

A COAL GASIFICATION — GAS CLEANING TEST FACILITY

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Abstract

A general purpose coal gasification - gas cleaning facility is being constructed at North Carolina State University for research on effluents from coal gasification processes. The facility consists of a continuous, fluidized bed gasifier; a particulates, condensables, and solubles removal system; and an acid gas removal system. The gasifier operates at pressures up to 100 psig, has a capacity of 50 pounds of coal per hour, and can be run with either air or oxygen. The acid gas removal system is modular in design so that alternative absorption processes can be studied.

The facility is described in detail, the objectives of the research program are outlined, and details of the experimental plan are presented.

INTRODUCTION

Methods to gasify coal and to purify the resulting synthesis gas have been available for decades; several dozen commercial gasification processes are currently operable, and many more are in advanced developmental stages. At present, however, there is still inadequate knowledge of the environmental effects associated with the widespread large-scale implementation of coal gasification technology.

In recognition of this problem, the Environmental Protection Agency has contracted for the construction of a pilot plant coal gasification-gas cleaning test facility at North Carolina State University, to be operated by faculty and staff of the Department of Chemical Engineering. The facility consists of a continuous fluidized bed gasifier, a system for removing particulates, condensables, and soluble matter (PCS) from the raw synthesis gas, and an acid gas removal system (AGRS). The gasifier operates at pressures up to 100 psig,

has a capacity of 50 lb coal/hr, and can run with either steam -O₂ or steam-air feed mixtures. The AGRS is modular in design, so that alternative absorption processes may be evaluated with a minimal amount of system modification being required.

The overall objective of the project is to characterize completely the gaseous and condensed phase emissions from the gasification-gas cleaning process, and to determine how emission rates of various pollutants and methanation catalyst poisons depend on adjustable process parameters.

Specific tasks to be performed are as follows:

1. Identify and measure the gross and trace species concentrations in the gasifier product, including concentrations of sulfur gases (H₂S, COS), condensable organics (e.g. BTX and polynuclear aromatic hydrocarbons), water-soluble species (e.g. ammonia, cyanates, cyanides, halides, phenols, sulfates, sulfides, sulfites, and thiocyanates), and trace metals (e.g. antimony, arsenic, beryllium, bismuth, cadmium, lead, mercury, selenium, and vanadium).
2. Correlate measured emission levels with coal composition and gasifier operating variables, particularly temperature, pressure, and solid and gas phase residence time distributions.
3. Perform material balances around the gasifier, the raw gas cleanup (PCS) system, and the acid gas removal system, and determine the extent to which selected species are removed from the synthesis gas in each of the components.
4. Correlate measured removal efficiencies for various species with system operating variables, including temperatures, pressures, holdup times, and solvent circulation rates.
5. Evaluate and compare the performance characteristics of alternative acid gas removal processes, considering both CO₂ and H₂S removal capabilities and the degrees to which the processes remove trace pollutant species from the sour synthesis gas. Evaluate the

buildup of contaminants in the various acid gas removal solvents.

6. Use the results obtained in the above studies to develop models for the gasification and the gas cleanup processes. The models will take as input variables the composition and feed rate of the coal, bed depth, steam and air (or oxygen) feed rates and inlet temperatures, gasifier pressure, and operating conditions (temperatures, pressures, solvent flow rates, etc.) for the gas cleaning systems, and will predict the coal conversion and the product gas flow rate and composition, including trace pollutant levels. The model will be used as a basis for optimizing the pilot plant operating conditions, and for estimating emission levels for scaled-up versions of the processes investigated.

The sections that follow will present a brief description of the facility, the experimental program, and methods of analysis.

THE FACILITY

A sketch of the pilot plant facility is shown in Figure 1. The sketch is approximately to scale and shows the location of the major components of the plant and the important piping. Although no scale is indicated on the figure, the acid gas stripping column is the tallest unit and is approximately 13.5 meters (44 feet) in height.

The facility can be divided into nine subsystems as listed below:

1. Gasifier, Coal Feed, and Char Handling
2. Particulates, Condensibles, and Solubles Removal (Raw gas cleaning)
3. Acid Gas Removal
4. Product and By-Product Disposal
5. Sampling and Analysis
6. Measurement and Control
7. Safety
8. Synthetic Gas Mixture
9. Support

Only Items 1, 2, and 3 will be described in any detail here.

Schematic diagrams of the system are shown in Figures 2 and 3 and a drawing of the

gasifier is shown in Figure 4. The gasifier is a fluidized bed unit and was designed by personnel at the Illinois Institute of Gas Technology; it is essentially a copy of a gasifier now in operation at IGT. Although the gasifier, coal feed hopper and char receiver vessels are designed for much higher pressures, the remainder of the system limits the operation of the gasifier - PCS system to approximately 100 psig.

