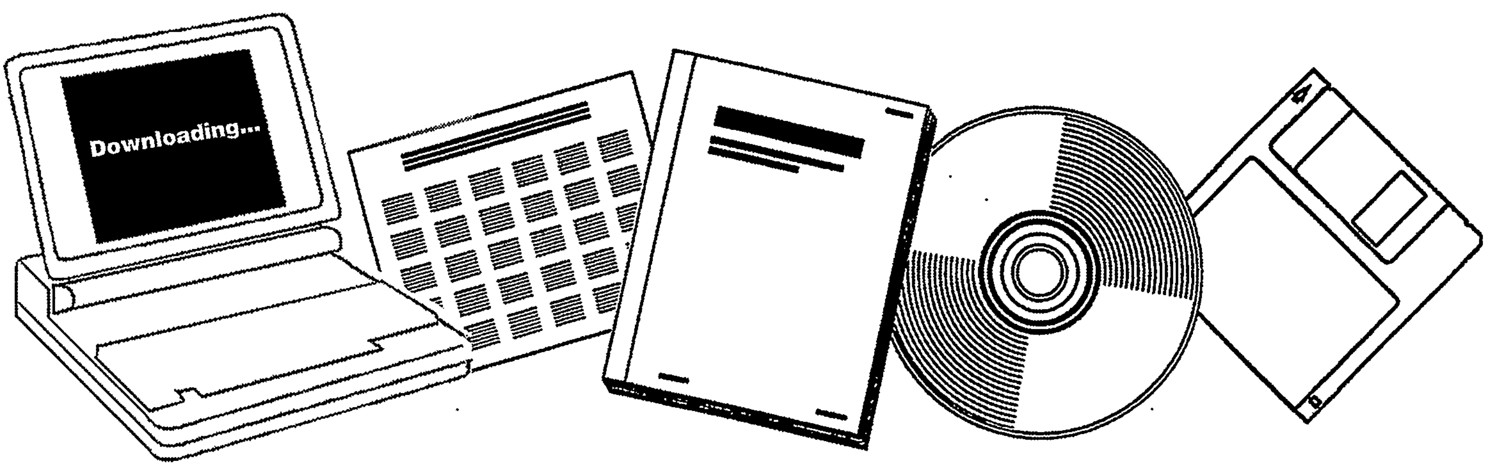
DE83004846

HANDBOOK OF GASIFIERS AND GAS-TREATMENT SYSTEMS

UOP/SDC
MCLEAN, VA

SEP 1982



U.S. Department of Commerce
National Technical Information Service

DOE/ET/10159-T24
(DE83004846)
Distribution Category UC-89

HANDBOOK OF GASIFIERS AND GAS TREATMENT SYSTEMS

Raj D. Parekh

September 1982

Prepared for the
United States Department of Energy

Under Contract No.
DE-AC01-78ET10159

UOP/SDC, A Joint Venture
7929 Westpark Drive
McLean, VA 22102

DISCLAIMER

ABSTRACT

In February 1976, the Energy Research and Development Administration (ERDA) published the Handbook of Gasifiers and Gas Treatment Systems. The intent of this handbook was to provide a ready reference to systems that are or may be applicable to coal conversion technology. That handbook was well received by users and was subsequently reprinted many times.

The Department of Energy (successor agency to the ERDA) expands, revises and updates the Handbook in this volume. This new Handbook is not intended as a comparative evaluation, but rather as an impartial reference on recent and current technology.

The Handbook now presents 39 gasification technologies and 40 gas processing systems that are or may be applicable to coal conversion technology. The information presented has been approved or supplied by the particular licensor/developer.

FOREWORD

This report describes work performed on Task Order No. 035 sponsored by the United States Department of Energy under Contract No. DEAC01-78ET10159 (formerly Contract No. ET-78-C-01-3117). The UOP/SDC program manager of gasification projects is Mr. James Cooper. The UOP/SDC task manager is Mr. Raj D. Parekh.

The following persons have participated in the various activities on which this report is based:

C. Bhatt	S. Katyal
L. Boesch	S. Lin
R. Figel	R. Parekh
M. Goodman	L. Spielberger
B. Hylton	W. Thomson

TABLE OF CONTENTS

TABLE OF CONTENTS (Con't)

INTRODUCTION

As part of its coal gasification program, the predecessor of the United States Department of Energy (DOE), the Energy Research and Development Administration (ERDA), published Handbook of Gasifiers and Gas Treatment Systems in February, 1976. The intent of that handbook was to provide a ready reference to systems that are or may be applicable to coal conversion technology.

In 1980, UOP/SDC was asked by DOE to update, expand, and revise this Handbook to reflect the most current technology status and engineering developments. This effort was carried out under Task Order 035, Contract No. DEAC01-78ET10159. The expansion and revision were deemed necessary because significant developments have occured over the past five years in the coal conversion technology. Several processes have progressed substantially enough to warrant inclusion in this Handbook. In all, 38 Gasifiers and 40 Gas Treatment processes have been included in this new Handbook.

The gasification processes selected for inclusion in this new Handbook reflect various levels of development. Some are in the research phase, some are ready for demonstration, some are of commercial significance,and some gasifiers are of historical value. Such a broad range was selected because this new Handbook is intended to be a ready reference on recent and current technology.

The selection of gas treatment processes, including the hydrogen purification processes, was also based on similar considerations, i.e., utilization of the new Handbook as a resource document. Neither DOE nor UOP/SDC directly or indirectly recommends or supports the processes selected. It is not the intention of this document to say that the processes included are the best processes available. Selection is based solely on their potential for application in the field of coal conversion.

The gasification processes are divided into four categories: Fixed Bed Gasifiers, Fluid Bed Gasifiers, Entrained Flow Gasifiers, and Other Gasifiers (i.e., those that can not be included in the first three categories). For an explanation of these categories, the reader is directed to the section on 'Explanation of Terms' in the appendix of the Handbook. A total of 38 gasifiers is presented, including 11 fixed bed gasifiers, 13 fluid bed gasifiers, 11 entrained flow gasifiers, and 3 'other' gasifiers. Each gasifier chapter contains information on history and state of development; a description of the mechanical construction and operation; typical quantitative data on operating conditions, gas composition, utility requirements, capacity, etc.; and appropriate sketches and simplified flow diagrams

The gas treatment processes are also divided into four categories: Acid Gas Treatment Processes, Ammonia Removal Processes, Organics Removal Processes, and Hydrogen Purification Processes. A total of 40 processes is presented. The acid gas treatment processes (24) include processes for the treatment of carbon dioxide, hydrogen sulfide, and other sulfur containing species, such as carbonyl sulfide (COS), carbon disulfide (CS_2), thiophenes, and mercaptans. The rest of the gas treatment processes include three for ammonia removal, five for organics removal, and eight for hydrogen purification. The hydrogen purification section is the new addition to this Handbook and includes process principles oriented toward coal conversion. Each gas treatment chapter includes the commercial status of the process; process and chemical description; operability and purification limits; typical quantitative data on utility requirements; and appropriate flow diagrams.

A comparative economic evaluation of the gasifiers or the gas treatment systems has not been included. Such an evaluation would require designing each system on a common basis of specific factors, such as the type of feed coal, plant capacity, plant location, environmental considerations, etc., and is beyond the scope of this Handbook.

The degree of detail of information presented for different gasification processes and gas treatment processes varies from one process to another.

This is dependent on the extent of information that could be derived from published data and the extent of information that individual developer/licensor could supply outside the bounds of proprietary information. Thus commercial and relatively old processes have more data available than do those that are in the research and/or development phase.

There are many other summary documents that present information on coal gasification and/or gas treatment processes. Some of these that the reader may refer to are as follows:

1. "Gas Generation Research and Development, Survey and Evaluation, Phase One, Volume Two," prepared for the Office of Coal Research, Department of the Interior, by Bituminous Coal Research, Inc.; under Contract No. 14-01-0001-324, BCR Report L-156, March 1975.

2. Howard-Smith, I., and Werner, G.J.; "Coal Conversion Technology: A Review," under the auspices of Millmerran Coal Pty. Ltd.; Brisbane, Australia; NP-20814, ISBN-0-815-0614-7, May 1975.

3. "Handbook of Gasifiers and Gas Treatment Systems," prepared for the U.S. Energy Research and Development Administration by Dravo Corporation, under Contract No. E(49-18) 1772, FE-1772-11, February 1976.

4. "Costs and Technical Characteristics of Environmental Control Processes for Low-Btu Coal Gasification Plants," Oak Ridge National Laboratory, ORNL-5425, June 1980.

5. "Low Btu Coal Gasification Processes, Volume 1 and 2," Oak Ridge National Laboratory, ORNL/ENG/TM-13/V1, November 1978.

All process information has been reviewed and approved by the developer and/or licensor. In cases where there are more than one licensor/developer, approval has been obtained from at least one of them. A glossary of definitions of terms used in this Handbook is presented in the Appendix.

This Handbook was prepared for publication in April 1981. The actual publication was delayed until September 1982 because of problems related with approvals from sponsors and licensors. Hence the information presented, unless otherwise noted, is what was prepared by April 1981.

GLOSSARY

AGA	American Gas Association
atm	atmospheres
BFW	Boiler Feed Water
Btu	British thermal units
BTX	benzene-toluene-xylene fraction
DOE	(U.S.) Department of Energy
ERDA	(U.S.) Energy Research and Development Administration (Predecessor of DOE)
°F	degrees Fahrenheit
FSI	Free Swelling Index
ft	feet
Gal, gal	Gallons
gpm	gallons per minute
HHV	higher heating value
LHV	lower heating value
HVAB	High Volatile A Bituminous
HVCB	High Volatile C Bituminous
I.D.	inside diameter
in	inches
kWh	kilowatt hours
lb	pound
LPG	Liquified Petroleum Gas
M	thousand
MM	million
mW	megawatts
OCR	(U.S.) Office of Coal Research (Predecessor of ERDA)
O.D.	outside diameter
PDU	Process Development Unit
pc	personal communication between UOP/SDC and the process developer/licensor
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gauge
scf	standard cubic feet
scfd(h)	standard cubic feet per day (hour)
sec	seconds
SNG	synthetic (or substitute) natural gas
tpd(h)	tons per day (hour)
vol%	volume percent
wt%	weight percent

EXPLANATION OF TERMS

High Btu Gas

A substitute for natural gas with a heating value above 950 Btu per standard cubic foot and a carbon monoxide content less than 0.1%. This can be mixed directly with and used as a natural gas.

Medium Btu Gas

A fuel gas or chemical feedstock with a heating value of approximately 250 to 350 Btu per standard cubic foot.

Low Btu Gas

A fuel gas with a heating value of approximately 100 to 200 Btu per standard cubic foot.

Fixed Bed Gasifier

Sized coal (3 - 50 mm) is fed at the top of a vessel. The reactant gases (e.g., oxygen and steam) are introduced at the bottom. As a result, there is a temperature distribution throughout the gasifier. The relative proportions of steam and air (or oxygen) introduced regulate the maximum temperature reached in the gasifier.

Gases exit the gasifier at temperatures in the range of 500 °F to 1000 °F. This is too low a temperature to effect any appreciable reaction between gas or steam and the tars and oils evolved during devolatilization. Consequently, the raw product gas contains appreciable quantities of these tars and oils that must be removed to avoid condensation in down-stream utilization of the gas. To facilitate this cleanup, some descending bed gasifiers are operated in a two-stage mode in which a portion of the gas is removed directly from the gasification zone, and only enough gas to heat the incoming coal moves up through the devolatilization and drying zones. This provides one stream of gas free of tars and oils. If it is desired to remove dry ash, enough steam is added to cool the combustion zone below the ash-fusion temperature. On the other hand, if a molten ash (slagging) operation is desired, the steam rate is reduced accordingly.

Fluidized Bed Gasifiers

In the fluidized bed system, coal is ground to a maximum of 8 MM and introduced into a vessel. The reactant gases are introduced through a perforated deck near the bottom of the vessel. The volume rate of gas flow is high enough to suspend the solids but not high enough to blow them out the top of the vessel. The resultant swirling behavior of the mixture gives it the appearance of a boiling liquid. The bed of solids has a very intimate contact with the upward flowing gas, and a very uniform temperature is established throughout. Reaction rates are faster than in the moving bed because of the intimate contact between gas and solids and the increased solids surface area resulting from the smaller particle size.

Entrained Gasifiers

The entrained flow gasifier uses a finer grind of coal (up to 100 microns) than either the fixed bed or fluid bed. It is fine enough that it can be readily conveyed pneumatically by the reactant gases. Velocity of the mixture must be high so that reacted solids are carried over with the gas. In this case, there is little or no mixing between the solids and gases, except where the gas initially meets the solids, and the reactions occur in a completely cocurrent fashion. This type of reactor is used only for very rapid reactions and usually for either combustion in oxygen or the initial reaction of fresh coal and hydrogen.

Licensor/Supplier/Developer

The organizations shown under this heading are not necessarily a complete listing of the available licensors and suppliers.

Feed Requirements

The statement that the gasifier accepts all types of coal implies that all types of coal are accepted without pretreatment. When pretreatment is required, it is so stated.

By-Product Steam

The total amount of steam generated in the gasifier and gas cooling train is based on cooling the gas to ambient temperature, unless otherwise stated. The pressure and temperature of the steam are provided where available; otherwise the steam is specified as low pressure (50-100 psig) or high pressure (over 300 psig) steam.

Utility Requirements

For the gasifiers, required amounts of the following utilities are given: oxygen or air, steam to be fed into the gasifier as a reactant, boiler feed water fed to the gasifier and gas cooling train to generate the steam stated under by-products, and electric power. Where applicable, required amounts of hydrogen and other reagents are also stated.

For the gas treatment systems, required amounts of cooling water, steam, electric power, and reagents are given.

Thermal Efficiency

Cold gas and overall thermal efficiencies are computed based on data available and the attached "Generalized Block Flow Diagram for Thermal Efficiencies of Coal Gasification Processes." See Page 10.

Receipt of raw coal and delivery of cooled gas, byproducts, and ash are assumed. Acid gas removal is not included, unless stated otherwise.

Definitions of thermal efficiency are given at the end of this section along with a generalized block flow diagram of the gasification system.

Capacity

Capacity of a typical commercial unit is given in terms of tons per day of coal fed to the gasifier or MM scfd of gas processed. These numbers depend upon the type of coal gasified and should be used with discretion.

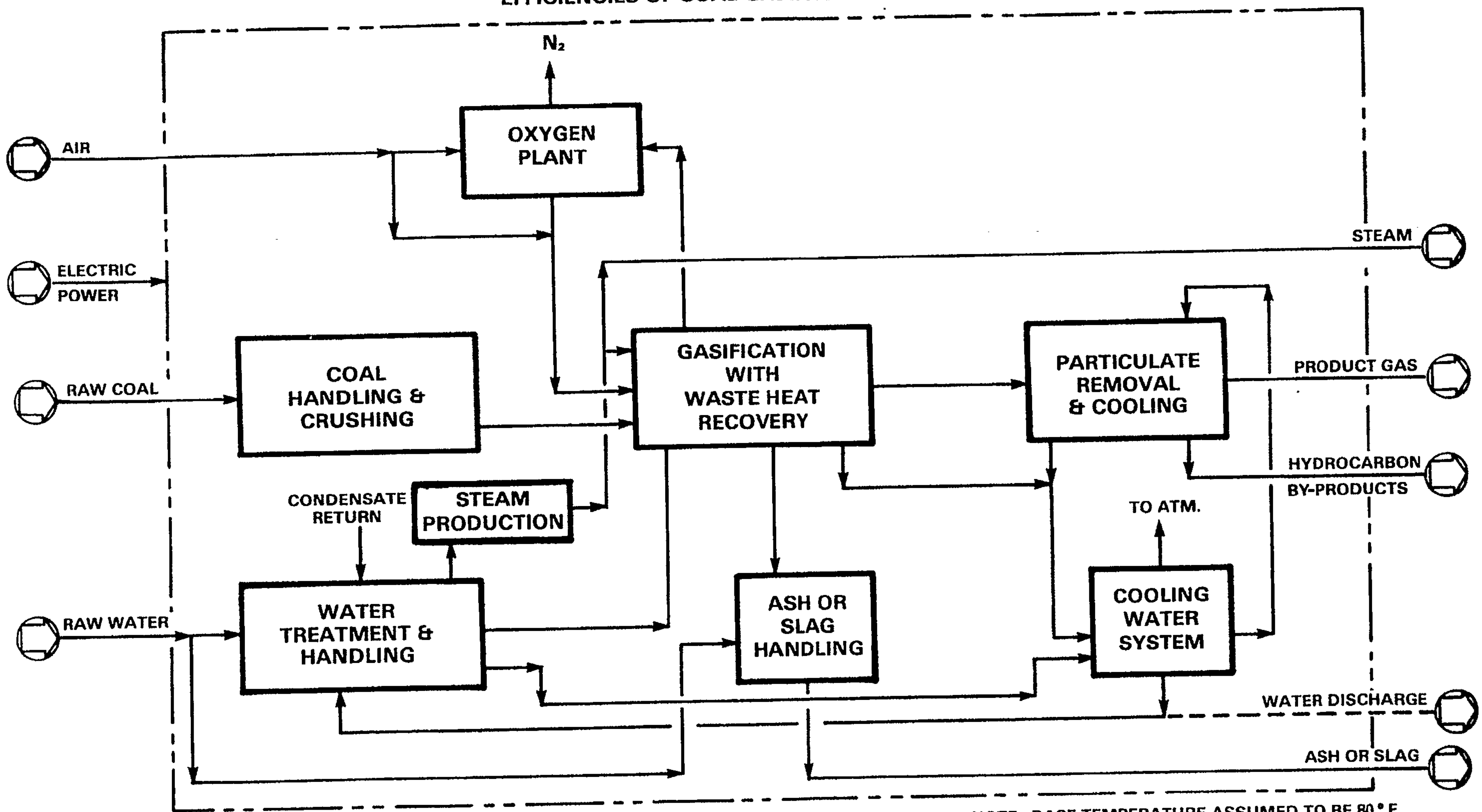
Environmental Considerations

For a typical coal gasification facility, various operations from coal handling through gas cooling and acid gas removal would have to be clearly defined and considered for their possible impact on the environment. The present write-up does not cover all these aspects. Only salient features having a positive or negative effect on the environment are pointed out here.

Remarks

Major advantages or limitations of the gasifier or gas treatment system are reiterated here based on the objective information available.

GENERALIZED BLOCK FLOW DIAGRAM FOR THERMAL EFFICIENCIES OF COAL GASIFICATION PROCESSES



NOTE: BASE TEMPERATURE ASSUMED TO BE 80 °F

$$\text{\% COLD GAS EFFICIENCY} - \frac{\text{ENERGY OUTPUT WITH PRODUCT GAS}}{\text{ENERGY INPUT WITH COAL}} \times 100$$

$$\text{\% OVERALL THERMAL EFFICIENCY} - \frac{\text{ENERGY OUTPUT WITH [PRODUCT GAS + H/C BY-PRODUCTS + STEAM]}}{\text{ENERGY INPUT WITH [COAL + ELECTRIC POWER]}} \times 100$$

2A.1 BRITISH GAS/SLAGGING LURGI

Type

Slagging fixed bed gasifier

Developer

British Gas Corporation
326 High Holborn
London WC1V 7PG

State of Development [2]

As early as 1953, Lurgi was experimenting with a slagging version of its fixed bed gasifier in a pilot plant at Oberhausen-Holten, Germany, but did not continue the development. The Ministry of Power (England) purchased Lurgi's pilot gasifier in 1955 and collaborated in erecting it at Solihull, England, and in operating it until 1958. The Ministry also let a contract to the British Coal Utilization Research Association (BCURA) to work on slagging gasification at Leatherhead, England. The BCURA program developed into an investigation of factors affecting slag behavior in gasification processes. In 1960, the gasifier at Solihull was extensively modified and equipped to operate at 20 atm. It was commissioned in 1962. The development work continued for two years and in 1964 reached a stage at which the gasifier could have been scaled up to a commercial prototype. By this time, however, North Sea natural gas had been discovered, and further work was suspended indefinitely

In May 1974, under the sponsorship of 14 United States oil, pipeline, and gas companies, the British Gas Corporation began modifying one of the Lurgi gasifiers at Westfield, Scotland, to operate under slagging conditions. Modifications on the gasifier were completed in March 1975, and the first run was carried out in April 1975.

In late 1975, ERDA (now DOE) issued a Request for Proposal (RFP) for high Btu gasification demonstration plants. A proposal by Conoco based on the British Gas Corporation's slagging Lurgi gasifier technology, was selected. Detailed design of this 3500 TPD coal gasification plant, concluded in mid-1981, completed phase one of this three-phase program. CONOCO then withdrew from the program with the concurrence of DOE.

A major step in the Conoco-sponsored work was to demonstrate that the slagging gasifier can convert the high-sulfur coal of eastern Ohio (Ohio #9) with which Conoco proposed to feed the demonstration-size plant. British Gas has performed tests on this coal at the Leatherhead unit.

British Gas has an ongoing development program including obtaining data for the use of British coals and developing the injection of fine coal through tuyeres. A larger commercial prototype has been designed and will be installed at Westfield. The current plant has gasified in excess of 60,000 tons of coal with a running time of over 5000 hours.

Description[3,4,5]

The British Gas/Lurgi slagging gasifier is a pressurized, oxygen-blown, fixed bed reactor (Figure 2A.1-1). It is operated at a bottom temperature that is above the melting point of the coal ash so that the ash is removed from the gasification reactor as a liquid slag. The slagging gasifier operates at an elevated pressure. The Westfield pilot plant is normally operated at 350 psig. The gasifier is water jacketed and refractory lined and is suitable for gasifying eastern bituminous caking coals, which are characterized by low reactivity and low ash-fusion temperatures.

A fluxing agent is added to some coals. This fluxing agent blends with the molten coal ash in the bottom of the gasifier to control its viscosity and to enhance the slag tapping operation.

The coal (and flux when used) feed is introduced into the reactor via a lockhopper system, since the gasifier operates at an elevated pressure. It flows by gravity from the pressurized lockhopper into the top of the gasification reactor and is mechanically distributed uniformly across the reactor by a rotating distributor system. Hot rising synthesis gases rapidly heat the coal to effect devolatilization and coking or charring. A stirrer is provided to fracture the coke as it is formed.

The devolatilized coal gradually moves downward through the reactor as it is gasified. Steam and oxygen are introduced at the bottom of the gasifier through tuyeres to effect the gasification reactions and to produce the hot synthesis gas, which flows upward countercurrently to the downward flowing fuel bed. Countercurrent flow of fuel and gases provides excellent heat exchange, which increases gasification efficiency. Heat is provided for the gasification reactions by combustion of the devolatilized fuel in a raceway zone in front of the tuyeres.

Temperatures in the raceway are above the melting point of the ash. The molten ash falls to the hearth at the bottom of the gasifier. It combines with the fluxing agent and is removed from the gasification reactor via a proprietary slag tapping system and procedure. The molten slag falls into a water quench vessel, where it is rapidly solidified to form a particulate frit. The solidified slag drops into a lockhopper from which it is periodically discharged from the system. Crude synthesis gas leaves the top of the gasification reactor and passes through a quench scrubber and waste heat boiler.

Because of the arrangement mentioned above, a number of chemical and physical processes occur simultaneously throughout the bed, often overlapping and interacting. Included among these processes are preheating, drying, and devolatilization of coal at the top of the bed; countercurrent flow of reacting gases and solids with heat exchange; for agglomerating coals, heating, swelling, and passage through the plastic stage, with subsequent resolidification and contraction; reaction of steam with fixed carbon and carbon monoxide and reaction of carbon dioxide with fixed carbon; heat release from the reaction of oxygen with fixed carbon; and phase change associated with melting of ash and flux to form slag.

Feed Requirements

The coal is crushed and screened to a nominal 2"x 1/4"size. The British Gas/ Lurgi slagging gasifier can handle caking coals. Refractory ash (i.e., ash with a very high fusion point) can be accommodated by adding fluxes such as dolomite. Coal fines (1/4" x 0) can be included in the feed to an extent of 15-25% and a proportion can be used by injecting them through tuyeres.[5]

Operating Conditions

Exit gas temperature = 800-900 °F
Reactor Pressure = 60-350 psig

Gas Produced

Typical gas composition (dry basis) with oxygen gasification

Feed Coal	Ohio #9	Pittsburgh #8
HHV of Coal, Btu/lb; dry	12,000	14,000
Mole % CO	53.7	55.5
CO_2	5.3	3.9
H_2	28.6	29.1
$CH_4 + C_nH_m$	8.0	7.5
N_2	4.5	4.0
HHV, Btu/scf, dry	355	355

By-Products[5]

	Ohio #9	Pittsburgh #8
Tars and oil,lb/ton of MAF coal	137.0	126.0
Net gas liquor,lb/ton of MAF coal	198.0	192.0

Utility Requirements[5]

	Ohio #9	Pittsburgh #8
Oxygen, lb/lb of MAF coal	0.564	0.562
Steam, lb/lb of MAF coal	0.407	0.423

Thermal Efficiency[pc]

Total products (gas, tar, oils, naphtha, & phenols)/coal for feed = 93%

Total products/coal for feed + steam generated at 80% efficiency + oxygen at 192 Btu/ft³ thermal equivalent = 82%

Purified product gas/coal for feed + steam generated at 80% efficiency + oxygen at 192 Btu/ft³ thermal equivalent = 71%

Capacity

The pilot plant gasifier is 6 ft in diameter and approximately 20 ft high. It can process 300-350 tpd coal. The turndown capability is to at least 25%.

Environmental Considerations

These are similar to dry bottom Lurgi (see Chapter 2A.3) except dry ash is replaced by inert slag, which has no leaching problems, and the amount of wastewater to be treated is less because of lower steam consumption. All hydrocarbon byproducts and phenols can be gasified to extinction by recycling to the gasifier.

Remarks

As the demand for coal increases, it will become increasingly desirable for any coal conversion process to use total mine output, i.e., the whole size range from lump to fines. The slagging gasifier has in large measure the ability to handle a considerable amount of fines, either in the feed or by injection with the steam and oxygen through the tuyeres, or both. It is planned to develop the slagging gasification process along lines that will enable the proportion of fines that can be efficiently gasified to be maximized while preserving the inherent advantages of fixed bed operation.

References

1. Roberts, G. F. I., "Planning for Future Gas Supplies in the United Kingdom," presented at First International Gas Research Conference, Chicago, Illinois, June 9-12, 1980.
2. Hebden, D., and Brooks, C. T., "Westfield - The Development of Processes," at for the Production of SNG from Coal," Institute of Gas Engineering. Communication 988.
3. Sudbury, J. D., et al., "Gasification of Caking Coals in the British Gas/ Lurgi Slagging Gasifier - A Status Report," presented at Fifth Annual International Conference on Coal Gasification, Liquefaction and Conversion to Electricity, Pittsburgh, Pennsylvania, August, 1978.
4. Roberts, G. F. I., et al., "The Application of Slagging Gasification to the Production of SNG from Coal," presented at 14th World Gas Conference, Toronto, Canada, 1979.
5. Hebden, D., "Gas from Coal - A British Gas Approach," presented at First International Gas Research Conference, Chicago, Illinois, June 9-12, 1980.

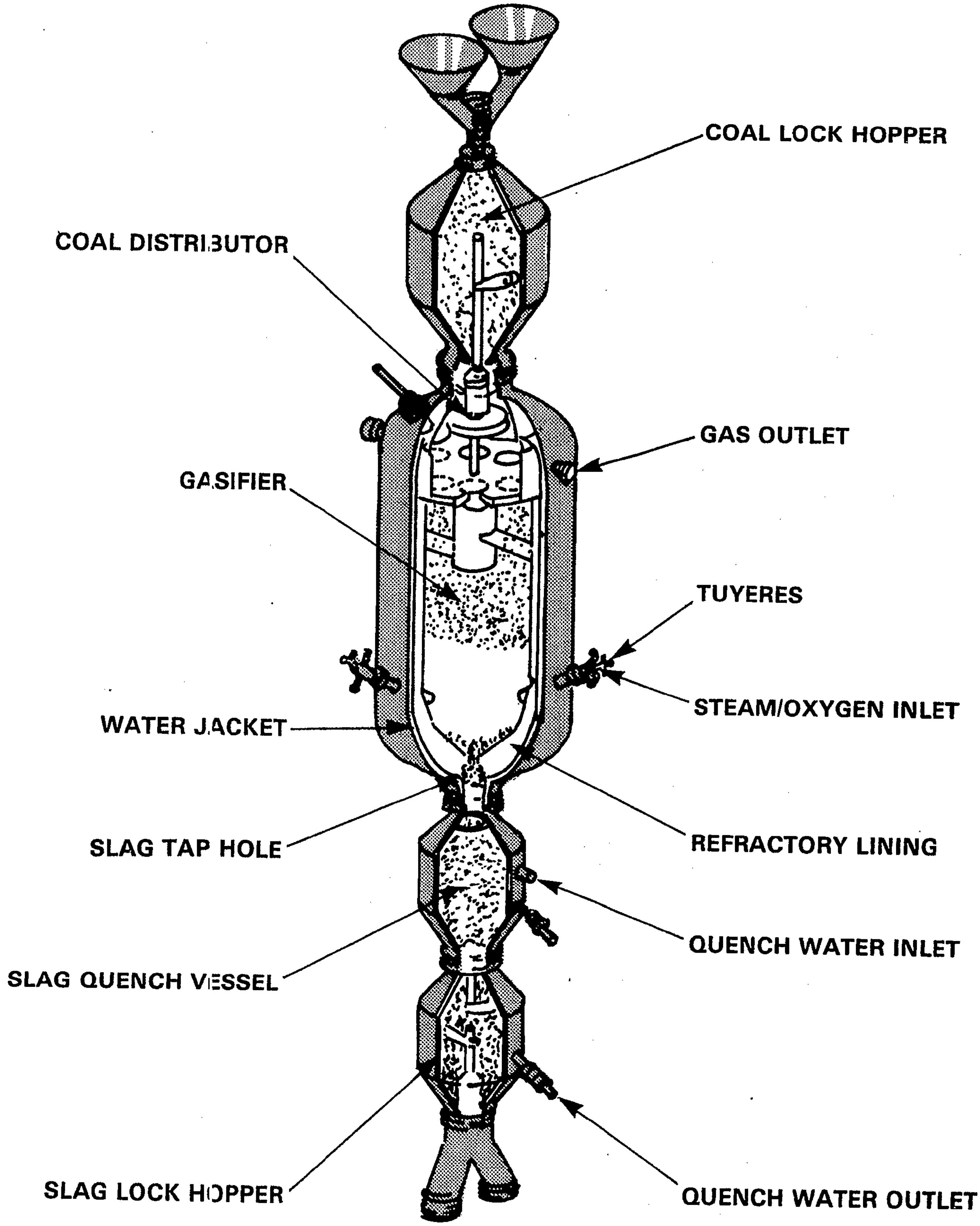


Figure 2A.1-1 British Gas/Lurgi Slagging Gasifier.

2A.2 GEGAS

Type

Fixed bed gasifier

Developer

General Electric Company
1 River Road
Schenectady, N.Y. 12345

State of Development[1]

The objective of the gasification research being conducted at GE is to provide a clean fuel supply from coal for gas-turbine combined cycle power generation. GE operated a similar process during the late forties and early fifties. The gasification research began in the early seventies and has focused on electric power generation using low Btu gas.[1] The process feasibility was investigated on a 50 lb/hour coal feed reactor that operated at atmospheric pressure. A pilot plant capable of gasifying up to 2000 lb/hour coal has been operational since 1976. It has been designed for maximum pressure of 350 psia. A prototype integrated plant has also been designed. This design shows a gasifier of 13 ft outside diameter that will convert 20 tpd coal into low Btu gas, which will then generate 39 MW electricity in the power plant.[2 3]

The Advanced Fixed Bed Gasifier, which has been constructed at the GE Corporate Research and Development site, is currently being used as an integrated component in an experimental simulation of a gasification gas turbine combined cycle system. The focus of this continuing R&D is to develop a technological understanding of this coal-to-electricity system. There are no current plans to scale the gasifier up to a demonstration sized, prototype unit.

Description

The pilot plant gasifier vessel is shown in Figure 2A.2-1. It consists of a 5-ft outer diameter by 24-ft high shell with 1-in thick walls and a hemispherical cap of 285 Grade C steel. It was constructed in four sections that are joined together with flanges for easy disassembly for repair or inspection. The steel shell is protected from the high temperatures of the gasification process by two layers of castable refractory: a hardcase, high alumina inner layer 3-3/4 in thick, and an insulating outer layer 8-3/4 in thick. This results in an effective vessel inner diameter of 35 in. Steam and air enter at the base of the gasifier under the grate. The hot raw gas exits from top of the gasifier and is immediately quenched with water.

Mechanical equipment associated with the gasifier includes a grate, an upper bed stirrer, and a coal feed auger. The grate is a blade and table type. The pan supports the bed; the centrally located stirrer arm discharges ash when it is rotated in its lowest position. The stirrer arm can also be raised axially to break weakly fused clinkers in the lower portions of the bed. A carbon steel ring is located in the vessel just above the grate pan to provide a hard surface against which the ash clinkers can be crushed. Discharged ash falls into a pit below the pan, from which it is pushed into a chute leading to the ash lockhopper. The grate paddle is fully water cooled, as are all the rabble arms on the stirrer.

The gasifier has a bed of coal through which air and steam (the "blast" reactants) are blown upward. The coal settles as it is consumed, and the ash is moved from the bottom of the bed and discharged. In this reactor, the exiting ash is exposed to fresh, hot air and has nearly all of its carbon burned away. The coal is dried and substantially devolatilized by contact with the upflowing gas when it is first added to the fuel bed. Most of the water and volatiles in the coal therefore do not participate in the major reactions near the bottom of the bed. The carbon settles toward the hotter zones and is partially consumed by the above gasification reactions. The hottest portion of the bed is at the combustion zone, where virtually all of the oxygen is consumed in oxidizing the carbon to CO and CO_2. There is an overlap of regions where fuel gas is manufactured and free oxygen is still being consumed, but that region is very small. At the very bottom of the ash zone, the burned ash is cooled by heat exchange with the incoming blast gases.

Feed Requirements

Illinois #6 and Pittsburgh #8 coals have been gasified in the gasifier. Feed coal is sized 1/8" x 2".

Operating Conditions[1 4]

Gasification temperatures in the combustion zone are on the order of 2100 °F. The gasifier has been operated at 85 psig (low pressure) and 320 psig (high pressure), and the average raw gas temperature is approximately 1000 °F.

Gas Produced[2]

Raw gas composition (dry basis) based on one of the gasification runs on Illinois #6 coal

		Low Pressure	High Pressure
HHV of Coal, Btu/lb, dry		Not Available	Not Available
Mole %,	CO	23.6	21.3
	CO_2	8.6	9.2
	H_2	18.4	18.9
	$CH_4 + C_nH_m$	3.2	3.5
	$N_2 + Ar$	44.9	48.9
ppm	$H_2S + COS$	7400	6000
	NH_3	2330	
HHV, Btu/scf, dry		168	166

By-Products

Expected yields of tar and oil with Illinois #6 coal gasification

Tar, lb/ton of MF coal = 56.0
Oil, lb/ton of MF coal = 20.0

Utility Requirements

Utility requirements based on the run for which gas composition is shown above

	Low Pressure	High Pressure
Air, lb/lb MF coal	2.27	2.44
Steam, lb/lb MF coal	0.57	0.51

Thermal Efficiency

Not available

Capacity

The pilot plant gasifier (24 tpd) is 5 ft in outside diameter and 24 ft high.

Environmental Considerations

Tars, oils, ammonia, and H_2S are recovered or converted to useful products. The dust trapped in cyclones may be mixed with ash for proper disposal.

References

1. Kydd, P. H., "The GEGAS Process," presented at Second Symposium on Clean Fuels from Coal, Chicago, Illinois, June 23 - 27, 1975.
2. Woodmansee, D. E., et al., "Gasification of Illinois #6 Coal in an Advanced Fixed Bed Reactor," presented at American Institute of Chemical Engineers Annual Meeting, San Francisco, California, November, 1979.
3. Corman, J. C., "Coal to Electricity - Integrated Gasification Combined Cycle," presented at Sixth Energy Technology Conference and Exposition, Washington, D.C., February 26 - 28, 1979.
4. Woodmansee, D. E., and Palmer, P. M., "Gasification of a Highly Caking Coal in the GEGAS Pressurized Gas Producer," preprinted paper for American Chemical Society Meeting, Division of Fuel Chemistry; 22, 1, 158; New Orleans, Louisiana; March 1977.

