4) = OO - OO(1)
7650 DP(5,1) = NI(1) + NI(2):DP(5,2) = NI(3) + NI(4):DP(5,3) = NO(1):DP(5,4) = NO - NO(1)
7600  FOR I = 1 TO 5:DP(I,5) = PC(I): NEXT
8000  REM -----PRINT MATERIAL BALANCE SUMMARY
8020 BS$ = "": FOR I = 1 TO 80:BS$ = BS$ +  CHR$ (8): NEXT : REM 80 BACKSPACE
8030 V$ =  CHR$ (124): REM VERT BAR ON EPSON PRINTER
8040 V1$ = V$ + "                    " + V$ + "           " + V$ + "           " + V$ + "           " + V$ + "           " + V$ + "
     " + V$
```

```
8045 V2$ = V$ + "                    " + V$ + "           " + "            " + V$ + "           " + "            " + V$ + "             "
+ V$
8050 V2$ = BS$ + V2$:V1$ = BS$ + V1$: REM BACKSPACE TO COL 0 & OVERSTRIKE WITH VERT BARS
8080 L$ = " ------------------------------------------------------------------": REM 66 "-"
8210 A$(1) = "OVERALL":A$(2) = "CARBON":A$(3) = "HYDROGEN":A$(4) = "OXYGEN":A$(5) = "NITROGEN"
8300  PRINT : PRINT : PRINT L$
8320  PRINT I$"27TKG/HR"I$"51TKG/HR";V2$
8330  PRINT I$"27TINPUT"I$"51TOUTPUT";V2$
8340  PRINT I$"71T%";V1$
8350  PRINT I$"21TFUEL        AIR        DRY GAS     OTHERS      CLOSURE";V1$
8450  PRINT V1$: PRINT L$
8500  FOR I = 1 TO 5
8530  PRINT V1$
8540  PRINT "   ";A$(I);I$"21T" FN RD(OP(I,1));I$"33T" FN RD(OP(I,2));I$"44T" FN RD(OP(I,3));I$"57T" FN RD(OP(I,4));I$"69T" FN RD(OP
(I,5));V1$
8550  PRINT V1$: PRINT L$
8580  NEXT I
8980  PRINT  CHR$ (12): REM FORM-FEED
8990  PRINT D$"PR#0": REM PRINTER OFF
9000  HOME : INPUT "READ ANOTHER FILE? (Y/N) ";A$: IF  LEFT$ (A$,1) = "Y" THEN  RUN : REM DO IT AGAIN
9050  END : REM ELSE, QUIT
```

```
10  REM *************************
15  REM *                       *
20  REM *    GASIFIER ENERGY    *
25  REM *        BALANCE        *
30  REM *                       *
35  REM * PREPARED FOR APPLE II *
40  REM * WITH EPSON DOT MATRIX *
45  REM * PRINTER, PKASO BOARD, *
50  REM *    AND DISK DRIVE     *
55  REM *       AUG 1982        *
60  REM *      L PHILLIPS       *
65  REM *************************
100 D$ =  CHR$ (4):I$ =  CHR$ (9): REM CTRL-D FOR DOS CMDS, CTRL-I FOR PRINTER CMDS
1000  REM
                      READ DATA FILE

1110  HOME : INPUT "READ FILENAME? ";F$: IF F$ = "" THEN 1110
1140  PRINT D$"OPEN"F$: PRINT D$"READ"F$
1160  INPUT DUMMY: REM DON'T NEED NDTA (# OF ITEMS IN FILE)
1165  REM READ MASS BAL I/P VARS
1170  INPUT FW,AD,H,GD,WF,CF,HF,OF,NF,D,WC,CC,HC,OC,NC,PC,TC,SC,CP,HP,OP,NP,CT,HT,OT,NT,CS,HS,OS,NS
1180  REM ADD'L ENERGY BAL VARS
1190  INPUT TSTACK,TFEED,TINAIR,TREF,HSTACK,HWOOD,HAIR,HREF,GCP,FCP,ACP,PARTCP,TARCP,SOLCP,GH,FH,PH,TH,SH,E1,E2,E3,HL
1200  PRINT D$"CLOSE"F$
2000  REM
                    CALCULATIONS

