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LOW-BTU COAL GASIFICATION IN THE UNITED STATES: COMPANY TOPICAL

By
L. P. Boesch
B. G. Hylton
C. S. Bhatt

July 1983

Work Performed Under Contract No.: DE-AC01-78ET10159

For
U. S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
UOP, Inc.
Des Plaines, Illinois

System Development Corporation
Santa Monica, California

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* These drawings are from a Black, Sivalls & Bryson, Inc., Houston, TX brochure.

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SECTION 1 - INTRODUCTION

Coal gasification became commercially useful in the United States in 1806 when Baltimore, Maryland lit the first gas street light. Through the years coal gasification became increasingly popular until an estimated 11,000 to 12,000 coal gasifiers were operational in the U.S. during the late 1920s. By the late 1940s, however, less than a score of operational gasifiers were in use outside the steel industry. Natural gas, cheap and clean, all but replaced low Btu gas from coal gasifiers.

Today there are 31 U.S. gasifiers in operable condition, and 5 more are in place and could be made operable rather easily. There are a few more disassembled gasifiers lying in storage or on scrap piles. The location of gasifiers is listed in Table 1.1. Appendices A through R detail the projects presented in Table 1.1.

In low Btu Gasification, the carbon content of coal is converted by gasifying agents (air and steam) to gaseous products. About half of the gaseous output is nitrogen (from the air) and nearly half of the remainder is highly toxic carbon monoxide. The output gas has a heating value that depends to some extent on the coal used but is never more than 250 Btu per standard cubic foot (scf) and usually less than 200. Because of its high CO content, the gas is suitable only for industrial uses, where proper CO monitoring can be maintained, and then only in applications in which the relatively low heat content is not a problem. As Table 1.1 shows, present industrial uses are principally in brick and lime kilns and as a boiler fuel.

DOE, along with the U.S. Bureau of Mines (USBM) of the Department of the Interior, and non-government cooperators, has supported a group called the Mining and Industrial Fuel Gas Group (MIFGA). This group operates a gasifier, leased from Hanna Mining for $1 per year, at the USBM Twin City Research Center (TCRC) in Minneapolis, Minnesota. The TCRC is a USBM metallurgical research center. The MIFGA group, originally known as the Pellet Energy Group (PEG), was formed in

TABLE 1.1

Commercially Operable Low Btu Gasifiers in the U.S. in 1982 (Exclusive of the Steel Industry)

Operator/Owner	Location	Gasifier	Current Status: Operable	Inoperable	Disassembled	Input Fuel	User of Output
Universary of Minnesota	Duluth, MN	10-foot FW-Stoic	1			Subbituminous Coals and Lignites	Gas and Oil for Boiler
CAN DO, Inc.	Hazelton, PA	10-foot Wellman-Galusha	2			Anthracite Coal	Industrial Park Pipeline
U.S. Bureau of Mines Twin Cities Research Center (Mining and Industrial Fuel Gas Group -- MIFGA)/ Hanna Mining Company	Minneapolis, MN	6.5-foot Wellman-Galusha	1			Subbituminous and Bituminous Coals, Briquettes and Lignites	Iron Pellet Kiln, Boiler
Pike County Kentucky	Douglas Site, Pike County, KY	6.5-foot Wellman-Galusha		2 (new)		Bituminous Coal	Boiler
Caterpiller Tractor Company	York, PA	10-foot Wellman-Incandescent	2			Bituminous Coal	Gas for Metal Furnance, Oil for Boiler
Chemical Exchange Industries (of Houston, TX	St. Genevieve, MO (Mississippi Lime Company)	10-foot Wellman-Galusha		1		WV Bituminous Coal	Lime Kilns
Glen-Gery Corporation (of Reading, PA)	Shoemakersville, PA, Watsontown PA, Wyomissing, PA, York, PA	10-foot Wellman-Galusha	2 2 1 2			Anthracite Coal	Brick Kilns
Glen-Gery Corporation	Allwine Brick Company, New Oxford, PA	10-foot Wellman-Galusha			1		--
U.S. Army, Holston Army Ammunition Plant	Kingsport, TN	10-foot Wilputte (Chapman)	12			Bituminous Coal	Burners for Acetic Anhydride Mfg.
Howmet Aluminum Company	Lancaster, PA	10-foot Wellman-Galusha	1			Anthracite	Metal Heating
National Lime and Stone Company, (of Findley, OH)	Carey, OH	10-foot Wellman-Galusha	2				Shaft Lime Kiln
Olin Corporation	Ashtubula, OH	6-foot Wellman-Galusha	1			Calcined Petroleum Coke	Phosaene Production
Riley Stoker Corporation	Worchester, PA	10-foot Riley-Morgan	1			All Ranks of Coal	Boiler, Kiln
Webster Brick Company (of Roanoke, VA	Hazelton Brick Company, Hazelton, PA	10-foot Wellman-Galusha	1	2		Anthracite	Brick Kiln
Totals			31	5	1		

1975 in cooperation with the U.S. Bureau of Mines and later (1977) with the Energy Research and Development Administration (ERDA) (now DOE), to find alternate fuels to natural gas to indurate (heat and harden) iron ore pellets. Rapidly increasing gas prices and interrupted gas deliveries prompted seeking alternative fuels. Low-Btu gas from a coal gasifier was selected as the best alternative fuel to natural gas for pelletizing rotary kilns, and the only alternative for pelletizing shaft kilns. A full description of MIFGA operations can be found in Appendix C.

Late in 1976 ERDA initiated the Gasifiers in Industry Program to expand the data base on small gasifiers and to develop and demonstrate low Btu gasification technology in an economically, technically feasible and environmentally acceptable manner. When DOE replaced ERDA, the program was continued.

The main objective of the program was to encourage industry to build small gasifiers to generate low Btu gas (LBG) as a replacement for natural gas in their processes. As an inducement, DOE would pay half the cost of construction.

A second objective was to assist in design and development of advanced state-of-the-art prototype coal gasification systems by collecting data on component and operating parameters. A third was to obtain economic and environmental data.

The Gasifiers in Industry Program consisted of 7 projects with gasifiers sized to run at rates of 24 to 72 tons per day of coal. The contractors, the gasifiers, and the specific gas end uses for each project included:

- CAN DO, Inc., using two Wellman-Galusha gasifiers to provide heating and cooling to an industrial park. (Continuing)

- Acurex-Aerotherm/Glen-Gery Corporation using a highly instrumented Wellman-Galusha gasifier to fire a tunnel brick kiln. (Data collection from instruments completed successfully)

- The University of Minnesota (Duluth) using a Foster Wheeler-Stoic gasifier to provide fuel gas and liquids to fire the University's boilers. (Successful completion - September 1982)

- Pike County, Kentucky, using two Wellman-Galusha gasifiers to provide community heating/cooling and industrial fuel gas. (Cancelled, but gasification facility partially constructed)

- General Refractories using one Woodall-Duckham two-stage gasifier to provide heat for brick kilns and dryers. (Cancelled)

- Irvin Industries using two single-stage Wellman-Galusha gasifiers to provide space heating and process steam for an industrial park. (Cancelled)

- Land O'Lakes using a two-stage Wellman-Incandescent gasifier for food (wye) drying. (Cancelled)

SECTION 2 -- STATE-OF-THE-ART LOW BTU GASIFICATION TECHNOLOGY IN THE U.S.

2.1 LOW BTU GASIFICATION TECHNOLOGY IN THE U.S.

Low Btu gas technology, proven in industrial operation in the U.S., is presently demonstrated by the Wellman-Galusha, Wilputte, Stoic, Riley-Morgan, and Wellman-Incandescent gasifiers. All are described in this section.

Low Btu gasifiers are of two types: single-stage and two-stage fixed bed.

Single-stage fixed bed gasifiers have a countercurrent flow of coal and gas. There are many variations in design, but in general principles are the same. In a single-stage gasifier, product gas exits from the top of the gasifier, A single-stage gasifier is simple in design, hence the construction cost is lower than that of a two-stage gasifier. However, because the gasifier is not pressurized, its product gas must often be compressed before use.

Caking coals can be gasified in a single-stage gasifier equipped with an agitator, but has only been proven in experimental gasifiers. On the other hand, a single-stage gasifier cannot normally tolerate more than 15% fines in the sized coal feed. Bituminous coal is difficult to use in a single-stage gasifier because heavy maintenance is required to keep the system clean. Coal having low volatility and friability is preferred for use in a single-stage gasifier to provide uniform bed permeability.

Like single-stage gasifiers, two-stage fixed bed gasifiers are also basically countercurrent reactors. A two-stage gasifier has two gas outlets, one at the top and another at the bottom of the gasifier. A portion of the gas produced in the combustion zone at the bottom is removed before it contacts the fresh coal. The remaining portion of gas passes up through the slowly descending coal and heats it in the upperstage (devolatilization zone) of the gasifier very slowly. This slow devolatilization process yields top gas with low-viscosity tar in the form of a fine mist. This tar is removed from the gas stream by an electrostatic precipitator and/or a cyclone. The bottom gas is free of any tar or pitch. The two gas streams are combined after tar is removed from the top gas.

The major advantages of the two-stage gasifier over the single-stage is cleaner operation. There is no pitch buildup, and no dirty burnout is required. Good quality, lower viscosity tar is produced with much less particulate content and low moisture. Tar is easily collected in fluid form from the electrostatic precipitator. Also, cold gas is produced more efficiently than in a single-stage gasifier.

Two-stage gasifiers cannot handle caking coals and very little fines content can be tolerated. Low caking, closely sized coal must be used.

Caterpillar Tractor Company, York, PA has recently installed a Wellman-Incandescent two-stage gasifier in York, PA. The University of Minnesota (Duluth Campus), has installed an FW-Stoic two-stage gasifier for campus building heating and cooling. Both will be used to test the suitability of various U.S. coals for gasification. A variety of coals have been tried in both installations.

LBG from single-stage or two-stage gasifiers can be made in three different modes of operation: (1) as a hot raw gas, (2) as hot detarred, and (3) as a cooled clean gas which is detarred and desulphurized. Figures 2.1 and 2.2 describe the process schematic of hot raw gas operation for single-stage and two-stage gasifiers respectively. In a single-stage set-up, the entire product gas flow goes through a cyclone for dust and particulate removal before burning. In a two-stage gasifier, the top gas goes through a tar collector cyclone and RSP and the bottom gas passes through a dust collector cyclone before the two gas streams are combined for final use. The process thermal efficiency is the highest in this mode because the product gas sensible heat is not lost. This mode can be used only when tar will not cause problems for any downstream process or equipment.

Hot detarred gas operation is pictured in Figures 2.3 and 2.4 for single-stage and two-stage gasifiers respectively. When product gas delivery lines are

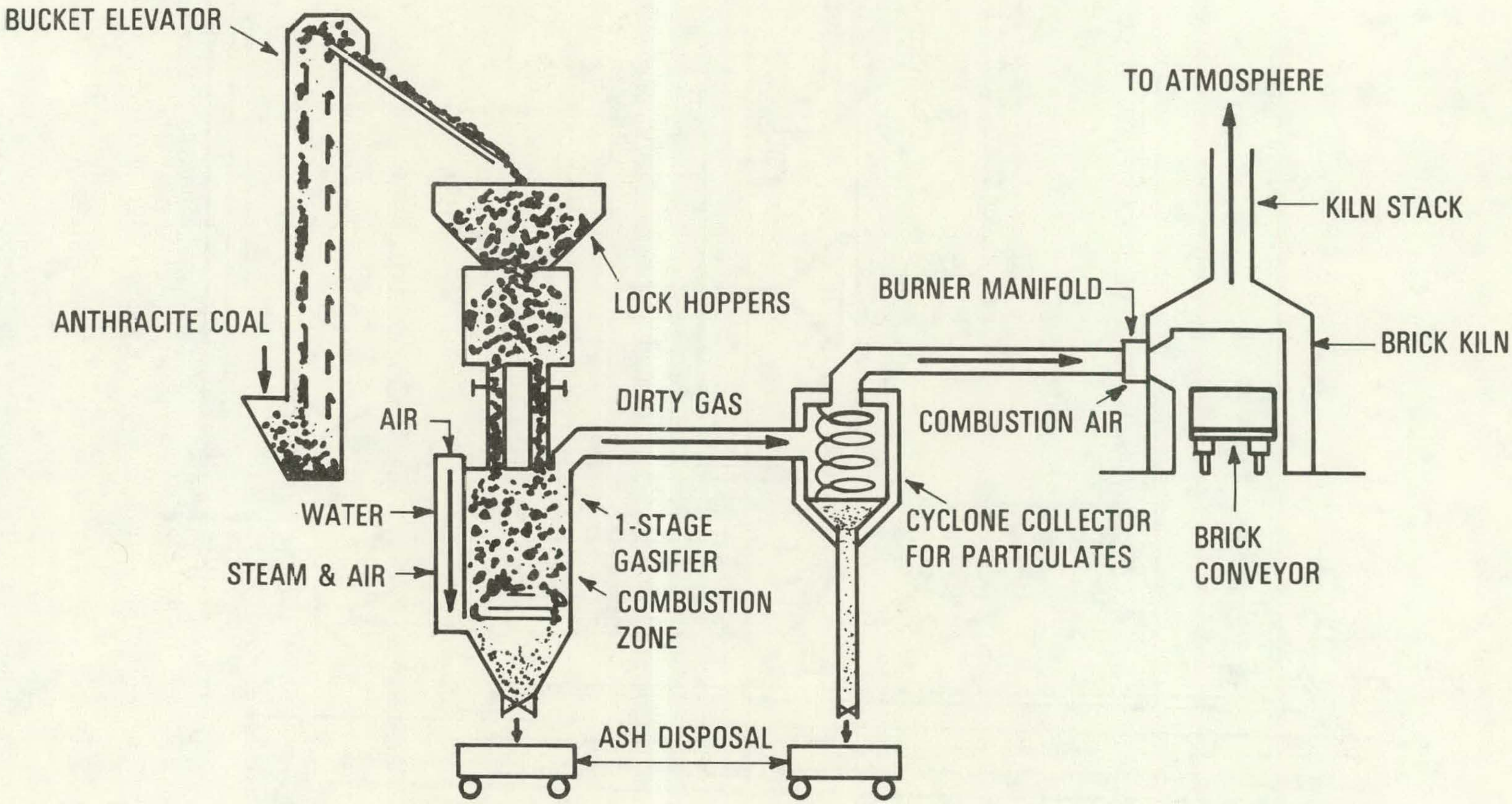

Figure 2.1: Single-Stage Gasifier Configured to Provide Hot Raw-Gas

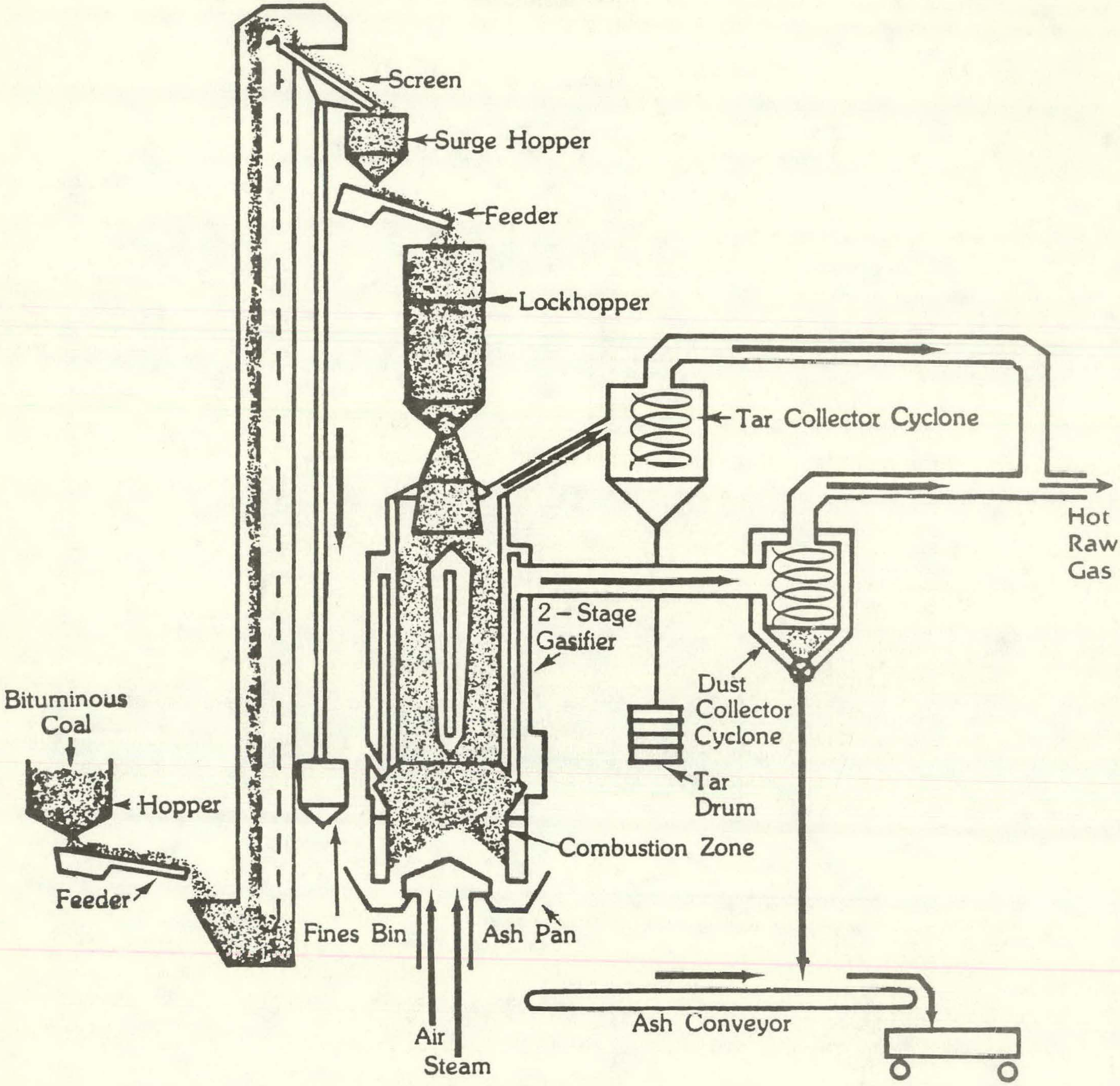

Figure 2.2: Two-Stage Gasifier Configured to Provide Hot Raw Gas

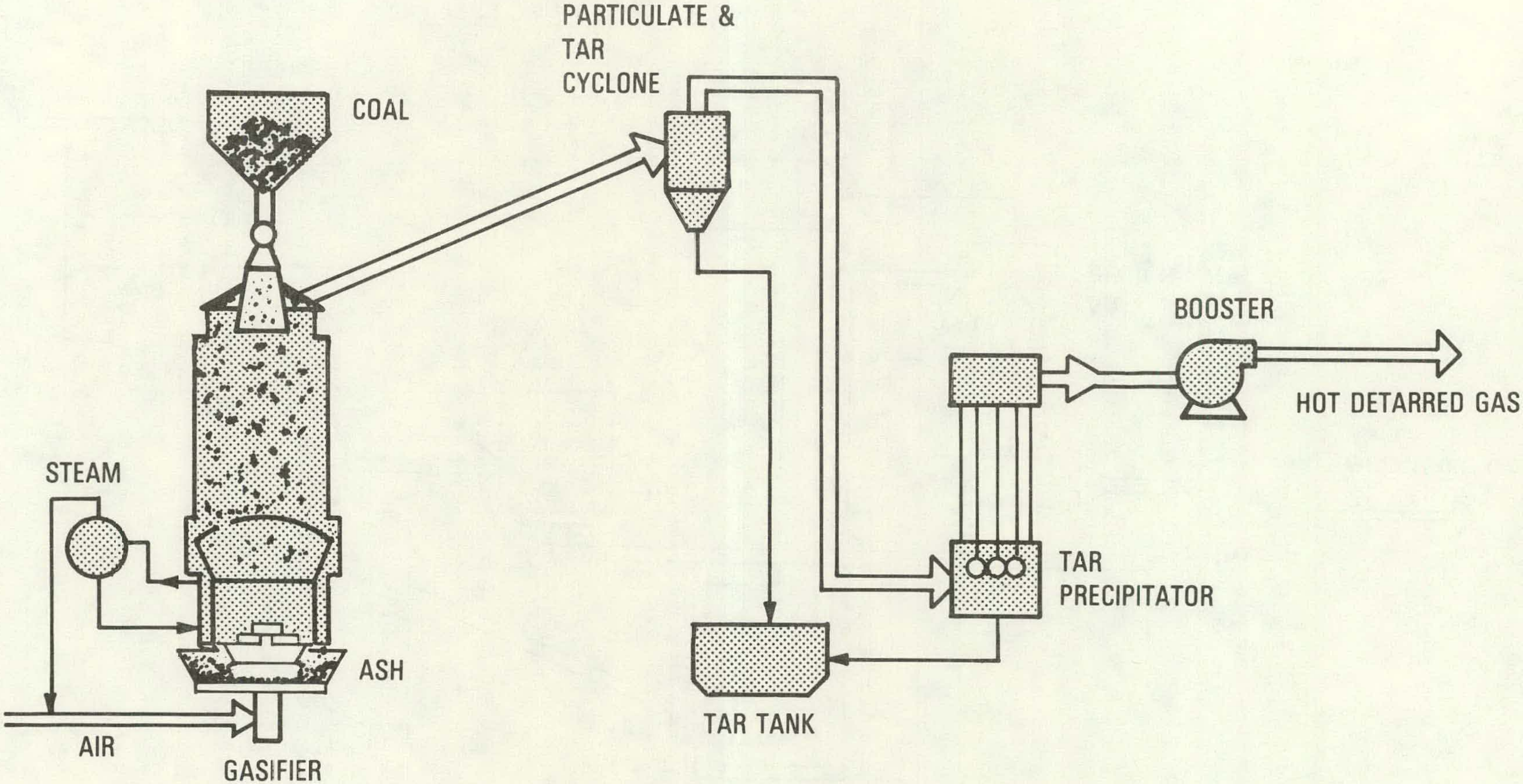

Figure 2.3: Single-Stage Gasifier Configured to Produce Hot Detarred Gas

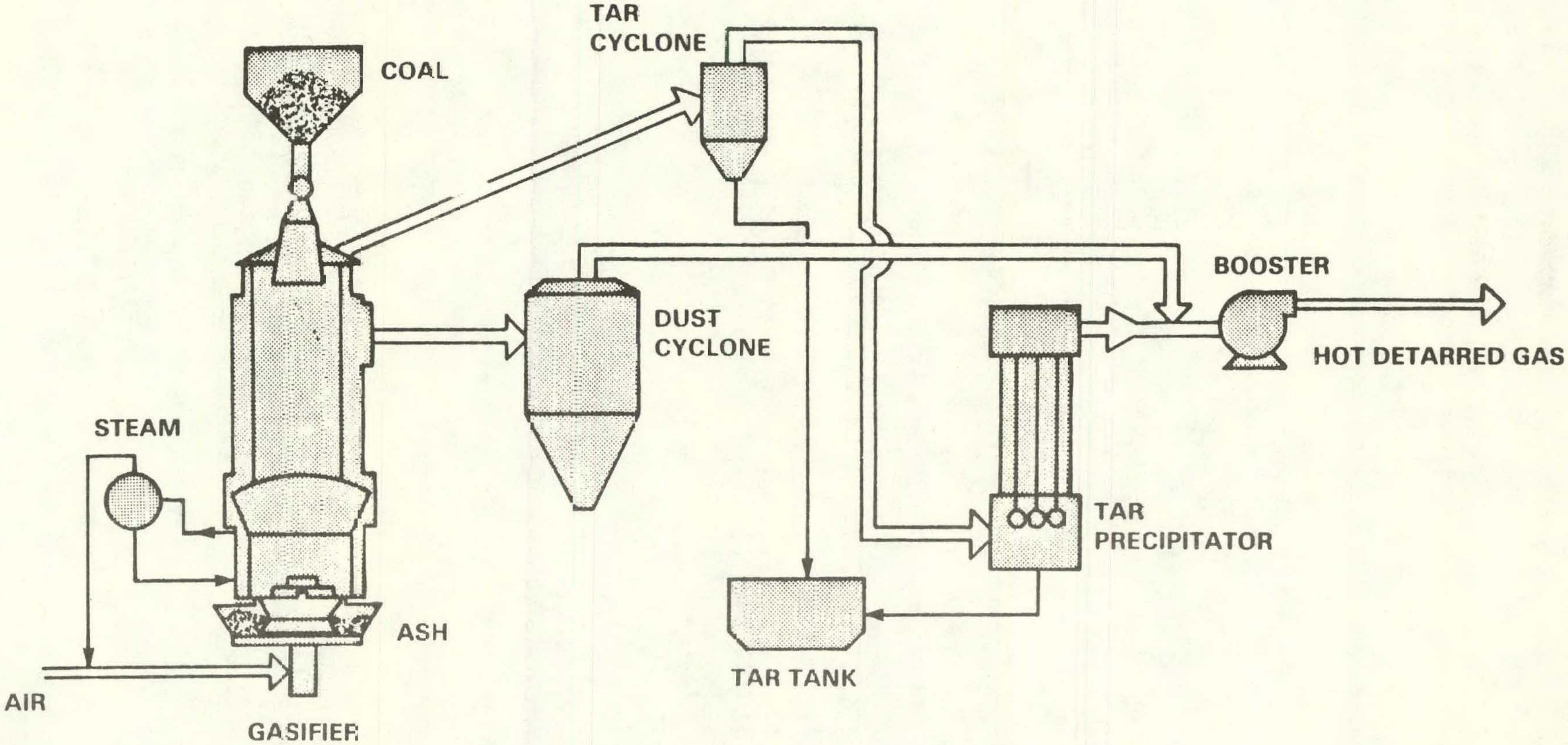

Figure 2.4: Two-Stage Gasifier Configured to Produce Hot Detarred Gas

long, tar condensation can plug the lines. Also, for some burner designs, tar in the product gas cannot be tolerated. For these cases, product gas must be tar free. In single-stage operation, product gas first flows through a cyclone that removes dust and the largest tar droplets. A tar precipitator (electrostatic detarrer) that follows the cyclone removes all the tar mist. Since the gas temperature in the detarrer is above the dew point, the condensed tar is virtually moisture free. In two-stage operation, only the upper stage gas flows through a tar cyclone and then a tar precipitator. The tar-free upper stage gas is then mixed with dust-free bottom gas for end use as hot detarred gas. Product gas thermal efficiency is above 80% because the gas sensible heat is maintained. Desulphurization may be required.

A fuel gas burner that requires fine control, acid gas removal process requirements, and/or environmental restriction may make a cold clean fuel gas necessary. Figures 2.5 and 2.6 show the cold clean gas schemes for single-stage and two-stage gasifiers respectively.

In single-stage operation, product gas flows through a cyclone, a spray tower, and an electrostatic precipitator to remove dust, tar/oil, and tar mist respectively. Cold detarred gas then flows through an acid gas removal unit. The exit gas from this final cleanup unit is a cold clean gas. In a two-stage gasifier, top gas flows through a tar cyclone and a tar precipitator to remove tar and is mixed with lower offtake gas that has been washed in a wash column. The mixed gas stream then goes through an oil removal unit and is then further cleaned of acid gases to meet sulfur content specification. Product gas thermal efficiency is the lowest of the three modes because gas sensible heat is lost in cooling and in tar and oil precipitation.

Gas condensate from spray tower and wash columns and wastewater from other process units contain organic wastes, such as phenols, suspended tar and oil, and dissolved gases such as H_2S and NH_3. These impurities are removed by proven wastewater treatment processes so that discharge water can be reused or discarded. These wastewater and gas cleanup processes are described in Section 3.

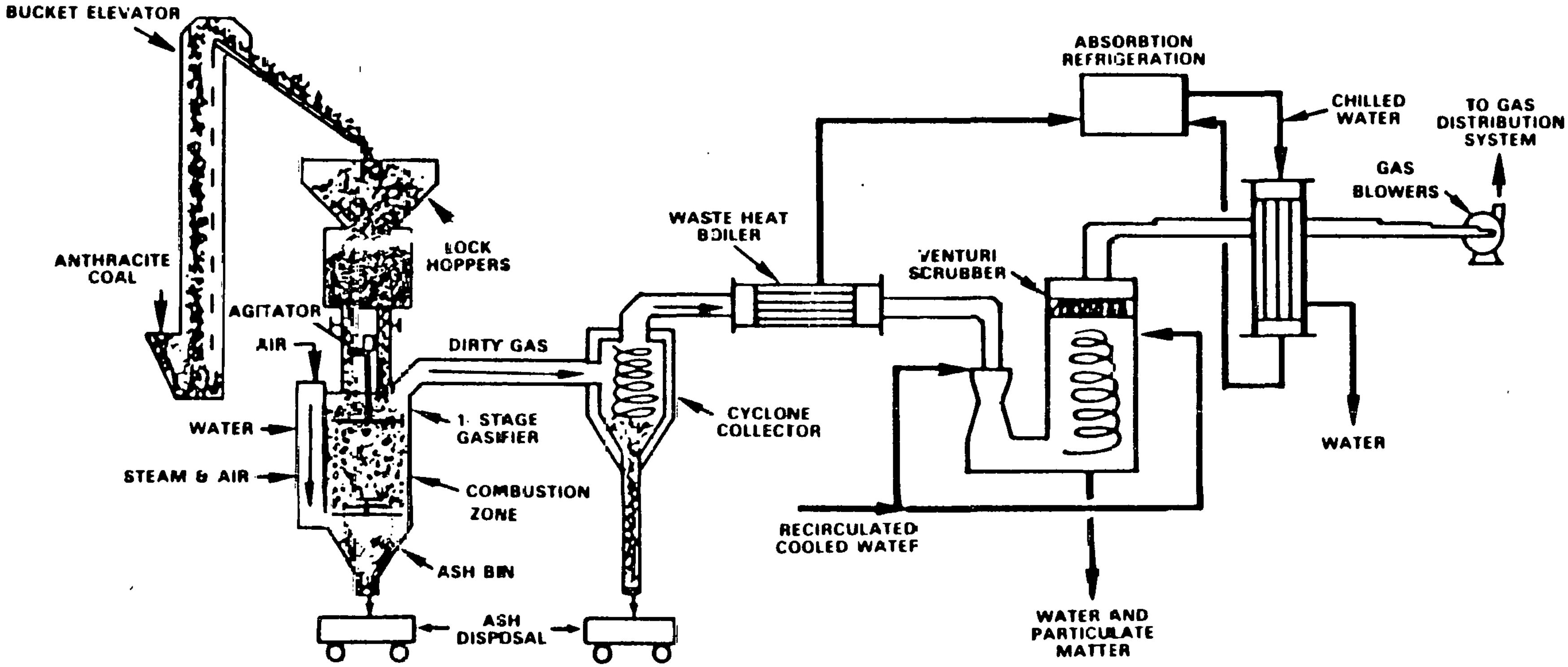

Figure 2.5: Single-Stage Gasifier Configured to Provide Cold Clean Gas

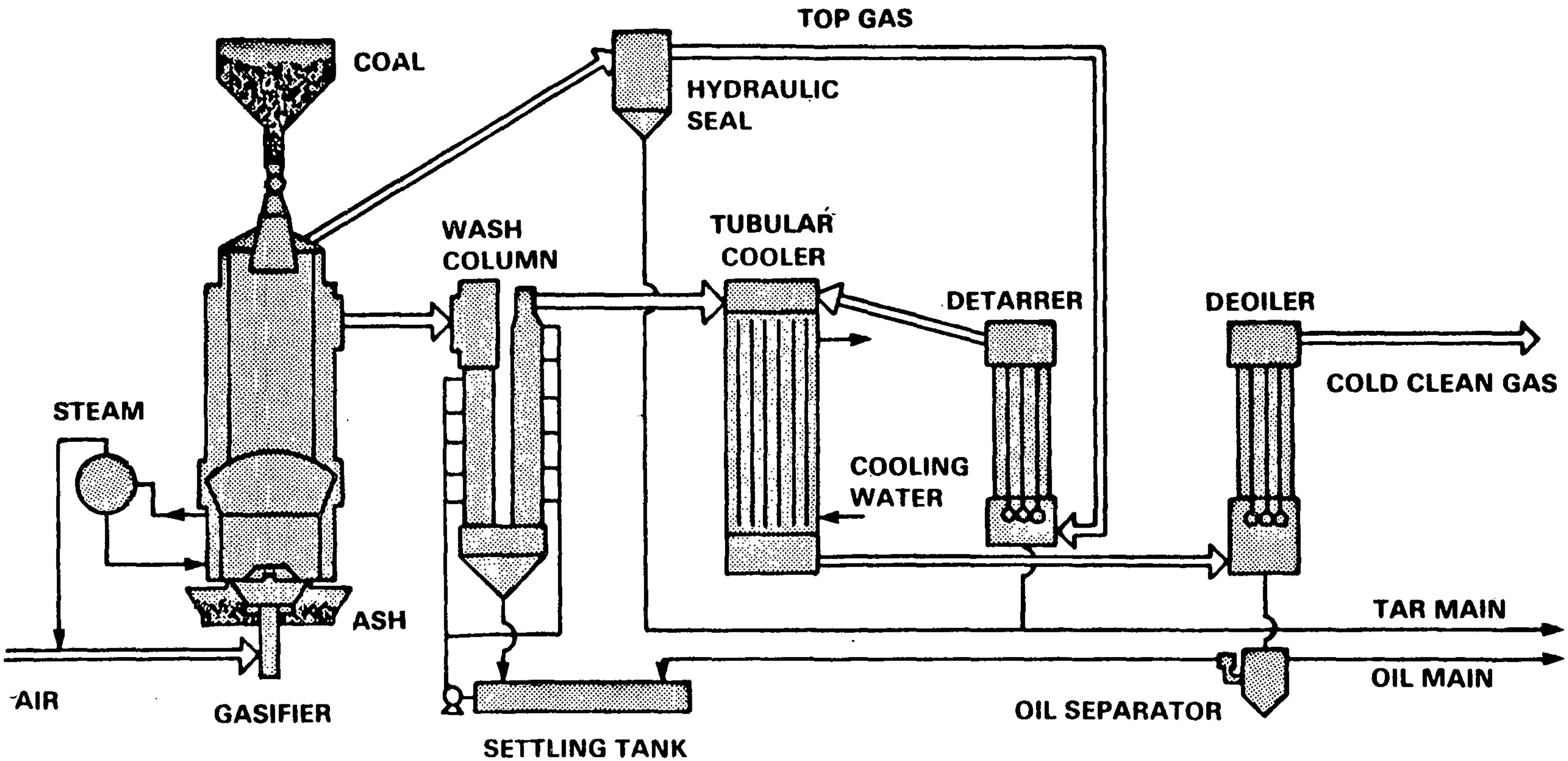

Figure 2.6: Two-Stage Gasifier Configured to Produce Cold Clean Gas

2.2 SINGLE-STAGE, FIXED-BED LOW BTU GASIFIERS IN THE U.S.

There are three types of full-scale single-stage, fixed-bed, low-Btu gasifiers operating in the U.S. These are the Riley-Morgan, Wellman-Galusha, and Wilputte gasifiers.

These three gasifiers are described in the "Handbook of Gasifiers and Gas Treatment Systems," September 1982, UOP/SDC, Report No. TR-82/008-010, produced for DOE at Germantown, Maryland, under contract DE-AC01-78ET10159. These three single-stage gasifiers are presented in the Handbook as follows.

2.2.1 Riley-Morgan Gasifier

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 2.7 and 2.8, 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.

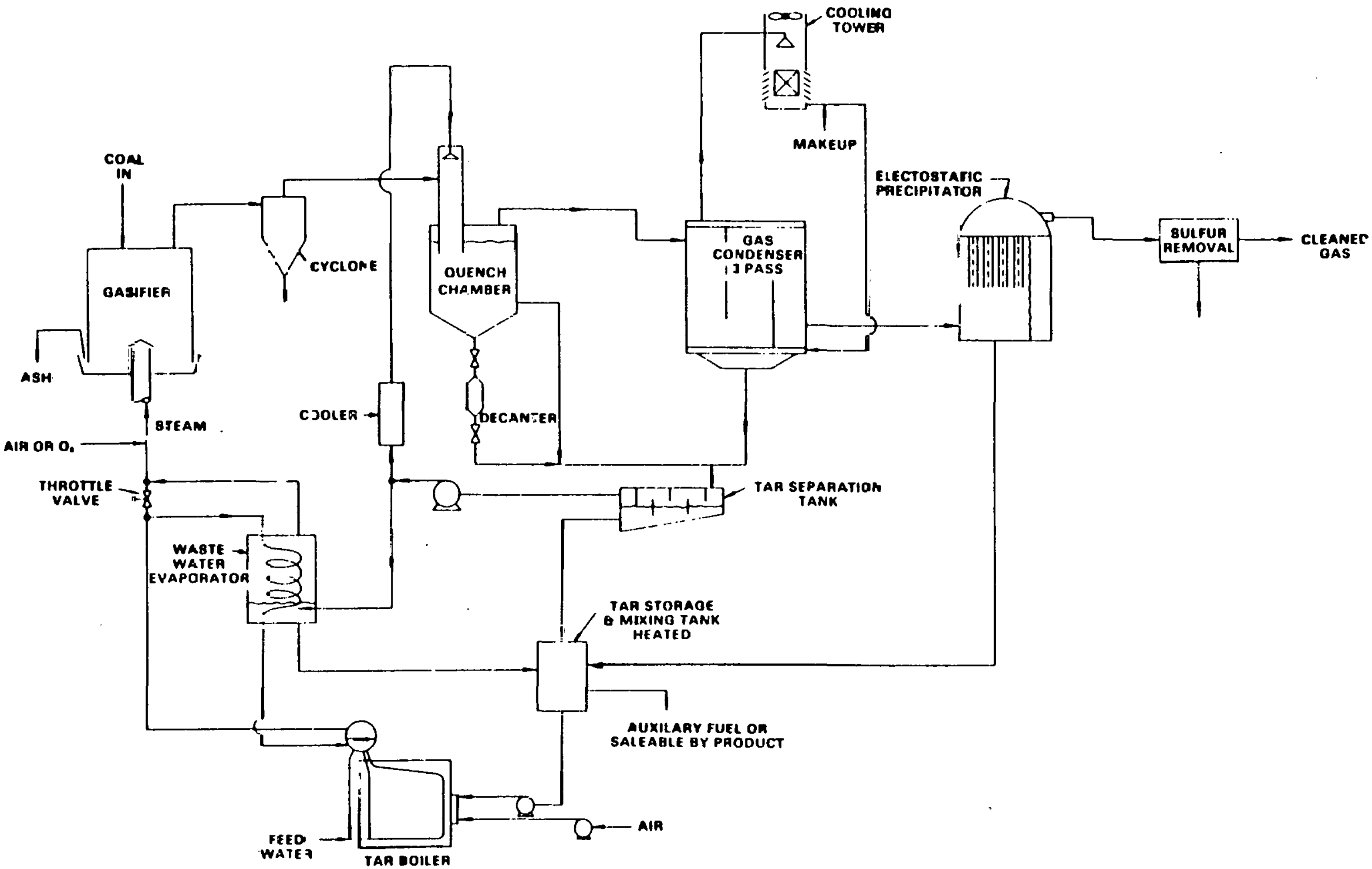

Figure 2.7: Riley-Morgan Gasification System

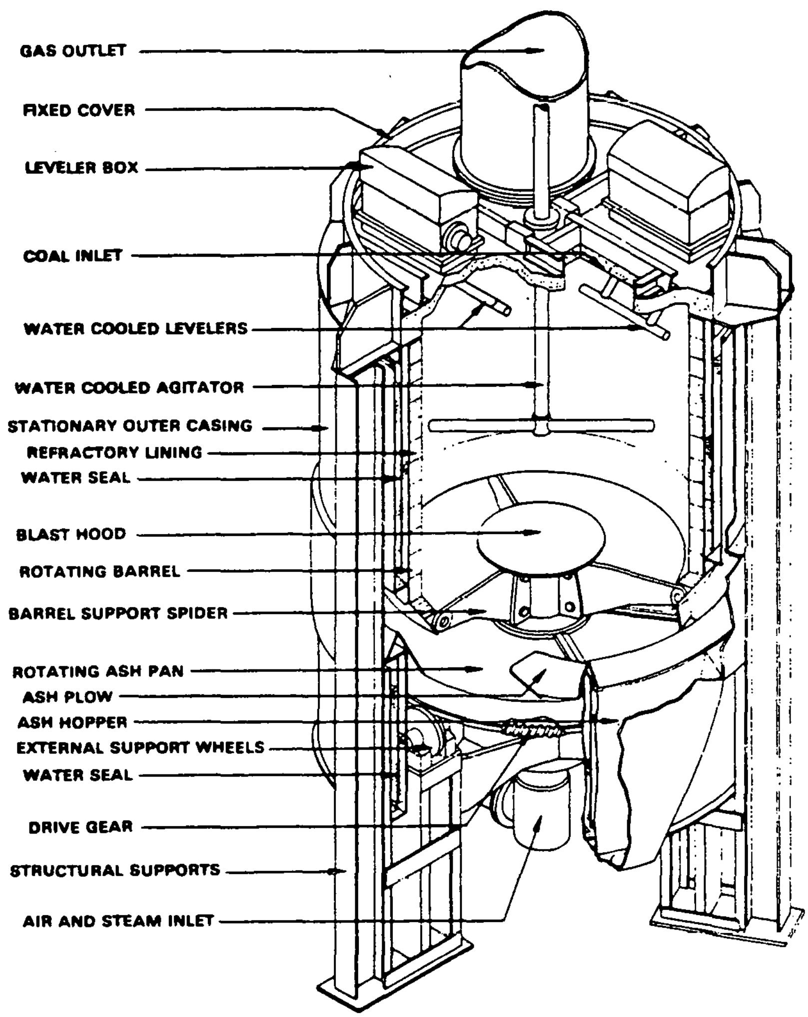

Figure 2.8: Riley-Morgan Gasifier

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.

- Uniform coal distribution over the top of the bed must be maintained, including continuous feed operation, since coals of different sizes will segregate

References for Riley-Morgan Gasifier

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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.

2.2.2 Wellman-Galusha Gasifier

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 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 1,2

There are two types of Wellman-Galusha gasifiers: the standard type and the agitated type. The rated capacity of an agitated gasifier is reportedly 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 2.9, 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 retractory 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-stream 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 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.

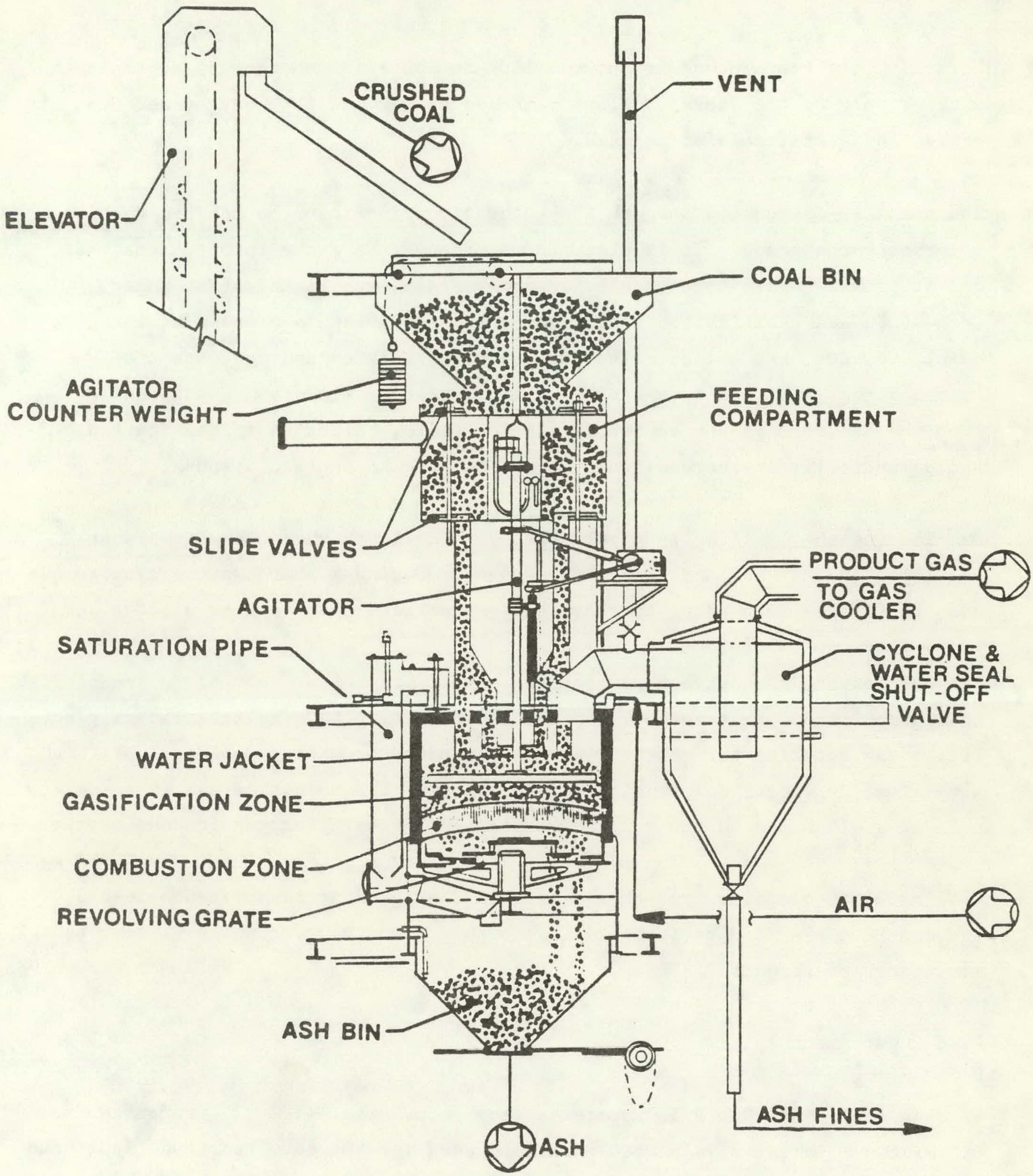

Figure 2.9: Wellman-Galusha Agitated Gasifier

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 recirculate . 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. The apparent limit on the free swelling index of coals that can be gasified in the agitated gasifier is about 3 to 5 in the commercial models; however, highly caking coals have been used in experimental models.

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-gasbl 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 for Wellman-Galusha Gasifier

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.