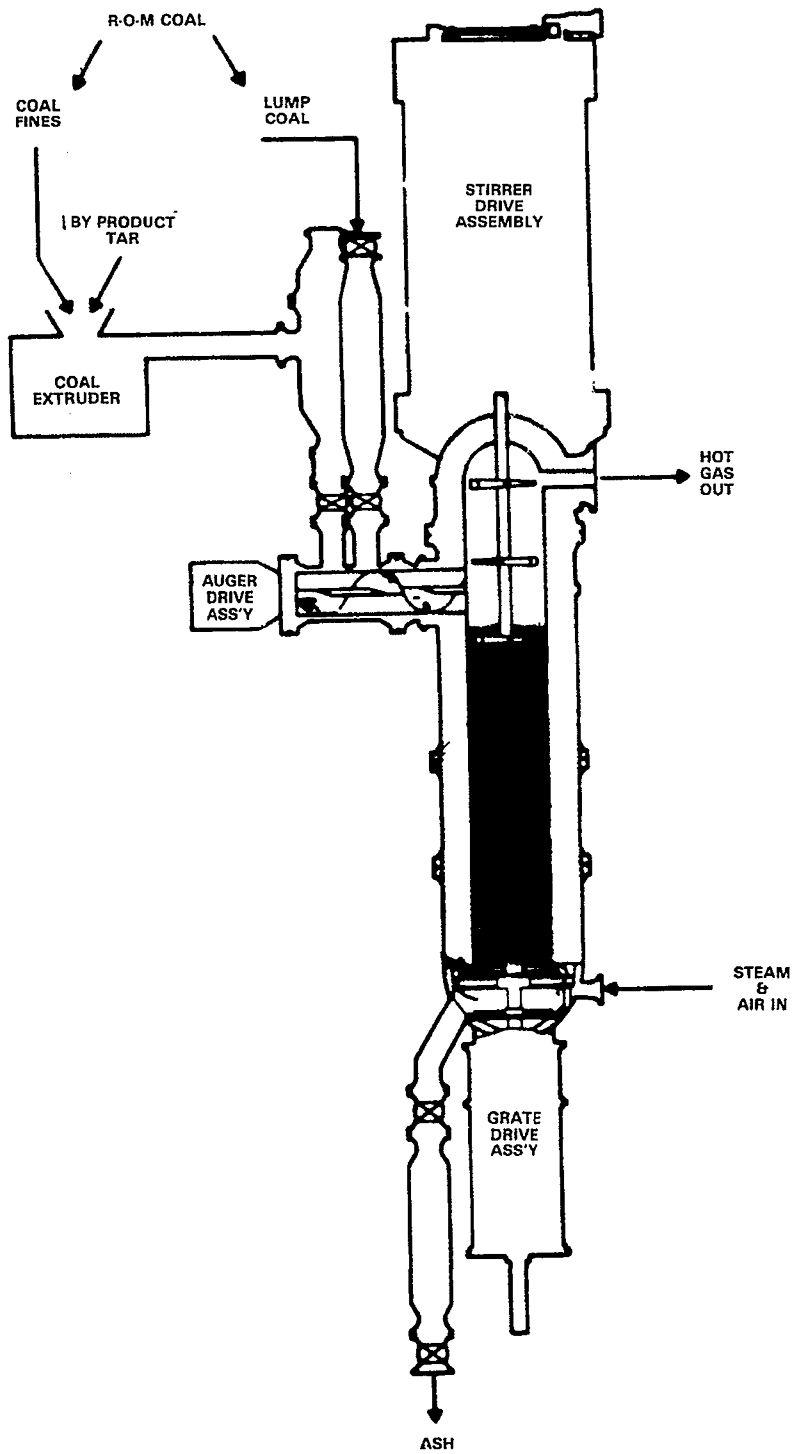


Figure 2A.2-1 GEGAS Gasifier.

2A.3 LURGI

Type

Fixed bed gasifier

Licensor

Lurgi Kohle und Mineraloeltechnik GmbH
Bockenheimer Landstrasse 42
Postfach 119181, D-6000
Frankfurt am Main 1
West Germany

State of Development[1 2 3 4 5 6 7]

The Lurgi process is a commercially proven gasification process for manufacturing fuel gas and other by-products from coal.

The first full-scale Lurgi coal gasification plant was constructed at Hirschfelde, Germany, in 1936. Since then, 18 commercial plants have been installed worldwide, and 4 others are under construction. These are summarized in Table 2A.3-1.[8 9]

Various bench and pilot scale units have also been erected to test different types of coal and alternate gasifier designs. For example, in 1946, bench scale Lurgi gasifiers of 4, 6, and 13.5 inches I.D. were built at the Central Experimental Station of the Bureau of Mines to test Alabama caking coals. In 1953, a pilot plant was erected at Holten, Germany, to test the Lurgi gasifier for various high-volatile coals and weakly caking coals. A 170 MW combined cycle plant utilizing the Lurgi pressure gasification system was tested in Lunen, Germany, in 1973.

Large plants utilizing Lurgi gasifiers for production of synthesis gas have been built for SASOL in South Africa.[2 3] The first U.S. plant for production of SNG is being planned to be built at Beulah Hazen, North Dakota; it is scheduled for completion in mid-80's.

Description[1 10]

The Lurgi gasifier is a fixed bed gasifier, operating at 350-450 psig. (See Figure 2A.3-1.) The main gasifier shell is surrounded by a water jacket. Boiler feed water is circulated through the jacket to recover heat escaping from the gasifier shell. A coal lockhopper is mounted on top of the gasifer to feed the coal, and a motor-driven distributor is used to spread the incoming coal evenly over the coal bed. A motor-driven grate at the bottom of the gasifier is used to withdraw the ash formed. The ash drops into an ash lockhopper, which is an integral part of the gasifier.

Coal received from the stockpiles is crushed and screened to obtain 1/4" x 2" sized coal. It is then transported to the gasifier lockhopper by a system of belt conveyors. Fines generated during the crushing and screening are removed and are available for use in the plant or for export. Steam and oxygen are introduced at the bottom of the gasifier and distributed into the coal bed through the rotating grate. The grate supports the coal bed and is continuously rotated to assure a constant and even withdrawal of the ash formed.

As the steam and oxygen pass upward, four different zones can be characterized in the coal bed by the prevailing reactions and temperatures. They are, from bottom to top, carbon combustion, gasification, devolatilization, and drying. As the coal descends through the bed, some volatile matter in the coal is first removed, and the remaining carbon is then gasified and combusted. The ash is withdrawn from the bottom of the gasifier into the ash lockhopper and subsequently sent to disposal. Excess steam is added to the ash layer just above the grate to prevent slagging of the ash.

Crude gas formed in the gasifier leaves from the top and flows through a scrubber cooler, where it is washed by circulating gas liquor. (See Figure 2A.3-2.) The gas then passes through a waste heat boiler, where it is cooled and low-pressure steam is generated. Condensate formed is subcooled and sent to a tar-liquor separator. Gas exiting the waste heat boiler is further cooled and the condensate recovered from this cooling is sent to the gas-liquor separation system.

In the gas-liquor separator, essentially all the tar and oils is removed from the gas-liquor, which then goes to phenol and ammonia recovery. These consist of Phenosolvan unit (see Chapter 3C.3) and a Chemie LinzLurgi (CLL) ammonia plant (see Chapter 3B.1), where crude phenols and anhydrous ammonia are recovered.

The cooled gas is desulfurized in an acid gas removal unit. Byproduct naphtha is recovered in a wash step prior to acid gas removal. The final product gas is a desulfurized medium-Btu gas.

Feed Requirements[6]

Coal sized to 1/4" x 2" is required. The gasifier will accept caking and non-caking coals. The following U.S. coals, which include caking coals, have been tested with satisfactory results in Lurgi gasifiers: Illinois #5 and #6, Pittsburgh #8, Montana Rosebud, and North Dakota Lignite. It has been observed that use of highly caking coals slightly reduces the gasifier throughput and increases the steam requirement.

Up to 30-35% moisture can be tolerated in the coal feed; therefore, predrying is rarely necessary.

To avoid clinker formation, the initial deformation temperature of the ash should not be significantly lower than the combustion zone temperature.[1 2] Control of the ash temperature by increasing steam flow or by variation in grate speed may avoid the problem.

Operating Conditions

Temperature in combustion zone = 1800-2500 °F
Temperature in gasification zone = 1200-1500 °F
Temperature of gas leaving the gasifier = 700-1000 °F
Pressure = 350-450 psig

Temperatures depend on the type of coal gasified.

Gas Produced

Typical gas composition (dry basis) after gas scrubbing and cooling

	O_2-Blown Operation
Feed Coal	Pittsburgh #8
HHV of coal, Btu/lb, dry	14,900
Mole%, CO	16.9
CO_2	31.5
H_2	39.4
CH_4	9.0
C_2H_4	0.1
H_2S + COS	0.8
N_2 + Ar	1.6
HHV,Btu/scf dry	285

By-Products[5]

Based on oxygen gasification of Pittsburgh #8 coal

Tar, lb/ton of coal	75
Oil, lb/ton of coal	25
Gas Liquor, lb/ton of coal	4000-6000
Steam Generated @ 100-135 psig, saturated (Typically H.P. steam + moisture in coal) lb/ton of coal	1300
Steam Generated @ 25-50 psig, saturated, lb/ton of coal	2500

Utility Requirements

Based on oxygen gasification of Pittsburgh #8 coal

Oxygen (98%), lb/lb of coal	0.6 (For caking coals) 0.3-0.4 (For Western coals)
Steam, lb/lb of coal	0.32
BFW, lb/lb coal to gasifier	0.3
Electric Power, kWh/ton of coal	23*

* From receiving crushed coal to delivery of cooled ash, gas, tar, oil, and liquor. Does not include oxygen compression.

Thermal Efficiency

Based on cooled and scrubbed product gas, and a coal with HHV of 8380 Btu/lb, dry

Cold Gas Efficiency = 63%
Overall Thermal Efficiency =76%

Capacity

A typical commercial Lurgi gasifier with a 12 ft I.D. can gasify approximately 800 tpd of coal to produce about 56 MM scfd of medium-Btu gas at 400 psig. Turndown ratio is of the order of 4 to 1.

Environmental Considerations

Extra handling of the fines from coal handling and crushing is required, and their final disposition must be determined for each installation.

Wastewater from the scrubber cooler, Phenosolvan unit, etc., has organic and inorganic contaminants and will require bio-oxidation treatment. Inorganic solids recovered may be mixed with ash and disposed of as landfill.

Tar, oil, phenol, naphtha, ammonia, and sulfur are the by-products produced in a Lurgi pressure gasification system. The quantity of these by-products varies according to the coal feedstock. Part of the tar is recycled to the gasifier.

Remarks

Lurgi is a proven commercially available coal gasification process. It is projected from the Westfield tests that it can gasify all types of coal. Use of highly caking coals, however, reduces the gasifier throughput and increases the steam and oxygen requirement. A modified Lurgi using a stirrer to break down agglomerates can gasify caking coals without pretreatment.

Coal preparation costs are reduced since the process does not require pulverizing and drying, but use and/or disposal of the fines generated in the sizing operation may be a problem at some installations.

The process produces by-products such as tar oil, crude phenols, and naphtha; the final disposition of these products must be ascertained for each installation.

References

1. Rudolph, P.E.H., "The Lurgi Process -- The Route to SNG from Coal," presented at the Fourth Synthetic Pipeline Gas Symposium, Chicago, Illinois, October 1972.

2. Hoogendoorn, J.C., "Gas from Coal with Lurgi Gasification at SASOL," South Africa Coal, Oil and Gas Corporation, LTD., Sasolburg, South Africa.

3. McIver, A.E., "SASOL: Processing Coal Into Fuels and Chemicals for the South African Coal, Oil and Gas Corporation," presented at Second Annual Symposium on Coal Gasification, Liquefaction, and Utilization, Pittsburgh, Pennsylvania, August 5-7, 1975.

4. Elgin, D.C., and Perks, H.R., "Results of Trials of American Coals in Lurgi Pressure-Gasification Plant at Westfield, Scotland," Proceedings of Sixth Synthetic Pipeline Gas Symposium, Chicago, Illinois, October, 1974.

5. Morgan, R.E., et. al., "Lurgi-Gasifier Tests of Pennsylvania Anthracite," Bureau of Mines Report of Investigations 5240, 1958.

6. Cooperman, J., et. al., "Lurgi Process -- Use for Complete Gasification of Coals with Steam and Oxygen Under Pressure," Bureau of Mines Bulletin 498, 1951.

7. "Report on the Trials of American coals in a Lurgi gasifier at Westfield, Scotland, for AGA & OCR, Department of Interior," by Woodall-Duckham Company, June, 1974.

8. "Lurgi Pressure Gasification: Performance Record," Lurgi Express Information Brochure No. O 1018/10.75, 1975.

9. "Lurgi Coal Pressure Certification: Performances," Lurgi Express Information Brochure No. 0-1352/3.80, March 1980.

10. Gallagher, J.T., "The Lurgi Process State of the Art," presented at Symposium on Coal Gasification, Liquefaction, and Utilization, Pittsburgh, Pennsylvania, August 5-7, 1974.

TABLE 2A.3-1 LIST OF GASIFIERS

	Location	First Operated Year	Type of Coal	I.D.	Output (MMscfd)	No. of Gasifiers
1	Hirschfelde, Central Germany	1936	Lignite	3'9"	1.1	2
2	Bohlen, Central Germany	1940	Lignite	8'6"	9.0	5
3	Bohlen, Central Germany	1943	Lignite	8'6"	10.0	5
4	Most, CSSR	1944	Lignite	8'6"	7.5	3
5	Zaluzi-Most, CSSR	1949	Lignite	8'6"	9.0	3
6	Sasolburg, South Africa	1954	Sub-Bitum. (greater than or equal to 30% ash)	12'1"	150.0	9
7	Dorsten, West Germany	1955	Caking Sub-Bitum. with high chlorine content	8'9"	55.0	6
8	Morwell, Australia	1956	Lignite	8'9"	22.0	6
9	Daud Khel, Pakistan	1957	High volatile coal with high sulfur content	8'9"	5.0	2
10	Sasolburg, South Africa	1958	Sub-Bitum. with 30% ash and more	12'1"	19.0	1
11	Westfield, Great Britain	1960	Weakly Caking Sub-Bitum.	8'9"	28.0	3
12	Jealgora, India	1961	Different grades	N/A	0.9	1
13	Westfield, Great Britain	1962	Weakly Caking Sub-Bitum.	8'9"	9.0	1
14	Coleshill, Great Britain	1963	Caking Sub-Bitum. with high chlorine content	8'9"	46.0	5
15	Naju, Korea	1963	Graphitic anthracite with high ash content	10'5"	15.0	3
16	Sasolburg, South Africa (Sasol I)	1966	Sub-Bitum. with 30% ash and more	12'1"	75.0	3
17	Luenen, GFR	1970	Sub-Bitum.	11'4"	1400 MM Btu/hr	5
18	Sasolburg, South Africa (Sasol II)	1973	Sub-Bitum. with 30% ash and more	12'4"	190.0	3
19	Secunda, South Africa (Sasol III)	1980	Sub-Bitum. with 20-25% ash	12'4"	1000	36
20	Beulah, Hazen, N.D.	1984(OP)	North Dakota Lignite	12'4"	125.0	14
21	Sasol IV	Not Available	Sub-Bitum.with 20-25%	Not Available	1000	36
22	China	Not Available	Low volatile, semi-anthracite	Not Available		

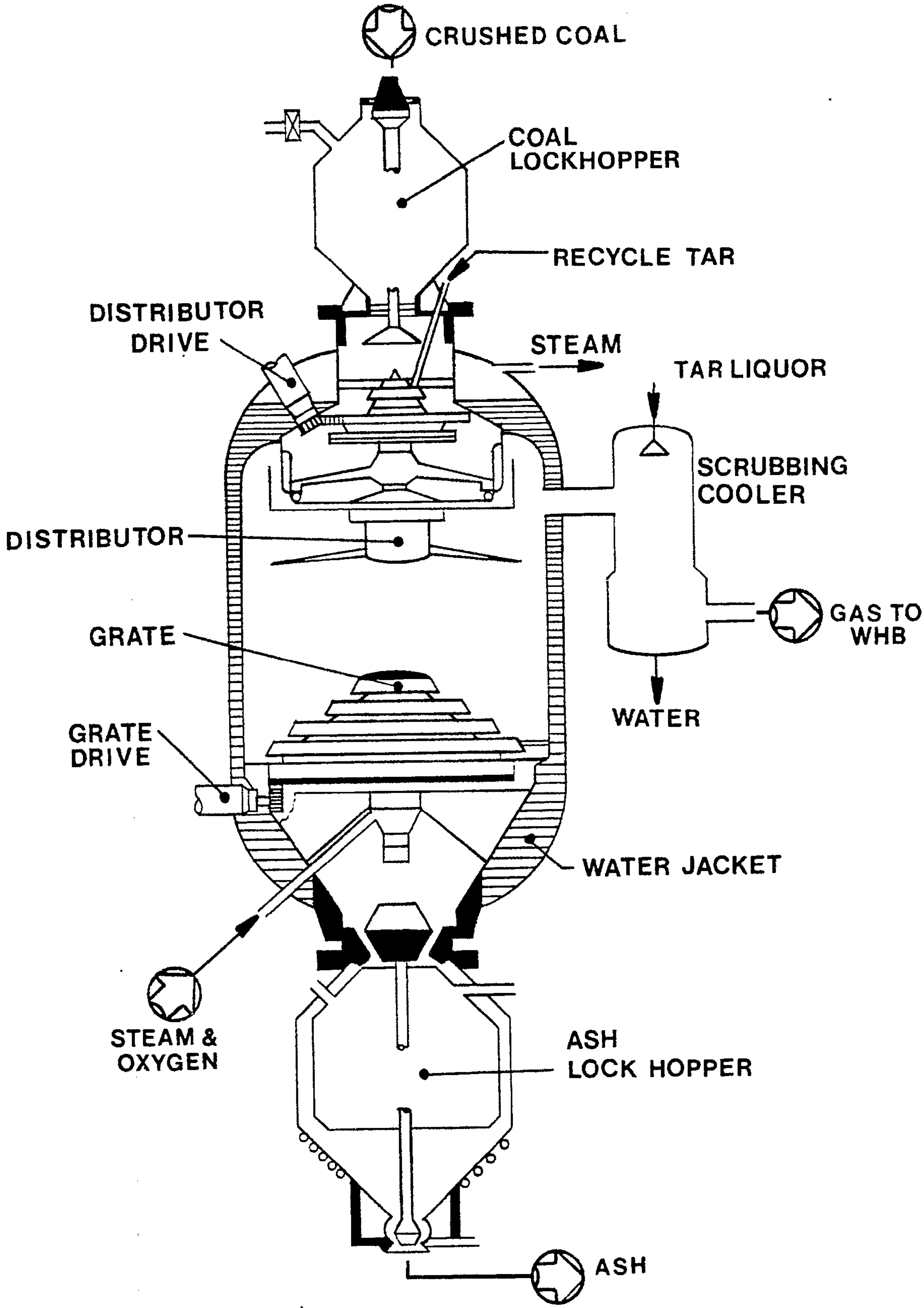


Figure 2A.3-1 Lurgi Pressure Gasifier.

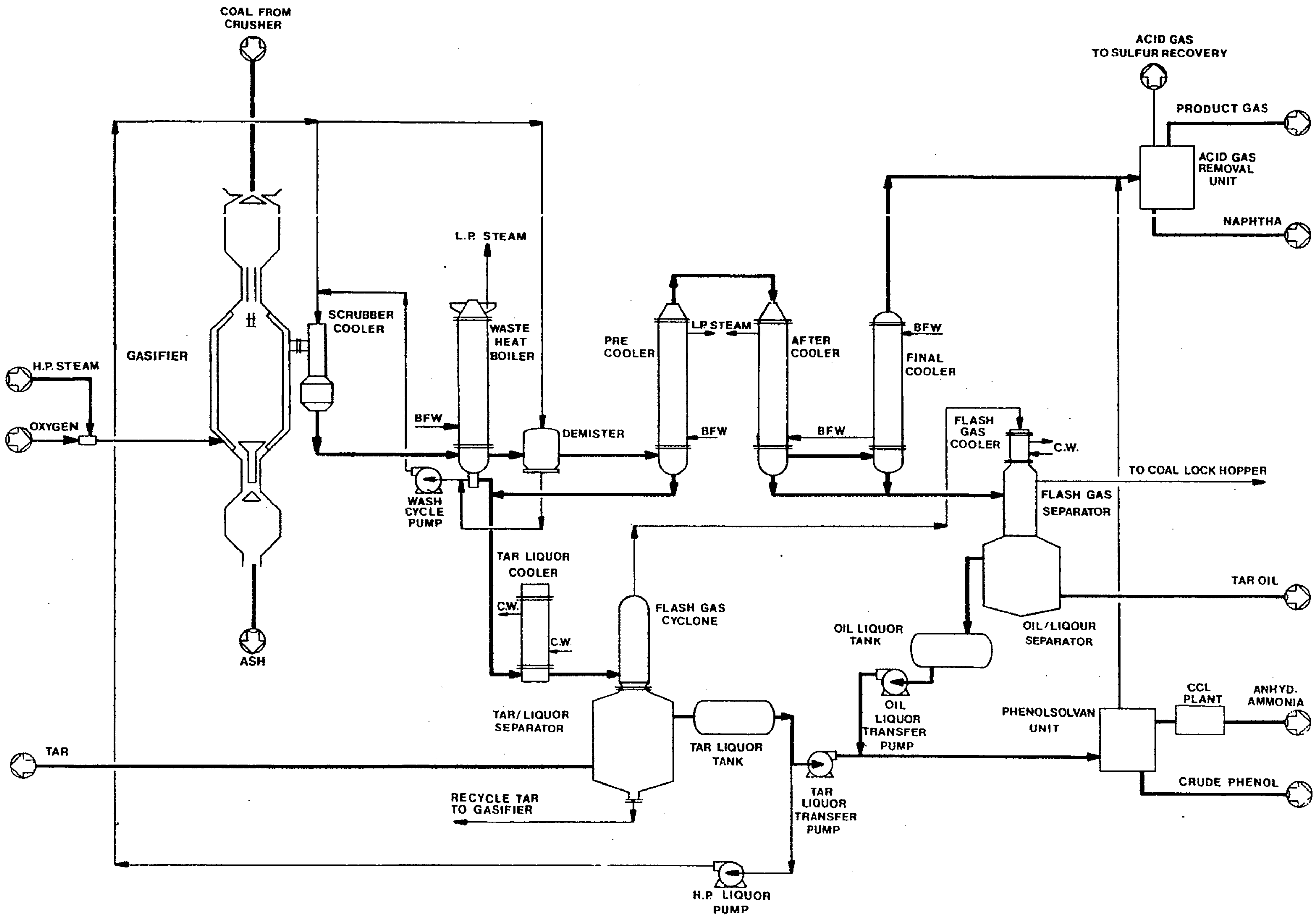


Figure 2A.3-2 Lurgi Coal Gasification System.

2A.4 METC STIRRED-BED

Type

Fixed bed gasifier with central agitator

Developer

U.S. Department of Energy
Morgantown Energy Technology Center
Collins Ferry Road
P.O. Box 880
Morgantown, WV 26505

State of Development

The METC (Morgantown Energy Technology Center) 42-in Stirred-Bed gasifier has been demonstrated in a 24 tpd pilot scale unit.

The METC Stirred-Bed gasifier has been under development since 1967. It is an extension of the Wellman-Galusha atmospheric pressure gasifier, modified for pressurized operation.

The pilot-scale unit, located in Morgantown, West Virginia, continues to be operated, but many modifications have been made over the years. Various U.S. coals have been tested, and the results confirm that strongly caking coals can be gasified in a fixed bed unit without pretreatment.[1] However, continuous stirring of the fuel bed is required for many coals to maintain gas quality and prevent ash agglomeration. The gasifier has been tested at pressures up to 300 psig with no significant effect on gas yield or heating value. In addition, testing has led to improvements in instrumentation, coal feed mechanisms, valve designs, the grate drive mechanism (hydraulic instead of a mechanical drive), and operating procedures, among other things.[2 3]

Description[4]

The METC Stirred-Bed gasifier, shown in Figure 2A.4-1, has inside dimensions of 3.5-ft diameter and 24-ft height. The lower portion of the steel shell is water jacketed; the upper section is expanded and lined with refractory to the same inner diameter as the lower portion. The fuel bed, which is normally kept at a depth of about 6 to 8 ft, is supported on a rotating grate composed of three flat circular plates, spread eccentrically one above the other, that support the fuel bed. The rotation of the grate pushes the ash horizontally between the plates so that the ash drops through centrally located holes in the lower two plates. The fuel-bed agitator consists of a vertically mounted rotating shaft to which two horizontal arms, or rabbles, located 3 ft apart are attached. The two rabble arms extend radially in opposite directions to each other. Each arm is equipped with three thermocouples. The entire length of the shaft that penetrates the hot, incandescent zones of the bed is cooled by circulating water, as are the two rabble arms. A variable-speed drive rotates the shaft and moves it vertically in either direction. Vertical travel of up to 6 ft for each arm is controlled by positioning of limit switches and can be adjusted so the lower arm reaches within 3 in. of the top of the grate. The total depth of bed that could be stirred is thus 9 ft, though beds are not normally that deep. With bituminous coals, the agitator is usually rotated at about 30 rph and set to pass vertically through the bed in about 20 minutes. These rates can be varied to suit the properties of the coal.

Figure 2A.4-2 shows the producer and its auxiliary equipment. Coal is stored in two adjacent silos (only one is shown in Figure 2A.4-1) and carried by a belt conveyor and a bucket elevator to two lockhoppers located near the top of the gasifier. Once fed via rotary screw feeders to the gasifier, the coal progresses down through the bed until the residue is discharged through the grate and subsequently lockhoppered out of the system. Ash removal is governed by the grate rotation speed and is normally adjusted to hold the combustion zone one foot above the grate. Several nuclear density gauges, installed during the early phases of the development program along the side of the gasifier, aid in the detection of the ash zone, the bed level, and voids.

Air, mixed with superheated steam, is introduced into the gasifier below the grate, and flows countercurrently through the descending coal, thus providing partial burning and then gasification of the coal. Both flow rates (air and steam) can be adjusted independently. The air rate, to a large degree, controls the rate of fuel consumption, while the steam rate controls the temperature. It is important that the temperature be held below the ash fusion temperature of the coal to avoid formation of clinkers that could clog the grate. The product gas, after leaving through a side outlet in the dome, passes through a cyclone separator that removes most of the entrained coal dust. The gas then flows through a quenching vessel, where gas temperatures are reduced from 1000 °F to approximately 350 °F. Temperature controlled nozzles atomizing recycled liquor (sour water) provide the required cooling medium. Essentially all of the resulting condensed heavy tars are removed in this vessel and the subsequent cyclone tar separator. Light tars and heavy oils are then removed by a venturi scrubber, using recycle liquor, and an electrostatic precipitator. The direct cooler, a counterflow tray scrubber using recycle liquor, then memoves the light oils condensed from the unreacted gasifier process stream and reduces gas temperature to that required for the downstream Holmes-Stretford desulfurizer. The direct cooler decanter is the only source of a wastewater effluent and is also the source of the coolant for the quench vessel nozzles. Heat is removed from the recycle liquor through an indirect process water heat exchanger and cooling tower. The high-pressure Holmes-Stretford desulfurizer converts H_2S to elemental sulfur, which is removed in a wet cake form.

The final cleaning step occurs in packed columns using recycle water to remove trace contaminants that may be entrained in the gas stream. System back pressure is controlled by a valve at the exit of the cleanup train, thus providing for long valve life. The gas is then flared, incinerated, or piped for various test uses. In addition, a small fraction is diverted, cooled, cleaned of dust, tar, and water, metered, and analyzed by gas chromatographs for carbon monoxide, carbon dioxide, hydrogen, methane, nitrogen, hydrogen sulfide, and oxygen.

Start-ups are made by packing the gasifier with, from the grate up, ash, kindling wood, charcoal, and pea size anthracite. The start-up ash is required to protect the grate from the combustion zone heat until ash from the feed coal itself can serve as the insulator. Anthracite or coke must be used initially to avoid the deposition of large amounts of tars that could result during cold starts with other coals.

Once exit gas temperatures reach about 700 °F, the test coal is introduced. It normally takes about 4 hours from the time the coal is first introduced until the anthracite is burned out and completely replaced by the coal.

A design for a 1200 tpd stirred-bed, dry bottom gasifier (15 ft in diameter and about 30 ft high) has been developed for a proposed DOE Coal Gasification Multi-Test Facility (GMTF).[5] The design is based on the METC stirred-bed gasifier and data provided from it, but the 1200 tpd unit is designed to operate at 600 psig in an oxygen blown mode for production of medium-Btu gas or in an air blown mode for production of low Btu gas. In the GMTF design report, gas and process stream compositions are presented for Illinois #6, Pittsburgh Seam #8, and Montana Rose-bud coals. In addition, heat and material balances, a master item index, utility requirements, process flow diagrams, and a cost estimate are presented.[1, 5]

Feed Requirements

Pre-sized and pretreated coals are not required - various coal sizes have been successful with various coals. Run-of-mine coal can also be used. The gasifier has been tested using both strongly caking and non-caking coals. With some coals, feed rates of over 2500 lb/hr have been maintained. Predrying of feed coal is not necessary.

Operating Conditions[4]

Temperature in combustion zone = 1800-2500 °F depending on the coal
Temperature of gas leaving the gasifier = 800-1300 °F
Pressure = Atmospheric to 285 psig

Gas Produced[4]

Typical gas composition (dry basis) after gas scrubbing and cooling and with air-blown operation.

Feed Coal	North Dakota Lignite	New Mexico Subbitum.	Arkwright Pittsb. Seam Bitumin.
HHV of coal, Btu/lb, dry	6890	8900	13,675
Free Swelling Index	2	2	8
Operating Pressure, psig	80	145	175
Mole%, CO	13.4	15.3	23.8
CO_2	12.4	12.7	7.0
N_2	58.2	59.3	48.7
H_2	14.7	10.7	16.5
CH_4	1.3	2.1	3.0
C_2H_6	0	0	0.3
H_2S	0	0.2	0.4
HHV, Btu/scf, dry	100	104	165

A comparison of gases using Illinois #6 bituminous coal in the air-blown METC 42-in unit based on measurements and on values calculated for the 1200 tpd GMTF oxygen-blown unit

	Air-Blown[4] METC 42-in	Oxygen-Blown[5] GMTF Stirred-Bed
Feed Coal	Illinois #6 Bituminous	Illinois #6 Bituminous
HHV of coal, Btu/lb, dry	11,750	12,675
Free Swelling Index	4.5	4.5
Operating Pressure, psig	144	600
Mole%, CO	18.2	31.1
CO_2	10.6	22.7
N_2	52.3	0.6
H_2	15.6	35.0
CH_4	2.4	8.7
H_2S	0.7	0.9
O_2	0	0.4
HHV, Btu/scf, dry	138	308

By-Products[4]

The quantities of tar produced are 59 lb/ton of coal for New Mexico subbituminous and 98 lb/ton of coal for Arkwright bituminous.

Utility Requirements[5]

	Lignite	Sub-bituminous	Bituminous
Air, lb/lb of coal	3.1	2.6	2.8-3.3
Steam, lb/lb of coal	0.5	0.4	0.4-0.5

These data are for an air-blown system based on operating conditions presented above for the METC 42-in gasifier. In a commercial system, the steam will be generated in the water jacket, so BFW requirements are not presented.

Thermal Efficiency[2, 4]

Based on cooled and scrubbed product gas and air-blown operation, efficiencies ranging from 65% to 70% during recent pressurized operations have been calculated.

Capacity

The pilot scale METC Stirred Bed gasifier, 3.5 ft in I.D. and 24 ft tall, can gasify about 24 tpd of coal to produce up to 2.4 MM scfd of low-Btu gas. Expected turndown ratio = 4/1.

Environmental Considerations

The ash produced from the stirred bed gasifier contains a minimal amount of carbon. Normally it can be disposed of as landfill, but ash from each coal must be tested to determine the disposal procedure.

The tar and oil produced will require additional facilities for storage or for further disposal. Processes are under development for the direct and indirect reinjection of these products.

Wastewater generated in the process will require treatment for phenolics and other organic removal before it is discharged.

Remarks

The METC Stirred-Bed gasifier will accept both caking and non-caking coal. The thermal efficiency of a commercial plant, taking into account the tar and oil produced, will be high. The disposition of the tar and oil must be determined for each particular installation. Further process development is underway at Morgantown for their direct injection or indirect use as a binder for coal fines in briquetting or extrusion.

References

1. Lewis P.S., et al., "Strongly Caking Coal Gasified in a Stirred-Bed Producer," Bureau of Mines Report of Investigations 7644, 1972.

2. Rahfuse, R.V., et al., "Non-caking Coal Gasified in a Stirred-Bed Producer," Bureau of Mines Technical Progress Report 77, March, 1974.

3. Lewis, P.S., et al., "Bituminous Coal Gasified in a Stirred-Bed Producer," ERDA Report MERC/R1-71/1, 1975.

4. Wilson, M.W., and Bissett, L. A., "Development and Operation of METC 42-inch Gas Producer during 1964-1977," DOE Report METC/RJ-78/12, October, 1978.

5. Hefferan, J.K., et al., "DOE Coal Gasification Multi-Test Facility," UOP, Inc. and System Development Corporation Conceptual Design, DOE Report No. DOE/ET/03117-TI, 13 July 1979.

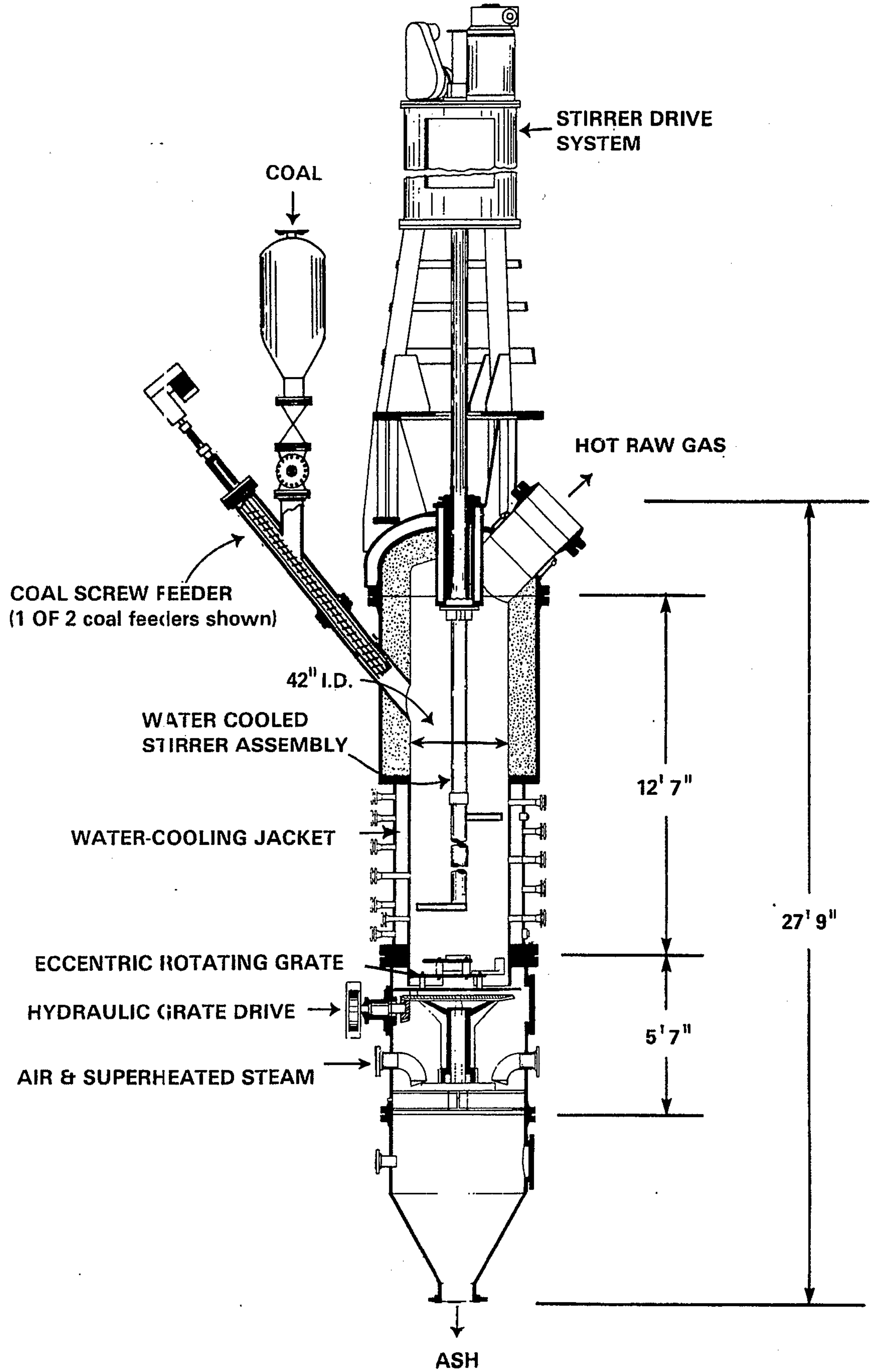


Figure 2A.4-1 METC Stirred Bed Gasifier

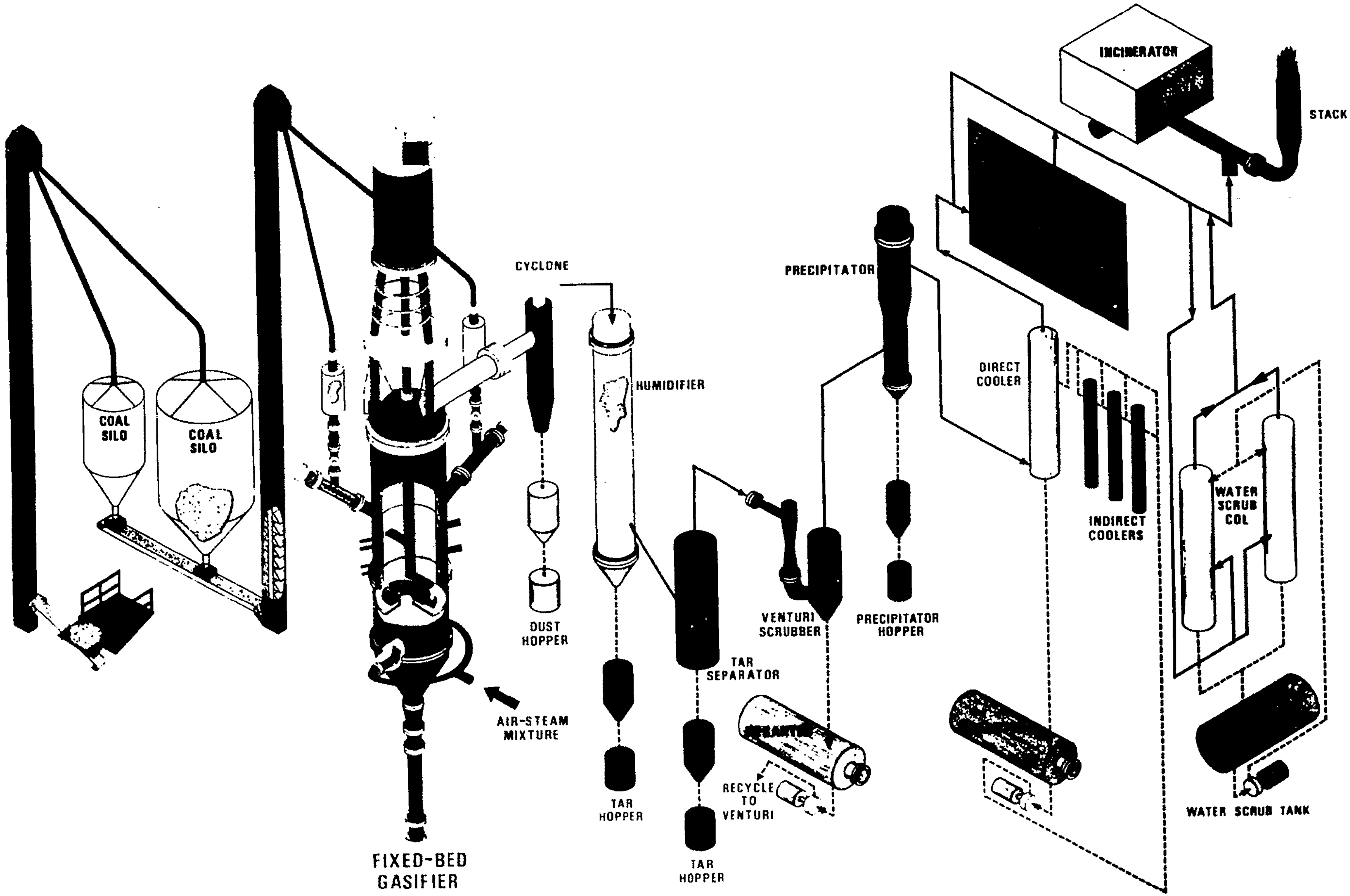


Figure 2A.4-2 METC Gasifier/Gas Cleanup Systems.