The internal dimensions of the gasifier allow fluidized bed dimensions of 6 inches in diameter and up to 5 1/2 feet in height. Coal is fed at the top by a screw feeder from a pressurized coal feed hopper and char is removed from the bottom into a pressurized char receiver. The gasifier is instrumented with a bed height detector, and temperature and pressure sensors are located at several positions within the bed. A preheated air-steam or O₂-steam mixture is introduced into the bottom of the gasifier bed.

The raw gas goes to a cyclone separator for removal of most of the particulates and then to a venturi scrubber where it is cooled and water soluble and condensable compounds are removed. A portion of the effluent is subjected to further cooling and condensate removal, and is then sent to the acid gas removal system.

The AGRS consists of an absorber column for removal of the acid gases, primarily CO₂ and H₂S, and a stripper column for regeneration of the solvent. At least four processes will be studied: refrigerated methanol, hot potassium carbonate, monoethanolamine and Dimethylether of Polyethyleneglycol. Table 1 shows the operating conditions expected in each process. The first process investigated will use methanol which will also be used for the plant shakedown and startup runs.

For the methanol system the cool, dry sour gas is compressed to 500 psig and fed to the bottom of the absorber column where the CO₂ and H₂S are absorbed. The methanol is introduced into the top of this column at approximately minus 30 degrees Fahrenheit. The acid gases are stripped with nitrogen in the stripper column operating at approximately 15 psig and 0°F. Although the AGRS is not designed to duplicate a commercial system, it has sufficient flexibility to cover the full range of operating parameters applicable to commercial units.