2.2.3 Wilputte Gasifier

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 2.10) 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

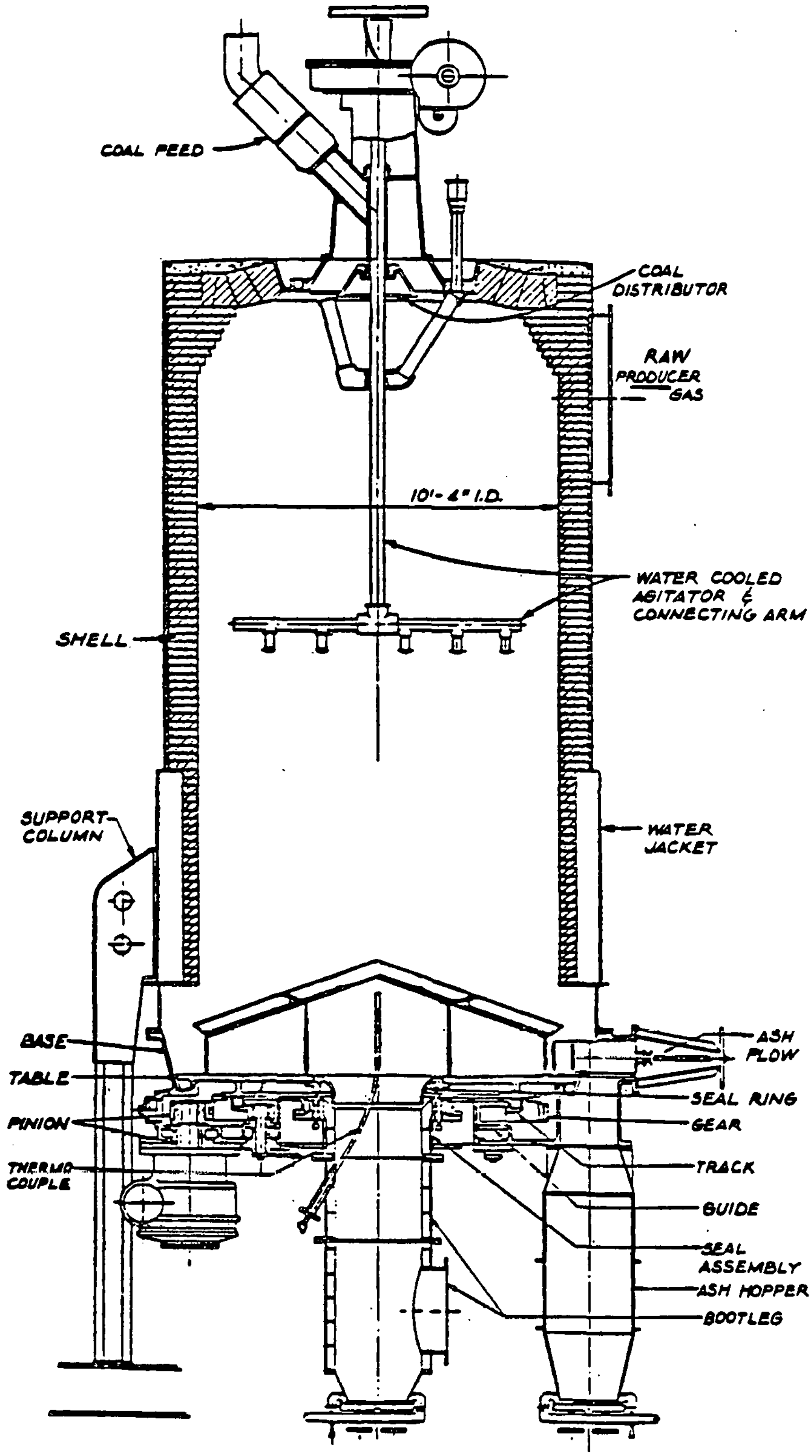

Figure 2.10: Wilputte Coal Gasifier

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:

$$C + H_2O \longrightarrow CO + H_2 - 70{,}900 \text{ Btu} \qquad (1)$$

$$2C + O_2 \longrightarrow 2CO + 104{,}000 \text{ Btu} \qquad (2)$$

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, antracite, bituminous coal, and subbituminous 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 exits 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 is as follows:

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

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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% 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 for Wilputte Gasifier

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.

2.3 TWO-STAGE, FIXED-BED, LOW BTU GASIFIERS IN THE U.S.

There are two types of full-scale two-stage, fixed-bed gasifiers operating in the U.S. in the 1980's. These are the Foster Wheeler-Stoic and Wellman Incandescent gasifier. A third two-stage, fixed-bed gasifier, the Woodall-Duckham Gas Integrale gasifier is also included here because it was selected for one of the DOE Gasifier In Industry projects--the particular project was withdrawn before construction commenced.

These three two-stage, fixed-bed gasifiers have been described in the "Handbook of Gasifiers and Gas Treatment Systems," as follows.

2.3.1 Stoic Gasifier

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 2.11 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

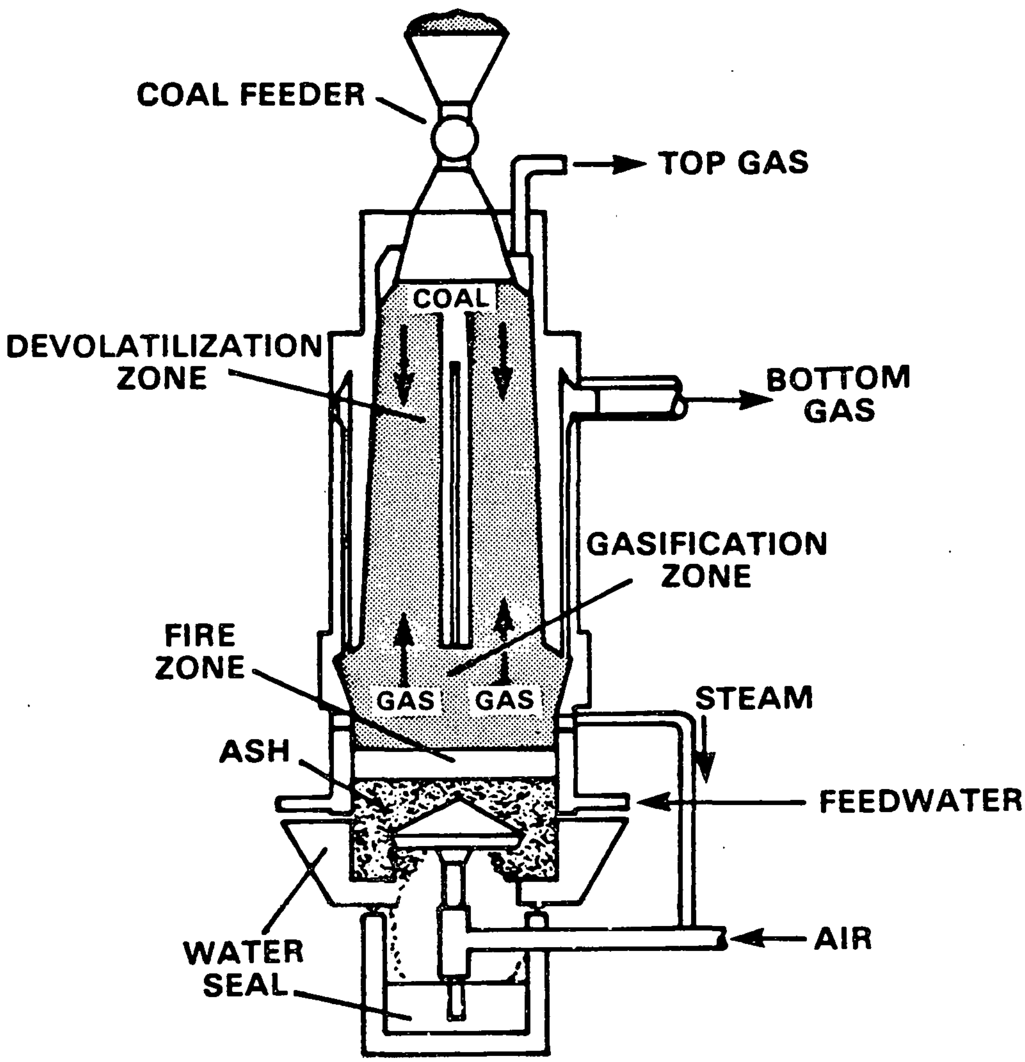


Figure 2.11: Stoic Gasifier

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 FW-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 for Stoic Gasifier

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.

2.3.2 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 2.12) 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.

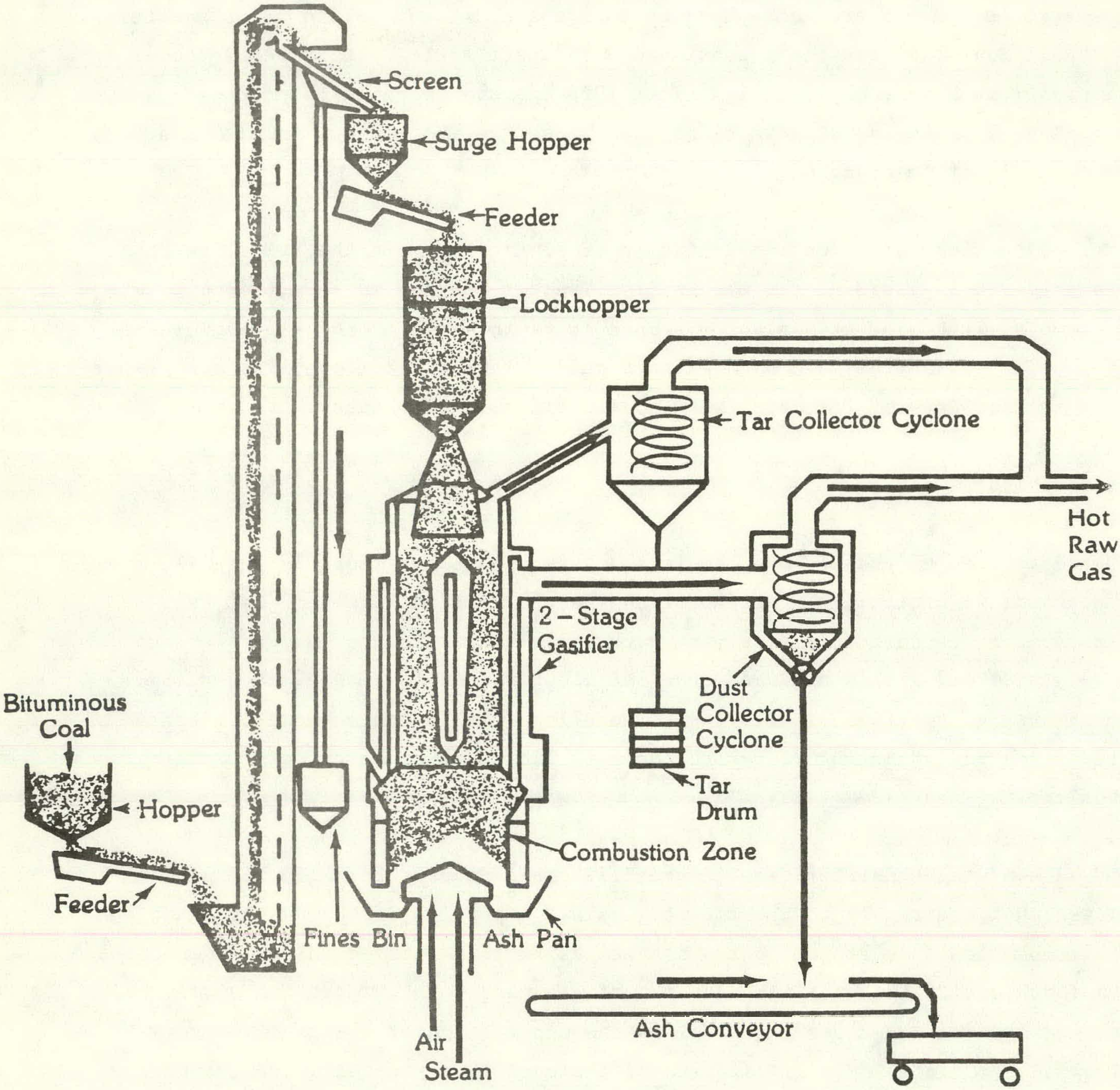


Figure 2.12: Wellman Incandescent Two-Stage Gasifier Configured To Provide Hot Raw Gas

As seen in Figure 2.12, coal is fed to the gasifier via gravity through lock-hoppers 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 2.1 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 2.12, 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 2.13, 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 2.14, 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

Table 2.1 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

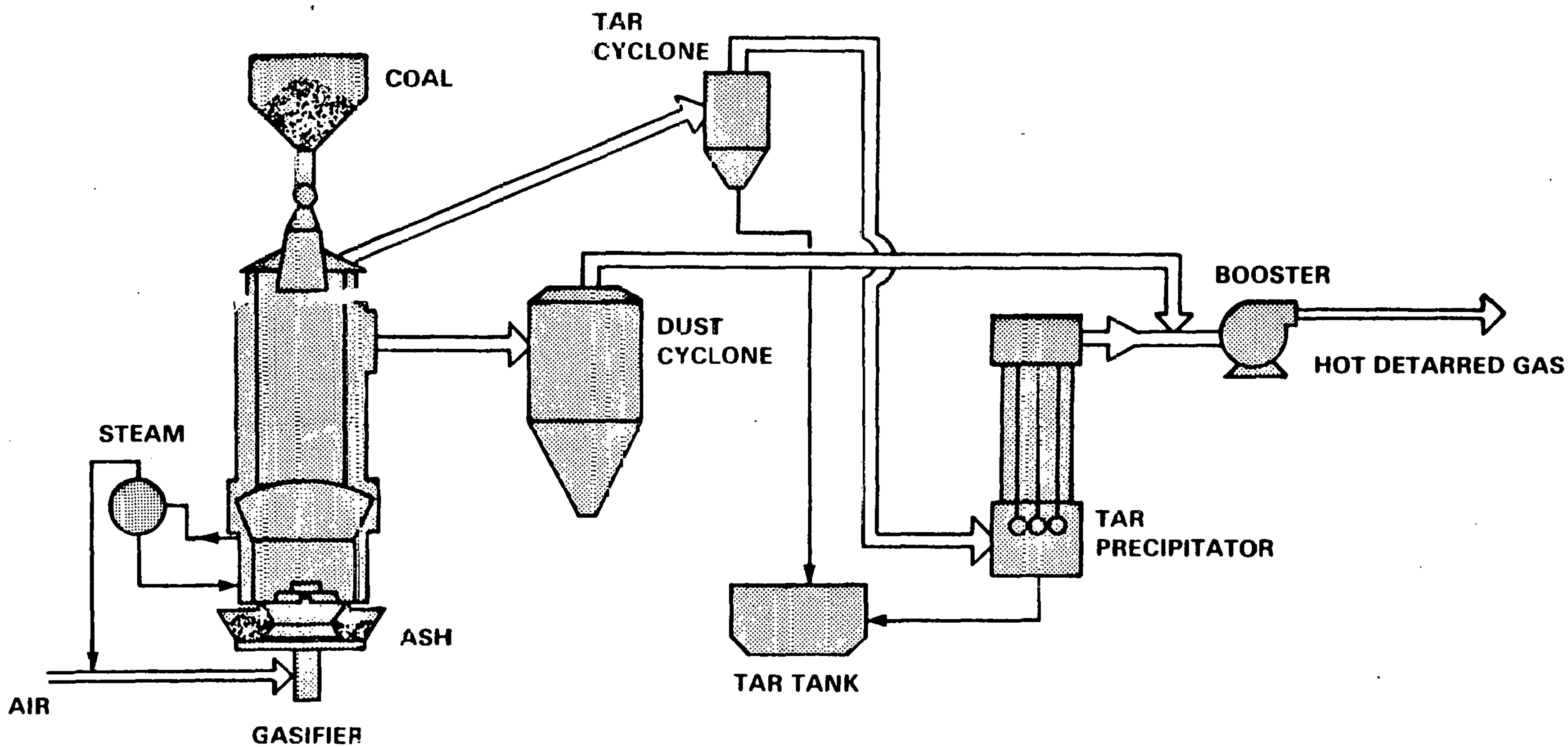


Figure 2.13: Two-Stage Wellman Incandescent Gasifier Configured To Produce Hot Detarred Gas

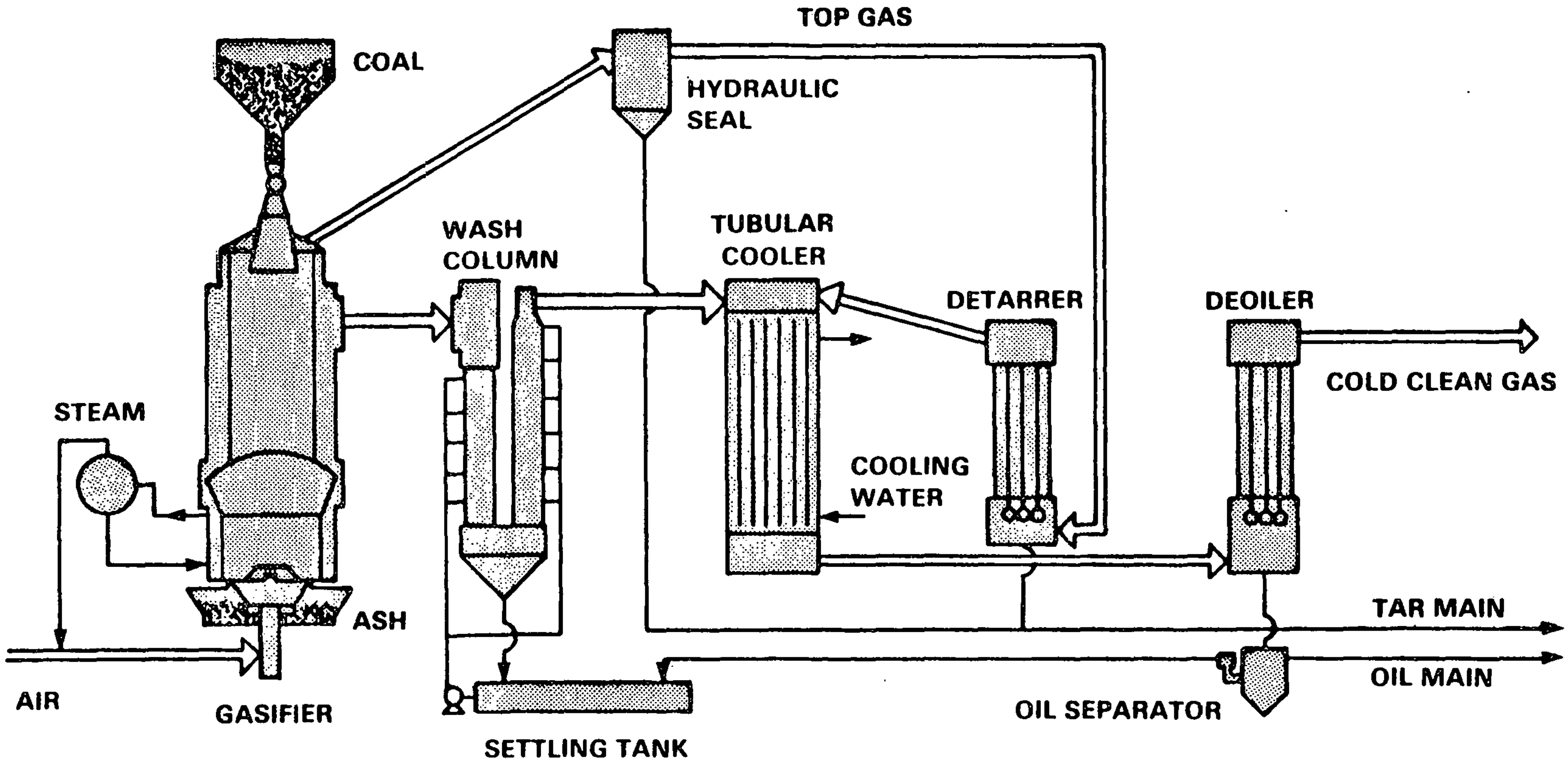


Figure 2.14: Two-Stage Wellman Incandescent Gasifier Configured To Produce Cold Clean Gas

Subsection 2.2.2 of this report 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 2.1.

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 for Wellman Incandescent Gasifier

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.

2.3.3 Woodall-Duckham/Gas Integrale Gasifier

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 2×10^9 Btu/day. The process is suitable for incorporation in plants producing from 1 to 30×10^9 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 2.15.) 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 2.16). 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

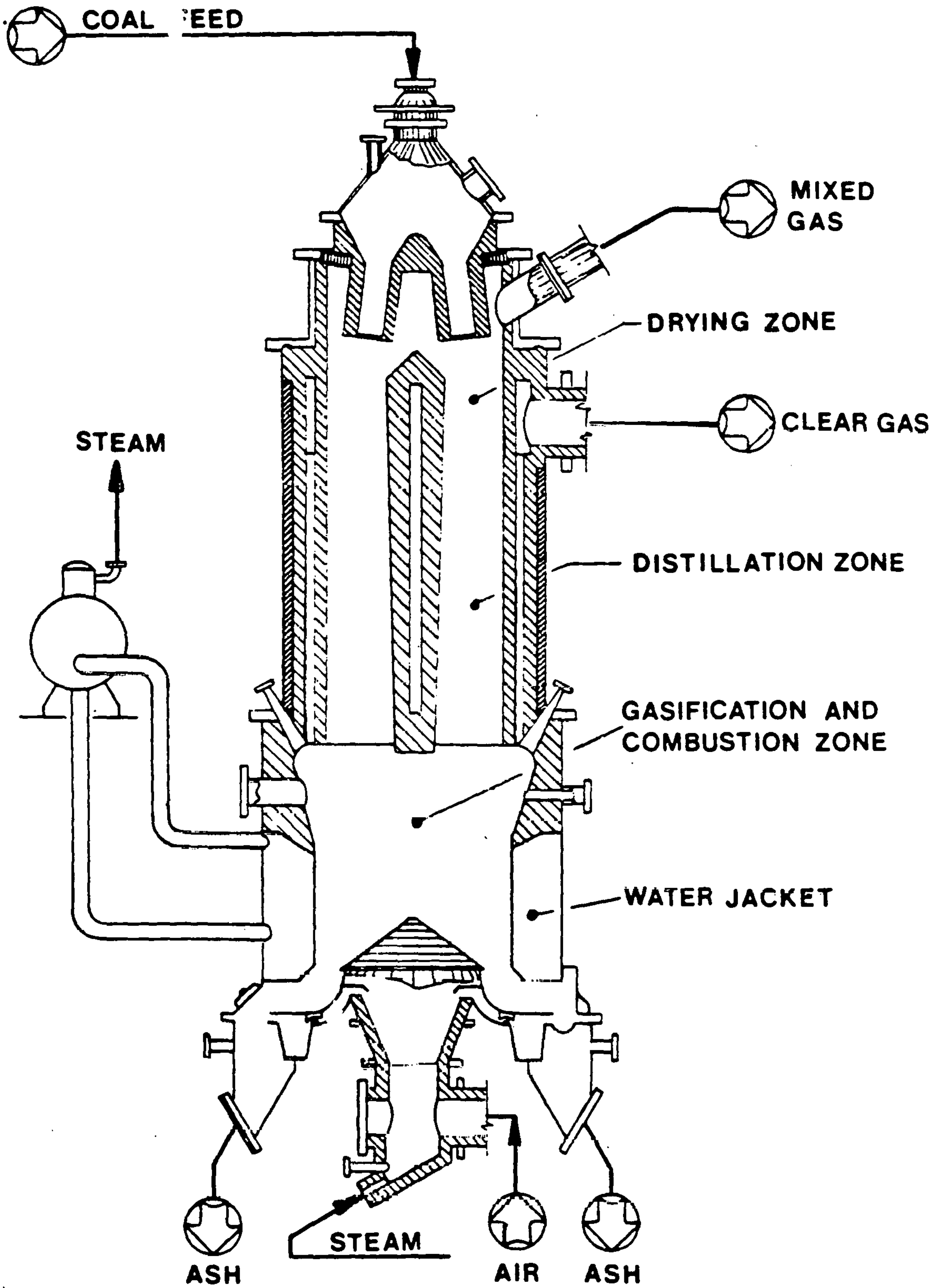


Figure 2.15: Woodall-Duckham/Gas Integrale Gasifier

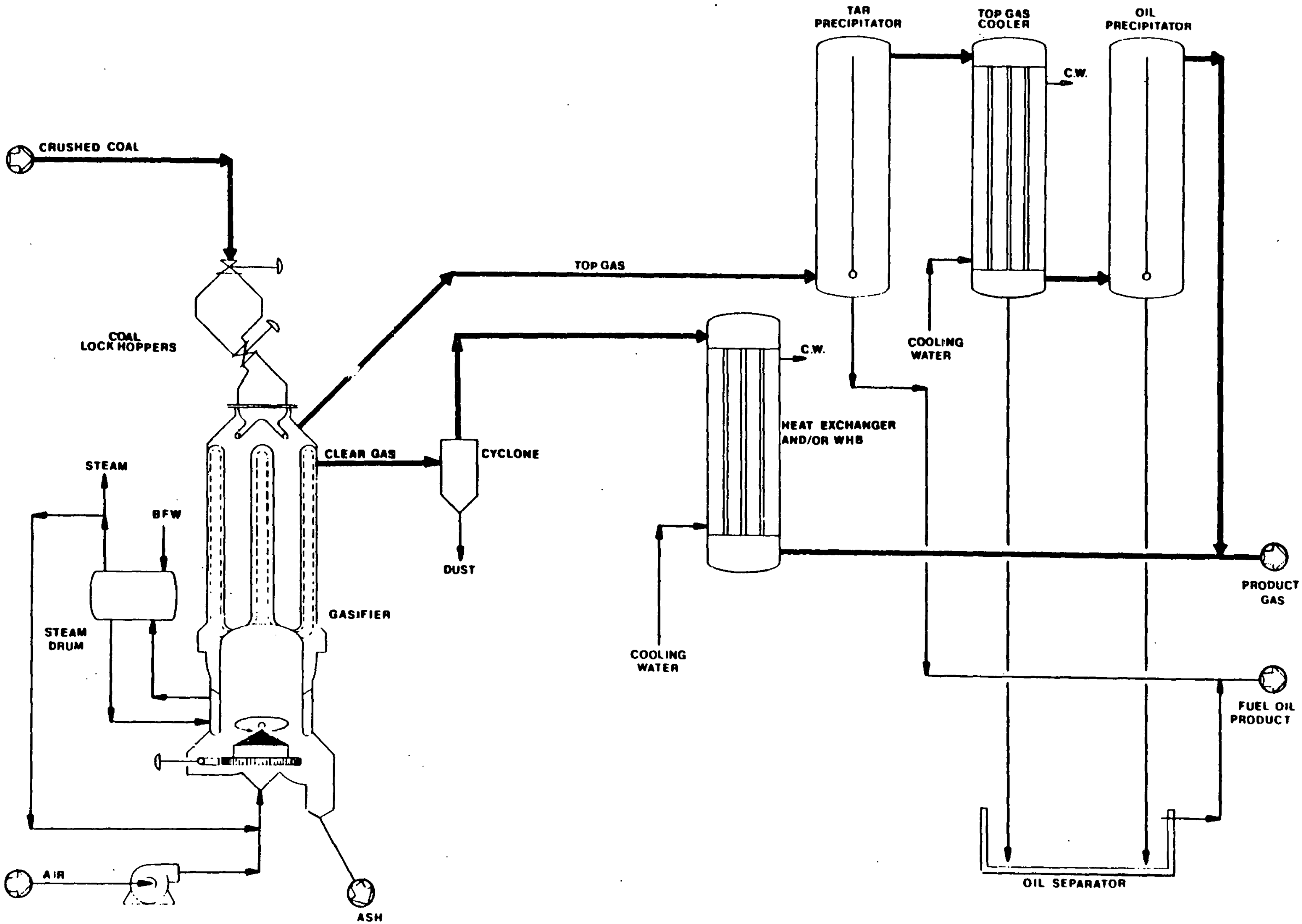


Figure 2.16: Woodall-Duckham/Gas Integrale Gasification System

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 4×10^9 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, plus 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 for WD/GI Gasifier

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.

SECTION 3 - GAS CLEANUP SYSTEMS

3.1 INTRODUCTION

Product gas from a gasifier contains entrained particles (fly ash as well as coal dust), tars, acid gases, ammonia, and organic matter as impurities. These impurities often must be removed from the gas to meet the end use and downstream process requirements, as well as environmental constraints.

3.2 PARTICULATE REMOVAL

Solid particles, mainly fly ash and entrained coal dust, are removed from the product gas by a cyclone or a bag house. They can be further removed during tar removal by an electrostatic precipitator. More elaborate cleaning can be accomplished by scrubbing the product gas in a quench tower or venturi scrubber. It is essential to remove particulates from product gas to prevent line erosion and pluggage, damage to instrumentation, and deactivation of catalyst and to meet environmental standards for solid effluents.

A high-velocity wedge separator for high-temperature particulate removal will be tested soon at a coal gasification pilot plant. This particulate removal system is being developed by Linhardt and Associates, Newport Beach, California, for a combined-cycle coal gasification application.

Curtiss-Wright, Wood-Ridge, New Jersey, is to test and evaluate three hot gas clean up techniques for use with a pressurized fluidized bed combustor. DOE has sponsored these two projects for removing particulate matter smaller than 10 microns so that clean gas can successfully be coupled with a gas turbine.

3.3 TAR REMOVAL

Tar, in product gas, is present as droplets or as tar mist and is removed by a tar cyclone or an electrostatic precipitator. Certain downstream end uses can tolerate tar in product gas. In this hot raw form, product gas has the highest heating value, but tar-contaminated gas may cause pitch build-up in pipe lines. If gas is to be transported over a long distance or if a downstream process or equipment cannot tolerate tar in the gas, the tar must be removed. Tar/pitch build-up can create line pluggage, require attentive maintenance, and induce process outage if alternate fuels are not available during line cleanout.

A typical procedure to remove build-ups in the gas line is to burn out tar from the line. During a burnout operation, heavy smoke, air pollution, and personnel safety are of concern. For a single-stage, fixed-bed gasifier, tar build-up requires frequent process shutdown and burnout to unplug the lines (typically every two months on many bituminous coals, or annually on anthracite coals). Two-stage gasifiers eliminate these troubles by having the two gas outlets. Process upsets are minimized and good quality by-product tar is produced practically moisture free. This tar can be stored and often used as supplemental fuel. However, two-stage gasifiers are constrained to use only low free-swelling index coals, a severe limitation.

3.4 ACID GAS REMOVAL

During gasification of coal, some carbon is combusted to provide the heat for the endothermic reaction, and carbon dioxide is thereby generated. Also during gasification, sulfur in coal is converted to hydrogen sulfide and other sulfur containing chemicals, such as carbonyl sulfide (COS), carbon disulfide (CS_2), thiophines, and mercaptans. To upgrade the product gas as well as to meet environmental constraints, acid gases (H_2S and CO_2) and other sulfur components must be removed.

Gas purification involves the removal of vapor phase impurities from gas streams. The processes that have been developed to accomplish gas purification vary from simple once-through wash operations to complex multiple-step recycle systems. In many cases, the process complexities arise from the need for recovery of the gas impurities or reuse of the materials employed to remove the impurities.

The primary operation of the gas-purification processes generally falls into one of the following three categories:

1. Absorption into liquid
2. Adsorption on a solid
3. Chemical conversion to another compound.

Absorption - Absorption is probably the most important gas-purification technique and is common to a great number of processes. It involves the transfer of one or more components of a gas mixture from the gaseous to the liquid phase through the phase boundary. The absorbed material may dissolve physically in the liquid or react chemically with it. Desorption (or stripping) represents a special case of the same operation in which the absorbed material moves from the liquid to the gaseous phase. Thus, the liquid is recovered for reuse and the liberated (and concentrated) gaseous impurities are treated further to meet environmental standards.

The great majority of absorbers used for gas-purification operations are packed, plate, or spray towers. These absorber types are interchangeable to a considerable extent, although certain specific conditions may favor one over the other.

Adsorption - In adsorption, as applied to gas purification, the impurities are removed from the gas stream by concentration on the surface of a solid material (called adsorbents). Adsorbents are natural or synthetic materials of microcrystalline structure, whose internal pore surfaces are accessible for selective combination of solid and solute. Since the quantity of material adsorbed is directly related to the area of surface available for adsorption, commercial adsorbents are granular solids that have been prepared to have a very large surface area per unit weight.

Although adsorption can be practiced with many solid compositions, the great majority of gas-purification and dehydration adsorbents are based on some form of silica, alumina (including bauxite), carbon, or certain silicates, the so-called molecular sieves. Of these materials, activated carbon has the specific ability of adsorbing organic vapors and some gaseous sulfur compounds.

To purify, the gas must be passed through a bed of adsorbent material at a velocity consistent with pressure drop and other requirements and conditions that will allow the required material transfer to occur. The bed will eventually become loaded with the impurities and must then either be discarded, removed for reclaiming, or regenerated in place. Heat and a stripping vapor are generally used to recover the adsorbent bed.

Chemical Conversion - With few exceptions, chemical conversion of gas-phase impurities for gas purification is accomplished by heterogenous catalysis using solid catalysts. Fixed-bed catalytic reactors are by far the most common for this type of operation, and the construction of these units is very similar to that of adsorption beds.

Acid Gas Removal Processes for Low Btu Gasification - Catalysts used in most gas-purification processes are metal salts or metals, usually supported on an inert carrier of large surface area. Typical carriers are alumina, bauxite, asbestos, china clay, activated carbon, and metal wires. Principally, these processes are used for organic sulfur removal, hydrogen and methane gas purification (by catalytic shift and methanation reaction), and gas purification by catalytic oxidation and reduction. The activated carbon adsorption process and iron oxide process have an inherent catalytic reaction mechanism for the removal of hydrogen sulfide. Only adsorption and absorption processes (mainly applicable for H_2S and CO_2 removal) are discussed here.

Acid gas removal (AGR) processes considered applicable to low Btu gas are listed in Table 3.1.

Table 3.1 Acid Gas Removal Processes Considered Applicable to Low Btu Gas

Process Name	Acid Gas Removal By Chemical Absorption	Acid Gas Removal By Physical Absorption	Acid Gas Removal By Physical Adsorption
Activated Carbon Adsorption	--	--	X
Alkazid Process	X	--	--
Iron Oxide Process	--	--	X
MEA Process	X	--	--
MDEA Process	X	--	--
Molecular Sieve	--	--	X
Purisol Process	--	X	--
Stretford Process	X	--	--
Sulfiban Process	X	--	--
Sulfinol Process	X	--	--
Zinc Oxide	--	--	X

Activated Carbon Process - In this process, activated carbon by catalytic effect promotes the oxidation of H_2S to elemental sulfur at ordinary temperature. The sulfur deposited on the activated carbon is recovered by extraction with an appropriate solvent, ammonium sulfide, and the carbon is reused until attrition of the carbon particles becomes excessive. The activated carbon process has the distinct advantage that very pure sulfur is obtained in a relatively simple operation. Its main drawback is rapid deactivation of carbon from tar and polymeric materials deposit on the surface. This requires complete removal of such materials prior to acid gas removal treatment. Although the process was designed for H_2S removal only, it is claimed that by selection of the proper carbon, both H_2S and organic sulfur compounds can be removed in two successive treating steps.

The actual mechanism of sulfur removal by activated carbon has not been clearly understood. It is believed that desulfurization is accomplished by a combination of chemical absorption and physical adsorption.

Alkazid Process - The Alkazid (alka-acid) process was originally developed in Germany by BASF Corporation. The process could be classified as three separate processes as three different absorption solutions are used. However, all of the process variations use a solution of the salt of a strong inorganic base and weak, non-volatile organic acid. The solutions are designated as Alkacid solution "M", Alkacid solution "dik," and Alkacid solution "S," and each has a specific field of application. The "M" solution contains sodium alanine and is used for absorbing either H_2S and CO_2 when present alone, or for absorbing both gases simultaneously. The "dik" solution contains the potassium salt of diethyl- or dimethylglycine and is used for the selective removal of H_2S. The use of "S" solution has not been commercialized.

Iron Oxide Process - The iron oxide process is one of the oldest methods used for the removal of objectionable sulfur compounds from industrial gases. The process is still used on a large scale for the treatment of coal gases, although more recently developed wet-purification processes are gradually replacing it. The process is well suited for sweetening small volumes of gas having low H_2S contents.

The adsorption of H_2S on a ferric oxide bed takes place according to the following reaction:

$$Fe_2O_3 + 3\ H_2S \rightarrow Fe_2S_3 + 3\ H_2O. \qquad (1)$$

The bed is regenerated according to the following reaction:

$$2Fe_2S_3 + 3\ O_2 \rightarrow 2Fe_2O_3 + 6S. \qquad (2)$$

The combined equation is:

$$6\ H_2S + 3\ O_2 \rightarrow 6\ H_2O + 6S. \qquad (3)$$

For regeneration, the bed is exposed to oxygen at atmospheric pressure. Most commonly, a small amount of air is introduced continuously into the feed gas so that H_2S adsorption and oxide regeneration take place in the bed simultaneously.

The moisture content and pH in the bed should be controlled to maintain the adsorption reaction.

MEA Process - Alkanolamines are widely used to absorb acid gases (CO_2 + H_2S) from sour feed gas. In particular, mono-ethanolamine (MEA) has been used for many years to remove low concentration of H_2S and CO_2 from natural and synthesis gases. The process has been improved by the incorporation of an amine guard corrosion inhibitor (developed by the Union Carbide Company) in the MEA solution.

The principal chemical reactions occurring when MEA solution is used to chemically absorb CO_2 and H_2S are as follows:

$$RNH_2 + H_2S \longleftrightarrow RNH_3{\cdot}HS \text{ and} \qquad (1)$$

$$RNH_2 + CO_2 + H_2O \longleftrightarrow RNH_3.HCO_3, \qquad (2)$$

where R denotes C_2H_4OH, ethanol group.

MEA is a strong base and reacts rapidly and non-selectively with acid gases. Because of its lower molecular weight, it can remove more acid gases than can other amines on a unit weight or volume basis. This reduces the amount of recirculation necessary to remove given amount of acid gases. The solution is regenerated by steam stripping.

MDEA Process - The process uses an aqueous solution of methyl-di-ethanol-amine (MDEA) to remove H_2S by chemical absorption from industrial gases. MDEA has a higher selectivity toward H_2S in the presence of CO_2 than do other primary or secondary amines, such as MEA or DEA.

H_2S, HCN, organic acids and a portion of the CO_2 are chemically absorbed from the gas in a 30-50 wt% aqueous solution of MDEA ($(HOC_2H_4)_2(NCH_3)$). The process can be modified to remove substantial quantities of carbonyl sulfide. Normal absorption reactions proceed as follows:

$$R_2NCH_3 + H_2S \longleftrightarrow R_2\ NHCH_3{\cdot}HS \text{ and} \qquad (1)$$

$$R_2NCH_3 + CO_2 + H_2O \longleftrightarrow R_2\ NHCH_3{\cdot}HCO_3, \qquad (2)$$

where MDEA is represented as R_2NCH_3.

Rich solution with absorbed acid gases is steam stripped to regenerate MDEA for reuse in the absorber.

Molecular Sieve - The process uses molecular sieves (which are synthesized zeolites) to physically absorb H_2S, COS, and mercaptans from natural gas and other petroleum gases. Synthetic zeolites have significantly different structures from those occurring in nature. Molecular sieves having the proper pore size to remove sulfur compounds will preferentially remove H_2O, so that gas leaving the absorber will be completely dry.

Sulfur compounds, other impurities, and water are adsorbed on the bed until it is saturated. The hot slip stream of purified product gas is used to regenerate the bed. The number of beds required for adsorption and regeneration depend upon gas feed rate and impurity concentration.

Molecular sieves are highly selective adsorbents. Impurities are removed on the basis of the molecular size or selectivity. The process can remove H_2S and mercaptans from streams also containing CO_2.

Purisol Process - In this process, N-Methyl-2-Pyrolidone (NMP or M-Pyrol) is used to physically absorb acid gases from hydrogen, natural gas, and synthesis gas. NMP, a high boiling liquid, has an exceptionally high solubility for H_2S; thus, it is particularly suitable for selective hydrogen sulfide absorption in the presence of carbon dioxide.

Since the absorption is physical, this solubility increases as the absorption pressure and sour gas concentration increase. The absorption is easily reversed, and the H_2S and CO_2 are separated from the NMP simply by reduction of the pressure. The NMP warms as it absorbs H_2S and CO_2 and cools when they are flashed out; therefore a small amount of cooling, usually by cooling water, is customarily provided to offset frictional heat produced in the system. High pressure favors the solubility of acid gases and thus, it has an advantage over a chemical solvent process.

Stretford Process - The process removes H_2S from gas streams by chemical absorption. It was originally designed to purify coal gas; however, it proved to be equally suitable for desulfurization of refinery gases, synthesis gas, natural gas, and hydrocarbon liquids.

Originally, the process utilized an aqueous solution containing sodium carbonate and bicarbonate in proportion of about 1:3 (pH range 8.5 to 9.5) and sodium salts of the 2,6 and 2,7 isomers of anthraquinone disulfonic acid (ADA). The postulated reaction mechanism involves five steps:

1. Absorption of hydrogen sulfide in alkali.

2. Reduction of ADA by addition of hydrosulfide ion to carbonyl group.

3. Liberation of elemental sulfur from reduced ADA by interaction with oxygen dissolved in the solution.

4. Reoxidation of the reduced ADA (by air).

5. Reoxygenation of the alkaline solution providing dissolved oxygen for step 3.

To improve process economics, sodium vanadate is now used as an additive to the original system. The vanadate-ADA system works at a lower pH than the original Stretford system without loss of washing efficiency. HCN can also be removed by the Stretford process. The H_2S and HCN removal reaction mechanism is as follows:

$$2Na_2CO_3 + 2H_2S \rightarrow 2NaHS + 2NaHCO_3 \quad (1)$$

$$4NaVO_3 + 2NaHS + H_2O \rightarrow Na_2V_4O_9 + 4NaOH + 2S \quad (2)$$

$$Na_2V_4O_9 + 2NaOH + H_2O + 2ADA \rightarrow 4NaVO_3 + 2ADA\ (reduced) \quad (3)$$

$$2NaHCO_3 + 2NaOH \rightarrow 2Na_2CO_3 + 2H_2O \quad (4)$$

$$2ADA\ (reduced) + O_2 \rightarrow 2ADA + H_2O \quad (5)$$

$$2H_2S + O_2 \rightarrow 2H_2O + 2S \quad (6)$$

$$Na_2CO_3 + H_2S \rightarrow Na_2S + CO_2 + H_2O \quad (7)$$

$$Na_2S + nS \rightarrow Na_2S_{(n+1)}\ (formation) \quad (8)$$

$$HCN + Na_2S_{(n+1)} + Na_2CO_3 \rightarrow NaCNS + NaHCO_3 + Na_2Sn \text{ and} \quad (9)$$

$$Na_2Sn + S \rightarrow Na_2S\ (n+1)\ (regeneration). \quad (10)$$

The Stretford process selectively removes H_2S from feed gas and yields elemental sulfur as a product in one integrated step. The effluent stream of Stretford solution containing cynates and thiosalts requires further treatment before discharge.

Sulfiban Process - The process uses an aqueous solution of mono-ethanol amine (MEA) to remove H_2S from industrial gases. Other acidic components can also be removed by selecting proper operating conditions. Proprietary inhibitors are added to the solution to minimize MEA degradation and corrosion of process equipment.

H_2S, HCN, organic sulfides, and portion of CO_2 are chemically absorbed from the gas in a 12-20 wt% aqueous solution of mono-ethanolamine ($HOCH_2CH_2NH_2$). Representing MEA as RNH_2, normal absorption reactions proceed as follows:

$$RNH_2 + H_2S \leftrightarrow RNH_3 \cdot HS \quad (1)$$

$$RNH_2 + HCN \leftrightarrow RNH_3 \cdot CH \text{ and} \quad (2)$$

$$2RNH_2 + CO_2 + H_2O \leftrightarrow (RNH_3)_2 \cdot CO_3. \quad (3)$$

When heat is applied in the stripper, the above reactions are reversed to regenerate MEA. Some MEA is lost due to irreversible reaction between MEA and organic sulfides (CS and COS).

Sulfinol Process - The process was originally developed for treating gases very rich in H_2S. It uses a mixture of an organic solvent, a physical absorbent called Sulfolane (tetrahydrothiophene dioxide), an alkanolamine (di-iso propanolamine; DIPA, a chemical absorbent) and water. The Sulfinol process can effectively remove H_2S, CO_2, COS, CS_2, mercaptans, and organic sulfides and disulfides from feed gas.

H_2S and CO_2 absorption reactions are as follows:

$$R_2NH + H_2S \longleftrightarrow R_2NH_2{\cdot}HS \quad \text{and} \tag{1}$$

$$R_2NH + CO_2 + H_2O \longleftrightarrow R_2NH_2{\cdot}H\ CO_3. \tag{2}$$

DIPA does get chemically degraded by certain impurities (such as O_2 and HCN) in the feed gas. CO_2 also degrades DIPA to a small extent, depending upon its concentration, residence time and temperature.

Zinc Oxide Adsorption Process - In this process, high surface area zinc oxide in the form of spheres or extrudates is used to adsorb hydrogen sulfide. Nominal size particles are in the range of 1/8" to 3/16" (+6-4 mesh screen).

The process is primarily used as a sulfur guard to protect down stream sulfur sensitive catalyst. It reduces H_2S in a process gas to a fractional ppm level.

The zinc oxide adsorbent is discarded after it becomes loaded with sulfur. The adsorption reaction is:

$$ZnO + H_2S \rightarrow ZnS + H_2O.$$

The spent zinc oxide, containing ZnS, is sent for landfill.

3.5 AMMONIA REMOVAL

During gasification, nitrogen in coal converts to ammonia. This ammonia, during downstream gas processing steps of quenching, scrubbing, purification, etc., ends up in gas liquor, sour water, and process condensate. These process streams require treatment to remove ammonia-phenol and other polluting materials before discharging.

There are three commercial processes to remove ammonia from process effluents. These processes are Chemie Linz/Lurgi (CLL), Chevron Wastewater Treating (WWT), and USS Phosam-W processes.

Chemie Linz/Lurgi (CLL) Process - This technology was jointly developed by Chemie Linz AG and Lurgi, mainly to remove ammonia from the dephenolized gas liquor of the Lurgi gasifier and ammonia wash water (in case of coke oven plants). The ammonia product of the CLL is salable as ammonia of either agricultural or chemical grade. Separation of components in the stripper and scrubber is accomplished by using pressure and temperature control to vary the kinetic parameters.

Chevron Wastewater Treating (WWT) Process - The Chevron Wastewater Treating (WWT) process is a commercially used, patented process for treating sour water streams generated by petroleum refineries, coal processing and gasification plants, and synthetic fuel plants.

The WWT process recovers high purity ammonia and hydrogen sulfide while producing clean water suitable for reuse or discharge. There are 3 main steps in this process: (1) degassing and feed storage, (2) acid gas (H_2S and CO_2) stripping, and (3) NH_3 stripping and purification.

USS PHOSAM-W Process - The USS PHOSAM-W Process is the application of PHOSAM technology to coal gasification and liquefaction and other energy and chemical processes outside the coke-oven field. The process was originally developed to recover ammonia from coke-oven gas and gas liquors as high quality anhydrous ammonia. The PHOSAM-W technique can be used to recover ammonia from any gas or vapor stream and is particularly advantageous when CO_2, H_2S, and other acidic gases are present.

The PHOSAM-W process uses a chemisorption system to absorb the ammonia selectively in the presence of other chemical species. The absorbent liquid contains ammonia and phosphoric acid of the general formula $(NH_4)_nH_{3-n}PO_4$. The absorption reaction is as follows:

$$(NH_4)_{1.3}H_{1.7}PO_4 + 1/2NH_3 \leftrightarrow (NH_4)_{1.8}H_{1.2}PO_4$$

3.6 ORGANIC REMOVAL

Organic waste, mostly phenolic, is present in sour water and should be treated because phenols act as a fish poison and even in minute quantities affect the taste of the water. Processes applicable for phenol removal in gasification are biodegradation (activated sludge), Chem-Pro, Phenosolvan, and Rohm and Haas Phenol Recovery processes.