2150 FD = (1 - WF) * FW: REM DRY FEED MASS FLOW
2160  REM --ENERGY IN
2180 EIN(1) = FD * FH
2190 EIN(2) = E1 + E2 + E3
2200 EIN(3) = AD * ACP * (TINAIR - TREF) + AD * H * (HAIR - HREF)
2210 EIN(4) = GD * WC * (HWOOD - HREF)
2220 EIN(5) = FD * FCP * (TFEED - TREF)
2500  REM --ENERGY OUT
2550 EOUT(1) = GD * GH
2560 EOUT(2) = GD * D * GCP * (TSTACK - TREF)
2570 EOUT(3) = GD * WC * (HSTACK - HREF)
2580 EOUT(4) = GD * PC * PH
2590 EOUT(5) = GD * TC * TH
2600 EOUT(6) = GD * SC * SH
2610 EOUT(7) = (PARTCP * PC + TARCP * TC + SOLCP * SC) * GD * (TSTACK - TREF)
2620 EOUT(8) = HL
2800  REM -----SUM THE INS & OUTS
2820  FOR I = 1 TO 8
2830 EIN = EIN + EIN(I):EOUT = EOUT + EOUT(I)
2840  NEXT I
2900  REM --INS & OUT AS %'S
2910  FOR I = 1 TO 8
2920 PIN(I) = EIN(I) / EIN * 100:POUT(I) = EOUT(I) / EOUT * 100
2930  NEXT I
3000  REM -----% CLOSURE
3020 PC = EOUT / EIN * 100
3030  REM -----GROSS EFFICIENCY
3040 GE = (EOUT - HL) / EIN * 100
3300  REM -----NET EFFICIENCY
3340 NE = EOUT(1) / EIN * 100
5000  REM
                        PRINT REPORT

5050  PRINT D$"PR#1": PRINT  CHR$ (15): PRINT I$"132N": REM PRINTER ON, CONDENSED CHARS, 132 PER LINE
5080  PRINT F$: PRINT
5100  DEF  FN RD(N) =  INT (N / 1000 + .5) * 1000: REM ROUNDS TO NEAREST 1000
```

```
5110  DEF  FN R1(N) =  INT (N * 10 + .5) / 10: REM ROUNDS TO 1 DEC PT
5200 I$(1) = "H OF C FEED":I$(2) = "PROCESS ENERGY INPUT":I$(3) = "ENTHALPY PROCESS AIR":I$(4) = "ENTHALPY FEED MOIST":I$(5) = "SENS
 HEAT DRY FEED"
5210 O$(1) = "H OF C DRY GAS":O$(2) = "SENS HEAT DRY GAS":O$(3) = "ENTHALPY GAS H2O":O$(4) = "H OF C PARTICULATES":O$(5) = "H OF C T
ARS":O$(6) = "H OF C WAT SOL ORGANICS":O$(7) = "SENS HEAT OF PART + TAR + SOL":O$(8) = "PROCESS HEAT LOSS"
5340 T1$ = I$ + "35T":T2$ = I$ + "48T":T3$ = I$ + "60T":T4$ = I$ + "95T":T5$ = I$ + "108T": REM TABS
5500  PRINT "ENERGY IN:";T3$;"ENERGY OUT:": PRINT
5520  PRINT T1$"JOULES/HOUR";T2$;" %";T4$;"JOULES/HOUR";T5$;" %": PRINT
5550  FOR I = 1 TO 8
5560  IF I <  = 5 THEN  PRINT I;") ";I$(I);T1$; FN RD(EIN(I));T2$; FN R1(PIN(I));
5563  IF I <  = 8 THEN  PRINT T3$;I;") ";O$(I);T4$; FN RD(EOUT(I));T5$; FN R1(POUT(I));
5566  PRINT
5570  NEXT I
5575  PRINT : PRINT "TOTAL =";T1$; FN RD(EIN);T3$;"TOTAL =";T4$; FN RD(EOUT)
5580 T1$ = I$ + "40T":T2$ = I$ + "63T": REM TABS
5600  PRINT : PRINT : PRINT T1$;"% CLOSURE =";T2$; FN R1(PC)
5610  PRINT T1$;"GROSS EFFICIENCY =";T2$; FN R1(GE)
5620  PRINT T1$;"NET EFFICIENCY =";T2$; FN R1(NE): PRINT : PRINT
8980  PRINT  CHR$ (12): REM FORM-FEED
8990  PRINT D$"PR#0": REM PRINTER OFF
9000  HOME : INPUT "READ ANOTHER FILE? (Y/N) ";A$: IF  LEFT$ (A$,1) = "Y" THEN  RUN : REM DO IT AGAIN
9050  END : REM ELSE, QUIT
```

APPENDIX L

GAS ANALYSIS PROGRAM RESULTS

RUNS 4-8

```
RUN 4

BASIS = 288 K & 101300 PASCALS

                                             MASS CONCENTRATION  (KG/CU M)