2A.5 RILEY-MORGAN

Type

Fixed bed gasifier

Developer

Riley Stoker Corporation
P. O. Box 547
Worcester, MA 01613

State of Development[1 2]

During the first half of the twentieth century, the Morgan Gas Producer was one of the successful coal gasifiers. Over 9,000 of these fixed bed units were built throughout the world. Riley Stoker Corporation obtained the rights to this fixed-bed gasifier from the Morgan Construction Company in late 1973. After redesigning the Morgan unit for modern manufacturing practices, Riley then began two parallel programs to develop operating data and techniques.

In the early part of 1974, Riley installed a small pilot plant in its Worcester facility to provide operating experience and to explore problems associated with tar formation from bituminous coals. This unit was operated for over a year on low-ash-fusion-temperature and highly caking varieties of eastern bituminous coals, using both air and oxygen.

During June of 1975, experience gained from the pilot plant was utilized to install a commercial size unit. Various coals have so far been tested, and Riley has completed a series of tests on Illinois #6 coal using air, enriched air, and pure oxygen. Western sub-bituminous coal and lignites have also been tested.

Description[3 4 5]

A schematic of the gasification system and the gasifier details are shown in Figures 2A.5-1 and 2A.5-2, respectively. Coal is unloaded into a truck hopper, then elevated to a 60-ton bunker, from which it flows to a standard Riley Stoker Drum Feeder. The metered coal then drops into a twin lockhopper arrangement designed so that the coal gates do not close against a head of coal. The discharge of the lockhopper is governed by a count from the feeder. Coal enters the top of the gasifier and is spread evenly on top of the bed by the action of the rotating barrel and the pivoting leveler arms. As coal is consumed by the gasification process, the level of the top of the bed goes down. This level is automatically read out via a load cell on the leveler control, and level is restored by coal feed.

A fan supplies the air for the system. Metered steam is introduced into the bottom of the rotating ash pan through a blast hood. There is no grate in the system; the ash bed performs the function of a grate. The air-steam mixture moves countercurrently to the descending coal, first through the oxidizing zone, and then through the reducing gas zone and devolatilization zone. The raw product gas passes through a refractory-lined duct to a cyclone for fines separation and then to a quench chamber. Gas is then passed through a condenser, where tars and oils separate out, then through a electrostatic precipitator for dust removal, and then through a sulfur removal system.

Ash from the gasifier is removed by means of a helical plow located in the ash pan. As coal is consumed, the remaining ash builds up. To maintain level, ash is removed according to a calculated schedule in conjunction with leveler arm position. Ash is moved radially outward and over the tip of the pan when the plow is engaged. From there it is discharged through a water seal and conveyed to disposal.

Feed Requirements[4]

During the past several years, Riley has conducted gasification studies on a number of U.S. coals in both the commercial size gasifier and the smaller 2-ft diameter pilot unit. These coals have included anthracite (pea and nut size), high volatile and medium volatile bituminous, and Northern Plains lignite. Coal is sized to 2 in x 1 1/2 in (bituminous) or 2 in x 1/2 in (lignite).

Operating Conditions

With high volatile bituminous coal gasification, the maximum temperature attained in the reaction zone is about 2000 °F; raw gas exits at 1000-1200 °F. With lignite, the exit gas temperature is 518 °F. The gasifier operates at atmospheric pressure.

Gas Produced[4 6 7]

Typical raw gas composition with air gasification of different coals is as follows

Feed Coal	High Volatile Bituminous	Lignite
HHV of coal, Btu/lb, dry	14,570	10,760
Mole %, CO	21.6	28.1
CO_2	7.5	6.1
H_2	13.9	17.3
CH_4 + C_nH_m	3.1	1.7
N_2 + Ar	52.1	45.0
COS + H_2S	0.1	0.1
H_2O	1.7	1.7
HHV, Btu/scf	156	166

By-Products[3 4 7]

	High Volatile Bituminous	Lignite
Tar, lb/ton of coal	74	40
Light oil, lb/ton of coal	80	Not Available

Sulfur can be recovered as a by-product with downstream processing. Ash leaving the gasifier bottom is disposed of.

Utility Requirements

	High Volatile Bituminous	Lignite[7]
Air, lb/lb MAF coal	3.11	2.44
Steam, lb/lb MAF coal	0.44	0.44

Thermal Efficiency

	High Volatile Bituminous	Lignite[7]
Cold gas efficiency (%)	71.3	79.5
Cold gas + tar + oil (%)	78.3	82.8

Capacity

The full size gasifier is 10.5 ft in internal diameter and can process about 3 tph of HVAB coal.

Environmental Considerations

H_2S, NH_3, HCN, and COS are properly treated in proven processes. Tars and oils are recovered. Fines (0.5 to 3% of coal feed) carried over with the gas are separated in cyclones and may be reused.

Remarks

There are operating and design principles governing the capacity, smoothness of operation, and the operational efficiency. Some of these are:

- Careful sizing is a must for maximum throughput.
- For a swelling coal, an optimum exit temperature exists, which can be governed by bed height. In general, the higher the swelling index, the shallower the fuel bed. Optimum agitation depth for caking coals is 6 in.
- Even coal distribution over the top of the bed must be maintained, including continuous feed operation, since coals of different sizes will segregate.

References

1. Rutherford, R. J. and Rawdon, A. H., "The Riley-Morgan Gasifier," Power Generation...Clean Fuels Today: Seminar, Monterey, California, April 1974.
2. Lisauskas, R. A., et al., "Control of Condensible Tar Vapors from a Fixed Bed Coal Gasification Process," presented at Fourth Energy Resource Conference, Lexington, Kentucky, January 1976.
3. Rawdon, A. H., et al., "Operation of a Commercial Size Riley-Morgan Gasifier," presented at American Power Conference, Chicago, Illinois, April 19-21, 1976.
4. Earley, W. P., et al., "Practical Operating Experience on a Riley Gasifier," presented at 88th National Meeting of American Institute of Chemical Engineers, Philadelphia, Pennsylvania, June 8-12, 1980.
5. Walsh, T. F., "Update of Coal Gasification for Industry," presented at Industrial Fuel Conference, Purdue University, Indiana, October 5-6, 1977.
6. Walsh, T. F., "The Riley-Morgan Gasifier," presented at Third Annual International Conference on Coal Gasification, Liquefaction, and Conversion to Electricity, Pittsburgh, Pennsylvania, August 3-5, 1976.
7. Kolesh, V. A., et. al.; "Low Btu Gasification of Northern Plains Lignite in a Commercial Sized Unit," presented at American Power Conference, Chicago, April 27-29, 1981.

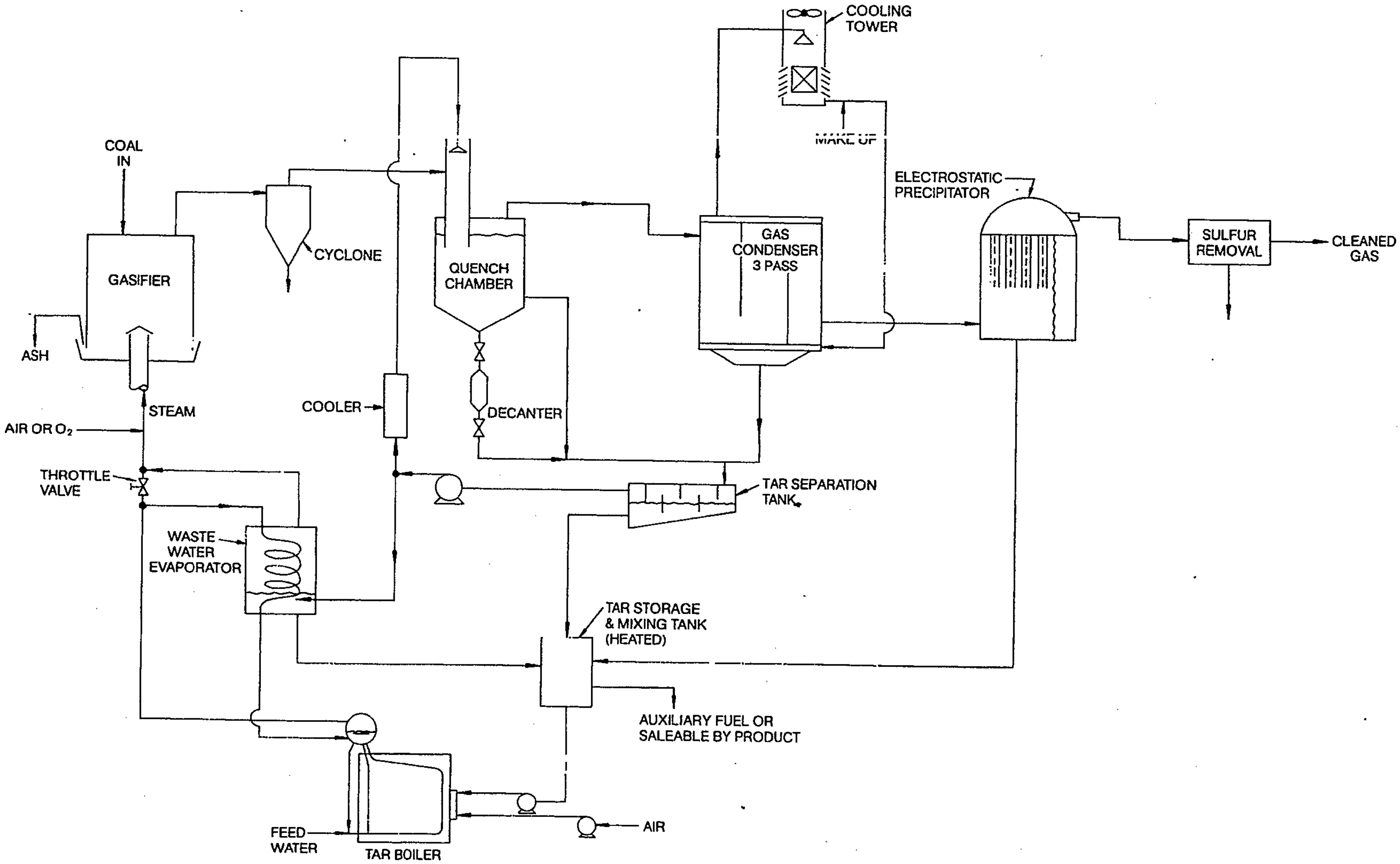


Figure 2A.5-1 Riley-Morgan Gasification System.

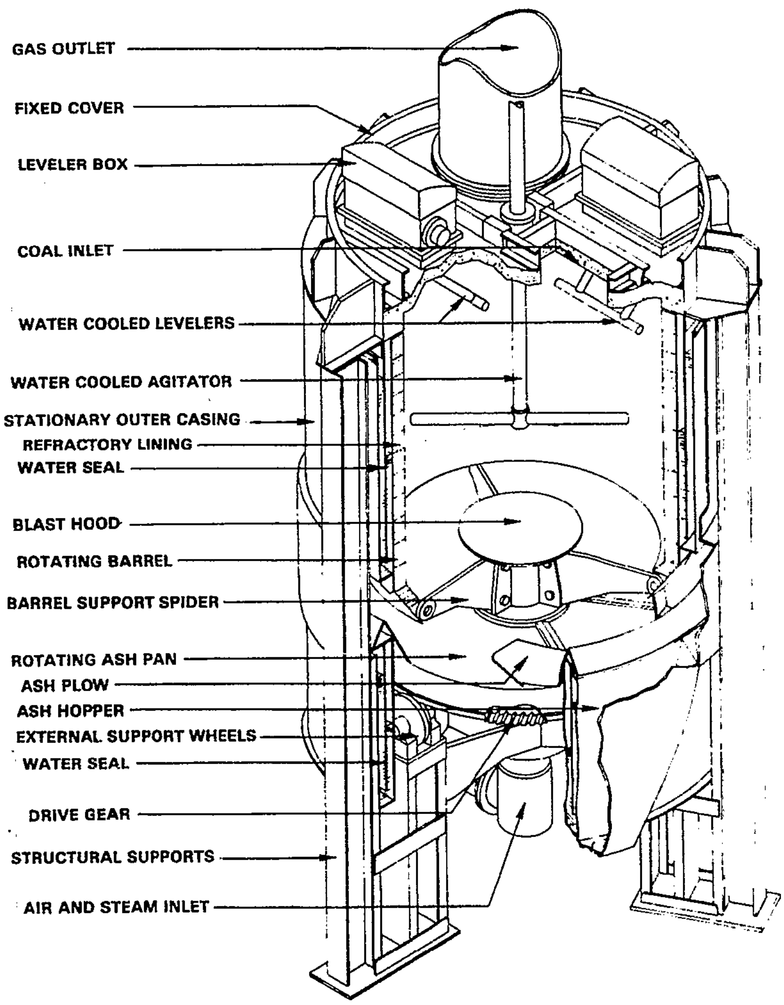


Figure 2A.5-2 Riley-Morgan Gasifier.

2A.6 RUHR 100 GASIFICATION

Type

Fixed Bed Gasifier

Developer

Arbeitsgemeinschaft Druckvergasung
Ruhrgas A.G./Ruhrkohle A.G./Steag A.G.
Huttropstrasse 60
D 4300 Essen-1
West Germany

State of Development[1 2]

The Ruhr 100 gasification process is being developed by a Joint Venture of Ruhrgas AG, Ruhrkohle AG, and Steag AG, all of West Germany, under the sponsorship of the West German Ministry of Research and Technology. The purpose of the work is to develop a pressurized Lurgi process for the production of substitute natural gas and synthesis gas.

The development of the process began in 1976 when Lurgi Kohle und Mineraloeltechnik GmbH of Frankfurt was given a contract to design the gasifier, shift converter, and raw gas reformer for a 7 tph MAF coal (maximum) pilot plant. Construction began in Dorsten, West Germany in 1977, and operation of the plant began in late 1979.

More than 4900 tons of coal had been gasified by November, 1980 in 12 test runs (1850 operating hours) at a maximum working pressure of 1015 psig. These runs employed three types of coal: anthracite, Furst Leopold caking coal, and Westerholt non-caking coal. Caking coal gasification resulted in severe problems and was postponed to a later date. The anthracite middlings performed better than the nut size anthracite. The Ruhr 100 gasifier will eventually be operated at a maximum pressure of 1450 psig. Compared to normal Lurgi operation, this process has advantages of increased coal throughput, improved methane content of the product gas, and reduced production of liquid by-products. A preliminary study of a 3 million tpy commercial size plant is being prepared for the State of North-Rhine Westphalia.

The Ruhr 100 pilot plant was built in Dorsten because Ruhrgas operated a commercial size long-flame coal gasification plant to manufacture town gas at this location between 1955 and 1967.

Description

The Ruhr 100 gasifier is shown in Figure 2A.6-1. The gasifier is basically a Lurgi type with modifications for high-pressure operation. The reactor is equipped with an externally driven rotating grate through which the gasification agents (steam and oxygen or air) are fed into the gasifier. The coal is fed to the reactor through two coal lockhoppers operated in an alternating mode to minimize lock gas losses. The ash is removed through an ash lockhopper. The product raw gas can be tapped from the reactor at two points: the clear gas outlet and the carbonization gas outlet. These outlets are located at the top of the reactor and at the top of the gasification zone of the reactor, respectively. Either one or both gas streams are cooled separately to 390 °F in scrubbers and waste heat boilers. The coal distributor and the water-cooled stirrer are arranged in the center of the gasifier. The three blade stirrer is used to prevent the caking coals from fusing inside the reactor. The reactor itself weighs approximately 135 tons. The inner shaft diameter is 5 ft, and the structure is 37 ft high.

The coal throughput is increased by raising the working pressure of the gasifier. The pilot plant gasifier has been designed for a coal feed rate of 3 tph MAF coal at 362 psig. As the working pressure is raised to 1450 psig, the coal feed rate will increase to approximately 7 tph MAF coal. The gasifier grate has been designed for an ash rate of 3.5 tph when the reactor is operated at the maximum coal feed rate. As the hydrogen partial pressure increases as a function of the increase in working pressure, the methane content of the raw gas also increases. Maximum methane content of the raw gas is expected to be approximately 18% by volume for gasifier operation at 1450 psig, compared to about 10% by volume at 362 psig. The heat liberated by the formation of the methane reduces the need for the production of heat by partial combustion of the feeder coal and thus lowers the oxygen and coal consumption.

Conventional Lurgi gasifiers do not allow operations to influence the rate of gas flow and the coal heat-up rate in the gasification zone. The second gas outlet of the Ruhr 100 gasifier makes it possible to control coal heating. Also, it reduces the rate of flow in the carbonization and drying zones, and less fines are entrained into the scrubber.

Transformation of the gaseous and liquid hydrocarbons in the raw gas occurs in a downstream reformer. The mode of operation of the reformer depends on the type of gas produced. It can be run either as a partial oxidation plant in which the methane is also converted into carbon oxide and hydrogen or as a catalytic reformer in which the methane is not transformed.

Feed Requirements[1]

The anthracite middlings were sized to 95% below 1.2 inches with almost 20% fines. The sulfur and ash content were 1.28% and 27.1%, respectively. The Westerholt middlings were sized to approximately 90% below 1.2 inches. The average sulfur and ash contents were 1.85% and 28%, respectively.

Operating Conditions[1]

The gasifier has been operated at 1015 psig pressure. The next phase is operation at 1160 psig. Gradually pressure will be increased to 1450 psig, which is also the goal for a commercial gasifier. Gasifier temperature is approximately 1750 °F. The raw gas exits at 750 °F at 362 psig.

Gas Produced[1]

Typical gas composition at the gasifier outlet for the two types of coal (oxygen-blown gasifier) at an operating pressure of 362 psig

Feed Coal	Anthracite	Westerholt
HHV of Coal, Btu/lb.	Not Available	Not Available
Gas Production, ft^3/lb coal, MAF	35.5	35.5
Mole %, CO	17.0	16.0
CO_2	30.2	33.3
H_2	40.9	39.0
$CH_4 + C_nH_m$	9.7	9.7
$N_2 + Ar$	1.7	1.3
H_2S	0.5	0.7
HHV, Btu/scf	292.9	291.9

By-Products

Gaseous and liquid hydrocarbons are treated in a downstream reformer for conversion to CO and H_2. Tars, sulfur, and ash are the other by-products.

Utility Requirements[1]

	Anthracite Coal	Westerholt Coal
Oxygen, lb/lb of MAF coal	0.46	0.55
Steam, lb/lb of MAF coal	2.3	2.7

Thermal Efficiency

The overall thermal efficiency is expected to be 75 to 80% (at 350 psia). Data for the other types of efficiency are not available.

Capacity

The 7 tph (maximum) pilot plant gasifier has an inner shaft diameter of 5 ft and a height of 37 ft. It weighs approximately 135 tons.

Environmental Considerations

The process is still in the testing phase, and an integrated system is being developed. Some of the potential pollutants that must be controlled or recovered within the process area are coal fines and by-products, such as tars, phenols, sulfur, and ammonia. Currently, phenols are removed from the effluent at a neighboring coking plant owned by Ruhrkohle.

Remarks

The raw gas reformer has not yet been started up; the work has so far centered on gas production. When data from further test runs are available, the catalytic reforming route would be investigated first. The pilot plant will be operated for a period of four years. Apart from the tests discussed, the gasification of compacted coal feedstock and cocurrent gasifier operation are also on the program.

References

1. Specks, R., et al; "Status of the Ruhr 100 Gasification Process," presented at First International Gas Research Conference; Chicago, Illinois; June 9-12, 1980.

2. Lohmann, C., et. al., "Ruhr 100 Development Work on the Pressurized Lurgi Gasifier in Dorsten," presented at Workshop on Synthetic Fuels, Status, and Future Direction, San Francisco, California, October 13-17, 1980.

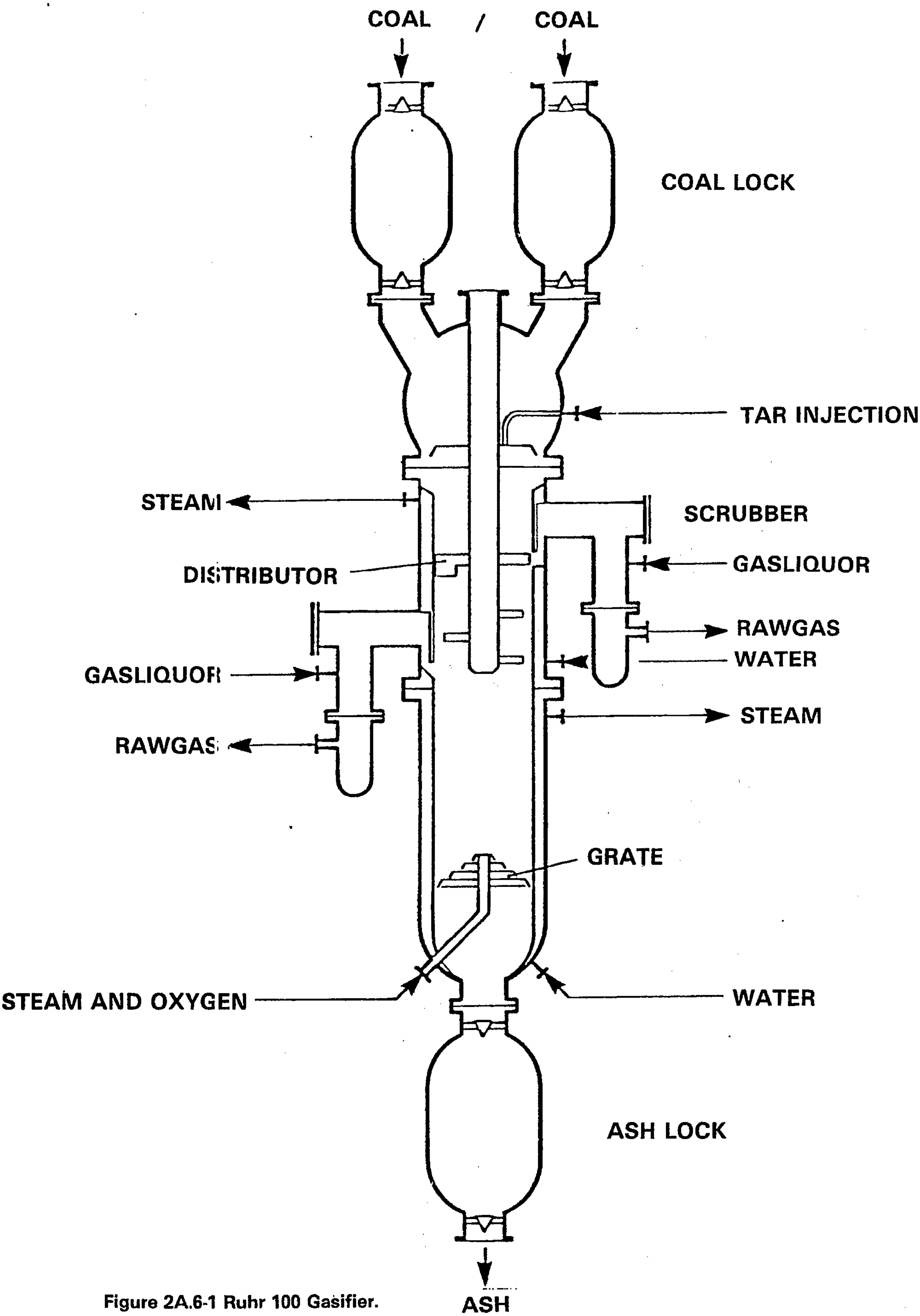


Figure 2A.6-1 Ruhr 100 Gasifier.

2A.7 STOIC

Type

Two stage fixed bed gasifier

Licensor

Foster Wheeler Energy Corporation
110 South Orange Ave.
Livingston, New Jersey 07039

State of Development

The Stoic gasifier developed by Stoic Combustion (Pvt.) Ltd. of Johannesburg, South Africa has been commercially available for over 10 years.[1] It is available in the U.S. through Foster Wheeler Synfuels Corporation. The first U.S. installation of this two-stage gasifier is located in the Duluth Campus of the University of Minnesota.[2] It is designed to generate steam to heat 30 campus buildings and incorporates many of the design innovations commercialized at Lydenberg, South Africa.

Description[1]

Figure 2A.7-1 illustrates the Foster Wheeler (FW) Stoic two-stage fixed bed gasifier. The upper stage of this gasifier is the devolatilization zone, and the lower is the gasification zone. Coal enters the top of the vessel and flows into the upper stage. A portion of the hot gas produced in the gasification zone is routed up through the upper zone, where it exchanges heat with incoming coal and promotes its devolatilization. By the time coal reaches the bottom of the lower zone, it is reduced to coke.

A sized coal of 1/2" x 1 1/2" or 1 1/2" x 3" is given a final screening at ground level to remove fines and then is moved by bucket elevator to a bunker atop the gasifier. Coal is transported down from the bunker to the top of the gasifier by means of a series of three slide valves. The levels of coal in the top of both the gasifier and the bunker are maintained automatically.

A mixture of air and steam is fed to the bottom of the gasification zone. After being heated by passage through the bed of hot ash, the steam-air mixture enters the fire zone, where a partial oxidation reaction takes place. This step produces CO and CO_2 and generates the heat for the balance of the gasification reactions that take place above the fire zone.

The gas exiting the devolatilization zone is called "top gas" and is at 250 °F. The gas leaving the gasification zone is called "bottom gas" and is at 1200 °F. These two gas streams leave the gasifier separately. After minor cleanup steps on each stream, they are combined; the resulting gas temperature is about 750 °F.

The sensible heat in the bottom gas entering the devolatilization zone provides the heat for driving the volatiles off the coal. This step is accomplished slowly and gently without cracking, repolymerizing, or otherwise forming undesirable by-products. Temperature of the top gas is controlled by means of a butterfly valve mounted in the gasifier bottom gas outlet line, which allows more or less bottom gas to flow upwards through the upper zone.

Fine droplets of tar-oil in the top gas are removed in a cyclone, and the resulting mixture of top and bottom gas, called "hot raw gas," has the highest Btu content for product gas. Additional tar-oil may be removed by the inclusion of an electrostatic precipitator. In this optional case, the combined stream of top and bottom gas product is then referred to as "hot detarred gas." Its Btu content is slightly lower than that of hot raw gas. The tar-oil recovered by the cyclone or the precipitator is similar to #6 fuel oil and experience has shown this oil is stable and can be stored in tankages without degrading. The bottom gas exiting the gasifier flows through a cyclone for removal of dust prior to mixing with the top gas stream.

The rate of generation of product gas is regulated by a pressure controller on the product gas line. As line pressure falls, more air and steam flow to the bottom of the gasifier, thereby increasing gas make. The steam generated in the gasifier water jacket is slightly above atmospheric pressure and is added to the air entering the gasifier from an air blower. The ratio of steam to air is varied to control the quantity of the ash.

The coke is reduced to ash in the fire zone. Ash moves down onto the grate and out of the gasifier via the water seal. The bed of ash between the fire zone and the grate is cooled by the incoming blast of air and steam. Water jacketing is used in the gasification zone to cool the shell and at the same time generate the steam required for the gasification reaction. The ash removal facilities rotate to drive the ash on to the ash conveyors.

As an alternative to producing hot raw gas or hot detarred gas, there is a third mode of operation for the FW-Stoic Gasifier that produces cold clean gas having a lower Btu content. In this mode, the bottom and top gas streams are water cooled to remove condensibles. Most of the condensibles are recovered as liquid fuel, and the remainder is incinerated.

Feed Requirements

The FW-Stoic gasifier, in its present form, is suitable for operation on sub-bituminous and anthracite or on bituminous coals having a free-swelling index less than 3. The feed coal must be sized to 1/2" x 1 1/2" or 1 1/2" x 3".

Operating Conditions[1]

The highest temperature in the reaction zone of the atmospheric gasifier is about 1700 °F. The top gas is at 250 °F and bottom gas at 1200 °F; the combined stream temperature is 750 °F.

Gas Produced[1]

Approximate analysis range of hot raw gas (dry basis)

HHV of Coal, Btu/lb, dry:	Approx. 12,000
Mole %, CO	29.3 - 30.0
CO_2	3.0 - 4.0
H_2	14.0 - 16.0
CH_4	2.6 - 3.0
N_2	47.6 - 51.4
HHV, Btu/scf, dry	186 - 207
HHV of cold clean gas, Btu/scf, dry	160 - 175

By-Products

Tar oil with heating value of 148,265 Btu/gal is the major by-product.

Utility Requirements[1]

For a 12.5-ft gasifier (approximately 4.5 tph coal feed rate) operating at capacity and making hot detarred gas

Air, lb/lb of coal: Not Available
Steam, lb/lb of coal: Not Available
Softened Water (Gal/ton of coal): 10
Electric Power (kWh/ton of coal): 3.33

Thermal Efficiency[1]

The overall thermal efficiency for operation under three different modes is

Hot raw gas mode 85 - 93%
Hot detarred gas mode 77 - 87%
Cold clean gas mode 69 - 76%

Capacity[1 2]

The F-W Stoic Gasifiers are available in four sizes: 12'6", 10'0", 8'6", and 6'6" internal diameter. The coal feed rates for these gasifiers are 4.5, 3.0, 2.2, and 1.3 tph, respectively. The nominal coal feed rates are based on a coal having a Btu content of about 12,000 Btu/lb with the gasifier producing hot detarred gas. It is feasible to manifold several gasifiers together in one production facility. When the gasifier is operating at capacity, its coal holdup is 8 hours. Each individual gasifier has a turndown ratio of about 5 to 1 on automatic control. It is possible to go to 10 to 1 on manual control. A gasifier can be put on standby. In such a case, the necessary air for maintaining the large mass of gasifier refractory and carbonaceous contents at temperature is furnished by natural draft. Turndown can be substantially increased in the case of manifolded gasifiers.

Environmental Considerations

For the hot raw gas and hot detarred gas operations, there are no aqueous effluents requiring treatment nor dust produced in the system. For the cold clean gas operation, the effluent streams would consist of an oil stream (which can be recovered and used as fuel), phenolic water, and water quench blowdown. The flow rates for the phenolic water and quench blowdown streams are very small and these two streams can be fed to plant water treatment facilities.

References

1. "The F-W Stoic Gasifier," Foster Wheeler Energy Corporation, Livingston, New Jersey.

2. "How to Make Your Plant Self Sufficient in Gas," Foster Wheeler Energy Corporation, Livingston, New Jersey, 1978.

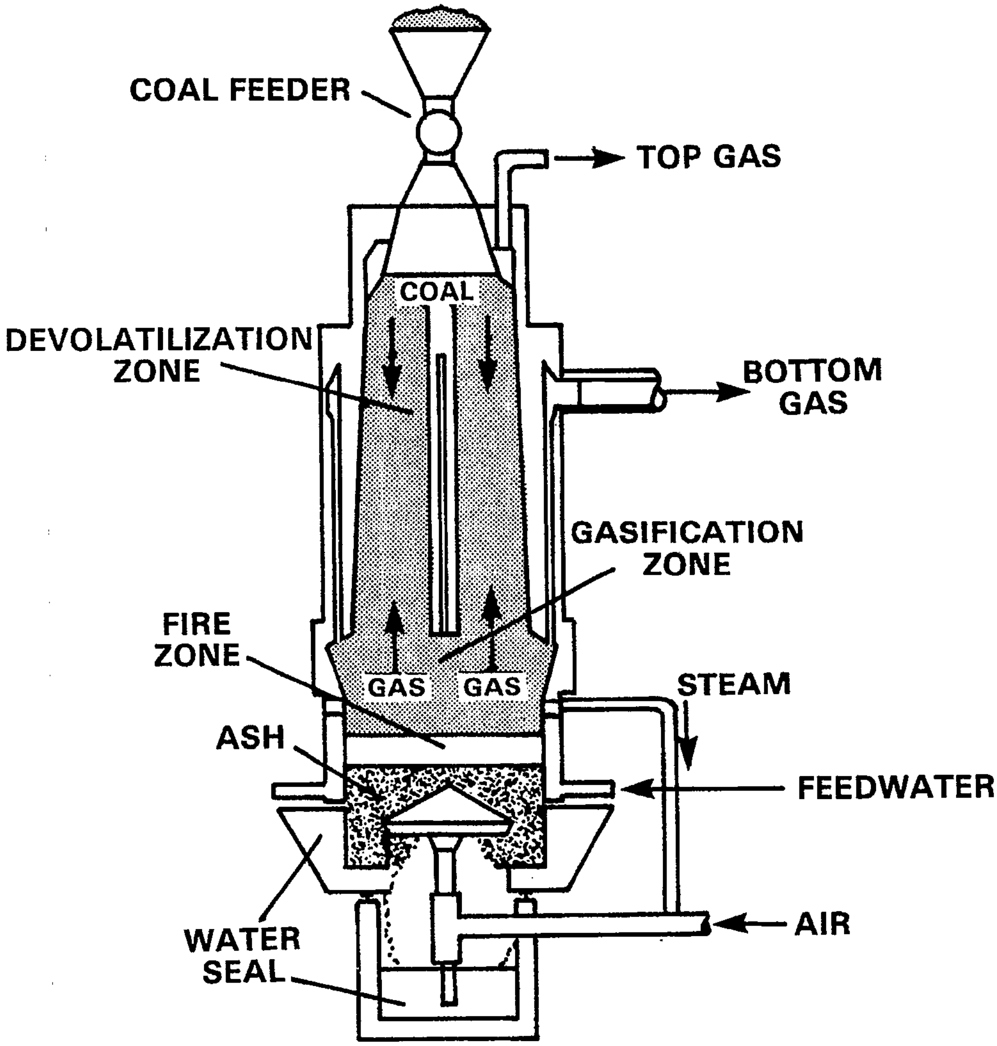


Figure 2A.7-1 STOIC Gasifier

2A.8 WELLMAN-GALUSHA

Type

Fixed bed gasifier with or without a central agitator.

Developer

Dravo Corporation
Synthetic Fuels Department
One Oliver Plaza
Pittsburgh, PA 15222

State of Development[1]

The Wellman-Galusha process has been commercial since the 1920s. It was originally developed by the Wellman Engineering Company, which had been making other types of gasifiers since 1896, but during 1979 Dravo purchased the Wellman-Galusha technology. Worldwide, more than Over 150 of the more recent Wellman-Galusha gasifiers have been operated for different industrial applications. Feedstocks including anthracite, coke, and bituminous coal have been used in the gasifiers. Both anthracite and coke have been gasified with a steam-oxygen blast and it is conceivable that bituminous coal could also be gasified with oxygen. Recently, sub-bituminous coal and lignite have been successfully used as gasifier fuels.

About 14 Wellman-Galusha gasifiers are operating in the U.S., serving industrial plants, and more are being planned. Improvements are incorporated with each installation. Also, a gasifier is being operated as a demonstration unit at the Twin Cities Research Center (Minneapolis, Minnesota) of the U.S. Bureau of Mines, in cooperation with the Mining and Fuel Gas Association (MIFGA) and the U.S. Department of Energy. The Center tests feed materials for the gasifier and process equipment, as requested by participants.

Description[1, 3]

There are two types of Wellman-Galusha gasifiers: the standard type and the agitated type. The rated capacity of an agitated gasifier is about 25% higher than that of the standard gasifier of the same size, and, unlike the standard gasifier, it can handle volatile caking bituminous coals. The agitated gasifier, as shown schematically in Figure 2A.8-1, is described in the following discussion. (The only significant difference between the two designs is the agitator.)

The gasifier itself is water-jacketed. Water in the jacket completely surrounds the gasifier. The inner wall of the gasifier is steel plate, which does not require a refractory lining. The agitator is a horizontal arm mounted on a vertical, rotatable drive shaft. The drive shaft can move vertically, so the agitator can move in a spiral below the surface of the coal bed to retard channeling and maintain a uniform fuel bed. The agitator arm and its vertical drive shaft are made of water-cooled heavy steel tubing. The arm can be revolved at varying speeds, and its height within the fuel bed may be changed, as desired, for different feedstocks and operating rates. A revolving eccentric step-type grate is mounted at the bottom of the gasifier on a center post. It distributes the air-steam blast into the coal bed and forces the ash formed to fall to the ash bin.