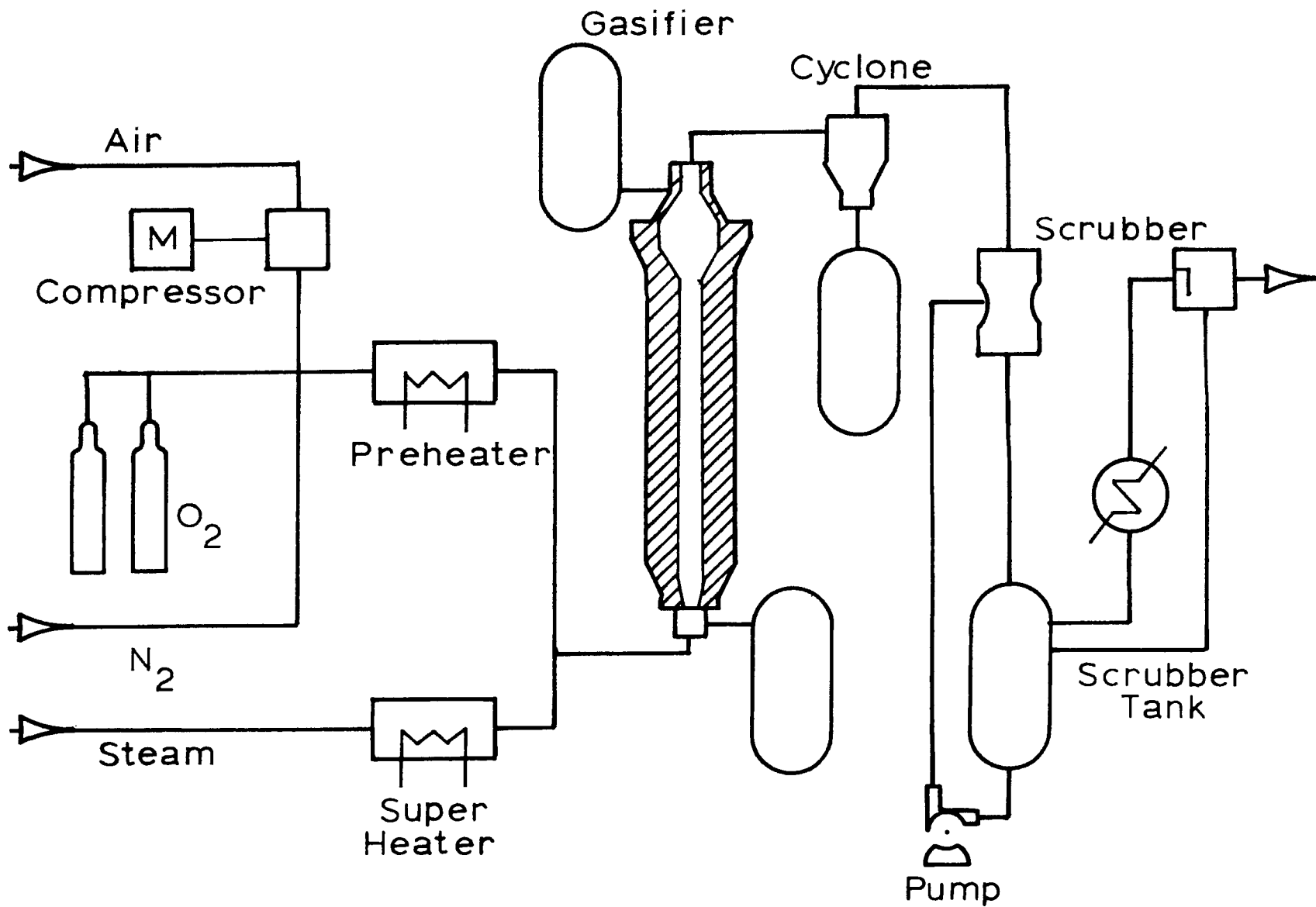


Figure 2. Gasifier and gas quench system.

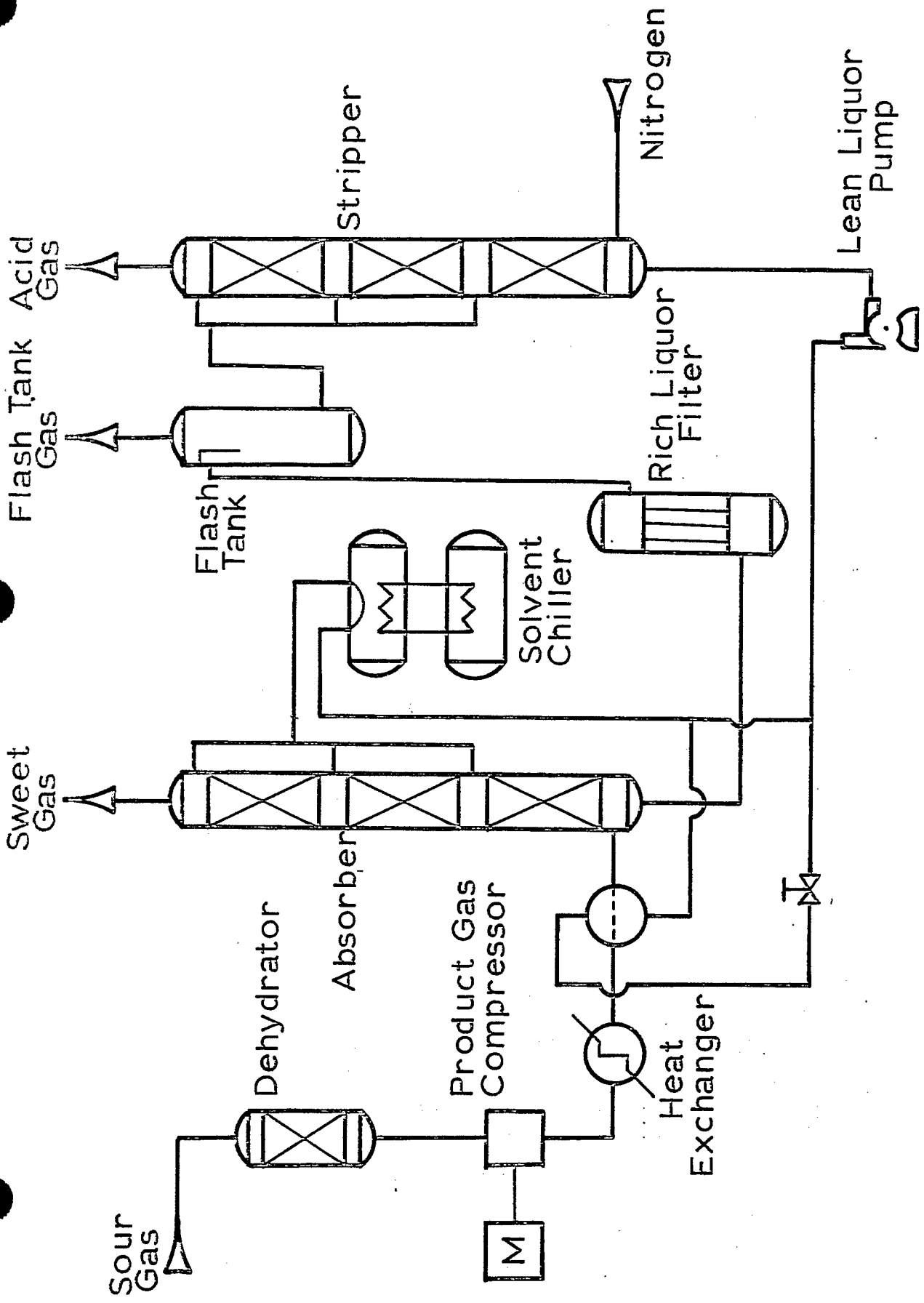


Figure 3. Acid gas removal system.