                          VOL %        C               H               O               N               S                 TOTAL

METHANE          CH4      2.88         .0146105769     4.87019231E-03 0                0               0                 .0194807692
CARBON DIOXIDE   CO2      17.73        .0899806294     0              .239981341       0               0                 .329961971
ETHENE(-YLENE)   C2H4     .87          8.90599417E-03 1.4848519E-03   0                0               0                 .0103908461
ETHANE           C2H6     .45          4.57129964E-03 1.14282491E-03 0                 0               0                 5.71412455E-03
OXYGEN           O2       5.79         0               0              .0783289263      0               0                 .0783289263
NITROGEN         N2       60.43        0               0              0                .720522481      0                 .720522481
CARBON MONOXIDE  CO       9.33         .0473581053     0              .0631367741      0               0                 .110494879
HYDROGEN         H2       2.53         0               2.15993292E-03 0                0               0                 2.15993292E-03
PROPANE          C3H8     0            0               0              0                0               0                 0

TOTAL                     100.01       .165426605      9.65780203E-03 .381447042       .720522481      0                 1.27705393


                                             MASS CONCENTRATION %

                          VOL %        C               H               O               N               S                 TOTAL

METHANE          CH4      2.88         1.14            .38             0               0               0                 1.53
CARBON DIOXIDE   CO2      17.73        7.05            0               18.79           0               0                 25.84
ETHENE(-YLENE)   C2H4     .87          .7              .12             0               0               0                 .81
ETHANE           C2H6     .45          .36             .09             0               0               0                 .45
OXYGEN           O2       5.79         0               0               6.13            0               0                 6.13
NITROGEN         N2       60.43        0               0               0               56.42           0                 56.42
CARBON MONOXIDE  CO       9.33         3.71            0               4.94            0               0                 8.65
HYDROGEN         H2       2.53         0               .17             0               0               0                 .17
PROPANE          C3H8     0            0               0               0               0               0                 0

TOTAL                     100.01       12.95           .76             29.87           56.42           0                 100


STD HIGHER HEAT OF COMBUSTION  (J/CU M)

CH4          1081182.69
CO2          0
C2H4         524363.656
C2H6         296391.64
O2           0
N2           0
CO           1115998.28
H2           306710.474
C3H8         0

TOTAL        3324646.74


HEAT CAPACITY (CP) = 887.797233 + .527768473 T + -1.29160919E-04 T^2 + -4.25665532E-09 T^3  (J/KG K)
                                        (TEMPERATURE IN KELVIN)


INTEGRAL AVG CP BETWEEN 288 & 550 = 1085.17403  J/KG K
```

```
RUN 5

BASIS = 288 K & 101300 PASCALS

                                                MASS CONCENTRATION  (KG/CU M)

                               VOL %         C               H               O               N               S               TOTAL

METHANE           CH4          2.79          .0141539964     4.71799888E-03  0               0               0               .0188719952
CARBON DIOXIDE    CO2          19.63         .0996232238     0               .265698462      0               0               .365321686
ETHENE(-YLENE)    C2H4         .91           9.31546517E-03  1.55312096E-03  0               0               0               .0108685861
ETHANE            C2H6         .14           1.42218211E-03  3.55545528E-04  0               0               0               1.77772764E-03
OXYGEN            O2           5.64          0               0               .0762996795     0               0               .0762996795
NITROGEN          N2           58.9          0               0               0               .702279896      0               .702279896
CARBON MONOXIDE   CO           9.25          .0469520336     0               .0625954084     0               0               .109547442
HYDROGEN          H2           2.83          0               2.41605144E-03  0               0               0               2.41605144E-03
PROPANE           C3H8         0             0               0               0               0               0               0

TOTAL                          100.09        .171466901      9.04271672E-03  .40459355       .702279896      0               1.28738306


                                                MASS CONCENTRATION %

                               VOL %         C               H               O               N               S               TOTAL

METHANE           CH4          2.79          1.1             .37             0               0               0               1.47
CARBON DIOXIDE    CO2          19.63         7.74            0               20.64           0               0               28.38
ETHENE(-YLENE)    C2H4         .91           .72             .12             0               0               0               .84
ETHANE            C2H6         .14           .11             .03             0               0               0               .14
OXYGEN            O2           5.64          0               0               5.93            0               0               5.93
NITROGEN          N2           58.9          0               0               0               54.55           0               54.55
CARBON MONOXIDE   CO           9.25          3.65            0               4.86            0               0               8.51
HYDROGEN          H2           2.83          0               .19             0               0               0               .19
PROPANE           C3H8         0             0               0               0               0               0               0

TOTAL                          100.09        13.32           .7              31.43           54.55           0               100


STD HIGHER HEAT OF COMBUSTION  (J/CU M)

CH4               1047395.73
CO2               0
C2H4              548472.33
C2H6              92210.7326
O2                0
N2                0
CO                1106429.16
H2                343079.305
C3H8              0