Sized coal is fed into the coal bin, from which it then flows into the feeding compartment by gravity. The feeding compartment continuously feeds the coal into the gasifier by gravity through the vertical feed pipes. Four slide valves control the flow of coal in and out of the feeding compartment. The upper valves are always closed except for brief intervals when refilling; the lower valves are always open except when refilling. The continuous flow of coal into the gasifier is highly desirable because it assists in maintaining the coal bed and gas quality in a stabilized condition.

A fan supplies the air required for gasification. The air is passed over the top of the water in the jacket, and thus picks up water required for the blast. Saturation of the blast is regulated by adjusting the jacket water temperature. Normally, the temperature is between 150° to 180°F. A thermostat controls the water supply to the jacket. Blast mixtures of air and CO_2, oxygen and CO_2, or oxygen and steam can also be used.

The blast is introduced through the saturation pipe into the ash bin section underneath the grate. It is distributed through the grate into the coal bed, and it passes upward through the ash, combustion, and gasification zones. Combustion and gasification reactions occur, resulting in a gas containing mainly CO, CO_2, H_2, and N_2. The hot gas product dries and preheats the incoming coal and then leaves the gasifier. Ash is withdrawn continuously from the bed through the eccentric stirred grate, collected in the ash bin, and periodically discharged from the ash hopper and sent to disposal.

Gas leaving the gasifier is passed through a cyclone, where the heavy dust particles (mainly ash and char) are removed. During a shutdown the cyclone can also be flooded with water to above the gas outlet, thus forming a water seal.

The gas leaving the cyclone can be used hot if its sulfur content is acceptable. Otherwise, it can be scrubbed, cooled, and then sent to a sulfur removal plant. If the gas contains tar, the tar may be separated from the cooled gas by mechanical or electrical precipitation methods. The resulting gas is a low-Btu product gas. A medium Btu-gas can be produced by using oxygen instead of air.

Cooling-water overflow from the jacket and the agitator is not contaminated and can be cooled and recirculated. Blowdown from the gas cooler is sent to wastewater treatment.

Feed Requirements[1]

Crushed coal: +5/16" - 9/16" preferred for anthracite; +1" - 2" preferred for bituminous. Larger size particles can be used for the more reactive bituminous coal. The optimum sizes for subbituminous coal and lignites are being determined. Briquette binders and sizes are also being analyzed.

The standard Wellman-Galusha gasifier can gasify anthracite and coke. The agitated gasifier can gasify anthracite, coke, caking bituminous coals, subbituminous coals, and lignites. There is no apparent limit on the free swelling index of coals that can be gasified in the agitated gasifier.

The moisture content of the coal can limit operation by affecting handling of the crushed coal. A higher moisture content of the coal reduces the off-gas temperature. In the case of bituminous coals, too high a coal moisture content could cause condensation of the tar in the gas leaving the gasifier.

Coal ash softening points higher than 2200 °F are preferred.

Operating Conditions

Temperature in combustion zone = 2400 °F
Temperature of gas leaving the gasifier
= 500-900 °F for anthracite
= 600-1200 °F for bituminous
= 300-500 °F for lignite
Pressure = Near atmospheric

Gas Produced[4]

Typical compositions (dry basis) of gas leaving the gasifier in air-blown operation

Feed Coal	Bituminous	Anthracite
HHV of coal, Btu/lb, dry	14,000	13,500
Mole %, CO	28.6	27.1
CO_2	3.4	5.0
H_2	15.0	16.6
CH_4	2.7	0.5
N_2	50.3	50.8
Tar (lb/ft^3)	0.001	–
HHV, Btu/scf, dry	168	146

By-Products[3]

Tar produced from bituminous coals, lb/ton of coal = 120
Water vapor generated from bituminous coals, lb/ton of coal = 800

Utility Requirements

Approximate values for bituminous or anthracite coals. For air-blown operation

Air, lb/lb of coal	3.50
Steam (generated in jacket), lb/lb of coal	0.40
Water to Jacket (net), gal/lb of coal	0.05†
Cooling Water for agitator, gal/lb of coal	0.10
Electric Power, kWh/ton of coal (hot raw gas)	18.00
Electric Power, kWh/ton of coal (cold clean gas)	50.00

† Circulation to jacket, 0.75 gal/lb of coal. To cool the gas, about 7 gallons of water are needed per pound of coal gasified.

Thermal Efficiency

Based on cooled and scrubbed product gas, steam-air-blown operation, and gasification of bituminous coal

Cold Gas Efficiency = 75%
Overall Thermal Efficiency = 81%

For a hot raw gas, the overall thermal efficiency is about 91%.

Capacity

The capacity of a 10-ft I.D. Wellman-Galusha agitated gasifier varies from about 30 tpd for anthracite to about 84 tpd for bituminous coal and up to about 125 to 150 tpd for lignite. Thus the capacity is higher for the more reactive lower rank coals. Use of oxygen rather than air for gasification will also increase the capacity.

Expected turndown ratio = 4:1.

Environmental Considerations

The ash produced from the Wellman-Galusha gasifier contains about 0.1% carbon, but ash from each coal type must be analyzed to determine suitable disposal procedures. Many ashes can be used for landfills.

A small amount of tar is produced with bituminous coal (0.001 lb/ft^3 of gas) and carried with the product gas. If it is removed from the gas before use, final disposition of this material would have to be determined for each installation. Exit gasifier jacket water and cooling water for the agitator arm are relatively uncontaminated and can be recirculated after cooling. However, water discharged from the combination cyclone and water seal shutoff valve and the gas scrubber will require treatment before disposal.

Remarks

Wellman-Galusha gasifiers have been used commercially for over 35 years. The gasifier can be started up in about four hours, and can be readily turned down to 25% of nominal capacity without affecting gas quality. The gasifier can be banked (zero output) for a period of days by using a few minutes per day of air blowing to maintain the combustion zone temperature.

References

1. "Wellman-Galusha Gas Producers," McDowell-Wellman Engineering Company Brochure, Form No. 576.

2. Hamilton, G. M., "Gasification of Solid Fuels," Cost Engineering, pp. 4-11, July, 1963.

3. Hamilton, G. M., "Gasification of Solid Fuels in the Wellman-Galusha Gas Producer," presented at the Annual Meeting of the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., St. Louis, Missouri, February 26-March 2, 1961.

4. Stewart, J. T., "Coal Gasification Processes and Equipment Available For Small Industrial Applications," presented at Fifth International Conference on Coal Gasification, Liquefaction, and Conversion to Electricity', Pittsburgh, Pennsylvania, August 1-3, 1978.

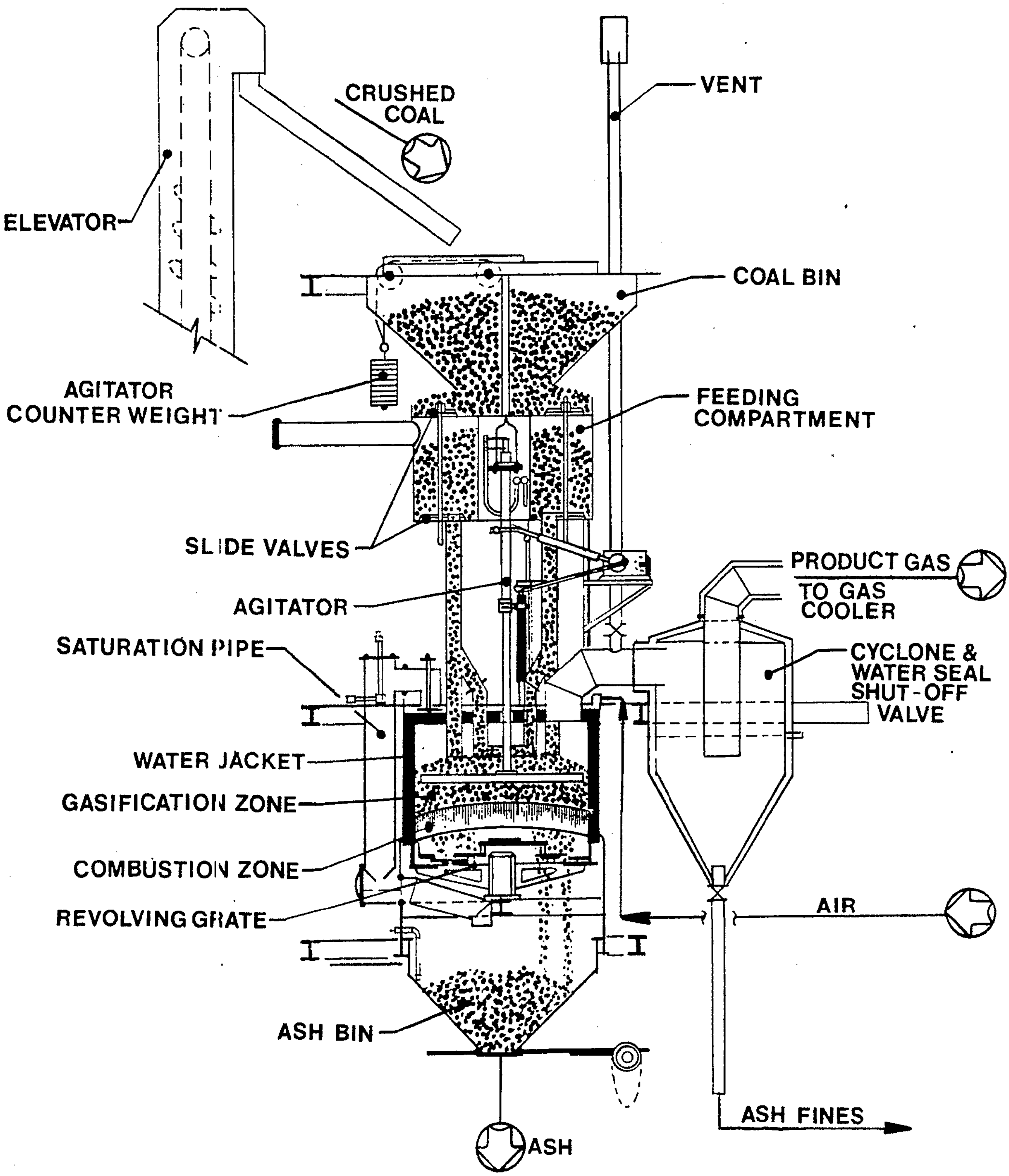


Figure 2A.8-1 Wellman-Galusha Agitated Gasifier.

2A.9 WELLMAN INCANDESCENT

Type

Single-stage and two-stage, fixed bed, low-Btu gasifiers

Developer/Licensor/A&E

Wellman Incandescent, Ltd, England
Wellman Engineering Group

Wellman Thermal Systems Corporation
One Progress Road
Shelbyville, Indiana 46176

Licensee/A&E

Black, Sivalls & Bryson, Incorporated
8303 Southwest Freeway
P.O. Box 27125
Houston, Texas 77027

State of Development[1]

The basic design of the Wellman Incandescent (WI) gasifier began in England during the mid-1800s. In the early 1900s Mr. A. L. Galusha licensed Wellman-Smith-Owen Engineering to market the Galusha single-stage gasifiers. These were sold throughout Europe with several installations in South Africa. The single-stage technology is also available through the above mentioned companies.

The two-stage gasifier was developed to improve the quality of the gas produced by gasification of certain coals. Many of the coals in the United Kingdom suited the two-stage gasifier, so numerous units of this type were installed there in the early 1900s. Many units were installed in the U.S. also.

The availability and economics of natural gas and oil during the 1940s saw a rapid decline in the use of all low-Btu gasifiers, including WI gasifiers. However, in the Eastern Hemisphere nations where natural gas is not plentiful, installation of WI gasifiers continued. In South Africa, specifically, over 30 WI gasifiers have been installed since 1963 and are operated to produce gas for many applications at several sites. These gasifiers range in size from 6-1/2 to 12 ft in diameter.

The only commercial recent installation of WI gasifiers in the U.S.A. began operation during 1978 at the Caterpillar Tractor Company in York, Pennsylvania. The two gasifiers at this plant are each 10 ft in diameter and use bituminous coal. The gas streams are each cleaned and cooled; the combined gas streams are used to provide heat for metal working and miscellaneous uses.

Description[2]

The advantages of the WI, and, in fact, of two-stage gasifiers in general, are that there is little or no pitch buildup in the gasifiers, a good tar is produced in the form of a fine mist with a low viscosity and low particulate level, and cold gas is produced more efficiently than in single-stage units. The two-stage gasifier are limited in handling friable coals because of the fines created. Handling of caking coals is limited because of agglomeration problems.

The WI two-stage gasifier (see Figure 2A.9-1) is a reactor in which the gas flows countercurrently to the flow of coals. A portion of the gas produced in the combustion zone at the bottom of the gasifier is removed before it contacts the fresh coal. The remaining portion of gas passes up through the slowly descending coal and heats that coal in the upper stage of the gasifier very slowly. The gentle devolatilization of the coal in the upper stage provides a gas and a relatively low-viscosity tar that is in the form of a fine mist. Part of this tar mist is removed from the gas stream by a cyclone.

As seen in Figure 2A.9-1, coal is fed to the gasifier via gravity through lockhoppers or a bunker and a feeder to the top of the upper stage (the devolatilization stage). The feed system automatically and intermittently adds coal in small increments to assure that product gases are of constant quality and to prevent fugitive gas emissions via the coal feed system.

As the coal moves slowly downward in the upper stage, it increases gradually in temperature. Tar and volatile matter are liberated and exit through the top gas offtake as components of a relatively cool gas (212 to 303 °F) that is directed to a tar collector cyclone (or, in some configurations, an electrostatic precipitator).

As the coal descends to the combustion bed in the gasifier and becomes essentially a semi-coke, it is contacted by a mixture of steam and air that enters the base of the gasifier and is distributed evenly through the rotating grate. The carbon in the coke is gasified almost completely. Except for the controlled portion of gas that is allowed to rise to supply heat for the upper stage, most of this hot gas departs through the lower gas offtake and into a dust collector cyclone. From there it can join the cooler gas exiting the tar collector cyclone. The hot gas revaporizes any remaining tar and oils in the upper stage gas and minimizes condensation in the distribution lines.

The bottom of the gasifier section is surrounded by a water jacket that, in conjunction with a steam boiler (not shown in the figure), provides steam to saturate the air blast. Elimination of a refractory lining in this section helps to prevent clinker formation and adhesion. The gas production rate is controlled by varying the air-steam blast in accordance with gas demand. The rate can be automatically controlled simply by sensing the pressure in the distribution line. Full instrumentation and controls can provide a high degree of automation.

Additional cleaning and/or cooling of the fuel gas can be provided if the distribution distances, continuity of consumption, and gas burner sizes make it necessary to do so.

The fuel gas streams from the gasifier can be handled in several modes - (1) as a hot raw gas, (2) as a hot detarred gas, or (3) as a cold clean gas. The coal consumption and gas production quantities for each mode are given in Table 2A.9-1 for a bituminous coal with a heating value of 12,000 Btu/lb.

The hot raw gas mode of plant operation, as illustrated in Figure 2A.9-1, requires the least capital cost and provides gas at the highest thermal efficiency of the three modes.

In this mode, the tar cyclone removes the largest tar droplets from the upper stage gas, which exits the top offtake, and the dust cyclone removes particulates from the hot (932 to 1112 °F) tar free gas from the lower takeoff. Any tars and oils in the top gas are vaporized when this gas is mixed with the hot gas, thus minimizing deposits in the distribution lines.

Hot detarred gas provides a high thermal efficiency (85%) for gas distribution to small burners with varying load demands. As seen in Figure 2A.9-2, in this mode the top gas from the tar cyclone is passed through an electrostatic detarrer that removes all tar mist. The gas temperature in the detarrer is above the dew point, so the tars are recovered virtually moisture free. The tar is high quality and usable as a separate fuel.

If the fuel gas is to be distributed to burners that require fine control, or if it has to be distributed over substantial distances, or for environmental considerations, a plant producing cold clean gas is needed. In this mode, as seen in Figure 2A.9-3, the gas from the upper stage first passes through a hydraulic seal vessel and then is detarred in an electrostatic detarrer at a temperature above the dew point. The recovered tar is low in moisture, so it can be used as a medium viscosity coal tar fuel.

The hot tar-free gas from the lower offtake is quenched in a wash column. Both gas streams can be mixed in an indirect tubular cooler and then sent through a second electrostatic precipitator to recover light oils that are tar free.

The WI single-stage Galusha gasifier is based on the same technology as the Wellman-Galusha single-stage gasifier. Description of this latter gasifier in Chapter 2A.8 of this Handbook provides the necessary description of the gasifier design and its operation.

Feed Requirements[1 2]

The gasifier is designed to accept a wide range of bituminous coals. The coal is sized to 1 1/2" x 2 1/2" in with maximum undersize at 15% less than 5/16 in.

The moisture content should preferably not exceed 15%. Too high a coal moisture content could reduce capacity and efficiency. Typical ash fusion temperature is 2200 °F.

Operating Conditions[1 2]

Temperature in combustion zone = 2000 to 2200 °F
Temperature of top offtake gas = 212 to 303 °F
Temperature of bottom offtake gas = 932 to 1112 °F
Pressure = Near Atmospheric

Gas Produced

Typical raw gas analysis (dry basis) averaged from three operating plants

Feed Coal	Bituminous
HHV of coal, dry, Btu/lb	Not Available
Mole %, CO	30.4
CO_2	3.5
H_2	15.8
CH_4	2.6
N_2	47.7
HHV, Btu/scf	180 to 200

By-Products[pc]

In the hot raw gas mode
Tar, lb/ton of coal = 18 (typical)

Utility Requirements[pc]

For a 10-ft diameter unit the approximate values are

	Hot Raw Gas	Cold Clean Gas w/o Desulfurization	Cold Clean Gas with Desulfurization
Air, lb/lb of coal	2.2-2.5	2.2-2.5	2.2-2.5
Steam, lb/lb of coal	0.3	0.3	0.3
Electric Power, kWh/ton of coal	47	84	185
BFW, gpm/ton of coal	1.11	1.11	1.11
Makeup water, gpm/ton of coal	0	2.42	2.42

Thermal Efficiency[pc]

Mode of Operation	Overall Thermal Efficiency (Typical)
Hot raw gas	88% - 93%
Hot detarred gas	83% - 87%
Cold clean gas	74% - 78%

Capacity[2]

Refer to Table 2A.9-1.

Environmental Considerations

The ash produced by the Wellman Incandescent gasifier is low in carbon and is often satisfactory for landfill, but ash from each coal must be tested to determine suitable disposal techniques.

Tars (if recovered) are similar to No. 6 oil, and oils (if recovered) are similar to No. 2 oil. Suitability of disposal methods for each of these by-products should be determined for each coal at each installation. Water is recirculated, so treatment is not required. Phenolic liquors can be disposed of in a thermal oxidizer.

Remarks[1]

The data presented are for bituminous coals, but during 1980, and continuing thereafter, other ranks of U.S. coal and lignites are being tested at a Wellman Incandescent, Ltd., test facility in England.

As of 1979, in addition to being a licensor, Wellman Incandescent, Ltd., markets the Wellman Incandescent gasifier through its subsidiary, Wellman Thermal Systems Corp. Black, Sivalls & Bryson, Inc. (U.S.A.) is a licensee of the Wellman Incandescent design per the 1979 agreement.

References:

1. Brewer, G.E., "Economic Evaluation of the ATC/Wellman Incandescent Two-Stage Low-Btu Coal Gas Producer," presented at Coal Technology '78, Houston, Texas, October 18, 1978.

2. "Coal Gasification," Brochure from Wellman Thermal Systems Corporation, 1981.

Table 2A.9-1 Coal Consumption and Gas Production for Wellman Incandescent Gasifiers (Typical for coal with HHV = 12,000 Btu/lb)

Gasifier Diameter (Feet)	Coal Consumed (lb/hr)	Delivered Energy (MM Btu/hr)		
		Hot Raw Gas	Hot Detarred Gas	Cold Clean Gas
4.5	1160	12.5	11.6	10.6
5.5	1700	18.4	17.1	15.5
6.5	2450	26.5	24.7	22.3
8.5	4325	46.8	43.6	39.4
10.0	5950	64.3	60.0	54.3
10.75	6880	74.7	69.6	63.0
12.0	8600	93.0	86.7	78.4

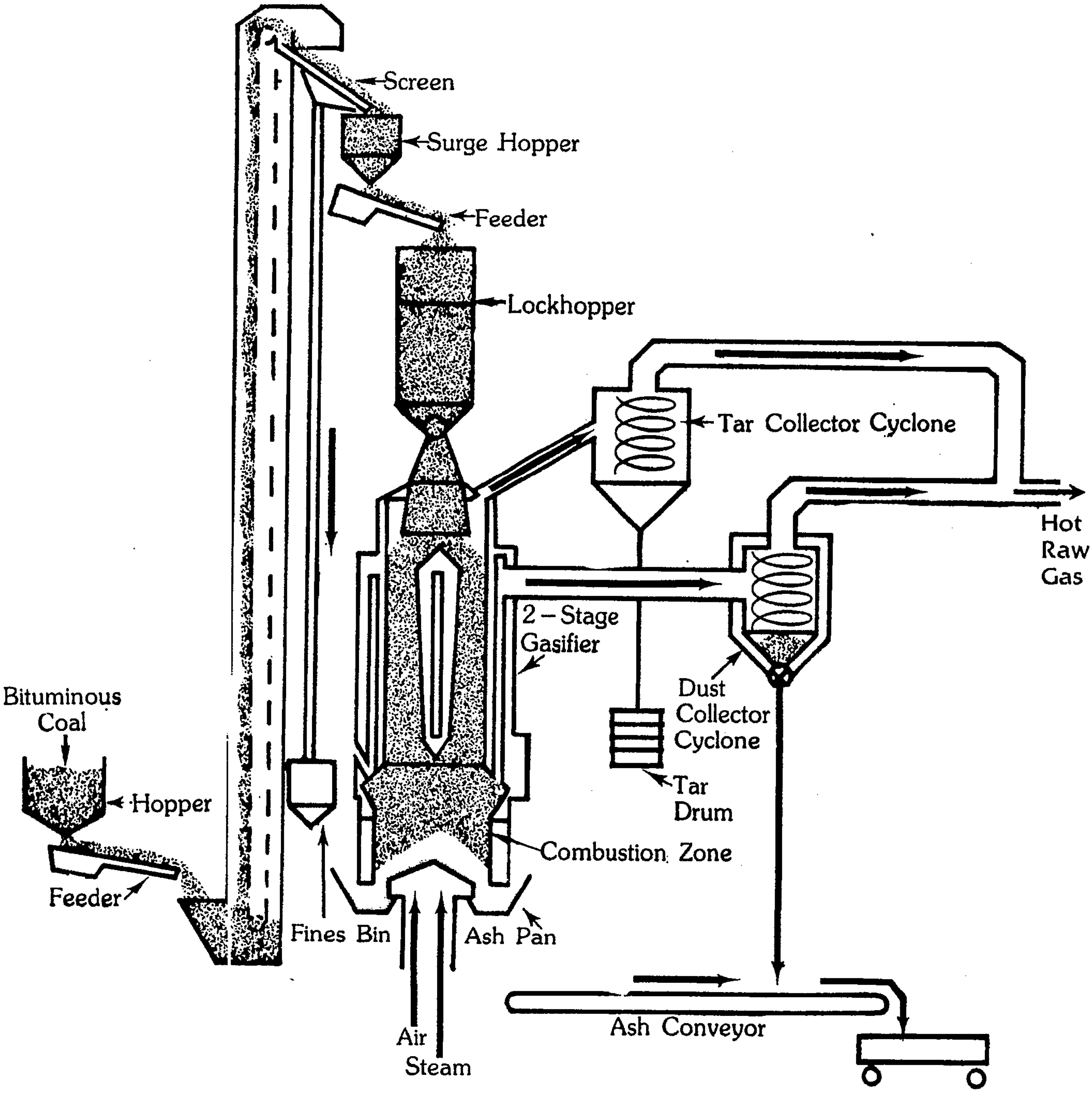


Figure 2A.9-1 Wellman Incandescent Two-Stage Gasifier Configured To Provide Hot Raw Gas.

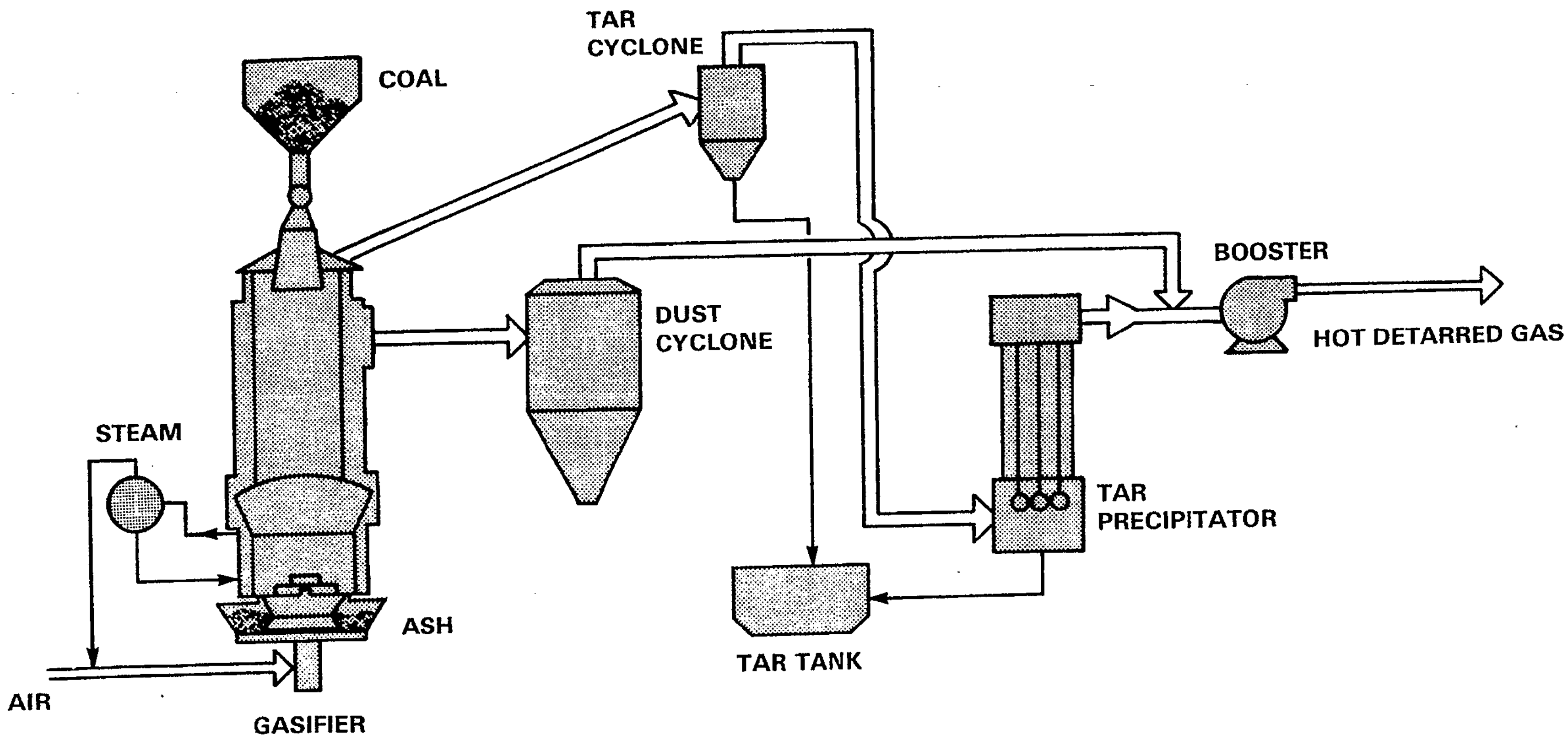


Figure 2A.9-2 Two-Stage Wellman Incandescent Gasifier Configured To Produce Hot Detarred Gas.

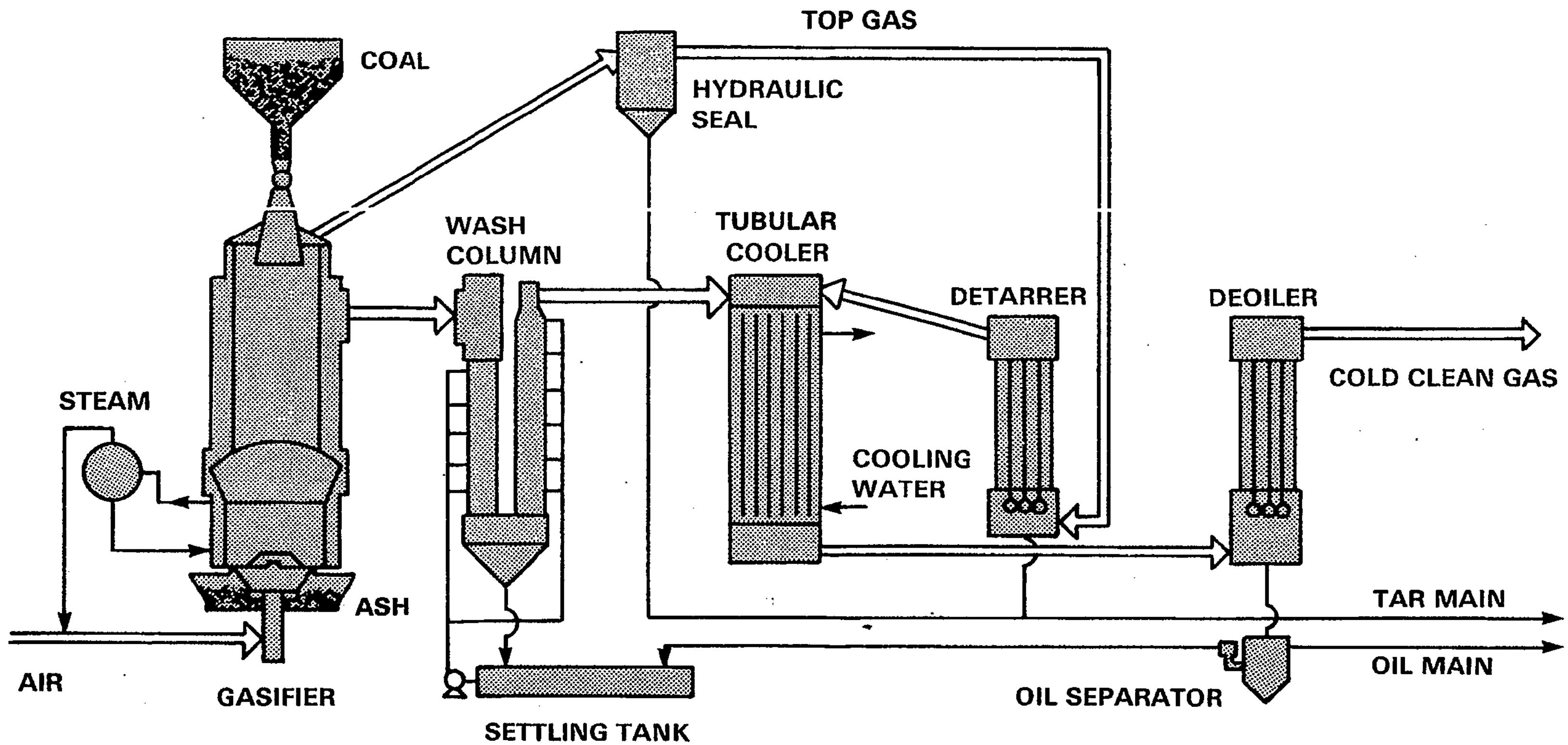


Figure 2A.9-3 Two-Stage Wellman Incandescent Gasifier Configured To Produced Cold Clean Gas.

2A.10 WILPUTTE

Type

Fixed bed gasifier with rotating grate and rabble.

Developer

Wilputte Corporation
152 Floral Avenue
Murray Hill, New Jersey 07974

State of Development[1 2]

The Wilputte Gas Producer was developed over the past 50 years by modifications of the design for water gas production to the design for producer gas production. The desirable features of the acquired Smith, Steere, Koller, Chapman and Semet designs were incorporated progressively into the present Wilputte design. Many installations were made prior to the availability of natural gas but only a few still exist in a stand-by condition. An operating plant is a 12-producer plant built in 1942 with the Semet design at the Holston Army Ammunition Plant, Kingsport, Tennessee and operated by the Holston Defense Corporation, a subsidiary of Eastman Kodak.

Description[3]

The Wilputte Gas Producer (see figure 2A.10-1) is an agitated, non-slagging, partially-jacketed, brick-lined reactor operated at atmospheric pressure. Agitation is accomplished by the rotation of a grate in the ash zone and by the rotation of a water-cooled rabble near the top of the reactor bed. The only difference between the up-to-date Semet design and the Wilputte design for the producer is the grate. The Semet design grate is a center-perforated, cone-shaped, wet-sealed grate, whereas the Wilputte design grate is an overall-perforated, sectored, cone-shaped, dry-sealed grate. The grate agitates the bottom of the bed, directs the ash to the periphery of the reactor for removal by the ash plow, and evenly distributes the upward flowing air-steam feed. The ash plow is adjustable in order to maintain a constant ash level above the grate. The rabble levels the coal feed, prevents blow holes in the bed, and mixes the plasticizing coal if the feed is a caking coal. The reaction temperature during gasification is maintained below the softening temperature of the ash in order to obtain a granular ash rather than a slag. A water jacket on the lower section of the reactor aids in controlling the temperature at the periphery of the bed to prevent ash from sticking to the brick lining. The brick lining aids in retaining heat in the bed and also prevents coal in the plastic state from sticking to the walls. Two principal reactions involved in producer gas production convert the carbonized coal to carbon monoxide and hydrogen. These reactions are:

$$C + H_2O \longrightarrow CO + H_2 - 70{,}900 \text{ Btu} \quad \text{.......(1)}$$
$$2C + O_2 \longrightarrow 2CO + 104{,}000 \text{ Btu} \quad \text{.......... (2)}$$

The endothermic steam reaction (1) partially consumes the heat produced by the exothermic air reaction (2) to aid in maintaining the temperature below the softening temperature of the ash. When oxygen is used instead of air to produce a higher Btu fuel gas (285 instead of 165 Btu/scf), additional steam is supplied to compensate for the sensible heat contribution of the nitrogen that would have been available if air were used. Atmospheric pressure at the exit of the producer is maintained by supplying sufficient blower air pressure to overcome the back pressure of the scrubbing system.

Feed Requirements

Producer gas can be made in a Wilputte producer from coke, anthracite, bituminous coal, and sub-bituminous coals. Caking coals, non-caking coals, and coal with up to about 10% fines can be used. Any size coal from about 1/4" to about 4" can be used. However, a uniform size aids in a uniform operation, since the rate of gas production increases with a decrease in size. An increase in moisture and ash only increases the coal feed rate.

Operating Conditions

During passage down through the bed in the reactor, the coal is progressively dried, heated, carbonized, and gasified. The temperature in the bottom (gasification) zone is maintained below 2200 °F in order to operate below the ash softening temperature in an oxidizing atmosphere. A reducing atmosphere exists in the carbonization zone, and the ash softening temperature in a reducing atmosphere is lower than in an oxidizing atmosphere but the temperature in the (endothermic) carbonization zone is also lower, so clinkering of the ash does not occur. The product gas exists from the producer at about 1150 °F at atmospheric pressure.

Gas Produced

A typical composition (dry basis) of cold clean product gas from a typical coal

Feed Coal	Bituminous
HHV of coal, Btu/lb	14,010
Mole %, CO	22.7
CO_2	5.9
H_2	16.6
CH_4	3.6
O_2	0.2
N_2	50.5
Illuminates	0.5
HHV, Btu/scf	170.0

By-Products

The flow rate of by-product tar, with a HHV value of 16,040 Btu/lb, averages 22.5 gallons per ton of typical coal consumed. The typical tar has a specific gravity of 1.07, contains 0.6% sulfur and is 0.95% quinoline insoluble.

Utility Requirements[pc]

Air, lb/lb of coal	2.9
Steam, lb/lb of coal	0.6
Cooling Water, gal/ton of coal	600.0
Electric Power, kWh/ton of coal	25.0

Thermal Efficiency

A thermal balance indicated the distribution of the heat value of the coal to be 75% resulting as potential heat in the gas, 11% as potential heat in the tar, 2% as heat lost as radiant heat, and 12% as sensible heat in the product gas. A weight balance based only on the coal indicated the weight distribution to be 84% as the product gas, 10% as the tar, and 6% as the ash. An overall weight balance with an air-steam blast indicated a production per pound of coal of 4.1 pounds of gas, 0.1 pound of tar, and 0.06 pound of ash.

Capacity

The capacities of the 9 ft-2 in water-sealed Semet producer and the 10 ft-4 in dry-sealed Wilputte producer with air-blown operation are

	Semet Producer	Wilputte Producer
Coal used, tons per day	30.0	60.0
Gas produced, MM scf/day	3.6	7.2
MM Btu/day	600	1200

Environmental Considerations

An up-to-date Semet producer plant would (1) use hot valves instead of pitch traps for closing each producer from the gas main, (2) use a tar decanter provided with a grit remover instead of a concrete tank for separating the tar from the recycle liquor, (3) grind the grit into the tar in a ball mill for combined disposal as boiler fuel, (4) use a spiral heat exchanger instead of a pipe rack for cooling the recycle liquor, (5) use an afterburner on the exhaust pipe to avoid air pollution during burnouts, (6) use sand and carbon filters to purify the excess waste liquor instead of applying evaporation, and (7) have steam-purged top-access openings for observation or poking. The Wilputte design includes all of these features.

Remarks

The Wilputte gas producer is a sturdy reactor that requires little maintenance. The ease in control of production rate is an asset for supplying nearby requirements for a fuel gas.

References

1. Cooper, G., "Operating Overview of a Producer Gas Plant (12 Machines) at Kingsport, Tennessee," presented at Fifth Annual International Conference on Coal Gasification, Liquefaction and Conversion to Electricity, Pittsburgh, Pennsylvania, August 2, 1978.

2. Cooper, G., "Low and Medium BTU Gas: Markets and Applications," Gorham International, Inc. Intensive Conference at Chateau Louise, Dundee, Illinois, June 24-26, 1979.