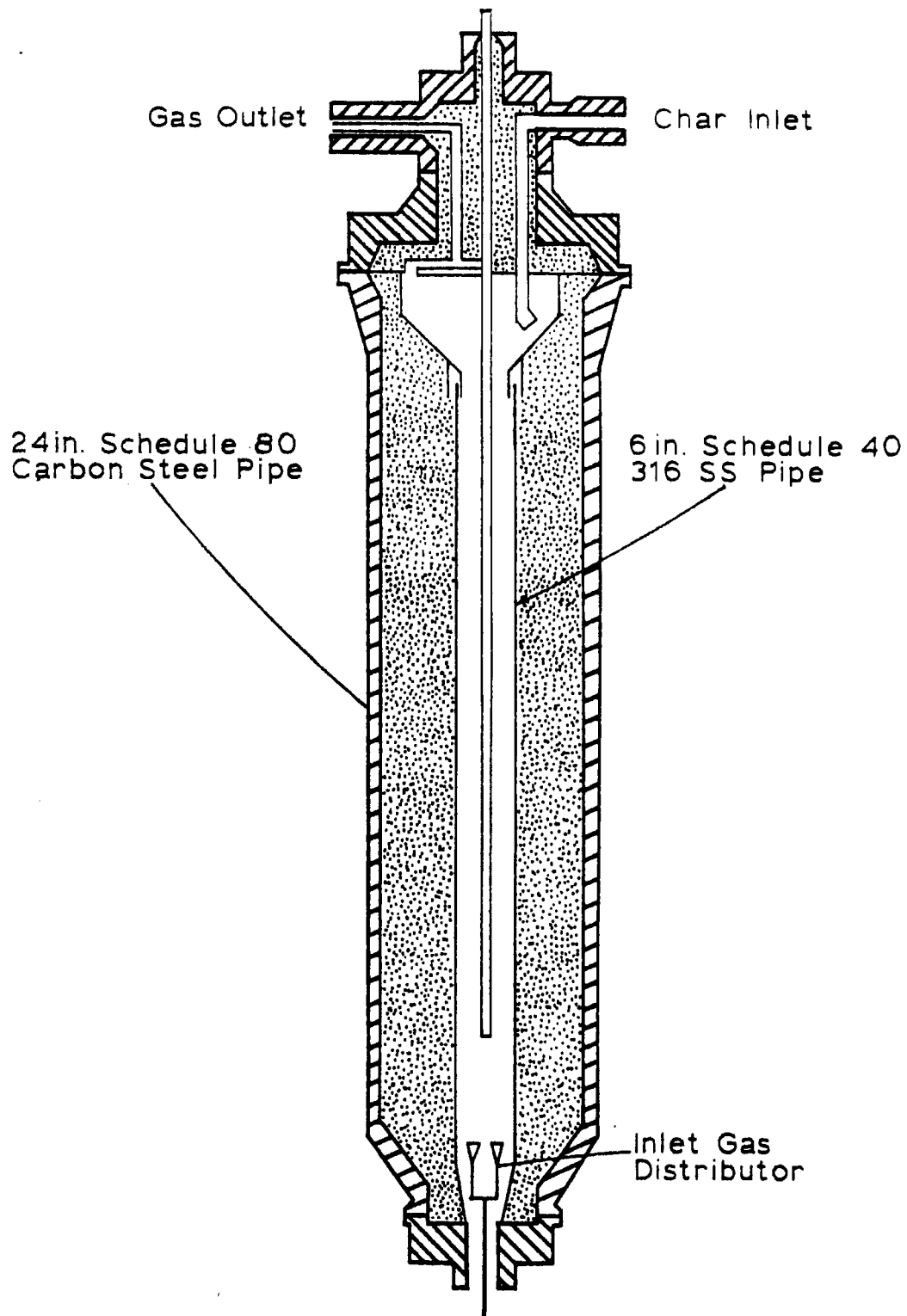


Figure 4. Gasifier cut-away.