TOTAL             3137587.26


HEAT CAPACITY (CP) = 882.867603 + .529742952 T + -1.314574E-04 T^2 + -4.40457847E-09 T^3  (J/KG K)
                                        (TEMPERATURE IN KELVIN)


INTEGRAL AVG CP BETWEEN 288 & 538 = 1082.2614  J/KG K
```

```
RUN 6

BASIS = 288 K & 101300 PASCALS

                                         MASS CONCENTRATION  (KG/CU M)

                          VOL %        C                H                O                N                S                TOTAL

METHANE          CH4      2.01         .0101969651      3.39898838E-03 0                0                0                .0135959535
CARBON DIOXIDE   CO2      12.84        .0651636369      0                .173793594       0                0                .238957231
ETHENE(-YLENE)   C2H4     .75          7.67758118E-03 1.28004474E-03 0                0                0                8.95762592E-03
ETHANE           C2H6     .11          1.1174288E-03    2.793572E-04     0                0                0                1.396786E-03
OXYGEN           O2       3.61         0                0                .0488372062      0                0                .0488372062
NITROGEN         N2       67.37        0                0                0                .803269892       0                .803269892
CARBON MONOXIDE CO        6.36         .0322826956      0                .0430385727      0                0                .0753212682
HYDROGEN         H2       5.58         0                4.76380461E-03 0                0                0                4.76380461E-03
PROPANE          C3H8     0            0                0                0                0                0                0

TOTAL                     98.63        .116438308       9.72219494E-03 .265669373       .803269892       0                1.19509977


                                         MASS CONCENTRATION %

                          VOL %        C                H                O                N                S                TOTAL

METHANE          CH4      2.01         .85              .28              0                0                0                1.14
CARBON DIOXIDE   CO2      12.84        5.45             0                14.54            0                0                19.99
ETHENE(-YLENE)   C2H4     .75          .64              .11              0                0                0                .75
ETHANE           C2H6     .11          .09              .02              0                0                0                .12
OXYGEN           O2       3.61         0                0                4.09             0                0                4.09
NITROGEN         N2       67.37        0                0                0                67.21            0                67.21
CARBON MONOXIDE CO        6.36         2.7              0                3.6              0                0                6.3
HYDROGEN         H2       5.58         0                .4               0                0                0                .4
PROPANE          C3H8     0            0                0                0                0                0                0

TOTAL                     98.63        9.74             .81              22.23            67.21            0                100


STD HIGHER HEAT OF COMBUSTION  (J/CU M)

CH4              754575.421
CO2              0
C2H4             452037.634
C2H6             72451.2899
O2               0
N2               0
CO               760744.809
H2               676460.255
C3H8             0

TOTAL            2716269.41


HEAT CAPACITY (CP) = 941.645489 + .456436623 T + -1.0708313E-04 T^2 + -2.80126982E-09 T^3  (J/KG K)
                                          (TEMPERATURE IN KELVIN)


INTEGRAL AVG CP BETWEEN 288 & 909 = 1172.2619  J/KG K
```

```
RUN 7

BASIS = 288 K & 101300 PASCALS

                                              MASS CONCENTRATION  (KG/CU M)

                           VOL %        C               H               O               N               S               TOTAL

METHANE          CH4       2.89         .0146613081     4.8871027E-03   0               0               0               .0195484108
CARBON DIOXIDE   CO2       15.44        .0783587659     0               .208985443      0               0               .287344209
ETHENE(-YLENE)   C2H4      .76          7.77994892E-03  1.29711201E-03  0               0               0               9.07706093E-03
ETHANE           C2H6      .2           2.03168873E-03  5.07922182E-04  0               0               0               2.53961091E-03
OXYGEN           O2        1.92         0               0               .025974359      0               0               .025974359
NITROGEN         N2        62.1         0               0               0               .740434322      0               .740434322
CARBON MONOXIDE  CO        9.54         .0484240433     0               .064557859      0               0               .112981902
HYDROGEN         H2        7.06         0               6.02732268E-03  0               0               0               6.02732268E-03
PROFANE          C3H8      .04          6.26653209E-04  1.39239249E-04  0               0               0               7.65892458E-04

TOTAL                      99.95        .151882408      .0128586988     .299517661      .740434322      0               1.20469309