3. Cooper, G., and Eck, J. C., "Operating Overview of a Producer Gas Plant (12 Machines) at Kingsport, Tennessee," American Institute of Chemical Engineers Meeting on Operability of Low/Intermediate BTU Coal Gasifiers, Philadelphia, Pennsylvania, June 11, 1980.

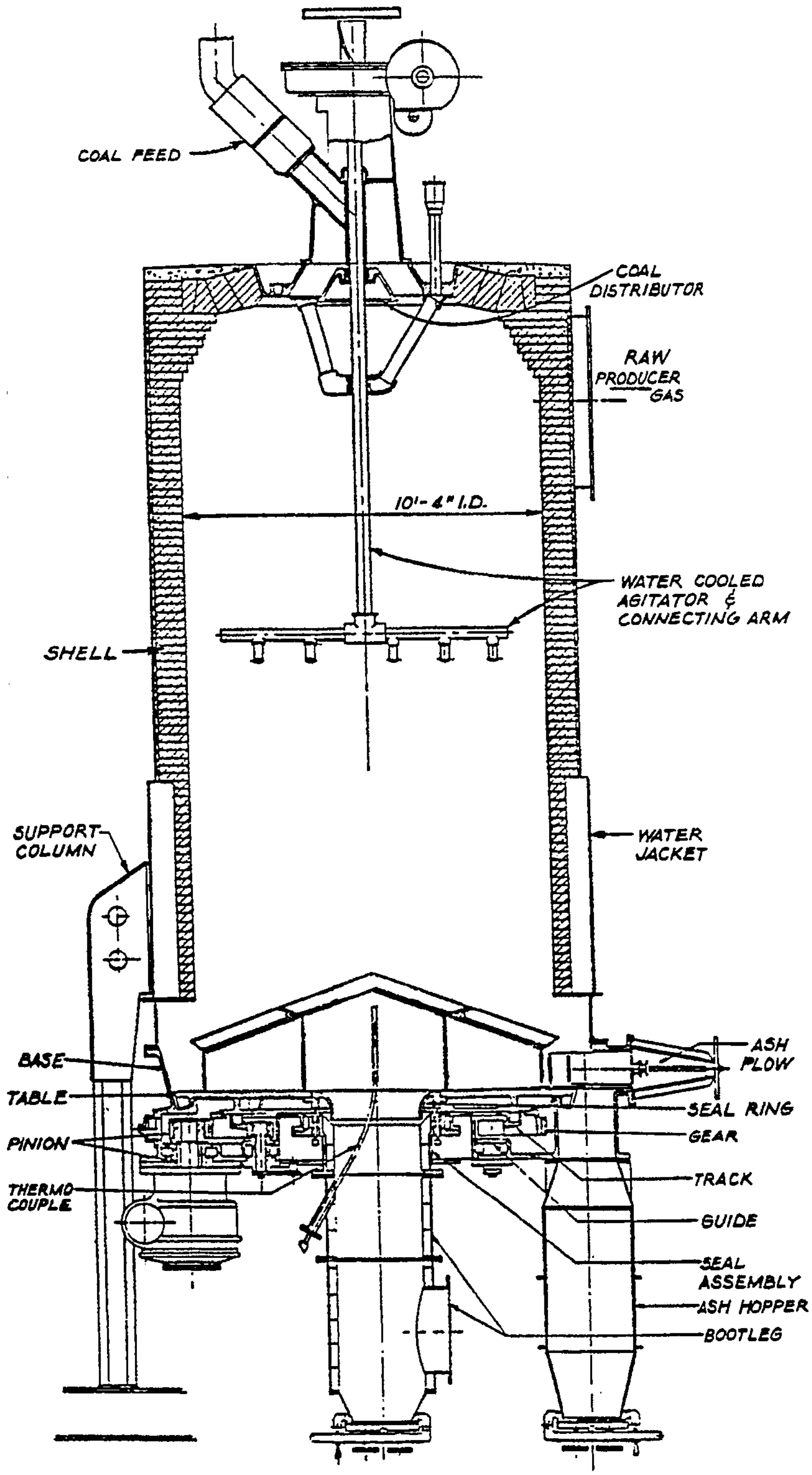


Figure 2A.10-1 Wilputte Coal Gasifier

2A.11 WOODALL-DUCKHAM/GAS INTEGRALE

Type

Two-stage fixed bed gasifier

Developer

Impianti Gas Internazionale Spa
Via Pompeo Litta n.g, 20122
Milano, Italy

Licensor

Babcock Woodall-Duckham
921 Penn Avenue
Pittsburgh, PA 15222

State of Development[pc 1]

This two-stage gasification process, developed by Gas Integrale, Milan, Italy, has been in operation over 30 years producing industrial fuel gases. The gasifier was used for about 20 years before that in a cyclic process to produce medium Btu gas. This process was marketed as the Woodall-Duckham/GI (WD/GI) process.

Over 100 air-blown gasifiers of this type have been successfully operated in Europe, South Africa, and Australia, and at least 15 oxygen-blown gasifiers have been operated in Europe. Various standard gasifier sizes are available with unit gas outputs up to 2 x 10^9 Btu/day. The process is suitable for incorporation in plants producing from 1 to 30 x 10^9 Btu of gas per day. It is suitable for gasification of lignites, and sub-bituminous and bituminous coals with swelling numbers up to 2 1/2.

Description[2 3]

The WD/GI gasifier is a vertical cylindrical type with a rotating grate in the bottom of the reactor. (See Figure 2A.11-1.) The grate, composed of concentric rings, distributes the incoming air and steam while removing the ash. The gasifier contains two main zones: a lower gasification zone, which is water-jacketed, and a refractory lined devolatilization zone and coal drying zone.

The gasifiers are supplied with sized coal, which is normally delivered into a ground hopper adjacent to the gasification plant from which it is transferred by vibrating feeder to a bucket elevator. The elevator discharges to a shuttle conveyor and hence to the overhead feed bunkers serving the gasifiers.

Coal is admitted to each gasifier through an automatic coal lock system that operates on a batch basis activated by a level probe in the top of the gasifier (see Figure 2A.11-2). The top zone of the two-stage gasifier is a retort in which the coal is gently heated by rising hot gas to drive off the moisture and volatile constituents. The quantity of gas that flows upwards through the retort is controlled to maintain the temperature of the gas leaving the top at about 250 °F. When the coal is heated gently in this way, the tar is not cracked: it condenses in the downstream sections of the plant as a low viscosity liquid, and the formation of carbonaceous deposits is minimized.

The coal leaves the retort zone of the gasifier at about 930 °F and enters the gasification zone as a semi-coke. In the gasification zone, the semi-coke reacts with the blast of steam and air to form carbon oxides and hydrogen. Part of this gas leaves through a port at the top of the gasification zone at about 1200 °F as clear gas; the rest flows upwards through the retort section to heat the incoming coal.

The temperature in the gasification/combustion zone is maintained at a level that produces a gritty ash. The temperature can be varied by varying the steam/air ratio. Thus, a change in the ash fusion point will not affect the ash quality but will change the gas composition to some extent.

The blast air is supplied by air blowers and is saturated at 140 °F by adding low pressure steam from the LP steam drum associated with the gasifier. Boiler feedwater from the LP steam drum circulates by natural convection through the gasifier cooling jacket. The saturated air is admitted through the rotating grate of the gasifier, thus recovering some of the sensible heat in the ash. The ash is quenched with water and discharged through a lockhopper system for disposal.

The clear gas from the gasifier at 1200 °F passes through a dust cyclone to remove entrained ash particles and is then cooled to 400 °F in a waste heat boiler, generating steam at 150 psig. It then mixes with the 250 °F top gas, which has passed through a tar cyclone to remove entrained coal particles and droplets of tar. This mixed gas is cooled by cooling water to 95 °F in a mixed gas cooler, where tar, oil, and water vapors are condensed and removed from the gas stream. Oil mist remaining in the mixed gas is removed by an electrostatic oil precipitator. The tar/oil and water are collected in an oil/condensate separator, and the separated liquids are pumped to battery limits for storage.

Feed Requirements

Sized coal is required. Process is suitable for coals with swelling numbers up to 2.5.

Operating Conditions[2]

The actual temperatures vary with the type of coal gasified. Typical values are as follows

Temperature in gasification zone = 2200 °F
Temperature of gas leaving the gasifier
  Mixed Gas = 250 °F
  Clear Gas = 1200 °F
Pressure = Atmospheric

Gas Produced[2 3]

Typical gas composition (dry basis) after gas scrubbing and cooling, for an air-blown operation

Feed coal	Bituminous
HHV of coal, Btu/lb, dry	13,860
Mole %, CO	26.2
CO_2	6.4
H_2	16.0
CH_4	0.6
C_nH_m	0.2
N_2	50.4
H_2S	0.2
HHV, Btu/scf, dry	Not Available

By-Products

Oil and tar, lb/ton of coal	150

Utility Requirements[4]

Based on bituminous coal, HHV (dry) = 13,860 Btu/lb, and air-blown operation

	Air-Blown Operation
Air, lb/lb of coal,	2.3
Steam, lb/lb of coal	0.25
BFW, gal/ton of coal	66
Electric Power, kWh/ton of coal	35*

* From receiving coal to delivery of cool gas, oil, tar, and ash.

Thermal Efficiency

Based on cold clean gas and air-blown operation.
Cold Gas Efficiency = 77%
Overall Thermal Efficiency = 88%

Including the heat in the vaporized tar oil, and the sensible heat of the gas, hot raw gas has an HHV of about 210 Btu/scf, and the overall efficiency is about 92%.

Capacity

A typical small industrial air-blown WD/GI plant, consisting of two WD/GI gasifiers each having a nominal diameter of 12 ft, can gasify approximately 200 tpd of coal to produce about 4 x 109 Btu/day of combined fuel gas and fuel oil products. The fuel oil represents approximately 13% of the total product Btu's.

Environmental Considerations

The ash discharged from the WD/GI gasifier, containing less than 1% unconverted carbon, is disposed of by landfill. The steam/air ratio in the gasification zone can be adjusted to produce an easily handled gritty ash with some small clinkers.

The tar and oil condensed from the gas stream require additional facilities for storage and handling. They could be used either as feedstock for chemical manufacture or as fuel oil blended with low sulfur oils. Their disposition must be determined for a particular installation.

Remarks

The WD/GI gasifier has been proven over many years of commercial application. It can be started up in about 24 hours and can be placed in a standby condition with a minimal air supply. Full gas production can be restarted within minutes. The gasifier can be turned down to 25% of maximum throughput without affecting gas quality. The two-stage operation of the gasifier yields a high thermal efficiency.

The standard WD/GI gasifier accepts only coals with a free swelling index of less than 2.5. Tar and oil are produced as by-products; the final disposition of these should be determined for each installation.

For lignites and some sub-bituminous coals, internal details of the gasifier may sometimes be modified with resultant cost savings. Detail designs have been developed for a stirred variation of the WD/GI gasifier that should permit the satisfactory gasification of more highly caking coals: this modification has yet to be demonstrated in a commercial scale installation. The process described above is for the production of cold clean gas having an HHV of approximately 150 Btu/scf, dry, glus a yield of low viscosity oil that may be used as a standby fuel. Alternatively, the hot mixed raw gas, with an HHV of about 175 Btu/scf, may be fed directly to a combustion furnace.

A variety of processes may be added to the system for desulfurizing cold clean gas. The Stretford process is frequently specified.

References

1. WD/GI Coal Gasification, Woodall-Duckham (USA), Brochure.

2. Grant, A. J., "A Discussion of Fluidized Bed Combustion and Two-Stage Coal Gasification," presented at 1978 Industrial Fuel Conference, Purdue University, Indiana, October, 1978.

3. Grant, A. J., "Commercially Available Clean Industrial Energy From Coal," presented at Fourth National Conference on Energy and Environment, Cincinnati, Ohio, October 7, 1976.

4. Grant, A. J., and Hemingway, M. J., "Low- and Medium-Btu Gas -- The WD/GI Process," presented at the Institute of Gas Technology Symposium of Efficient Use of Fuels in the Metallurgical Industries; Chicago, Illinois; December, 1974.

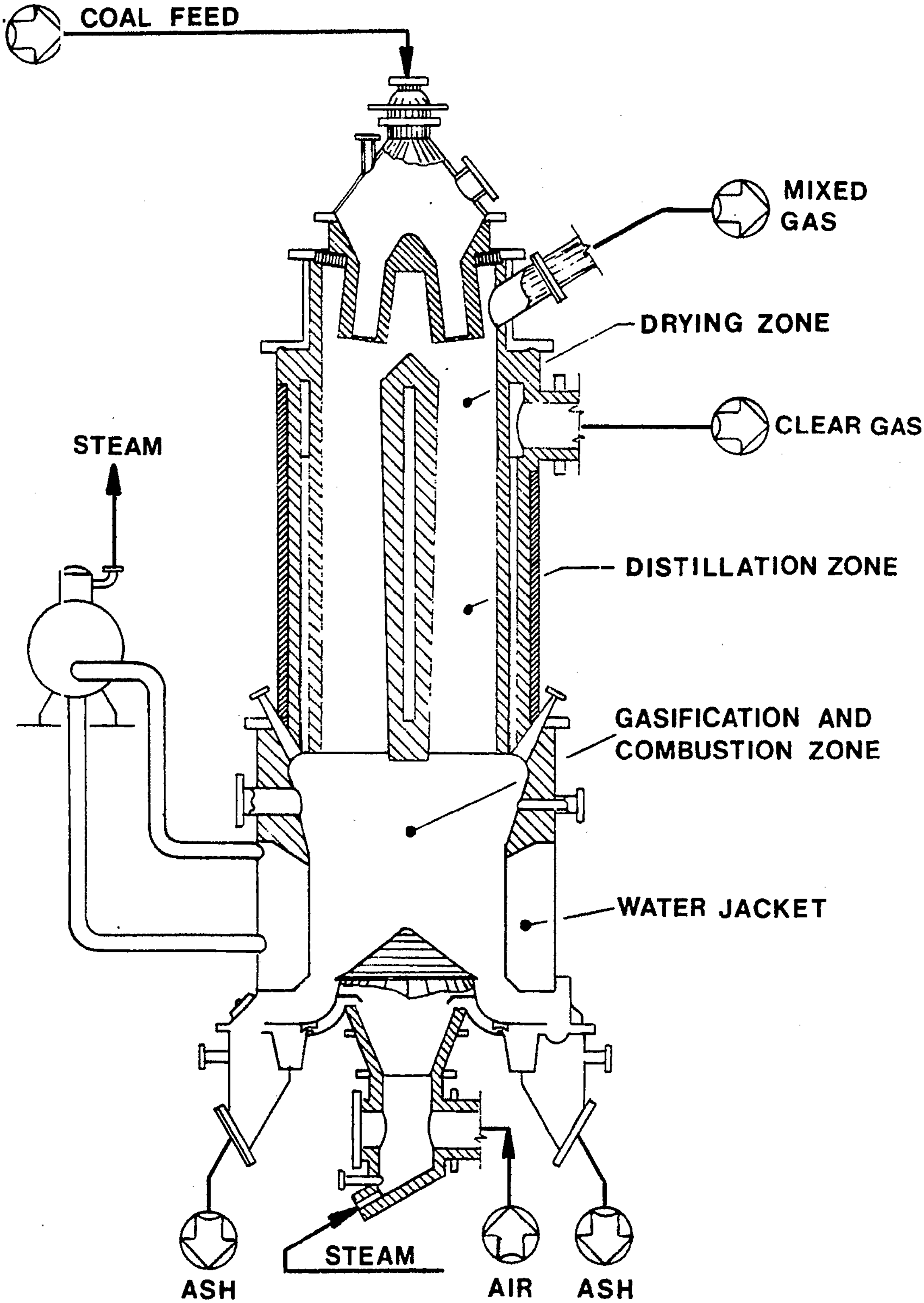


Figure 2A.11-1 Woodall-Duckham/Gas Intergrale Gasifier.

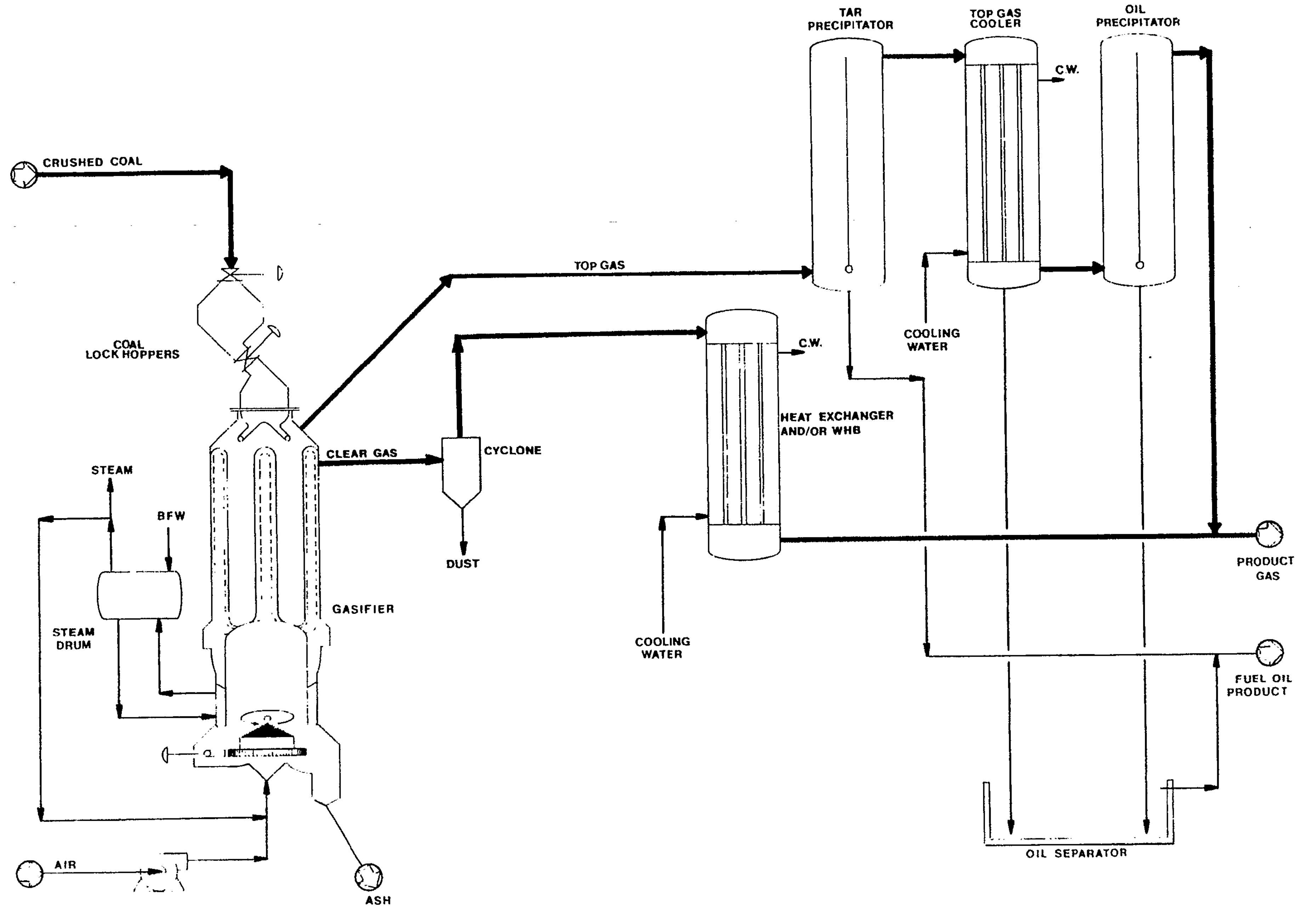


Figure 2A.11-2 Woodall-Duckham/Gas Integrale Gasification System.

2B.1 BATTELLE/CARBIDE

Type

Fluid bed gasifier and a fluid bed ash agglomerating burner

Licensor

Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

State of Development[1 2]

A 25 tpd PDU of the Battelle/Carbide gasifier at West Jefferson, Ohio was operated by Battelle from 1976 to 1978, when work was terminated and the plant deactivated. Further development work is necessary before commercial application. The process is applicable to the production of medium- to high-Btu gas.

Initial development work on the process was sponsored by Union Carbide Corporation and was conducted at the Battelle laboratories in the early 1960s. In the process, recirculating hot agglomerated ash is used as a medium to transfer heat from a burner to a gasifier. A continuous bench scale fluidized furnace and several pilot scale furnaces of up to 1-ft I.D. were used to study agglomeration of ash at near atmospheric pressure. Integration of fluidized bed gasification and coal combustion with ash agglomeration has also been studied on a bench scale using various configurations.[3] Since the burner operates under pressure, the burner flue gas could be expanded through a gas turbine for power recovery. Therefore, erosion caused by fly ash entrained in the burner flue gas was studied under simulated turbine conditions.[3]

The PDU was designed to gasify 25 tpd of Eastern bituminous coal at 100 psig and produce 1 MM scfd of medium-Btu gas. Battelle operated the PDU from September 1976 through January 1978. Tests were conducted to study the agglomerating characteristics of the process, combustion efficiency obtainable, and the feasibility of integrated operation. Some work was also done on turbine erosion.

Description[1 4]

The following description pertains to the 25 tpd process development unit.

The Battelle/Carbide fluidized bed gasification process uses two vessels: a burner and a gasifier. The burner is shown in Figure 2B.1-1. The fluidized bed is confined to the lower section of the vessel; the upper section, with a larger I.D., provides disengaging space. The gasifier, Figure 2B.1-2, is similarly constructed, except that it has three sections with I.D.'s progressively increasing from bottom to top. Both the burner and the gasifier are lined with castable refractory.

Sized, dried coal is pnuematically conveyed by inert gas to two identical lockhopper trains maintained at a pressure higher than the system pressure. Coal is transferred to the gasifier from the first train and to the burner from the second.

Feed coal is mixed with recycle char from the gasifier and injected into the burner with air. (See Figure 2B.1-3.) Recirculating ash agglomerates from the gasifier are also injected with air, and the two streams enter the burner fluidized bed through two separate openings provided for them in the air distributor. Additional combustion air is injected into the burner through the numerous holes in the distributor, and the air fluidizes the coal-char-ash mixture as combustion of coal and char occurs. The distributor is fabricated from refractory material with close spacing between the holes to minimize flat surfaces on the grid. This precludes formation of any static zones at the base of the fluidized bed, and thus the possibility of uncontrolled agglomeration is minimized.

The temperature of the fluidized bed is controlled at a level close to the ash fusion point. As the carbon in the coal and char is oxidized, the ash particles consolidate into free-flowing spherical pellets, which overflow out of the burner. They are then transferred to the gasifier by a steam lift. Hot flue gas exiting the burner from the top passes through a cyclone and is expanded in a power recovery turbine. A scrubber is shown downstream of the cyclone. This is a venturi scrubber used in operation of the PDU before the turbine was added.

Ash agglomerates from the burner enter the gasifier through the lower of the two nozzles on the left of the gasifier. Fluidization is provided by superheated steam injected through a distributor plate located at the bottom of the gasifier. Additional superheated steam is injected at a higher level through an externally mounted, ring type distributor.

Because of the varying superficial gas velocities in the gasifier, the char and the ash agglomerates, which have different densities and mean particle sizes, segregate into two distinct zones separated by an intermediate zone. The lower zone, occupying a depth of about two-thirds of the 18-in-diameter section, is predominantly filled with ash agglomerates maintained at a condition of incipient fluidization. The intermediate zone is a mixed zone containing ash agglomerates, untreated coal, and char. The 36-in-diameter upper zone is predominantly char in a fluidized condition, and it extends up to the char withdrawal point. Above this is a 48-in-diameter disengaging section.

In the PDU, the weight ratio of recirculating ash agglomerates to gasifier feed coal is about 30. There is a net downward flow of hot ash agglomerates through the gasifier, and a portion of their sensible heat is transferred to the coal and rising steam. This heat supports the endothermic gasification reactions. The ash agglomerates are finally removed through a special opening in the steam distributor plate, and most of them are returned through a lockhopper system at a rate equal to the ash contained in the coal fed to the system.

The coal is only partially gasified, and the char formed is withdrawn from the gasifier and fed into the burner along with the coal. The gas leaving the gasifier passes through a cyclone and venturi scrubber to remove residual char particles. In the PDU, the medium-Btu product gas is burned in a thermal oxidizer.

Blowdown from the flue gas and product gas venturi scrubbers is sent to a settler. Settled solids, primarily ash and coal particulates, are disposed of by landfill along with the ash agglomerates removed from the process. Water and other liquids from the settler are sent to the thermal oxidizer.

Feed Requirements[4]

Coal is crushed to -100 mesh for the burner and +100-8 mesh for the gasifier.

The gasifier could accept non-caking coals. To ensure operation with caking coals, a coal pretreatment section was provided in the PDU.

Coals having practically any level of ash fusion point could be gasified as long as the ash fusion qualities are uniform. The ash fusion point influences the rate of recirculating ash agglomerates, the kinetics of gasification, and, therefore, the gas quality.

Operating Conditions[5]

Based on Eastern bituminous coal and air-blown operation in the 25 tpd plant

Temperature in the burner = 2000-2100 °F
Temperature in the gasifier = 1600-1800 °F at the top
Operating pressure = 100 psig

Gas Produced

Based on Eastern bituminous coal and air-blown operation with 25 tpd plant

Feed Coal	Eastern bituminous
HHV of coal, Btu/lb, dry	Not Available
Mole %, CO (O_2, N_2, and benzene-free)	0.0-38.6
CO_2	3.3-28.2
H_2	47.9-66.2
CH_4	1.1-6.3
C_2H_6	0.0-2.3
C_2H_4	0.0-1.6
C_3	+
C_2H_2	0.0-0.6
H_2S	0.0-0.2

By-Products

Oils and tars are produced in minute quantities only. Quantity of other by-products, such as steam, not available.

Utility Requirements

Not Available.

Thermal Efficiency

Not Available.

Capacity

The Battelle/Carbide PDU at West Jefferson, Ohio, operated at 100 psig, could gasify 25 tpd of Eastern bituminous coal to produce approximately 1 MM scfd medium-Btu gas.[4]

Turndown capability is not available.

Environmental Considerations

In a commercial plant, the product gas would be desulfurized. A stack gas scrubber may be required for the flue gas and pretreatment gas. Also, the liquid effluents would require biological treatment before discharge. The ash agglomerates contain a negligible amount of carbon and can be disposed of by landfill.

Remarks

This process has been studied for SNG production but may better be applied for intermediate Btu gas. A cost estimate based on the production of medium Btu gas has been published by Scientific Design Inc.[6] An operating pressure above 300 psig is advantageous. Process advantages are the use of any coal and low air/ oxygen requirement in the gasifier.

References

1. Mink, W. H. et al., "Production of Utility Gas With the Agglomerating Burner Coal Gasifier," presented at 85th National Meeting of American Institute of Chemical Engineers, June, 1978.

2. Goldberger, W. M., and Corder, W. C., "Status of the Battelle/Union Carbide Coal Gasification Process Development Unit Installation," presented at Sixth Synthetic Pipeline Gas Symposium, Chicago, Illinois, October, 1974.

3. Goldberger, W. M., "The Union Carbide Coal Gasification Process Status of the Development Program," presented at Fourth Synthetic Pipeline Gas Symposium; Chicago, Illinois, October, 1972.

4. Corder, W. E., et. al., "The Union Carbide/Battelle Coal Gasification Process Development Unit Design," presented at Fifth Synthetic Pipeline Gas Symposium; Chicago, Illinois; October, 1973.

5. Bodle, W. W., and Vyas, K. E., The Oil and Gas Journal, August 26, 1974.

6. Chang, T. Y. and West A. S., "Evaluation of the Battelle Agglomerating Ash Burner Process for the Production of Medium Btu Gas," by Scientific Design Co., under Subcontract #7240; Division of Fossil Fuel Processing, U.S. Dept. of Energy.

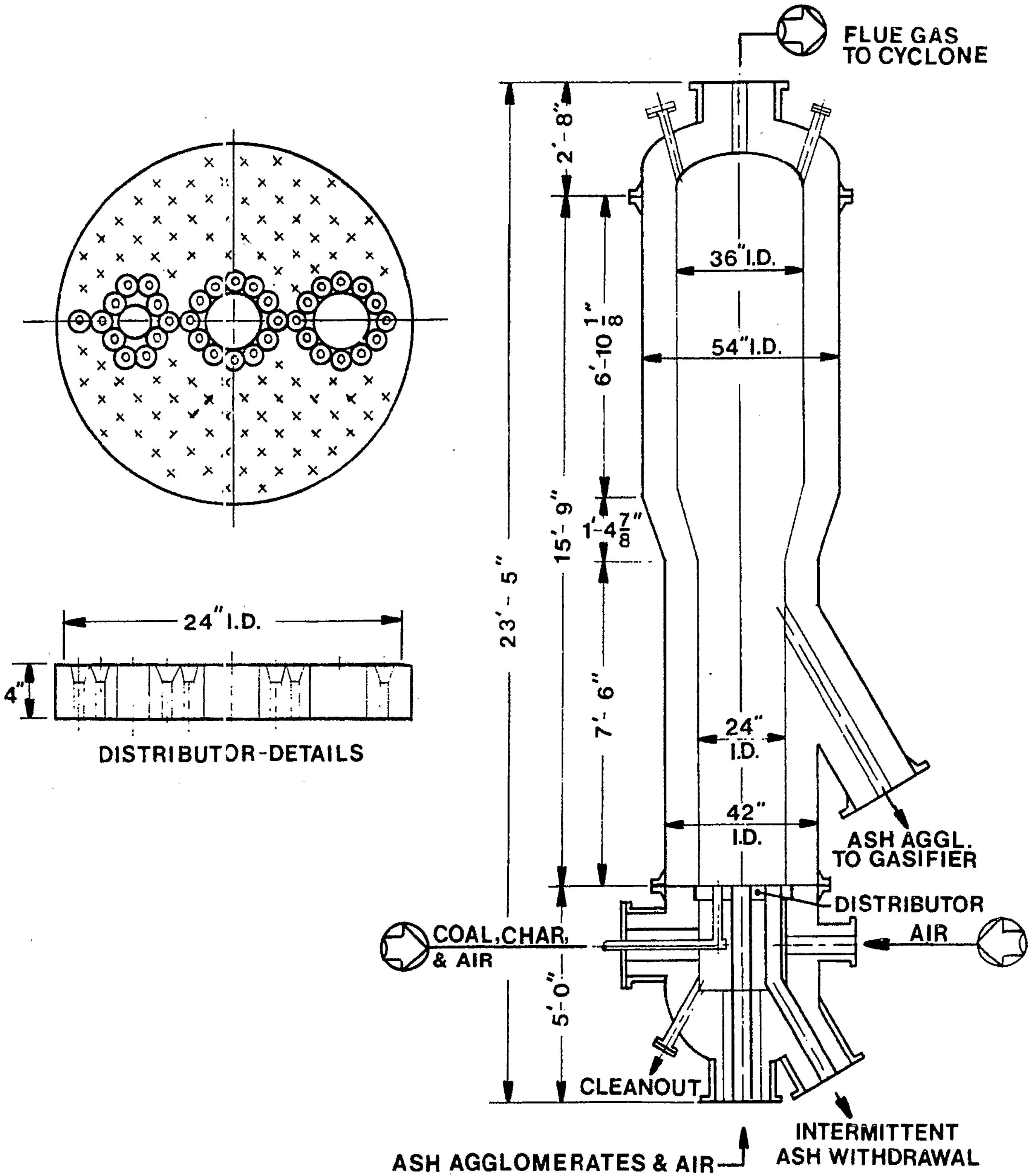


Figure 2B.1-1 Battelle-Carbide Burner.

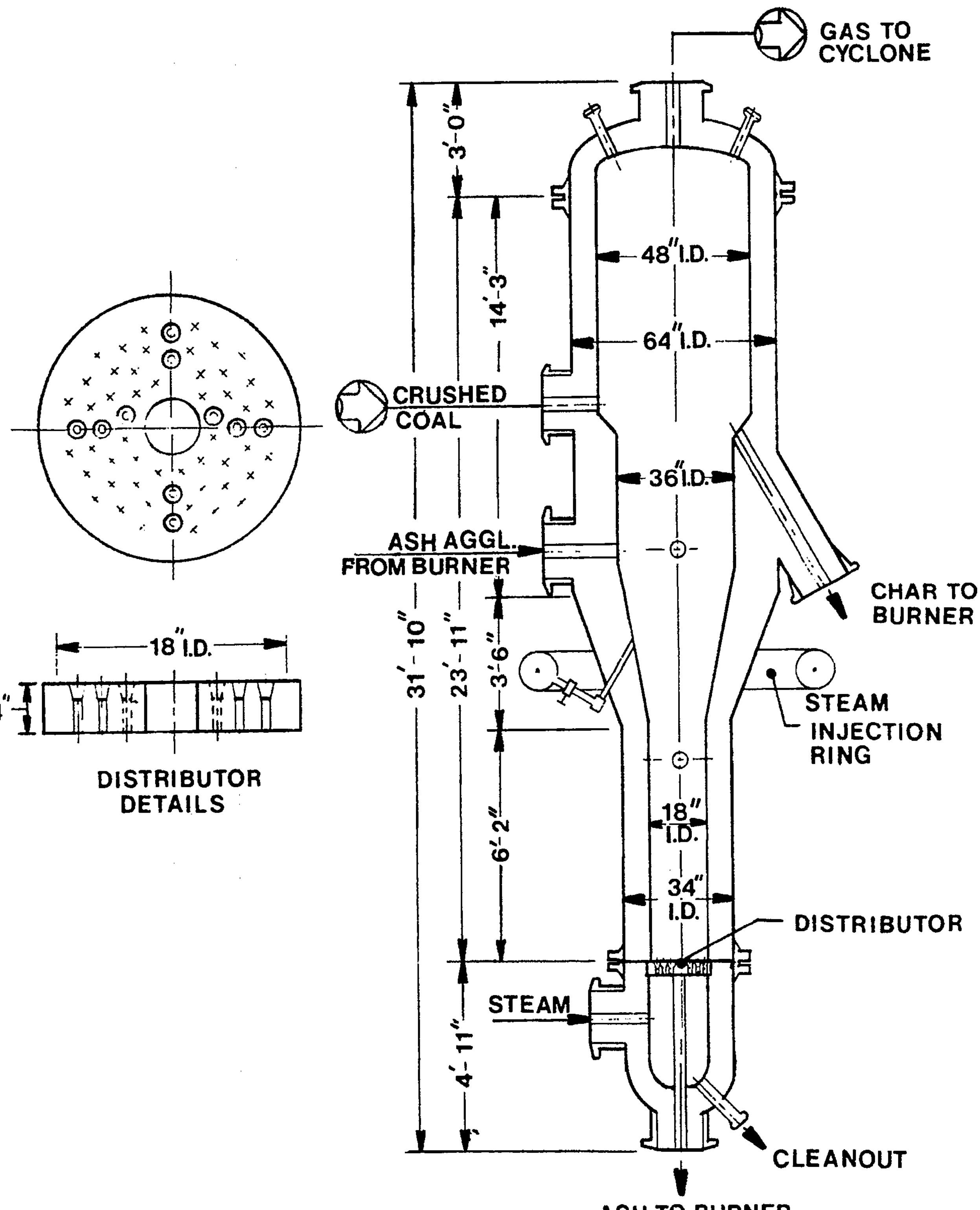


Figure 2B.1-2 Battelle-Carbide Gasifier.

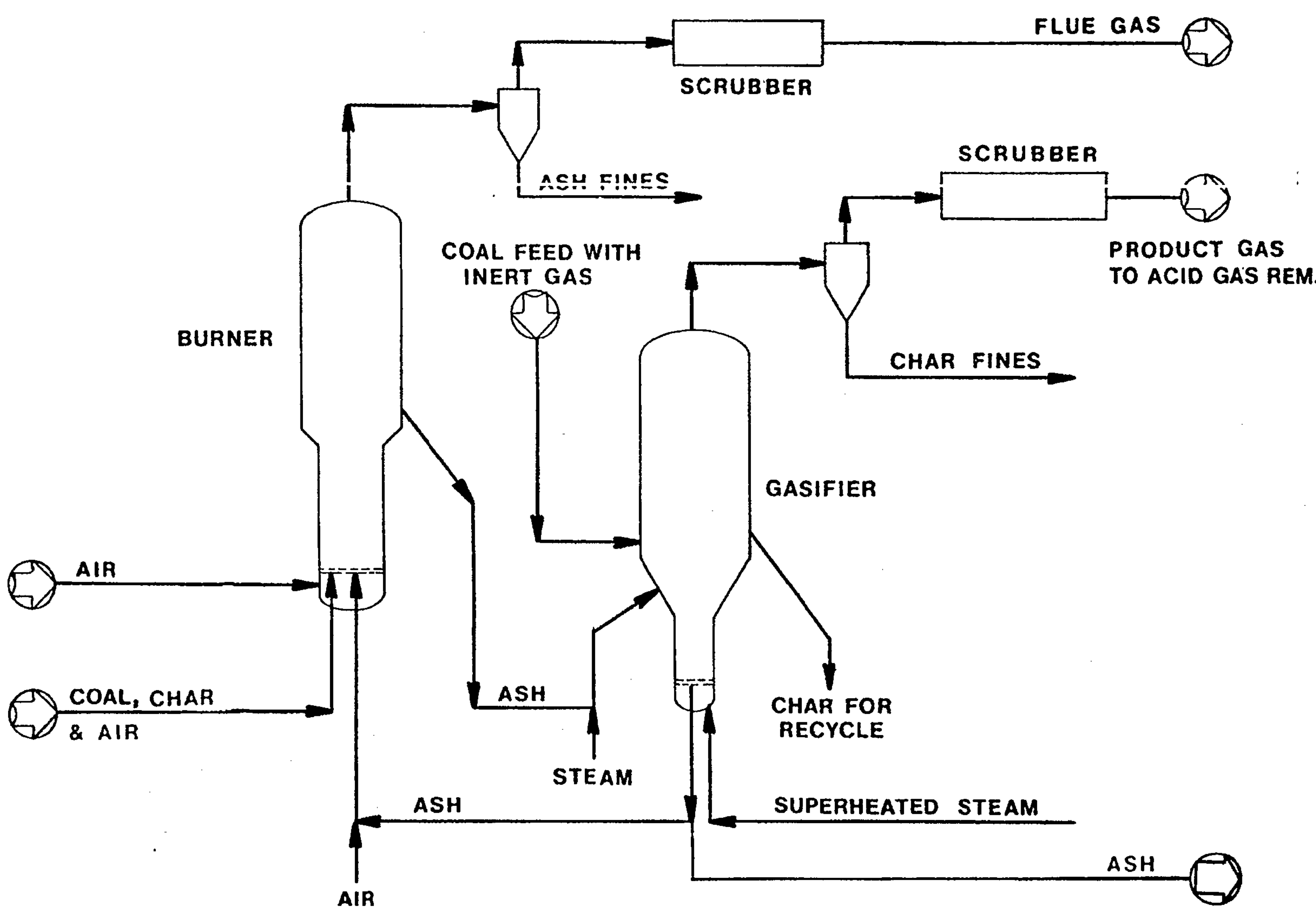


Figure 2B.1-3 Battelle-Carbide Gasification Process.