TABLE 1
ACID GAS REMOVAL SYSTEM OPERATING CONDITIONS

Solvent	Absorber		Stripper		Flash Tank	Composition	
	Pressure (psia)	Temperature (°F)	Pressure (psia)	Temperature (°F)	Pressure (psia)	Percent CO ₂	PPM H ₂ S
MeOH	315-	-30	15-	0	115-	1.7	700
	515		45		215		
DMPEG	315-	20	15-	30	115-	3.0	500
	515		45				
K ₂ CO ₃	115-	230	20-	230	Not Used	0.45	200
	315		55				
MEA	115-	120	20-	260	Not Used	Trace	Trace
	315		55				

The excess raw gas, the sweet gas, and the sour gas are recombined and sent to an incinerator for disposal.

The facility is instrumented so that approximately 100 of the process variables, temperatures, pressures, flow rates, and liquid levels, and some chemical compositions are available in real time for the data acquisition system. Process control is implemented by a Honeywell TDC 2000 digital control system.

A schematic diagram of the data acquisition system is shown in Figure 5. The system also has the capability of presenting process variables in engineering units on a real time log for operator information, computing mass flow rates, and performing material and heat balance calculations.

THE EXPERIMENTAL PROGRAM

The experimental program will begin when the facility is turned over to North Carolina State University in the late spring or early summer of 1978.

The first phase of the program will be devoted to testing the acid gas removal system using synthetic feed gas mixtures, and operating the gasifier with a pretreated coal or char feed—first alone, then in combination with the AGRS. At the conclusion of this phase of the program, the following objectives should be achieved:

1. The analytical chemical procedures to measure all gross and trace components of interest will be standardized.
2. Mass transfer coefficients and vapor-liquid equilibrium parameters for the methanol absorption system will be measured, and the CO₂ and H₂S removal capabilities of the system will be determined as functions of the operating temperatures and pressures of the absorber and stripper units. Also measured will be the degree to which the CO and H₂ are removed from the sour synthesis gas, and the rate at which methanol is lost due to entrainment and evaporation.
3. The gasifier startup, operating, and data collection procedures will be standardized.
4. The gross and trace emissions from the gasifier will be measured, and their levels will be correlated with operating conditions. Material balances will be obtained, and the operating characteristics and efficiency of the particulate condensation and scrubbing system will be determined.
5. The operation of the integrated gasifier - gas cleaning system will be tested at several conditions, and the degree to which the system performance can be