                                              MASS CONCENTRATION %

                           VOL %        C               H               O               N               S               TOTAL

METHANE          CH4       2.89         1.22            .41             0               0               0               1.62
CARBON DIOXIDE   CO2       15.44        6.5             0               17.35           0               0               23.85
ETHENE(-YLENE)   C2H4      .76          .65             .11             0               0               0               .75
ETHANE           C2H6      .2           .17             .04             0               0               0               .21
OXYGEN           O2        1.92         0               0               2.16            0               0               2.16
NITROGEN         N2        62.1         0               0               0               61.46           0               61.46
CARBON MONOXIDE  CO        9.54         4.02            0               5.36            0               0               9.38
HYDROGEN         H2        7.06         0               .5              0               0               0               .5
PROPANE          C3H8      .04          .05             .01             0               0               0               .06

TOTAL                      99.95        12.61           1.07            24.86           61.46           0               100


STD HIGHER HEAT OF COMBUSTION  (J/CU M)

CH4              1084936.8
CO2              0
C2H4             458064.803
C2H6             131729.618
O2               0
N2               0
CO               1141117.21
H2               855879.82
C3H8             38570.3442

TOTAL            3710298.6


HEAT CAPACITY (CP) = 941.536012 + .511435081 T + -1.18973766E-04 T^2 + -5.41723775E-09 T^3  (J/KG K)
                                    (TEMPERATURE IN KELVIN)


INTEGRAL AVG CP BETWEEN 288 & 811 = 1182.83114  J/KG K
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RUN 8

BASIS = 288 K & 101300 PASCALS

                                         MASS CONCENTRATION  (KG/CU M)

                          VOL %         C               H               O               N               S               TOTAL

METHANE          CH4      2.82          .0143061899     4.76872997E-03 0               0               0               .0190749199
CARBON DIOXIDE   CO2      17.18         .0871893522     0              .232536912      0               0               .319726264
ETHENE(-YLENE)   C2H4     1.1           .0112604524     1.87739896E-03 0               0               0               .0131378514
ETHANE           C2H6     .09           9.14259928E-04 2.28564982E-04 0               0               0               1.14282491E-03
OXYGEN           O2       1.77          0               0              .0239451122     0               0               .0239451122
NITROGEN         N2       55.97         0               0              0               .667344751      0               .667344751
CARBON MONOXIDE  CO       9.16          .046495203      0              .061986372      0               0               .108481575
HYDROGEN         H2       5.02          0               4.28571669E-03 0               0               0               4.28571669E-03
PROPANE          C3H8     .04           6.26653209E-04 1.39239249E-04 0               0               0               7.65892458E-04

TOTAL                     93.15         .160792111      .0112996499    .318468396      .667344751      0               1.15790491


                                         MASS CONCENTRATION %

                          VOL %         C               H               O               N               S               TOTAL

METHANE          CH4      2.82          1.24            .41             0               0               0               1.65
CARBON DIOXIDE   CO2      17.18         7.53            0               20.08           0               0               27.61
ETHENE(-YLENE)   C2H4     1.1           .97             .16             0               0               0               1.13
ETHANE           C2H6     .09           .08             .02             0               0               0               .1
OXYGEN           O2       1.77          0               0               2.07            0               0               2.07
NITROGEN         N2       55.97         0               0               0               57.63           0               57.63
CARBON MONOXIDE  CO       9.16          4.02            0               5.35            0               0               9.37
HYDROGEN         H2       5.02          0               .37             0               0               0               .37
PROPANE          C3H8     .04           .05             .01             0               0               0               .07

TOTAL                     93.15         13.89           .98             27.5            57.63           0               100


STD HIGHER HEAT OF COMBUSTION  (J/CU M)

CH4           1058658.05
CO2           0
C2H4          662988.53
C2H6          59278.3281
O2            0
N2            0
CO            1095663.91
H2            608571.77
C3H8          38570.3442

TOTAL         3523730.93


HEAT CAPACITY (CP) = 909.441754 + .551754192 T + -1.38437242E-04 T^2 + -3.44171288E-09 T^3  (J/KG K)
                                        (TEMPERATURE IN KELVIN)