2B.2 BCR LOW-BTU (TRI-GAS)

Type

Three-stage fluidized bed gasifier

Developer

Bituminous Coal Research, Inc.
Research Center
350 Hochberg Road
Monroeville, PA 15146

State of Development[1 pc]

Bench scale work on the BCR Low-Btu gasification process began in the late 1960s. A 1.2 tpd PDU was completed in 1976 and operated until October 1980. Successful operation was achieved using a non-caking subbituminous coal and a mildly caking Illinois coal. There are no current plans for further work.

The goal of the multiple fluid bed process is the gasification of both caking and non-caking coals, with low- to medium-Btu fuel gas as the only product. The process is aimed toward application to steam boilers and gas turbines in a combined cycle operation for electric power generation.

Description

The PDU for the BCR Low-Btu process is shown schematically in Figure 2B.2-1. Pulverized coal is metered from a pressurized lockhopper through a rotary air lock feeder and flows by gravity to the first of three fluidized bed reactors in series. The operating temperature is progressively higher in each reactor from Stage 1 through Stage 3. Stage 1 provides a pretreatment step by contacting the fresh coal with hot gas from Stage 3. This gas also serves as the Stage 1 fluidizing medium. The coal is devolatilized in Stage 1 and flows by gravity to the lower part of the Stage 2 bed. The Stage 1 off gas, containing entrained volatiles, enters Stage 2 below the gas distributor.

Stage 2 is the major gasification stage. Here the devolatilized coal from Stage 1 and the tars and oils entrained in the Stage 1 off gas are gasified with air mixed with steam to generate the desired product gas. Product gas exiting Stage 2 flows to a cyclone, which removes entrained solids. The solids are returned to Stage 2. The product gas is cooled, and any remaining char fines are removed in a bag-house filter. Product gas is then taken to a scrubber-cooler and finally to a sulfur recovery unit. The resulting cleaned cooled gas is a low-Btu fuel gas.

Char from Stage 2 flows by gravity to Stage 3, where it is fluidized and gasified by air and steam. The ash formed flows to an ash lockhopper for removal. Stage 3 off-gas passes through a cyclone, where entrained ash is removed and returned to the Stage 3 bed. Flue gas is then sent to Stage 1 to continue the process.

Product gas heating value requirements dictate the operating conditions as well as the gasifying medium in Stage 2. Air and steam gasification yield a low-Btu fuel gas, oxygen and steam yield a medium-Btu gas.

Feed Requirements

Coal is pulverized to 60% + 200 mesh and 40% - 200 + 325 mesh. Moisture content of the raw coal is not critical, as moisture is reduced to approximately 2% during pulverization. Ash initial deformation temperature should be above 2200 °F.

Operating Conditions

	Stage 1	Stage 2	Stage 3
Temperature, °F	600-1200	1700-2000	2100
Pressure, psig	Up to 235	Up to 235	Up to 235

Gas Produced[2]

Typical gas composition (dry basis) after gas scrubbing and cooling for air-blown operation

Feed Coal	Eastern Coal
HHV of coal, Btu/lb, dry	14,900
Mole %, CO	25.7
CO_2	5.2
H_2	23.4
H_2S + COS	0.2
N_2 + Ar	45.5
HHV, Btu/scf, dry	160

By-Products

Oils or tars are not produced in minute quantities. Quanitity of steam generated is not available.

Utility Requirements[2]

Based on Eastern coal and steam-air operation

Air, lb/lb of coal	3.25
Steam, lb/lb of coal	0.7
BFW	Not Available
Electric Power	Not Available

Thermal Efficiency[2]

Based on cooled and scrubbed product gas, and steam-air gasification of eastern coal.

Cold gas efficiency = 88%
Overall Thermal Efficiency = Not Available

Capacity

The process development unit has the following dimensions

	I.D. (in)	Height (ft)
Stage 1	10	11
Stage 2	16	11
Stage 3	12	11

Capacity is 1.2 tpd of coal gasified to produce approximately 0.2 MM scfd of low-Btu gas at 235 psig.

Environmental Considerations

The Stage 2 off-gas passes through a cyclone and then through a bag-house filter to remove the char fines. The char fines are recycled to Stage 2 for gasification and do not constitute a disposal problem. A fine grain ash, typical of pulverized coal operation, is produced. The ash is disposed of by landfill, but it must be covered with soil to prevent dusting.

Remarks

The program, recently term nated, was oriented toward application of the system to a steam boiler and gas turbine in a combined cycle operation The process handles both caking and non-caking coals. Oils or tars are not produced.

References

1. Colaluca M. A. et al, "Development of the TRI-GAS Gasification Process," presented at American Institute of Chemical Engineers Meeting, November, 1978.
2. Stewart, J. T., and Diehl, E. K., "Fluidized Bed Coal Gasification Process and Equipment Development," presented at Third International Conference on Fluidized Bed Combustion, Hueston Woods, Ohio, October, 1972.

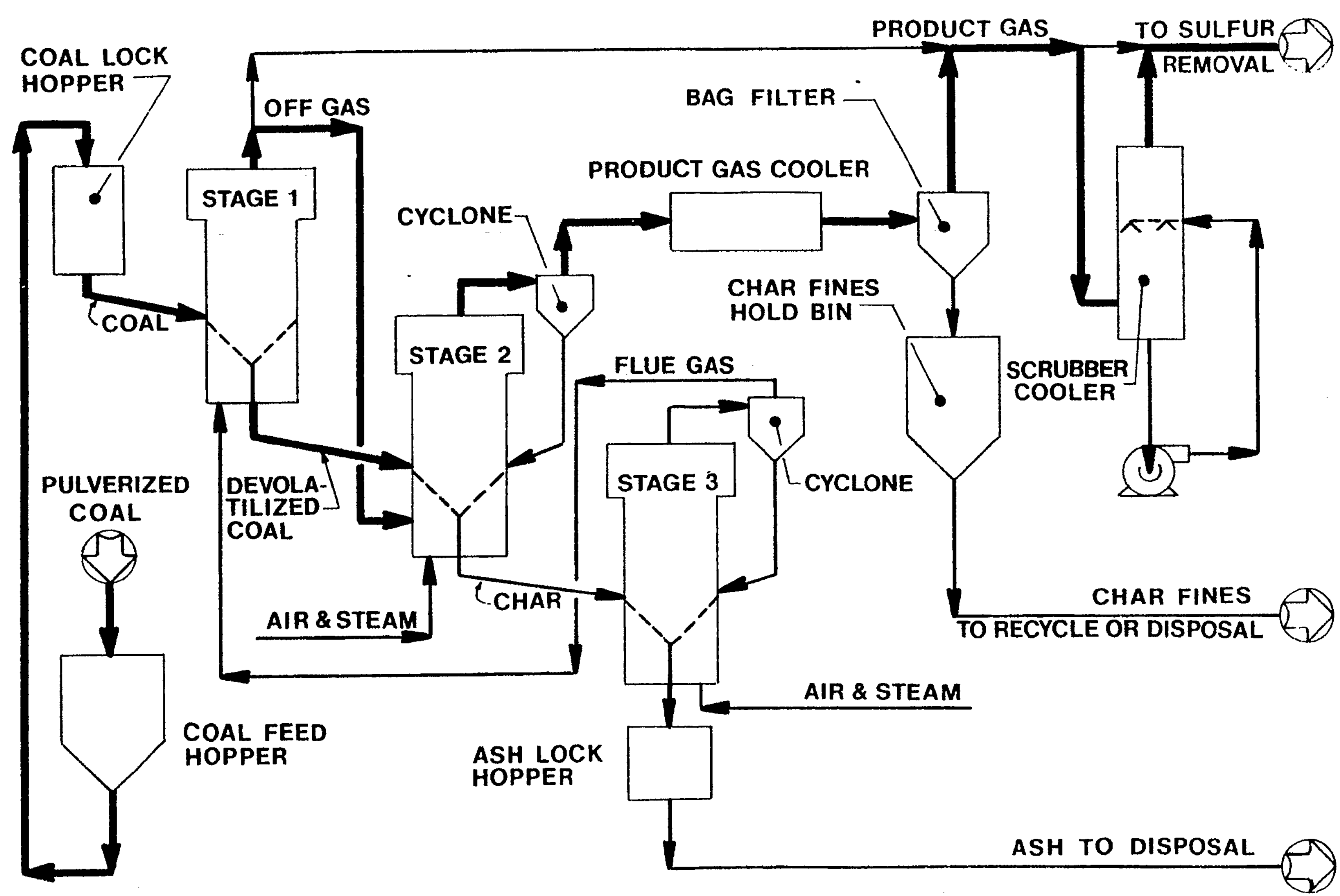


Figure 2B.2-1 BCR Low Btu Coal Gasification Process (PDU Set-Up).

2B.3 CHEMICALLY ACTIVE FLUID BED

Type

Chemically active fluid bed gasifier

Developer

Foster Wheeler Energy Corporation
110 South Orange Ave.
Livingston, N.J. 07039

State of Development[1,2]

Exploratory work on the Chemically Active Fluid Bed (CAFB) process began at Esso Research Center, Abington, England in 1966. In 1969, a six-phase program of work was defined to develop the process from the laboratory state to a demonstration plant to be located in the United States. Phase I studies at ERCA were begun in June 1970 under Environmental Protection Agency (EPA) Contract CPA 70-46 and consisted of batch reactor screening studies and initial operation of a pilot plant incorporating continuous gasification and regeneration. Phase II studies, conducted under EPA Contract No. 68-02-0300, consisted of three tasks: Task I, Operation of the Continuous CAFB Gasifier; Task II, Study of Additional Limestones and Fuels in Batch Gasification Units; and Task III, Scoping of the Engineering Effort to Scale Up the CAFB to a 100-MW Steam Generator. Concurrent with ERCA's work for EPA, two British affiliates of Foster-Wheeler Corp. (FW) and a British subsidiary provided engineering services in appraisal of the CAFB process for commercial application. These services covered conventional and combined cycles.

In May 1973, a license was obtained by FW for the commercial development of the CAFB process. In 1974, as part of the licensing agreement, a detailed engineering study was made of a combined-cycle plant based on the pressurized CAFB process. In May 1975, an agreement was reached between FW and Central Power and Light Company (CPL) to retrofit a 20 mW steam generator plant at La Palma Station at San Benito, Texas. The design rate for coal is 288 tpd and the design rate for #6 fuel oil is 24 gpm or 138 tpd. (11,631 lb/hour). The data base provided by the San Benito plant provides the basis for the conceptual design of a Department of Energy sponsored demonstration plant of 1920 tpd capacity on coal. Allegheny Power Service Corp. (APS) and FW will jointly develop this plant, which will be integrated with a power plant of 150 mW capacity.

Description[3]

Following description pertains to the San Benito plant. In this process, high-sulfur fuel oil is injected into a 1600 °F bed of limestone fluidized by a mixture of flue gas and air. The air is admitted in substoichiometric proportions (approximately 22 percent) to limit the amount of oil combustion and heat release. Flue gas is used as an inert, heat-absorbing medium to control the overall gasifier temperature. Under the above conditions, the high-sulfur oil partially burns, furnishing sufficient heat release to vaporize and crack the remaining oil. Hydrogen sulfide is formed during the partial combustion, reacts with lime, and forms calcium sulfide and steam. The 1600 °F product gas is essentially sulfur-free and will be burned in the steam generator with specially designed low-Btu gas burners.

In addition to sulfur removal, the process has consistently demonstrated the ability to remove 95+% of the vanadium and 50% of the sodium from the incoming fuel oil.

Because tests on other fuels, such as coal, lignite, and petroleum pitch, indicate that they can be used in the CAFB process, their use is planned as an integral part of the test program for the demonstration plant. In addition to the possible 90+ percent fuel-sulfur capture in the limestone bed, tests indicate that almost all of any SO_2 or H_2S in the fuel gas recycled to the gasifier section will be absorbed in the bed. This absorption has been demonstrated qualitatively: it was shown that seeding the incoming flue gas with SO_2 or H_2S did not create an increase of sulfur in the product gas.

To maintain the sulfur-removal capacity of the CAFB process, the calcium sulfide is removed from the gasification zone and replaced with sulfur-free lime. The calcium sulfide is then reacted with air at 1900 °F, driving sulfur from the lime in the form of a relatively concentrated SO_2 off gas. The other major components of this off-gas are carbon dioxide and nitrogen. The regenerated lime is then reinjected into the gasification zone for further sulfur absorption, thus minimizing lime consumption and solids disposal. After a period of time at high temperature, some of the lime tends to lose its reactivity. Therefore, to ensure the continuing sulfur capture ability of the system, a certain amount of the bed material is drained out and replaced with fresh limestone. The removed material is then cooled and pneumatically conveyed into the spent bed material storage silo to be stored for subsequent disposal. The SO_2 in off-gases is further converted into elemental sulfur.

Feed Requirements[3]

The data available on this gasifier are primarily those for the gasification of #6 fuel oil. Design conditions are based on deliverying 210 MM Btu/hour. At these conditions, fuel oil flow rate is 11,631 lb/hour (HHV = 18,423 Btu/lb and sulfur = 2.67% by weight). The demonstration plant plans for APS call for gasification of 1920 tpd coal. The information provided below is for fuel oil gasification unless otherwise noted.

Operating Conditions[3]

Temperature in the gasifier = 1600 °F
Pressure in the gasifier = 1.5 psig
Temperature in the regenerator = 1900 °F
Pressure in the regenerator = 1.5 psig

Gas Produced

Gas Composition: Not Available
HHV, Btu/scf (projected for demonstration plant) = 218

By-Products

The by-products are sulfur, some light oils, and ash. Approximately 610 lb/hour of spent bed material (CaS + $CaSO_4$) are produced. Also, 240 lb/hour of commercial grade sulfur are produced. These figures are for full load design conditions.

Utility Requirements

	Gasifier	Regenerator
Air, lb/lb of #6 fuel oil	2.68	0.38
Limestone, lb/lb of #6 fuel oil	0.12	0

Thermal Efficiency

Not Available

Capacity

Static bed depth = 16 inches (minimum),
24 inches (actual)
Expanded bed depth = 36 inches
Freeboard above expanded bed = 9 ft

Environmental Considerations

The only data available on the system are the predicted values for the gasifier combined with an existing steam generator. For the total system, the emissions are

	Coal Gasification (Predicted)	#6 Fuel Oil Gasification (Actual)
NO_x, lb/MM Btu input	0.18	0.13-0.17
SO_2, lb/MM Btu input	1.09	0.3-0.7
Particulates, lb/MM Btu input	0.1	0.1

Remarks

The development of the CAFB process is being pursued by Foster Wheeler as a retrofit for front-end fuel processing to supply clean combustible gas to existing utility steam generators.

References

1. "Study of Chemically Active Fluid Bed Gasifier for Reduction of Sulphur Oxide Emissions," ESSO Research Center final report prepared under EPA Contract No. CPA 70-46, June 22, 1970 to March 1972.

2. "Chemically Active Fluid-Bed Process for Sulphur Removal During Gasification of Heavy Fuel Oil - Second Phase," ESSO Research Center report prepared for Office of Research and Development, Environmental Protection Agency, EPA-650/2-74-109, November, 1974.

3. McMillan, R.E., et.al., "A discussion of the Chemically Active Fluid Bed Process," Spring Technical Meeting of the Combustion Institute; Columbus, Ohio, April 5-6, 1976.

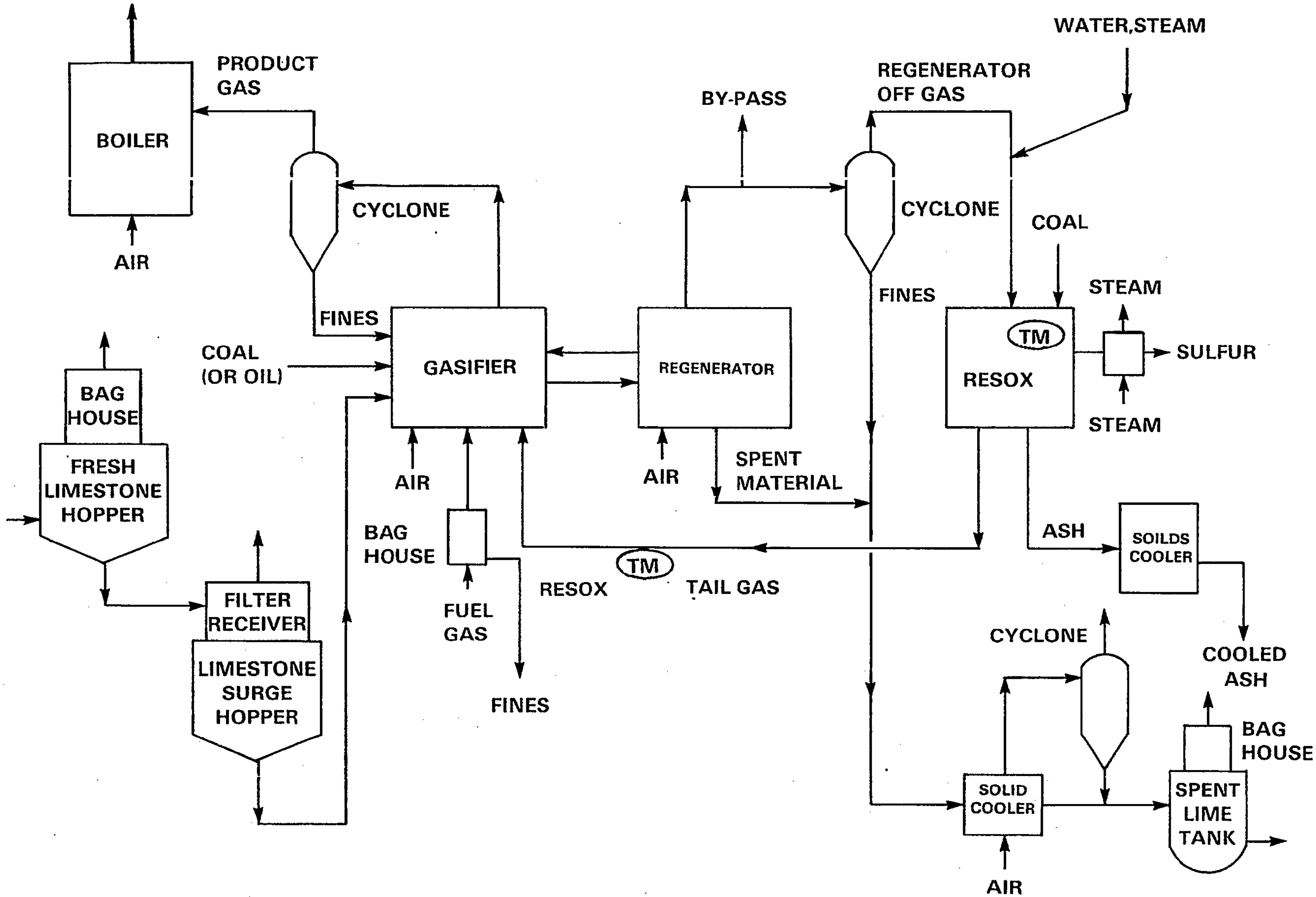


Figure 2B.3-1 Chemically Active Fluid Bed (CAFB) Process.

2B.4 CO_2 ACCEPTOR

Type

Fluid bed gasifier

Licensor

Conoco Coal Development Company
Research Division
Library, PA 15129

State of Development[1 2 3]

The CO_2 Acceptor process has been tested in a 40 tpd pilot plant at Rapid City, South Dakota. The development program was carried out by the Conoco Coal Development Company (CCDC) under contract from the Energy Research and Development Administration (now DOE). ERDA sponsorship began in 1964 after extensive bench-scale studies by Consolidation Coal Company, the originator and developer of the process. Construction of the 40 tpd pilot plant at Rapid City began in August 1969. Plant construction was essentially complete by November 1971 and the operation began in August 1972.

Seventy-five runs consuming 6500 tons of dry coal were completed in the pilot plant; 3 North Dakota lignites, a Texas lignite, and 3 sub-bituminous coals were successfully processed. Major achievements were (1) 2300 hours at controlled process conditions, (2) demonstration of system mechanical integrity, (3) verification of mechanisms influencing rate of decline of acceptor activity, (4) development and demonstration of a process for reviving spent limestone, (5) demonstration of gas conversion to SNG of over 900 Btu/scf HV, (6) comprehensive environmental studies, and (7) production of 45,000 scfd per ton of coal.

CCDC continued laboratory research to resolve the problems and to improve the overall process design. CCDC issued a subcontract to the South Dakota School of Mines and Technology to (1) conduct studies of dolomite sources, activity, and reconstitution, (2) study sodium removal from lignite, (3) investigate the environmental aspects of the acceptor process, and (4) conduct verification analyses using test samples provided from pilot plant operation.

Under two subcontracts, the Radian Corporation conducted an intensive environmental analysis of the CO_2 acceptor process, and in 1977 Stearns-Roger Inc. performed a preliminary design of a commercial size (250 billion Btu per day) CO_2 acceptor process for cost estimate and comparative study with the Lurgi process.[1] The program was terminated in 1979.

Description[1]

A distinguishing feature of the CO_2 Acceptor process (Figure 2B.4-1) is its use of an acceptor medium - generally limestone or dolomite - that circulates between a coal gasifier and an acceptor regenerator. Both the gasifier and the regenerator are fluidized bed reactors. In the gasifier, the acceptor reacts with CO_2 and H_2S to form bicarbonate and sulfides, thus reducing downstream gas removal requirements. In the regenerator, the acceptor absorbs heat of reaction that it gives up in the gasifier to provide energy for the exothermic gasification reactions.

The gasifier (Figure 2B.4-2) is a vertical, cylindrical pressure vessel flanged at both ends. The pressure bearing wall is a low alloy carbon steel clad with stainless steel on the inner surface. It is encased in an outer jacket and lined with refractory on the inside. Steam entering the side nozzle is distributed across the fluid bed by a ring-type distributor. Additional steam is fed into the lower section to strip the acceptor as it is withdrawn from the unit. An internal cyclone is provided for fines removal.

The acceptor regenerator is similar in construction to the gasifier. It has a 33-in diameter inside the refractory lining and a ring-type air distributor. An internal cyclone is not provided in the regenerator.

Feed coal is crushed, dried, and preheated prior to gasification. It is then transferred to the gasifier by gravity from the lockhopper feeding system. (See Figure 2B.4-1.) The coal enters the gasifier close to the base of the fluidized bed, and steam is introduced at about the same level. Hot recirculating acceptor from the regenerator enters the gasifier above the fluidized bed level, showers through the bed, and collects in the 20-in I.D. section of the gasifier. Thus, the fluidized bed above the narrow section is a mixture of acceptor and char, with more of the lighter char present near the top of the bed.

In the narrow section, steam is injected to strip the char from the acceptor. In the main fluidized bed, the acceptor reacts exothermally by the CO_2 acceptor reaction:

$$CaO + CO_2 \longrightarrow CaCO_3$$

The CO_2 is formed by the exothermic CO-steam reaction:

$$CO + H_2O \longrightarrow CO_2 + H_2$$

Heat released by these reactions and the sensible heat of the acceptor are used to carry out the endothermic steam-carbon-hydrogen reactions and coal devolatilization:

$$C + H_2O \longrightarrow CO + H_2$$
$$2C + H_2O + H_2 \longrightarrow CH_4 + CO$$

Gas thus formed leaves the gasifier through the internal cyclone. Then it is cooled and scrubbed in a water spray tower, resulting in a medium-Btu product gas. In a commercial plant, the hot gas from the gasifier would be passed through a waste heat boiler to generate steam.

The carbonated acceptor accumulated in the narrow section flows out through a standleg and is conveyed to the bottom of the regenerator by air or regenerator recycle gas. Residual char is withdrawn through a standleg from near the top of the fluidized bed and conveyed to the regenerator by regenerator recycle gas. The char is burned with air in the regenerator fluidized bed at approximately 1850 °F. At this temperature, the carbonated acceptor is calcined by the endothermic reaction:

$$CaCO_3 \longrightarrow CaO + CO_2$$

The calcined hot acceptor is returned by gravity to the gasifier through a standleg. A small amount of acceptor is continuously discarded from the regenerator. Flow of solids through the three standlegs between the gasifier and the regenerator is controlled by butterfly valves placed near the lower ends of the standlegs. Seals between the gasifier and regenerator are maintained by purging the standlegs with recycle gas. Flue gases leave the regenerator with elutriated ash and are passed through external cyclones to remove the ash.

Feed Requirements

Coal is crushed to + 100 to - 8 mesh size. The process can use lignite or subbituminous coal, which is dried to 5% by weight moisture before being fed to the preheater. In the preheater, it is heated to 500 °F and dried completely. To avoid agglomeration, coal ash initial deformation temperature should be about 100 °F above the regenerator operating temperature. Makeup acceptor, which can be either limestone or dolomite, is sized to +9 to -6 Tyler mesh and then is fed to the regenerator. Makeup requirement is 2 moles per 100 moles circulating.

Operating Conditions[2]

Temperature in regenerator = 1850 °F
Temperature in the gasifier = 1500 °F
Pressure = 150 psig

Gas Produced[2]

Typical gas composition (dry basis) after gas scrubbing and cooling

Feed Coal	Lignite
HHV of Coal, Btu/lb, dry	11,350
Mole %, CO	15.5
CO_2	9.1
H_2	58.8
CH_4	13.7
H_2S + COS	0.0
N_2 + Ar	2.9
HHV, Btu/scf, dry	380

By-Products

Oil and tars negligible.
Steam generated, lb/ton of coal = 2140
Ammonia, lb/ton of coal = 15

Utility Requirements

The utility requirements for lignite gasification are

For the gasifier	
Steam, lb/lb of coal	1.1
Recirculating acceptor, lb/lb of coal	3.60
For the regenerator	
Air, lb/lb of coal	2.3
Makeup dolomite, lb/lb of coal to gasifier	0.25
BFW, Gal/ton of coal	260
Electric Power, kWh/ton of coal	Not Available

Thermal Efficiency

Based on cooled and scrubbed product gas
Cold Gas Efficiency = 77%
Overall Thermal Efficiency = Not Available.

Capacity[3]

The pilot-scale unit at the Rapid City site could gasify 40 tpd of coal at 150 psig to produce 500,000 scfd of high-Btu gas.

Environmental Considerations

The ash discharged from regenerator cyclone contains about 5% carbon. Also, ash from the low rank Western coals typically contains lime. In the CO_2 Acceptor process, the lime reacts with the H_2S produced in the gasifier to form CaS. The ash is disposed of by landfill, after converting its CaS content to $CaCO_3$ in an aqueous slurry stirred tank reactor, where the following reaction occurs in the presence of CO_2:

$$CaS + H_2O + CO_2 \longrightarrow CaCO_3 + H_2S$$

Char from the gasifier is burned in the regenerator, and the flue gas is exhausted to the atmosphere. Because of the low sulfur levels in the lignites tested at Rapid City, SO_2 content in the flue gas was low enough so that it could be directly exhausted. For some coals, the SO_2 content may be too high, and the flue gas may require SO_2 scrubbing.

Remarks

The process uses a recirculating acceptor to provide heat for the endothermic reactions occurring in the gasifier. Therefore, carbon is not burned in the gasifier, and pure oxygen is not needed to produce a medium-Btu gas.

H_2S and CO_2 formed reacts with the acceptor, thus reducing product gas treatment requirements. Also, the H_2 content of the product gas is high, and CO-shift is not required prior to methanation.

References

1. "CO_2 Acceptor Process Gasification Pilot Plant," Executive Summary, Commercial Plant, Conceptual Design and Cost Estimate, Final Report, Vol. 13, August 1976 - December 1977.

2. Fink, C. E., et. al.; "CO_2 Acceptor Process Pilot Plant -1975," presented at the Seventh Synthetic Pipeline Gas Symposium, Chicago, Illinois, October 1975.

3. "Coal Gasification," U.S. Department of Energy, Quarterly Report, January 1978 - March 1978.

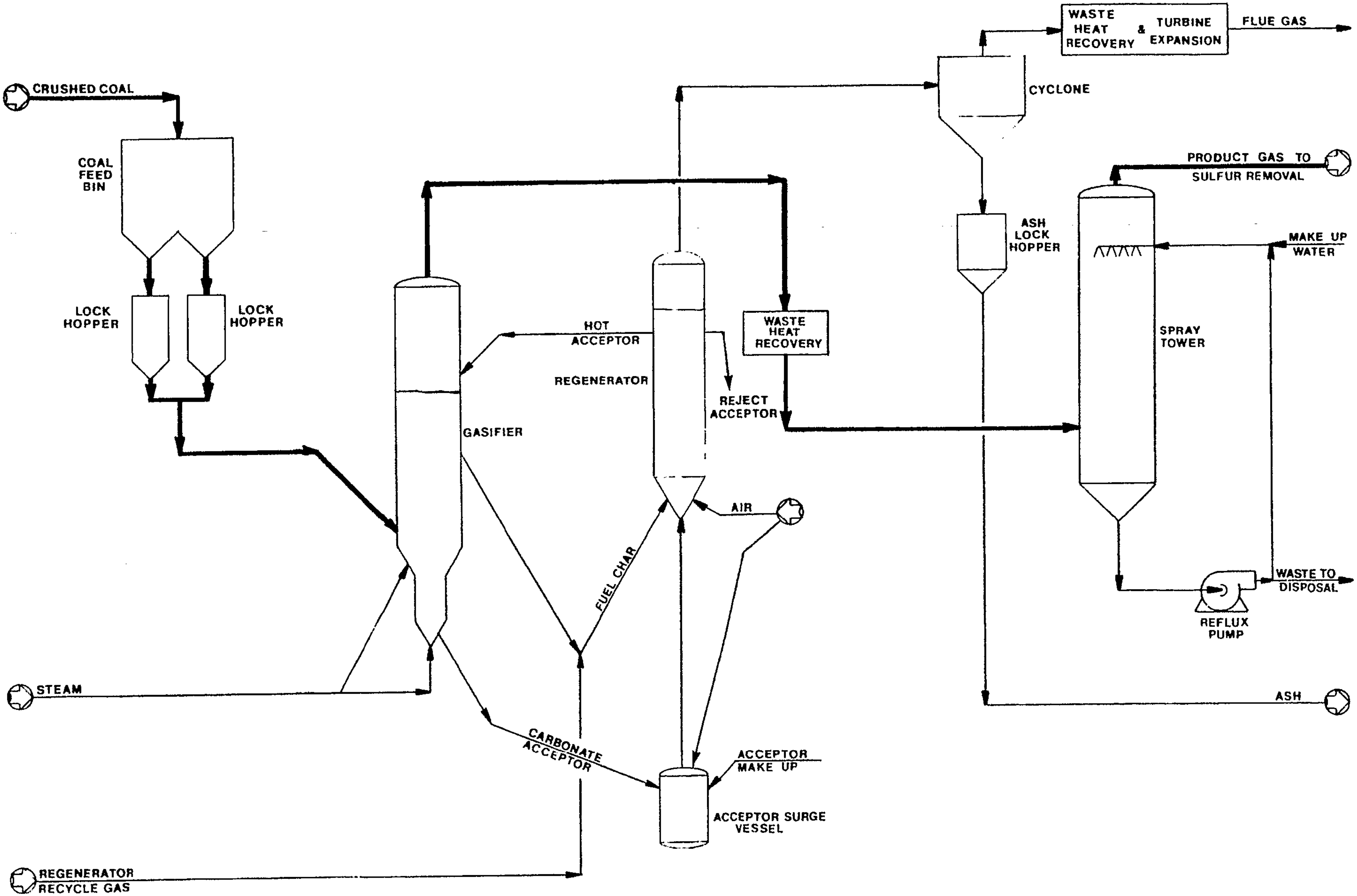


Figure 2B.4-1 CO_2 Acceptor Coal Gasification Process.

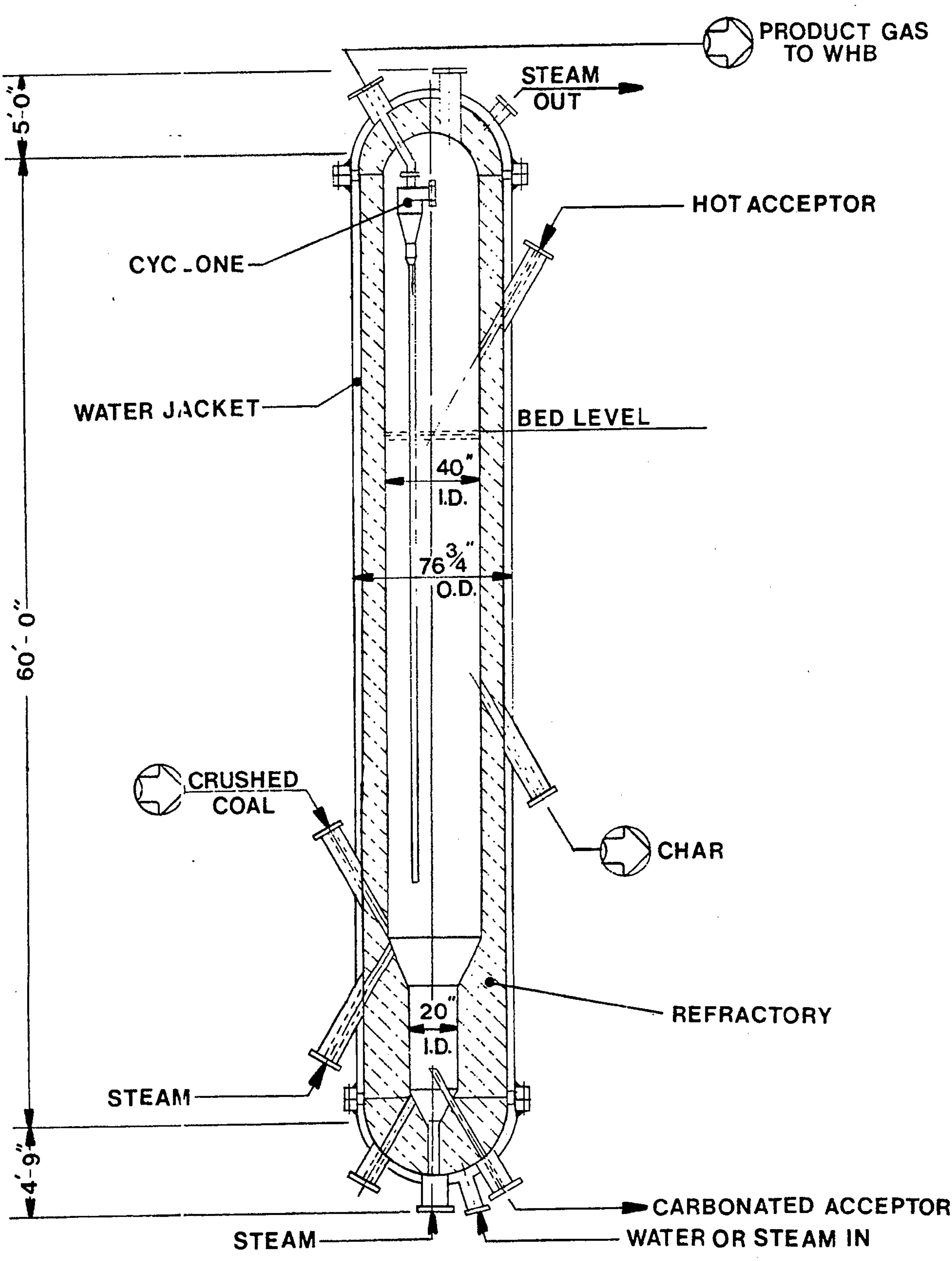


Figure 2B.4-2 CO_2 Acceptor Gasifier.

2B.5 COGAS

Type

Fluidized-bed pyrolysis and gasification

Licensor

COGAS Development Company
P.O. Box 8
Princeton, N.J. 08540

State of Development[1 2 3 4 5]

The COGAS Process for concurrent production of synthetic high-Btu gas, #2 fuel oil, #6 fuel oil, and reformate-grade naphtha from coal is a development of the COGAS Development Company of Princeton, New Jersey, the process licensor. The coal conversion is performed by multiple-stage pyrolysis and single-stage steam gasification of the char.

Piloting and design studies have been conducted since 1972. Process design of a 2200 tons/day demonstration plant for the Illinois Coal Gasification Group (ICGG) was initiated in 1978. Detailed design, Phase One of a three-phase Pipeline Gas Demonstration Plant Program supported by the U.S. Department of Energy, was not completed at the scheduled mid-1981 date. DOE and ICGG then mutually agreed to terminate the program.

The demonstration plant was to process a mixture of Illinois #5 and 6-seam coal. The plant was also to be operated on a Pittsburgh-seam and a Western subbituminous coal.

Multi-stage fluidized-bed pyrolysis was developed over the period 1964-1975. A 1.2 tpd process development unit (PDU) was operated for 2-1/2 years. Piloting was conducted in a 36 tpd plant. Seventeen coals were run in the PDU. Eight coals ranging in rank from lignite through high-volatile A bituminous were run in the pilot plant.