<u>Biodegradation Process</u> - In Biodegradation or activated sludge process, the bacteria use noxious compounds, such as phenol, as their source of food, and produce carbon dioxide and water as the end products. The bacteria are aerobic -- that is, they require oxygen to live -- and each reaction is performed by a specific enzyme. These organisms are not solely restricted to phenol destruction but may also readily feed on other phenolic type compounds, such as cresols, as well as most other organic compounds, including acids, aldehydes and alcohols. This process has advantages over chemical treating and incineration. The process is highly sensitive to pH levels, presence of heavy metals, and oxygen supply.

<u>Chem-Pro Phenol Recovery Process</u> - The Chem-Pro process uses liquid-liquid extraction to recover phenol from wastewaters. The proprietary immiscible solvent extracts phenols from a wide range of aqueous wastes. Extraction is carried out in a multi-stage reciprocating plate column. The solvent-phenol mixture is sent to the distillation column to separate phenols from solvent. The solvent is recovered at the top and recycled. The phenols stream from the bottom is cooled and sent to storage. Phenols free wastewater is stripped to recover the extraction solvent.

Phenosolvan Process - The Phenosolvan process was developed by the Lurgi Company in Germany to remove phenols from coke-oven liquors. The process uses isopropyl ether as solvent to extract phenols. In a newer version of the process, a proprietary solvent called phenisol is used. The new process is used at the Sasol Coal Liquefaction plant in South Africa.

Rohm and Haas Phenol Recovery Process - In this process, phenolic compounds from an aqueous stream are adsorbed on a porous organic resin. The main process steps are polymeric adsorption, the regeneration of the adsorbent by acetone, and phenol recovery.

The Rohm and Haas process uses amberlite polymeric adsorbents to remove phenolics from aqueous, as well as non-aqueous process streams. Phenol, being a moderately polar molecule, can be adsorbed on the surface of amberlite XAD-4. The process is reversed by regenerating the bed with acetone.

3.7 H_2S REMOVAL PROCESS

Scientific advancement continues to explore newer, cheaper, and more efficient processes for H_2S removal. One such process in the development stage is being studied in Switzerland. In this process, hydrogen sulfide can be split catalytically into its components by visible light. The key to the process is the use of an aqueous transparent suspension of collodial cadmium sulfide particles loaded with ruthenium dioxide. This finding could provide a simple alternative to conventional methods of removing hydrogen sulfides from sour gases from refinery and industrial operations.

The mechanism is such that photo induced electrons in the cadmium sulfide particle conduction bands reduce water to hydrogen and hydroxide ions. The hydroxide ions strip hydrogen from hydrogen sulfide, reforming water and resulting in negatively charged sulfide ions. These ions are oxidized to elemental sulfur. The oxidation process is made more efficient by the use of ruthenium oxide on the particle surface. The process is at laboratory bench scale level.

SECTION 4 - LOW BTU GASIFICATION ENVIRONMENTAL AND REGULATORY ISSUES

4.1 INTRODUCTION

Before proceeding with the detailed planning of a low Btu gasification facility (system), a prospective industrial developer should review the local, state and Federal environmental issues and regulatory and permitting procedures that will govern the development and operation of the facility. The matrix in Figure 4.1 shows the environmental and related types of issues that must be considered for each of the major elements of an LBG facility, which are 1) coal (or other gasifier fuels) transportation; 2) coal handling, storage, and coal preparation; 3) gasification, gas conditioning and environmental controls; and 4) LBG end user concerns. The issues as they apply to each element are discussed below.

4.2 COAL TRANSPORTATION ENVIRONMENTAL ISSUES

An LBG facility may require from 10 to 200 tons of coal per day. Shipping in so much coal can create environmental problems that should be thoroughly analyzed and addressed by the project management. The importance of this factor will depend on the surrounding environs, the site layout, and characteristics of the LBG system. The coal transportation system may or may not be compatible with the plant's setting or with the current industrial traffic at the site. For example, within a large industrial setting with an existing rail network, the addition of 20 to 40 coal rail car movements per week would go relatively unnoticed. In a small non-rail linked industrial park or non-rail facility area where coal or other bulk commodity is not currently transported, however, the movement of 4 to 10 large highway coal trucks per day could raise adverse public comment. The expected public concerns could deal with highway safety, noise, dust, road maintenance, and the "decline in quality of life." These public attitudes would manifest themselves as concerns along the transportation routes, and may involve a greater public group resistance toward the transportation system than toward the low Btu gasification plant development.

FUNCTIONAL SYSTEM ELEMENTS / ENVIRONMENTAL ISSUES OF CONCERN	COAL TRANSPORTATION	COAL HANDLING AND STORAGE	COAL PREPARATION; GASIFICATION & GAS CONDITIONING	PRODUCT GAS AND THE END USER
ZONING & SITING	X	X	X	
AIR EMISSIONS	X	X	X	X
NOISE EMISSIONS	X	X	X	
WASTEWATER DISCHARGE		X	X	
SOLID WASTE DISPOSAL			X	
HAZARDS & RISKS			X	X
WATER SUPPLY			X	
SOCIOECONOMIC FACTORS	X	X	X	

Figure 4.1: Low Btu Gasification Facility Development - Primary Environmental Issue Matrix

For these reasons, proper emphasis should be placed on the transportation area and a consciencious transportation analysis should be conducted by the system developers.

A transportation analysis is often required for securing local zoning or construction permits and as a part of or state/Federal environmental assessments. In either case, the industrial participant(s) should coordinate their transportation requirements with the rail authorities and local and state departments of highway, safety, and planning.

The current general Federal and state environmental regulations that might impact the coal transportation system are mobile source air emissions, noise, traffic safety, and the siting and zoning of a new rail spur or roadways. These regulations are site specific and must be addressed on a case by case basis. The calculation of potential air and noise emissions from the coal transportation can be accommodated by utilizing algorithms approved by the EPA, and consultation with the state and federal air polluition regulators as shown in Table 4.1.

4.3 COAL HANDLING AND STORAGE SYSTEM ENVIRONMENTAL ISSUES

The environmental aspects of coal storage and handling for low Btu gasification facilities are similar to those affecting other industrial facilities that use coal. The quantity and location of coal storage are management decisions that must be made individually for each gasification facility. In the designs for proposed DOE sponsored synfuel plants, a 30 nominal day active coal supply and often a 30 day inactive coal pile have been designed for coal delivery and supply security reasons. As illustrated in Figure 4.1, the primary environmental concerns in the coal storage and handling areas are related to zoning and siting of the storage piles, fugitive air emissions, noise propagation, and potential surface and groundwater contamination.

4.3.1 Zoning and Siting

With coal consumption at a normal size LGB facility ranging from 50 to 200 tons per day, a thirty day coal supply would need 2 to 4 acres for storage. The siting of the coal storage facility could be directly on the plant site, or at a remote site where a weekly bulk coal shipment could be received and daily transhipments made to the gasifier. The options for alternative onsite or offsite bulk coal storage should be carefully weighed where sensitive transportation siting, zoning, and space limitations exist, and for defining alternative mitigation actions and designs.

4.3.2 Fugitive Air Emissions

The coal handling involved in bulk unloading, stockpiling, and handling generates of fugitive particulate air emissions, as shown in References 1 to 5 in Table 4.1. These particulate emissions are a pollutant regulated under the state/Federal Clean Air Act Implementation Programs and consequently can become a sensitive issue in a clean nonindustrial park or institutional setting. The overall environmental mitigation program for dust control and suppression systems is well known and can be easily incorporated into the project.

4.3.3 Surface and Groundwater Pollution Controls

The open pile storage of coal leads to oxidation and leaching of coal constituents to the surrounding surface and groundwater environments. These pollutant discharges are receiving increased state and Federal scrutiny under point and non-point wastewater discharge regulations governed by the Clean Water and Safe Drinking Water Acts. As indicated in Tables 4.2 and 4.3, representative leachates from two common eastern coals exceed the drinking water standards for certain parameters and consequently require some level of treatment prior to discharge.

The mitigation of groundwater contamination can be easily accomplished by lining the storage areas with concrete, asphalt, clay, or synthetic liners and

Table 4.2 Summary of Leachate Data Collected from Illinois No. 6 Coal

Parameter	Mean	Minimum	Maximum	Mean Exceeds Drinking Water Standard by
Runoff, % of rainfall	73	65	83	
Percent transmission before filter	80.1	19.1	94.2	
Percent transmission after filter	88.6	81.9	97.9	
pH	2.2	2.1	2.4	4.3
Acidity, mg/liter as $CaCO_3$	21,200	6,500	25,400	
Electrical conductivity, μmhos/cm	15,200	6,500	21,700	
Sulfate, mg/liter	21,500	5,850	37,200	86X
Iron, mg/liter	7,710	2,090	12,000	25,700X
Arsenic, μg/liter	147	9.4	258	2.94X
Barium, mg/liter	0.2			0
Cadmium, μg/liter	268			26.8X
Chromium, μg/liter	438	21	560	8.7X
Lead, μg/liter	14	7.2	21	0
Selenium, μg/liter	438	19	808	43.8X
Silver, μg/liter	0.35	less than 0.05	0.81	0
Mercury, μg/liter	0.12	0.03	0.30	0

Table 4.3 Summary of Leachate Data Collected from Kentucky No. 9 Coal

Parameter	Mean	Minimum	Maximum	Mean Exceeds Drinking Water Standard by
Runoff, % of rainfall	71	65	100	
Percent transmission before filter	32.5	0.9	86.3	
Percent transmission after filter	48.0	13.3	87.1	
pH	2.1	1.8	2.5	4.4
Acidity, mg/liter as $CaCO_3$	33,100	7,760	78,200	
Electrical conductivity, μmhos/cm	10,500	4,480	20,000	
Sulfate, mg/liter	27,300	5,820	72,600	109X
Iron, mg/liter	9,850	1,780	26,200	32,833X
Arsenic, μg/liter	9,050	2,040	17,500	181X
Barium, mg/liter	less than 0.2			0
Cadmium, μg/liter	166	47	386	16.6X
Chromium, μg/liter	724	330	1,220	14.4X
Lead, μg/liter	12	7.2	35	0
Selenium, μg/liter	829	56	3,000	82.9X
Silver, μg/liter	·0.05			
Mercury, μg/liter	0.20	0.05	0.60	0

by installing of a leachate collection and treatment system, or by providing pile coverage. The advantages of a roofed enclosure are the control of some air emissions, and the elimination of surface and groundwater discharges and the need for treatment and monitoring. The disadvantages of this option are increased capital costs and perhaps loss of operational flexibility. The common design parameters for a pile runoff collection, storage and treatment system are design the system to handle the 10 year 24 hour storm event; provide for control of discharge effluent with a pH between 6.0 and 9.0; and provide for control of the average discharge of suspended solids concentrates so that they remain below 50 milligrams per liter.

Important options to consider in the coal pile runoff design analysis should include reuse of collected coal pile runoff in the gasification or end user facility, or treatment of runoff by an existing or future industrial wastewater treatment facility associated with the coal pile; or pretreatment and discharge of the runoff to the coal pile site's municipal wastewater facility. Each of these wastewater treatment alternatives should be carefully reviewed during the facility design.

Another factor that may affect design decisions is the need to obtain a wastewater discharge permit under the state/Federal programs. If there is an existing wastewater discharge facility, it may require modification to accommodate this new intermittent source (coal pile runoff). The wastewater from the coal pile runoff should feed into the gasification and industrial process area wastewater treatment system, if the coal storage area is near the gasifier.

4.3.4 Noise Emissions

Offsite noise resulting from onsite activities is the subject of Federal regulations and frequently of state and local regulations also. Careful monitoring and analysis of daytime and nighttime background noise conditions at the site during the design phase and noise modeling of the proposed facility should be conducted where potential noise problems are foreseen. Currently, the EPA has a recommended day-night short term noise goal of 65 dB and long term goal of

44 dB. Local and state regulations on background and impulsive noise sources may be lower. To meet the recommended Federal noise standards, standard industrial noise suppression techniques should be applied to attenuate impulsive and background noise levels from equipment such as stationary coal handling, machinery, loaders, trucks, rail cars, and engines.

4.4 COAL PREPARATION, LOW BTU GASIFICATION, GAS CONDITIONING, AND ENVIRONMENTAL CONTROL SYSTEMS ENVIRONMENTAL ISSUES

The environmental issues associated directly with the process of gasifying coal relate to the coal preparation unit, the coal gasification unit, and the system of environmental control units for the gases, liquids, and solids produced in the gasification process. Coal preparation consists of washing the coal (if required), screening the coal to remove fines, and delivering the coal to the coal hopper above the gasifier. The gasifier unit consists of the gas producer and the cyclone(s) for removing particulate matter (ash, tar, and oil) from the hot raw gas exiting the gasifier. The environmental control system incorporates any units (the number and kind of which depend on the gasifier, coal, and gas and oil end uses) that remove or reduce gasification process materials that could violate environmental standards, the instruments that monitor and control these units, and the methods used to operate the process to keep it in compliance with environmental standards. A discussion of the units that can be used for gas cleanup with low Btu gasification are discussed in this report in the section "State-of-the-Art--Gas Cleanup Systems."

There are no standardized formulas or procedures for performing environmental analyses and securing local, state, and Federal environmental permits and various building and zoning permits required at each industrial, commercial, or institutional site. These factors must all be taken care of on a case by case basis. If the project management or its A&E contractor does not have substantial experience in the environmental area, it would be wise to hire qualified consultants to make sure that all requirements are met.

4.4.1 Air Pollution Control Systems

Possible air pollution resulting from the gasification of coal is one of the most sensitive environmental concerns about a gasification project. Air pollutants of concern within the gasification process area result from fugitive gas emissions from the gasifier, raw gas cleanup, and the pipeline system, and the process effluents from the gas cleanup system.

Fugitive emission controls and air pollutant monitoring systems are designed for the processing area to control and monitor principally CO, SO_2, H_2S, HCN, NH_3, traces of other elements, and organics, specifically benzo(a) pyrene. These systems are specifically designed to ensure that the workplace air environment meets OSHA standards.

The emission regulated air pollutants CO, hydrocarbons COS, SO_x, NO_x, and particulates that are generated within the gasification process must be controlled to meet existing state and Federal standards. Because there has been little industrial interest in LBG until recent years, EPA has not yet promulgated National Emission Standards for Hazardous Air Pollutants (NESHAPs) and New Source Performance Standards (NSPS) for low Btu gasification facilities, but they are now under study, and NSPS are expected to be promulgated in the near future. [The duration of public forums for Pollution Control Guidance Documents (PCGD) for low Btu gasification has been extended by EPA, and the target date for promulgating the PCGD for low Btu gasification delayed until during 1983. There is now also an EPA promise to consider the end use of the gas in applying emission regulations, rather than considering the gasifier as an entity unto itself.]

The addition of a LBG facility to a site will probably initiate a Prevention of Significant Deterioration (PSD) review. A sample of the potential PSD review process is illustrated in Figure 4.2.

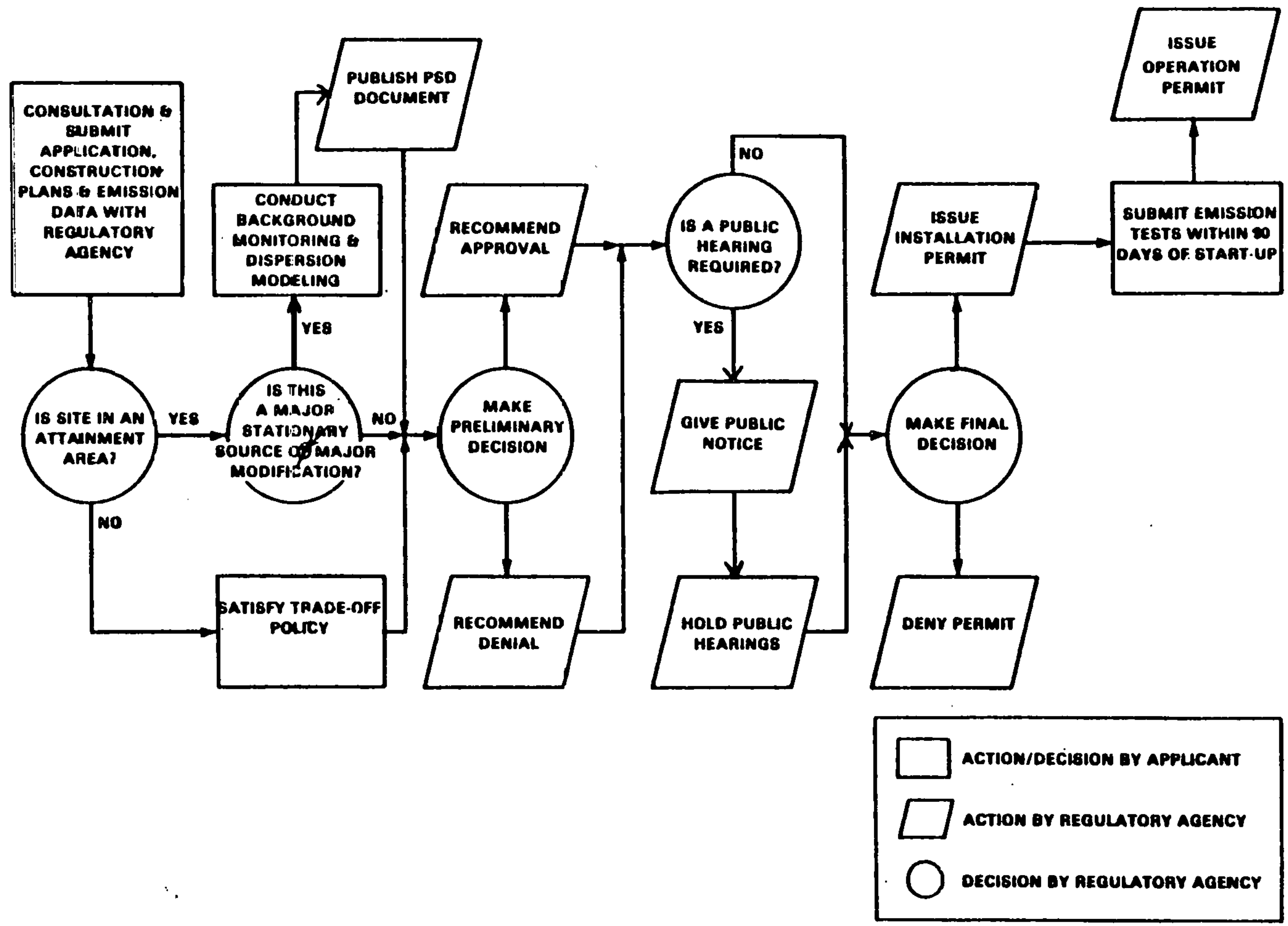


Figure 4.2: General Regulatory Process for Securing Air Quality Permits

For stringent and non-attainment airsheds, the particulate and sulfur removal processes currently available should allow the facility to operate in conformance within any environmental setting.

4.4.2 Wastewater Treatment and Control Systems

The generation of wastewater within the process area originates from the facility runoff, ash quench, and condensate blowdown areas of the process. Direct discharge of this small volume of treated wastewater will require securing state and Federal wastewater discharge permits. The wastewater treatment options are 1) non-discharge option of complete recyling; 2) concentration of waste constitutents by condensation or evaporation and ultimate disposal as a process sludge; 3) pretreatment and discharge to an existing municipal or industrial wastewater facility; 4) complete self contained treatment and discharge; or 5) shipment to an off-site wastewater treatment facility. The discharge of process effluents into a publicly owned wastewater treatment facility or into the end users industrial wastewater facility should be planned only after a treatment design analysis has concluded that adequate treatment can be provided by these options. The addition of process wastewater effluents to an existing system will require modification of the existing municipal/state/Federal discharge permits for the treatment plant and will require design analysis to indicate effluent treatability and control effectiveness of the plant. A general flow chart for securing new wastewater discharge permits is illustrated in Figure 4.3.

4.4.2.1 Gasifier Ash Sluice Water

Ash sluice water is generated when hot ash is removed from the bottom of the gasifier and quenched for handling purposes. During this operation, the water comes into direct contact with the hot ash and becomes contaminated with a variety of anions, cations, and organics. Although the amount of wastewater generated in this process step is small, generally 2 to 3 times the mass amount of ash removed, there is concern about the concentrations of total suspended solids, biological oxygen demand (BOD), phosphates, barium, chromium,

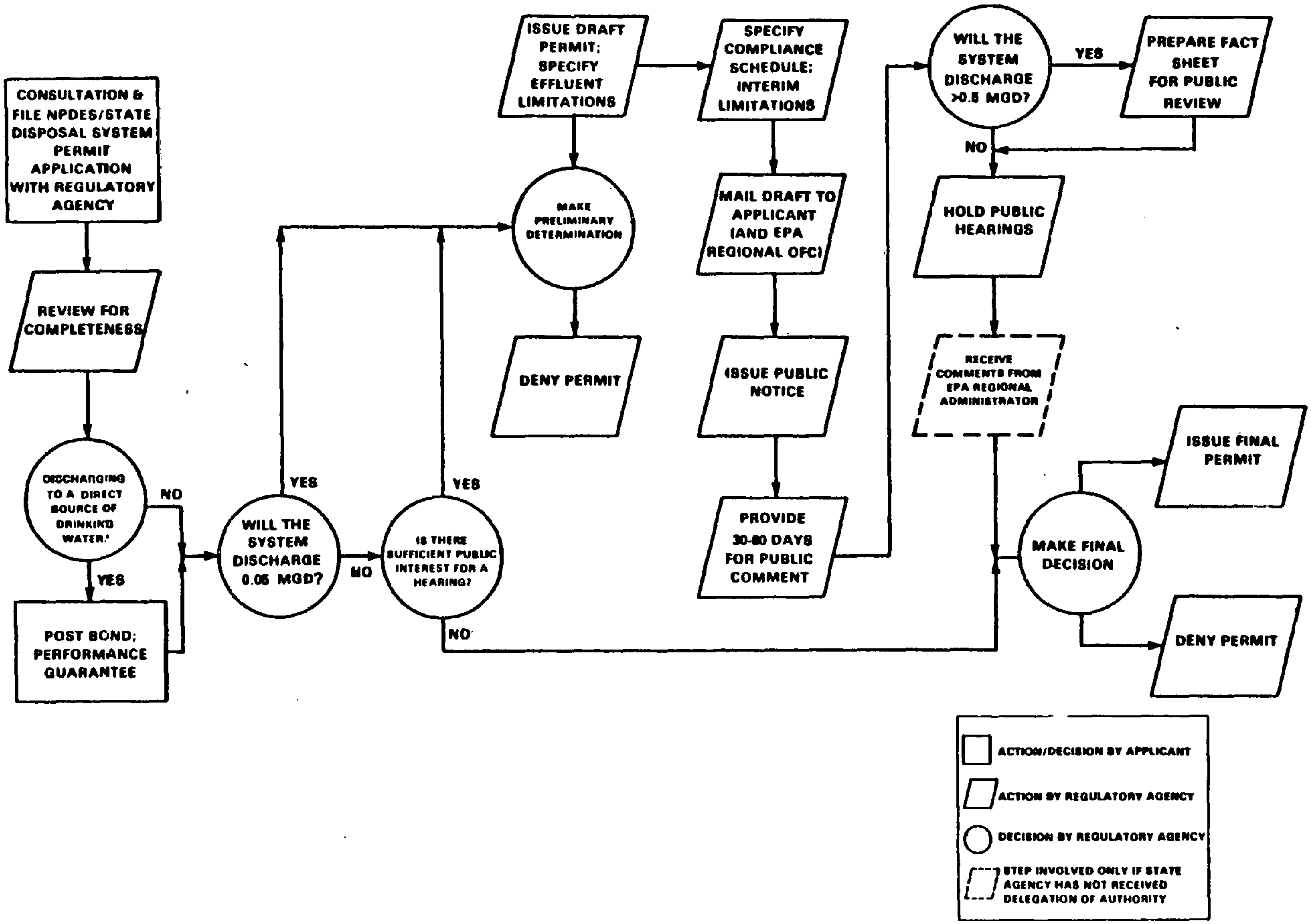


Figure 4.3: General Regulatory Process for Securing Wastewater Discharge Permits

cyanide, maganese, nickel, copper, arsenic, iron, complex organic compounds and other compounds on the EPA priority pollutants list. The primary treatment control of this wastewater stream would be to recycle it to the gasifier and provide pH control and additional treatment in the gasification facility's wastewater treatment plant.

4.4.2.2 Process Condensates

Process condensates are formed in the process when the LBG is upgraded by cooling the gas to below its dewpoint, and when the gas is desulfurized. In these two process steps the water comes in intimate contact with the gas and becomes contaminated with dissolved gases, organics, and other elements in trace amounts. The contaminants of greatest concern in this process are dissolved gases, such as NH_3, H_2S, phenolic compounds, and phthlate esters. Several of these compounds are on the EPA priority pollutants list; consequently, wastewater treatment at the plant site prior to discharge to a river or appropriate wastewater pretreatment at the site prior to discharge to an offsite treatment facility is required. Depending on the cleanup process components and the coals being gasified, the general quantity of wastewater generated is on the order of magnitude of 0.04 to 0.13 gpm per 10^6 Btu/hr of product gas.

4.4.2.3 Other Wastewater Sources

Other sources of process wastewater come from cleanup operations, spillage, and runoff from the process area. The quantity and quality of these wastestreams will be varied, and control and treatment will be required prior to discharge from the site. Domestic sanitary requirements at the site should be kept segregated and treated separately from process wastewater.

The low volume, high strength wastewater streams can be treated either in a dedicated wastewater treatment plant and discharged to a stream or be discharged to an offsite sewerage plant with appropriate wastewater pretreatment at existing site facilities. In either case, a detailed wastewater treatment and analysis program will have to be presented prior to securing the discharge permits. The common options for wastewater treatment are activated carbon absorption, biological oxidation, air stripping, chemical oxidation, evaporation/concentration, or recycling to other process requirements. Effective means of treatment are available off the shelf, but design should be entrusted to someone experienced in industrial wastewater treatment.

4.4.3 Solid Waste Issues

The generated sources of solid wastes are the gasifier ash, cyclone dust, and sulfur cake if a sulfur removal process is included in the air pollution control section. The amount and type of solid wastes generated are controlled by the characteristics of sulfur and ash in the feed coal, the coal friability, and design of the gasifier. The data to date for low Btu fixed-bed gasifiers indicate that the generated solid waste streams are generally non-hazardous and can be controlled under the non-hazardous RCRA regulations.

For a gasification plant the solid wastes development disposal plan will have to stress several points: onsite storage solid wastes controls at the facility, solid wastes transportation methods, and solid wastes controls at the ultimate disposal site(s). Case studies of operating low Btu gasification facilities indicate that gasifier ash is acceptable for landfill and can possibly be marketed to the construction industry. Sulfur cake may also be salable, but the market is not large.

Because of the differences in feed coals, gasifier and cyclone ashes will have to be tested to determine their RCRA classification. The disposal of these wastes would then be made in accordance with RCRA standards for the specific waste classification designation.

Gasifier ash consists of the non-combustible mineral trace constituents of the coal, carbon, hydrogen, nitrogen, oxygen, sulfur, and trace levels of other molecules. Comparative studies between low Btu gasifier ash and powerplant boiler ash for similar coals indicate that the ash analyses are very similar.

Cyclone ash is produced as a result of the removal of entrained solids in the raw fuel gas stream. Entrained solids in the product gas stream result from the fuel gas velocity, poking, and coal feeding. The ash is composed of ungasified and partially gasified particulates, and often precipitated tars and oils agglomerated onto the particulate matter. The quality of this waste must be carefully evaluated to characterize its RCRA classifications and to determine which waste segregation and disposal options can be used.

The transport and onsite or offsite disposal of the solid wastes should be well integrated into the environmental management plan. The public is very sensitive to problems associated with solid waste disposal and, consequently, a definitive mitigation program (and option programs) should be developed to alleviate public concern. The programs can be very simple and straightforward, but addressing them is essential.

4.4.4 Water Supply Issues

The process water requirements for steam production, cooling, quench water, and tail gas cleanup systems will vary widely for different processes.

Although the ultimate water demand is not large at a low Btu gasificatin plant in comparison to other industrial and energy processes, an analysis of water demands should be considered by project management. Data from existing facilities indicates that water consumption varies from approximately 0.75 to 1.5 lbs of water per pound of coal throughput. With the nominal LBG facility ranging in high coal throughputs of 1000 to 6000 lbs per hour the water demands in gallons per day (gpd) would be those given in Table 4.4.

Table 4.4: Gasification Plant Water Requirements

Coal Use Rate	@0.75 lb H_2O/lb coal	@1.5 lb H_2O/lb coal
1000 lb/hr (12 tpd)	2,168 gpd	4,337 gpd
6000 lb/hr (72 tpd)	13,012 gpd	26,024 gpd

These small demands can generally be met within an industrial setting; however, if the size of the gasification facility is expanded and the tail gas cleanup system is expanded or becomes more complex, water demands could become an operational concern.

4.5 END USER ENVIRONMENTAL ISSUES

The management of a plant that uses LBG has the options of purchasing the LBG over the fence or producing the gas on the user site, but the choice of either option has environmental ramifications to the user. If the end user purchases the LBG over the fence, his principal environmental concern will be about pollutants resulting from consumption of the LBG, such as stack emissions. On the other hand, if the gasification plant is a part of the site with the end use process, the gasification plant and end use process are taken as a whole with regard to effluent discharge regulations. In addressing the question of which option to choose regarding the use of LBG, the LBG user plant management must make the gasification plant designer aware of the organizational structure and priorities of the user so that the advantages/disadvantages of each option can be full addressed - the financial advantage of an option will most often be the bottom line, but fuel security or user control of the gasification facility may be more important to some organizations.

4.5.1 End User Air Permit Ramifications

The end user concerns for the use of LBG as an alternative or new fuel in an industrial commercial or institutional setting are primarily centered on the modifications of existing equipment to permit use of LBG and modifications to the existing facility air permits. The complex nature and requirements of the end user air permits will vary on a case by case basis, possibly as a function of one of the following points:

- Air quality classification of the site;

- Promulgation of New Source Performance Standards for LBG within the end user facility;

- Whether the facility is under orders for cleanup or mandatory use of an alternative fuel;

- Amount of hazardous air pollutants ultimately emitted by the end user;

- Air quality attainment status of the given airshed;

- Size and air pollution cleanup equipment used before or after the end user's process fuel change;

- EPA eventual publication of Pollution Control Guidance Documents; and

- Incorporation of new bubble policies at the state and Federal levels.

Although these points seem to imply major barriers to securing the required air permits, or to determining whether a given LBG facility is compatable with the end user's intended use, they can generally be resolved during careful pre-planning discussions with the appropriate local, state and Federal air pollution control agencies.

Constructive preplanning meetings should allow the prospective end user to rapidly determine the regulatory air environment the end user facility will be placed in and the permit requirements the LBG facility and end user will be governed by. From the preplanning meetings it is expected that the regulations and requirements for all four issue areas - 1) Coal Transportation, 2) Coal Handling and Storage, 3) Coal Preparation, Gasification, and Gas Conditioning, and 4) Product Gas and the End User - would be identified and defined. If the regulatory authorities would regard a gasification system on the user site and LBG uses on this site as a unit source (composed of all four issue areas) - a bubble concept - the approach could be one of amending the present end user permits (for an existing gas, oil, or coal user plant). In the event that one or more end users are situated in an industrial/commercial complex where LBG would be supplied over-the-fence, it is doubtful that the bubble concept could be applied all the individual business entities; rather it is expected that the end users would have to have permits modified to include use of LBG, and the gasfication facility would require permits covering the first three (of the four) issued areas referred to above. It is noted, however, that the policies are evolving, so liaison with appropriate agencies might prove that the "expected" is not the rule.

Fortunately, indications from many agencies are that the existing regulatory framework should pose only minor impacts on LBG systems and that they are generally committed to giving priority to permit processing for energy related air permits. Under this regulatory climate the regulatory process may still appear to be complex, but the process is certainly not impossible when proper agency liaison is established.

4.5.2 End User Health and Safety Concerns

The end user is faced with the health and safety concerns that are similar to those experienced in the low Btu gasification facility. The reasons for this concern is the presence in the raw gas feed stream of high concentrations of carbon monoxide and the presence of potentially toxological and biologically active materials. Hot raw gas would pose a greater relative danger to the end user than cooled clean gas; however, for either case, the major worker safety concern would be the presence of high concentrations of carbon monoxide, which is the primary active gas constituent of LBG. In the case of the cleaned gas, the removal of solid and liquid constituents from the raw gas reduces the relative level of the carcinogenicity and toxicity potential of the gas, but the major risk hazard - carbon monoxide asphyxiation - remains unchanged.

Constant CO monitoring is the minimum level of health and safety security that must be provided throughout the LBG user facility (and gasification facility). Addition security is provided by continual monitoring of the delivery and combustion systems for mechanical defects and failures and unplanned changes in operating conditions.

The use of LBG for non-process applications within the end user facility should be reviewed on a case by case basis, but generally discouraged where not essential. This analysis should balance the economic considerations against the safety and health problems associated with LBG usage. For example, piping of LBG for firing small hot water heaters and for fueling space heaters within warehouses and office spaces is not considered to be a reasonable use of LBG. Supplying heat from a LBG fired central boiler would be more prudent than replacing the natural gas supply with LBG to the space heaters and the small hot water heaters. If the space heaters and small water heaters are in a process area where LBG is used, then CO monitors for the process would provide security for the heaters.

LBG is best used in industrial units requiring relatively large energy inputs. These units would be expected to have the adequate monitoring and maintenance and consequently would provide the system security required for dealing with this potential lethal gas mixture. The fuel switchover to LBG will necessitate a redesign of some components of the process facility combustion system (e.g., burners), added safety training of all management and operation personnel, installation of an adequate CO monitoring system, and the establishment of some new operating and maintenance procedures.

4.5.3 End User Wastewater Treatment Concerns

Prior to the acceptance of raw or pretreated LBG wastewater streams into the existing plant process wastewater treatment facility, the industrial manager must apply for a modification to his existing state and Federal National Pollutant Discharge Elimination System (NPDES) wastewater permits and receive the approval of the appropriate state and Federal agencies.

The decision regarding the suitability of the existing treatment system to accept the new waste streams should only be made after a detailed wastewater engineering evaluation has been made and bench scale studies have indicated that acceptable discharge standards can be met. The fact that the treatment plant is on site does not necessarily provide that the LBG wastewater streams are compatible with the existing processes and wastewater facility design. The end user consultants should review the options as illustrated in Figure 4.4 for treatment, pretreatment, blending, altering process controls, devising new processes, incorporating wastewater reuse, or recycling between the end user and gasification/coal handling facilities prior to deciding on a given course of action. Also, for the scheme in Figure 4.3, a similar planning procedure for a water discharge permit as presented in Figure 4.3, may be required for modifying existing discharge permits.

4.6 HAZARDS AND RISKS ISSUES

LBG gasification processes produce potentially hazardous gaseous liquids and solid products that pose an element of hazard and risk in the workplace and surrounding environments if uncontrolled releases are allowed. Although the gasification process is contained in a closed system, fugitive emissions that cause health concerns do occur. The hazardous components contained in the fugitive may include carbon monixide, hydrogen sulfide, cyanide, polycyclic and aromatic hydrocarbons, sulfur and nitrogen oxides, hydrocarbons, aza heterocyclic compounds, and biologically active ingredients (within the coal tar and oil components). Experience indicates that certain hazardous vapors, liquids, and solids are given insufficient attention with regard to operation and design--these require positive engineering and operational controls to avert inadvertent releases. A typical example is the release of CO during manual poking of the gasifier fuel bed. These engineering and operational controls are available, and generally accepted within the industry, to reduce these risks to within the current and foreseeable workplace and environmental regulations.

The data base with which to quantitatively analyze the hazards and risks within an LBG facility is currently not available; however, DOE, EPA, NIOSH and industry are currently cooperatively reviewing designs and monitoring operating facilities to identify the operational problem areas and the pollutants of concern to establish emission criteria, to provide guidance, and to define mitigation control options.

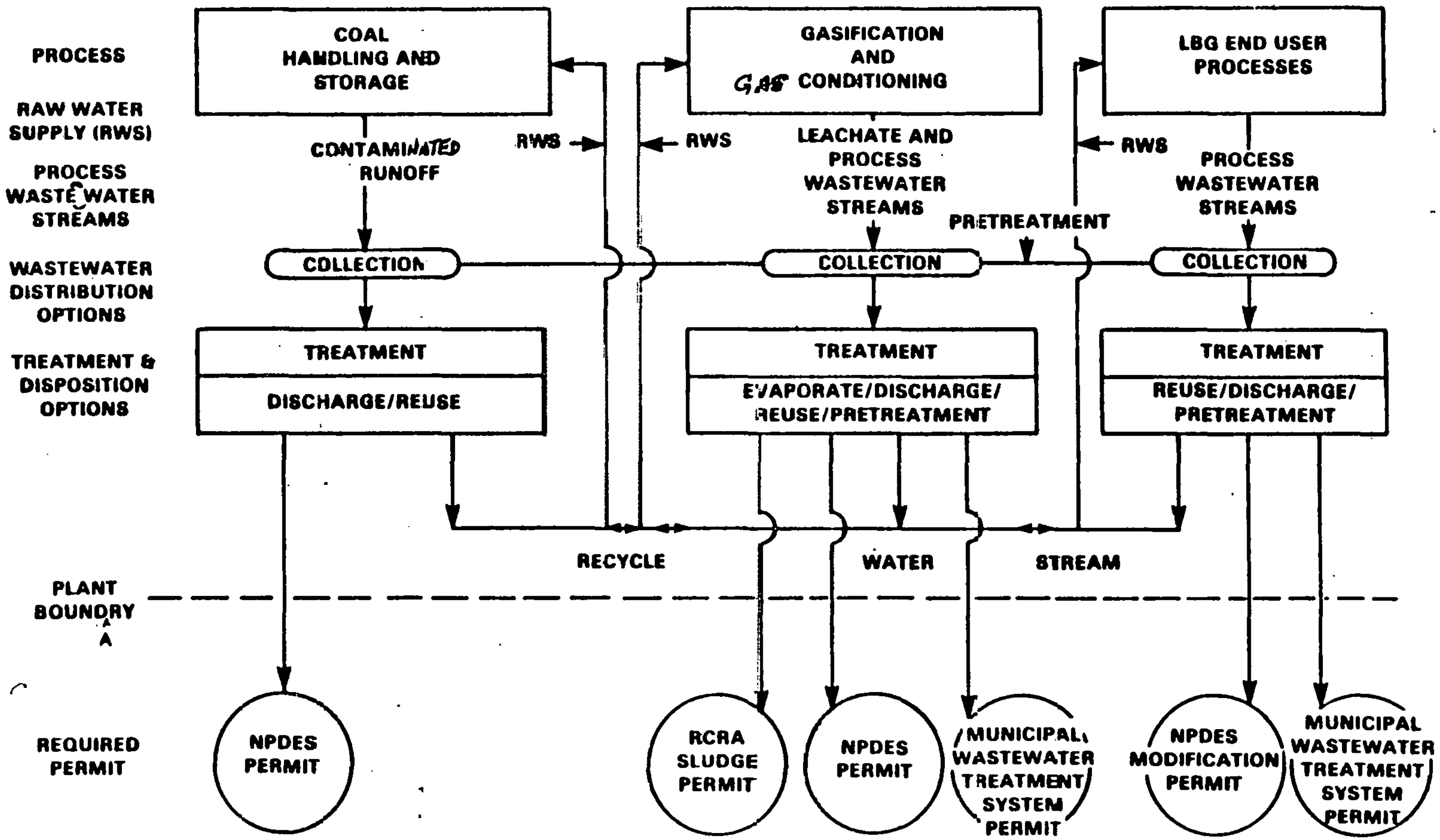


Figure 4.4: Low Btu Gasification Facility Water Supply and Wastewater Treatment and Discharge Options

Since the emission pathways for the fugitive releases are from the vapor, liquid, and solid waste streams, all the process and environmental control systems have to be designed for a high degree of control security and efficiency. The current method of providing for public security and safety is to provide the safest workplace environment that is possible. To provide the public and workers assurances that the design and operation of the facity will be safe and hazard free, a prime management concern must be to incorporate the best available controls and monitoring technology.

4.7 SOCIOECONOMIC ISSUES

The development and operation of an industrial, commercial, or institutional low Btu gasification facility will generally initiate public concerns for issues beyond those discussed so far, so these are included under the category of socioeconomic issues. These issues will vary widely and will concern themselves with qualitative social values that are difficult to address quantitatively. In some instances these concerns do have a legal basis; an example is zoning. Other issues involve society's needs and requirements, such as employment, education, housing, taxes, quality of life, and aesthetics.

The recognition and addressing of these factors is important in the environmental planning process so that programs will have been sufficiently planned and answers adequately prepared when the socioeconomic questions are posed. It is doubtful that any LBG development can totally escape questions; consequently, management should anticipate the lines of potential questions and provide answers and programs to allay the public and agency concerns.

The development of a small to nominal sized LGB facility for one or several industries or institutions within a given area is not considered a major engineering project when compared to other powerplant or synfuel construction programs. However, as with any industrial or commercial development, public sentiment can be a strong force acting to either promote or curtail a proposed energy development project. The community relations of an existing facility may well determine whether the addition of an LBG plant will be acceptable. For example, if the industry has a poor environmental record and generally poor community relations, the addition of new low Btu gasification facilities will most likely be fought; whereas if the project sponsors have a good community record, gaining acceptance from a socioeconomic standpoint will be much easier.

SECTION 5 - ECONOMICS OF LOW BTU GASIFICATION

5.1 INTRODUCTION

The purpose of this economics section is to present a method for estimating the cost of producing LBG in terms of capital expenditure, operation and maintenance costs, and the cost of feedstock. Sensitivities are also evaluated. In addition, the effect of a possible government incentive on cost of gas (COG) is discussed, as well as the competition of LBG with other fuels. The correlations developed are considered best for estimating in the range of 20 to 300 TPD process coal feed (about 0.5 to 5 Billion/Btu/day).

Future investment in LBG production facilities will be determined largely by the economic attractiveness or the ability to make a monetary profit. The "profit" may be as a less expensive fuel or raw material or as insurance against a large financial loss during a shortage of natural gas or petroleum. Gas may be essential to an industrial process and be unavailable in some parts of the country where the industry is ideally located. Some qualitative factors for a favorable choice of investment in LBG are shown in Figure 5.1.

The satisfactory commercial production and use of LBG is an accomplished fact with reactivated facilities (closed earlier when natural gas became available at a low price); however, capital costs have already been written off and some of such facilities are not required to return a profit in themselves. Some facilities were recently built with Government assistance. It is expected that the Government will continue to provide limited economic incentives for such projects to further decrease the drain on critical natural resources. The effect of currently discussed incentives on the economics of LBG is estimated in this report.

The production of LBG can be shown to be competitive today with petroleum distillates and natural gas for certain conditions and uses. Meanwhile, the real cost of the natural fuels is escalating and natural gas is expected to be equal

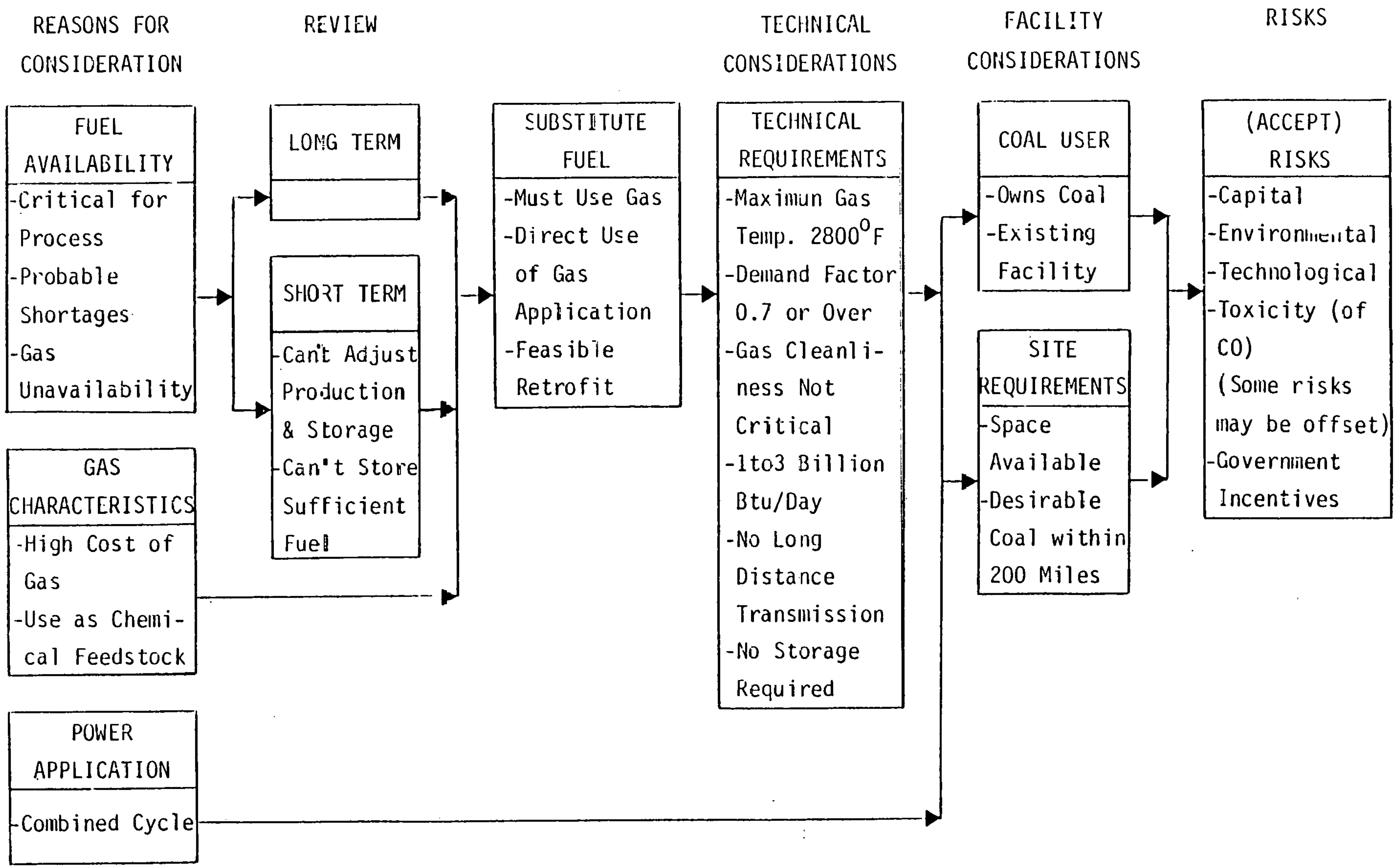


Figure 5.1: Qualitative Factors for Industrial Use of LBG

in real Btu costs with distillate in 1990 at about $10/MMBtu. Coal cost will also escalate but the net result may be to increase the economic advantage of LBG. Estimates of future costs for natural and other synthetic fuels are presented to estimate economic attractiveness for investment in LBG facilities.