INTEGRAL AVG CP BETWEEN 288 & 874 = 1178.47169  J/KG K
```

APPENDIX M

MASS BALANCE PROGRAM RESULTS

RUNS 4-8

RUN 4

IN - KG/HR	OVERALL	(%)	CARBON	(%)	HYDROGEN	(%)	OXYGEN	(%)	NITROGEN	(%)
1) DRY FEED	48.019	22.57	22.871	10.75	2.924	1.37	22.084	10.38	.154	.07
2) FEED MOISTURE	17.841	8.38	0	0	1.982	.93	15.859	7.45	0	0
3) DRY AIR	145.9	68.57	0	0	0	0	33.849	15.91	112.051	52.66
4) AIR HUMIDITY	1.021	.48	0	0	.113	.05	.908	.43	0	0
TOTAL	212.781	100	22.871	10.75	5.02	2.36	72.699	34.17	112.205	52.73
OUT - KG/HR										
1) DRY GAS	151.324	79.92	19.6	10.35	1.145	.6	45.196	23.87	85.379	45.09
2) PARTICULATES	1.232	.65	.748	.4	.014	.01	0	0	9E-03	0
3) TARS	1.446	.76	1.08	.57	.129	.07	0	0	0	0
4) WATER SOL ORGANICS	.972	.51	.5	.26	.092	.05	.373	.2	0	0
5) WATER	34.365	18.15	0	0	3.818	2.02	30.547	16.13	0	0
TOTAL	189.339	100	21.928	11.58	5.198	2.75	76.116	40.2	85.388	45.1

	KG/HR INPUT		KG/HR OUTPUT		% CLOSURE
	FUEL	AIR	DRY GAS	OTHERS	
OVERALL	65.86	146.92	151.32	38.01	88.98
CARBON	22.87	0	19.6	2.33	95.88
HYDROGEN	4.91	.11	1.14	4.05	103.54
OXYGEN	37.94	34.76	45.2	30.92	104.7
NITROGEN	.15	112.05	85.38	.01	76.1

RUN 5

	OVERALL	(%)	CARBON	(%)	HYDROGEN	(%)	OXYGEN	(%)	NITROGEN	(%)
IN - KG/HR										
1) DRY FEED	48.019	23.02	22.871	10.96	2.924	1.4	22.084	10.59	.154	.07
2) FEED MOISTURE	17.841	8.55	0	0	1.982	.95	15.859	7.6	0	0
3) DRY AIR	141.7	67.92	0	0	0	0	32.874	15.76	108.826	52.17
4) AIR HUMIDITY	1.053	.5	0	0	.117	.06	.936	.45	0	0
TOTAL	208.613	100	22.871	10.96	5.024	2.41	71.753	34.4	108.979	52.24
OUT - KG/HR										
1) DRY GAS	149.807	81.83	19.963	10.9	1.052	.57	47.095	25.73	81.748	44.66
2) PARTICULATES	.78	.43	.402	.22	6E-03	0	0	0	0	0
3) TARS	.698	.38	.475	.26	.079	.04	0	0	0	0
4) WATER SOL ORGANICS	.582	.32	.339	.19	.054	.03	.188	.1	0	0
5) WATER	31.195	17.04	0	0	3.466	1.89	27.729	15.15	0	0
TOTAL	183.062	100	21.179	11.57	4.658	2.54	75.012	40.98	81.748	44.66

	KG/HR INPUT		KG/HR OUTPUT		
	FUEL	AIR	DRY GAS	OTHERS	% CLOSURE
OVERALL	65.86	142.75	149.81	33.26	87.75
CARBON	22.87	0	19.96	1.22	92.6
HYDROGEN	4.91	.12	1.05	3.61	92.71
OXYGEN	37.94	33.81	47.1	27.92	104.54
NITROGEN	.15	108.83	81.75	0	75.01

RUN 6

	OVERALL	(%)	CARBON	(%)	HYDROGEN	(%)	OXYGEN	(%)	NITROGEN	(%)
IN - KG/HR										
1) DRY FEED	48.019	21.91	22.871	10.44	2.924	1.33	22.084	10.08	.154	.07
2) FEED MOISTURE	17.841	8.14	0	0	1.982	.9	15.859	7.24	0	0
3) DRY AIR	152.1	69.4	0	0	0	0	35.287	16.1	116.813	53.3
4) AIR HUMIDITY	1.217	.56	0	0	.135	.06	1.082	.49	0	0
TOTAL	219.177	100	22.871	10.44	5.042	2.3	74.312	33.9	116.966	53.37
OUT - KG/HR										
1) DRY GAS	180.804	78.38	17.611	7.63	1.471	.64	40.2	17.43	121.539	52.69
2) PARTICULATES	1.543	.67	.048	.02	0	0	0	0	0	0
3) TARS	3.465	1.5	2.436	1.06	.371	.16	0	0	0	0
4) WATER SOL ORGANICS	.832	.36	.491	.21	.081	.03	.258	.11	0	0
5) WATER	44.028	19.09	0	0	4.892	2.12	39.136	16.97	0	0
TOTAL	230.672	100	20.586	8.92	6.814	2.95	79.595	34.51	121.539	52.69

	KG/HR INPUT		KG/HR OUTPUT		
	FUEL	AIR	DRY GAS	OTHERS	% CLOSURE
OVERALL	65.86	153.32	180.8	49.87	105.24
CARBON	22.87	0	17.61	2.97	90.01
HYDROGEN	4.91	.14	1.47	5.34	135.15
OXYGEN	37.94	36.37	40.2	39.39	107.11
NITROGEN	.15	116.81	121.54	0	103.91

RUN 7

	OVERALL	(%)	CARBON	(%)	HYDROGEN	(%)	OXYGEN	(%)	NITROGEN	(%)
IN - KG/HR										
1) DRY FEED	48.407	23.9	23.192	11.45	2.943	1.45	22.117	10.92	.155	.08
2) FEED MOISTURE	17.453	8.62	0	0	1.939	.96	15.514	7.66	0	0
3) DRY AIR	135.5	66.89	0	0	0	0	31.436	15.52	104.064	51.37
4) AIR HUMIDITY	1.201	.59	0	0	.133	.07	1.067	.53	0	0
TOTAL	202.561	100	23.192	11.45	5.016	2.48	70.134	34.62	104.219	51.45
OUT - KG/HR										
1) DRY GAS	144.6	80.1	18.252	10.11	1.548	.86	35.988	19.93	88.848	49.22
2) PARTICULATES	2.088	1.16	1.38	.76	2E-03	0	0	0	0	0
3) TARS	2.328	1.29	1.667	.92	.221	.12	0	0	0	0
4) WATER SOL ORGANICS	1.692	.94	.797	.44	.174	.1	.722	.4	0	0
5) WATER	29.82	16.52	0	0	3.313	1.84	26.507	14.68	0	0
TOTAL	180.528	100	22.096	12.24	5.259	2.91	63.217	35.02	88.848	49.22

	KG/HR INPUT		KG/HR OUTPUT		
	FUEL	AIR	DRY GAS	OTHERS	% CLOSURE
OVERALL	65.86	136.7	144.6	35.93	89.12
CARBON	23.19	0	18.25	3.84	95.27
HYDROGEN	4.88	.13	1.55	3.71	104.84
OXYGEN	37.63	32.5	35.99	27.23	90.14