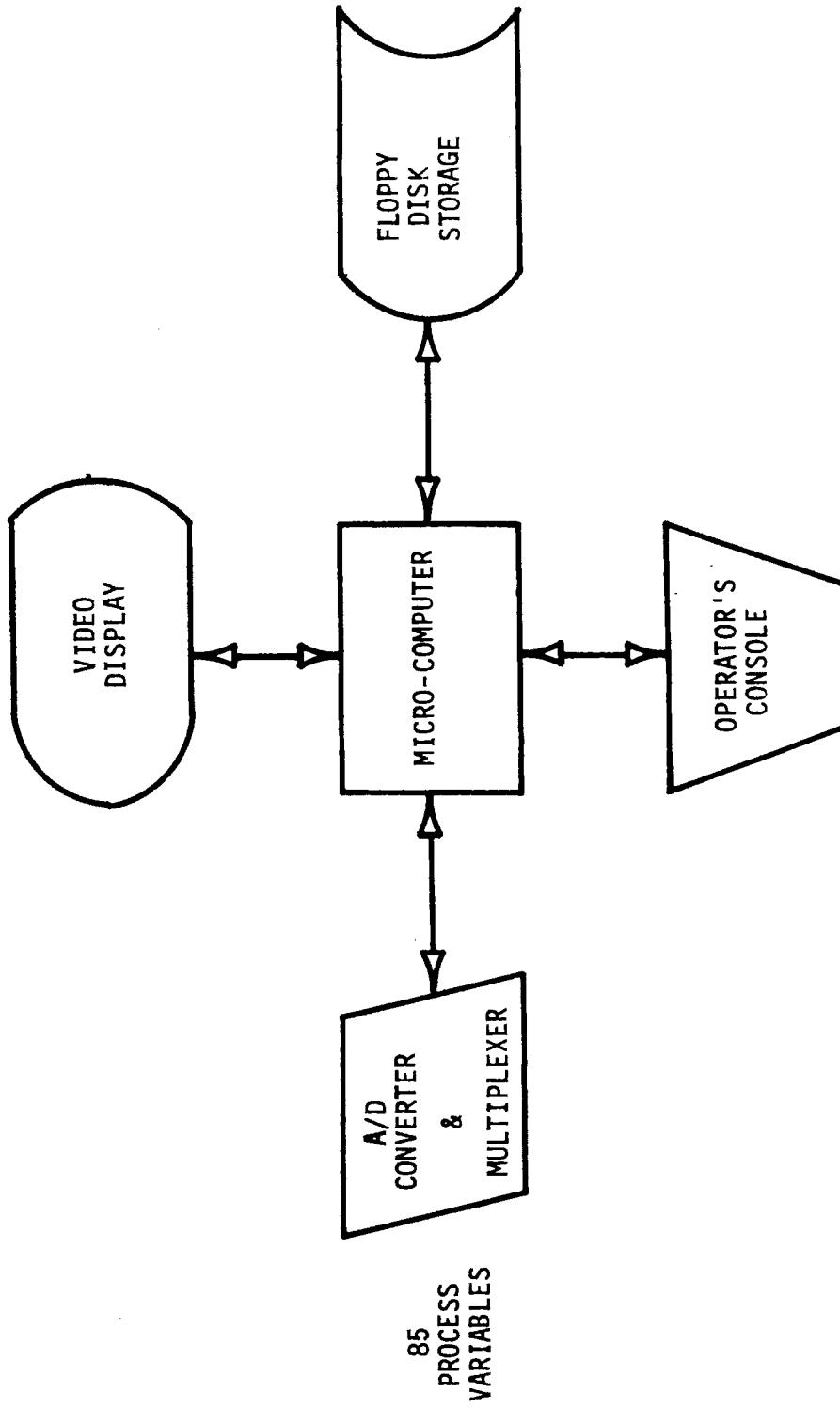


Figure 5. Schematic of data acquisition system.

predicted from the models and correlations established in the previous studies will be determined.

Upon the completion of these studies, the program will shift to the more difficult task of operating with a non-pretreated, non-caking coal. A detailed experimental plan for this stage of the program will be developed in light of the first-stage results.

During the first week of operation, the complete gasification facility will be pressure tested and inspected for physical integrity. Later, flooding velocities will be determined for the absorber and stripper at anticipated operating pressures.

In the remaining six months detailed experimental work will begin. We will determine CO_2 , H_2S , COS , CO , and H_2 transfer rates as functions of absorber and stripper temperatures and pressures, solvent circulation rate, and feed gas inlet temperature. Later the gasifier will be operated using a pretreated char. The emission rates of principal synthesis gas components, sulfur-containing gases, volatile organics, and trace elements will be determined. The emission levels will be correlated with various operating parameters in an attempt to develop predictive emission models. Near the end of the six month period, the gasifier and AGRS system will be operated as an integrated unit. These runs will be used to check the consistency of the results with predictions based on operation of the individual system components.

At least three sets of operating conditions for the gasifier and two sets for the AGRS will be tested in all six possible combinations: the particular conditions will be chosen based on the results of the previous studies.

Sampling

Duplicate grab samples will be obtained from the sampling points shown in Figure 6. The sampling will be done during steady state operation of the pilot plant. Composite sampling will be required for some streams, such as the aqueous condensate obtained from sampling point 7. Gas samples will be taken using a sampling train like that shown in Figure 7.

Analytical Procedures

The various chemical species to be monitored in the gasification unit are shown in Table II. Elemental analyses will be limited to those elements in the first two columns of Table II. The bulk element balances ensure that the entire stream has been accounted for before any other analyses are made. The trace elements selected are those expected to have the most adverse impacts on the environment adjacent to a coal gasification facility.

The water-borne compounds and ions of interest include hazardous species such as cyanide and cyanate, and industrially important species, such as benzene, toluene, xylene, and phenols.

The analysis samples can be classified into four major types:

1. Solid samples - coal, char, and particulates.
2. Aqueous liquid samples - feed water, water condensate, and scrubber water.

TABLE 2
ANALYSES OF INTEREST IN
THE COAL GASIFICATION PROCESS

Trace Elements	Bulk Elements	Water-Borne Compounds	Gaseous Compounds
As	C	CN^-	H_2
Be	H	CNO^-	H_2
Bi	N	CNS^-	CO
Gd	O	Cl^-	CO_2
Hg	S	S^-	SO_2
Pb		SO_3^-	H_2S
			H_2O
Sb		SO_4^-	CH_4
Se		NH_4^+	C_2H_6
V			COS
Cr		Benzene	CH_3OH
		Toluene	
		Zylene	
		Phenols	