Studies to date have shown that production facilities for LBG must be located near the point of use (within a few miles) since it is not economic to compress and distribute low energy gas. The user has the option of building and operating the facility or purchasing the gas from the owner, an over-the-fence arrangement that has been proposed to prospective users even with the facility located on his own property. The advantages of this arrangement are the relative freedom from risk and operational difficulties; however, the user would be required to accept a term contract and must ultimately pay the capital costs and return on investment. An economic analysis would not differ (other than in minor details) for either case although there may be significant advantages in financial management for one of these arrangements. This consideration is beyond the scope of the economic study.

The use of LBG as industrial fuel is the most promising short term application. Use for a combined power cycle (combustion of gas and direct feed to a turbine-generator) is considerably in the future--five to ten years--and depends on advances in turbine technology (higher temperatures) for this specialized application. Also LBG has limited immediate application as a commercial chemical feedstock although versions have been successfully used to produce phosgene and ammonia. This economic study does not consider particular uses but presents estimates of gas generation costs.

A uniform and representative heating value (HHV) is assigned to the LBG of 140 Btu/scf. Hot, raw gas will have an effective heat content of 185 Btu/scf. This value is somewhat dependent on the type of coal and gasifier used and could be upgraded substantially if oxygen enriched air were used in the production process [in which case the gas would be called medium Btu gas (MBG)].

The economics of scale for large plants have not been considered for this study. However, a recent report by Booz, Allen and Hamilton (Ref. 4) presented economic factors of scale that may be useful to readers interested in feed rates greater than 300 TPD.

5.2 COST DATA

5.2.1 General

The cost of LBG is estimated by the general method prescribed in the report of C.F. Braun Company (Ref. 1) and recommended by the Government for cost comparisons. All costs are in 1981 dollars.

The method considers three cost elements: feedstock, operation and maintenance costs, and capital costs. In general, feedstock cost is presented here parametrically, operation and maintenance costs are based on the data, and capital costs have been broken down in processing blocks as shown in Figure 5.2 to enable estimates for each grade (of cleanliness) of LBG. Financial factors such as taxes, interest, and investment equity are input as mathematical operators. The financial aspects and details of calculation are discussed in other sections.

Cost data are meager for the commercialization of this new (to the USA) LBG technology. The available LBG data have been collected, converted to 1981 prices using available escalation factors (Refs. 2 & 3), and arranged as necessary for presentation. Capital costs were sometimes combined (lumped) in a manner different from that desired, requiring a review of component costs and reassignment to the adopted categories. Some capital costs could not be distinguished or assigned to the adopted categories and were considered miscellaneous. These included some engineering, site development, contingency, flares, utilities, etc. A conservative approach was taken in costing so that costs are now on the high end.

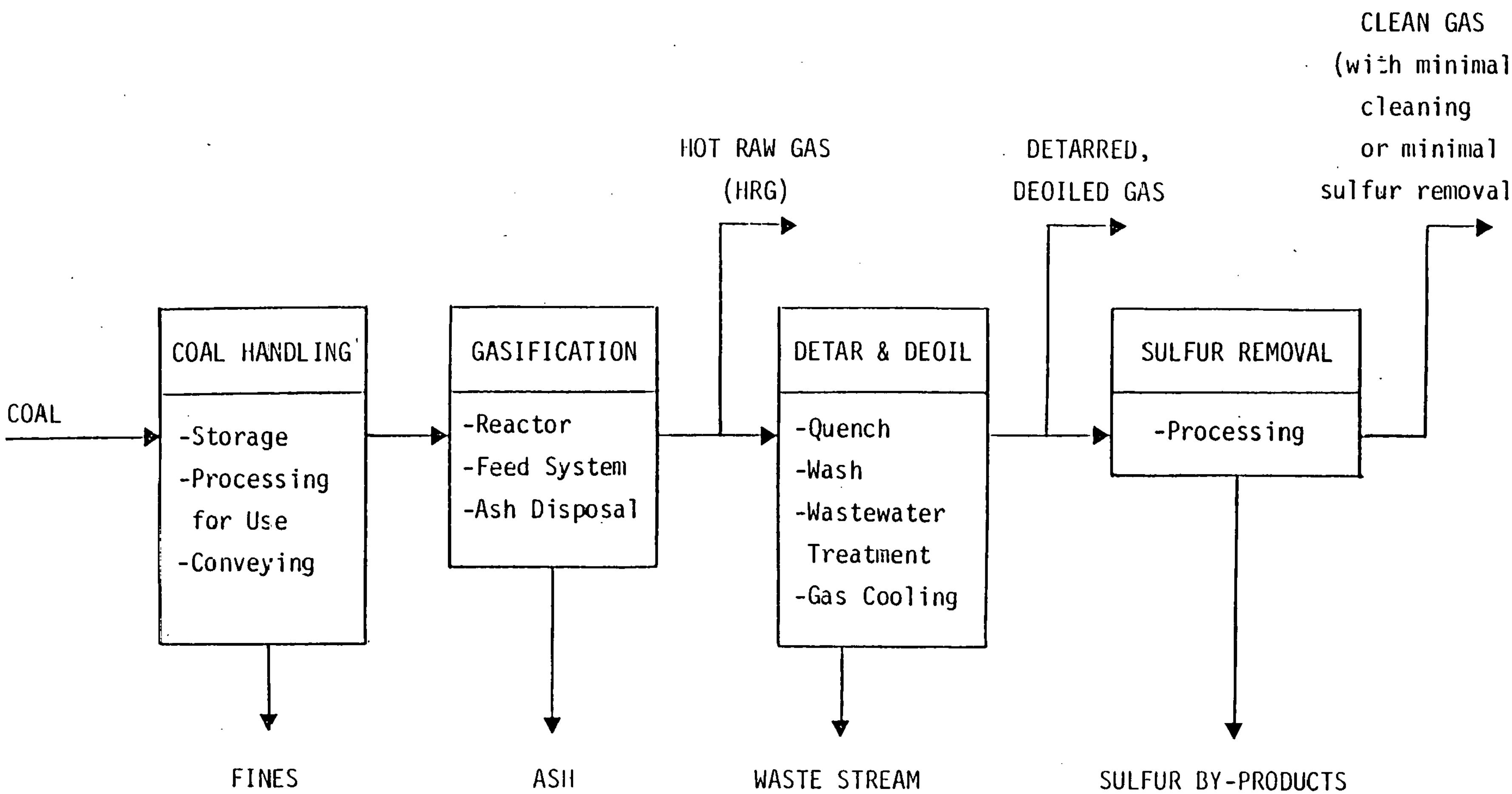


Figure 5.2: LBG Processing and Products

5.2.2 Coal

Although other carbonaceous feedstocks are possible, only coal has been considered. Peat and lignite are considered here as grades of coal. The type of coal must be considered in the application of the gasifier but was not identified as a process cost determinant. This cost is presented parametrically in $/MMBtu. Substantial quantities of coal fines (as high as 30% of incoming coal) may be produced and rarely can be charged to the gasifier. The fines can be sold for boiler feed at coal price or briquetted and used in the gasifier. This economic analysis is not affected by the disposition or quantity of the fines.

5.2.3 Coal Handling

The coal handling category includes rail and unloading facilities, storage bins, conveyors, crushing and grinding, and feed storage. The cost data are shown plotted in Figure 5.3. There is considerable data scatter but all data lie below $4000/TPD. Since this is only 3-4% of the total capital cost with minor cost effect, this (highest) cost level was adopted.

5.2.4 Gasifier

The gasifier includes the feed system, reactor, steam system as applicable, and initial cyclone gas/particle separator. The ash slagging and disposal system costs could not be separated from the gasifier and the associated costs are included.

Figure 5.4 shows a plot of the cost data. The type of gasifier apparently has no significant effect on cost. Data scatter is minimal in the area of primary market interest, 20 to 300 TPD of process coal.

5.2.5 Detar and Deoil

This category includes gas quenching, condensation of tars and oils and production of steam as applicable. Cost data scatter was great as may be seen in the

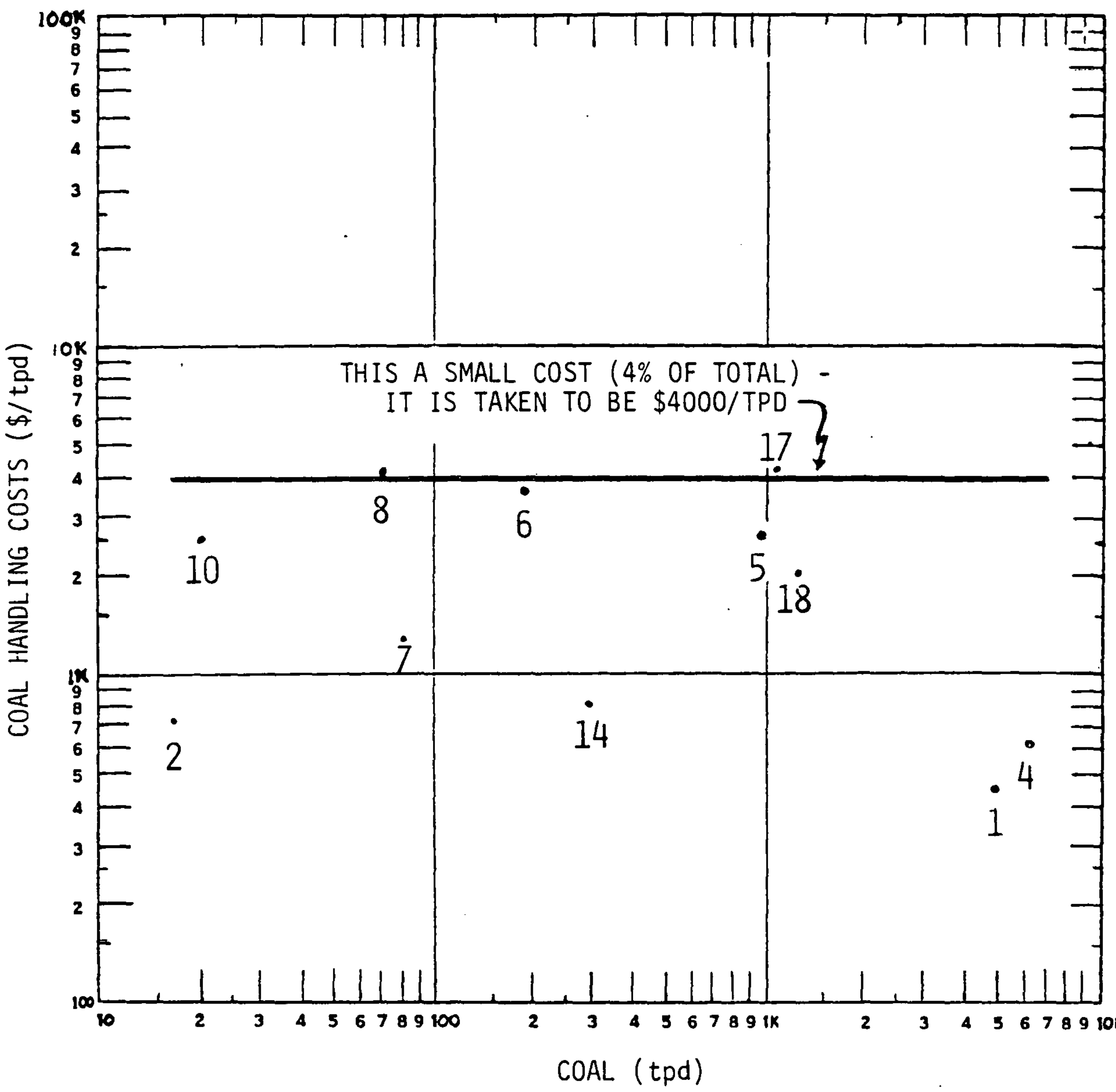


Figure 5.3: Coal Handling Capital Costs

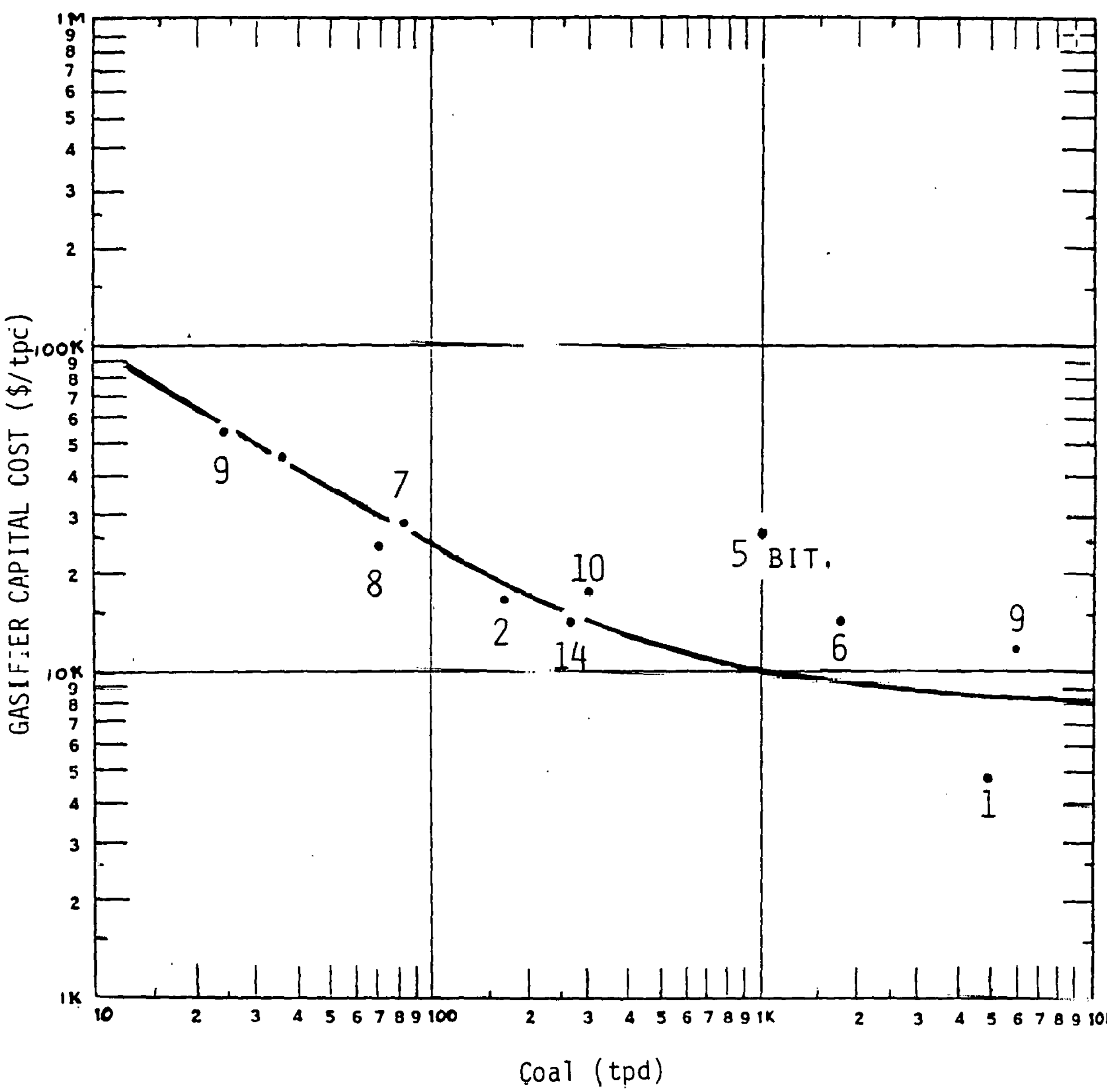


Figure 5.4: Gasifier Capital Cost

bottom line of Figure 5.5. The curve drawn is somewhat arbitrary but after 100 TPD coal process use, the cost of this category is less then 12% of the gasification system cost at the $10,000/TPD level and thus not a critical cost item.

5.2.6 Sulfur Removal

This category includes "detar and deoil", removal of sulfur and sulfur compounds from gas, and reduction of sulfur to elemental form as applicable.

There are several processes for sulfur removal with variable application depending on gas quality and flow rate. The cost data are shown plotted in Figure 5.6. Data are quite scattered. Cost of sulfur removal did not correlate with sulfur content in coal and, in some cases, relatively little sulfur content required high costs for removal. The method adopted for using these data is to plot the two lines defining the cost range of sulfur treatment and letting the user assess the cost severity. Use of these cost curves should preclude the use of the lower, detar and deoil, curve since the sulfur removal curves include detar and deoil.

5.2.7 Miscellaneous Costs

Miscellaneous (capital) costs consist of such items as flare stacks, cooling tower, utility systems, miscellaneous engineering, contingency, land and site development, foundations, and other minor items that could not adequately be categorized.

This cost was determined as the difference between total gasification system cost and components. Table 5.1 lists this difference in the range of 20 to 300 TPD process coal use. The number is very constant and was taken at $50,000/TPD of coal.

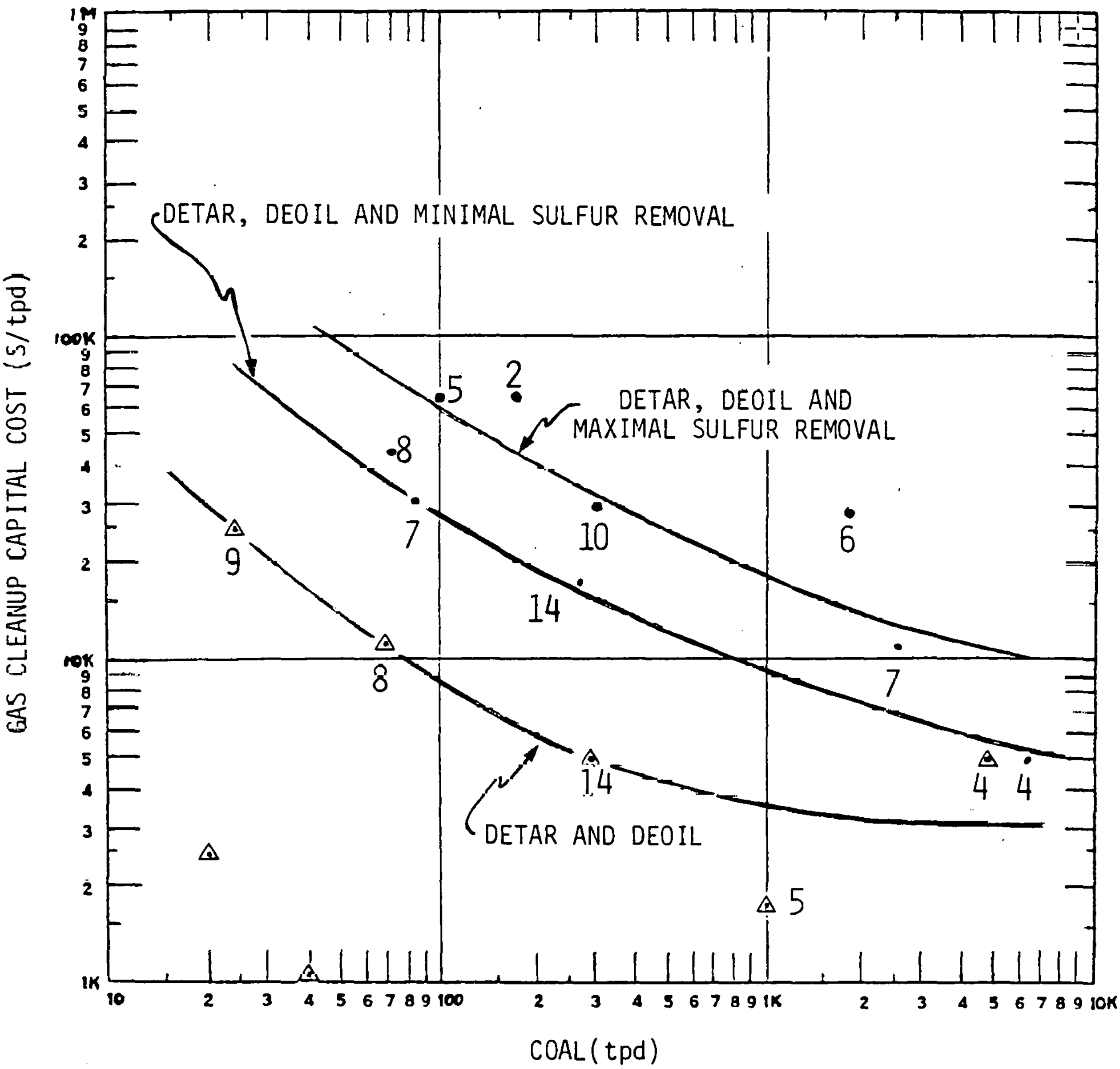


Figure 5.5: Gas Cleanup Capital Costs

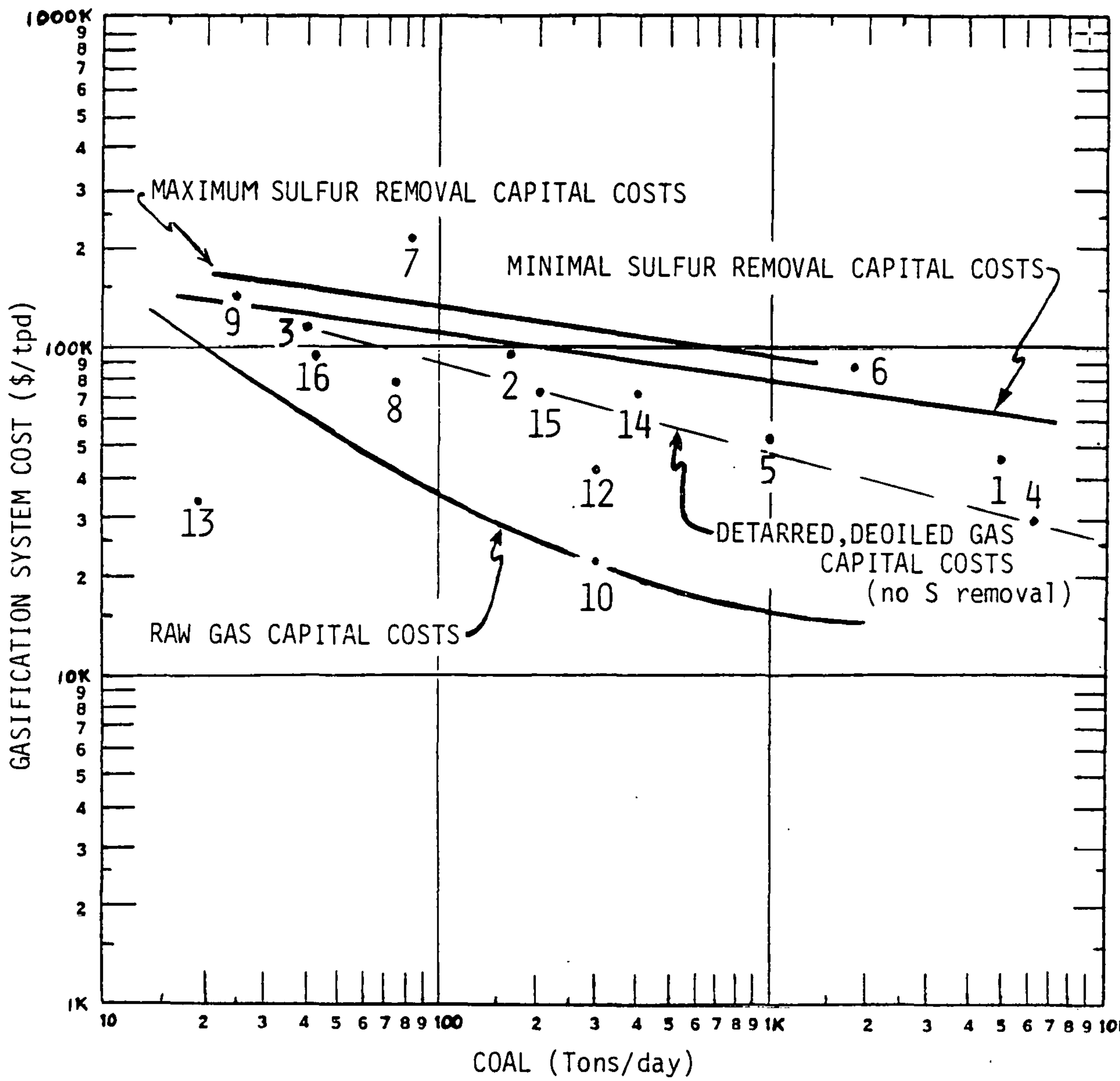


Figure 5.6: Gasification System Costs (Total Capital Costs)

Table 5.1: Miscellaneous Cost (Capital)

Capacity	Miscellaneous Cost
(TPD)	($/TPD)
20	44,000
50	56,000
100	53,000
150	49,000
200	45,000
300	46,000

5.2.8 Total Gasification System Cost

The total gasification system cost includes all of the foregoing mentioned capital costs and the costs of miscellaneous items as noted in Section 5.2.7. Figure 5.6 shows the plotted capital cost data for LBG reported in the surveyed literature (and escalated to 1981 dollars). Curves for the four product types were drawn based on a composite of the data displayed earlier in this section. The hot raw gas and detarred, deoiled gas capital costs curves include no sulfur removal. Of the two sulfur removal curves, the minimal removal curve is based on data reported in Ref. 4 as seeming to summarize costs for gasification installation and is assumed to represent average sulfur treatment. The upper lines drawn from 50 to 500 TPD coal use was derived to represent complete (and severe) sulfur removal treatment. It was obtained by maintaining a $50,000/TPD miscellaneous costs between the summation of components costs for high sulfur removal costs and the complete gasification system cost.

5.2.9 Operation and Maintenance Cost

Costs included here are labor, overhead, utilities, maintenance, and all other operating expenses. (Feed costs are normally included under this heading but are treated separately here). Figures 5.7 and 5.8 show production costs as $/TPD and as the percent of capital costs respectively.

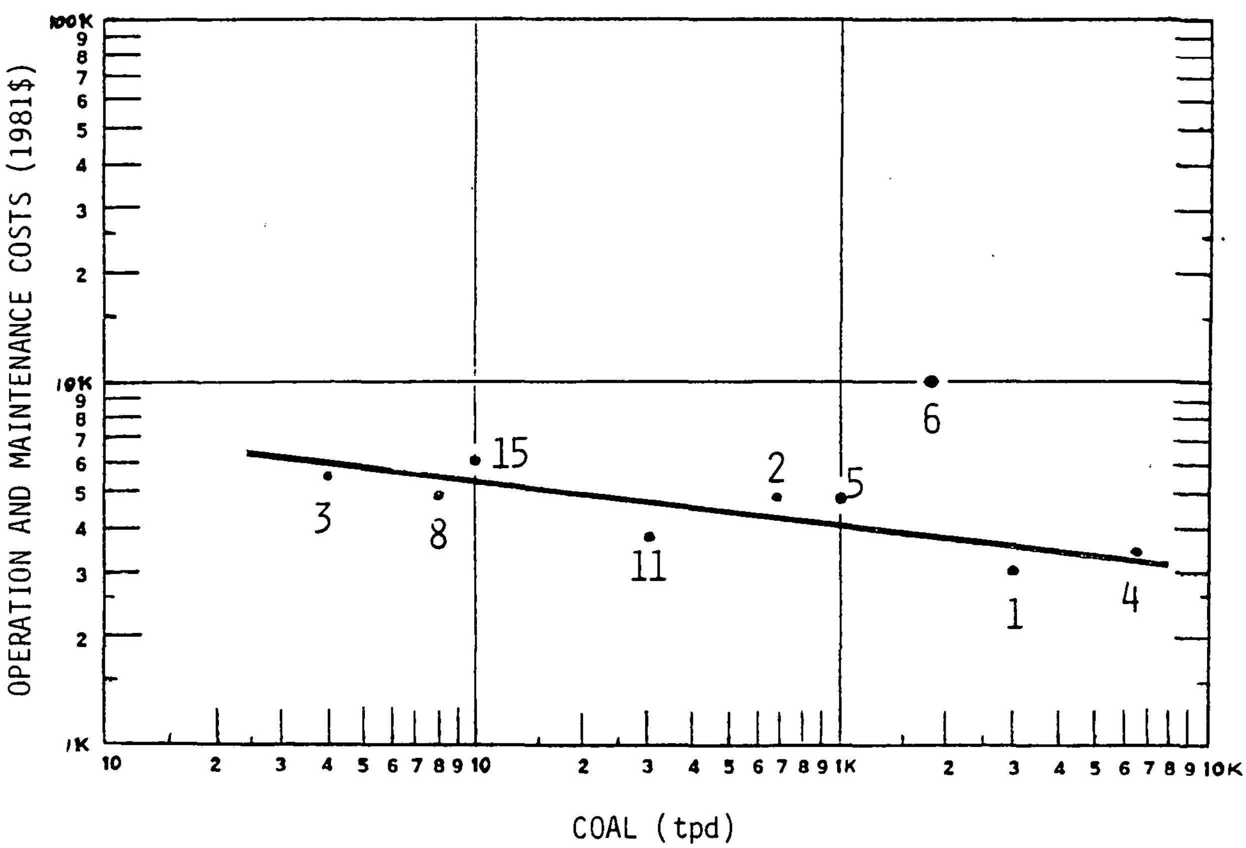


Figure 5.7: Operation and Maintenance Costs (1981)

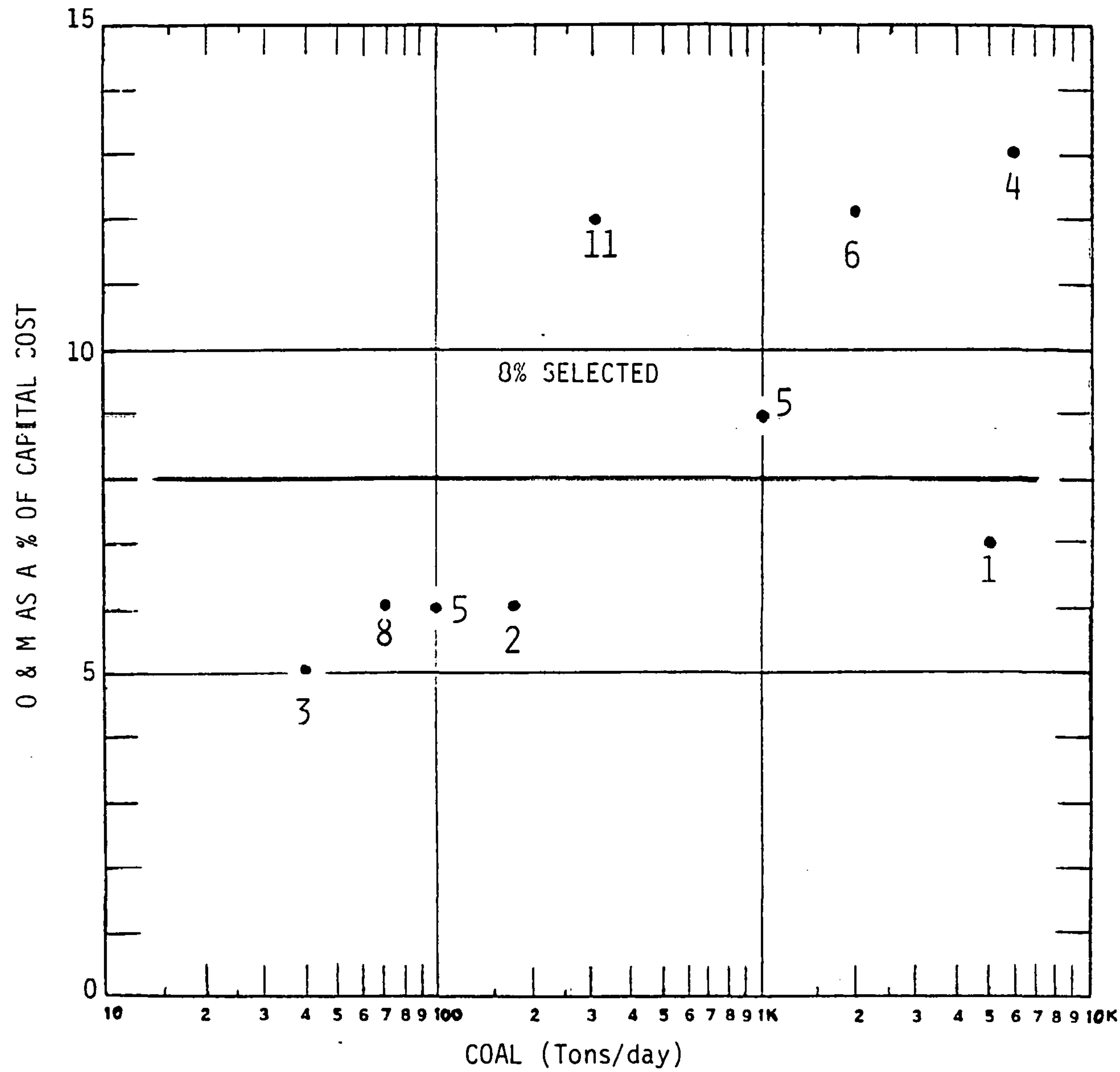


Figure 5.8: Operation and Maintenance Costs as a Percentage of Capital Costs

As shown in Figure 5.8, most points fall below 10% (and all below 15%). In the range of interest (20 to 300 TPD), the percentage was even lower. For this reason, 8% of total capital was selected as the standard O&M costs to be used in this analysis. This study uses the percent of capital costs as being adequate for gas cost estimation.

5.3 COST OF GAS (COG)

5.3.1 General

The production cost of gas is calculated using the following:

$$COG = \frac{F + OM + kC}{G} \qquad (1)$$

where F = Feed cost, \$/yr (parameterized in this study)
OM = Operation and Maintenance cost, \$/yr (from section 5.2)
C = Capital cost, \$(from section 5.2)
G = Equivalent heat production, MMBtu/yr
k = Constant reflecting financial parameters

The constant k is obtained from an adaption of Ref. 1, which gives an average cost of capital in 1981 dollars.

$$k = \frac{0.05(C-W) + .005(P+48/52\ (1-d)r)\ (C-.025(C-W))}{C} \qquad (2)$$

where W = working capital (this is normally about 3% of the capital cost and is set as zero for this study since the accuracy of costs presented does not warrant this consideration).

$$P = di + (1-d)r$$

i = Interest on debt, %/yr

d = Debt fraction

r = Return on equity, %/yr

Some factors inherent in this equation are shown in Table 5.2.

The results of COG calculations are presented for the utility financing method (UFM) with parameters shown in Table 5.2. The resultant factor is k = 0.14.

The UFM may be considered the lowest cost of capital. The (modified) discounted cash flow method (DCFM) may be assumed to be at the high end of capital cost. Using the DCFM parameters shown in Table 5.2, k = 0.17. The cost of capital is about 40 +% of the COG; thus the use of DCFM instead of UFM financing makes a difference of 15% (higher) in COG. Estimates of COG for other financial arrangements require assembling capital costs from data presented in Section 5.2.

5.4 DISCUSSION AND RESULTS

5.4.1 General

The purpose of the economic section of this report is to provide a methodology to enable the reader to estimate the cost of gas (COG) for LBG. The inputs for this methodology are: gas production in BBtu/D or coal usage in TPD; type of product gas desired, and cost of delivered coal. For this study four options are provided for type of product gas: hot raw gas (HRG); detarred and deoiled gas; and two levels of sulfur removal for clean gas - minimal and maximal. Figure 5.2 defines the process system for each of these gas types. The cost components for estimating the COG are coal handling, gasifier, detar and deoil, sulfur removal, and O&M. Estimates of the contribution of each of these were presented in Section 5.2.

TABLE 5.2

FINANCIAL PARAMETERS FOR
CALCULATION OF AVERAGE COST
OF CAPITAL

	UFM		DCFM (Modified)
Factors inherent in Equation 1			
Inflation		none	
Project Life		20 yr	
Depreciation		5%/yr straight line	
Federal Income Tax		48%/yr	
Plant Usage		330 days/yr	
Interest of Debt (i)	14%/yr		14%/yr
Debt Fraction (d)	0.75		1.35
Return on Equity (r)	15%/yr		15%/yr

The financial parameters used in calculating COG are shown in Table 5.2 and explained in Section 5.3. For the reader's convenience, the UFM COG curves were determined and are shown with parametric costs of coal in Figures 5.9, 5.10, 5.11, and 5.12. The DCFM COG curves are not shown but can be readily determined by the method given in Section 5.3. The costs of coal in Figures 5.9, 5.10, 5.11, and 5.12 are for bituminous coal and are given in $/MMBtu. For anthracite coal, the $/MMBtu are shown in parentheses. The costs differences are based only on heat content differences in anthracite and bituminous coals, anthracite being on the average for 1980-1981 11,800 Btu/lb and bituminous being 11,300 Btu/lb (Ref. 25). Any advantages to anthracite due to higher carbon content or reduced clean up requirements have been ignored.

The remainder of the discussion of results will be devoted to comparison of the COG values calculated in this study with literature reported values, sensitivities of the COG values to capital cost and plant usage, comparison of LBG COG to cost of alternate fuels, and a discussion of the effect of a possible government incentive.

A sample calculation of COG is given in Appendix A to assist the reader.

5.4.2 COG Calculation Comparisons

To verify the methodology developed for determining COG, several literature values for conceptual and proposed LBG processes were compared to the calculated values of this study. Given the plant capacity and type of gasification system, Figures 5.9, 5.10, 5.11, and 5.12 were used to determine the calculated COG values. The reported literature COG values were escalated to 1981 dollars and plotted versus the calculated values (Figure 5.13). As shown, almost all values calculated in this study were higher than reported values, indicating the conservative approach used in this analysis.

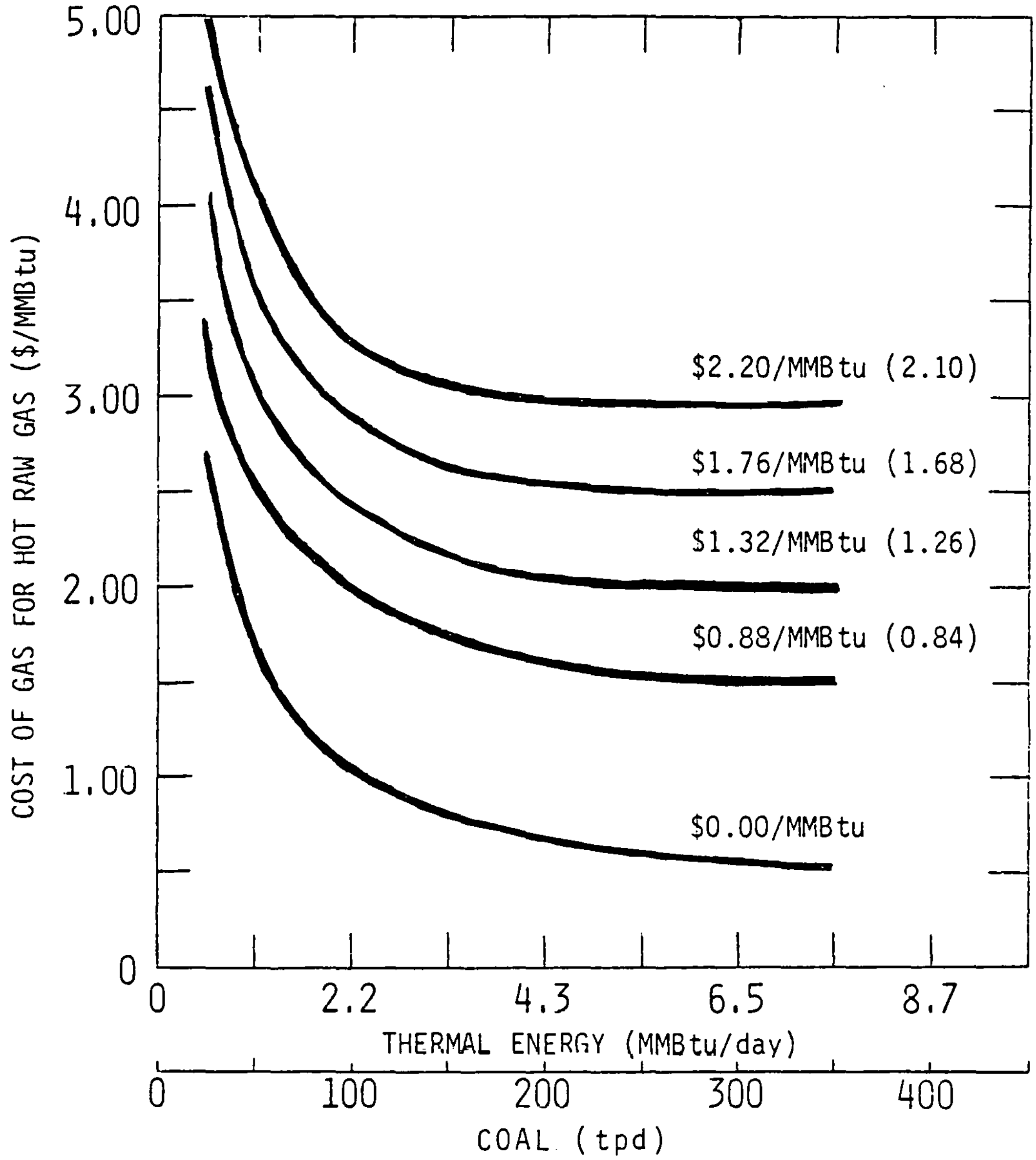


Figure 5.9: COG for Hot Raw Gas Using Utility Financing

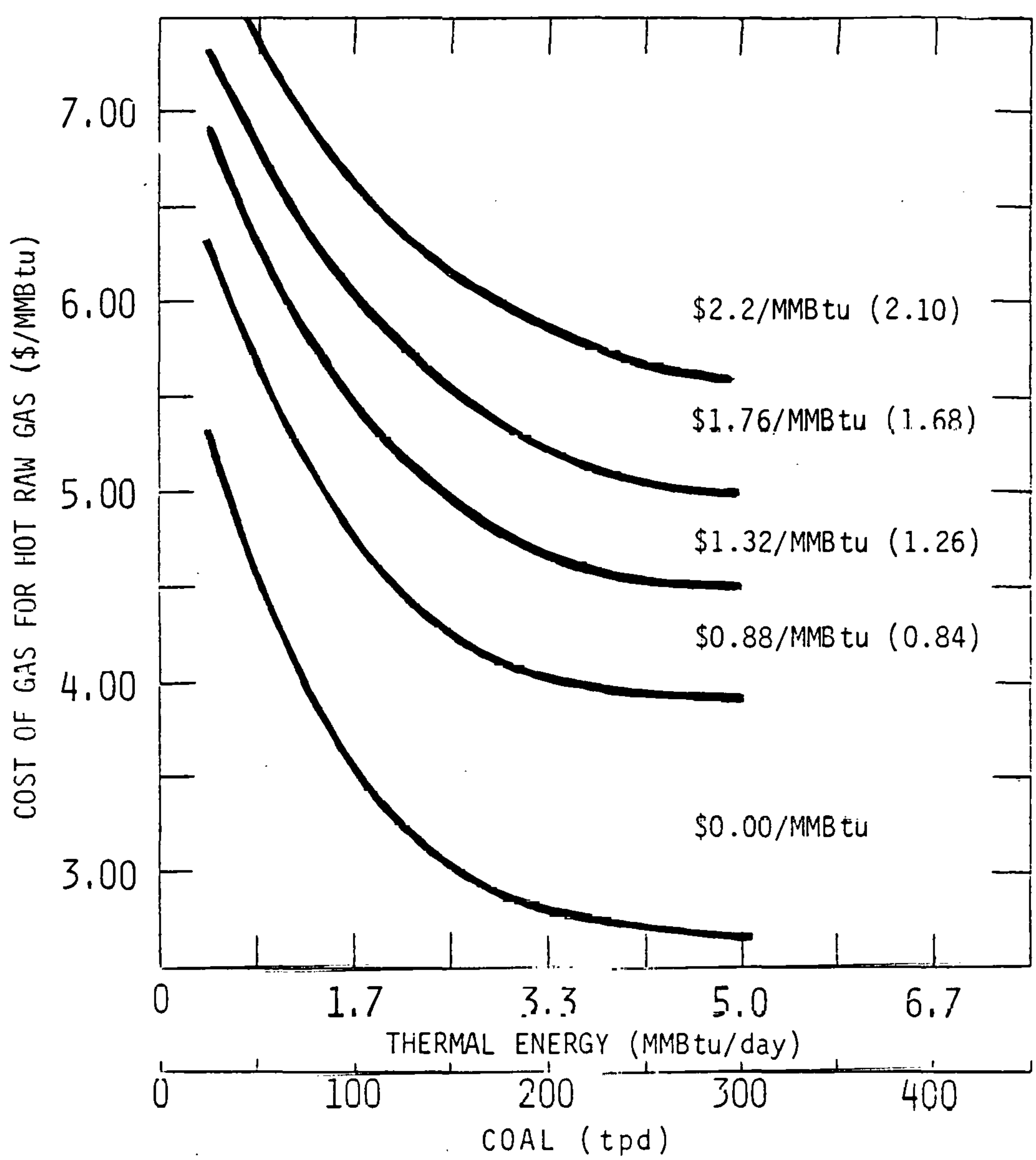


Figure 5.10: COG for Detarred, Deoiled Gas Using Utility Financing Method

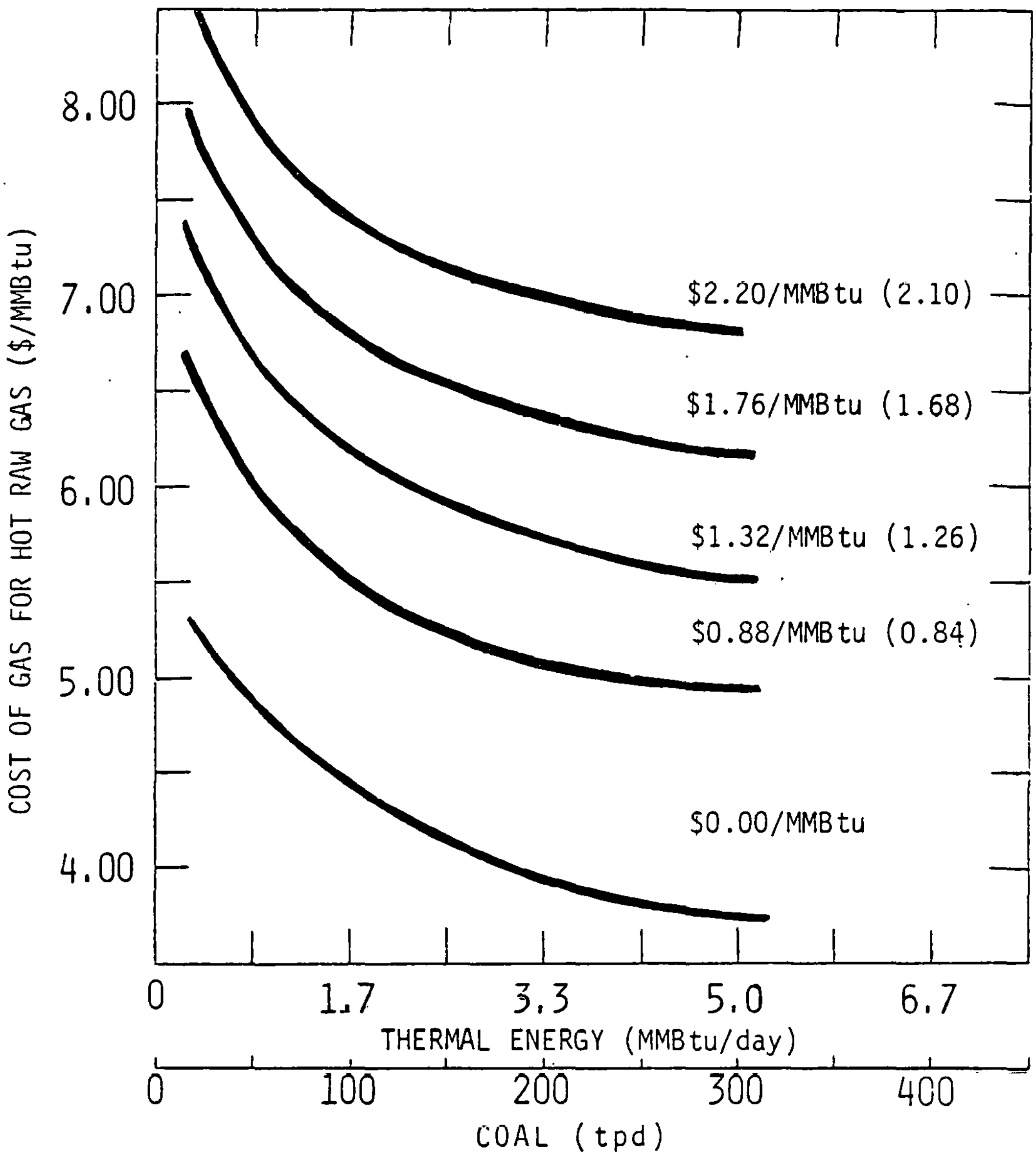


Figure 5.11: COG for Gas with Minimal Sulfur Removal Using Utility Financing Method