NITROGEN	.15	104.06	88.85	0	85.25

RUN 8

	OVERALL	(%)	CARBON	(%)	HYDROGEN	(%)	OXYGEN	(%)	NITROGEN	(%)
IN - KG/HR										
1) DRY FEED	47.637	20.74	22.551	9.82	2.896	1.26	21.765	9.47	.152	.07
2) FEED MOISTURE	18.223	7.93	0	0	2.025	.88	16.199	7.05	0	0
3) DRY AIR	162.6	70.78	0	0	0	0	37.723	16.42	124.877	54.36
4) AIR HUMIDITY	1.254	.55	0	0	.139	.06	1.114	.49	0	0
TOTAL	229.714	100	22.551	9.82	5.06	2.2	76.801	33.43	125.029	54.43
OUT - KG/HR										
1) DRY GAS	157.48	82.93	20.422	10.75	1.435	.76	40.45	21.3	95.123	50.09
2) PARTICULATES	.782	.41	.362	.19	5E-03	0	.101	.05	4E-03	0
3) TARS	3.104	1.63	2.154	1.13	.335	.18	.546	.29	9E-03	0
4) WATER SOL ORGANICS	.466	.25	.231	.12	.034	.02	.114	.06	.087	.05
5) WATER	28.067	14.78	0	0	3.119	1.64	24.948	13.14	0	0
TOTAL	189.899	100	23.169	12.2	4.928	2.6	66.159	34.84	95.223	50.14

	KG/HR INPUT		KG/HR OUTPUT		% CLOSURE
	FUEL	AIR	DRY GAS	OTHERS	
OVERALL	65.86	163.85	157.48	32.42	82.67
CARBON	22.55	0	20.42	2.75	102.74
HYDROGEN	4.92	.14	1.44	3.49	97.38
OXYGEN	37.96	38.84	40.45	25.71	86.14
NITROGEN	.15	124.88	95.12	.1	76.16

APPENDIX N

ENERGY BALANCE PROGRAM RESULTS

RUNS 4-8

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RUN 4

ENERGY IN:                                                ENERGY OUT:

                            JOULES/HOUR   %                                                JOULES/HOUR   %

1) H OF C FEED              860012000     99.3            1) H OF C DRY GAS                394013000     61.6
2) PROCESS ENERGY INPUT     6710000       .8              2) SENS HEAT DRY GAS             43017000      6.7
3) ENTHALPY PROCESS AIR     -18000        0               3) ENTHALPY GAS H20              101858000     15.9
4) ENTHALPY FEED MOIST      -619000       -.1             4) H OF C PARTICULATES           16021000      2.5
5) SENS HEAT DRY FEED       0             0               5) H OF C TARS                   49298000      7.7
                                                          6) H OF C WAT SOL ORGANICS       24195000      3.8
                                                          7) SENS HEAT OF PART + TAR + SOL 0             0
                                                          8) PROCESS HEAT LOSS             11300000      1.8

TOTAL =                     866085000                     TOTAL =                          639702000

                              % CLOSURE =          73.9
                              GROSS EFFICIENCY =   72.6
                              NET EFFICIENCY =     45.5


RUN 5

ENERGY IN:                                                ENERGY OUT:

                            JOULES/HOUR   %                                                JOULES/HOUR   %

1) H OF C FEED              860012000     99.2            1) H OF C DRY GAS                365263000     64.7
2) PROCESS ENERGY INPUT     6710000       .8              2) SENS HEAT DRY GAS             43765000      7.8
3) ENTHALPY PROCESS AIR     3000          0               3) ENTHALPY GAS H20              92962000      16.5
4) ENTHALPY FEED MOIST      94000         0               4) H OF C PARTICULATES           10684000      1.9
5) SENS HEAT DRY FEED       0             0               5) H OF C TARS                   24444000      4.3
                                                          6) H OF C WAT SOL ORGANICS       16121000      2.9
                                                          7) SENS HEAT OF PART + TAR + SOL 0             0
                                                          8) PROCESS HEAT LOSS             11300000      2

TOTAL =                     866819000                     TOTAL =                          564539000

                              % CLOSURE =          65.1
                              GROSS EFFICIENCY =   63.8
                              NET EFFICIENCY =     42.1


RUN 6

ENERGY IN:                                                ENERGY OUT:

                            JOULES/HOUR   %                                                JOULES/HOUR   %

1) H OF C FEED              860012000     99.2            1) H OF C DRY GAS                410931000     47.1