Char gasification was tested in a pilot plant with a capacity equivalent to 90 tons of coal per day consisting of a fluidized-bed gasifier and slagging cyclone combustor (Figure 2B.5-1). Over 1300 hours of gasification were achieved. Chars from three different coals were gasified, producing the data base for the demonstration-plant design and for the conceptual commercial-plant design and economic estimates.

Description

Coal is crushed, screened, and pressurized to about 50 psig. The coal is transported to multistage pyrolysis, where it is dried and heated in stages to drive off volatile matter. The residue, or char, flows to the fluidized-bed gasifier, where it is gasified with steam to produce synthesis gas. The syngas is sent back to pyrolysis, where it mixes with the volatile products of pyrolysis. The mixed gas and oil-vapor stream is sent to oil recovery, where it is quenched and the condensed oil is separated from the synthesis gas. The condensed oil is then reacted with hydrogen (hydrotreated) to produce naphtha and fuel oils, or a syncrude oil. The raw syngas is compressed and purified, and then the gas undergoes shift and methanation, bulk CO_2 removal, dehydration, and compression to form a pipeline-quality gas.

Heat for the reaction of steam with the char in the gasifier to form H_2 and CO is supplied from a slagging cyclone combustor, in which a portion of the char - the fines from the system - is burned with air. A recirculating stream of char from the gasifier is used as the heat-transfer medium. This char is heated in a transport lift tube by flue gas from the slagging cyclone combustor, and returns to mix with the gasifier bed. Coal ash is discharged from the combustor as molten slag via a water-quench system. The ability to remove ash in this manner without carbon is a key advantage. Thermal and kinetic energy in the flue gas, after supplying heat for gasification, is recovered by a gas-turbine expander and waste heat boilers. The pyrolysis and gasification step is illustrated in Figure 2B.5-2; the complete process block flow diagram, in Figure 2B.5-3.

Feed Requirements

Coal is crushed to 1/8-in x 0. Lignite to high-volatile A bituminous coals are acceptable for the process. Some chars may require a fluxing agent in the combustor.

Operating Conditions

Typical operating conditions are
- Pyrolyzer Temperature = 600 - 1000 °F
- Gasifier Temperature = 1600 °F
- Combustor Temperature = 3500 °F
- Gasifier Pressure = 50 psig

Gas Produced[1]

Feed Coal	Illinois #6
HHV of coal, Btu/lb	Not Available
Mole %, CH_4	94.0
CO_2	0.2
N_2	5.2
CO (ppm by volume)	9.0
HHV, Btu/scf	951
Yield, scf/ton coal	10,175

Liquid Fuels Produced From Illinois #6 coal

#2 Fuel Oil, bbl/ton of coal	0.48
#6 Fuel Oil, bbl/ton of coal	0.18
Naphtha, bbl/ton of coal	0.15

Byproducts

From Illinois #6 coal	
Sulfuric Acid, lb/ton of coal	168.0
Anhydrous Ammonia, lb/ton of coal	8.1

Utility Requirements[1]

Projected for Demonstration plant	
Water, gal/ton of coal	583
Electric Power, kWh/ton of coal	Not Available

Thermal Efficiency[2]

Projected overall thermal efficiency = 65%

Capacity[1]

Conceptual commercial design was made for a three-train plant processing 26,000 tons/day of Illinois #6-seam coal yielding 265 MM scfd of pipeline gas, 12,450 bbl/day of No. 2 fuel oil, 4760 bbl/day of No. 6 fuel oil, 3815 bbl/day of naphtha, 2180 tons/day of sulfuric acid, and 105 tons/-day of anhydrous ammonia with a thermal efficiency of 65 percent.

Environmental Considerations

Slag from the process would be disposed of by landfill. Flue gas would be cleaned of SO_2 by a gas scrubbing system. The demonstration plant had been designed for zero discharge of liquid effluents. Water from the process was stored in lined holding ponds, treated, and recycled. The fuel oil products meet major ASTM specifications for these fuel oils and are essentially sulfur-free products. The product naphtha has a nitrogen concentration of less than 1 ppm.

Remarks

The COGAS Process is a second-generation low-pressure (50 psig) fluidized-bed process for producing gas and oil from a wide range of coals. The principal products from the process are synthetic pipeline-quality gas (950 Btu/scf) and fuel oils and naphtha. The liquid fuels represent about 35 percent of the total Btu yield from a bituminous coal.

References

1. Bloom, R., Jr., and McCray, R.L., "The COGAS Process Demonstration Plant," presented at 8th Energy Technology Conference, Washington, D.C., March 10, 1981. 2. Paige, W.A., et. al., "Status of the COGAS Process - ICGG Coal Gasification Demonstration Plant Project," presented at the Coal Technology '80 Conference, Houston, Texas, November 18-20, 1980.

3. Eddinger, R.T., "The Pyrolysis Route to Gasification," presented at the 14th Intersociety Energy Conversion Engineering Conference; Boston, Massachusetts, August 6, 1979.

4. Jones, J.F., et. al., "Char Oil Energy Development," U.S. Energy Research and Development Administration Final Report, Contract No. E (49-18)-1212, September 1975.

5. McCray, R.L., et. al., "The Illinois Coal Gasification Group - What It Is and Where It Is Going," presented at the 85th National American Institute of Chemical Engineers Meeting, June 4-8, 1978.

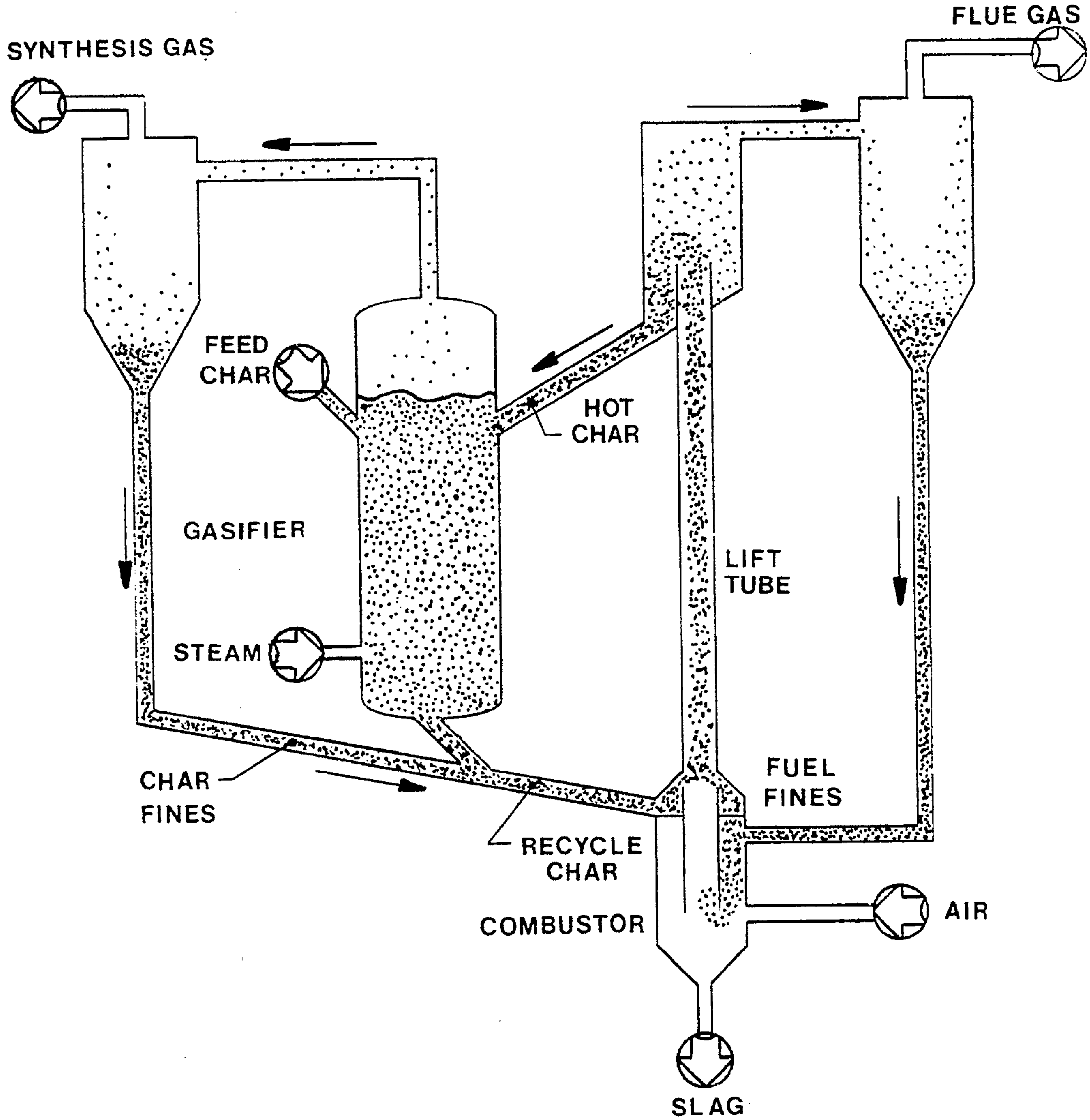


Figure 2B.5-1 COGAS Gasification—Combustion

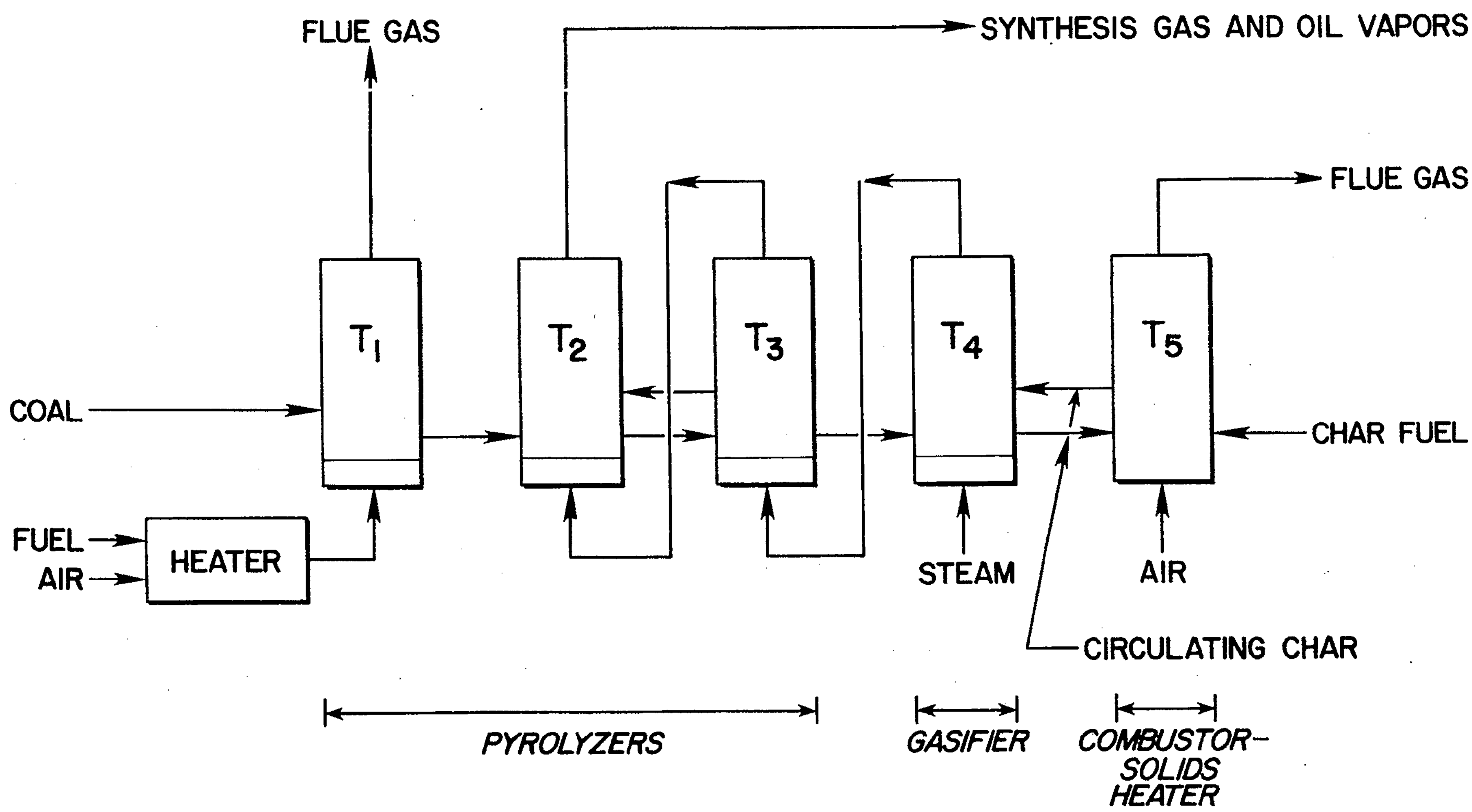
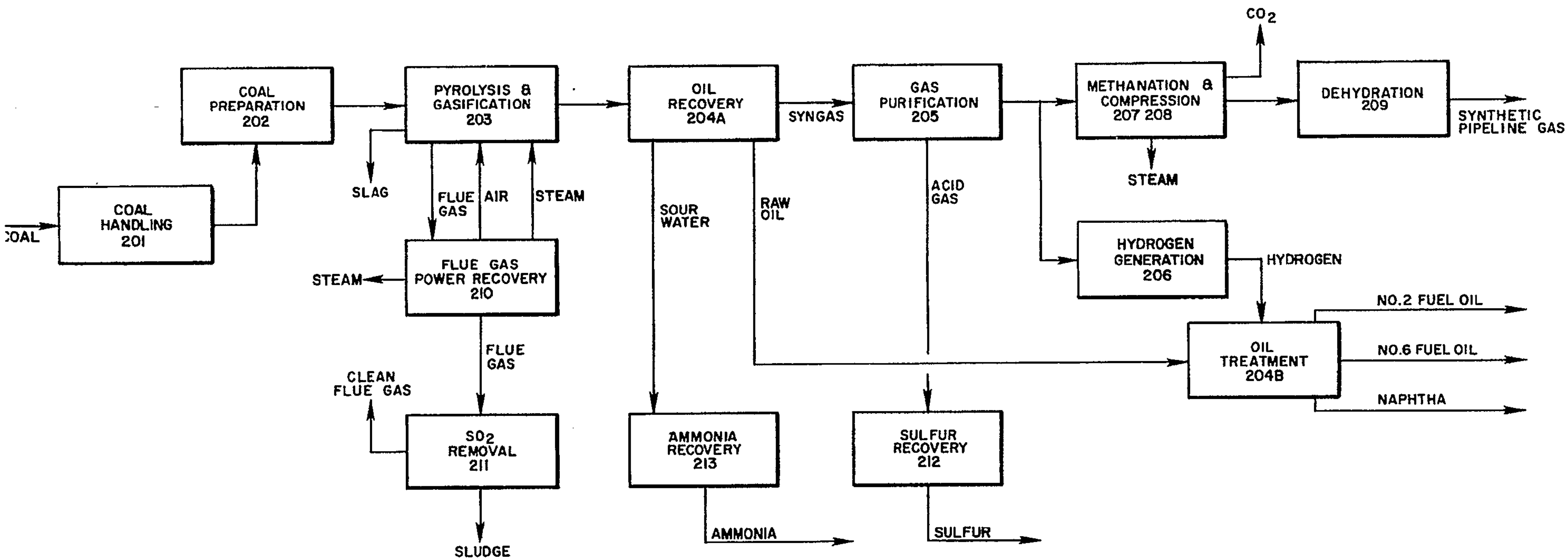


Figure 2B.5-2 Cogas Pyrolysis—Gasification



NOT SHOWN:

214 THERMAL OXIDIZER AND FLARE
215 UTILITIES
216 WATER SUPPLY
217 WATER TREATMENT
218 WASTE TREATMENT
219 FIRE PROTECTION
220 FACILITIES (STORAGE)

Figure 2B.5-3 ICGG Demonstration Plant Simplified Block Diagram

2B.6 EXXON CATALYTIC COAL GASIFICATION

Gasifier Type

Fluid Bed Catalytic Gasifier

Developer

Exxon Research and Engineering Co.
P.O. Box 4255
Baytown, TX 77520

State of Development

Exxon has been working on catalytic coal gasification (CCG) since 1971. This process entered the development phase in July 1978, following the successful completion of the predevelopment research phase. The development program is a coordinated laboratory and engineering effort involving R&D in both bench-scale equipment and a one tpd PDU.[1 2 3] This work, being performed by the Exxon Research and Engineering Company, is supported by the U.S. Department of Energy and the Gas Research Institute. The construction of the one tpd PDU has been completed, and the unit has been successfully started up.[4]

The PDU gasification section has operated successfully on catalyzed Illinois coal and data have been obtained for over 50 material balance periods covering a wide range of conditions.[pc] The carbon conversions and product gas compositions from these runs have approached study design targets. In earlier operations, agglomerates were formed in the bottom of the reactor, but these were reduced or eliminated primarily by increasing the feed gas velocity. Integrated operation of the gasifier, gas separation, and catalyst recovery sections is now in progress.

Description[4]

The chemistry of CCG can be broken down into three major reaction steps. The first reaction is the steam gasification reaction, where carbon and steam react to form hydrogen and carbon monoxide. This reaction is endothermic and requires heat input. The second reaction is the water gas shift reaction, which is slightly exothermic. The third reaction is the methanation reaction, which reacts hydrogen and carbon monoxide to make methane and steam. The methanation reaction is highly exothermic and gives off about as much heat as was consumed by the steam gasification reaction above. In CCG, all of these reactions take place in one reactor, and thus the requirement for heat is minimized.

Coal is impregnated with potassium hydroxide or potassium carbonate catalyst solution and reacted with steam at 1275 °F in a fluid bed gasifier. The mixture of product gases is then separated, and all of the hydrogen and carbon monoxide in the product gas is recycled back to the gasifier. The catalyst increases the steam gasification rate and also catalyzes the methanation reaction, which makes the H_2/CO recycle concept work. In net, then, only carbon dioxide and methane are produced, and the overall reaction is:

$$2C + 2H_2O \longrightarrow CH_4 + CO_2.$$

A flow diagram of the Exxon catalytic coal gasification process is shown in Figure 2B.6-1. In the PDU, coal is ground to 16 mesh top size, and a solution of potassium catalyst is sprayed on it. This mixture of catalyst and coal is then dried and sent to a fluid bed gasifier. The operating conditions of the reactor are 1275 °F and 500 psia. A mixture of steam, hydrogen, and carbon monoxide is fed to the fluid bed, where it gasifies the coal to a product gas containing hydrogen, carbon monoxide, carbon dioxide, methane, hydrogen sulfide, ammonia, and unconverted water.

This product gas is then cleaned in the gas separation section. First, heat is recovered from the hot product gas, and then condensed steam and ammonia are removed. The gas is then sent to an acid-gas removal system, where hydrogen sulfide and carbon dioxide are removed. The remaining methane, hydrogen, and carbon monoxide gas are then fed to a cryogenic distillation column, where product methane is removed from the hydrogen and carbon monoxide. Hydrogen and carbon monoxide are preheated in a furnace and recycled back to the reactor. This completes the gas separation loop.

The material coming from the bottom of the reactor is a mixture of unconverted carbon, catalyst, and ash. This char material is then washed with water to recover the water soluble potassium salts. The washed char is sent to a landfill for disposal. The recovered catalyst is mixed with makeup catalyst and sent back to the gasifier. Thus there are three major sections for the catalytic gasification process: the fluid bed gasifier, the gas separation section, and the catalyst recovery section. Detailed descriptions of gas separation and catalyst recovery sections follow.

The PDU gas separation system components use conventional technology. A monoethanolamine (MEA) acid-gas removal system (see Chapter 3A.13) is used to remove carbon dioxide and hydrogen sulfide from the product gas. The gas is then further cleaned with both molecular sieve (Chapter 3A.15) and activated carbon (Chapter 3A.1) columns to remove the small quantities of water, CO_2, and H_2S that escaped the acid-gas separation system. The hydrogen, carbon monoxide, and methane are cooled by a heat exchanger in the reboiler of the cryogenic distillation tower and then fed into the center of the packed distillation tower. The condenser for the tower is cooled by liquid nitrogen. A product gas containing 99.9% methane (nitrogen-free) is produced, and the recycled gas contains hydrogen, carbon monoxide, and about 10% methane.

The last system of the PDU is the catalyst recovery section. In this system, a char slurry containing about 10 wt% solids from the PDU gasifier is mixed with a lean potassium solution in a mixer vessel. In this mixer, the water soluble potassium on the char dissolves in the aqueous solution to form a rich potassium solution containing 1% potassium. (In a commercial system, potassium concentrations of about 10% are predicted.) This slurry is then sent to a vertical leaf filter, where the potassium solution is filtered from the solids. This filtrate solution is sent to an evaporator, where it is concentrated to about 10 wt% potassium. The solution is then ready to be sent back to the catalyst addition unit for the PDU gasifier. The solid cake from the filter still contains about 70% rich catalyst solution. These solids are reslurried with water and filtered again to produce a spent filter cake and a lean catalyst solution containing 0.5% potassium. This lean solution is sent back to the mixer vessel, where it is mixed again with fresh char from the gasifier.

Feed Requirements

The process can use all types of coals. Coal is ground to 16 mesh top size. Lignite requires a catalyst loading higher than subbituminous coals for an acceptable carbon conversion.

Operating Conditions

The fluid bed gasifier operates at 1275 °F. The range of pressure being tested in the PDU is 265 to 485 psig. The commercial process will operate at 485 psig.

Gas Produced[4]

The PDU has been designed to achieve 30-34 mol% methane in the product gas from the gasifier. After acid-gas removal and H_2 + CO recycle to the gasifier, the net product from the process is expected to be 99.9% methane.

By-Products

Char, H_2S, and ammonia are produced in the gasifier. Char produced in the PDU is sent to a landfill, but options for the char produced in commercial units are being studied.

Utility Requirements[4]

The utility requirements for three different coals gasified in the PDU are:

Feed Coal	Illinois bituminous
Catalyst (lb/lb coal)	0.15
Steam (lb/lb coal)	1.5

Thermal Efficiency

Not available.

Capacity

Not available.

Environmental Considerations

The MEA acid gas removal system used in the PDU may be replaced in a commercial process by a selective heavy glycol solvent system to reduce acid gas concentrations to less than 0.1 mol%. Traces of water, H_2S, and CO_2 are removed, and the spent char from the PDU is sent to a landfill.

References

1. Epperly, W. R. and Siegel, H. M., "Catalytic Coal Gasification for SNG Production," presented at the Eleventh Intersociety Energy Conversion Engineering Conference, State Line, Nevada, September, 1976.

2. Furlong, L. E. and Nahas, N. C., "Catalytic Coal Gasification - Process Research and Development," presented at the Tenth Synthetic Pipeline Gas Symposium, Chicago, Illinois, October, 1978.

3. Gallagher, Jr., J. E. and Euker, Jr., C. A., "Catalytic Coal Gasification for SNG Manufacture," presented at the Sixth Annual International Conference on Coal Gasification, Liquefaction, and Conversion to Electricity, Pittsburgh, Pennsylvania, July 31, - August 2, 1979.

4. Fant, B. T. and Euker Jr., C. A., "Exxon's Catalytic Coal Gasification Process," presented at the First International Gas Research Conference, Chicago, Illinois, June 9-12, 1980.

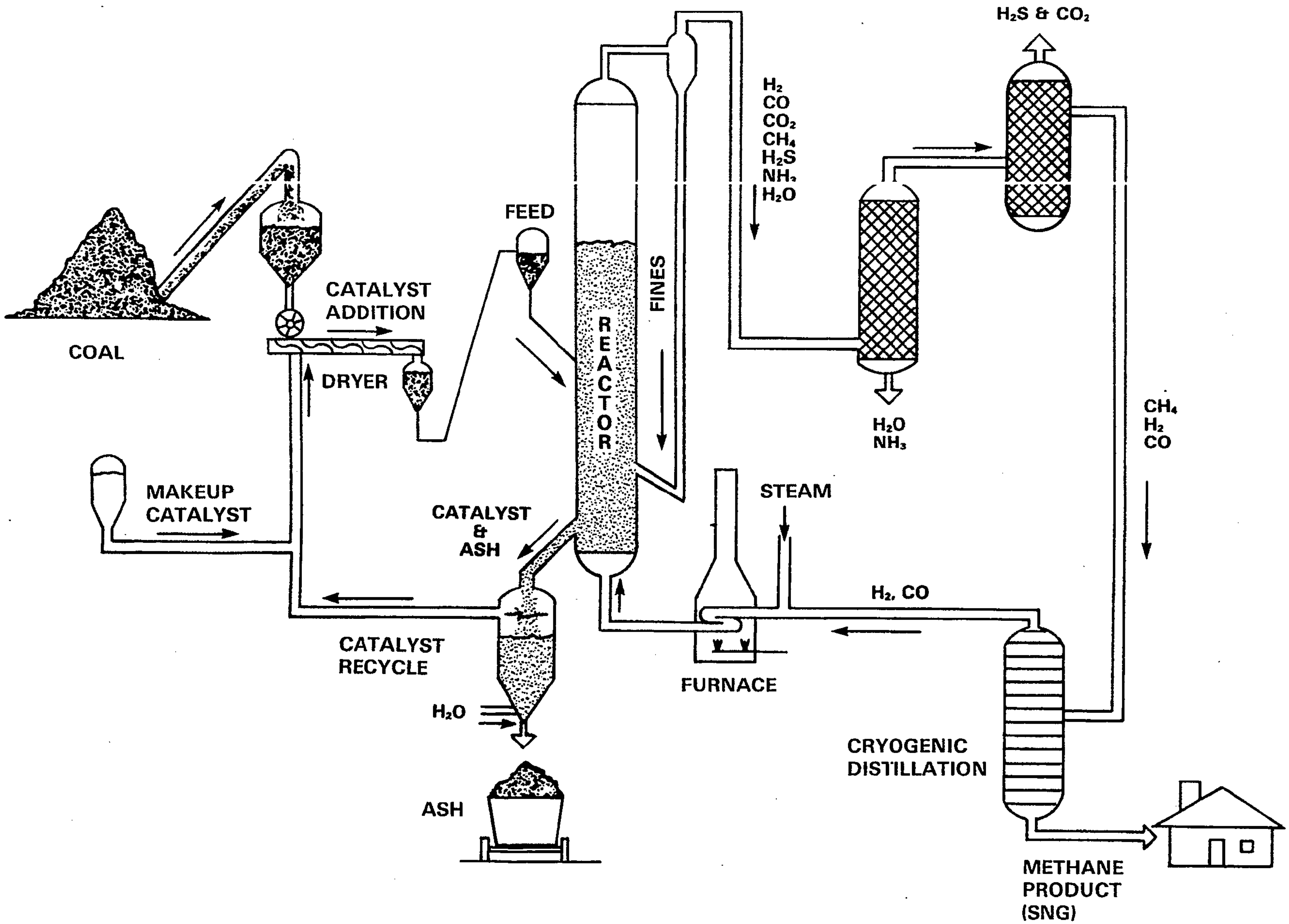


Figure 2B.6-1 Exxon Catalytic Gasification.

2B.7 HIGH-TEMPERATURE WINKLER

Type

Fluid bed gasifier

Developer

Rheinische Braunkohlenwerke AG
Stuttgenweg 2
5000 Koln 41
Federal Republic of Germany

State of Development

The Winkler process, the only commercially available fluid bed process for coal gasification, is discussed separately in Chapter 2B.13. High-Temperature Winkler (HTW) is a further development of this conventional process; its objectives of development are discussed in the "Description" section.

After preliminary tests were conducted in a small plant at Rheinisch-Westfalische Technische Hochschule - Rheinish Westphalian Technical University (RWTH Aachen) - the HTW process has been further developed and tested in a pilot plant at Frechen near Cologne since 1978.[1,2]

The approximately 1.3 tph pilot plant had undergone 9600 hours of operation through October 1980. Gasification conditions (1700 °F, 13 to 125 psig) were attained for 5200 hours. In June 1979, pilot plant operations using air as the gasifying agent had been completed, and oxygen gasification tests were being conducted.[3]

The mechanical testing has been completed, and the influence of various process parameters on the product gas analysis, the specific coal consumption, and carbon conversion has been studied. Further tests will be carried out for reaction temperatures higher than 1750 °F. The test program has been expanded. A wet scrubbing system and a two-stage CO shift converter have recently been added to the pilot plant to test some proprietary sulfur-resistant shift catalysts.

This experience has led Rheinbraun to decide to erect a HTW demonstration plant for gasifying dry lignite at 100 metric tph. Following an appropriate gas treatment, the generated synthesis gas will be transported to Union Rheinische Braunkohlen Kraftstoff AG at Wesseling (UK Wesseling), where it will be used for methanol synthesis, substituting for the synthesis gas that has so far been generated from crude oil products. The plant is to be built in two stages. The first stage, which will comprise one gasification and gas preparation line, is scheduled to be completed by 1983/84. The second stage, to be completed in approximately 1987, will have three further gasification and gas preparation lines if start-up of the first line is successful. After the plant's completion, it will have a synthesis gas output of some 34 billion scf per year and a raw lignite consumption of some 2 MM metric tons per year.

Description[4]

The conventional Winkler process offers several advantages compared to fixed and/or entrained gasifiers. Some of these are that oxygen demand is lower; pre-crushed coals with high content of fines can be gasified; high ash content in coal is permissible; and heavy hydrocarbons and organic impurities in the product gas are negligible.

However, this process also has certain limitations. As compared to pressurized operation, the atmospheric Winkler gasifier operation not only limits the equipment throughput capacity but also requires recompression of gases downstream. In addition, at low process temperatures, the quality of gas and carbon conversion efficiency are not as good as those at high temperatures.

The objective of developing the HTW process is to overcome these limitations without losing the advantages of the conventional Winkler process - in other words, gasification of coal at high temperature and high pressure in a configuration similar to the Winkler. Figure 2B.7-1 shows the HTW gasifier. The HTW pilot plant (see Figure 2B.7-2) is fed with dry coal from conventional rotary tubular lignite dryers. To obtain greater flexibility, provision has been made for further drying of the coal in this pilot plant. The coal is pressurized to the reaction pressure in a lockhopper system and fed to the fluidized bed reactor by means of a screw conveyor. Controlled quantities of limestone, lime, or dolomite can be supplied to the reactor at the same time as the coal.

In the gasifier, the coal reacts with either preheated steam and oxygen or steam and air. The product gas, which is laden with dust, leaves the gasifier at the top. The coarse grains of dust are removed from the gas in the first separator and returned to the fluidized bed of the gasifier. Further dust removal takes place in a second separator, with the dust leaving the pressure chamber via a lockhopper system. In the pilot plant, the purified gas is cooled in a waste heat boiler and incinerated in a power station. The ash that collects in the bottom of the gasifier and the dust removed in the second separator are discharged from the pressure zone by means of appropriate lockhopper systems. The hopper discharge systems operate on the same principle as the coal lockhopper feed systems.

These features represent a significant improvement over the conventional Winkler process. A commercial HTW plant need not necessarily be operated within the pressure limits of the pilot plant. However, the pressure range of 55 to 265 psig should cover most of the commercial applications. The operating temperatures, higher than those reached in a conventional Winkler, are dependent on the type of feed coal and the intended final product of the plant. The carbon conversion is primarily improved by recycle of entrained coal particles. The methane content of the raw gas increases with pressure and decreases as temperature is increased. A 3% methane level has been adopted as a reasonable compromise for most HTW applications. Increased pressure and temperature both result in a greatly increased gasification rate. Whereas conventional oxygen-blown Winkler generators have been operated at gasification rates of about 2.1 MM scfh of raw gas, future HTW gasifiers will be designed for more than 5.2 MM scfh of raw gas.

Feed Requirements[5]

Pilot plant feedstock is Rhenish lignite (screened, crushed and dried from 59% to 12% by weight water content). The ash content of the coal (dry basis) is 3%. The process can use other coals, including the mildly caking type.

Operating Conditions

The pilot plant is operated at pressures of 13 to 130 psig and a temperature of 1700 °F. The goal is to reach 2000 °F. The commercial gasifier may be able to operate at a higher pressure.

Gas Produced

Rate of syngas production (including shift and CO_2 removal) at the pilot plant, based on gasification of Rhenish coal, is 23.3 scf/lb dry coal. The gas composition (dry basis) is[3] pc

Feed Coal	Rhenish lignite
HHV of Coal, Btu/lb	10,224
Mole % CO	51.86
CO_2	8.91
H_2	35.28
CH_4	3.18
N_2 + Ar	0.69
H_2S + COS	0.08
HHV, Btu/scf, dry	372

By-Products

The raw gas contains negligible quantities of tars, phenols, oils, or other heavy hydrocarbons. Sulfur in the coal is, to an extent, removed by the dolomite added to the reactor. The amount of high-pressure stream produced from Rhenish lignite at the pilot plant is approximately 0.82 to 1.0 lb/lb dried coal.

Utility Requirements[3] pc

Utility requirements based on gasification of Rhenish lignite coal

Oxygen, lb/lb dried coal = 0.5
Process Steam, lb/lb dried coal = 0.16 to 0.25

Thermal Efficiency[pc]

$$\text{Cold Gas Efficiency} = \frac{\text{Heat content of cold product gas after shift and } CO_2 \text{ removal}}{\text{Heat content of coal}} = 84.0\%$$

Capacity

It is envisioned that a gasifier with an 18-foot outside diameter would produce over 5 MM scfh gas. Eight reactors of this size would be sufficient for a 300 billion Btu/-day commercial plant. Turndown capability = 33%

Environmental Considerations

Higher operational temperature promotes cracking of heavy hydrocarbons, and thus tars, phenols, and oils are negligible. Using Rhenish dry lignite, a H_2S content of approximately 0.1% by volume can be expected in the raw gas. Experiments have shown that the H_2S content in the raw gas can be reduced to about 30 to 60 ppm when limestone is added. As the coal feed contains fines, the raw gas leaving the gasifier contains a relatively high proportion of dust. This dust contains unreacted carbon. To achieve a high carbon conversion, the entrained fines are recovered and returned to the gasifier. Ash, which contains spent dolomite, is withdrawn from the gasifier bottom and sent to landfill.

Remarks

The pilot plant has been in successful operation for more than a year (as of June, 1980).[3] It was demonstrated that coal can be gasified by reaction with air or oxygen under pressure without sacrificing any of the advantages of the conventional Winkler process.

References

1. Franke, F. H., "Rheinbraun High-Temperature Winkler (HTW) Process," presented at the Sixth Annual Conference on Coal Gasification, Liquefaction and Conversion To Electricity, Pittsburgh, Pennsylvania, August, 1979.

2. Franke, F. H., et al., "First Experimental Results in Operation of the High-Temperature Winkler Process in a Semi-Technical Plant," presented at the Lignite Symposium, Grand Forks, North Dakota, 1979.

3. Teggers, H., and Theis, K. A., "The Rheinbraun High-Temperature Winkler and Hydrogasification Processes," presented at the First International Gas Research Conference, Chicago, Illinois, June 9-12, 1980.

4. Franke, F. H., et al., "Coal Conversion via Rheinbraun HTW Process," presented at the Coal Technology 1979 Symposium, Houston, Texas, November 6-8, 1979.

5. Franke, F. H., et al., "The High-Temperature Winkler Coal Gasification Process," presented at Ammonia from Coal Symposium, Muscle Shoals, Alabama, 1979.