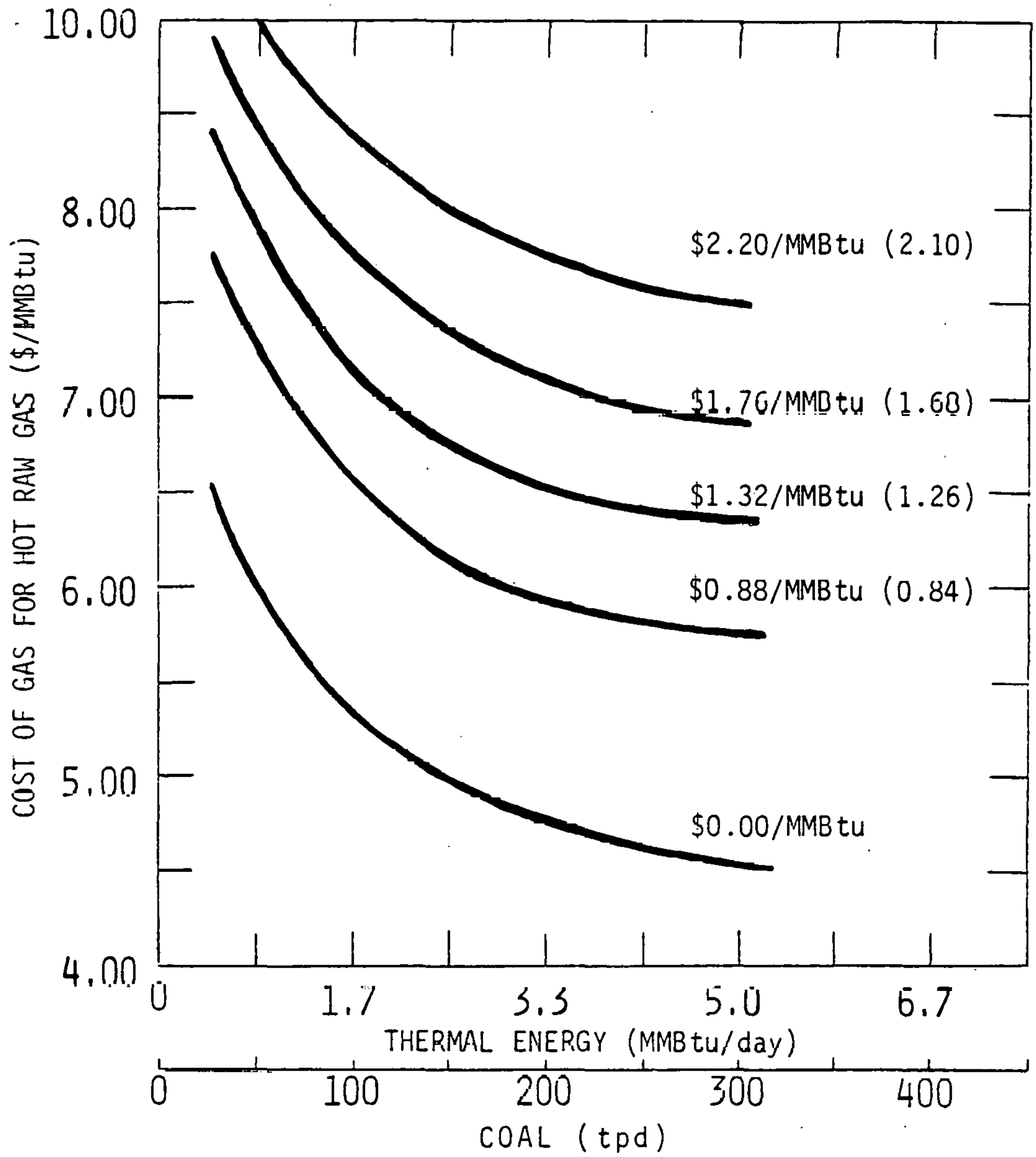


Figure 5.12: COG for Gas with Maximal Sulfur Removal
Using Utility Financing Method

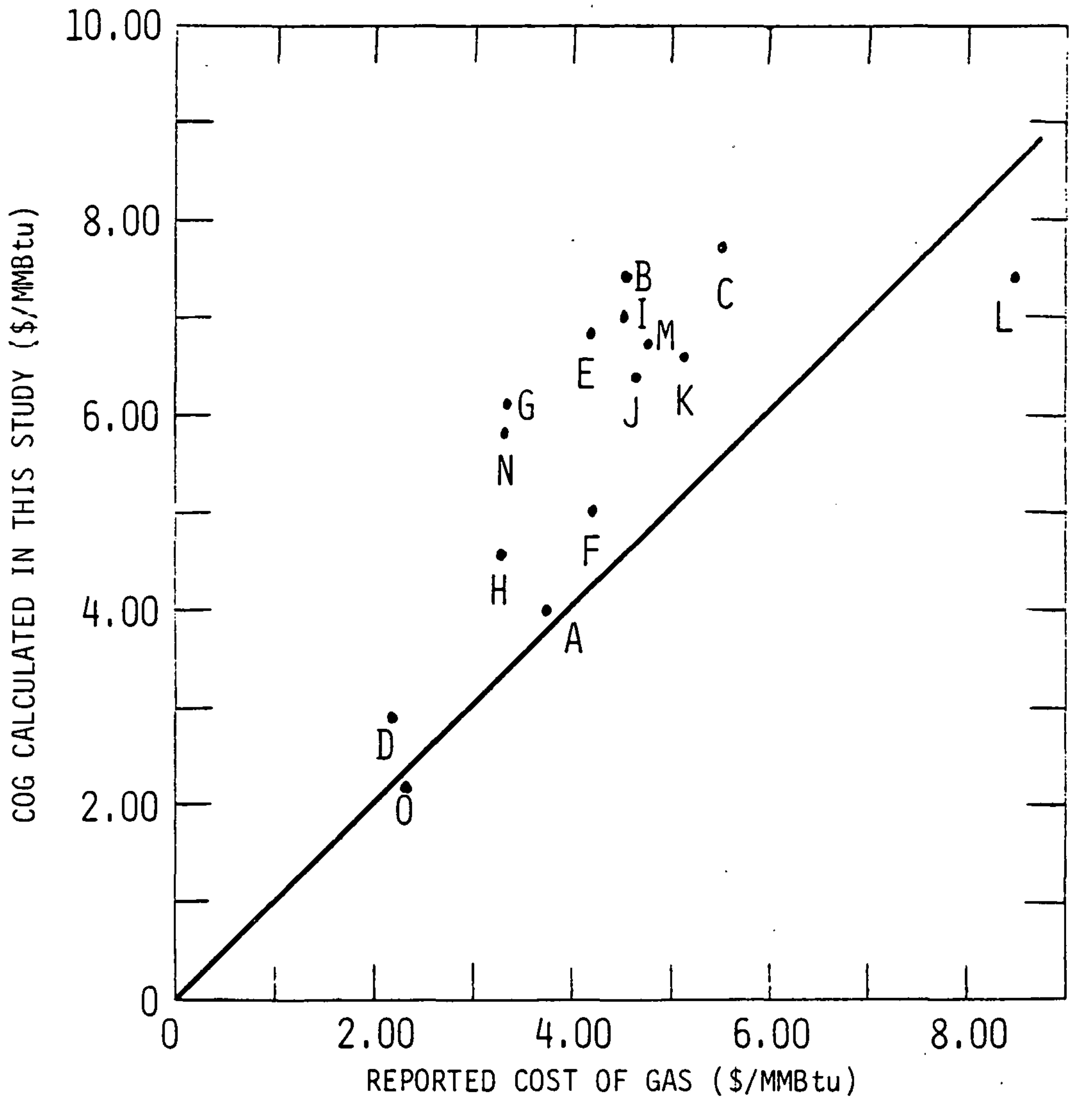


Figure 5.13: Comparison of Values Calculated in This Study Vs. Reported Values

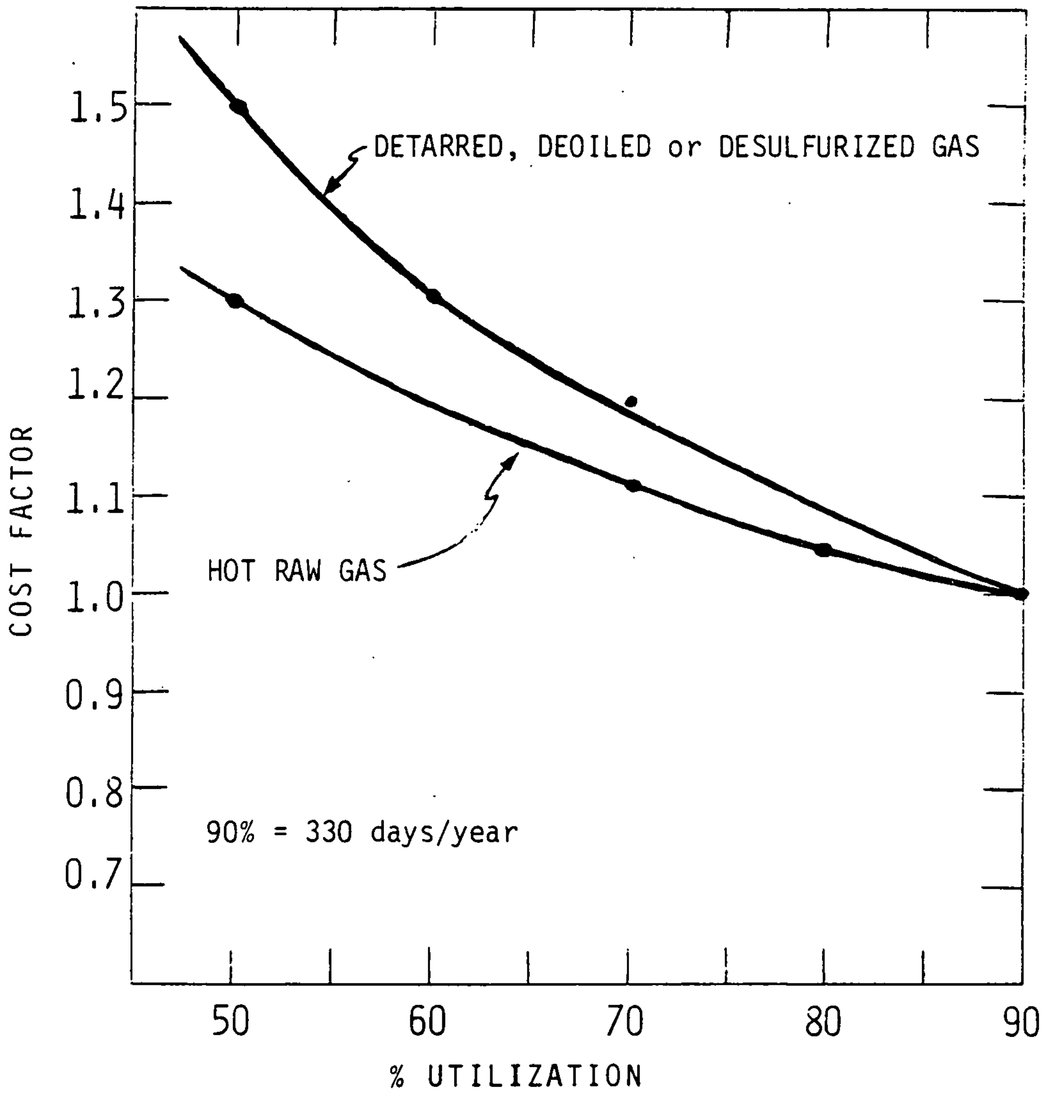
5.4.3 Sensitivites

The sensitivity of COG to plant usage and to capital cost were determined by consideration of the basic cost equation: (Feed costs are presented parametrically and operation costs are too small to be significantly affected by changes in plant usage or capital cost).

$$COG = \frac{F+OM+kC}{G}$$

The sensitivity of COG to gas production (utilization) was determined by applying a factor (f + % utilization/90%) to the feed coal cost (F) and to the yearly production of heat (G). Operation and maintenance charges were assumed to remain the same. The resulting graphs for systems for hot raw gas and detarred, deoiled and desulfered gas are shown in Figure 5.14. All cost values given in this study are for 90% utilization. The sensitivity of COG to capital costs is facilitated by the zero coal cost on the graphs presented. This curve represents that portion of the COG attributed to operation and maintenance plus capital costs. O&M costs have been taken at 8% of capital costs, so the portion of COG due to capital is readily calculated. An assumed percentage change may now be added to the COG given by the graph.

As an example of determining sensitivity to capital cost, assume a 175 TPD plant designed for minimal sulfur removal (Fig. 5.11). Using the $0/MMBtu curve, the COG due to capital and O&M would be $4.00/MMBtu of which $3.70/MMBtu would be due to capital (8% of capital being O&M). If the capital cost data are 5% higher, then the actual COG due to capital is $3.52/MMBtu and the difference between the new COG due to capital and O&M (3.52 x 1.08) and the original ($4.00/MMBtu) can be subtracted from the original COG for the coal cost of interest to obtain the actual COG. (For coal at $1.32/MMBtu, the actual COG would be 5.80 - (4.00 - (3.52 x 1.08) or $5.60/MMBtu).



COG = Cost of Gas

Figure 5.14: Sensitivity of COG to % Utilization (Load Factor)

5.4.4 Alternative Fuels

For LBG to be used it must be economically favorable over the other available fuels (oil or natural gas). Prices for No. 6 residual fuel oil for 1981 and natural gas for 1980 are \$6.87 (Ref. 22) and \$3.08 (Ref. 23) respectively. These values already lie within the cost range of the low cost LBG systems (HRG and detarred, deoiled gas). With the expected increase in the prices of these fuels as projected by the Energy Information Administration's "Annual Report to Congress" (Ref. 24), the cross over points for favoring LBG are now or in the near future. The EIA report projects industrial use prices of natural gas for 1985 to range (in 1979\$) from \$3.47 to \$4.10 per MMBtu (nonfeedstock prices). From the results obtained in this report, HRG and detarred, deoiled gas range from \$1.50 to \$5.70 depending on the cost of coal. Although there is no accurate way of making these ranges directly comparable, considering the future effects of price decontrol of natural gas, it seems obvious that the financial advantage of using LBG over natural gas will soon be established. For residual oil, the financial advantage of LBG usage may now be a fact for many applications.

5.4.5 Government Incentives

For this analysis, one government incentive was considered, accelerated depreciation at 10% per year. COG using tax credit incentives were not determined because it is unlikely that LBG systems will be profitable the first few years of operation. However, it was determined that a 20% tax credit could be applied over as long as 12 years, which makes this type of incentive appear very desirable from the LBG user's point of view. The accelerated depreciation incentive analyzed in this study required modification of Equation 2 in Section 5.3 which resulted in the k values shown in Table 5.3. (The base values are shown for comparison.) Representative COG values for the hot raw gas system for the incentive are shown in Figure 5.15. COG values for the other gasification systems can be easily obtained by substituting k and other appropriate values (given earlier in this report) in the equation:

$$COG = \frac{F + OM + kC}{G}$$

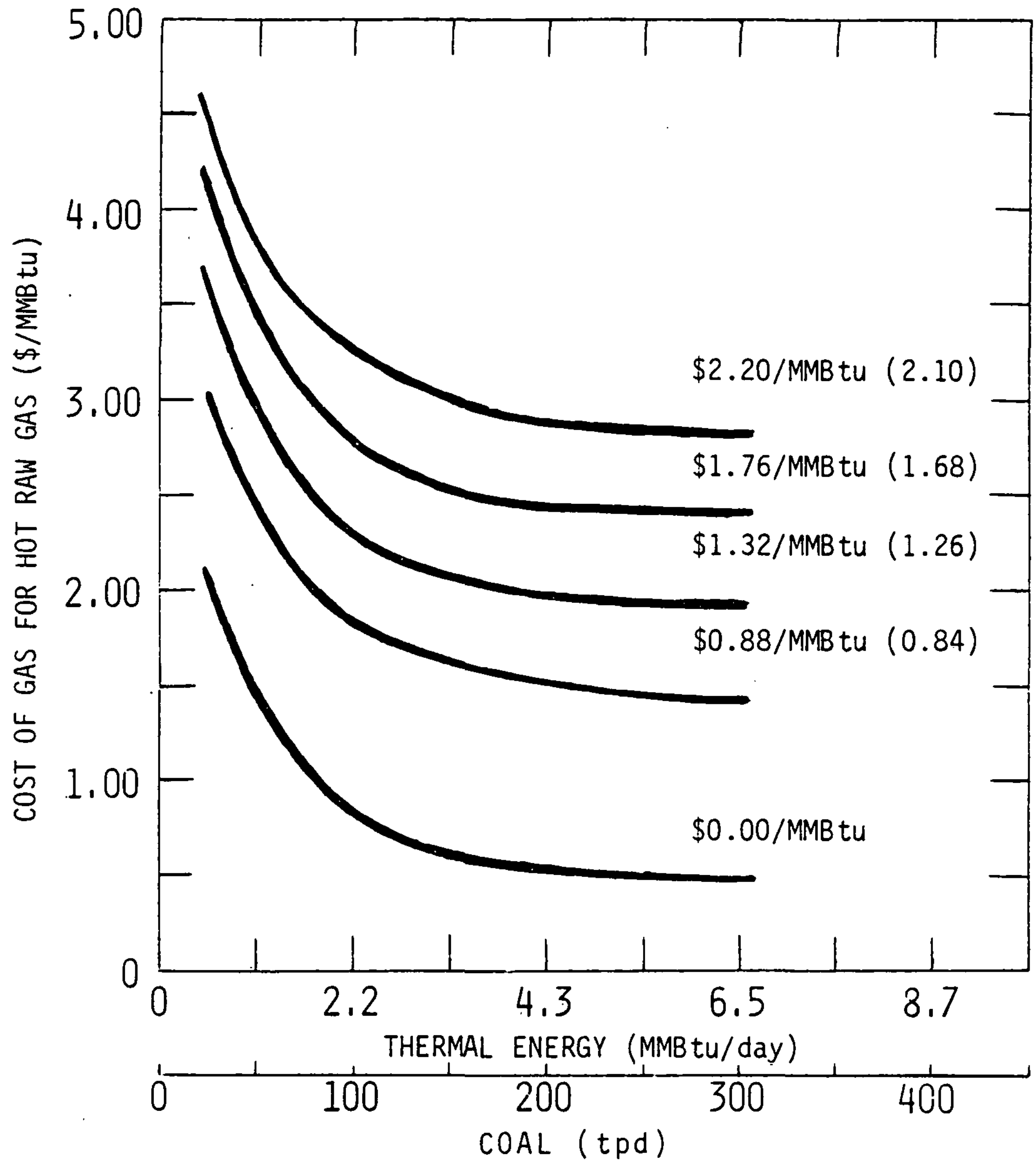


Figure 5.15: COG for Hot Raw Gas Using Government Incentives- 10% Depreciation/Year

In general, the incentive decreases the COG by 4% to 15% with the higher percentage applying to smaller plants (20 TPD) and the lower percentage applying to larger plants (300 TPD).

TABLE 5.3

Cost of Capital Factors (k) for
Base and Government Incentive Cases

CASE	OPTION	COST OF CAPITAL FACTOR (k)	
		UFM*	DCFM**
Base	Depreciation 5%/yr	.14	.17
Incentive	Depreciation 10%/yr	.10	.10

*UFM is defined as 75/25 debt/equity
**DCFM is defined as 35/65 debt/equity

5.5 SAMPLE CALCULATION FOR COG

The calculation for COG is based on the modified (C.F. Braun) equation:

$$COG = \frac{F + OM + kC}{G}$$

where: F = Cost of Feedstock - coal (user input)

OM = Operation & Maintenance cost per year - levelized (8% of C)

k = Constant reflecting financial parameters (obtained from Section 5.3 or Table 2)

C = Total gasification system capital cost (obtained from Figure 6 and the desired capacity TPD or MMBtu/D)

G = Heat (gas) production (MMBtu/yr)

COG = Cost of gas (MMBtu)

To illustrate the use of the equation, COG from a 100 TPD plant for producing detarred and deoiled gas (as defined in Figure 2) will be determined. Assume that bituminous coal can be obtained for $40/ton ($1.76/MMBtu).

The cost of feedstock, F, is:

$$\$40/\text{ton} \times 100 \text{ TPD} \times 330 \text{ days/yr} = \$1,320,000$$

The cost of capital, C, is obtained from the second curve in Figure 6 as $90,000/TPD or $9,000,000.

The cost of operation and maintenance, OM, is taken as 8% of C or $720,000.

The financial parameter constant, k, can be recalculated from Equation 2 if financial parameters other than those shown in Table 2 are desired. For illustrative purposes UFM financing with the shown parameters will be assumed here with k = 0.14.

The gas or heat production rate can be estimated using the relationship of 1 BBtu per 60 tons for all product types except HRG. Because of the heat credit given to HRG, 1.3 BBtu per 60 tons should be used for HRG plants. Using the given relationship, a 100 TPD plant for detarred, deoiled gas, produced 1.7 BBtu per day or 561,000 MMBtu per year.

Substituting these values in the equation, we have:

$$COG = \frac{1,320,000 + 720,000 + .14(9,000,000)}{561,000}$$

$$= \$5.88/\text{MMBtu}$$

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SECTION 6 - CONCLUSIONS

Coal gasification has provided mankind with a good source of fuel for two centuries. During this period coal gasification has had periods of greater are lesser popularity. These periods of popularity have been dependent on other fuel sources, both from availability and cost points of view.

The choice of using or not using low-Btu gas depends primarily on the process designated to use the gas. The choice must be made also on the overall economics of the use of low-Btu gas versus other fuels or chemical feedstock sources. In addition, the continued availability of other sources, and the future availability of fuel for the gasifier should be considered.

It is suggested that after natural gas deregulation the price of natural gas will rise to or above the price of oil on a cost per Btu basis. This will occur in the time-frame of 1985, a very near time when one considers the time required for evaluations, designing, construction, and production.

SECTION 7 - 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, produced by using oxygen instead of air as a gasifying agent.

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 full of such solids. The reactant gases (e.g., air 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 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."

Receipt of raw coal and delivery of cooled as, by-products, 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.

SECTION 8 - 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

APPENDIX A - UNIVERSITY OF MINNESOTA, DULUTH/DOE GASIFIERS IN INDUSTRY PROGRAM

This gasification project was begun in response to Program Opportunity Notice (PON) FE-4 from the U.S. Energy Research and Development Administration (ERDA - now the U.S. Department of Energy) in 1976 by the Regents of the University of Minnesota at Duluth. The plant has been operating since 1978 and has tested several coals. An environmental assessment was written for the plant.

Gasification Site - University of Minnesota, Duluth Campus Power Plant at Duluth, MN

Main Physical Plants Office - University of Minnesota, Minneapolis, MN

A&E - Foster Wheeler Energy Corporation, Livingston, NJ

Gasifier - One two-stage, 10-foot diameter FW-Stoic gasifier

Type of Fuel Feed - Colorado-Wyoming Bituminous Coal (0.5% sulfur) western subbituminous coal, lignites, and coke (start-up only)

Fuel Rate - 3 ton/hr (maximum)

Gasification Products - 1.44 X 10^9 Btu/day of low Btu (160 Btu/scf) gas and ____ Btu/day of oil

Application of Products - Fuel for campus power plant's 2 Keeler boilers which supply heat to campus buildings; boiler uses low Btu "producer" gas when gasifier is operating and uses the oil when the gasifier is not operating

Estimated Cost - $4.818 million dollars for capital cost and three years of operation

Cost Share by Participants - Regents of the University of Minnesota, 50% and U.S. Department of Energy, 50%

A.1 BACKGROUND

University of Minnesota had responded to U.S. Department of Energy's Program Opportunity Notice (PON) FE-4 to demonstrate low Btu gasification technology using a Foster Wheeler, two-stage, Stoic gasifier. Low Btu gas produced at the Duluth site would be combusted in two Keeler boilers, and the steam would be used for the direct heating of 27 campus buildings. Fuel oil, also produced, would be stored in underground tanks during spring, summer, and fall months, to be combusted as a supplemental fuel during periods of peak wintertime demands. The third standby boiler could be used for peak period demand. The two Keeler boilers would be able to burn oil as well as low-Btu gas produced by the gasifier.

The University of Minnesota proposed this demonstration system to DOE on 9 July 1976. The proposal covered the engineering, design, construction, operation, and evaluation of the integrated gasifier/heating plant system. The objectives of the 55-month program were to reduce dependence on Canadian oil, compensate for interruption and eventual termination of the natural gas supply, provide reliable fuel source for the Duluth heating plant, and evaluate operations characteristics.

Foster Wheeler provided the construction and technical assistance for this project. The University of Minnesota's project is one of the seven in DOE's Gasifier in Industry Program. The project is intended to demonstrate integration of an LBG system with existing heating plants.

A.2 PROCESS DESCRIPTION

The Foster Wheeler-Stoic (FW-Stoic) two-stage gasifier represents a system that has been successfully employed in South Africa. All low Btu coal gasification processes yield a gas with a high content of carbon monoxide and hydrogen. The fixed-bed approach of the FW-Stoic gasifier combines pyrolysis of coal with gasification of carbon by reaction with steam and carbon dioxide to produce LBG that is then directly burned in the retrofitted Keeler boilers.

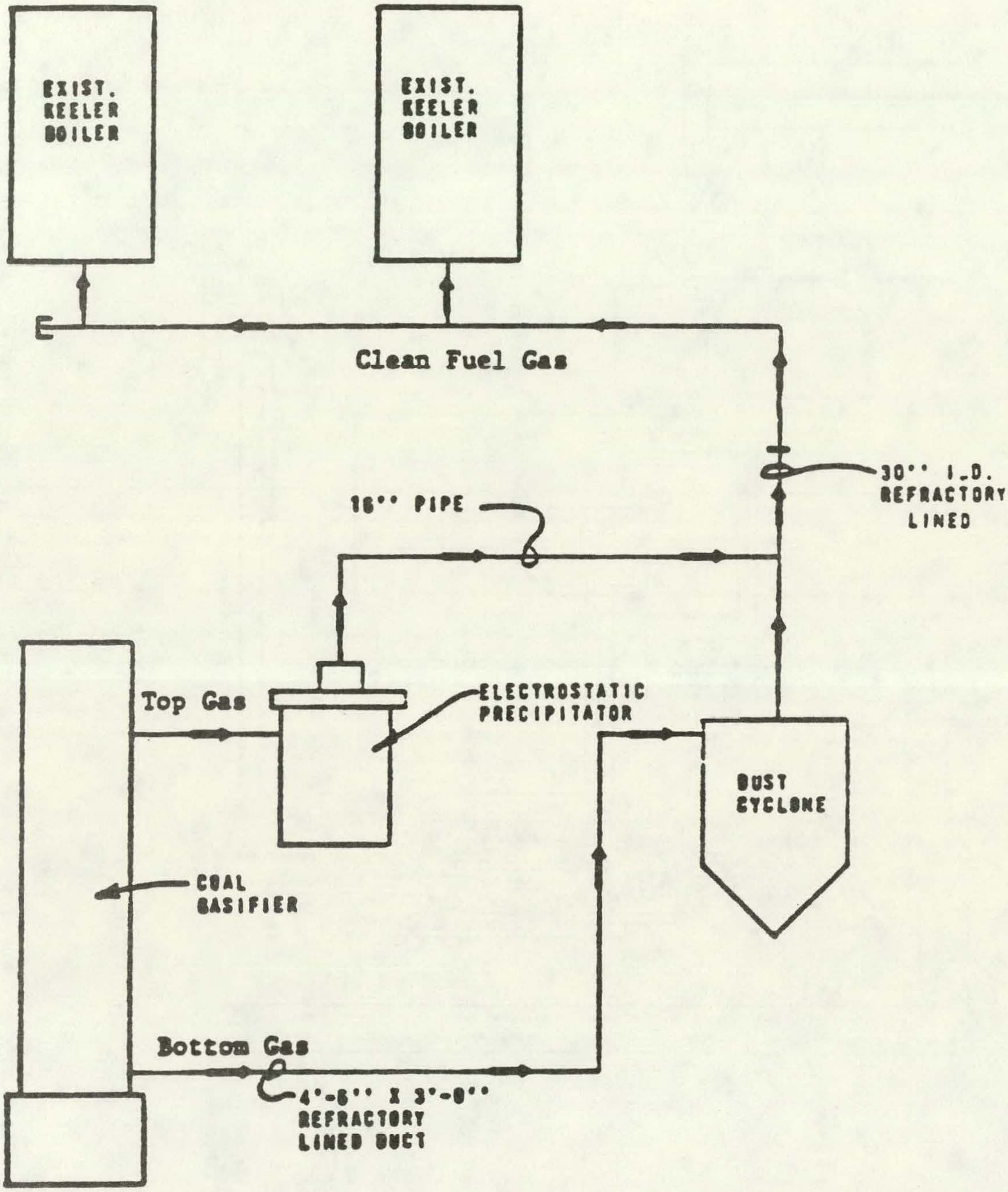
Screened coal (with tramp iron magnetically removed) is automatically fed from a bunker into the top of the gasifier by a lockhopper coal feeder. The coal feeding system is under negative pressure to prevent coal dust from escaping during operations. The feed rate is automatically controlled according to the coal level in the gasifier. Steam and air are introduced through a rotary grate into the base of the coal bed as it descends and is gradually devolatilized. The bottom gas is withdrawn from the lower section where the fire zone operates at over 1800°F (980°C) under oxidizing conditions. The top gas rises into the reducing zone where the product is withdrawn at a temperature of 250°F (120°C). This top gas contains the heavy hydrocarbons present in both the liquid and gaseous states. Liquid droplets are subsequently removed by an electrostatic precipitator. The resultant oil has a Higher Heating Value (HHV) of 6.2×10^6 Btu per barrel and can be used as a heat source in the No. 3 Boiler in a peak-shaving operation during periods of heavy demand.

Ash is removed from the base of the gasifier through a water-sealed pan that rotates with the grate. It then drops into two bucket elevators that discharge the ash into conveyors. These conveyors in turn carry it to an ash storage and loading facility. Automatic instrumentation controls the gasification process. A feedback pressure controller adjusts the fuel gas generation. The temperature of the air-stream mixture fed to the grate is monitored to control the steam flow. The rotating grate agitates the ash in order to maintain uniform downward flow of the coal bed and upward flow of the gas. Condition of the bed is further maintained by periodic actions of a steel poke rod. Figures 1, 2 show the process flow diagrams.

A.3 OPERATIONAL EXPERIENCE

During shakedown and baseline testing, the gasifier would operate on presized Elkol Wyoming coal taken from the southwest corner of the state near Kemmerer in Lincoln County. The proximate (as received) analysis of this coal is as follows:

	WT. %	
Volatile Matter	32.68	
Fixed Carbon	43.19	
Ash	5.37	
Moisture	18.75	
Total	100.00	
Sulfur	0.41	
HHV, Btu/lb		10,259



Source: University of Minnesota

Figure A.1: Low-Btu Gas Flow Diagram

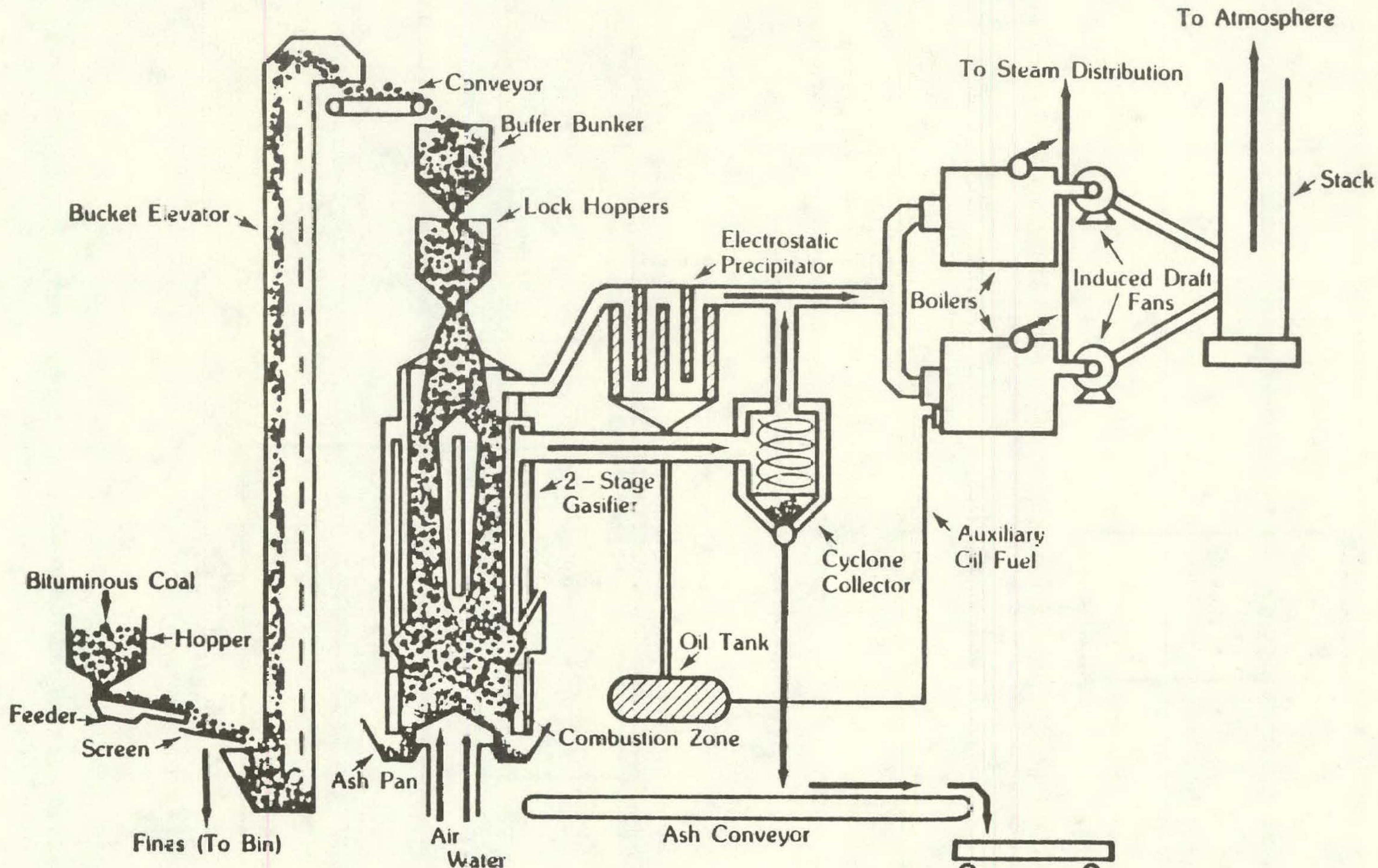


Figure A.2: University of Minnesota - Heating Plant Duluth Campus - Stoic Two-Stage Gasifier

In addition to this coal, six alternative coals may be used for testing and evaluation during the second and third years of the demonstration. These coals are as follows:

- Indian Head Mine - Beulah, North Dakota
- Western Energy Mine - Colstrip, Montana
- Peabody Big Sky Mine - Colstrip, Montana
- Big Horn Mine - Kleenburn, Wyoming
- West and East Decker Mines - Decker, Montana
- Westmoreland - Sarpy Creek Mine - Sarpy, Montana

Analysis of each of these alternate coals is presented in Table 1. It should be noted that combustion of the Indian Head Mine lignite would produce the greatest sulfur emissions per million Btu, and that combustion of the Peabody Big Sky Mine coal would produce the highest ash emissions per million Btu.

Two fuels are produced by the gasifier, low Btu gas and fuel oil. The fuel oil can be stored and used as a supplement during periods of peak demand. The hot cleaned gas at a temperature of 750°F has a Higher Heating Value of 166 Btu per standard cubic foot.

The sulfur content of the product fuels will vary depending upon the chemical composition of the feedstock coals. However, for purposes of calculating emissions it is assumed that 75 percent of sulfur in the feed would be transferred to the product gas and oil.

The efficiency of the combined demonstration boilers is 80.8 percent, resulting in peak load steam generation of 48,000 pounds per hour. This peak load generation occurred only during one day of 1975 and required a gas heat input of approximately 58.9 x 10^6 Btu per hour. This maximum heat requirement can be met by consumption of 58.9 x 10^3 scf per hour of natural gas at 1,000 Btu per scf or by 3.55 x 10^5 scf per hour of LBG at 166 Btu per scf. During a brief wintertime period of peak load requirements, when gasifier capacity is exceeded, the LEG is supplemented by product oil.

Fuel requirements for the Duluth Campus heating plant in 1975 were 1.62×10^8 scf of natural gas and 378,880 gallons (9,017 barrels) of number 5 fuel oil. Thus, the total heat input required for operation in 1975 was 2.17×10^{11} Btu. This indicates that the boilers were used approximately 42 percent of capacity during that year. By 1979, the total heat requirements are expected to increase by approximately 11 percent to 2.41×10^{11} Btu per year.

The capacity of the FW-Stoic gasifier is estimated at 6,000 pounds of Elkol coal per hour. It is expected that the total thermal efficiency of the gasifier will be 93.9 percent, resulting in a maximum of 54.7×10^6 Btu per hour of gas and 3.1×10^6 Btu per hour of liquid fuel.

Coal, hauled to the site by truck, is initially screened prior to transportation and covered as necessary to prevent dust emissions. Unloading takes place within a covered enclosure provided with a filtered exhaust as part of the ventilating system. Final screening of the coal, as it is fed into the gasifier through a bunker system, occurs within an area ventilated by a filtered exhaust.

The bottom gas exits the gasifier at 1200°F (649°C) and goes through a refractory-lined duct and a cyclone for removal of particulates. Dust removed by the cyclone from the bottom gas is emptied via the cyclone drop leg. The cyclone has the following recovery efficiency specifications (Washburn, 1977):

Size Particulate Microns	Percent Collection Efficiency	Typical Size Distribution
>100	100	22.5
100 to 60	100	27.5
60 to 10	98.9	25.0
10 to 6	84	13.0
6 to 4	48	6.0
4 to 2	32	3.0
2 to 1	10	2.0
<1	10 to 0	1.0

For purposes of this analysis, the overall average efficiency for this unit is 90 percent. The top gas goes from the gasifier through an electrostatic precipitator, a tube-type unit with cylindrical shell. Here the liquid droplets of heavy hydrocarbons are removed as an oil fraction and drained via a sealed pot to a heated storage drum. The electrostatic precipitator removes particulates from the top gas stream at an estimated efficiency of 98 percent.

The oil produced as a by-product to gasification is stored in two 30,000-gallon (1.14×10^5 liter) tanks buried near the four existing oil storage tanks. If a tank should develop a leak, it would be immediately emptied and repaired. Leakage is not expected to result in contamination because the oil would solidify in the soil at ambient temperatures.

Flue gas resulting from combustion of the cleaned product gas and oil passes through mechanical separators with a particulate removal efficiency of 82 percent. No recovery of sulfur for commercial purposes is planned at any stage of the process.

A.4 EVALUATION AND ENVIRONMENTAL MONITORING

A.4.1 Product Gas

Gas analysis is performed continously on the top and bottom gas streams leaving the gasifier. Measured parameters include temperatures, pressures, heating values and gas composition. The gas composition is determined by analysis for carbon monoxide, carbon dioxide, methane, water, and hydrogen. Daily average values are recorded.

A.4.2 Stack Gas

The flue gas from the boilers is continously monitored for oxygen, carbon monoxide, water, sulfur oxides, nitrogen oxides, and opacity. Flue gas temperatures and pressures are also measured continously. Periodic particulate emission sample tests are performed using the U.S. Environmental Protection

Agency methods. Other monitoring is undertaken as necessary. Carbon monoxide and other hazardous pollutants are monitored in the workplace and surrounding environment.

A.5 PROJECT HISTORY AND STATUS

Operation of the gasifier began during October 1978 using low sulfur (0.55%) Elhol coal (a Wyoming coal). High moisture (19%) of the coal proved to remove excessive amounts of heat from the system. Trouble with automatic push rods and electrostatic precipitator operation required design modifications. Coals with high moisture content and those that are very friable appeared to be unsuitable. A Colorado coal and Grass Creek (Wyoming) Coal, which have a low moisture and low friability proved to be the best suited for this gasifier. These coals have also produced a more suitable fuel oil than produced by other coals tested.

Between October 1978 and October 1979 there were four start-ups. These initial operations revealed few mechanical problems, material handling difficulties, equipment failures (e.g. electrostatic precipitator's frequent tripping; automatic pokerods failure, mercury seal failure, etc.). Fire zone temperature control was a burdensome task which was reflected with heavy labor turn over.

UOP/SDC monitored the first four start-up operations and recommended changes to improve future start-ups. After the fall 1979 start-up, the project was transferred to Morgantown Energy Technology Center's (METC) supervision. Incoming coal quality control was a problem due to relatively low volume (50-80 tons/day). Major factors were moisture, fines, and rocks in incoming coal. The volume was too small for the coal supplier to provide any kind of quality control. University of Minnesota receives presized coal from the supplier. There is no coal processing facility at the plant. Sized coal is shipped by rail and truck to the site.

The fifth start-up of November-December 1979 was a successful run of 103 hours. Average feed rate for this run was 2 tons/hour.

During the first 1980 run (1-31-80 thru 3-2-80), coal feed rate was 13/4 ton per hour. Eighty tons of Pennsylvania sub-anthracite coal, supplied by Caterpillar Tractor Company, was tested on February 18, 1980. Boilers #1 and #2 were entirely on coal gas. The second 1980 run (April 14-19, 1980) was short because of cracks in grate holder. The gasifier was down for the remainder of the year for the summer months (June - July - August) and for grate replacement and other maintenance selected repair.

In 1981, the gasifier ran continously from January 17 to June 25, 1981. The coal feed rate varied between 3/4 ton/hour and 2-1/2 ton/hour based on weather. Colorado coal from Milner, Colorado, was used for this run.

After the summer outage, the gasifier was started on September 19, 1981 for winter months to supply fuel for the boiler plant. The coal feed rate was variable between 1-2 ton per hour. UMD was able to reach the present agreement with Detroit Edison to supply it Montana coal (0.25% sulfur) sized and screened at $42/ton. This Montana coal comes in a unit train to Duluth area for transship on barge to Wisconsin, and sized and screened coal is trucked to the plant. UMD and Detroit Edison are studying the long term coal supply contract. UMD will test this coal in winter months for excessive moisture content (23%) and its impact on the gasifier operation.

It appears UMD has taken care of major operational problems associated with poke rods and the electrostatic precipitator. Automatic poke rod operation is replaced by once per hour manual operation to maintain the fire zone control. No trouble was reported for the electrostatic precipitator after internal insulator rebalance and repair. The DOE contract (45% support for labor and maintenance) ran out in September 1982, but UMD intends to continue to operate the gasification plant. At present prices of coal oil and natural gas, natural gas use proves economical, and gasifier operation is competitive with oil. Projected natural gas price deregulation by 1985 and higher prices for premium low sulfur oil will single out the cost benefits to meet the originally outlined coal gasification project objectives.

APPENDIX B - CAN DO, INCORPORATED/DOE GASIFIER IN INDUSTRY PROGRAM

Gasification Site - CAN DO Humboldt Industrial Park, Hazelton, PA

Home Office - CAN DO, Inc., Hazelton, PA

Gasifiers - 2 single-stage, fixed bed, 10 ft diameter, Wellman-Galusha® gasifiers

Licensor - Dravo Corporation, Pittsburgh, PA (Original Licensor - McDowell-Wellman Engineering Company, Cleveland, OH)

Type of Fuel Feed - Pennsylvania Anthracite (+3/16 in -12/16 in, includes "pea", "buckwheat", and "rice" sizes)

Feed Rate - 25-30 ton/day (per gasifier) (maximum)

Gasification Product - 600-700 x 10^6 Btu/day, low Btu (140 Btu/scf) gas per gasifier

Application of Product - Pipeline distribution throughout Humboldt Industrial Park - one current user, Inland Container Corporation, fires a boiler and process heat; potentially provide fuel for a vinyl wall covering process, plastic pipe manufacturing, chocolate bar factory, roofing materials manufacture, and others

B.1 BACKGROUND

The Humboldt Industrial Park is an 1140 acre park located west of greater Hazelton, PA. It is the second major park developed by the Greater Hazelton Community-Area New Development Organization, Inc. (CAN DO, INC.), a non-profit Industrial Development Agency for the area.

This park is a new park, and contains its own water and wastewater facilities. Four industries originally located in the park use fuel oil and propane for fuel. No natural gas is available to the park.

The Hazelton community recognized the need for a reliance upon domestic energy sources long before the energy crisis became a popular consideration. In 1974, CAN DO, INC. was awarded a grant to study the "Preliminary Design and Economic Feasibility for Manufacturing and Distributing Anthracite Based Produced Gas in Humboldt Industrial Park." (Applachian Regional Commission.) The conclusions of the study were favorable. The estimated project cost was approximately four million dollars, which was beyond reach for CAN DO. A few years later in 1976, the Economic Development Administration reviewed (through a consultant) projects that had the potential of providing employment while utilizing domestic energy sources. The CAN DO Project stood out in the comprehensive review as the project most likely to produce demonstrable results in the shortest time and for the least investment.

In December 1976, at a meeting of the Economic Development Administration (EDA), the Appalachian Regional Commission (ARC) and the U.S. Energy Research and Development Administration (ERDA) (now the U.S. Department of Energy-DOE), CAN DO, INC. was offered a 50% grant from EDA (based upon the recommendations of the consultant) for the design and construction of an anthracite coal gasifier. ERDA also offered a grant to CAN DO for the first two years of operation. In addition, ARC offered a grant of 30% of the cost of the design and construction of this project.