2) PROCESS ENERGY INPUT     6710000       .8              2) SENS HEAT DRY GAS             131591000     15.1
3) ENTHALPY PROCESS AIR     0             0               3) ENTHALPY GAS H20              163829000     18.8
4) ENTHALPY FEED MOIST      0             0               4) H OF C PARTICULATES           23458000      2.7
5) SENS HEAT DRY FEED       0             0               5) H OF C TARS                   118475000     13.6
                                                          6) H OF C WAT SOL ORGANICS       23799000      2.7
                                                          7) SENS HEAT OF PART + TAR + SOL 0             0
                                                          8) PROCESS HEAT LOSS             1060000       .1

TOTAL =                     866722000                     TOTAL =                          873163000

                              % CLOSURE =          100.7
                              GROSS EFFICIENCY =   100.6
                              NET EFFICIENCY =     47.4
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RUN 7

ENERGY IN:                                                    ENERGY OUT:

                                      JOULES/HOUR   %                                             JOULES/HOUR   %

1) H OF C FEED                        869876000    99.2       1) H OF C DRY GAS                   445920000    55.5
2) PROCESS ENERGY INPUT               6710000      .8         2) SENS HEAT DRY GAS                89390000     11.1
3) ENTHALPY PROCESS AIR               14000        0          3) ENTHALPY GAS H2O                 104549000    13
4) ENTHALPY FEED MOIST                358000       0          4) H OF C PARTICULATES              43639000     5.4
5) SENS HEAT DRY FEED                 0            0          5) H OF C TARS                      78686000     9.8
                                                              6) H OF C WAT SOL ORGANICS          39931000     5
                                                              7) SENS HEAT OF PART + TAR + SOL    0            0
                                                              8) PROCESS HEAT LOSS                1060000      .1

TOTAL =                               876958000               TOTAL =                             803175000

                                         % CLOSURE =          91.6
                                         GROSS EFFICIENCY =   91.5
                                         NET EFFICIENCY =     50.8
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RUN 8

ENERGY IN:                                                    ENERGY OUT:

                                      JOULES/HOUR   %                                             JOULES/HOUR   %

1) H OF C FEED                        850312000    99.1       1) H OF C DRY GAS                   447548000    57.1
2) PROCESS ENERGY INPUT               6710000      .8         2) SENS HEAT DRY GAS                108710000    13.9
3) ENTHALPY PROCESS AIR               31000        0          3) ENTHALPY GAS H2O                 102052000    13
4) ENTHALPY FEED MOIST                702000       .1         4) H OF C PARTICULATES              8136000      1
5) SENS HEAT DRY FEED                 0            0          5) H OF C TARS                      105532000    13.5
                                                              6) H OF C WAT SOL ORGANICS          10907000     1.4
                                                              7) SENS HEAT OF PART + TAR + SOL    0            0
                                                              8) PROCESS HEAT LOSS                1060000      .1

TOTAL =                               857755000               TOTAL =                             783944000

                                         % CLOSURE =          91.4
                                         GROSS EFFICIENCY =   91.3
                                         NET EFFICIENCY =     52.2
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