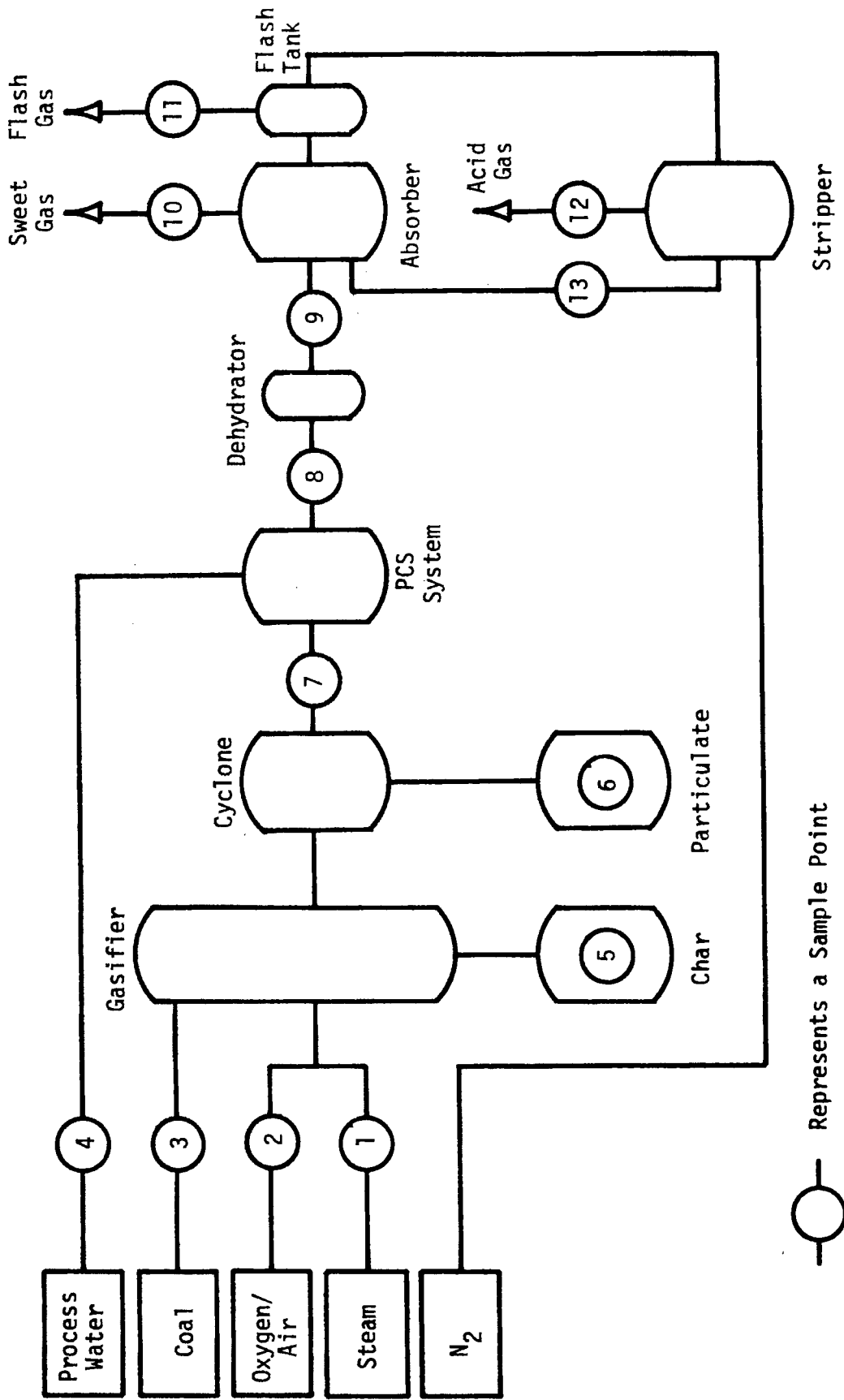


Figure 6. Location of sample points.