In September 1977, EDA and ARC approved CAN DO's grant application. In April 1978 CAN DO, INC. awarded a contract for the design and construction monitoring of the gasifier to Ebeco Associates, Inc., a consulting engineering firm located in Hazelton.

The CAN DO anthracite gasification facility is designed to convert anthracite coal into a clean, dry industrial fuel gas. The gas is distributed to industrial users through underground gas lines that exit throughout the Humboldt

Park. The gas being generated for use within the Humboldt Park will displace fuel oil and/or propane currently used for either steam raising or process heating.

Black, Sivalls and Bryson, Incorporated was awarded the contract by CAN DO, INC. to operate the gasification facility in October 1980. The contract between CAN DO and BS&B for checkout and operation of the facility is funded by a cooperative agreement between CAN DO and the U.S. Department of Energy.

During the spring of 1981 the gasifiers were individually started up following a checkout procedure, but as each gasifier began to produce gas, it became obvious that excessive CO was escaping from the system. Each gasifier was then shut down and leakage points located. Several repairs were made and minor design changes instituted. During October, UOP/SDC made an operational readiness review and determined that certain additional alterations were desirable.

The next start occurred during December 1981. The shakedown period continued through February 1982. Inland Container, a manufacturer in the Park, began receiving gas and lit off its boiler No. 1 on 24 February 1982 and continued to have satisfactory operation.

B.2 PLANT DESCRIPTION

Since gas produced from anthracite is low in tars and sulfur, the cleanup process is relatively simple -- gas sequentially passes through a system that provides dust removal in a low pressure cyclone, cooling in a waste heat boiler, scrubbing in a W.W. Sly Impinjet scrubber, compression to 6-7 psig, scrubbing in a variable throat venturi and another Impinjet scrubber, chilling in a gas heat exchanger, separating condensed water in a demister, reheating in a reheater, and distribution in a 20-inch pipe system.

The CAN DO anthracite coal gasification plant has in place a system with two gasifiers; two cyclones; five water systems, plus a boiler feed water system; four cooling towers, one of which is for gasifier jacket and agitator cooling;

nine process heat exchangers; four scrubber systems; a scrubber water stripper; two types of refrigeration systems; two air blowers and three turbo blowers; twelve process pumps; an emergency power generator; and two plant air compressors. A schematic diagram of the major elements in the gasification train of the CAN DO plant and a process flow diagram are shown in Figure B.1.

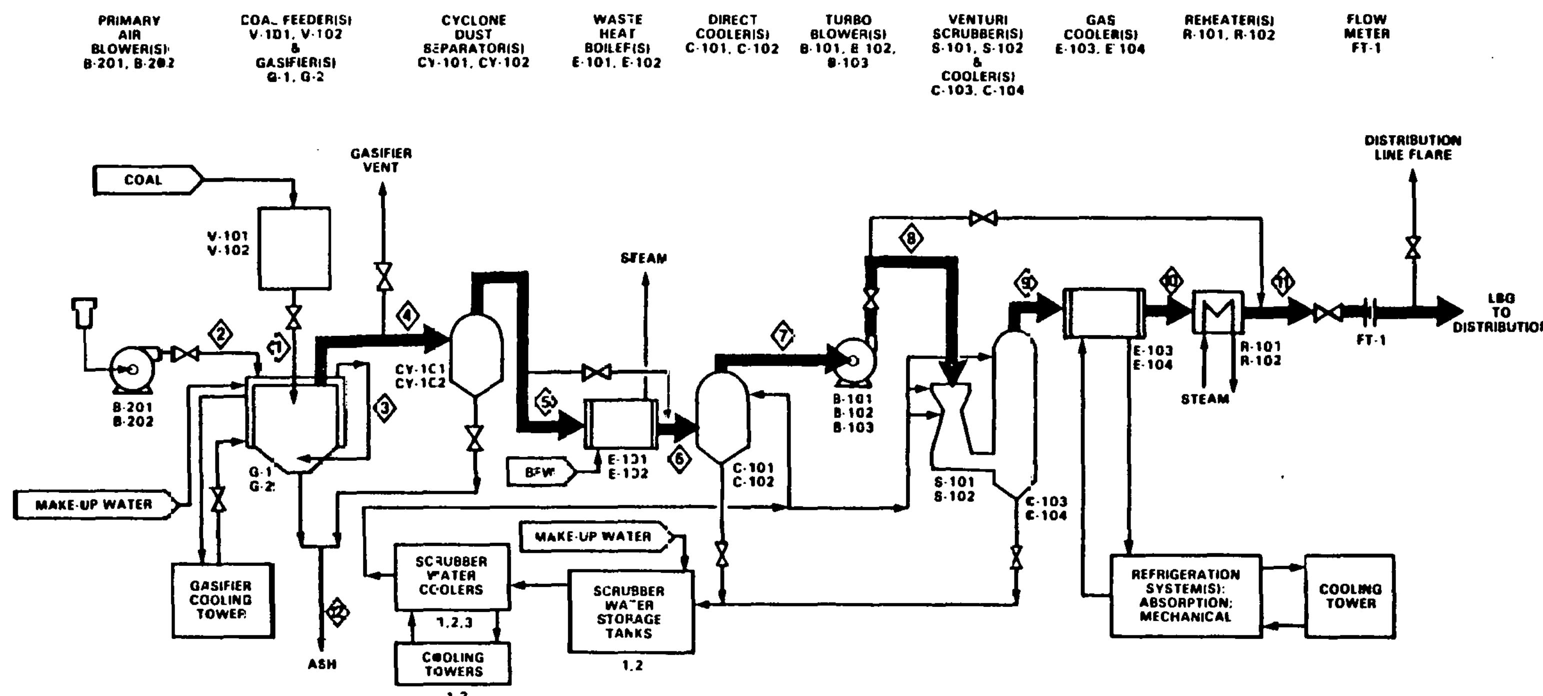
These systems are housed in or supported on a steel framed, grate-floored, insulated, panel-walled building. Ventilation of approximately 30,000 scfm is provided by four automatic 2-speed fans. Operation of these fans is normally triggered by the presence of excessive amounts of CO in the plant, but they can also be switched on manually. In cold weather, operation of the fans adds a substantial requirement for building heat (as much as 3 million Btu/hr on a 20°F day).

Shakedown operations of gasifier No. 1 for one month beginning 24 February 1981 and of No. 2 for four days starting 8 June 1981 disclosed a number of mechanical problems. The problems were evaluated and efforts were made to solve them. The plant was again started up during December 1981. The plant reached operational status during February 1982.

While initial operation of the gas cleanup systems was delayed because of a discovery of a major underground break in the distribution system, discovery of a number of other problems of various severities added to the delay. These problems were resolved.

The gas leakage experienced initially from cracked welds has been stopped and leakage from major flanges repaired. Leakage will continue from unsealed poke holes and coal valves until design changes are made.

The principal operating problems have been associated with valves. Most of the valve positioners have been replaced, and valves with buna-N seals in control and hot services have either been moved to cooler locations or replaced with valves having metal seals. A spill-back system was installed to keep turbo blowers out of surge, and a stop has been installed on each discharge control



STREAM* / COMPOSITION	UNITS	1 COAL FEED	2 AMBIENT AIR FLOW	3 SATURATED AIR FLOW	4 PRODUCER GAS	5 DUST FREE PRODUCER GAS	6 COOLED GAS	7 QUENCHED GAS	8 COMPRESSED GAS	9 QUENCHED H.P. GAS	10 CHILLED GAS	11 REHEATED GAS	12 ASH
SOLIDS	lb/h	2000			2								180
GASES	lb/h / scfm		7200 / 1400	8220 / 1765	9848 / 2455	9348 / 2465	9848 / 2465	9848 /	9848 /	9848 /	9848 / 2430	9848 / 2430	
MOISTURE	lb/h			1020	122	122	122	872	872	1074	62	62	
TOTAL	lb/h / scfm	2000	7200 / 1400	9240 / 1765	9972 / 2455	9370 / 2455	9970 / 2455	10,720 / 2723	10,720 / 2723	10,922 / 2795	9900 / 2430	9900 / 2430	180
TEMP.	°F		AMB.	142	690	690	300	115	173	110	60	100	
PRESS.	in.W.C / psig		/ 1.52	/ 1.51	11.0 /	6.0 /		2.0 /	/ 6.0	/ 5.8	/ 5.5	/ 5.4	

*NOMINAL CAPACITY FOR ONE GASIFICATION TRAIN

A JOINT VENTURE OF UOP INC. AND SYSTEM DEVELOPMENT CORPORATION
7929 WESTPARK DRIVE • McLEAN, VIRGINIA 22102
TELEPHONE (703) 790-9850

PROCESS FLOW DIAGRAM FOR THE CAN DO COAL GASIFICATION FACILITY

11-31-81
DWG 78ET10159
008-001 | 2

Figure B.1: A Process Flow Diagram for the CAN DO Coal Gasification Facility valve of the turbo blowers to avoid a complete shut-off. The 24" hot gas cross-over pipe between cyclone outlets was blanked off, but the system is still interconnected at the turbo blower section and discharge headers.

Identified mechanical problems were corrected or reduced to a level tolerable for plant start-up.

B.3 PRESENT STATUS

The gasification facility continued to produce gas at the rate of 60% of the capacity of one gasifier and supplied Inland Container Company until June 1982. At that time a scheduled shutdown was made and some system modifications begun. It was anticipated that operations would again commence later in the summer of 1982.

It is reported that Inland Container was pleased with the operation of its boiler on the gas. It is also anticipated that other leases in the park will convert over to the low Btu gas shortly.

APPENDIX C - TWIN CITIES RESEARCH CENTER

Gasification Site - Twin Cities Research Center of the U.S. Department of Interior, Bureau of Mines, Minneapolis, MN

Support Group - The Mining and Industrial Fuel Gas Group (MIFGA)

Gasifier - One single-stage, 6.5 ft diameter Wellman-Galusha® gasifier (leased for $1/year by Hanna Mining Company, Cleveland OH)

Licensor - Dravo Corporation, Pittsburgh, PA (Original licensor - McDowell-Wellman Engineering Company, Cleveland, OH)

Types of Fuel Feed - All ranks of coal (except anthracite), lignites, and refuse derived fuel/bituminous coal briquettes

Feed Rate - Up to 2 tons per hour (North Dakota Indianhead lignite)

Application of Product - Fuel for iron ore pellet indurating tunnel kiln, 30 x 10^6 Btu/hr combustor, and other applications

Contact Point - Dr. John C. Nigro
U.S. Department of Interior
Bureau of Mines
Twin Cities Research Center
5629 Minnehaha Avenue, South
Minneapolis, MN 55417
(612) 725-4638

C.1 BACKGROUND

The Mining and Industrial Gas Group (MIFGA) was formed to promote development and demonstration of coal gasification and its usefulness in industrial applications. MIFGA is a cooperative, cost-sharing organization consisting of the U.S. Department of Energy, the U.S. Bureau of Mines, and U.S. commercial firms interested in the production and use of fuel gas for mineral processing and other applications.

MIFGA is the successor to the Pellet Energy Group (PEG) formed during 1975 in response to gas supply interruptions that led to tripled gas costs. The pelletizing industry, that provides about 70-75% of the nation's iron ore, had relied heavily upon natural gas for its process heat. PEG consisted of a consortium of 18 companies with interests in iron ore, coal, gas, engineering, and construction, along with the U.S. Bureau of Mines and U.S. Department of Energy.

To limit reliance on uncertain fuel supplies, the U.S. Bureau of Mines and the pelletizing industry examined direct coal-buring as an alternative energy source. Also a U.S. Bureau of Mines feasibility study found LBG might be suitable for use in iron ore pellet induration, so PEG developed and implemented plans to demonstrate the concept in a pilot plant.

Since November 1978 performance tests have been conducted on a commercial-sized Wellman-Galusha gasifier for converting various coals to low Btu gas at the Bureau of Mines' Twin Cities Research Center near the Minneapolis/St. Paul airport. So far the gas produced has been used in a kiln to harden powdered iron ore pellets for blast furnace feedstock, as well as to test low Btu gas burner designs in a 22-foot combustion chamber. Both the kiln and combustion chamber are connected to the gasification structure. At the Research Center practical applications of established gasification techniques are emphasized: this gasifier is a simple, well instrumented, state-of-the-art unit.

When PEG completed its original objectives, the function of the Twin Cities gasifier was broadened to accommodate other gas-consuming end-use processes. In April 1980 MIFGA was formed to recruit these other users.

MIFGA members participate, direct, and operate the gasifier and downstream process equipment. The gasifier and some process equipment are owned by industry; the building and construction were provided with government funding. Operation, materials, and maintenance are shared by both.

For low and medium Btu gases derived from coal or other non-petroleum fuel sources to be accepted by industry, the gas produced must be compatible with the application process. The gas must also meet operational availability, environmental, safety, and cost requirements.

MIFGA has the following objectives and provides the following important benefits:

- Development and demonstration of low and medium Btu gasification--the test program is flexible and is revised semi-annually, or as required;
- Establishment of operating and design parameters for a variety of coal types;
- Development/demonstration of gasification of fuels other than coal--peat and combustible waste, for example;
- Definition of gasification operating conditions and, as a result, gas output and characteristics for different end-use processes--the facility test-bed can be fine tuned;
- Gain "hands-on" operating experience--the facility can be used as a training center for a member's operating and maintenance personnel;
- Obtain access to a model upon which to select gasification and process equipment for your own plant;
- Share problems and experience with other members, but retain control over proprietary process information brought to the project;

- Establishment of environmental baselines for actual fuels that members plan to use; and

- Participation in upgrading the gasifier to produce medium Btu gas--this gas with its higher heating value of 250-400 Btu/scf has wider industrial uses.

The Mining and Industrial Fuel Gas Group is organized so that each member has an equal say in its operation; members collectively decide the test schedule.

An elected nine member executive committee ensures that the program objectives are carried out in accordance with Group directives and prepares meeting agendas. Subcommittees are formed as needed to handle specific technical tasks.

MIFGA members meet as often as necessary, usually monthly, to hear progress reports, to contribute to gasifier development/demonstration operation plans, to share technical experiences with each other, and to determine financial commitments. The executive committee reports to the Group at these meetings, as do the various subcommittees.

The Group contributes support to the individual members in accordance with their needs. MIFGA members define these needs and then contribute information, manpower, raw materials, transportation, or money. Members share in the support of the Group and in turn receive support from it. Members' contributions and operating costs are carefully accounted for and regularly reported to the membership. Members can fund special tests, subject to Group approval.

In order to join the Group, each company must sign a memorandum of agreement with the U.S. Department of Interior, Bureau of Mines.

The gasifier program has a budget with funding provided by the U.S. Bureau of Mines, U.S. Department of Energy, and MIFGA members. Industrial members are expected also to supply either manpower or materials. All contributions made by members are recorded.

The operation of the TCRC gasification facility is provided by Black, Sivalls & Bryson, Inc. (BS&B) under contract to the U.S. Department of Interior, but funded by the U.S. Department of Energy. BS&B received a two year contract to operate the gasifier May 1982. Prior to this time MIFGA member companies supplied the sole manpower to operate the gasifier. Since May 1982 MIFGA members participate in the operation, but under the supervision of BS&B.

The MIFGA group (under PEG) was set to initially attract companies and individuals interested in iron ore pelletizing but then expanded to include those who are interested in other processes that can use low Btu (and medium Btu) gas (also referred to as producer gas). The varied uses for producer gas should attract many organizations to consider the benefits of belonging to MIFGA.

- Coal and mining interests--coal testing;
- Iron and steel industry--iron ore and steel processing;
- Boiler industry--test boilers and burners;
- Brick, glass, and ceramic industries--improve fuel options for kilns and driers;
- Lime production--provide options to natural gas in kilns;
- Pulp and paper manufacture interest--expand flexibility of fuel sources;
- Industrial interests requiring process heat from gas or oil--provide an option to fuel sources;
- Non-ferrous metal industry--fuel option for smelting and casting;
- Industrial parks--learn the secret of pipeline producer gas for an industrial park;

- Architectural and engineering firms--design and construction;

- Transportation--fuels need to be moved;

- Research groups--gasification/process facilities provide test beds and sample/data sources;

- Trade associations--energy consumption, product-cost improvement, and reliable process fuel supplies are important to their members;

- State energy departments--conservation of premium fuels and local resource utilization are important to states; and

- Educational/research institutions--gasification facility can be made available as part of laboratory research programs.

C.2 PROCESS DESCRIPTION

The Twin Cities Research Center gasifier is a 6.5 ft diameter, fixed-bed, atmospheric pressure unit with a water cooled agitator arm and a rotating ash grate. It has a nominal bituminous coal consumption rate of 3000 lb/hr, and is fed from above by a 10-ton storage hopper. Moist, warm air is generated for the gasification process by passing air over water heated in the gasifier cooling jacket. The air and steam react with heated coal to form the low Btu gas, often called "producer gas" or "coal gas".

From the gasifier the low Btu gas flows through a refractory lined cyclone. Then the gas flows to a combustor chamber via a 24-inch I.D. duct and to the pelletizing kiln via an 8-inch I.D. duct. The combustion chamber is designed to match the full gas producer output (about 30 million Btu/hr). The original scroll-type gas burner with register vanes to control flame shape has now been replaced by an axial-type burner.

Exhaust gases from the combustion chamber are cleaned with an impingement tray-type scrubber with pH control. A combination ignitor-incinerator is installed on the gasifier vent stack to ignite gases during flaring or to burn completely the small amount of gas generated during banking.

Instrumentation and controls for the gasifier are centrally located in a control room near the main operating floor of the gasifier building.

At various times other equipment has been tested by MIFGA members in the system. Several tar scrubbers have been tested to determine their efficiencies in removing tar from low Btu gas, monitors and control equipment have been added and tested, various burners have been tested and photographs made of the flame patters via the viewing ports on the combustion chamber, and a steam generator has been installed to improve gasifier operation with lignites fuels. EPA supplied a skid mounted, Holmes-Stretford (HS) gas desulfurization unit for the 1982 test program. To protect the Stretford unit from tar contamination, MIFGA members provided a test unit for removing tar from the gas and for cooling the gas prior to entering the HS unit.

C.3 OPERATIONAL EXPERIENCE

MIFGA has tested many coals and other fuels since 1978 which have not been tested in a fixed-bed gasifier previously. It had been said by many people, for example, that lignites were not suitable for fixed bed gasifiers. Through its testing program, MIFGA learned the secret of gasifying some lignites like North Dakota Indianhead lignite; but others like Texas lignite have proved very difficult to handle during gasification. A briquette--the Simplex briquette--was very successfully gasified during 1981; but a previously tested (1979) briquette using a tar binder was a total failure.

Fuels tested so far include:

Eastern Kentucky bituminous coal

- Colowyo (Colorado) subbituminous coal

- Absaloska (Montana) subbituminous coal

- Indianhead (North Dakota) lignite [5 tests, one being on fines (lignite "dust")]

- Decker (Montana) subbituminous coal briquettes

- Coke

- Western Kentucky bituminous

- Texas lignite

- Weyerhauser (West Virginia) bituminous coal

- Simplex (refuse derived fuel and bituminous coal) briquette

- Colstrip subbituminous coal

- Levcite Hills coal, and

- Other subbituminous coals and lignites.

C.4 STATUS

The MIFGA program has been well planned and is being carried out very well. The cost of the program has been the lowest of any recent program in gasifier operation that has been sponsored by DOE--this includes the contributions by all sources, not just DOE's. The reason is that MIFGA numbers have provided low cost and free services to keep costs down and make the program work well. Much of the coal has been donated; many times the transporation of coal has been free via the Burlington Northern Railroad; and the gasifier is provided by

Hanna Mining Company for $1 per year. This spirit has made the whole program go rather smoothly.

The test program for 1982 continued through November, at which time the gasifier was shut down for the winter (the unit has not yet been winterized--a future goal) and the 1983 test program drawn up.

The major problems in the project so far have been troubles with the draft fans and recording instruments. The fans have corroded because non-stainless steel blades were used. Recording instruments have failed because of tar blockage in test ports or because of corrosion of probes.

A big and important point of the testing program has been the very successful use of low Btu gas to indurate iron ore pellets. Secondly, the ability to gasify lignites and Western subbituminous coals has been a milestone for fixed-bed gasifiers. The use of a steam generator to produce steam, in addition to what the gasifier produces, for use in the gasification process with the Wellman-Galusha gasifier has been a big plus. Since lignites and subbituminous coals gasify at lower temperatures than anthracite and bituminous coals, the added steam proved necessary. The successful gasifying of carefully sized coal and lignite fines has been a milestone--fines mixed with the sizes of coal normally used in gasification often present control problems.

During 1982 the Holmes-Stretford (HS) desulfurization unit is being tested for the first time on a full-scale process in the United States. Many designs have been put forth with the HS process as part of the design, but none have been previously tested. The results of the Twin Cities test will be available during the fall of 1982.

APPENDIX D - ACUREX - GLEN-GERY CORPORATIONS/DOE GASIFIERS IN INDUSTRY PROGRAM

This gasification project was begun in response to Program Opportunity Notice (PON) FE-4 from the U.S. Energy Research and Development Administration (ERDA - now the U.S. Department of Energy) in 1976 by the Acurex Corporation of Mountain View, CA and the Glen-Gery Corporation of Reading, PA. The specific gasifier has been operating since October 1977 at the Glen-Gery Brick Plant at York, PA. The program was of 18 months duration and designed to instrument and take data on a fixed bed gasifier.

Gasification Site - York Division, York, PA

Home Office - Reading, PA

Gasifier - 1 single-stage, fixed-bed, 10 ft diameter, Wellman-Galusha gasifier without agitator (there is also another previously installed Wellman-Galusha gasifier in use at the York plant); the rest of the seven Glen-Gery gasifiers are discussed in Appendix K - Glen-Gery Corporation.

Licensor - Dravo Corporation, Pittsburgh, PA (Original Licensor - McDowell-Wellman Engineering Company, Cleveland, OH)

Type of Fuel Feed - Pennsylvania Anthracite (+5/16 in 9/16 in, 50/50 Buckwheat/Pea sizes)

Feed Rate - 24 tons/day

Gasification Product - 576 x 10^6 Btu/day, low Btu gas at an average heating value of 143 Btu/scf

D.1 BACKGROUND

Most of the material in Appendix D was taken directly from the undated Acurex Corporation report to DOE on this Gasifier In Industry project, DOE Contract No. EF-77-A-01-2573. The report title is "Integration and Evaluation of Low Btu Gasifier at the Glen-Gery Corporation Plant, York, Pennsylvania," printed approximately March 1980. Also used was the UOP/SDC report to DOE, "Analysis of Data on Gasifier Performance under 'Gasifier In Industry' Program," Report No. TR-MC-024-001, dated 28 December 1979, and performed under contract DE-AC01-78ET10159 (formerly numbered ET-78-C-01-3117).

In early 1976 the Department of Energy (then ERDA) established what is termed a Program Opportunity Notice, designed to stimulate industry to install and evaluate gasification systems. The programs were cost shared by both industry and the United Stats government. This program was the initial project to be funded in late 1976 because it possessed the potential of producing an extensive anthracite gasification data base within a short time period.

Although anthracite represents a small percentage of the United States total coal reserves, it represents a significant amount of energy for the industrial middle Eastern states. Available anthracite reserves are between 7 and 8 billion tons. At the current consumption rate of approximately 6 MM tons/year, these reserves will last over 1000 years. Assuming an order of magnitude increase in anthracite consumption to approximately 60 MM ton/year, the reserves still exceed a 100 year supply. These numbers illustrate that anthracite utilization can contribute to the solution of the industrial energy supply questions in the middle Atlantic states.

Washed, sized Pennsylvania anthracite is the premium coal available in this country. Gasification of anthracite has historically been demonstrated to be both economic and technically feasible using fixed bed, atmospheric gasifiers. This program was designed to generate a thorough data base for an established gasification technology. Anthracite gasification in fixed bed atmospheric gasifiers is nearly automatic. The high quality of the fuel required no process equipment to clean or condition the gas when it is used hot at relatively low pressures. This simplicity results in high conversion efficiencies to be achieved.

Data presented herein contributes to the data base from which industry and the United States government can reationally assess the following trade-offs.

- Inexpensive gasifiers/relatively expensive processed coal
- Gasifiers with expensive control systems/relatively inexpensive coal

This program first established a baseline set of anthracite gasification data corresponding to the following historical operational procedures of Glen-Gery Corporation.

- Coal Usage: approximately 24 T/day (anthracite)
- Coal Size: 50/50 Buckwheat/Pea
- Air Saturation Temperature: 146° - 150°F
- Ash Depth: 10 - 12 inches
- Load: (limited operation at 70% turndown)
- Coal Size: (Rice through Nut)
- Air Saturation Temperature: (140° to 156°F)
- Ash Height: (10 to 20 inches)

Anthracite coal is processed and categorized into ten discrete sizes. These standards are established by the Anthracite Standards Law and regulated by the Commonwealth of Pennsylvania. The seven largest sizes (through Rice) are tabulated below:

THE ANTHRACITE STANDARDS LAW
Commonwealth of Pennsylvania, Harrisburg, PA
Approved and Adopted by
ANTHRACITE COMMITTEE
ANTHRACITE INDUSTRY

Size of Coal		Test Mesh-Round Through	Over
1	Broken	10"	3-1/4"
2	Egg	3-1/4"-3"	2-7/16"
3	Stove	2-7/16"	1-5/8"
4	Nut	1-5/8"	13/16"
5	Pea	12/16"	9/16"
6	Buckwheat	9/16"	5/16"
7	Rice	5/16"	3/16"

The majority of tests were run with Pea, Buckwheat, and combinations thereof. Limited tests were run with blends of Pea/Rice and Pea/Nut. Coal size is an important operational parameter as a function of load.

The gasifier system installed on this project was the second of two 10 foot diameter Wellman-Galusha® gasifiers at Glen-Gery's colonial division plant, York, Pennsylvania. The original gasifier (No. 1) was installed in the late fifties when the plant was built. This original gasifier supplied all gas required for plant operation until the mid-sixties when natural gas became available. The original gas producer was not used at York for approximately 12 years while natural gas was plentiful throughout the sixties and early seventies.

The Wellman-Galusha® gasifier installed on this project was originally installed at the New England Lime Company plant in Canaan, Connecticut during the early part of World War II (i.e. 1942-43). It was one of a total of five gasifiers installed at New England Lime to support World War II production of magnesium. All gasifiers at New England Lime were on-line for 3 to 4 years until approximately 1946. All were deactivated at that time.

In the early seventies the Pullman-Kellogg Corporation purchased all five units in anticipation of an anthracite and bituminous gasification project with the State of Pennsylvania, Pennsylvania State University, and the Federal government. The gasification equipment was all disassembled from the Canaan, Connecticut site and stored at Pullman-Kellogg's Williamsport, Pennsylvania facility prior to being refurbished and installed in College Park, Pennsylvania. The Pullman-Kellogg project was not funded, thus the equipment became available.

Late in 1975 the Glen-Gery Corporation purchased four of the units from Pullman-Kellogg. The first of the four to be installed by Glen-Gery was the unit installed on this project. The gasifier is a non-agitator with manually operated coal feed valves.

The Number 2 gasifier system was designed to supply hot producer gas to the Number 2 tunnel kiln. The production of this kiln is rated at 1MM brick equivalents/week. Both gasifiers are located in the middle of the York plant. The distance between the Number 2 gasifier and the second kiln burner section is approximately 300 feet. The main gas delivery line is a 16 inch ID insulated line, located approximately 15 feet above floor level.

Installation of the second gasifier at York began in January 1977. Construction was complicated by the fact that the second gasifier was installed adjacent to the first unit, which was located in the center of the brick plant.

Excavation for the foundation began in early January 1977. This excavation required some rock blasting to install the bucket elevator pit. The blasting extended the foundation installation by a couple of weeks. The foundation was completed in mid February 1977.

Erection of the structural steel and gasifier began during the first week of March 1977. The structural steel and the gas producer were in place on Friday, April 10, 1977. Steel and gasifier erection, plus placement of major equipment, spanned five weeks, which is typical for an industrial hot gas anthracite gasifier installation.

The mechanical and piping installation was performed by Glen-Gery's Engineering maintenance personnel. This effort spanned approximately six months. The gasifier was started up October 17, 1977.

D.2 PROCESS DESCRIPTION

The Wellman-Galusha® gasifier installed on this project is a non-agitator unit suited for anthracite, coke, and non-caking bituminous fuels. A schematic of the non-agitator gasifier is shown in Figure D.1. The height of the unit from the ground to the top of the coal elevator is nominally 70 feet. The reaction chamber is a 10 foot diameter cylinder approximately 10 feet high. The top of the reaction chamber is located on the second floor (i.e. approximately 30 feet above the ground) as shown in Figure D.1. The nominal capacity of a 10 foot diameter Wellman-Galusha® operating on anthracite is 1 ton/hour of coal.

The coal is transported from the storage pile (at ground level) to the upper storage bin via a bucket elevator. The total capacity of this gasifier is over 50 tons of anthracite. Under normal operating conditions coal is loaded in batches. Twice per shift approximately 3 to 4 tons are loaded into the upper storage bin. The coal is gravity fed through four vertical pipes into the reaction chamber. These pipes are always full. The lockhopper (i.e. lower fuel bin), located between the upper bin and the coal feed pipes, assures uninterrupted coal flow into the feed pipes and reaction chamber without loss of producer gas.

The reaction chamber is completely water jacketed, the inner wall of the water jacket being constructed of 1 inch thick steel plate. The 1 inch steel plate forms the outer surface of the reaction chamber. The water jacket maintains an inner steel surface temperature below 300°F. This design eliminates the requirements for refractory lining and the corresponding maintenance and operational problems associated with refractories (e.g. clinker build-up on the inner surface and liner replacement).

The hot water in the jacket (approximately 209°F) generates the steam required to produce the gas. A blower supplies air to the reaction chamber. The air enters the top of the reaction chamber, passing through a 4 inch gap between the top of the vessel and the water in the jacket. The top of the reaction chamber is always covered with approximately 4 to 5 inches of water. As the air passes across the water it is both heated and saturated. The saturated air

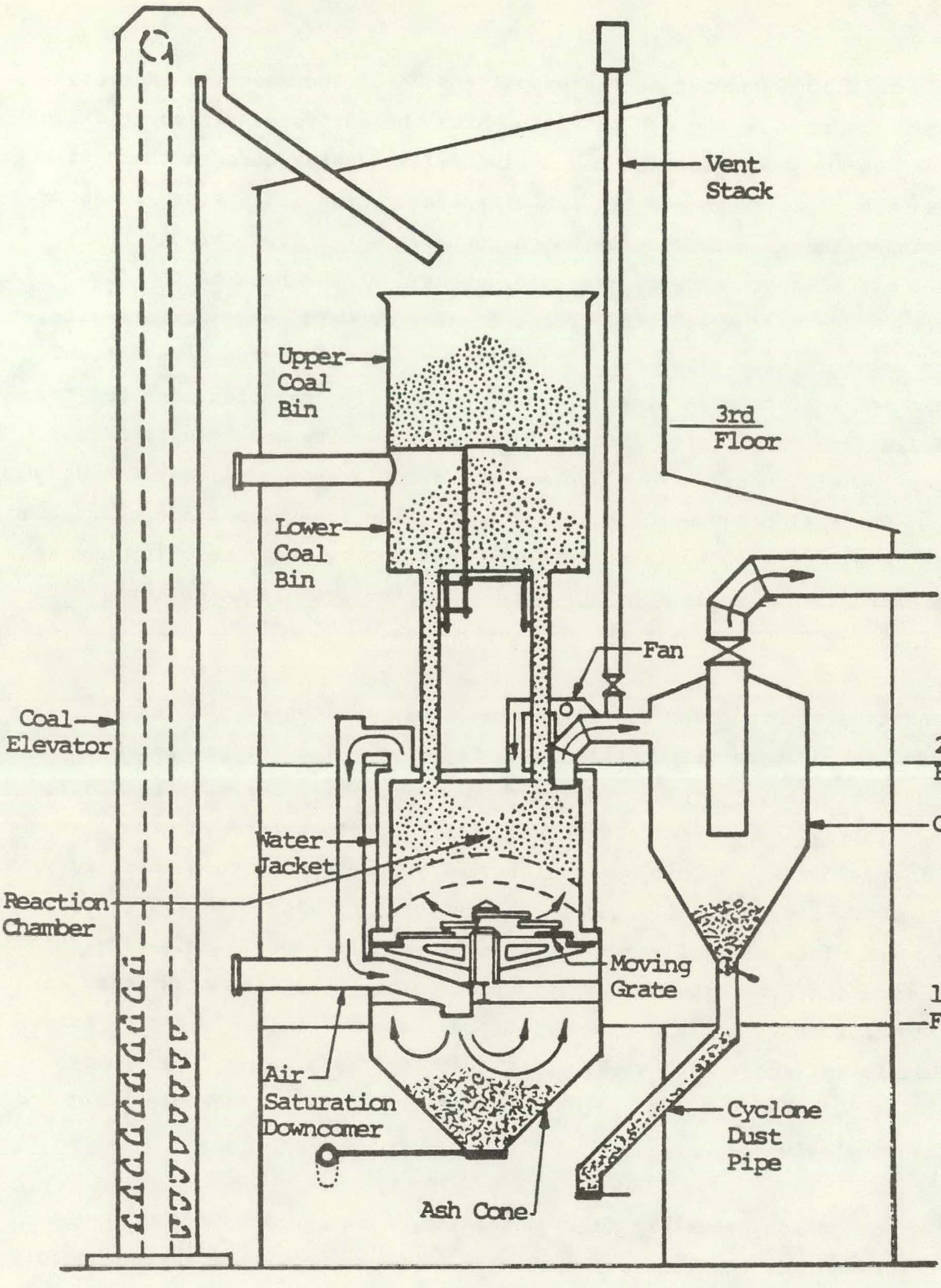


Figure D.1: Non-agitator Wellman-Galusha® Gasifier used for the Gasifier In Industry Program at Glen-Gery Brick Corp., York, PA enters an 18 inch ID downcomer on the opposite side of the reaction chamber. The downcomer connects to the ash pit into which the saturated air enters. The air is forced through the reaction bed by initially passing through the horizontal gaps between the grate rings and the ash. Air saturation temperature is automatically controlled by a thermostat which controls water flow through the jacket. The air saturation temperature is measured at the base of the downcomer near its attachment to the ash pit. Reduced water flow to the jacket results in a higher water jacket temperature and a higher air saturation temperature. A higher air saturation temperature reduced the gasifier reaction zone bed temperature and higher water input results in a lower quality gas being produced. The producer gas will contain more H_2O and CO_2 as dilutants and less CO and H_2 when the air saturation temperature is too high. The lower limit air saturation temperature is established by maintaining the ash bed temperature below the ash fusion temperature. Normally, the air saturation temperature is controlled between 140°F to 150°F when operating with anthracite.

The gas generated within the reaction chamber exits the top of the vessel through a 24 inch diameter externally insulated pipe. The hot gas immediately enters an 8 foot diameter cyclone adjacent to the gasifier for particulate removal. When gasifying anthracite, the gas off-take temperature is generally between 650 and 750°F. The cyclone is internally insulated with a refractory brick lining. Particulate collected in the cyclone contains both ash and carbon. The particulate are collected in the cyclone dust pipe. Cyclone dust is collectedd from the dust pipe on a weekly basis. The dust from anthracite is dry (no oils or tars). At full capacity approximately 150 to 250 pounds of cyclone dust is collected each week. This dust typically has a "loss on ignition" (LOI) of 60 to 70 percent, which means it can be discarded to a great extent by incineration.

The gasifier operation is nearly fully automatic. The gas delivery pressure is maintained constant as the load may vary with a pneumatic system which controls the inlet air flow to the gasifier. Coal feed within the gasifier follows the load. Coal is loaded into the upper storage bin on a required basis. Monitoring the reaction chamber does require periodic involvement by an operator. This monitoring occurs twice a shift (i.e. every four hours). The bed is monitored by the operator pushing steel rods into the reaction chamber from the top of the vessel. Nine 12 foot rods are inserted into the bed every four hours. The rods are left in the bed for about 5 minutes. When removed, the two major thermal zones are marked on the rod. From this information, the operator determines (1) the height of the ash zone and (2) the size of the reaction zone. By probing the entire bed in this manner, the operator evaluates the bed uniformity, ash depth, and ash character (e.g. too wet or the existence of clinkers). The operator controls the gasifier bed and the gas quality principally by: (1) grate rotational speed (e.g. the rate of ash removal), (2) air saturation temperature, and (3) size and quality of coal.

Generally problems in a firebed begin with the development of chimneys or high temperature streamlines. If allowed to continue, they may develop into blow holes where channeling can occur. Channeling occurs when air passes through the bed without reacting with the coal. This results in burning of the gas at the top of the reaction chamber, severely reducing the gas quality. Hot spots in a gas producer are often caused by a lack of uniformity in one or more of the following operations: (1) feeding and spreading the fuel, (2) coal size variations or dirty coal, which changes the bed permeability, (3) a nonuniform ash zone. The ash depth should be maintained within 10 to 12 inches. If the ash depth is too low, the grate can be thermally damaged by the fire zone. Conversely, if the ash zone becomes too deep the gas quality will drop, plus the bed pressure drop will rise, increasing the potential of channeling. Maintaining a uniform bed in the reaction chamber is the principal responsibility of the operator. Ash removal and the ash bed uniformity are the most critical operational parameters for consistent high quality gas production from anthracite.

Ash is continuously removed from the bottom of the reactor vessel by a slowly revolving grate, which makes about two revolutions per day. The grate is constructed of circular heavy steel plates. Each plate is flat, solid, and is set one above the other with overlapping edges so that ash is removed by passing horizontally through the vertical space between the plates. The ash rests on the eccentrically stacked plates and is pushed between them as the grate rotates. Clinkers (when formed) are ground up by the rotational action of the grate and its eccentricity with the inner reactor wall.

Ash is collected in the ash hopper directly below the reactor. The ash hopper is generally emptied once or twice a day by dumping the ash into a truck driven under the gasifier. Most anthracite yields about 2 tons of ash daily (e.g. 9 to 10 percent ash). The ash is removed from the cone in a water slurry. This is done for two reasons (1) to continually maintain a seal at the ash gate valve so that the reactor pressure does not drop appreciably, and (2) to expedite ash removal via the water flow. The ash always remains wet because it is continuously exposed to saturated air between 140 to 150°F. Therefore, the ash has a tendency to stick and pack within the cone. The water slurry aids removal.

D.3 PRESENT STATUS

The gasifier performed as expected during the entire program of monitoring the operation of the gasifier. Some time after the program was completed, the monitoring equipment was deactivated. During much of 1981 the gasifier was shut down because the cost for the low Btu gas, which includes $75/ton for anthracite (about $3/MMBtu heating value) plus the operating cost of the gasifier, exceeded the price of purchased natural gas at around $4/MMBtu. As natural gas prices continued to rise in 1982 the construction market softened and at last word the gasifier was not yet operating. It is expected to operate in the future, especially in light of rapidly escalating natural gas prices. Operation of the gasifier will depend upon future anthracite coal prices.

APPENDIX E - PIKE COUNTY/DOE GASIFIERS IN INDUSTRY PROGRAM

This gasification project was begun in response to Program Opportunity Notice (PON) FE-4 from the U.S. Energy Research and Development Administration (ERDA - now the U.S. Department of Energy) in 1976 by the Pike County, Kentucky Administration. The gasification plant was partially built at the Douglas Site in Pike County--the gasification building and flue gas stack was constructed, two gasifiers, two cyclones, two boilers, and one chiller were put in place.

Participant/User - Pike County, Kentucky at Douglas Site

A&E - Mason and Hanger-Silas Mason Co., Inc., and changed in 1974 to Stearns-Roger

Gasifier - Two single stage 6.5 foot diameter Wellman-Galusha gasifiers

Type of Fuel Feed - Eastern Kentucky bituminous (0.8% Sulfur)

Fuel Rate - 1.5 ton per hour per gasifier (Total feed rate 3 TPH)

Gasification Product - 440 billion Btu/year (150-165 Btu/scf)

Application of Product - Fuel for boilers (and originally to provide low Btu gas to industrial customers)

Estimated Total Cost - $5,788,000 (1977)

E.1 BACKGROUND

This project was submitted in the local and state government category to gasify low sulfur Kentucky Coal. The Kentucky Center for Energy Research (KCER) and the Appalachian Regional Commission (ARC) each contributed 25% of the project cost. The rest of the funding came from DOE. The cooperative agreement was signed in April 1977 with Mason-Hanger providing the A&E Service. The low Btu gas produced would provide fuel for hot water for heating and chilling units for cooling in a new 65-acre development. The community was to include 500 multi-dwelling housing units, a day-care facility for 80 children, a 750-student school, and a 10,000-square foot shopping center.

Two Wellman-Galusha gasifiers required agitators due to caking nature of the coal. The original design did not include gas clean up system as the feed coal has low sulfur (0.8%). However, the requirement to incorporate a gas cleanup system as an integral part of the facility required design changes, component design and approval, and a revised construction schedule.

This project was one of the DOE's seven Gasifier in Industry Program project. The objective of this program was to demonstrate the integration of a gasification system with an industrial end use for the low Btu gas produced, using state-of-the-art components. For a variety of reasons - primarily economic - plans for the plant and the complex were scaled down considerably. DOE finally considered direct firing of the plant boilers--there was a lack of interest in the industrial park on the part of the industrial communities, so gas is not needed. (The industrial park would not have had railroad sidings.)

E.2 PROCESS DESCRIPTION

Sized coal (1-1/4" x 2") is fed to the top of the gasifier through lockhoppers at 3 ton per hour. Steam saturated air is blown in from the bottom by fan blast. The gasifier is water-jacketed, which generates steam. Cyclones remove dust from the single stream; no provision for tar removal is provided. The clean gas is then fed to the boilers burners. High efficiency multiple cyclones are used on boiler stack gases to prevent fly ash discharge.

Gas at 150-165 Btu/scf is generated with an annual output of 440 billion Btu. Typical Composition of the gas is:

Component	Volume %
H_2	14.7
CO	28.1
CO_2	3.5
CH_4	2.7
N_2	50.0
H_2O	(dry)
H_2S + Cos	1.0
others	--

E.3 PROJECT STATUS

Construction of the 72-ton/day gasifier (two Wellman-Galusha units) facility at Pike County, Kentucky began in October 1978. The original design was by Mason-Hanger (A&E firm) and did not have a gas cleanup system. The gasifier installation began in June 1979.

An environmental and health monitoring and testing program to study the Pike County Coal Gasification Facility was submitted to the Office of Environment (EV), DOE. A supplemental plan to include the gas cleanup system (sulfur and tar removal) was necessitated. This required major design changes.

Delays encountered because of an expansion in job scope pushed the startup date back into 1983. The project had continuous problems, including Pike County Project Management, equipment deliveries, acquisition of a new A&E, establishment of a new base line, slippage in cost, and schedule.

DOE asked UOP/SDC to review these problems. The initial objective of UOP/SDC review (which began in November 1978) was to provide technical assistance to DOE by reviewing construction activities, identifying problems, and recommending solutions to over come these difficulties.

UOP/SDC made recommendations for the Pike County Project Management Team (emphasizing technical as well as administrative support to meet the schedule and integration of the Douglas Site Complex with the coal gasification plant schedule), and submitted a report to DOE on October 10, 1979 on economic viability of the Pike County Project.

In part as the result of UOP/SDC's recommendations, DOE changed the baseline of the project to include gas cleanup and solicited bids from experienced process plant construction firms to complete the entire plant on a turnkey basis.

Construction on the project was temporarily halted (around August 1979), while design changes and bid solicitations were prepared. By this time the project cost (design, construction, and 3 years of operation) had skyrocketed to as high as six and ten times the original estimate of $5.8 million. The Federal and state sponsors had already spent $4.2 million on the Project.

In April 1980, UOP/SDC was requested to begin technical and cost assessments of providing user energy by firing the Pike County Coal Gasification Facility (PCCGF) Steam generators with alternative fuels in direct combustion. The alternative fuels considered were coal, coal-oil mixture, No. 2 fuel oil, and a SRC-I liquid product. It was assumed that each project alternative would use existing components of the PCCGF to the degree possible. Significant results of the study were:

- Operation of the coal fed steam generators is the most economical mode for PCCGF, even if flue gas desulferization is required.

- The difference in operating costs between coal and oil or coal-oil mixture fuel is greater during one year of operation than the environmental control equipment capital costs that may be required for coal.

- The environmental requirements for sulfur control on a coal fuel system will have to be negotiated with Kentucky Environmental and EPA Air Quality Control Region authorities.

In wake of DOE's warning of its intention to kill the Pike County Project (due to excessive cost), Pike County officials submitted five proposals to Federal officials (in December 1980) that listed alternatives to ending the project. Two of the alternatives called for completing the plant and three others involved converting it into a coal fired boiler to supply hot or cold water to other units on site.

Subsequent to the submission of the five proposals, the Pike County administration changed. The newly elected administration cancelled the project. State energy officials met with Pike County officials and representatives of Appalachian Regional Commission to see if the equipment could be used elsewhere. The equipment (2 gasifiers, 2 cyclones, two boilers and one chiller) still remains in place in the enclosed gasification building on the Douglas Site.