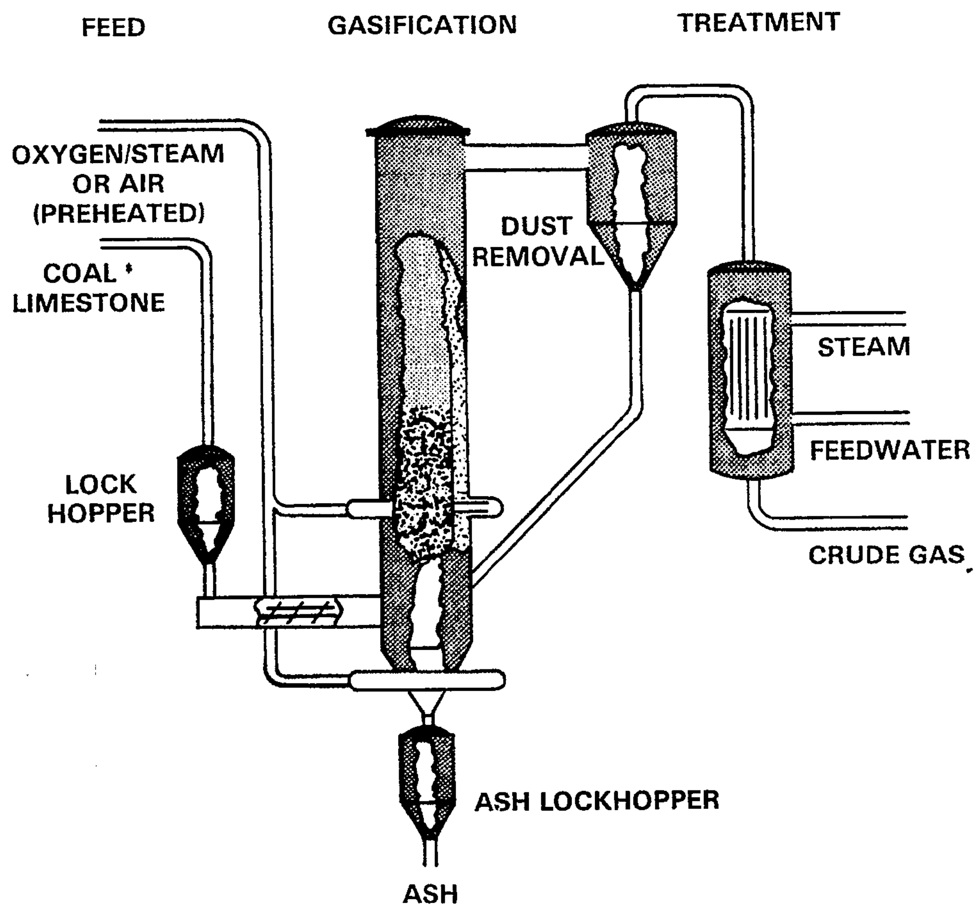


Figure 2B.7-1 HTW Gasifier

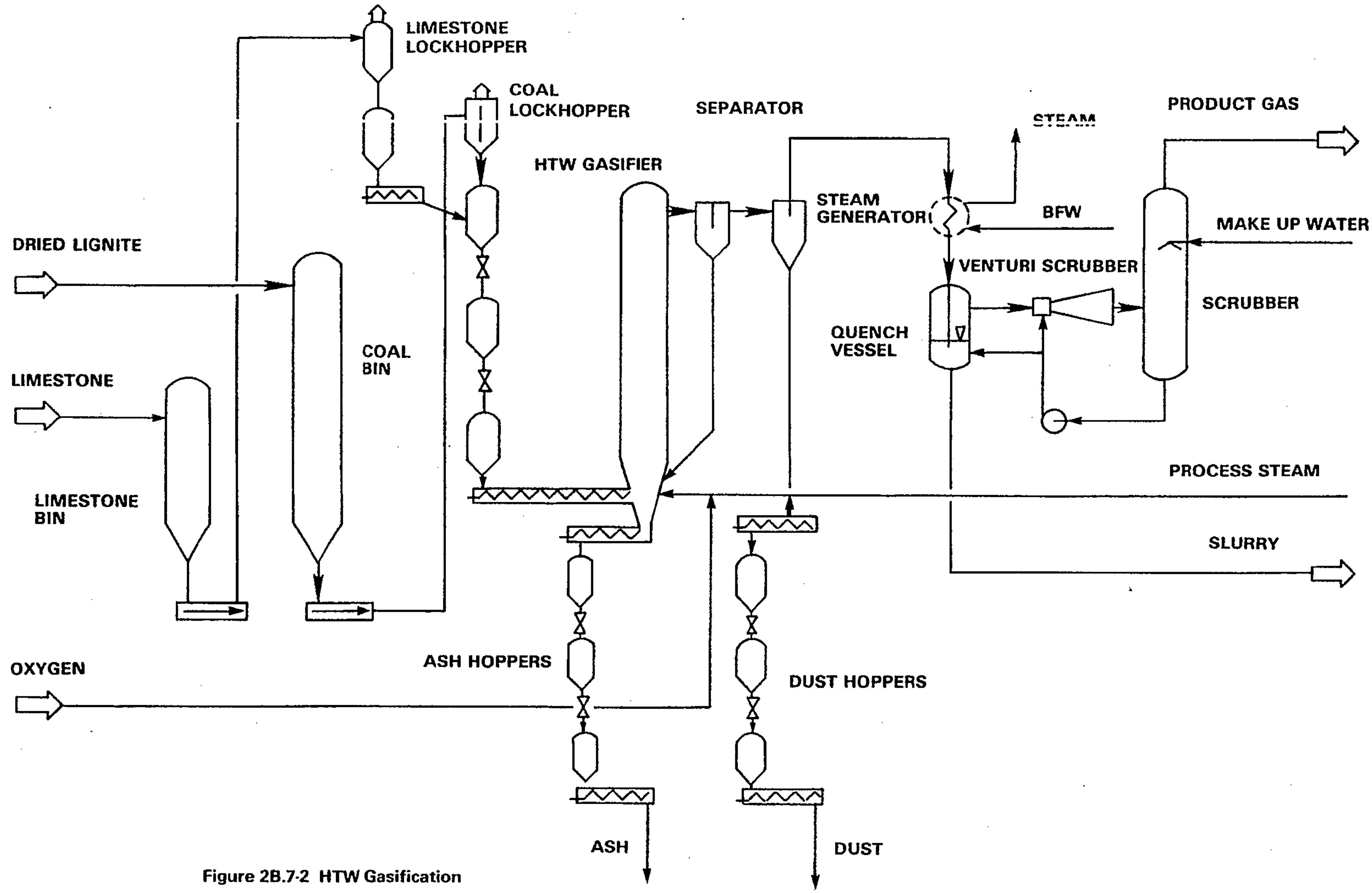


Figure 2B.7-2 HTW Gasification

2B.8 HYDRANE

Type

Hydrogasifier with free-fall dilute phase section superposed on a fluid bed section.

Developer

U.S. Department of Energy
Morgantown Energy Technology Center
Morgantown, WV 26506

State of Development[1 2 3]

The Hydrane process has been developed on a bench scale. No work has been done since 1978.

The first bench-scale unit, known as the "hot-rod" reactor, was built in 1955 to investigate the hydrogenation of subbituminous coal to yield a high-Btu gas and low-boiling aromatics. The hot-rod reactor was a 6-ft type 304 S.S. tube having a 5/16-in I.D. and a 5/8-in O.D. Satisfactory results were obtained from tests on Wyoming coal at 6000 psig and 1470 °F.

An entrained flow type reactor was designed and constructed in the late 1950s to test bituminous coals. The reactor failed because of plugging at 950 °F. This agglomeration of bituminous coals in hydrogen was a major problem encountered in these early reactors. A 5/16 in I.D., 20 ft horizontal tube reactor was also tried without success.

In the mid-1960s, a 3-in I.D. vertical reactor, with a heating section located below the coal entry point, was designed. Rapid heating of the solids to over 950 °F during free fall reduced the agglomeration problem by nullifying caking tendencies prior to particle contact in the reactor bed.

Experiments were performed with HVAB coal from the Pittsburgh seam at 3000 psig and temperatures of 1400 °F and 1650 °F. Based upon satisfactory results from these experiments, a reaction kinetics model was developed, which led to the design and construction of a 12 lb/hr bench-scale unit.[4]

This bench-scale unit is a two-stage hydrogasifier, built in separate sections. The first stage, a free-fall dilute phase reactor, has an I.D. of 3.26 in and an effective length of 5 ft and is enclosed in a 10-in pressure vessel. It has been operated at pressures of 500 to 3000 psig and temperatures of up to 1740 °F. Both a moving bed and a fluid bed have been used in the second stage. The fluid bed has a 2-in I.D. and is 10 ft high. The moving bed has a 3.26-in I.D. and is also 10 ft high. Both Illinois #6 and HVAB coal from the Pittsburgh seam have been tested in these units. Results show that 95% of the methane can be produced in the two-stage hydrogasifier.

Subbituminous coals and lignite were processed with elimination of the fluidized bed. Hydrogasification tests were run with up to 45-hour duration at 900 °C and 1,000 psig. Product gas had heating value of up to 1,000 Btu/scf after cleanup and minor CO removal by light methanation. Carbon conversion was 68% methane from lignite and 87% from HVCB coal (Illinois).

Description[2 5 6]

A preliminary design for a PDU of 10-30 tpd coal capacity was made and, although never built, is useful to describe the process.

The PDU version of the Hydrane gasifier, shown in Figure 2B.8-1, consists of two sections: an upper free-fall dilute phase (FDP) section and a lower fluid bed (FB) section. The two sections are interconnected by a dipleg for char transportation.

The feed coal is dried and pulverized to 70% minus 200 mesh. It is then pneumatically transported to two series lockhoppers located above the gasifier. (See Figure 2B.8-2.) The top lockhopper is filled with coal and pressurized with CO_2 to the same pressure as the bottom lockhopper, and the coal is then transferred by gravity. The pressure of the lockhoppers is maintained approximately 10 psi above the reactor operating pressure. Coal is transported from the lockhoppers to the gasifier coal distributor and then devolatilized and hydrogenated in the FDP section by gases from the FB section flowing cocurrently with the coal. Product gas at 1000 °F and 1000 psig is withdrawn after free-fall, while the FDP char continues through the dipleg to the fluid bed section.

The bed is fluidized by a gas stream of fresh hydrogen. Recycle product gas can also be used for fluidization, so a wider range of char particles can be handled without changing the fluid bed dimensions. After establishing a narrow range of operating conditions, the bed can be sleeved to the proper size and the recycle product gas stopped. In the fluid bed, the char is further hydrogenated to produce a 50:50 hydrogen-methane gas mixture. This mixture is then passed through the annulus between the FDP reactor shell and the inner wall of the hydrogasifier into the FDP reactor. Here it meets the incoming coal and flows cocurrently downward.

The unreacted char, containing approximately 85% carbon by weight, is withdrawn from the fluid bed section and disposed of; in a commercial plant, it could be used as a hydrogen plant feedstock.

The product gas withdrawn from the FDP section flows to a cyclone, where entrained solid particles are removed. The gas stream is then passed through a venturi scrubber and a cooler. Oils and water are condensed and collected at the bottom of the cooler. The cooled gas is then processed in an acid gas removal unit. At this point, the cleaned product gas has a heating value of approximately 800 Btu/scf and can be upgraded further by methanation.

Feed Requirements[pc]

Coal is pulverized to 70% through 200 mesh size. The gasifier can accept all types of coal. Initial testing was performed with mildly caking (Illinois #6) and severely caking (Pittsburgh #8) coals. Gasifier throughput may increase if noncaking coals are used.

Desirable moisture content of coal is 2% or less to facilitate feeding.

Ash initial deformation temperature should be greater than the 1800 °F FB operating temperature. This should not be a major problem, since char leaving the FB is about 85% carbon.

Operating Conditions

Temperature in FB = 1800 °F
Temperature of hydrogen entering FB = 1000 °F
Max. Temperature of the gas leaving FDP = 1000-1500 °F
Pressure = 1000 psig

Gas Produced

Typical gas composition (dry basis) after gas scrubbing and cooling

Feed Coal	Pittsburgh # 8
HHV of coal, Btu/lb, dry	13,860
Mole%, CO	6.0
CO_2	1.7
H_2	21.7
CH_4	68.2
C_2H_6	0.4
H_2S+COS	0.6
N_2+Ar	1.4
HHV, Btu/scf, dry	784

By-Products

Char withdrawn from the FB contains 85% carbon at a rate of 0.5 lb/lb of coal.

Oil produced, lb/ton of coal	26

Utility Requirements

Based on Pittsburgh #8 coal

H_2 (100%), lb/lb of coal	0.08
Steam for H_2 generation, lb/lb of coal	1.7
BFW, gal/ton of coal	68
Electric Power, kWh/ton of coal (from receiving coal to delivery of cool char and gas)	194

Thermal Efficiency

Based on cooled and scrubbed gas and Pittsburgh #8 coal

Cold Gas Efficiency = 84%
Overall Thermal Efficiency = 81%

Heat in hydrogen is taken as input, and heat in char is taken as output. Thus, energy loss occurring in conversion of char to hydrogen is not taken into account. However, for an integrated plant (including conversion of char to hydrogen) producing pipeline quality gas, the overall thermal efficiency is estimated to be 77.8%.

Capacity[7]

A proposed commercial Hydrane gasifier consisting of a 14.2-ft I.D. FB with multiple FDP reactors can gasify approximately 5300 tpd of coal to produce 125 MM scfd of pipeline quality gas at 1000 psig.

Environmental Considerations

About 26 pounds of oil are produced per ton of coal feed to the reactor. The oil contains about 0.2% sulfur and must be treated before further use.

Char from the FB reactor contains about 85% carbon. This carbon rich char can be used in a char gasifier to produce hydrogen.

Remarks

In the Hydrane gasifier, about 94-95% methane of the total required for pipeline gas is produced. The $CO:H_2$ ratio in the gasifier outlet gas is such that CO shift is not necessary prior to methanation. Only a light methanation is required.

Integrated operation between the free-fall dilute phase (1st stage) and the fluid bed char hydrogasifier (2nd stage) has been demonstrated in the bench scale unit with respect to solids flow but not with respect to interstage gas flow.

No work has been done on this process since 1978.

References

1. Gray, J. A. and Yavorsky, P. M., "The Hydrane Process," presented at Second Symposium on Clean Fuels from Coal, Chicago, Illinois, June 23-27, 1975.

2. Chambers, H. F., et al., "Free-Fall, Dilute-Phase Hydrogasification of Coal for Production of High-Btu Gas," presented at ERDA/FE Divisional Meeting on Hydropyrolysis and Hydrogasification Projects, Pittsburgh Energy Research Center, Pittsburgh, Pennsylvania, September, 1977.

3. Hiteshue, R. W., et al., "Hydrogenating Coal at 800 °C," Industrial and Engineering Chemistry, 49(12), December, 1957, pp. 2008-2010.

4. Wen, C. Y., et al., "Application of the Bubble-Assemblage Model to the Hydrane Process Fluid-Bed Hydrogasifier," presented at the 67th American Institute of Chemical Engineers Meeting, Washington, D.C., December 1-5, 1974.

5. Gray, J. A., et al., "Hydrogasification Kinetics of Bituminous Coal and Coal Char," presented at Division of Fuel Chemistry Gasification Symposium, National American Chemical Society Meeting, Chicago, Illinois, August, 1975.

6. Wen, C. Y., et al., "Comparison of Alternate Coal-Gasification Processes for Pipeline-Gas Production," Energy Sources, Vol. 1, No. 1, 1973, pp. 31-71.

7. Feldmann, H. F., and Yavorsky, P. M., "The Hydrane Process," presented at the Fifth AGA/OCR Synthetic Pipeline Gas Symposium, Chicago, Illinois, October, 1973.

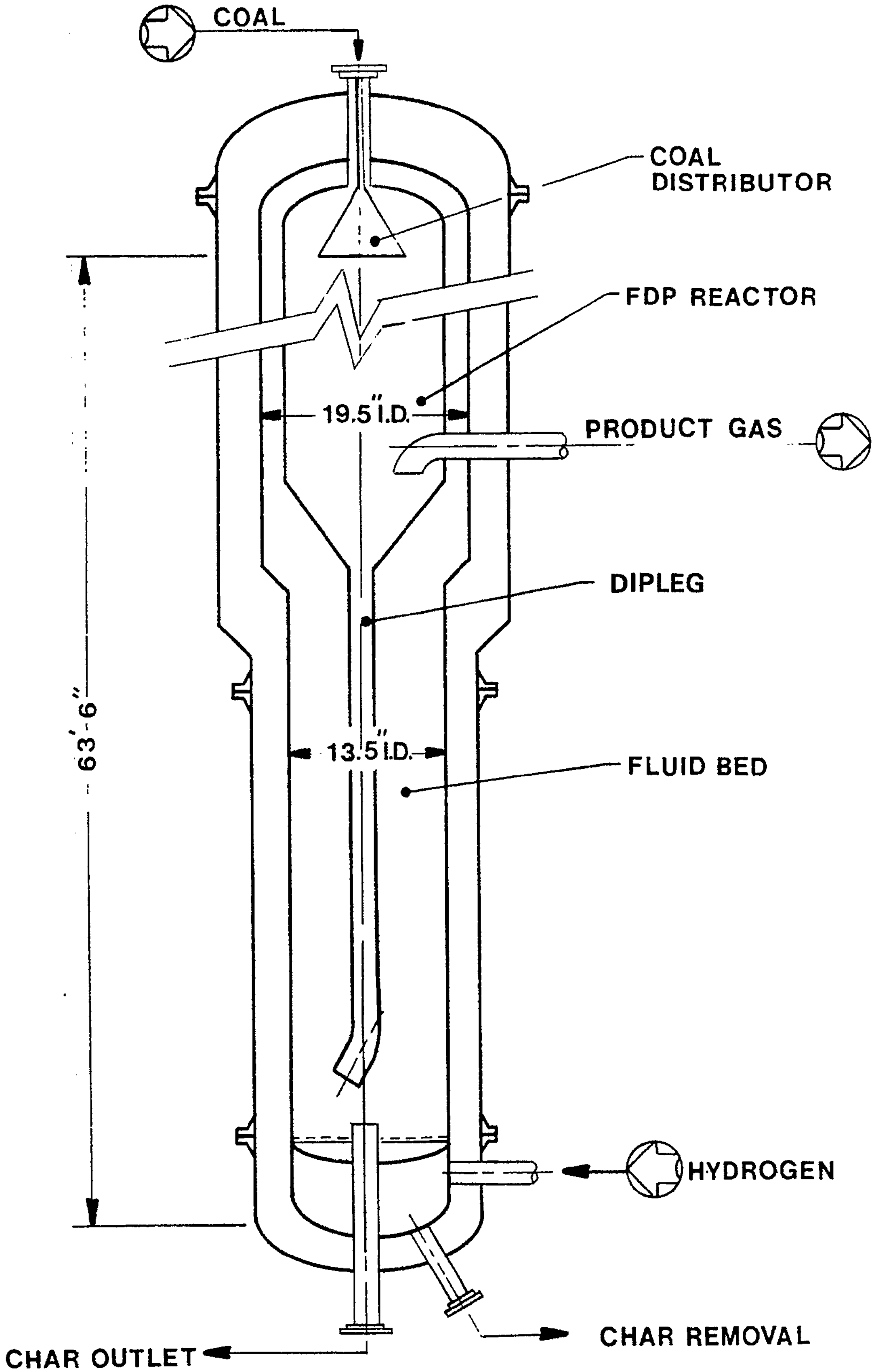


Figure 2B.8-1 PDU Hydrane Gasifier.

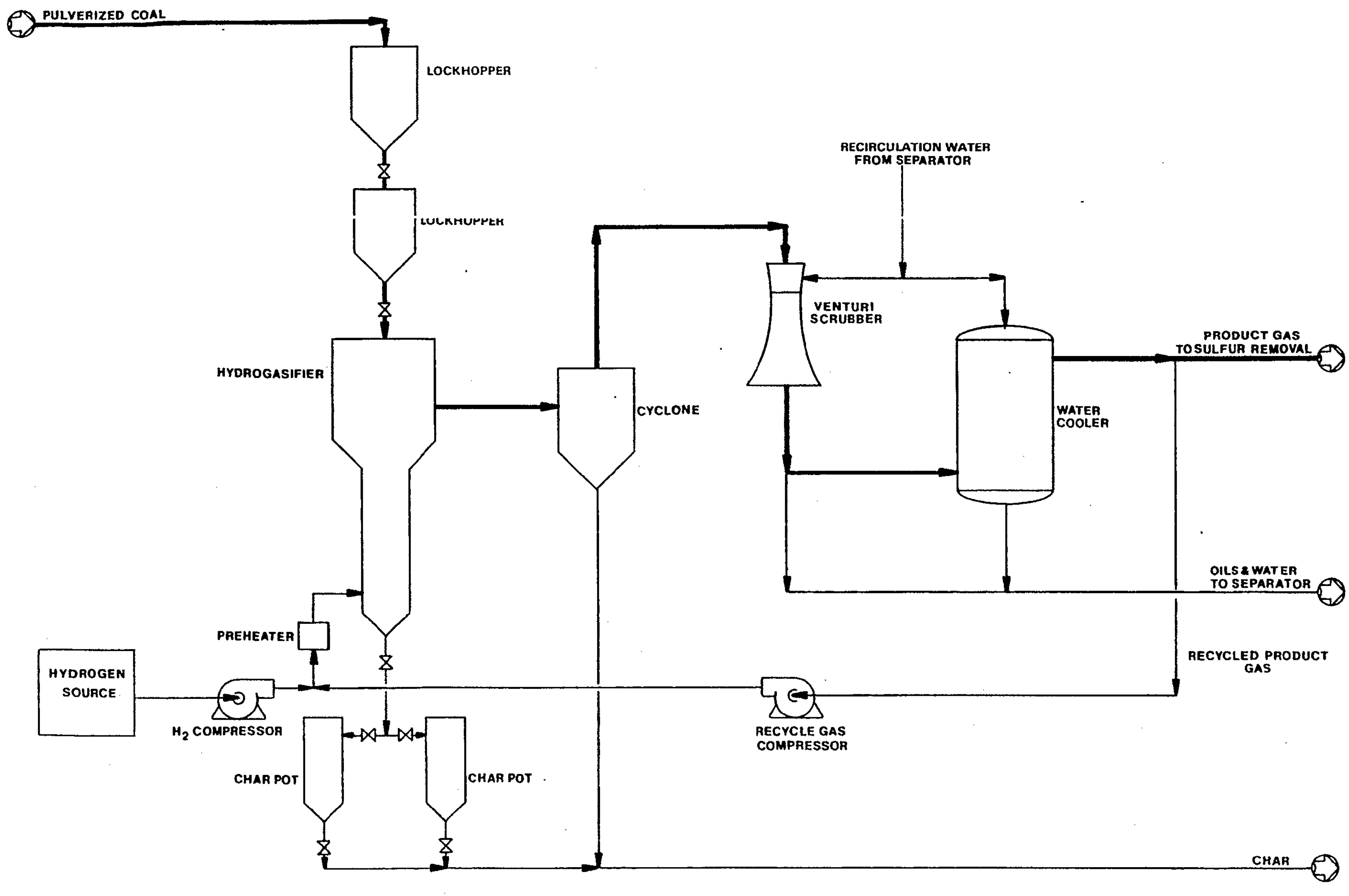


Figure 2B.8-2 Hydrane Coal Gasification Process.

2B.9 HYGAS

Type

Fluid bed hydrogasifier

Developer

Institute of Gas Technology
3424 South State Street
Chicago, IL 60616

State of Development[1 2 3]

Research on the HYGAS process was initiated in 1964 under the joint sponsorship of the American Gas Association, Inc. (AGA), and the Office of Coal Research (OCR), U.S. Department of the Interior. This program was based on earlier research conducted at the Institute of Gas Technology (IGT) from 1945 through 1964. Development work progressed from laboratory scale through bench scale and culminated in the construction of an 75 tpd pilot plant, which was dedicated in October, 1970. Checking and testing were completed in late 1971, and coal was first introduced in October of the same year. Initial operations tested the hydrogasification sections of the reactor at 500 and 1000 psig. Initially, the hydrogen used in the process was produced by steam reforming of natural gas. By August 1972, a run lasting two weeks was achieved with the hydrogasifier operating at 1000 psig.

Development work on steam-oxygen gasification was carried out at IGT during the early 1970s. Construction to revamp the existing hydrogasifier pilot unit to integrate the steam-oxygen stage started in early 1974 and was completed by June 1974. Tests were run at 500 to 1000 psi, and the plant soon produced pipeline-quality gas from coal in sustained test operations. Since then, the duration of test runs has increased, and longer, more stable operating periods have been achieved. This plant has logged over 11,000 hours of operation and processed more than 26,000 tons of coal.

Various coals have been processed, including high-caking Illinois #6 bituminous, washed and ROM sub-bituminous, and lignite. Several tests have proven char conversions to 90%, smooth operation, and improved equipment design. A generic commercial demonstration plant of 250 MM scfd has been designed by Procon, Inc. The pilot plant effort concluded in August 1980. The process is now ready for demonstration.

Development work has been done on three processes for producing hydrogen-rich gases for hydrogasification -steam-oxygen (selected), electrothermal, and steam-iron processes. The last two were evaluated in pilot studies as discussed below.

Description[2]

The following description pertains to the pilot plant operations and covers the two-stage hydrogasifier integrated with steam-oxygen gasification of the char produced in the hydrogasifier.

Figure 2B.9-1 shows the hydrogasifier vessel. The vessel has four gas-solids contacting stages, internally connected with transfer lines. The four sections, from top to bottom, are slurry drying, first stage hydrogasification, second stage hydrogasification, and steam-oxygen gasification.

The coal preparation system is designed to provide a coal feed having a maximum size of 14 mesh and a minimum of fines less than 100 mesh. Although agglomerating coals usually need pretreatment before they are fed into the hydrogasifier, nonagglomerating coals do not. An 8-ft-diameter fluidized bed pretreater is used in the pilot plant. Pretreatment involves mild air oxidation of the coal in a fluidized bed at atmospheric pressure and a temperature of about 750 °F. The reaction being exothermic, it is self-sustaining once the coal reaches this temperature. Excess heat is removed by steam generation.

Pretreated coal is slurried with light oil produced as a byproduct in the process. (See Figure 2B.9-2.) The slurry is then pumped to 1000 to 1500 psi and injected into the top of the hydrogasifier. In the fluidized bed slurry drying section, the oil is driven off as a vapor with the gases leaving the gasifier and subsequently recovered for reuse.

In hydrogasification, the carbon-hydrogen reaction is promoted to produce methane exothermally, and this heat is used to promote a steam-carbon reaction to produce additional hydrogen. In the HYGAS hydrogasifier, two stages are used to achieve the above reactions. Dry coal particles at about 600 °F from the slurry drying section flow by gravity through a dipleg into a lift pipe. The lift pipe serves as the first stage of hydrogasification. Here, a dilute phase contact occurs between the coal or pretreated char and the gases from the second stage. The gases are at approximately 1700 °F.

The gas lifts the solids to the gas-solid disengaging section. As the dried coal is lifted, it is flash heated in the presence of hydrogen and reacted at about 1200 ° to 1300 °F. Approximately 20% of the coal is thus converted to methane.[4]

The partially gasified char flows into the second stage hydrogasification section and is contacted with the H_2-rich gas from the steam-oxygen gasifier. This stage is a dense-phase, fluidized bed reactor operating at about 1700 °F. Here methane is formed simultaneously with the H_2 and CO produced by the steam-carbon reaction. Approximately 25% more of the coal is converted. Thus, 45 to 50% of the feed coal is converted by hydrogasification reactions. In this stage, with steam present, any increase in temperature drop slows the reaction.

The hot gases rise to the first stage and to the dryer, where much of the heat is used to vaporize and dry the feed coal. After leaving the hydrogasifier, the raw gas is quenched and scrubbed, shifted, treated for CO_2 and H_2S removal, and methanated to produce SNG. Oil condensed in the scrubber is recovered and recycled. Water blowdown from the scrubber is given further treatment.

The partially depleted coal char leaving the second hydrogasification stage is used to produce hydrogen in the steam-oxygen gasification section. The char is reacted at 1800 °F and 1000 psig. When steam contacts the char, the hydrogen produced reacts with carbon and CO to form methane. These exothermic reactions provide a portion of the heat required for the endothermic steam-carbon reaction. Therefore, the amount of carbon required to be burned to CO_2 is reduced, and consequently the O_2 consumption is reduced. This process, when compared with other oxygen-based designs, offers up to 75% reduction in O_2 requirements. The hydrogen, carbon monoxide, and methane produced here rise to the second stage hydrogasification area and provide the fluidization and gasification medium. Residual ash is sent to disposal.

Feed Requirements

Feed preparation includes drying and pulverizing to minus 14 mesh size. Coals of any rank, moisture content, or sulfur content can be processed. Agglomerating coals can be utilized with pretreatment.

Operating Conditions[2]

Based on oxygen gasification

	Test 74	Test 79	Test 85
Feed Coal	Illinois #6 Washed	Illinois #6 ROM	Western Kentucky Washed
Steady-state period, hr	40	178	147
Pressure, psig	549	511	521
SOG Temperature, °F	1724	1746	1766
Char Feed, lb/hr	3047	3669	3961
Steam/Char, lb/lb	1.75	1.36	1.26
Oxygen/Char, lb/lb	0.23	0.23	0.21
SOG Velocity, ft/sec	1.15	1.20	1.19
Char Conversion, %	78	76	75
Gas Make, lb/hr	3937	4891	5103

Gas Produced[2]

Composition at above conditions,

	Test 74	Test 79	Test 85
Mole%, CO	13.07	14.47	14.45
CO_2	29.72	28.44	27.86
H_2	32.56	32.48	32.75
CH_4	14.86	15.39	14.17
C_2H_6	0.28	0.36	0.21
N_2	8.01	6.32	9.73
H_2S	1.58	1.99	0.83
HHV, Btu/scf (calculated)	313	327	306

By-Products

Light oils, predominantly light aromatics of the benzene, toluene, xylene fraction, are expected from the process. Production of light oils is up to 5% of the coal feed.

Utility Requirements[5]

Based on oxygen gasification

	Montana Subbituminous	Pittsburgh Bituminous
O_2 lb/lb of coal	0.23	0.21
Steam, lb/lb of coal	0.96	1.00-1.25
Electric Power	Not Available	Not Available

Thermal Efficiency[5]

Based on the raw product gas from the HYGAS gasifier, and steam-oxygen gasification

	Montana Subbituminous	Pittsburgh Bituminous
Overall Thermal Efficiency	74	68

Capacity

Two (or three) vessels with a 24-ft I.D. (or 20-ft I.D.) and about 220 ft overall height will be required for a commercial plant producing 250 x 10^9 Btu/day.

Turndown capability = N/A.

Environmental Considerations

The ash would contain from 30 to 50% carbon (typically only 10% of the feed carbon) by weight and could be disposed of by landfill. The market value of the by-product oil would be significant. The light aromatics have a high octane value.

Remarks

The HYGAS process offers an integrated system for high pressure hydrogasification, with up to 65% of the methane in the SNG product formed in the gasifier. Long, stable operating periods have been achieved. A 25 tpd plant has logged more than 11,000 hours of operation and processed 26,000 tons of coal.

Alternate Char Gasification Processes

In the previous description of the HYGAS process, the steam-oxygen gasification method of producing hydrogen from char was considered. Two alternate methods, which were under development at IGT, are

1. Electrothermal Gasification
2. Steam-Iron Process

These are described below.

1. Electrothermal Gasification

State of Development: This was the first of the three hydrogen generation methods tested at the HYGAS pilot plant. Development work on electrothermal gasification was done in a 6-in-diameter high-pressure reactor rated at 300 kW input. The results from this formed the basis for an existing 2000 kW gasifier. The 2000 kW gasifier was completed in June 1972. During early 1973, the gasifier was checked out, and batch tests were made using both manual and computer control for the power input. The electrothermal gasification program was suspended at the end of March 1974 when the HYGAS reactor was converted to accept hydrogen from steam-oxygen gasification. Rapidly increasing power generation costs made the steam-oxygen gasification method economically more attractive, and work on the electrothermal process was suspended.[6]

Description: In this system, the heat required for the steam-carbon reaction is supplied by passing direct current through the high-resistance fluidized bed of char. (See Figure 2B.9-3.) The reaction takes place between 1800°

and 1900 °F and at 1000 to 1500 psig. The advantages offered by this process are as follows:

a. Oxygen is not required.
b. Gas compression is eliminated.
c. A concentrated reducing gas is available to the hydrogasifier, and this results in a rapid conversion to methane, thus reducing the residence time and size of the reactor. Lower amounts of CO_2 in the gas reduce the size of the CO_2 removal system.

2. Steam-Iron Process

State of Development: This process for hydrogen production has been used on a commercial basis in the past, and several fixed-bed, cyclic, steam-iron hdyrogen plants are operating today. In the late 1950s, the U.S. Bureau of Mines revived interest in the process and incorporated solids recirculation through reduction and oxidation zones, eliminating the cyclic operation.

Fuel Gas Associates initiated work at IGT in 1961, and IGT worked on various modified versions of the process until 1971. In May 1973, OCR awarded IGT a contract for construction and operation of a steam-iron facility. This pilot plant was adjacent to the HYGAS pilot plant in Chicago and was designed to operate independently of the HYGAS plant so that its feasibility could be proven separately. It was sized to produce about 1.2 MM scfd of hydrogen. Construction began in September 1974 and was completed in 1976. Operation was terminated in 1978 after feasibility was proven for 95% H_2 production (N_2-free), recirculation of iron solids, and low solids attrition.

Description: In this system, illustrated in Figure 2B.9-3, a stream of iron ore (Fe_3O_4 and FeO) is cyclically reduced with producer gas (H_2 + CO) and oxidized by decomposition of steam:

Reduction: $Fe_3O_4 + H_2 \longrightarrow 3FeO + H_2O$

$Fe_3O_4 + CO \longrightarrow 3FeO + CO_2$

$FeO + CO \longrightarrow Fe + CO_2$

Oxidation: $Fe + H_2O \longrightarrow FeO + H_2$

$3FeO + H_2O \longrightarrow Fe_3O_4 + H_2$

The resulting mixture of hydrogen and unreacted steam from the oxidizer is fed to the hydrogasifier. Residual char from the hydrogasifier is used to fuel a high-pressure producer, where the gas required for the reduction of iron ore is generated. The spent producer gas is used to drive expansion turbines to recover the potential mechanical energy.

The steam-iron pilot plant was designed to operate independently from the HYGAS pilot plant. It included a high-pressure char water slurry heater, a fluidized bed producer with a fluidized solids preheater, and a four-stage fluidized bed steam-iron reactor, with two stages for reduction and two for oxidation.

Char-water slurry (35 to 50% char) is heated in a direct fired heater to produce a char-steam mixture. The mixture is fed to a fluidized bed preheater, where the char is partially burned with air to raise the temperature to 1700° to 1750 °F. This step is necessary in the pilot plant to attain the typical char feed temperature expected in a fully integrated operation. The preheated char is then gasified with air in the producer at 1800° to 1850 °F, resulting in a high quality reducing gas.

The gas at 1800 °F enters the steam-iron reducer, where it is contacted counter-currently with the iron oxides and reduces them to FeO and to Fe. It then enters the second, upper stage, where the bulk of the conversion takes place by reducing Fe_3O_4 to FeO. Thus, high reducing gas conversion is attained, and sufficient metallic iron is produced to ensure the necessary hydrogen production.

The Fe and FeO flow by gravity to the two oxidizer stages. Steam fed to the lower oxidizer stage converts FeO to Fe_3O_4; in the upper oxidizer stage, Fe is converted to FeO. When hydrogen and the unreacted steam are intended as a feed to the HYGAS reactor, the production of Fe in the reducer will be controlled to produce an overall steam conversion of about 45% in the oxidizers.

References

1. DOE/FE-002/70/3, "Coal Gasification," Quarterly Report, July-September, 1979, Publ. July, 1980.

2. Tarman, P. B., "The HYGAS Process - Pipeline Gas From Coal," presented at the First International Gas Research Conference, Chicago, Illinois, June 3-12, 1980.

3. "Synthetic Fuels Data Handbook," published by Cameron Engineers, Denver, Colorado, 1975.

4. Schora, F. C., Jr., et al., "The Hygas Process," presented at the 12th World Gas Conference and Exhibition, Nice, France, June 5-9, 1973.

5. "Study of Conversion of Coal to Hydrogen, Methane, and Liquid Fuels," IGT Study for NASA. Final Report Spring, 1976.

6. Howard-Smith I., and Werner, G. J., "Coal Conversion Technology: A Review," under the auspices of Millmerran Coal Pty. Ltd., Brisbane, Australia, May, 1975.

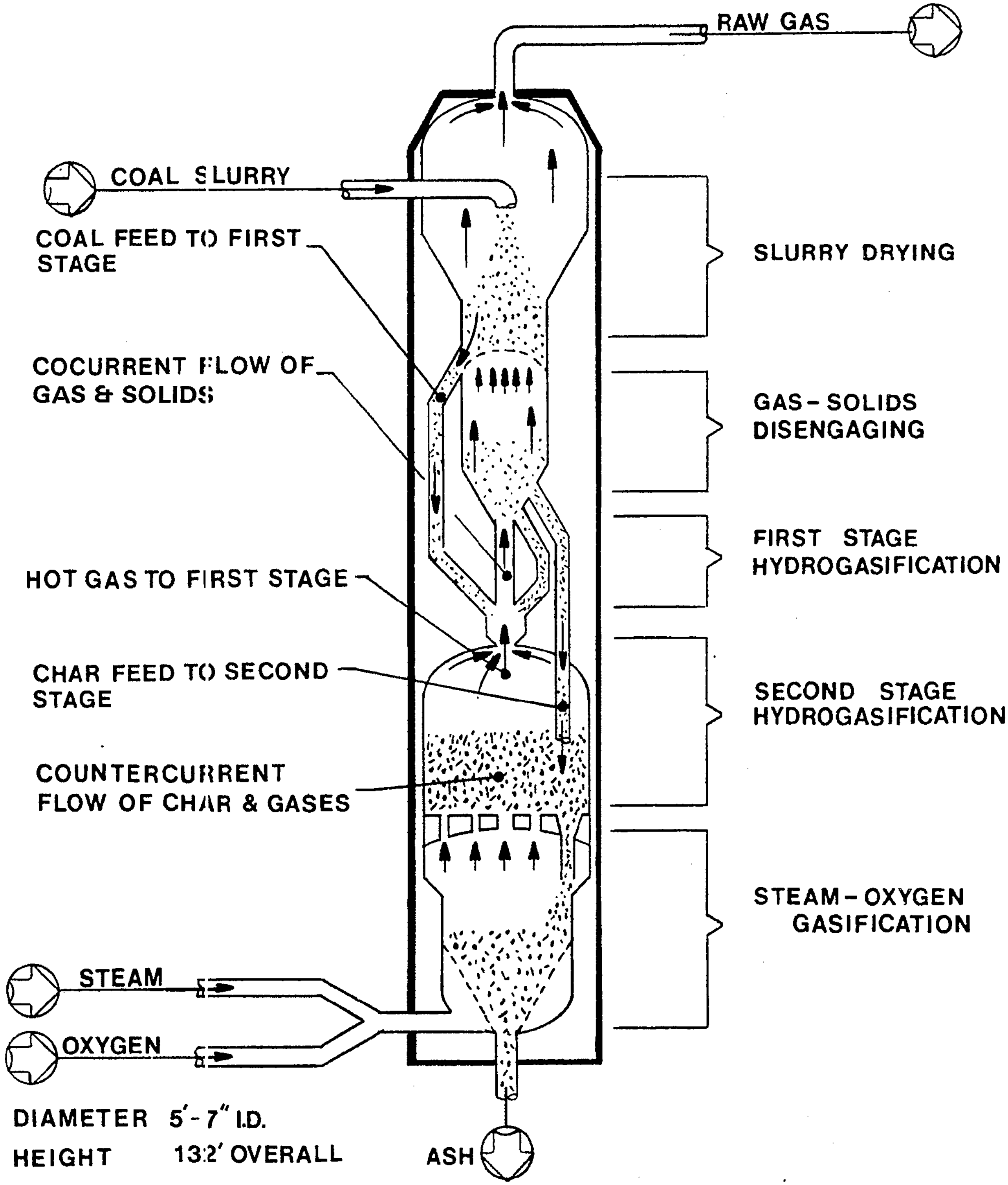


Figure 2B.9-1 Hygas Gasifier With Steam-Oxygen Gasification.