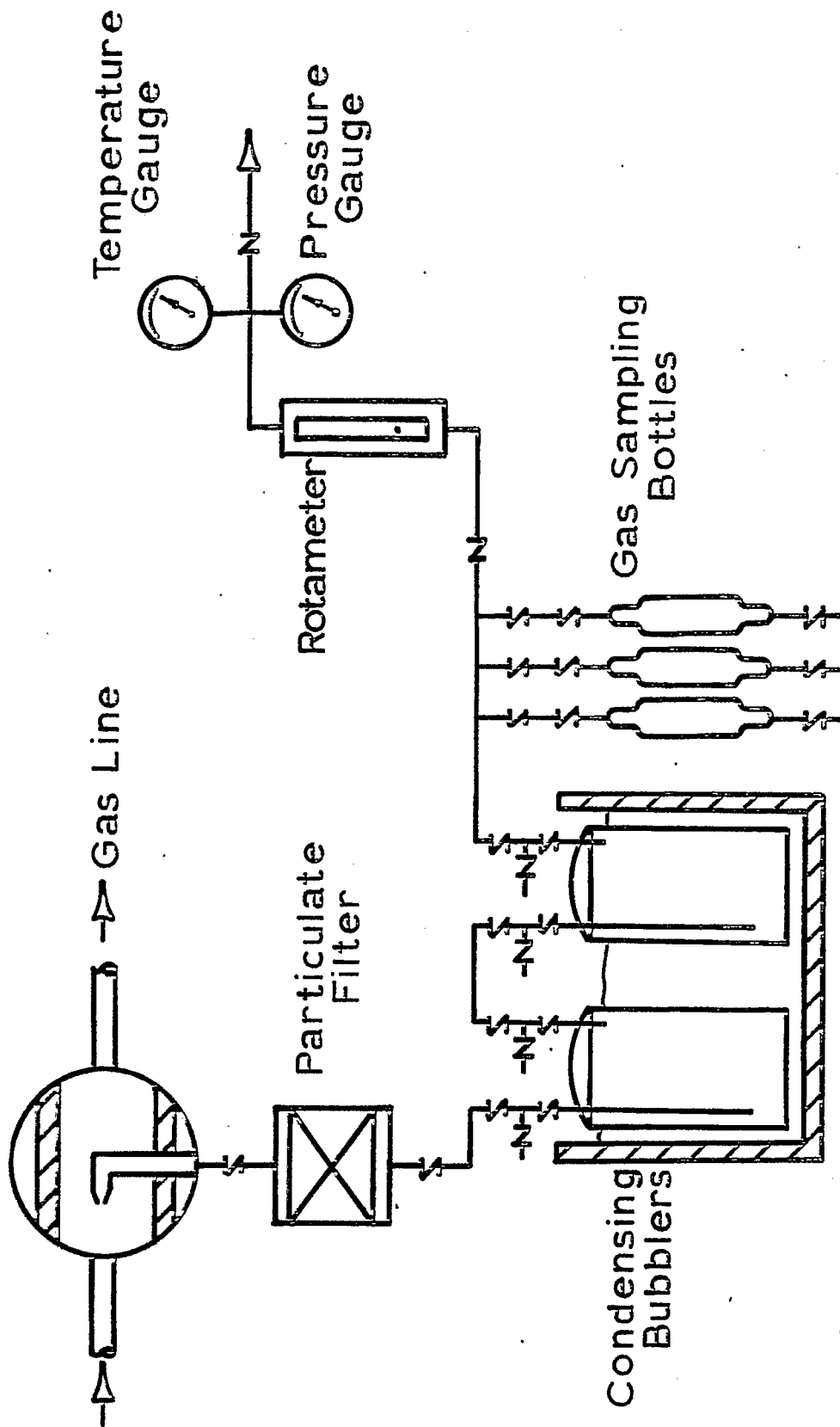


Figure 7. Prototype gas sampling train.

3. Organic liquids - AGRS liquors, organic fraction of tars.
4. Gaseous samples - product gas, sweet gas, flash gas, and acid gas.

Whenever applicable, standard ASTM¹, APHA² and EPA³ methods and procedures will be used initially; more highly automated methods of analysis may be substituted for the manual methods in later stages of the program. The standard methods will then serve to check the accuracy and reliability of the instrumental procedures.

Several instrumental analyses are currently being developed for use in the program. Trace elements will be determined by atomic absorption spectroscopy, neutron activation analysis, and colorimetric procedures. Gas analyses will be performed using gas chromatography. Some water analyses will be performed by atomic absorption spectrophotometry and selective ion electrode methods. Total carbon and total organic carbon in water will be determined using an FID-based instrumental analyzer. Instruments that will be used in later stages of

the program include an automated C, H, N, O, S analyzer for solid and liquid samples, an automated titrator, and a microprocessor-based specific ion electrode meter, and possibly a mass spectrometer and a liquid chromatograph.

REFERENCES

1. American Society for Testing and Materials, *1976 Annual Book of ASTM Standards*.
2. American Public Health Association, American Water Association, and Water Pollution Control Fed., *Standard Methods for the Examination of Water and Wastewater*, 14th ed., Washington, D. C., American Public Health Assoc., 1976.
3. Environmental Protection Agency, *Methods for Chemical Analysis of Water and Wastes*, Report No. EPA 625/6-74-003, Washington, D. C., Office of Technology Transfer, 1974.