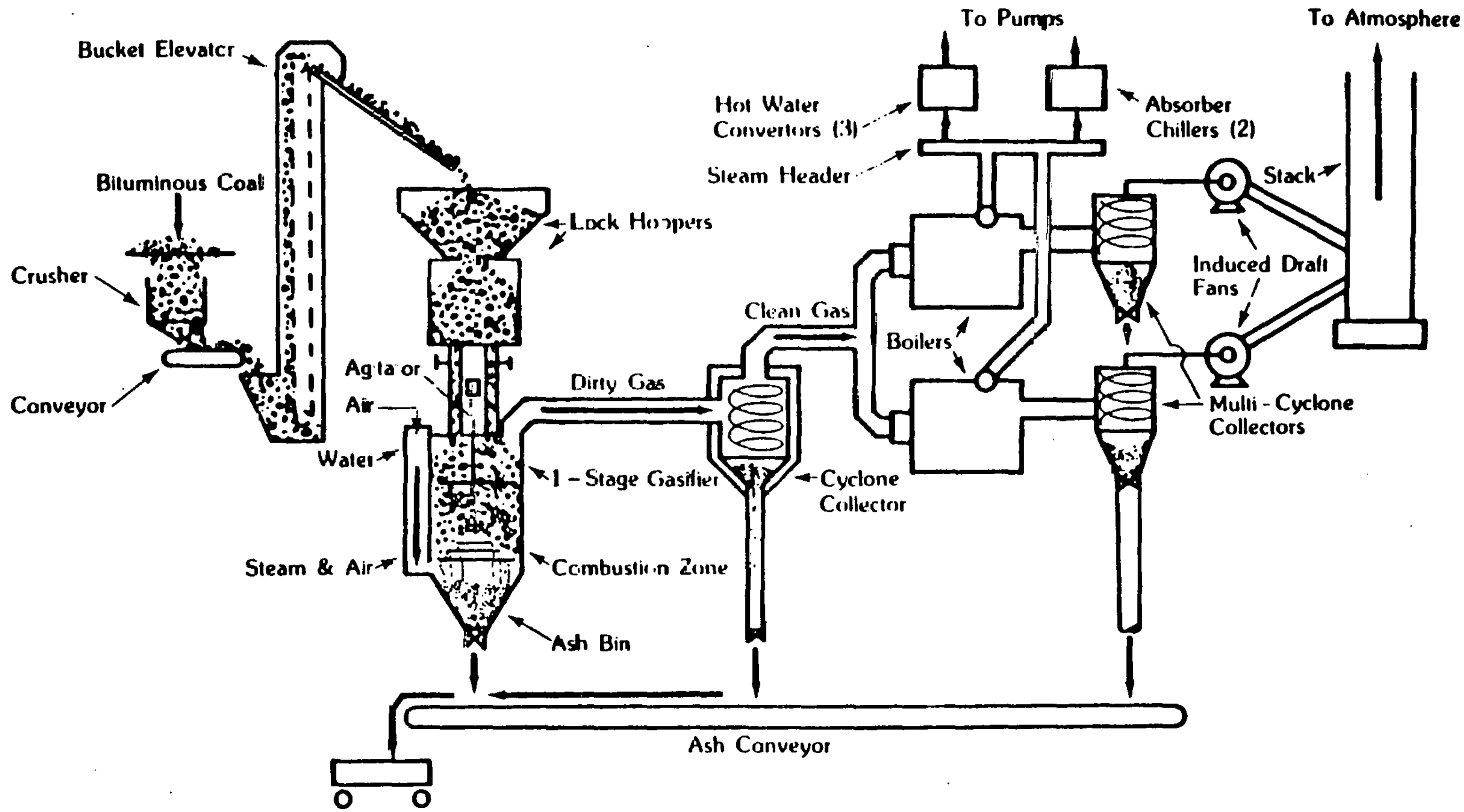


Figure E.1: Proposed (1977) Coal Gasification System with a Wellman-Galusha Gasifier for the Douglas Site in Pike County, Kentucky

APPENDIX F - GENERAL REFRACTORIES/DOE GASIFIERS IN INDUSTRY PROGRAM

This gasification project was begun in response to Program Opportunity Notice (PON) FE-4 from the U.S. Energy Research and Development Administration (ERDA - now the U.S. Department of Energy) in 1976 by General Refractories Company. Although the gasification plant was not built, the preliminary design and an environmental assessment were completed.

Potential Gasification Site - General Refractories Company, Hitchens, KY

Home Office - General Refractories Company, Bala Cynwyd, PA

A&E - Holley, Kenney, Schott, Inc., Pittsburgh, PA (now a part of Babcock Contractors, Inc.)

Gasifier - One two-stage, 10-foot diameter Woodall-Duckham gasifier

Type of Fuel Feed - Eastern Kentucky Bituminous

Fuel Rate - 2.25 ton/hour

Gasification Products - 1.325×10^4 Btu/day of gas and 0.220×10^9 Btu/day of tar-oil

Application of Products - Fuel for kilns to fire refractory brick and shapes (2 tunnel kilns, 12 periodic kilns, and one dryer), and tar-oil for sale

Estimated Cost - (in 1977 dollars) $3.084 million capital (for design through start-up) or $4.245 million capital and operating (for design through 2 years of operation)

Cost Share by Participants - General Refractories, Inc., 35%; Kentucky Energy Resource Center, 15%; and U.S. Department of Energy, 50%

F.1 BACKGROUND

General Refractories Company (GREFCO) is one of 130 refractory companies in the country that operate 250 plants with a total annual gas requirement of 75 trillion Btu's.

The GREFCO Hitchens Plant had faced natural gas curtailment with eventual loss of supply. These fuel shortage and supply problems, together with increasing fuel (natural gas) costs, provided further incentive to GREFCO for considering coal gasification to produce low Btu gas as fuel for various direct fired uses in the refractory plant. A suitable coal supply would provide a secure source of energy at a predictable cost in conjunction with a gasifier.

On October 4, 1976, the GREFCO proposal was selected to be part of the "Gasifiers In Industry" Program. This program resulted from a procurement action that solicited proposals from the industrial, commercial and local government/institutional sectors for the design, construction, integration and operation (one to three years) of low Btu coal gasification systems. A small number of constraints and/or conditions were placed on the selected projects. The constraints were: (1) an 8 ton per hour maximum coal feed was set to limit the size of the gasifier; and (2) the gasifier would have to be state-of-theart technology and commercially available. The conditions set for this project were a 50-50 cost share (actually 35-15-50 among GREFCO, Kentucky Center for Energy Research, and ERDA) in exchange for public access and availability of all technical, economic and environmental data from design through operation of the gasification system.

This project proposed the installation of one two-stage Woodall-Duckham gasifier that would handle local available low sulfur (1.4 lbs. SO_2 MMBtu) Eastern Kentucky bituminous coal from a company-owned mine six miles from the plant site. The two gases withdrawn from the gasifier would be cleaned separately by cyclones for removal of tar and dust. These cleaned effluents would be combined and distributed to fourteen kilns and one dryer having a total average gas requirement of approximately 1325 x 10^6 Btu/day.

F.2 PROCESS DESCRIPTION

The schematic for the proposed gasification process at GREFCO, Hitchens, Kentucky location is shown in Figure F.1. Crushed Eastern Kentucky bituminous coal (< 1 1/2") is delivered to the plant site by truck and off loaded into a ground hopper. A vibratory feeder then transfers the coal to a bucket elevator where it is raised approximately 100 ft. and discharged onto a vibratory screen feeder. The screen feeder separates fines (less than 3/8"), which constitute about 33% of the coal as received, while discharging the +3/8" fraction into the surge hopper above the gasifier. From the surge hopper, the coal is fed into the top of the gasifier by a coal feed system consisting of a vibratory feeder, coal feed lock hopper, level sensor, and diplegs.

Two gases are withdrawn from the gasifier (from above and below the retort section) and fed to separate cyclones. The upper stream cyclone removes tar while the lower stream cyclone removes dust. The by-product tar is collected and stored for possible further use, while the dust is collected and combined with the ash. The ash is removed from the gasifier ash grate dry using a rotating grate that also services to distribute the blast (air and steam) entering from the bottom of the gasifier. The steam required for gasification is generated in the gasifier jacket. The gases from the cyclones are combined and distributed as fuel to the various users in the plant.

Product gas temperatures are 250°F for the upper stream and 1200°F for the lower stream. The combined hot gas temperature varies from 600-850°F. The effective high heating value including sensible heat and higher hydrocarbons is approximately 210 Btu/scf.

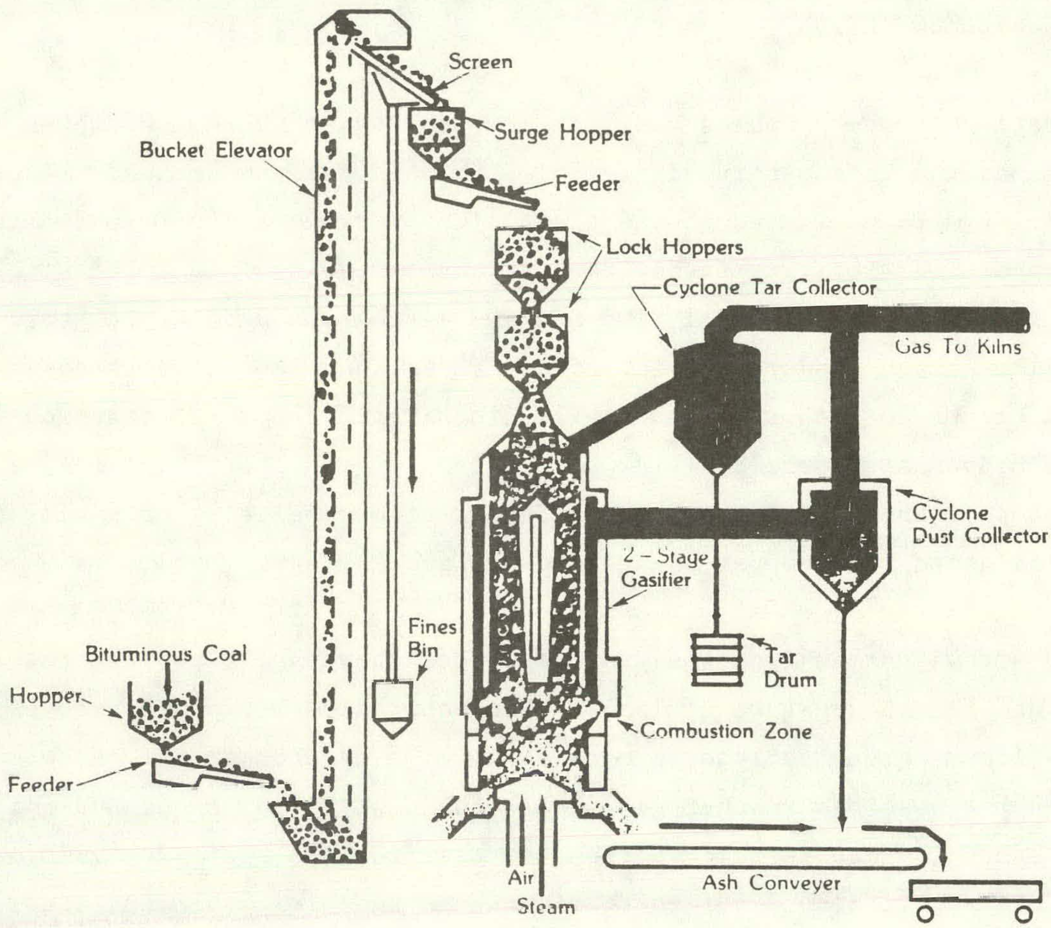


Figure F.1: Proposed (1977) Coal Gasification System with a Two-Stage, 10-Foot Diameter, Woodall-Duckham Gasifier for the General Refractories Co. Brick Kilns at Hitchens, Kentucky

F.3 PROJECT DESCRIPTION AND STATUS

The project was to be accomplished in three phases. Phase I was program development and preliminary design. Phase II was to comprise detailed engineering and design, procurement and construction. Checkout and operator training would have also been included. Phase III was to cover start-up, operations, data gathering, data evaluation and analysis of refractory products.

After selection as part of the "Gasifier in Industry" Program, negotiations for the cooperative agreement, rather than a contract, were conducted. The original proposal estimate for total project costs (mid-1976) was $ 3,220,000-$3,462,000 with the cost sharing arrangement being 50% ERDA and 50% participant. In this instance, the participant cost share was 35% by GREFCO and 15% by Kentucky Center for Energy Research. The original proposal operating cost was $1.63/MMBtu ($574,000/yr), exclusive of capital, based on $32/ton coal. However, for this project the annual operating cost was adjusted by deducting the cost of fuel gas/fuel oil from the annual operating cost of the gasifier. The data are presented in Table F.1 on a $/MMBtu basis.

Table F.1 Adjusted Annual Operating Cost
Estimated in 1976 Dollars

Cost Category	Gasifier Operating Cost ($/MMBtu)
Coal	1.28
Labor	0.24
Maintenance	0.06
Utilities	0.05
Total	1.63
	1976 Fuel Cost ($/MMBtu)
Gas/Oil	1.12

Adjusted Operating Cost ($/MMBtu)
1.63 - 1.12 = 0.51
Adjusted Annual Operating Cost ($/year)
180,000
Adjusted Three Year Operating Cost ($)
540,000

During the proposal evaluation, selection, and negotiation periods, the total project costs escalated further. First, the total estimated cost was revised upward by $915,000 to $4,377,000. By September 1976, the total project costs stated in a revised contract pricing proposal submittal were increased an additional 15% over the previously revised figure of $4,377,000 to $5,030,000. Operating cost estimates were also increased a minimum of 15% and could be more, depending on how the various increases in project costs were designated.

Approximately a year after selection (September 27, 1977) the cooperative agreement was signed and effected. At this time, the total project costs were diminished to $4,245,000 by shortening the operating period from three years to two years. The cost breakdown is shown in Table F.2.

Table F.2 Negotiated Estimated Costs - 1977 Dollars

Capital Cost Categories	Cost ($)	Costs ($)
Design/Engineering	495,000	
Procurement/Construction/ Installation/Start-up	2,589,000	
Subtotal (Capital Costs)		3,084,000
Operating Cost Categories		
2 yrs Operation @ $382,500/yr	765,000	
Product and Data Analysis	496,000	
Subtotal (Operating Costs)		1,245,000
Grand Total		4,245,000

During the Phase I period, several revisions were required and are described below.

F.3.1 Coal Feed

The coal size was narrowed from 1/4" x 1 1/2" to 3/8" x 1 1/4". The proposed feed coal characteristics were 0.85% sulfur, free-swelling index (FSI) 1.5 and approximately 20% fines rejects. However, the coal shipped through the Hitchen's works was 2.5% sulfur, FSI = 2.5 and had 33% fines rejects. This coupled with an estimated increase in plant heat demand (50%) necessitated a separate coal stock pile (30 days) to be added. Coal delivered to the site would increase from 17,500 tons/yr to 31,600 tons/yr. This added further to the fines handling operations (> 10,000 tons/yr).

F.3.2 Gasifier

The average end use fuel requirement (heat demand) presented in the original proposal was 0.895×10^9 Btu/day with a peak demand 10% higher. The projected demand was increased to 1.06×10^9 Btu/day. This estimate was revised during Phase I to 1.2×10^9 Btu/day with a peak demand 20% higher. Further analysis by operation scenario (types and numbers of end users) set a low Btu gas requirement of 1.325×10^9 Btu/day. Any additional heat demand would be provided by natural gas. The gasifier was nominally rated at 1.6×10^9 Btu/day. The capacity would be established during initial operation. However, with more complete tar removal (0.22×10^9 Btu/day), it appeared that it might be difficult to meet the low Btu gas requirement of 1.320×10^9 Btu/day.

F.3.3 Tar-Oil

More tar removal was deemed necessary and beneficial for numerous reasons downstream of the gasifier, but it also posed additional problems; namely, a more extensive disposal problem, and replacement of the heat value of product gas. First the original tar quantity to be handled was approximately one to two drums per day (15 lbs/hr), the latest quantity was twenty-six drums per day (505 lbs/hr). Furthermore the tar comprised 20% of the heat value in the gas (220 MMBtu/day). This coupled with sensible heat losses (150°) significantly affects the Btu value of the product gas. To utilize this tar-oil fuel heating value, a storage, handling and burner system would be needed. The tar produced from gasification is of a different composition than by-product tar from a coke plant. Gasifier tar has virtually no aromatics (BTX) and as such is likely to have a lower marketability than coke tar-oil, except possibly as a blending stock for a boiler fuel.

F.3.4 Gas Distribution System

Driplegs and cleanouts were required in the distribution system and at the gas burner(s). Piping design required severe slope (1 in 5), a special routing because of thermal expansion and tar trapping. Expansion joints (bellows-type) were deemed to be necessary. Automatic block and bleed valves were required to meet safety and insurance requirements. For these reasons and others (burner reliability and design), an electrostatic precipitator was added for detarring the producer gas. This distribution system would also experience temperature losses approaching 150°F.

Other revisions included the addition of venturis and steam purges. Higher operating and design pressures were necessary because of piping and instrumentation requirements.

F.3.5 End Use Requirements

The hot raw gas burner(s) presented two problems; namely, (1) increased burner size because of low allowable pressure drop, and (2) frequent burner cleaning. The instrumentation and piping requirements also necessitated a clean gas and substantial pressure drop. These problems were eliminated with the addition of a precipitator and product gas booster blower. The higher pressure would diminish burner maintenance and permit use of a smaller (higher pressure drop) gas burner(s). The steam purge that is used to prevent condensation and minimize breakdown causes further reduction of the gas heating valve. This reduction together with the reduction in heating value from tar removal and sensible heat loss could lead to possible problems with low kiln temperatures because of excess air quantities.

F.3.6 Utilities

Auxiliary steam would be required for blast, poke hole, purging, and tracing requirements. Natural gas would be required to offset any shortages because of gasifier capacity tar removal, sensible heat losses, purging, and low kiln temperatures.

F.3.7 Safety and Environmental

Tar cleaning is required on equipment piping and instrumentation because tar buildup on these surfaces reduces gas flow and clogs instrument sensors. Hot raw gas leakage is substantial even with steam purging of poke holes. Desulfurization was not included in the plant for this gasification project; however, the EPA limit of 1.2 lbs. SO_2/MMBtu would be exceeded by over 10%. The environmental impact assessment (EIA) states that the environmental impacts would be localized and temporary and not a major problem. The air quality standards (Federal and state) for sulfur oxide concentrations were not exceeded applying estimates that were developed using a gaussian plume dispersion model. These estimates were 10 to 100 fold less than the primary and secondary standards. In reality, the coal selected to be shipped through the Hitchen's works would contain up to 2.5% sulfur (approximately 3 times higher than the "as bid" coal). From the EIA it would appear that even that coal would produce estimated sulfur oxide concentrations that would not violate any primary and secondary standards either when using the model presented in the EIA.

F.3.8 Schedule

As of July 1978 Phase I was being completed, but project milestone dates stated that design and engineering (Phase II activity) were to be complete at this time. The project appeared to have been one year behind schedule, but the schedule was misleading because it had anticipated a much earlier cooperative agreement signing date.

F.3.9 Economics

At the time of submittal of the Phase I final report (July 1978), the estimated project costs had increased from the original proposal value of \$3.2MM to \$6.7MM--this was due in part because of the additional requirements previously stated. Operating costs (exclusive of capital) had increased to \$2.80/MMBtu based on \$40/ton coal from \$1.63/MMBtu (proposal) based on \$32/ton coal. It is noted that the \$8/ton incremental coal cost translates into \$0.32/MMBtu incremental increase.

F.3.10 Status

On September 11, 1979 the cooperative agreement was terminated (effective July 21, 1979) because of economic considerations.

F.4 FUTURE PLANS

Another coal gasifier project is being planned for GREFCO the General Refractories site at Florence, Kentucky as part of another DOE supported program.

F.5 CONCLUSIONS

The selection of this project as part of the "Gasifier In Industry" Program was certainly a satisfactory choice in meeting the stated objectives and goals of the program. The design approach and methodology presented a conceptual coal gasification system based on preliminary criteria and a possibly available coal feed. These data together with the existing two-stage Woodall-Duckham gasifier process and mechanical description were the technical basis for the project. Cost estimates were prepared for implementation of the projected program.

As the program developed and data evolved for the preliminary design, numerous additions and revisions were required. Virtually all areas of the program were affected. Project cost estimates (the majority being capital costs) increased over 100% while operating cost estimates increased over 70%. This would appear to be the primary basis for termination of the project three years after the submittal of the proposal.

It may have been an error in the preliminary estimate and excessive optimism that prompted such a miscalculation in the original energy requirement, coal analysis, and cost estimate. When a future low Btu gas project is to be undertaken, a more detailed preliminary study should be performed initially covering the technical operational and environmental aspects of such a facility to determine a little more accurately its economic feasibility bility. It can be said, however, that this project did provide a lesson in this respect.

APPENDIX G - IRVIN INDUSTRIES/DOE GASIFIER IN INDUSTRY PROGRAM

Irvin Industries project Georgetown, KY

Participant/user - Irvin Industrial Development, Inc.

A&E - Mason-Hanger - Silas Mason Co., Inc.

Gasifier - Two single stage, 6.5 foot diameter Wellman-Galusha gasifiers

Type of coal - Eastern Kentucky bituminous coal (0.8 to 2 percent Sulfur)

Coal feed rate - 1.5 tons/hour per gasifier, total feed rate 3 TPH

Product gas - 480 billion Btu/year (150-165 Btu/scf)

Estimates total cost - $5,600,000 (1976 dollars)

Application - Utility gas mains

G.1 BACKGROUND AND PURPOSE

In 1978 DOE (then ERDA), the Kentucky Center for Energy Research (KCER), and Irvin Industrial Development, Inc. with 50/15/35 participation, respectively, agreed to sponsor the demonstration of low Btu gas from two, single-stage, six and one-half foot diameter, Wellman-Galusha gasifiers using eastern Kentucky bituminous coal. The use of product gas was to provide space heating, process steam, and direct and indirect fired applications in a 172 acre industrial park. At Georgetown, KY 12 different companies (a metal plating firm, a brick plant, metal heat-training plant, etc.) were involved with this project.

G.2 PROCESS DESCRIPTION

Sized coal is fed to the lockhoppers and then to the top of the gasifiers. Descending coal gets devolatilized by gas flow from the bottom. Steam and air are introduced at the bottom and react with coal to gasify it. Dirty raw gas leaves the gasifier from the top and goes through series of clean up operations. Figure G.1 describes the process flow diagram. Clean low Btu gas (150-165 Btu/scf) is stored in a storage tank for distribution.

G.3 PROJECT STATUS

Contractual difficulties between DOE & Irvin Industries, and local public concern about the environmental impact resulted in cancellation of the project. As per A&E (Mason & Hanger), the industrial group was thinking of going ahead with the project without DOE funding.

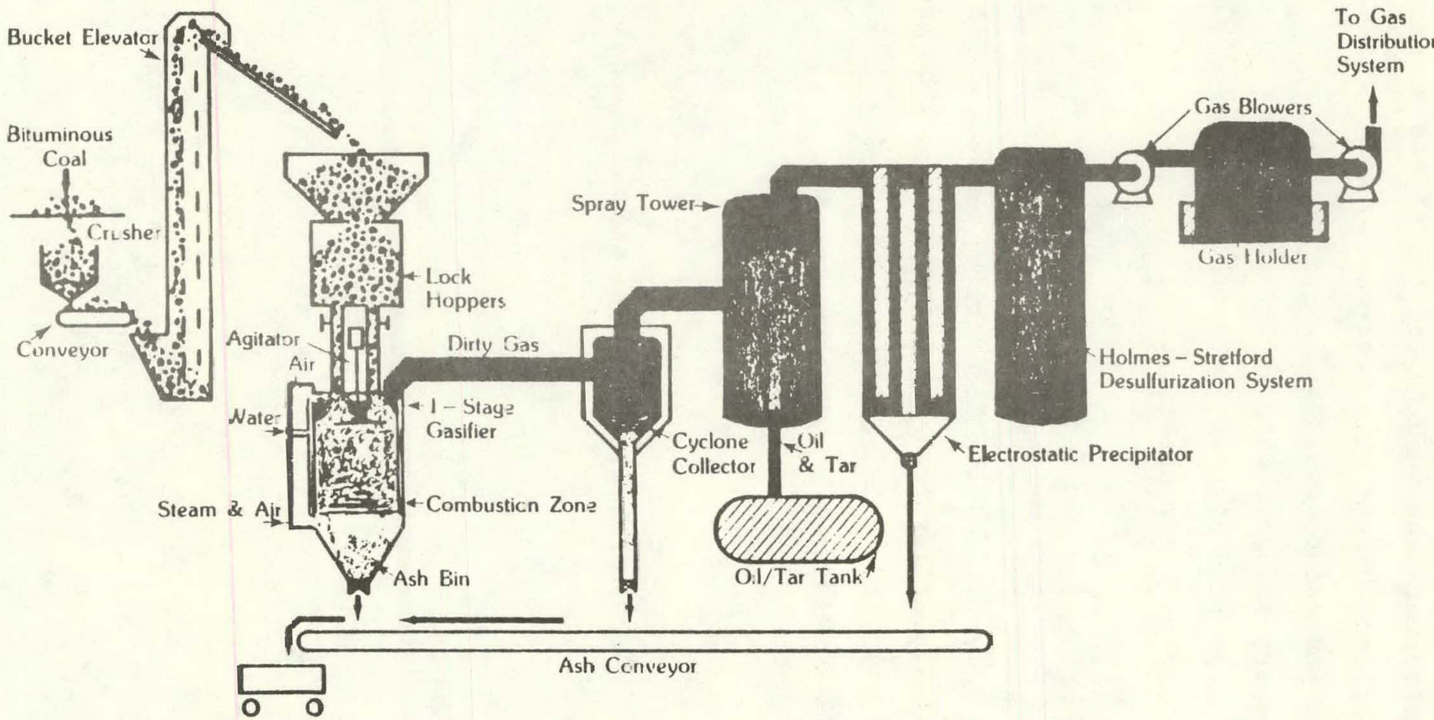


Figure G.1: Proposed (1977) Coal Gasification System with a Single-Stage, 6-1/2 Foot Diameter Wellman-Galusha Gasifier for the Irvin Industries Industrial Park at Georgetown, Kentucky

APPENDIX H - LAND O'LAKES/DOE GASIFIERS IN INDUSTRY PROGRAM

This gasification project was begun in response to Program Opportunity Notice (PON) FE-4 from the U.S. Energy Research and Development Administration (ERDA - now the U.S. Department of Energy) in 1976 by Land O'Lakes, Inc. (LOL). The gasification plant was not built, but a conceptual design was made to estimate the capital and operating cost, and an Environmental Impact Assessment was made.

Proposed Gasification Site - Land O'Lakes, Inc., Perkam, MN

Home Office - Land O'Lakes, Inc., Minneapolis, MN

Proposed A&E's - Applied Technology Corporation (ATC), Houston, TX (performed initial design work on gasification plant with a Wellman Incandescent gasifier - formal contract negotiation between LOL and ATC terminated 7/78). Davy Powergas, Inc., Houston, TX, negotiated to be A&E using a Winkler fluidized bed gasifier, but LOL announced withdrawal (5-17-79) from LOL/GII project before any agreement was made with Davy Powergas

Gasifier - One two-stage, 8.5 foot diameter Wellman Incandescent gasifier

Type of Fuel Feed - Utah or Colorado bituminous coals (less than 1% sulfur)

Fuel Rate - 3 ton/hr (maximum); 1.5 ton/hr (average usage)

Gasification Products - 1.6×10^9 Btu/day of low Btu (180 Btu/scf) and some tar. (Initial peak gas requirements for the plant were 40×10^6 Btu/hr, or 26×10^6 Btu/hr when the whey dryer was not operating)

Application of Products - Low Btu gas fuels the dairy whey dryer, boilers, and space heaters

Estimated Cost - $6,500,000 (1977 dollars), which includes $2,000,000 for three years of gasification plant operation

Cost Share by Participants - Land O'Lakes, 50%, and U.S. Department of Energy, 50%

H.1 BACKGROUND

The Land O'Lakes (LOL) food (dairy) processing plant at Perkam, Minnesota relies on natural gas for its heating fuel. In an effort to reduce its dependence on natural gas, LOL responded to PON FE-4 of ERDA during July 1976 and signed a cooperative agreement on 28 July 1977 with ERDA (hereafter referred to as DOE since DOE came into existence 1 October 1977) to construct and use low Btu gas produced by a two-stage, fixed-bed Wellman Incandescent gasifier. The product gas was to be used to provide fuel to the spray drier for milk whey, boilers, and space heaters. A low sulfur western bituminous coal from Utah or Colorado was among the candidate coals.

As initially proposed, the heat requirement of gas for the food processing plant was 40×10^6 Btu/hr, or only 26×10^6 Btu/hr when the whey drier was not operating. The average coal feed requirement to the gasifier over a year's period using 12,000 Btu/lb bituminous coal was 1.52 ton/hr. It was anticipated that the food processing plant heat requirements would escalate with plant expansion to over 54×10^6 Btu/hr. A 1979 gasification plant start-up was originally planned along with three years of gasifier operation with DOE cooperation.

During mid-1978 the originally designated A&E, who was the sole U.S. licensee of the Wellman Incandescent gasifier, was not allowed by DOE to enter into a contract with LOL, even though this A&E had provided a preliminary and plant cost estimate to LOL that was acceptable to DOE. From July 1978 to May 1979, when LOL announced its withdrawal from the project, negotiations were underway to use a Winkler fluidized bed gasifier. The cooperative agreement was officially terminated 17 July 1979.

One of the considerations in using low Btu gas in drying whey in the spray drier was the slight taste change imparted to the whey as a result of the sulfur content in the gas, if the sulfur in the coal was above a certain level. Consideration was given to changing the whey dryer configuration from one with the flame directly fixed on the whey, as it is done with natural gas, to one with an indirect heating method. Since one of the objectives of the project was to provide data for food processing with low Btu gas, finding the limits on sulfur content that produces a taste change was a significant finding; if an indirect heating concept had been proved out, the contribution would have been even more significant.

The project was still not started in the spring of 1979, a time when the plant was originally anticipated to have been nearing start-up. In addition to the frustration felt by LOL, there was the fact that the gas availability squeeze on commercial gas customers was easing. The frustration would certainly have been minimized if LOL had had more leeway in negotiating subcontracts on this project and not have had to wait so long for approvals and disapprovals from the cooperative partner.

H.2 PROCESS DESCRIPTION

A gasification process flow diagram for the Land O'Lakes, Perkam, Minnesota, plant is given in Figure H.1. Sized non-caking bituminous coal with a free swelling index between 1 and 3 is fed at a rate of up to 3 ton/hr through a sieve of two lockhoppers into the gasifier. Steam and air are introduced into the gasifier from the bottom up through the grate. The gas is taken from the gasifier at two points: (1) the cooler (200°-300°F) "top gas" steam from the upper stage of the gasifier goes through the "tar" cyclone for removal of tar and dust; and (2) the hotter (950°-1100°F) "bottom gas" from the lower stage of the gasifier is sent through the "dust" cyclone to remove particulates. The tar and oil collected by the tar cyclone is stored for later use in a boiler and the "top" gas is compressed and sent to the boilers and space heaters. The ashes from the gasifier and "dust" cyclone were designated to be trucked to a landfill. The dust-free "bottom" gas proceeds from the dust cyclone through

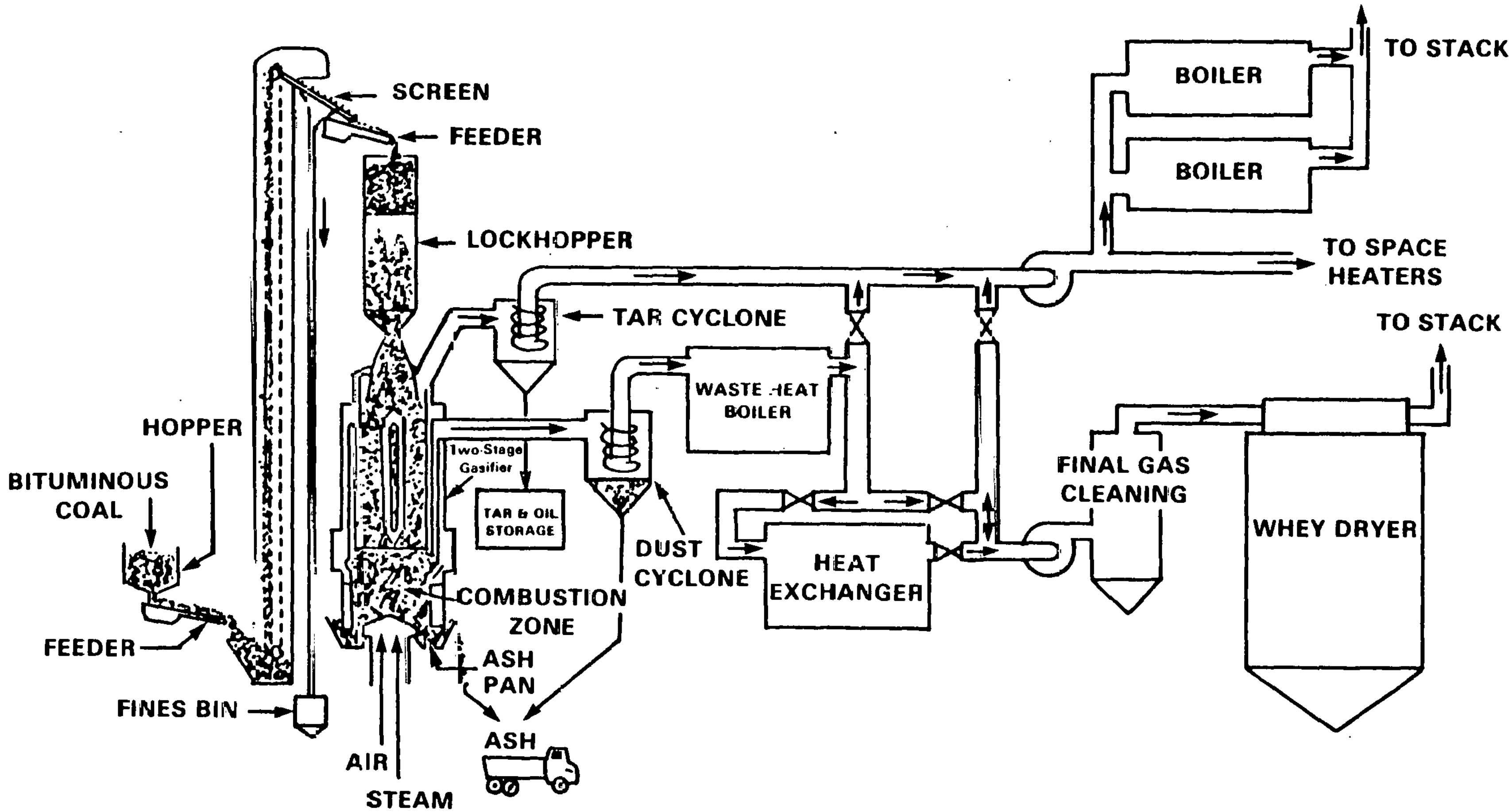


Figure H.1: Proposed (1977) Coal Gasification System with a Wellman Incandescent Gasifier for the Land O'Lake Food Processing Plant at Perham, Minnesota.

the waste heat boiler. At this juncture options exist for the bottom gas: (1) it can be combined with the "top" gas and sent to the boilers and space heaters; (2) it can be compressed and sent through the "final gas cleaning" unit, and then to the whey dryer; or (3) it can be sent through the heat exchanges and then either mixed with the top gas as in option (1) or compressed and sent through the "final gas cleaning unit" as in option (2).

A sulfur scrubbing unit was avoided in the process scheme so that the gas would not be contaminated with desulfurization chemicals and thus contaminate the food. This argument would not likely apply in the case of the indirect heating approach, were it used. The "top" gas was not designated for whey drying, presumably because of the tar content.

H.3 PROJECT STATUS

As previously stated, the project was officially terminated 17 July 1979.

APPENDIX I - CATERPILLAR TRACTOR COMPANY

Gasification Site - Caterpillar Tractor Company, York, PA

Gasifier - Two two-stage, 10-foot diameter Wellman Incandescent gasifier

License - Black, Sivalls, & Bryson, Inc., Houston, TX

Developer/Licensor - Wellman Incandescent, Ltd., Wellman Engineering Group, Warley, England

Type of Fuel Feed - High Sulfur Bituminous Coal with free swelling index less than 3

Feed Rate - 75 ton/day per gasifier (estimated)

Gasification Products - 1.16×10^9 Btu/day of low Btu (165 Btu/scf) gas per gasifier and an estimated 1350 lb/day of tar/oil [plant total (two gasifiers) gas = 2.31×10^9 Btu/day and oil = 2700 lb/day]

Applications - Low Btu gas is used to provide for the metal furnace, and the oil can be used in a boiler

Estimated Total Cost - $6 million (1977-8 dollars)

I.1 BACKGROUND

Faced with curtailment of natural gas and being in the middle of the coal country, Caterpillar Tractor Company sought to acquire an alternate energy source for its furnace fuel needs. In 1977 it installed two Wellman Incandescent (WI) gasifiers to produce low Btu gas to supplement its fuel supply. These gasifiers came to operation during 1978-1979 and have been operated since then.

Caterpillar bought these two gasifiers from ATC (now BS&B). BS&B is the Western Hemisphere licensee of Wellman-Incandescent Ltd. of Warley, England.

Designed by Gilbert Associates of Reading, PA, this 150 tons per day installation is the first privately-financed commercial operation in the U.S. to produce cold, clean low Btu gas from high-sulfur coal. The design product gas flow rate of these two gasifiers is 14 million cubic feet per day at a cost of $3.25/million Btu's.

The facility converts coal to gas with an efficiency of 78%, including energy losses due to sulfur and tar removal.

I.2 PROCESS DESCRIPTION AND OPERATING EXPERIENCE

The WI gasifier is a 2-stage, fixed-bed gasifier operating at atmospheric pressure and features continuous ash removal. Typical reliability is 98% (as claimed by the licensee).

The two gasifiers system has complete tar and oil recovery and sulfur removal facilities. Sulfur removal is accomplished in a Stretford process unit. The clean cold gas (165 Btu/scf) is used to fire furnaces in the plant.

Initially anthracite was used as feedstock, but now non-caking eastern and midwestern bituminous coals are gasified.

Currently (1981) one unit is in operation, while natural gas supplies the reminder of the Caterpillar plant fuel needs. Caterpillar is satisfied with the operation of the gasifier and cites that it does not have any environmental and operational problems with the gasifiers. It is not known yet when Caterpillar will satisfy all of their fuel needs from low Btu gas.

APPENDIX J - CHEMICAL EXCHANGE, INC.

Gasifier Site - Mississippi Lime Company, St. Genevieve, MO

Gasifier Owner/Home Office - Chemical Exchange, Inc. (CXI), Houston, TX

Gasifier - 1 single-stage, fixed-bed Wellman-Galusha gasifier with agitator

Licensor - Dravo Corporation, Pittsburgh, PA (Original licensor - McDowell-Wellman Engineering Company, Cleveland, OH)

Type of Fuel Feed - West Virginia Bituminous Coal

Feed Rate - 2-3 tons/hour

Gasification Product - 624 to 936 x 10^6 Btu/day, low-Btu (160 Btu/scf) gas

Application - Fuel for rotary lime kilns

J.1 BACKGROUND

This gasifier was operated for two years during the fall, winter, and spring months to hedge against natural gas curtailments. This operation occurred during 1959-1961. After this period of usage, the gasifier was mothballed because the gasifier owners/operators, the Mississippi Lime Company, obtained a better agreement on natural gas supply.

The low Btu gas produced by the gasifier was used to fire the rotary lime kilns used for calcining limestone. The one drawback of the gasifier to Mississippi Lime Company was that they could not produce chemical grade lime when using the gasifier. The tar and sulfur in the low Btu gas degraded the lime below the purity required of chemical grade lime. The lime produced was suitable for concrete, cement, agriculture, waste treatment, paper, etc. uses. A lower sulfur coal and a coal that produces less tars would have been a better choice. Illinois No. 6 bituminous coal had been tried in lieu of West Virginia bituminous coal in an effort to reduce coal costs, but the Illinois No. 6 was much more difficult to gasify (i.e. gasifier operation was more difficult).

J.2 PRESENT STATUS

Chemical Exchange, Inc. (CXI), a parent company to Texas Lignite, Inc., bought the gasifier during the 1970s in hopes of gasifying Texas Lignite. CXI will move the gasifier to another location when someone purchases the gasifier. It was determined that the Texas lignite is not suitable to the Wellman-Galusha gasifier.

APPENDIX K - GLEN-GERY CORPORATION

Gasification Sites - York Division, York, PA; Mid-Atlantic Division, Schoemakersville, PA; Reading Division, Wyomissing, PA; and Watsontown Division, Watsontown, PA

Home Office - Glen-Gery Corporation, Reading, PA

Gasifiers - 7 single-stage, fixed-bed, 10-ft diameter, Wellman-Galusha® gasifiers - 2 non-agitated gasifiers (one of which has stainless steel tubes for cooling instead of a water cooling jacket) at York, Pa; 2 gasifiers at Schoemakersville, PA; 1 agitated gasifier at Wyomissing, PA; and 2 non-agitated gasifiers at Watsonville, PA

Licensor - Dravo Corporation, Pittsburgh, PA (Original Licensor - McDowell-Wellman Engineering Company, Cleveland, OH)

Type of Fuel Feed - Pennsylvania Anthracite (+3/16 in -12/16 in, includes "pea", "buckwheat", and "rice" sizes)

Feed Rate - 16-24 ton/day (per gasifier)

Gasification Product - 576 x 10^6 Btu/day, low Btu (140 Btu/scf) gas per gasifier

Application of Product - Fuel for brick kiln

K.1 BACKGROUND

During the mid-1950s Glen-Gery Brick Corporation began installing new single-stage, 10 foot diameter, Wellman-Galusha gasifiers to produce low Btu gas for their brick kilns. Each gasifier supplies sufficient hot raw gas to fire one brick kiln. The gasifiers use a mixture of "pea" (+12/16 in -9/16 in) and "buckwheat" (+9/16 in -5/16 in) sized anthracite coal. "Rice" (+5/16 in -3/16 in) and "nut" (+1-5/8 -13/16 in) sized anthracite coal, blended with "pea" or "buckwheat" sized coal, are also sometimes used.

Much of the history about the gasification systems at the four Glen-Gery plants that use gasifiers is obscure, since the corporate offices were reluctant to discuss the subject in detail. Information was obtained from the report "Integration and Evaluation of Low-Btu Gasifier at the Glen-Gery Corporation Plant, York, Pennsylvania" prepared by the Acurex Corporation for the DOE Gasifier In Industry Program, a program in which Acurex Corporation and Glen-Gery Corporation participated. Also, information in the UOP/SDC report "Analysis of Data on Gasifier Performance under Gasifier in Industry Program," UOP/SDC Report No. TR-MC-024-001, on the data obtained by Acurex from a Glen-Gery gasifier at the York Division plant was used. Finally, an SDC staff member visited the Glen-Gery Mid-Atlantic Division Plant at Schoemakersville, PA during January 1978, and discussed some of the details of the various Glen-Gery plants.

Glen-Gery Corporation has seven operational gasifiers at four sites (divisions). An eighth gasifier remains disassembled at Glen-Gery's Allwine Brick Company at New Oxford, PA. Some history and unique information on the Glen-Gery gasification system is presented in Table K.1.

K.2 PROCESS DESCRIPTION

The coal gasification process for each Glen-Gery gasifier is the most basic of the gasification processes--the process is the same as that at the Hazelton Brick Plant (Webster Brick Company), given in Appendix R.

Each gasification system at the Glen-Gery Brick plants is based on a Wellman-Galusha gas producer using crushed anthracite coal (+3/16 in -12/16 in). The coal is carried from a coal hopper at ground level to the top of the gas producer that serves as a storage bin by a bucket elevator. The storage bin then continuously discharges coal into the fire chamber by gravity through vertical feed pipes. Fuel feed pipes control the flow of coal out of the storage area

Table K.1 Particulars on the Single-Stage, 10-ft Diameter Wellman-Galusha® Gasifiers at the Glen-Gery Brick Plants

Division/ Location	Agitator	Year Installed	Particulars
York Division/ York, PA	No	circa 1955	New when installed
	No	1978	Purchased used from Kellogg, originally installed (1942) and used (until 1946) at New England Lime Co. at Canaan, CT; Instrumented and used in the Gasifier In Industry Program
Mid-Atlantic Division/ Schoemakersville, PA	N/A	circa 1974/75	New unit when installed; included stainless steel tubing for cooling instead of normal water jacket; has performed well; one of a kind
	N/A	1978	Unit moved from a retired (old) GGC brick plant on the Schoemakersville site to the current plant--originally installed circa 1953/54
Reading Division/ Wyomissing, PA	Yes	circa 1953/54	New when installed during the early 1950's to serve one brick kiln
Watsontown Division/ Watsontown, PA	No	Early 1950's	New when installed
	No	1978	Purchased from Kellogg, originally installed (1942) and used (until 1946) at New England Lime Company plant at Canaan, CT

as well as prevent the drafting of product gas up through the storage area. The upper valves in the storage bin are always closed except for brief intervals when the bin is being refilled with coal and the lower valves are always open except when the upper valves are opened. A simple interlocking mechanism prevents the opening of the upper valves unless all lower valves are tightly closed.

A fan supplies the air required for gasification. The air is passed over the top of water in the gasifier water jacket, and thus picks up required water for the air-water vapor requirements of the gasification process. The water vapor content of the injection air is regulated by adjusting the jacket water temperature, which is maintained at 150° to 180°F. A thermostat controls the water flow rate to the jacket.

The air-water vapor mixture is introduced to the gasification zone of the gasifier through the saturation pipe that connects to the ash bin section underneath the grate. The air-water vapor mixture is distributed up through the grate into the ash zone, and then up into combustion and gasification zones. Combustion and gasification reactions result in formation of LBG that contains mainly CO, CO_2, H_2, and N_2. The hot raw gas from the gasification zone preheats, dries, and devolatilizes the incoming coal, and then this gas leaves the gasifier. Ash is withdrawn continously from the bed through the eccentric grate, collected in the ash bin, and periodically discharged from the ash hopper (usually twice daily). The hot raw gas is passed through a cyclone that removes heavy dust particles and is sent to the brick kilns. No sulfur cleanup is required because the feed anthracite has only 0.5-0.6% sulfur.

K.3 OPERATIONAL EXPERIENCE

The Glen-Gery Company successfully operated the Wellman-Galusha gasifiers from the time of installation of the first gasifier during the early 1950s. They provided the fuel-heat requirements of brick kilns and dryers. The gasfiers were intermittently out of service for periods during which cheap, clean, abundant (uninterrupted) natural gas was available. The gasifiers are shutdown once a year for two weeks for scheduled maintenance. In general, start-ups are smooth with no major problems. These single stage gasifiers are operated on Pennsylvania anthracite at 16-24 ton/day rate. Preferred coal size for these gasifiers is buckwheat to pea size and it will tolerate fines up to 15%. With the sulfur content of Pennsylvania anthracite being about 0.5 to 0.6%, no sulfur cleanup system is required, but particulates are removed from the gas via a cyclone. Since hot raw gas is used by the kilns the thermal efficiency of these gasification systems is 89-91%.

Annual maintenance is generally very simple. Some worn components are replaced, and pits in the steel jacket and grate are filled with a weld overlay.

K.4 STATUS

The significant reduction in residential building during 1981 has softened the brick market considerably, thus Glen-Gery is currently operating fewer kilns. Most of the kilns that are operating are using natural gas because it is currently (early 1982) cheaper, to operate on natural gas than to operate with anthracite costing $75/ton.

K.5 SUMMARY AND CONCLUSION

Glen-Gery and other brick producers have proved the reliability of the commercial size Wellman-Galusha gasifier. For this energy intensive business, gas cost is the major portion of the product cost. Although anthracite coal prices have skyrocketed from $34/ton (1979) to over $71.50/ton (1981) to $75/ton (1982) because of high demand (local as well as export) and rising labor costs, the delivered natural gas cost, which reached $3.90 to 4.20/million Btu in the Eastern Pennsylvania area during 1981, has allowed the producer gas from the gasifiers to barely remain competitive. The low Btu gas cost (at the escalated coal price) is estimated to be $4/million Btu. In addition to producing gas that is cost competitive with natural gas, Glen-Gery has the security of knowing that its gas supply will be constant when the natural gas would otherwise be interrupted.

Improvements in brick business and projected deregulation of the natural gas price may yield additional, attractive cost benefits to Glen-Gery through the use of low Btu gas from these gasifiers. Also, use of hot raw gas (that requires no tar or sulfur removal) keeps the overall process efficiency high.

APPENDIX L - HOLSTON ARMY AMMUNITIONS PLANT

Gasification Site - Holston Army Ammunition Plant, Kingsport, TN

Contractor Operator - Holston Defense Corporation (Tennessee Eastman - a Division of Eastman Kodak

Gasifiers - 12 single stage, 9 ft. 2 in. diameter Wilnutte (originally called "Chapman" gasifiers)(Semet-Solvay design 1930)

Licensor - Wilputte Corporation, Murray Hill, NJ. (Original licensor - Semet-Solvay Engineering Division of Alliad Chemical)

Type of Fuel Feed - Low Sulfur (1%) Virginia Bituminous coal (2 in. x 4 in, high volatiles)

Feed Rate - 24 ton/day (per gasifier), maximum

Gasification Products - 360 x 10^6 Btu/day flow Btu (160 Btu/scf) gas per gasifier

Application of Products - Gas provides process heat for acetic anhydride manufacture; tar is burnt in steam coal furnaces

Estimated Plant Cost - Plant cost was approximately $2 million in the 1940's (1941 construction costs not relevant to today's cost)

L.1 BACKGROUND AND PURPOSE

Holston Ordnance, Kingsport, Tennessee

Licensor - Wilputte Corporation, Murray Hill, NJ

Gasifier - 12 Chapman (Now Wilputte) single stage gasifiers (9'-2" diameter)

Type of feed - Bituminous coal (2" x 4", high volatiles, less than 1% sulfur)

Feed rate - 24 tons per day per gasifier (maximum)

Product gas - 2,250,000 cubic feet per day per gasifier (maximum)

Application - Provides process heat for acetic anhydride manufacture

Estimated total cost - Plant cost was approximately $2 million in 1940's (1941 construction, not relevant to today's costs)

This government-owned contractor operated (GOCO) plant began operation during 1942. The plant is operated by a contractor. Holston Defense Corporation, a subsidiary of Eastman Kodak. The plant has twelve 9'-2" I.D. gas producers (Chapman gasifier) that were engineered and installed by the Semet-Solvay Engineering Division of Allied Chemical during the period of 1941-1944. This engineering group was subsequently incorporated into Wilputte while Wilputte was a division of Allied Chemical. Wilputte Corporation is now a subsidiary of Salem Corporation. Wilputte now owns the marketing rights of the Chapman gasifier.

Initially, nine gasifiers were installed and three more were added in 1944 to meet increased gas production needs. Now the Holston plant has two banks of six gasifiers each. The plant was shut down between 1945 and 1949 because of the curtailed activity at the munitions plant.

During the Korean and Vietnam war periods, the plant was operated at full capacity. After both of these conflicts, the plant was run at the reduced capacity. Since the end of the Vietnam conflict, gas production had been provided from only two gasifiers at a time--two gasifiers are operated for 6 week intervals. In the sequential operation, the two gasifiers in use are shut down for routine maintenance and cleanout and two others are simultaneously brought into service. Thus all 12 gasifiers are kept in good operating condition and can be readied for full capacity, if needed.

These gasifiers produce low Btu gas (160/Btu/scf) from bituminous coal (low sulfur 0.8%). The producer gas is used as a furnace feed for acetic anhydride manufacture. During the early forties, natural gas was not widely available in the country and industries depended heavily on low Btu gasifiers to produce clean burning fuel.

L.2 PROCESS DESCRIPTION

Figure L.1 describes the simplified process flow diagram at the Holston plant. Sized (2" x 4") high volatile bituminous coal (less then 1% sulfur) is fed to the top of the gasifier through a barrel valve and is spread across the bed by a distribution arm. No coal grinding, crushing, sizing, or drying operations are used at the plant site. As shown in Figure L.2, steam and air are introduced into the bottom of the gasifier and pass through a grate which evenly distributes these gases and also supports the coal bed. Ash from the gasifier is collected in a water sealed ash pan and removed from the unit using an ash plow. The hot raw gas exits the top of the gasifier at 1050–1250°F and enters a cyclone that removes the entrained particles (ash and coal dust). Poke holes located on top of the gasifier are positioned so that rods can be periodically inserted to break up any coal agglomerates which form.

The inside of the gasifier is refractory lined and has a water jacket in the lower two or three feet of vessel. The gasifier has a water cooled stirrer which floats on coal bed. The gasifier does not have special controls or instrumentations.

The hot raw gas (at 1100°F) flows through refractory lined pipes to the cyclones which are also refractory lined. Each gasifier at Holston is equipped with its own cyclone. The cyclones remove coal dust, fly ash and tar entrained in the raw gas. Poke holes are provided in the hot gas ducts and on the top of the cyclone to break up agglomerated particles.

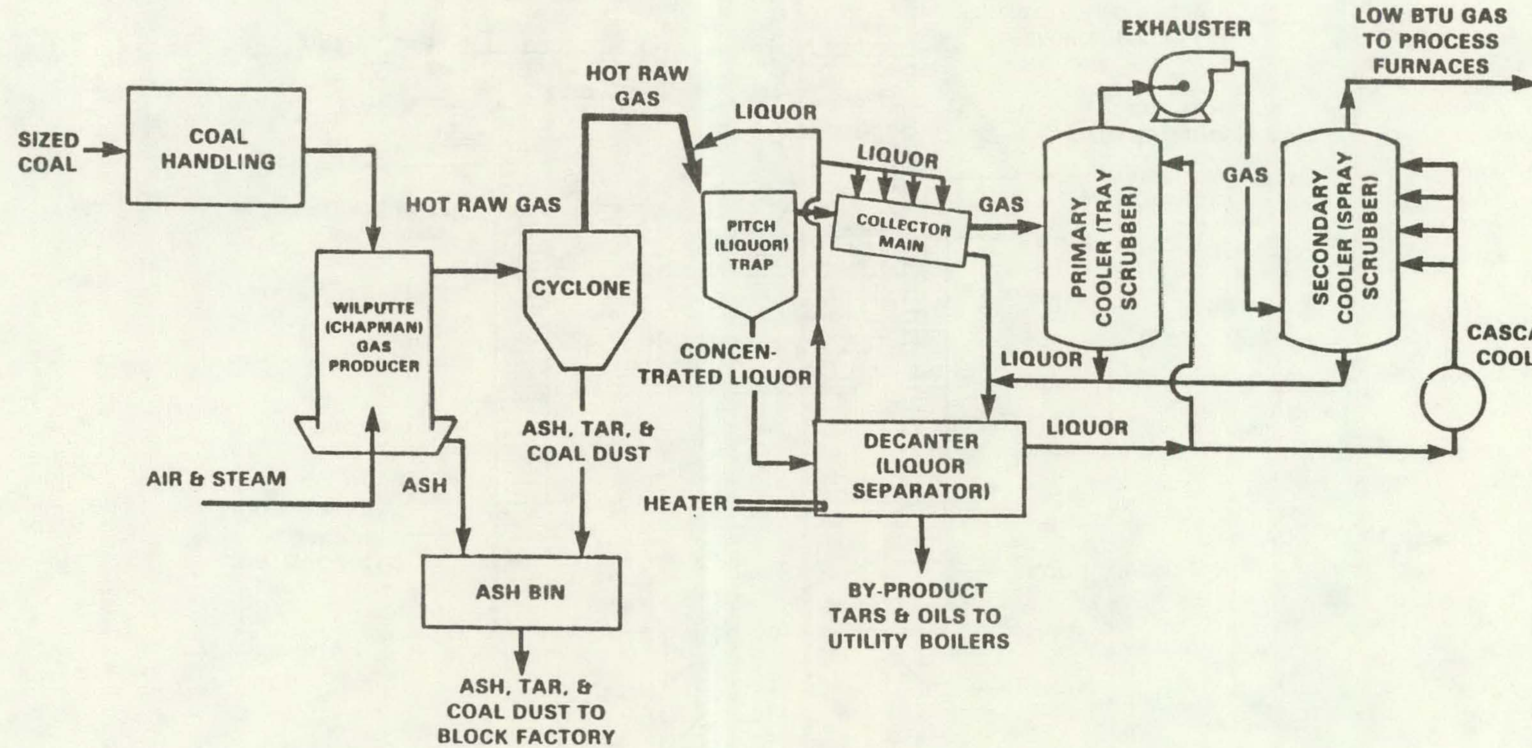


Figure L.1: Block Flow Diagram of Holston Gasification Process

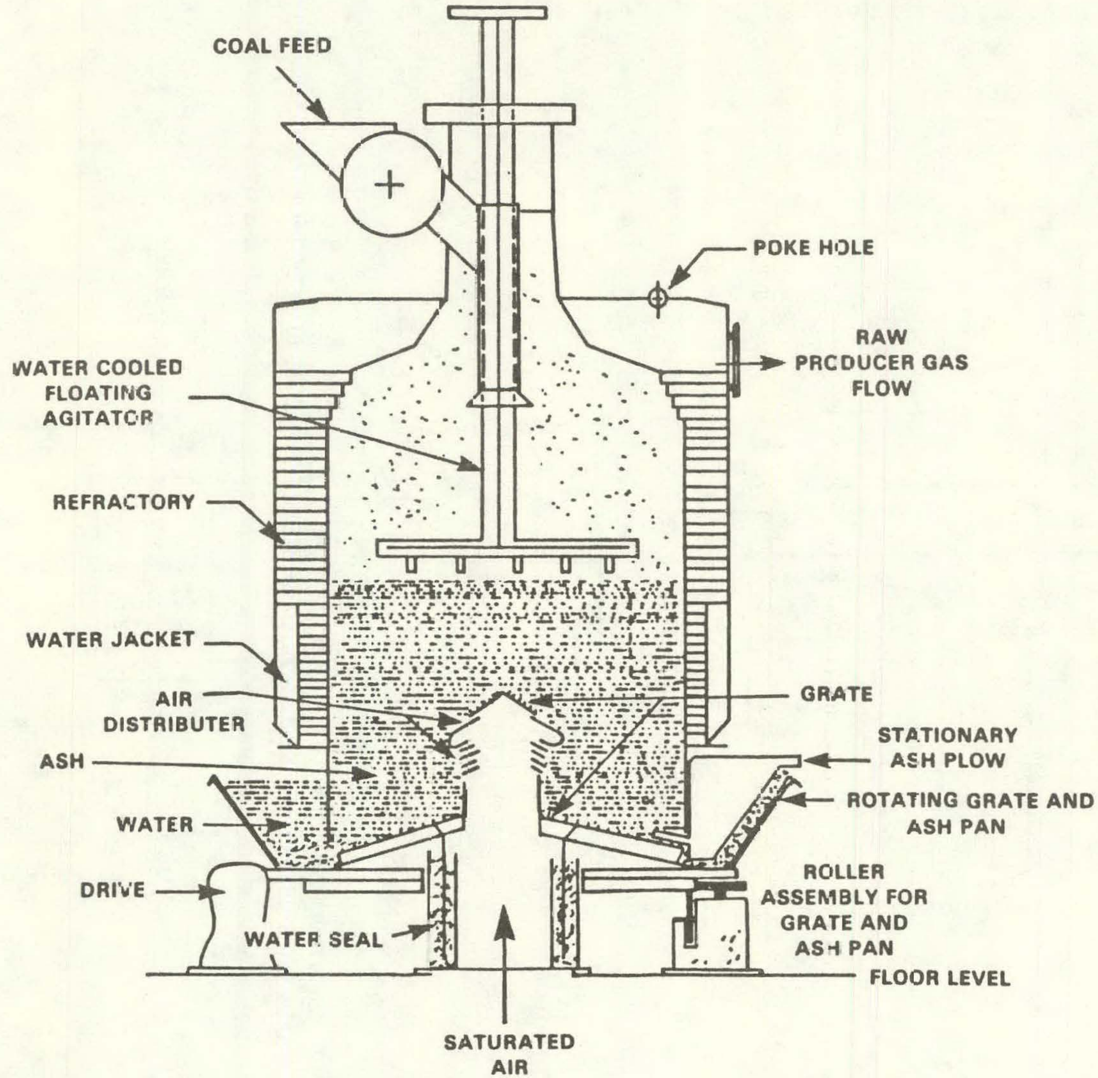


Figure L.2: Chapman Semet-Solvay Design Continuous Producer Used at Holston

From the cyclones the gas passes through the pitch trap, which removes remaining particles and some of the tar and reduces the gas temperature with injected liquor. The gas exits the pitch trap at approximately 180°F and enters a large collector main. Each bank of six gasifiers has a separate collector main.

The gas cools off to 150°F and enters two primary coolers. Most of the tars, oils and particulates are removed here and the gas is further cooled to 135°F. The gas is compressed by an exhauster before it enters the secondary cooler. This is the final gas cleanup treatment. Some residual tars, oils, and particulates are removed as the gas cools down to about 90°F. From here the gas goes to externally fired tube furnaces.

The liquid sprayed into the pitch trap, collector main, primary coolers, and the secondary coolers is supplied from the tar decanter. The concentrated liquor goes to the tar decanter to settle the tar--the liquor is recirculated. The liquor returning to the secondary coolers is cooled to about 120°F in a cascade cooler. The tars and oils are used as supplement fuel for the coal fired boiler.

L.3 OPERATIONAL EXPERIENCE

The Holston ordnance plant was one of only nine commercial-scale, low Btu coal gasification plants in operation in the U.S. during 1981. The facility has a well defined operating history. It is the oldest gasifier system still in operation in the U.S. with most of the original parts and has demonstrated exceptional reliability. To date only one gasifier has required brick relining.

Sized bituminous (2" x 4") coal from southwest Virginia and Kentucky is of good quality and does not have many fines. The coal cost is around $50/ton. The coal analyzed to have 38.7 volatile matter, 55.4 fixed carbon, 4.6% moisture, 5.9% ash, and 0.8% sulfur, with a HHV=14,130 Btu/lb (dry) and 13,480 Btu/lb (as received). The low Btu gas (160 Btu/scf) produced has 15% H_2, 25% CO, 55% N_2, 5% CH_4, C_2H_6 etc.

During the operation, tar keeps collecting, particularly in the connection between the gasifier and cyclone. This tar is removed by "burn out" for six hours during which time smoke and odors are in evidence. On occasion Holston has received notice of violation for heavy opacity emission during burn-outs, but these have been excused as a necessary part of start-ups and shutdowns. An attempt to flare the startup gas was not successful and it is vented to atmosphere.

Burn-out is essential to keep the piping from clogging. During burn-out, smoke and odor and tar odor become quite apparent with varied gusts of winds and thus have created an unpleasant environment around the gasifier. Start-up and shut-down procedures are modified in recent years to reduce pollution. Holston has obtained the permit of compliance for meeting environmental emission standards. Ash from the gasifier and cyclone is sold to a block company.

The gasifier can be turned down to 25% of the rated capacity (2.85 x 10^6 scf/day or 456 x 10^6 Btu/day) for extended periods. Any lower throughout results in erratic behavior of the gasifier. A gasifier can be shutdown in an hour. If the capacity to use fuel gas is lost at the process plant, each gasifier's auxiliary vent is opened by passing the fuel gas header. Saturated air must continue to be pumped through the gasifier to purge it of explosive mixtures. This action produces smoke and ordors from the auxiliary vents.

Once or twice during each shift, the gasifier operator probes the height of the coal bed by inserting a steel rod through 4" diameter holes. Six such holes are evenly spaced on the top of the gasifier. The operator breaks up any "bridging" in the coal bed and also looks at the color of the gas to judge its quality. During the 30 seconds to a minute necessary to perform this operation, dense yellow-brown smoke comes out that smells like roofing tar.

The producer gas plant, operating with 2 gasifiers requires one operator, an assistant operator, and a laborer for each shift. Maintenance is done on part time basis, as required, on the day shift.

L.4 ECONOMICS

Holston gas cost is $0.63/1000 ft^3 or $3.94/$10^6$ Btu. For this gasifier the design rating for gas production is 58 cubic feet/lb of coal. The plant thermal efficiency is around 65% which does not include benefits from by-product tar.

L.5 STATUS

With almost four decades of operation, the Holston plant reflects a very successful operational history of low Btu gasifier at commercial level. Even with an old design the plant seems to comply with today's tough environmental standards. At present only two gasifiers are operating at a time, and based on downstream process heat requirement these run at or below the rated capacity.

The current sequence of taking the two running gasifiers out of service for cleanup and maintenance, and bring in the two others in service is repeated every 6 weeks to two months.

L.6 SUMMARY AND CONCLUSION

Since natural gas is unavailable at Holston site, the Holston plant will continue to furnish its process fuel need from low Btu gas producers. The gas cost, operational reliability, and plant economics favor the production of gas from this 40 year old design. It is hard to predict the ultimate life of the plant but this plant has proved that producer gas plants can be engineered, installed, and operated safely over an extended period. Successful operational, maintenance history, and equipment durability should provide incentives toward developing gas producer designs.

Even though the plant has a very successful history, certain areas of the plant could be readily modified to improve efficiency, gas production, personnel safety, and exposure to undesirable effluents. A few of the modifications are:

- Connect vent gas stack to after burner to eliminate air pollution (getting rid of combustibles and particulate emissions)

- Add sand and carbon filter system to purify wastewater to acceptable EPA disposal levels (replacing present evaporative system)

- Replace existing pitch traps with steam purged hot valves to eliminate manual pitch trap cleaning

- Covered Wilputte steel tar decanters equipped with scrapers would keep the decanters clean, improve the tar handling and eliminate tar polymetization and condensation problem, which are inherent with the present concrete decanters.

- Providing the poke holes with steam injection would reduce the amount of CO and tar escapting during poking operations.

APPENDIX M - HOWMET ALUMINUM

Gasification Site - Howmet Aluminium, Mill Product Division, Lancaster, PA

Gasifier - One single-stage, 10-foot diameter Wellman-Galusha gasifier

Licensor - Dravo Corporation, Pittsburgh, PA (Original licensor - McDowell Wellman Engineering Company, Cleveland, OH)

Type of Feed Fuel - Pennsylvania Anthracite (+5/16, -9/16, includes "rice", "buckwheat", and "pea" sizes)

Feed Rate - 25 ton/day (estimated)

Gasification Product - 600 x 10^6 Btu/day, low Btu (152 Btu/scf) gas

Application - Hot Raw gas is used for aluminium processing (heating and melting)

Howmet Aluminum installed a 10-foot diameter Wellman-Galusha gasifier (with agitator) to produce low-Btu gas (152 Btu/scf) from anthracite coal. 600 million Btu/day of hot raw gas was used at its mill product division for aluminum processing (heating and melting). The gasifier was operated for 5-6 weeks early in 1981. After this period the gasifier was shut down because of a price advantage from using natural instead of producer gas.

Fuel security was the principal reason for Howmet to get into this project. Howmet is considering reactivation of the gasifier.

APPENDIX N - NATIONAL LIME AND STONE COMPANY

Gasification Site - National Lime and Stone Company, Carrie, OH

Home Office - Findley, OH

Gasifiers - 2 single-stage, 10-ft diameter, Wellman-Galusha gasifiers with agitators

Licensor - Dravo Corporation, Pittsburgh, PA (Original Licensor - McDowell Wellman Engineering Company, Cleveland, OH)

Type of Fuel - Low sulfur West Virginia and Eastern Kentucky coals

Feed Rate Per Gasifier - 48 to 60 tons per day

Gasification Product - 150-160 Btu/scf as hot raw gas

Application of Product - Fuel for 4 shaft (vertical) kilns per gasifier. Presently only 4 kilns are equipped with dust collectors, so only one gasifier is used at a time.

N.1 BACKGROUND

During 1955 the National Lime and Stone Company (NL&S) installed and started up the two Wellman-Galusha gasifiers currently in place at the Carrie, OH plant. The gasifiers used prior to 1955 were removed.

The low Btu gas produced by the two gasifiers can be ducted to all of the 10 shaft kilns, which calcine quicklime. Shaft kilns are erected in a vertical position and operated in a batch mode. To operate the kiln, limestone is charged into the kiln from the top, the cap is put in place with connections to the stack, ignited gas is introduced into the shaft kiln from the bottom, and the hot gas percolates through the limestone ($CaCo_3$) bed, converting it to quicklime (lime, CaO). When the limestone is fully reacted, the shaft kiln is shutdown to cool and discharge the lime.

NL&S also operates tunnel kilns and could fire them with low Btu gas, but it is more cost effective to fire these tunnel kilns directly with low sulfur coal. Deposit of coal ash among the quicklime particles is acceptable in the tunnel kiln. On the other hand, shaft kilns cannot tolerate direct firing with pulverized coal because the coal cannot effectively filter through the limestone bed--the hot, raw, low Btu gas is as suitable as natural gas for the shaft kiln, as long as the low Btu gas is sufficiently low in sulfur gases.

N.2 PROCESS DESCRIPTION

The NS&L gasification system is straight forward. The gasification process includes the gasifier and a cyclone to remove particulate matter from the hot, raw gas. Tars and pitch that remain in the gas stream are used as part of the combustible matter and thus provide some of the heating value of the gas.

Gas desulfurization is inherent in the calcining process--the calcium readily reacts with the sulfur components in the gas to form calcium-sulfur compounds that are in the solid state. SO_x pollution in the air does not present a problem; the potential problem is too much sulfur in the quicklime. To control the level of sulfur in the lime, low sulfur coal must be used in the gasifier.

Tar builds up in the hot gas ducts, so periodically the ducts have to be burnt out. The burning out of the deposits of tar and pitch in the duct is accomplished by igniting the flammable matter in the duct and supplying sufficient air to continue until the ducts are relatively clean of deposits. The burnout process produces a dirty black smoke, but efforts are made to limit the quantity of the black smoke entering the atmosphere.

N.3 OPERATIONAL EXPERIENCE

National Lime and Stone has been very satisfied with the gasifiers. It finds the burn out procedure of the ducts the major drawback of the gasification operation.

The operational history of the Wellman-Galusha gasifiers has been to depend soley on the gasifiers from 1955 to 1970. In 1970 to 1975 natural gas was more economical to use, so the plant switched to natural gas. However, in 1975 with the advent of natural gas curtailments to industrial customers, NL&S put the gasifiers in a standby mode and used them during curtailment periods. As of 1978 the gasifiers were brought back on line as the fuel source for the shaft kilns because it became cheaper to use coal than natural gas. During February 1980 the gasifiers were shut down because of decreases in business.

The shaft kilns and gasifiers are now used only when output demands exceed the capacity of the NS&L pulverized coal-fed rotary kilns. It is cheaper to coal fire the rotary kilns than to fire the shaft kilns with the low Btu gas from the coal gasifiers (or with natural gas, for that matter).

The bottom line on the use of fuels for line calcining is that it is cheaper to direct fire lime kilns with coal, if possible; it is a little less cheap to use coal gasifiers, if the gasifiers are already in place; it is more expensive to use natural gas, a little more expensive to use low Btu gas from new gasifiers, and most expensive to use oil. The economics of using a new gasifier to provide low Btu gas will shortly be better than using natural gas--during August 1982, for example, the gas price in the Washington area was increased over 25% and is in the range of eight dollars per million Btu. With further decontrol the price is slated to rise rapidly.

N.4 STATUS

NS&L would like to upgrade some of the gasification coal handling and ash handling equipment, but current economics with regard to the construction industry do not justify expenditures at the present time. Presently, the gasifiers are used only when the capacity of the rotary kilns is exceeded.

N.5 CONCLUSION

Fortunately for NL&S, it has the gasifiers ready to go on line when needed and has the option to use natural gas, if so desired.

APPENDIX O - OLIN CORPORATION

Gasification Site - Olin Corporation, Olin Chemicals Group, Ashtabula, OH

Gasifier - One single-stage, 6-foot diameter Wellman-Galusha gasifier (9-foot high cavity above grate)

Current Licensor - Dravo Corporation, Pittsburgh, PA (Original licensor - McDowell Wellman Engineering Company, Cleveland, OH)

Type of Feed Fuel - Calcined petroleum coke

Feed Rate - 20,000 lb/day calcined petroleum coke (screened $\geq$1/2-inch); 24,000 lb/day carbon dioxide; and 19,000 lb/day oxygen

Gasification Products - 52,000 lb/day carbon monoxide (90-95% of the product gas), methane and hydrogen which total less than 2% of the CO gas produced, and carbon dioxide which makes up the remainder of the gas

Application of Products - Carbon monoxide used for production of phosgene

O.1 BACKGROUND

The Wellman-Galusha unit was installed during 1963 at the Olin chemical plant as part of the original installation of the TDI unit at Ashtabula. The unit produces a 90-95% carbon monoxide product, which is used for the production of phosgene (Cl_2CO). The production of phosgene requires that concentrations of methane and hydrogen be minimized--this gasification process produces methane and hydrogen that total less than 2% (wt.) of the carbon monoxide produced. Carbon dioxide makes up the remainder of the product gas composition.

0.2 PROCESS

The gasifier has a 6-foot I.D. and 9-foot high cavity above the grate. The input feed fuels are calcined petroleum coke, carbon dioxide, and oxygen--no steam or air is used, since neither hydrogen nor nitrogen are desired in the product gas. Before putting the calcined petroleum coke into the gasifier the coke is screened to reject particles less than 1/2-inch in size.

The carbon monoxide product gas is treated first with water scrubbing, carbon purification, and monoethanolamine (MEA) scrubbing (removes CO_2, H_2S and COS), and then it is dried before entering the TDI unit. The CO_2 is thus scrubbed out of the gas before use in the TDI unit.

0.3 OPERATIONAL EXPERIENCE

The gasification and TDI units operate 24 hours a day, seven days a week. The units also operate at least seven or eight months a year.

This gasifier is equipped with slide valves at the poke-hole ports on the top of the unit, so there is leakage of carbon monoxide into the work area, even while the ports are covered by the slide-valves. Large amounts of CO escape during periods when poke rods are projected through the poke holes to break up ash slag formations (clinkers) that form in the combustion and in the ash zones. The loss of the carbon monoxide gas from the gasifier not only poses a potential hazard, but also decreases the efficiency of the unit.

The major operational problem occurs as a result of ash slag formation--this condition restricts gas flow through the bed. To correct this upset condition, the formations are broken up by sledge hammering poke rods that are inserted into the bed through the poke holes during the time necessary to reduce the formations. To protect the workers from CO poisoning during the period of poking there is adequate ventilation.

O.4 REFERENCES

Matson, A.L., production manager with Olin Chemicals Group, telephone conversation with C.S. Bhatt of System Development Corporation, March 5, 1981.

Matson, A.L., letter to C.S. Bhatt, UOP/SDC Joint Venture, March 27, 1981.

APPENDIX P - RILEY-MORGAN DEMONSTRATION PLANT

Gasification Site - Riley Stocker Corporation, Riley Research and Development Center, Worcester, MA

Gasifier - One single-stage, 10.5 ft. diameter (commercial sized) Riley-Morgan Gasifier

Licensor/Developer - Riley Stoker Corporation, Worcester, MA

Type of Fuel Feed - Numerous coals, including anthracite, eastern caking and non-caking bituminous coals, and Northern Plaines lignites

Feed Rates - 85-95 ton/day of bituminous coal (estimated)

Gasification Products - 1.73 x 10^9 Btu/day (air-blown) low Btu gas or 3.05 x 10^9 Btu/day (oxygen-blown) medium Btu gas using bituminous coal

Application of Products - Low or medium Btu gases for boilers, combustion turbines, chemical feed stock, heaters, fuel cells, and distribution through industrial park pipelines; in general, applications where oil or natural gas are used by industry

Estimated Cost - Capital cost (1981) of 10 ft. 6 in. gasifier - $1,000,000 FOB; cost of gasifier and installation - $1,300,000

P.1 BACKGROUND

During the first half of the twentieth century, the Morgan gas producer was one of the most successful coal gasifiers sold. Over 9,000 of these fixed bed units have been built and installed throughout the world. Riley Stocker Corporation obtained the exclusive manufacturing rights to this gasifier from the Morgan Construction Company during late 1973. The old Morgan unit was redesigned to simplify its manufacture, to insure its compliance with OSHA and EPA standards, and to allow it to operate over a wide range of bituminous coals. Riley then began two parallel test programs to develop operating data and techniques.

In the early part of 1974, Riley installed a small (two-foot I.D.) fixed bed gasifier in its Worcester, Massachusetts facility. This pilot plant was used to provide operating experience and to explore problems associated with tar formation from bituminous coals. Highly caking varieties of eastern bituminous coals were tested at low-ash-fusion temperature, using both air and oxygen.

In parallel with the pilot effort, Riley Stoker undertook a program of design, development, and commercialization of a full-scale low Btu coal gasification unit. This commercial-sized gas producer was installed during December 1974 and was operated using a number of eastern coals, including anthracite and caking and non-caking bituminous coals. The unit was successfully tested using air, enriched air (oxygen and air mixture), and pure oxygen to yield low through medium Btu gases. Western sub-bituminous coal and lignites were also subsequently tested.

Up to 1981, the Riley Stocker Corporation had invested more than three million dollars in the development and testing of the Riley-Morgan Gas Producer. In anticipation that a large potential market for gas producers would develop around 1976, Riley established a very elaborate test program. However, as the prospects for this market faded into the future, Riley stopped company-sponsored tests and instead undertook test programs for individual companies on specific fuels.

P.2 PURPOSE

The Riley Stoker Corporation has been a major supplier of industrial and utility boilers for more than 75 years. When it became evident that the availability of domestic supplies of natural gas was uncertain and that the U.S. had become dependent on oil imports for over half of its need, Riley Stoker became concerned with the options open to its customers who depended on these fuels. In most cases, boilers designed for these fuels can not be converted to direct coal firing without derating the capacity and making expensive modifications. The need became apparent to develop a simple coal gasification process that would provide fuel for direct, on-site applications that would replace natural gas or oil.

Medium Btu (300 Btu/scf) fuel gases produced using oxygen instead of air, results in flame temperatures and flue gas flows identical to those of natural gas. Gasification also provides a method of burning many coals cleanly without the need for stack gas scrubbing. Both particulate matter and sulfur can be removed from the gas prior to combustion in a boiler or furnace.

P.3 PROCESS DESCRIPTION

Figure P.1 shows a schematic of the gasification system at the Riley-Morgan demonstration facility. Details of the Riley-Morgan gasifier are shown in Figure P.2. Coal is unloaded into the truck hopper and then elevated to the bunker, from which it flows to a standard Riley Stoker Drum Feeder. This volumetric device feeds coal to a lockhopper system. 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 the level is restored by coal feed.

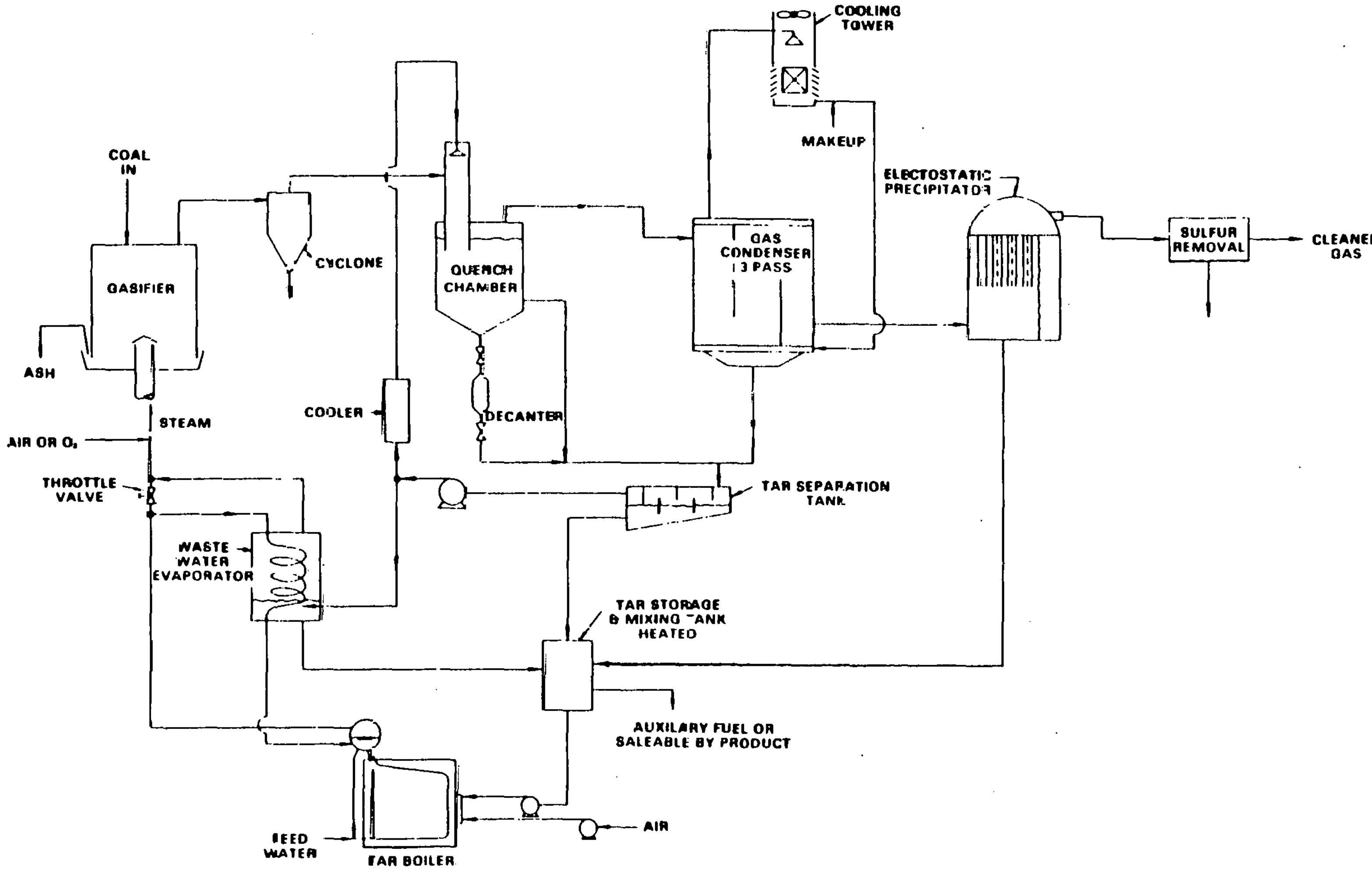


Figure P.1: Riley-Morgan Gasification System at Worcester, Massachusetts

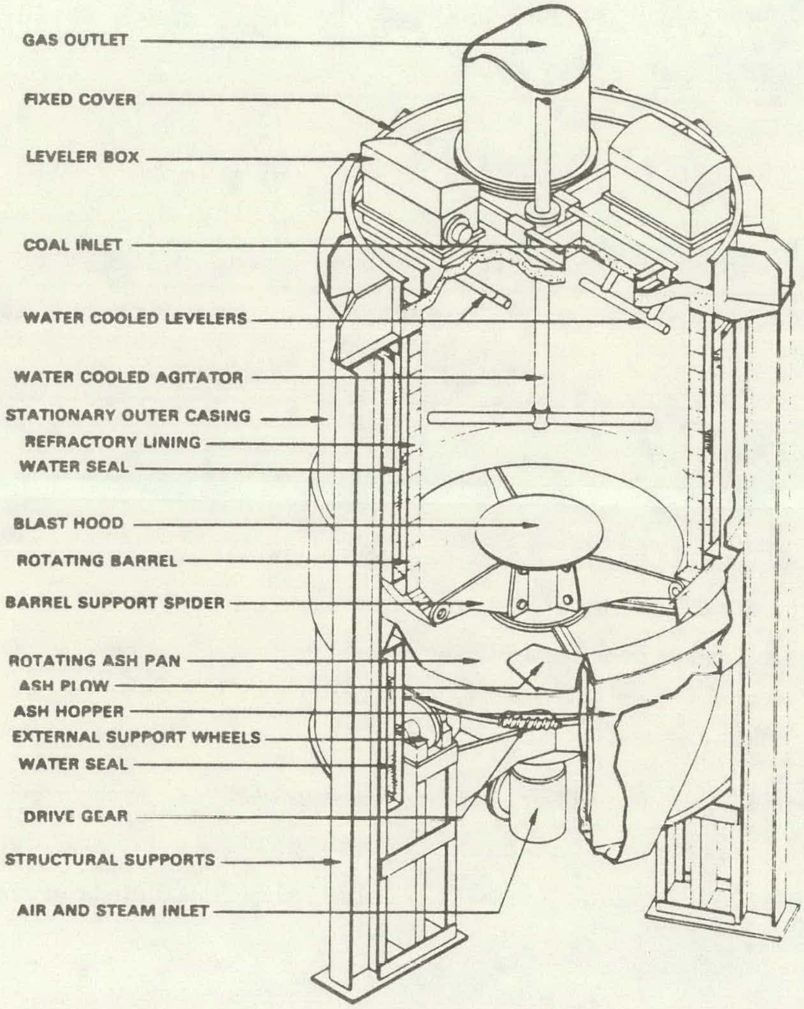


Figure P.2: Riley-Morgan Gasifier

A forced draft fan forces the air into the system. Metered steam is added after the air flow meter and 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 oxiding 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. The gas is further cooled in a condenser to separate out tars and oils. The electrostatic precipitator removes the dust, and a sulfur removal system provides the final gas clean up.

Ash is removed from the gasifier by means of a helical plow located in the ash pan. To maintain an ash 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 the ash is discharged through a water seal and conveyed to disposal.

P.4 STATUS

While no Riley-Morgan gasifier has been operated commercially, the Morgan gas producer, its forerunner, was employed until 1941 by over 9,000 users throughout the world. Units installed in 1933 and in 1948 are currently in operation in South Africa.

The full scale Riley-Morgan gasifier, which is a modified design of the Morgan gasifier for today's operation, has been successfully tested and demonstrated at Riley Research and Development Center. This full scale unit is now commercially available.

This fixed bed gasifier was designed for eastern bituminous caking coals, but it has also been tested successfully on Northern Plaines (North Dakota) lignite. Tests with Pennsylvania anthracite, Virginia Upper Banner Seam, Virginia Coronet No. 2, Kentucky Hazzard No. 4, and Kentucky Elkorn No. 3 coals were very successful.

Ashland oil company, the new owner of the Riley Stoker, is impressed with the Riley-Morgan gasifier and may install one in the near future.

P.5 OPERATIONAL EXPERIENCE

During the past several years, Riley has conducted gasification studies on a number of U.S. coals, both in the commercial size gasifier and in a small 2-foot diameter pilot model. For these tests anthracite coal, several bituminous coals, and lignites were used.

Anthracite coal was tested first to establish a performance baseline for later tests. Chestnut-sized anthracite is an ideal fuel for a fixed bed gas producer because it produces clean, tar free gas.

The size requirement for bituminous coal is 2" x 1-1/2"; for lignite it is 2" x 1/2". Coal fines have a slight adverse effect on the gasifier's capacity because fines lead to gas channeling and process upset.

The gasifier operates at atmospheric pressure. With high volatile bituminous coal gasification the maximum temperature attained in the reaction zone is about 2000°F. Raw gas exits at 1000 to 1200°F. With lignite the exit gas temperature is 518°F. Typical raw gas compositions from gasification of different coals are given in Table P.1.

Riley's water-cooled agitator in the full-scale commercial unit has allowed the successful gasification of two caking coals whose free-swelling indexes (a measure of caking tendency) are 6 and 8-1/2, respectively.

P.6 PROCESS EMISSIONS

The environmentally unacceptable components, H_2S, NH_3, HCN and COS, have been properly characterized and are treated in a proven gas treatment process. Tars, oils and sulfur are recovered as by-products. Fines (0.5% - 3% of coal feed) that carry over with the gas are separated in cyclones. Riley has also characterized the NO_x's that are formed when the low Btu gas is combusted in a boiler.

Table P.1 Compositions of Raw Gases Leaving the Riley-Morgan Gasifier

FEED COAL	HIGH VOLATILE BITUMINOUS	LIGNITE	ANTHRACITE
Gas Component/ Composition, Mole %			
CO	21.60	28.10	22.70
CO_2	7.50	6.10	9.10
H_2	13.90	17.30	16.60
CH_4 + CnHm	3.10	1.70	0.25
N_2 + Ar	52.10	45.00	51.26
COS + H_2S	0.10	0.10	0.09
H_2O	1.70	1.70	dry gas
HHV, Btu/scf	156	166	130
Air-Steam Ratio, lb/lb	7.14	5.56	4.81
Cold Gas Efficiency, %	71.4	78.0	80.6
Cold Gas + Tar + Oil, %	78.3	77.9	80.6

P.7 CONCLUSIONS

Coal gasification tests are being conducted on a commercial scale Riley-Morgan gas producer on additional coals as needs arise. This unit has allowed the manufacturer to accumulate valuable design data and operating techniques on typical caking bituminous coals, and to evaluate various improvements upon the original Morgan design. The design has worked well with anthracite coal, sub-bituminous coal, and lignite.

Results to date indicate that a deep-bed agitator allows the successful gasification of caking bituminous coals in Riley-Morgan gasifier. The amount of coal that can be gasified depends greatly on its particle size distribution and fixed carbon content. Major and minor gas constituents and process by-products have been identified and correlated with process operating parameters. The final result of this on-going research has been the evolution of a reliable gas producer system design that has been, in effect, commercially proven.

APPENDIX Q - WEBSTER BRICK COMPANY

Gasification Site - Webster Brick Company, Hazelton, PA

Home Office - Webster Brick, Roanoke, VA

Gasifiers - Three single-stage, 10 foot diameter Wellman-Galusha gasifiers

Licensor - Dravo Corporation, Pittsburgh, PA (Original Licensor - McDowell Wellman Engineering Company, Cleveland, OH)

Type of Fuel Feed - Pennsylvania Anthracite (+5/16 in, -9/16 in, includes "pea", "buckwheat", and "rice" sizes)

Feed Rate - 16-24 ton/day (per gasifier)

Gasification Product - 576 x 10^6 Btu/day, low Btu (140 Btu/scf) gas per gasifier

Application of Product - Fuel for brick kiln and dryer

Q.1 BACKGROUND

During 1979 the Webster Brick Company of Roanoke, Virginia bought the Hazelton Brick Company of Hazelton, Pennsylvania, which closed between 1976 and 1978 for economic reasons. In 1978, Hazelton Brick refurbished and activated one of the three gasifiers. The two remaining gasifiers require refurbishing before they can be put back into service.

In the pre-natural gas era of the 1940s and 1950s, producer gas derived from coal/coke was one of the prime energy source for several industries. The Wellman-Galusha gasifier, developed by Wellman Engineering Company, has been in commercial use to manufacture producer gas since the 1920s. Hazelton Brick installed three Wellman-Galusha gasifiers in the 1940-1950s to produce low Btu gas from anthracite coal to supply fuel for its brick kilns.

Being situated in the middle of the anthracite coal country, producer gas was attractive to this brick business until the 1960s. In 1965 at the Hazelton Brick Co. natural gas became available and replaced producer gas because it was cleaner and cheaper than producer gas.

During the 1970s, however, Hazelton Brick faced natural gas curtailments and price escalations, so its gasifiers were reactivated for fuel security and cost benefit reasons. The gasifiers were shut down when the Hazelton Brick Company closed. In order for Webster Brick to activate the gasification plant during 1981, the gas producer that was brought on line had to be refurbished but additional gas cleanup equipment did not have to be added to the system to meet environmental requirements.

Q.2 PROCESS DESCRIPTION

The gasification process at the Hazelton Brick Company is based on a Wellman-Galusha gas producer using crushed anthracite coal (5/16-9/16"). The coal is carried from a coal hopper at ground level to the top of the gas producer that serves as a storage bin by a bucket elevator. The storage bin then continuously discharges coal into the fire chamber by gravity through vertical feed pipes. Fuel feed pipes control the flow of coal out of the storage area as well as prevent the drafting of product gas up through the storage area. The upper valves in the storage bin are always closed except for brief intervals when the bin is being refilled with coal and the lower valves are always open except when the upper valves are opened. A simple interlocking mechanism prevents the opening of the upper valves unless all lower valves are tightly closed.

A fan supplies the air required for gasification. The air is passed over the top of water in the gasifier water jacket, and thus picks up required water for the air-water vapor requirements of the gasification process. The water vapor content of the injection air is regulated by adjusting the jacket water temperature, which is maintained at 150° to 180°F. A thermostat controls the water flow rate to the jacket.

The air-water vapor mixture is introduced to the gasification zone of the gasifier through the saturation pipe that connects to the ash bin section underneath the grate. The air-water vapor mixture is distributed up through the grate into the ash zone, and then up into combustion and gasification zones. Combustion and gasification reactions result in formation of low Btu gas that contains mainly CO, CO_2, H_2, and N_2. The hot raw gas from the gasification zone preheats, dries, and devolatilizes the incoming coal, and then this gas leaves the gasifier. Ash is withdrawn continously from the bed through the eccentric grate, collected in the ash bin, and periodically discharged from the ash hopper (usually twice daily). The hot raw gas is passed through a cyclone that removes heavy dust particles and is sent to the brick kilns. No sulfur cleanup is required because feed anthracite has only 0.5-0.6% sulfur.

Q.3 OPERATIONAL EXPERIENCE

The Hazelton Brick Company successfully operated the Wellman-Galusha gasifiers from the time of installation during 1953 until 1965. For 12 years they provided the fuel-heat requirements of brick kilns and dryers. The gasifiers were out of service for over a decade when abundant natural gas was available at low cost and were reactivated some time around 1978. It took 3 months to completely overhaul the idle gasifier. The start-up was smooth with no major problems. This single stage gasifier operated on Pennsylvania anthracite at 16-24 ton/day rate. The preferred coal size for the gasifier is buckwheat to pea size, and it will tolerate fines up to 15%. With the sulfur content of Pennsylvania anthracite being about 0.5 to 0.6%, no sulfur cleanup system is required, but particulates are removed from the gas via a cyclone. Hazelton reported no operational, environmental, or maintenance problems with the restarted old gasifier. Since hot raw gas is used by the kilns, the thermal efficiency of this gasification plant is 89-91%.

Q.4 STATUS

The significant reduction in residential building during 1981 has softened the brick market considerably, thus Webster is currently operating only one brick kiln. As of September 1979 low Btu gas has been providing all the brick kiln energy needs and thus has replaced natural gas completely. During gasifier upset and down time, natural gas is used in the kiln as the back up fuel. The two idle gasifiers would require major overhaul to put them in service, but Webster has no plans to reactivate them during this slow business period. The Webster Brick Company, as the new owner of the Hazelton Brick Company, considered direct firing of coal as the combustion fuel into brick kiln, but it was learned that coal ash affects the quality of their brick product.

Q.5 SUMMARY AND CONCLUSION

Hazelton and other brick producers have proved the reliability of the commercial size Wellman-Galusha gasifier. For this energy intensive business, gas cost is the major portion of the product cost. Costs required Webster/Hazelton to go back to the old, reliable alternative energy of low Btu gasification when the natural gas supply started to be curtailed and prices escalated. Although anthracite coal prices have skyrocketed from $34/ton (1979) to over $71.50/ton (1981) because of high demand (local as well as export) and rising labor costs, the delivered natural gas cost, which reached $3.90 to 4.20/million Btu in the Hazelton area during 1981, has allowed the producer gas from the gasifier at Webster Brick to remain competitive. The low Btu gas cost (at the escalated coal price) is estimated to be $4/million Btu. In addition to producing gas that is cost competitive with natural gas at the Webster Brick Hazelton plant, Webster has the security of knowing that its gas supply will be constant.

Improvements in brick business and projected deregulation of the natural gas price may yield additional, attractive cost benefits to Webster Brick through the use of low Btu gas from these gasifiers. Also, use of hot raw gas (that requires no tar or sulfur removal) keeps the overall process efficiency high.

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